Advanced Features

Rnic / H.-S. Zheng

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Outline

Unsafe

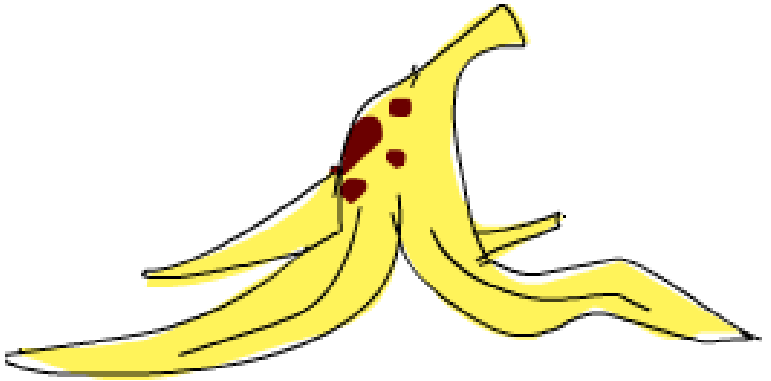
Macros

Lifetimes

Traits

Fn and Closure

Unsafe



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- Implement an unsafe trait

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    }
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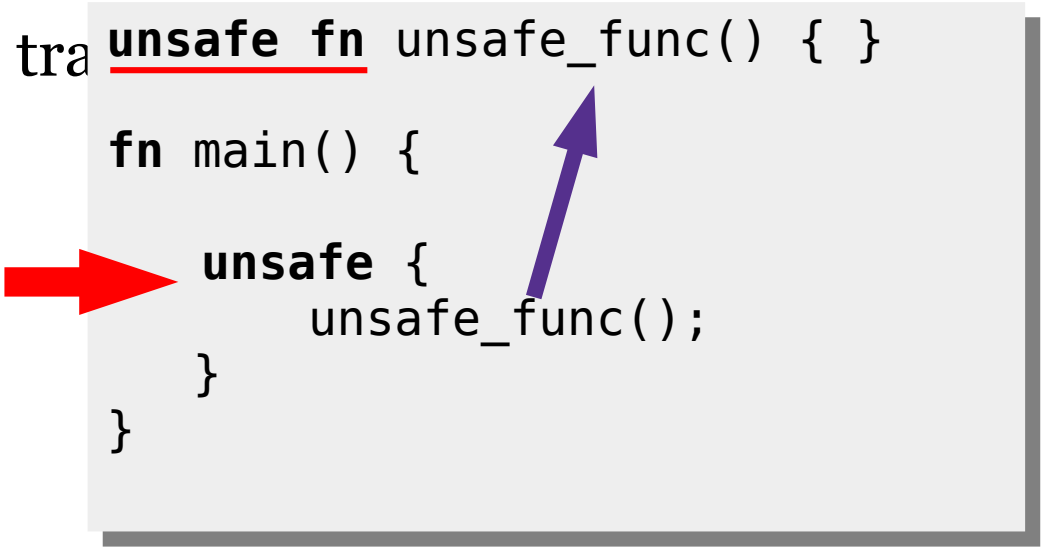

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```
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fn add_to_count(inc: u32) {
    unsafe {
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    }
}
fn main() {
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    unsafe {
        println!("COUNTER: {}", COUNTER);
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unsafe trait Foo {
    // methods go here
}
unsafe impl Foo for i32 {
    // method implementations go here
}
```

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```
struct MyBox(*mut u8);

unsafe impl Send for MyBox {}

unsafe impl Sync for MyBox {}
```

e.g. impl Send, Sync

What is unsafe operation in Rust ?

- Dereference a raw pointer
- Call an unsafe function or method
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- **Implement an unsafe trait**

e.g. impl Send, Sync

- **Raw pointer:** isn't **Send**, **Sync**
- **Unsafe Cell:** isn't **Sync** (and therefore Cell and RefCell aren't)
- **Rc:** isn't **Send**, **Sync**

Creating a Safe Abstraction over Unsafe Code

Wrapping unsafe code in a safe function is a common abstraction.

Example.

```
let mut v = vec![1, 2, 3, 4, 5, 6];

let r = &mut v[..];

let (a, b) = r.split_at_mut(3);

assert_eq!(a, &mut [1, 2, 3]);

assert_eq!(b, &mut [4, 5, 6]);
```

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```

We want to implement a **split_at_mut** funciton

```
fn split_at_mut(slice: &mut [i32], mid: usize)
-> (&mut [i32], &mut [i32])
{
    let len = slice.len();

    assert!(mid <= len);

    (&mut slice[..mid],
     &mut slice[mid..])
}
```

```
fn split_at_mut(slice: &mut [i32], mid: usize)
-> (&mut [i32], &mut [i32])
{
    let len = slice.len();

    assert!(mid <= len);

    (&mut slice[..mid],
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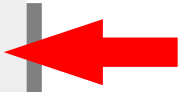
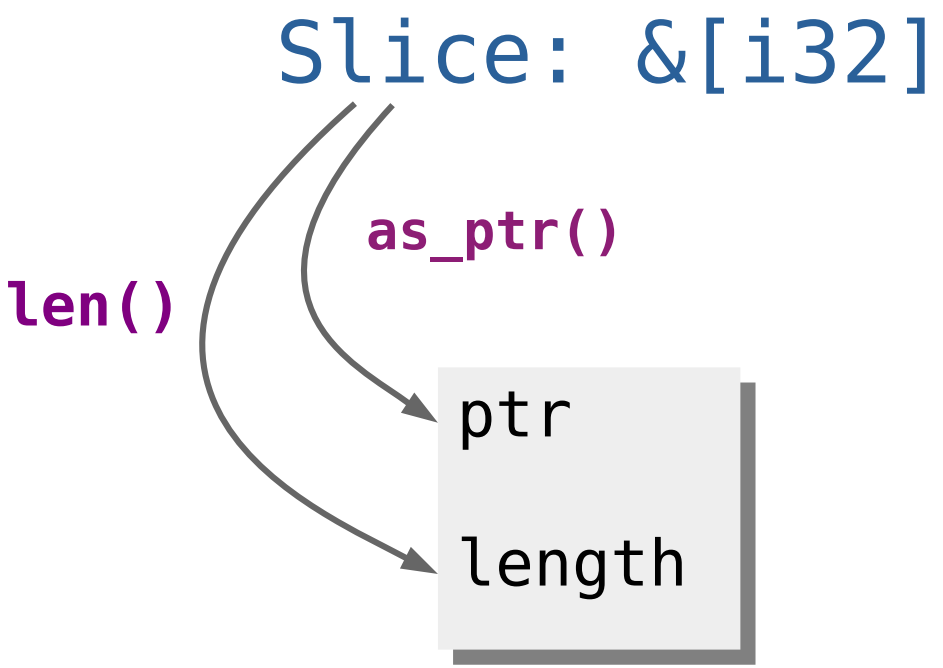
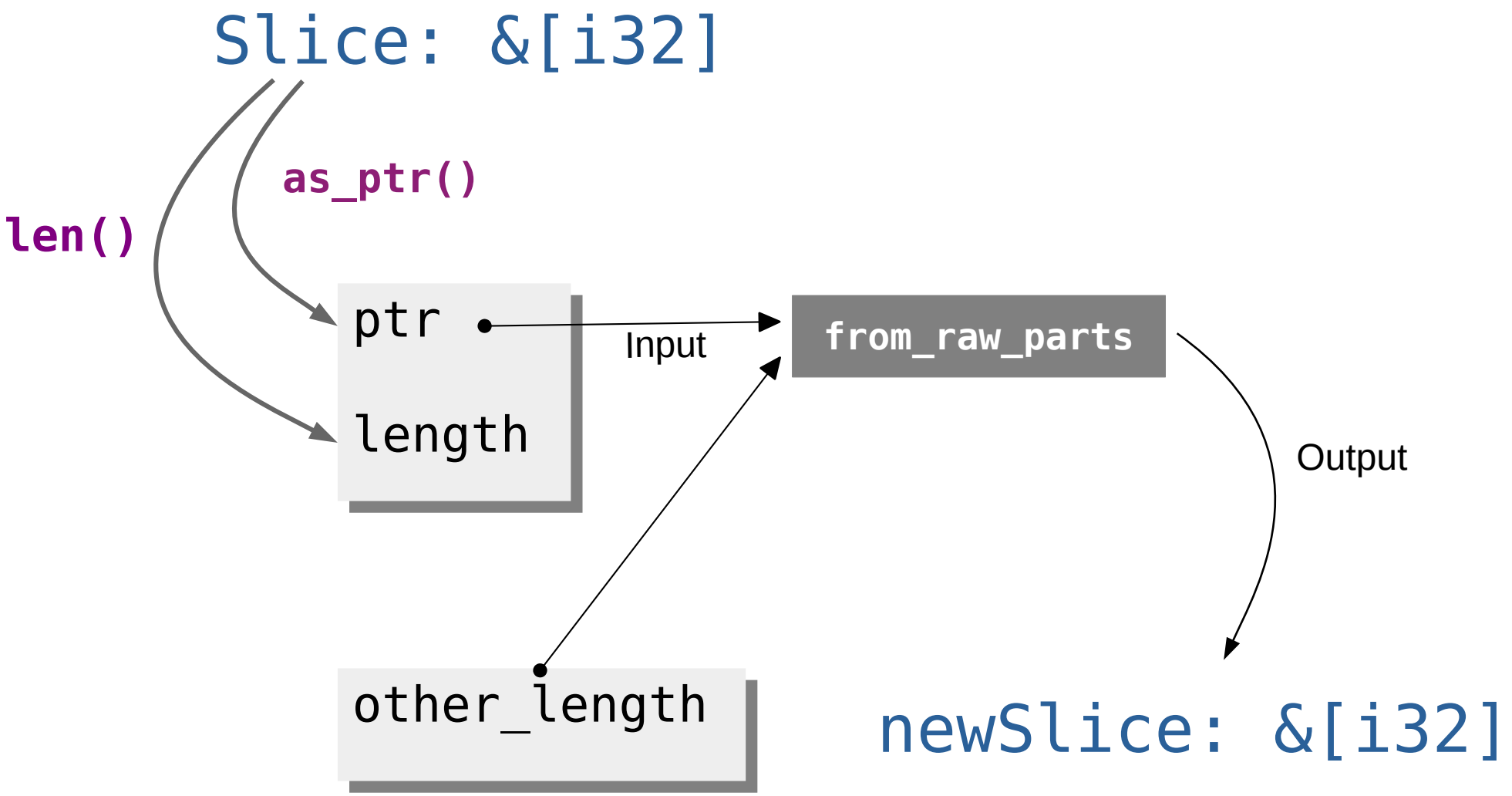
```



two Mutable Borrow occurs at the same time


Slice: &[i32]
as_ptr()
len()
ptr
length


Slice: &[i32]
as_ptr()
len()
ptr
length
Input
from_raw_parts
Output
other_length
newSlice: &[i32]

```
use std::slice;

fn split_at_mut(slice: &mut [i32], mid: usize)
-> (&mut [i32], &mut [i32])
{
    let len = slice.len();
    let ptr = slice.as_mut_ptr();

    assert!(mid <= len);

    unsafe {
        (slice::from_raw_parts_mut(ptr, mid),
         slice::from_raw_parts_mut(ptr.offset(mid as isize), len - mid))
    }
}
```

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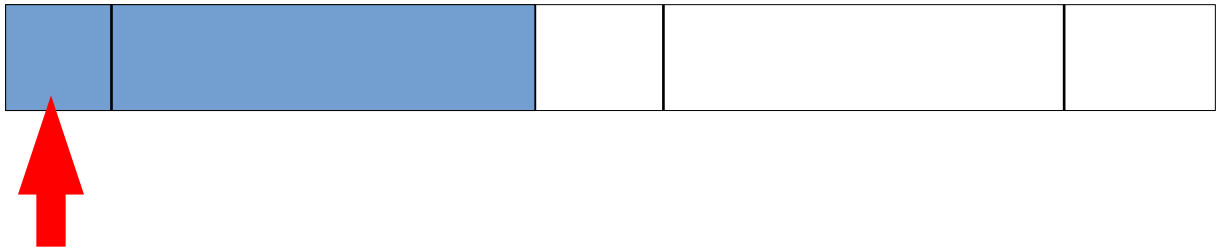

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}
```

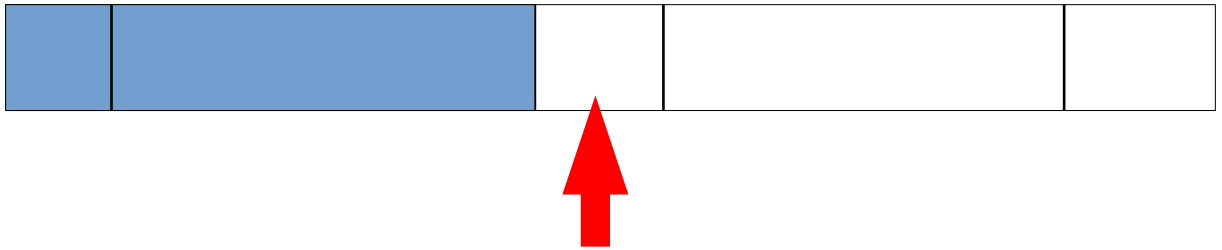

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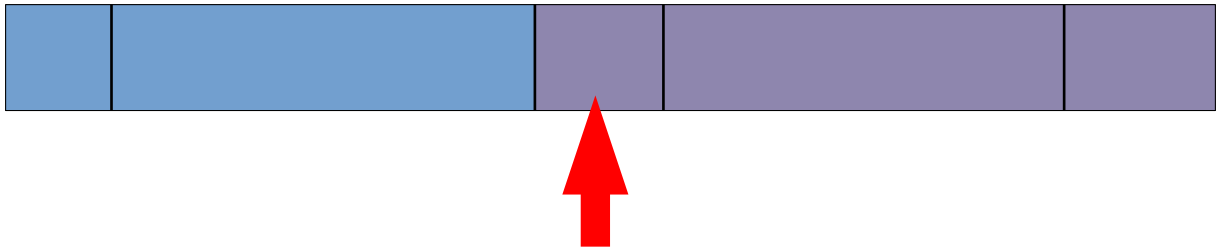

Convert raw pointer to reference

```
use std::mem::transmute;

fn main() {
    let r;
    {
        let x = 5;

        let p = &x as *const _;

        r = unsafe { transmute::<*const i32, &i32>(p) };
    }
    println!("{}", r);
}
```

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```

Then you can get a dangling pointer ~

來自異世界的魔法：Macros

Macros

- **起源**： Lisp
- **特色**： Syntax extension (語法擴展)
- **目的**：把 AST 轉換成另一個 AST ~
- **Rust 的 Macros 分為兩類**：
    1. **Declarative Macro**
    2. **Procedural Macro**

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Q. Why it's hard to read or understand ?

A. You’re writing Rust code that writes Rust code

Example

```
#[macro_export]
macro_rules! vec {
    ( $( $x:expr ),* ) => {

        {
            let mut temp_vec = Vec::new();
            $(
                temp_vec.push($x);
            )*
            temp_vec
        }
    };
}
```

Example

When match the token tree(tt) at left-hand side then expand the token tree at right-hand side

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macro_rules! vec {
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```

Declarative Macro

```
( $lhs: tt ) => ( $rhs: tt ); +
```

Declarative Macro

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```

```
$( … ) sep rep
```

Declarative Macro

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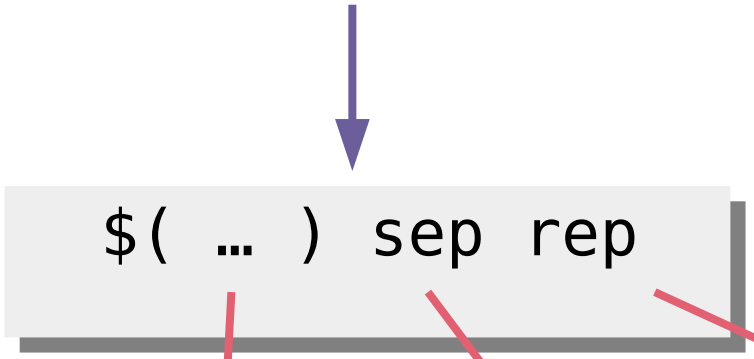

Pattern 放裡面 ~

‘+’ or ‘*’
至少 1 個 至少 0 個

分隔用的符號，可以是 Empty

Example

Usage.

```
let x = vec![1,2,3];
```

```
#[macro_export]
macro_rules! vec {
    ( $( $x:expr ),* ) => {

        {
            let mut temp_vec = Vec::new();
            $(
                temp_vec.push($x);
            )*
            temp_vec
        }
    };
}
```

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            let mut temp_vec = Vec::new();
            $(
                temp_vec.push($x);
            )*
            temp_vec
        }
    };
}
```

```
temp_vec.push(1);
```

Example

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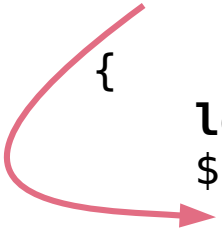

```
temp_vec.push(1);
temp_vec.push(2);
```

Example

Usage.

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    };
}
```

```
temp_vec.push(1);
temp_vec.push(2);
temp_vec.push(3);
```

但位子 SEP 是空的，所以結束匹配

Example

Usage.

```
let x = vec![1,2,3];
```

```
let x = {
    let mut temp_vec = Vec::new();
    temp_vec.push(1);
    temp_vec.push(2);
    temp_vec.push(3);

    temp_vec
};
```

Problem

1. `vec![1,2,3,]` is not allowed, how to modify it to accept this situation?

2. If you want to count the number of elements and initialize with `with_capacity` method, then how to modify it?

Solution 1

```
#[macro_export]
macro_rules! vec {
    ( $( $x:expr ),* $(,)*) => {
        {
            let mut temp_vec = Vec::new();
            $(
                temp_vec.push($x);
            )*
            temp_vec
        }
    };
}
```

Solution 2

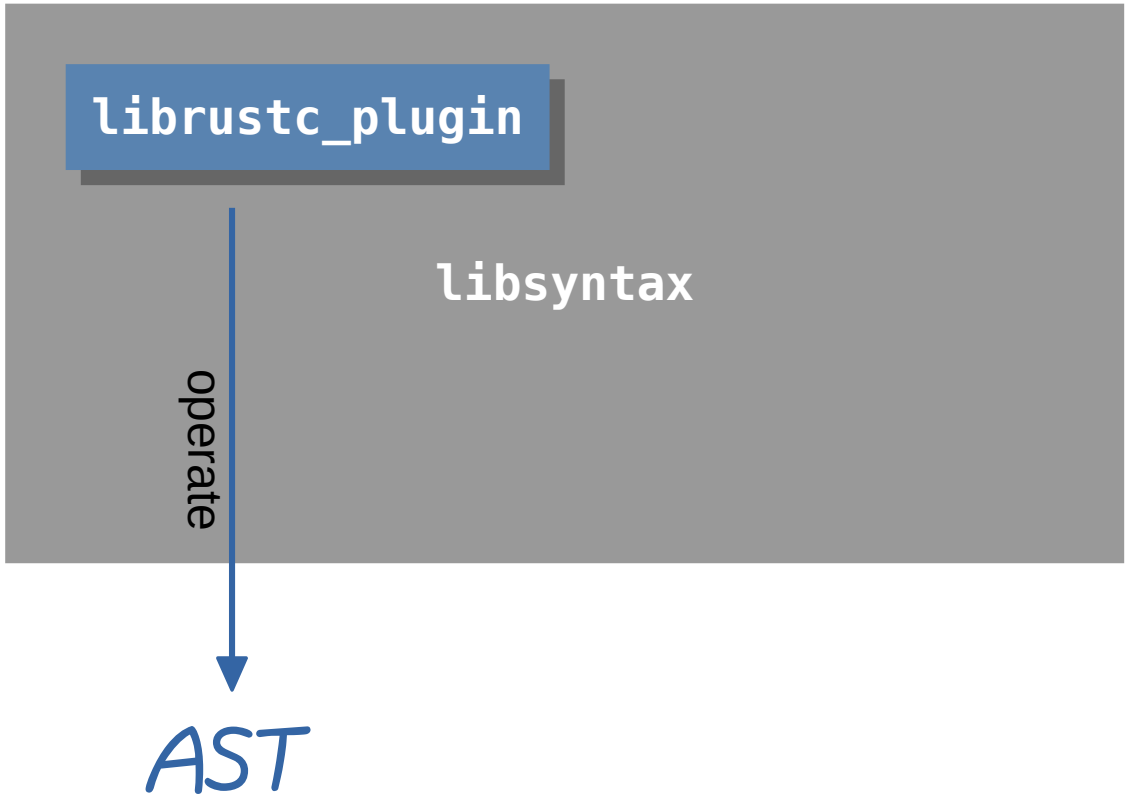
```
#[macro_export]
macro_rules! vec {
    (@unit $($x:tt)*) => (());

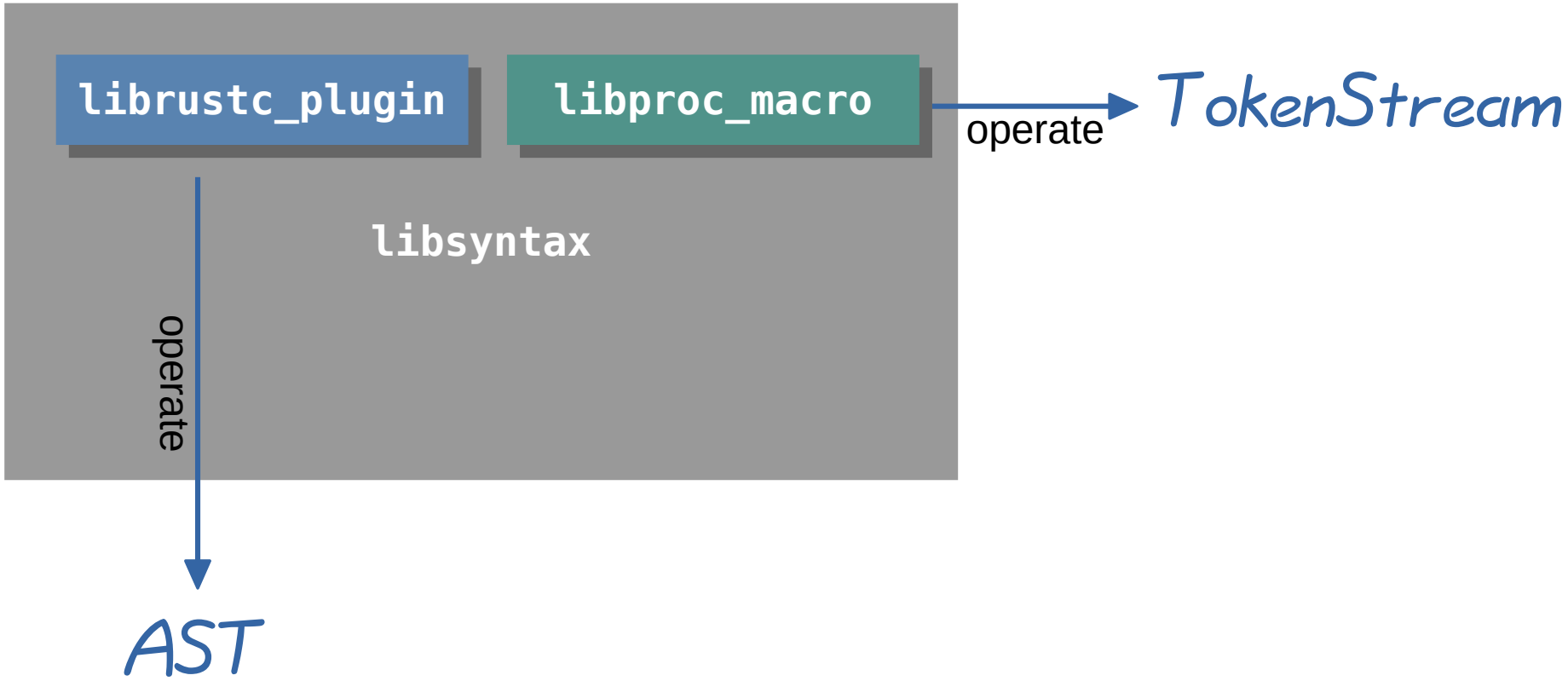
    (@count $($key:expr),*) =>
        (<[()]>::len(&[$(vec!(@unit $key)),*]));

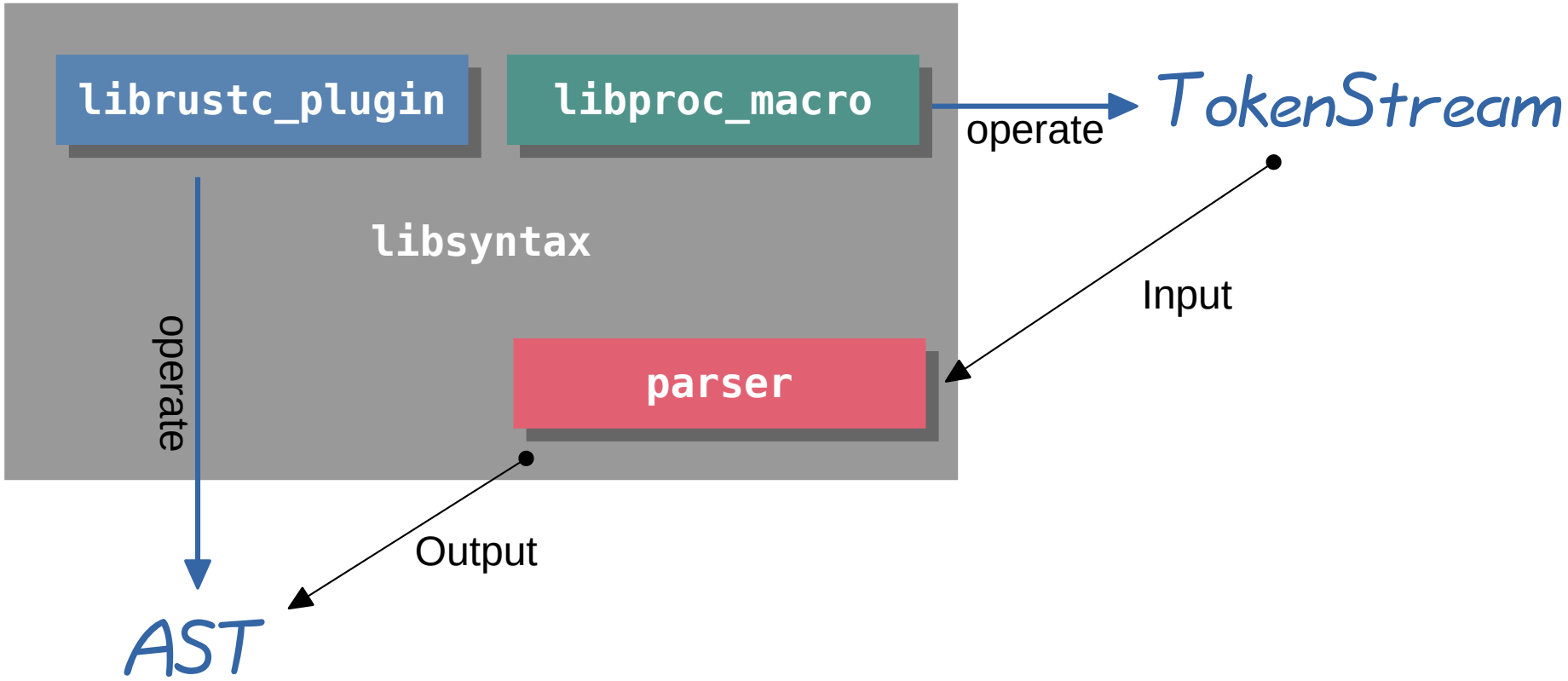
    ($($x:expr),* $(,)*) => {
        {
            let _cap = vec!(@count $($x),*);
            let mut temp_vec = Vec::with_capacity(_cap);
            $(
                temp_vec.push($x);
            )*
            temp_vec
        }
    };
}
```

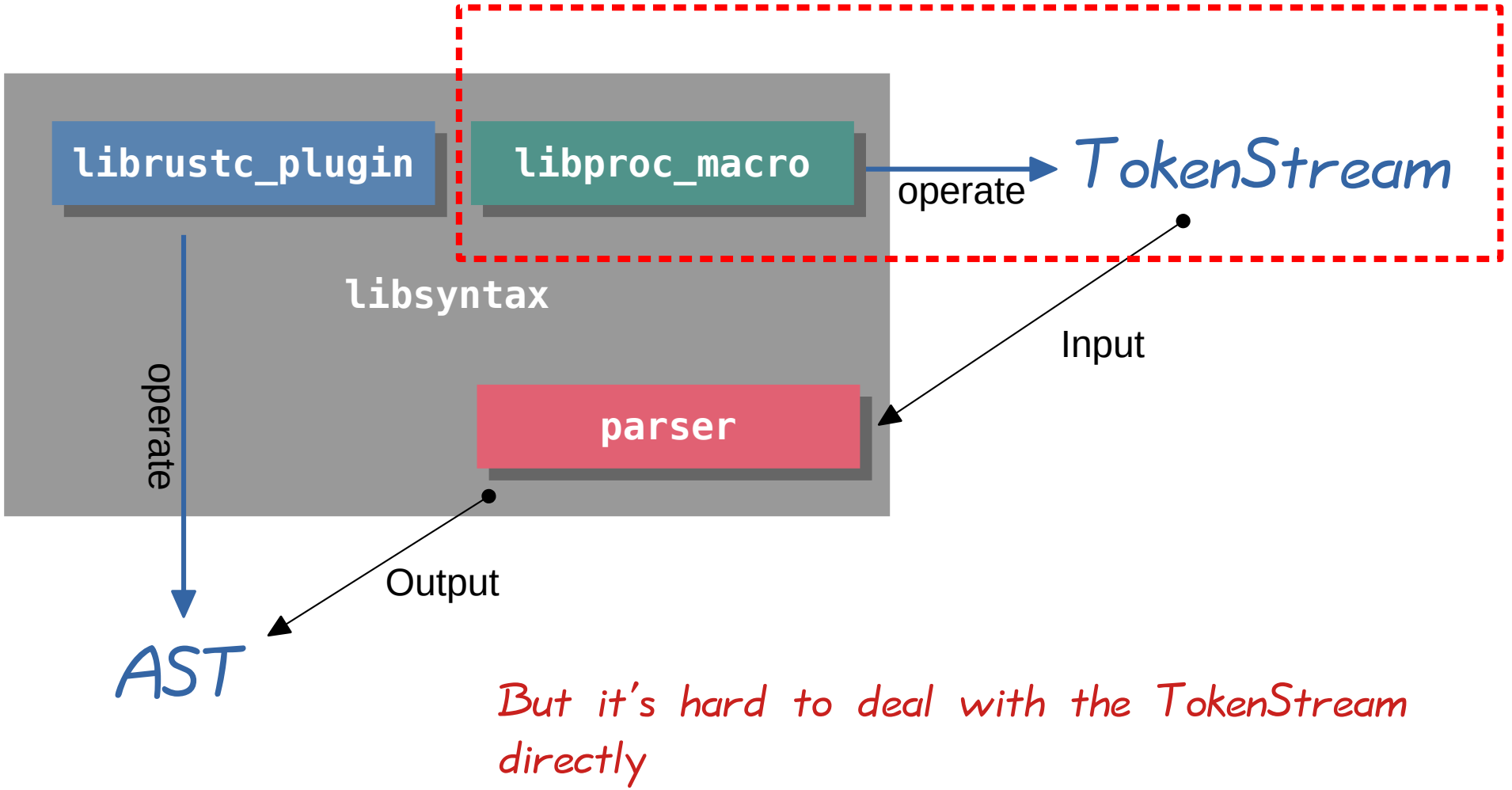
Procedural Macro

Goal : *Syntax extension !*

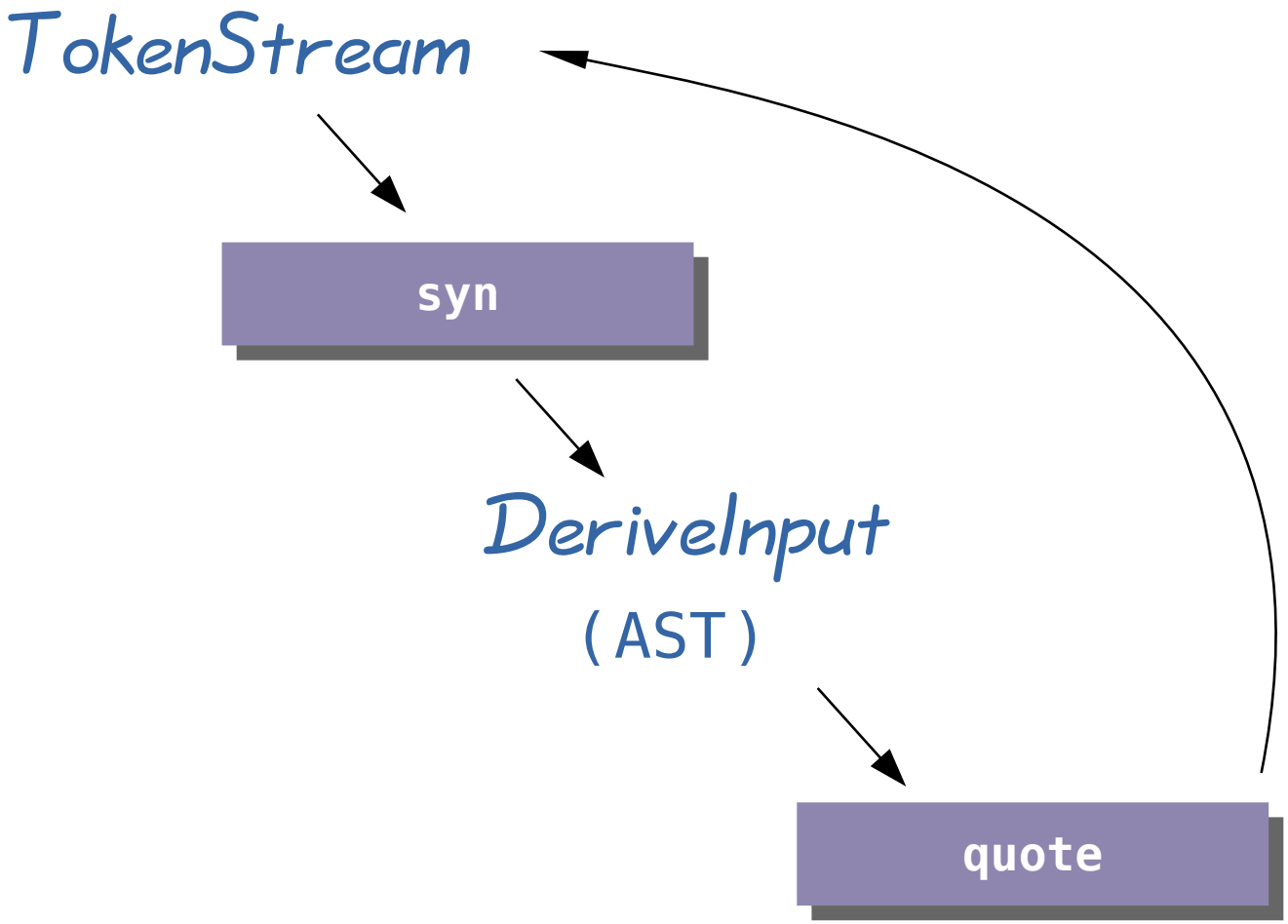

librustc_plugin
libsyntax
operate
AST

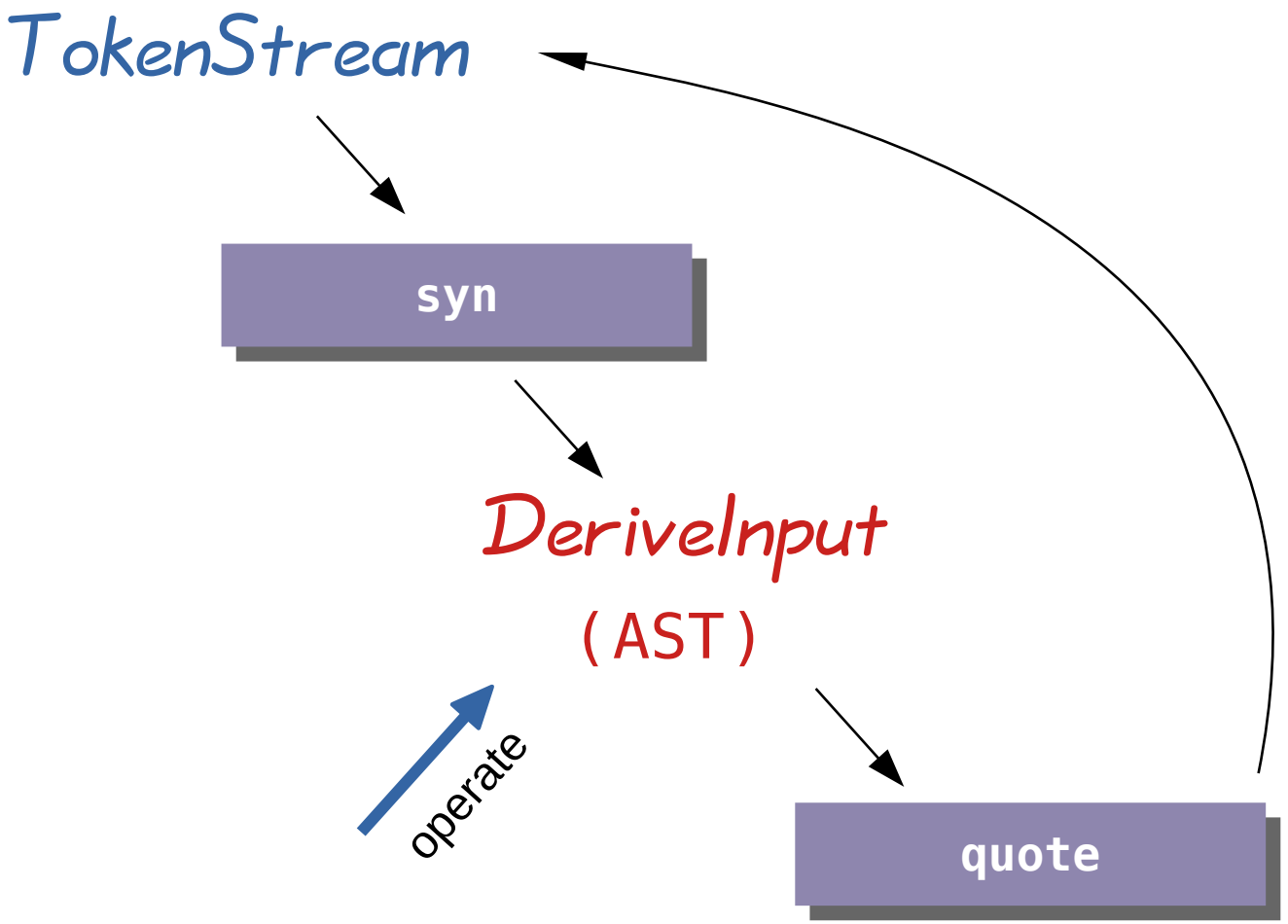

librustc_plugin
libproc_macro
operate
TokenStream
libsyntax
operate
AST


librustc_plugin
libproc_macro
operate
TokenStream
libsyntax
operate
Input
parser
Output
AST



But it's hard to deal with the TokenStream directly


TokenStream
syn
DeriveInput
(AST)
quote


TokenStream
syn
DeriveInput
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Example

```
use hello_macro::HelloMacro;
use hello_macro_derive::HelloMacro;

#[derive(HelloMacro)]
struct Pancakes;

fn main() {
    Pancakes::hello_macro();
}
```

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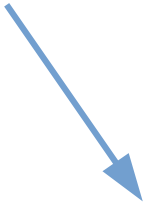

“Hello, Macro! My name is Pancakes”

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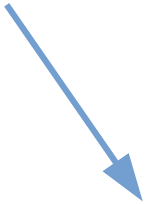

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#[derive(HelloMacro)]
struct Pancakes;

fn main() {
    Pancakes::hello_macro();
}
```
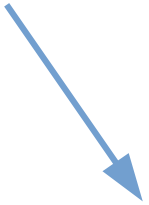

```
impl HelloMacro for Pancakes {
    fn hello_macro() {
        println!("Hello, Macro! My name is {}",
                 stringify!(Pancakes));
    }
}
```



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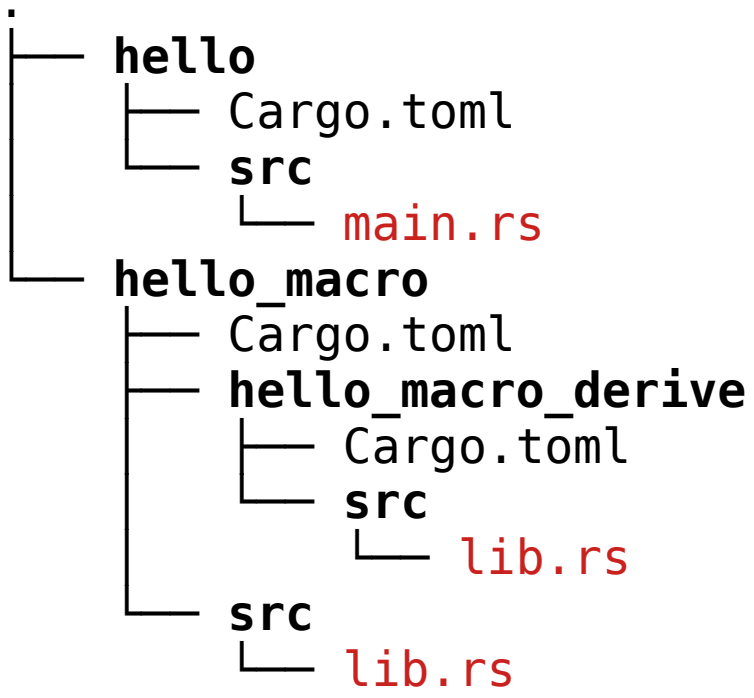
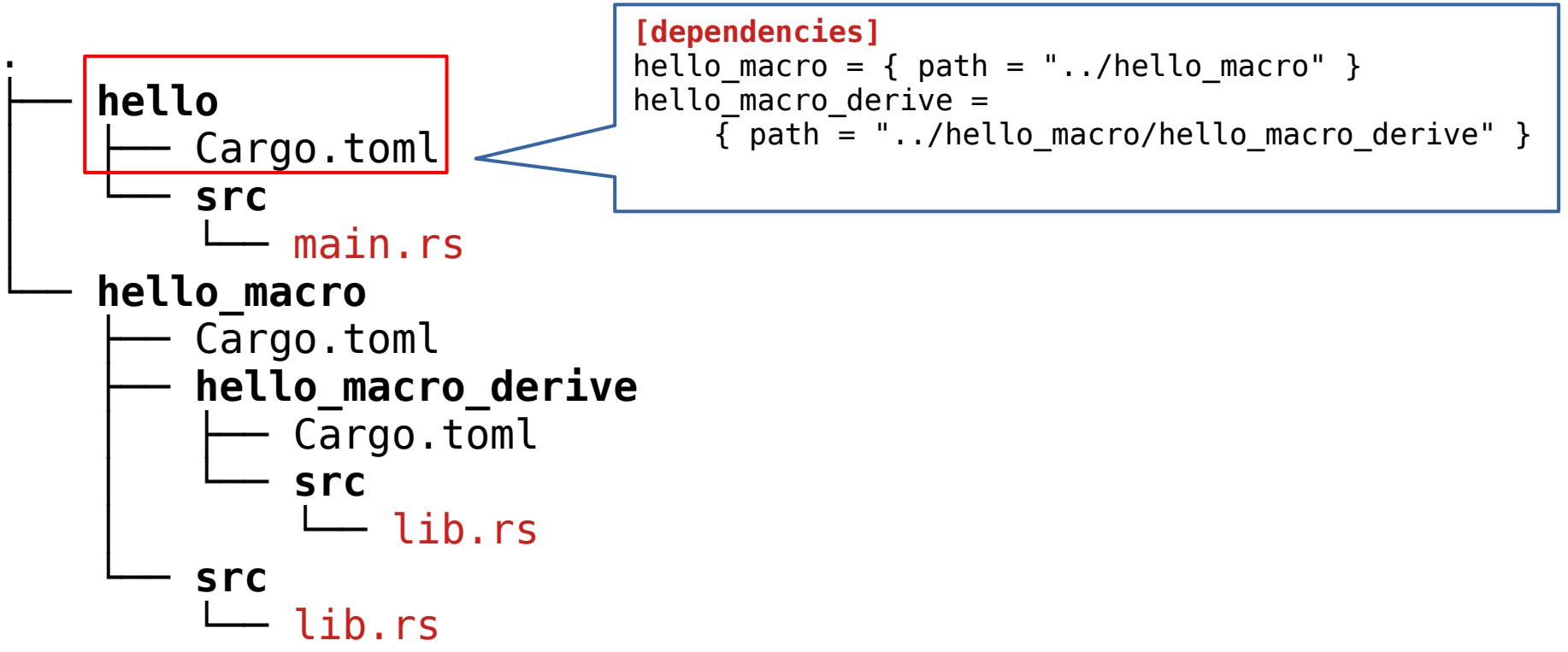

.
hello
Cargo.toml
src
main.rs
hello_macro
Cargo.toml
hello_macro_derive
Cargo.toml
src
lib.rs
src
lib.rs

Example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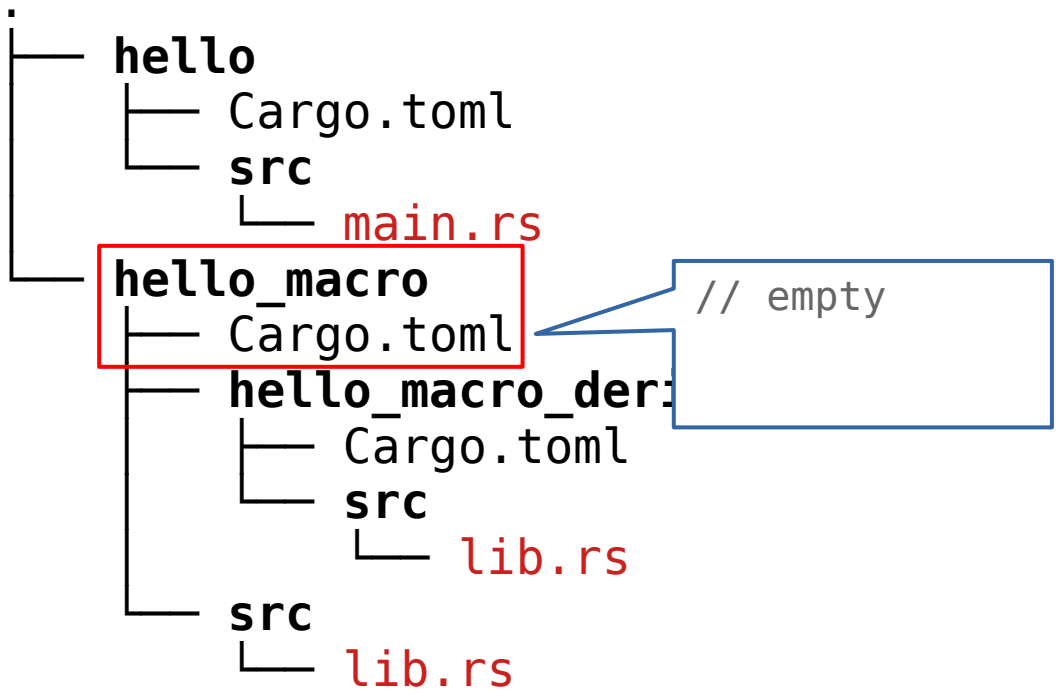
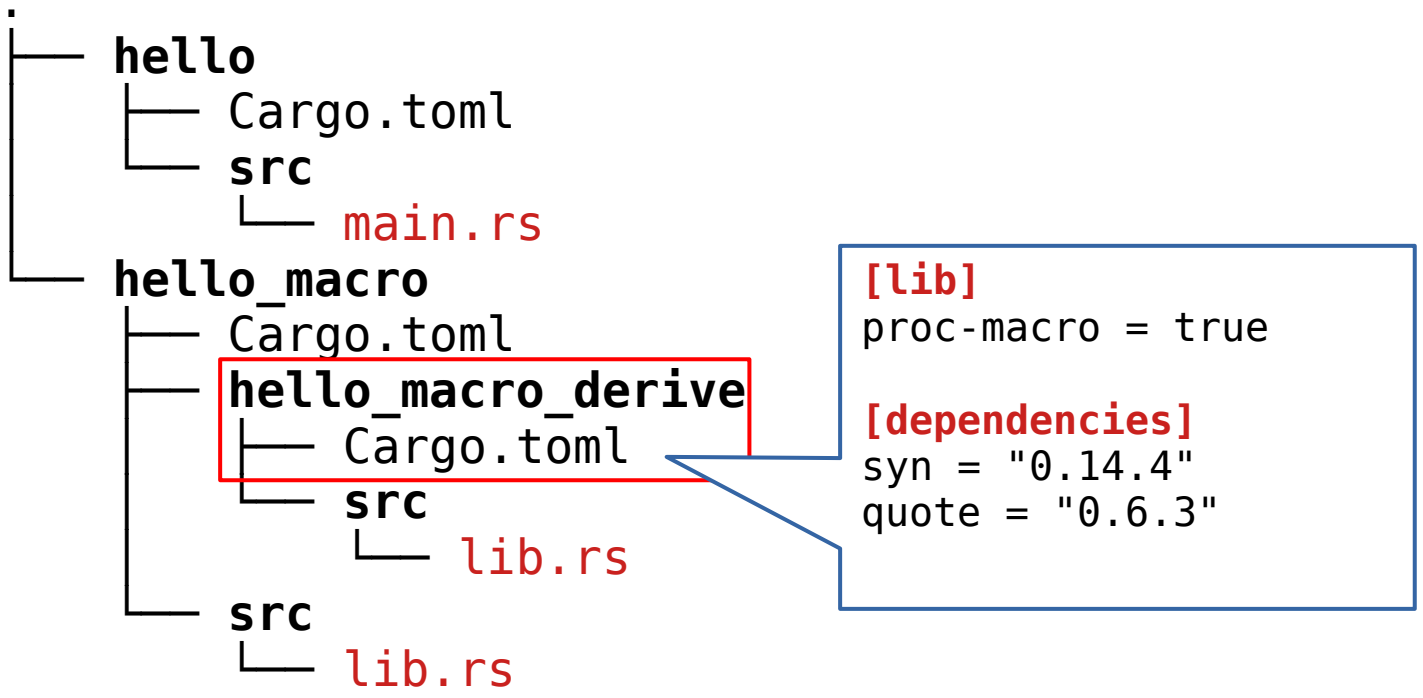
hello
Cargo.toml
src
main.rs
hello_macro
Cargo.toml
hello_macro_derive
Cargo.toml
src
lib.rs
src
lib.rs
[dependencies]
hello_macro = { path = "../hello_macro" }
hello_macro_derive =
{ path = "../hello_macro/hello_macro_derive" }

Example


.
hello
Cargo.toml
src
main.rs
hello_macro
Cargo.toml
hello_macro_deri
Cargo.toml
src
lib.rs
src
lib.rs
// empty

Example


.
hello
Cargo.toml
src
main.rs
hello_macro
Cargo.toml
hello_macro_derive
Cargo.toml
src
lib.rs
src
lib.rs
[lib]
proc-macro = true
[dependencies]
syn = "0.14.4"
quote = "0.6.3"

```rust
pub trait HelloMacro {
    fn hello_macro();
}
```

hello_macro/src/lib.rs

```rust
extern crate proc_macro;

use crate::proc_macro::TokenStream;
use quote::quote;
use syn;

#[proc_macro_derive(HelloMacro)]
pub fn hello_macro_derive(input: TokenStream) -> TokenStream {
    // Construct a representation of Rust code as a syntax tree
    // that we can manipulate
    let ast = syn::parse(input).unwrap();

    // Build the trait implementation
    impl_hello_macro(&ast)
}

fn impl_hello_macro(ast: &syn::DeriveInput) -> TokenStream {
    let name = &ast.ident;
    let gen = quote! {
        impl HelloMacro for #name {
            fn hello_macro() {
                println!("Hello, Macro! My name is {}", stringify!(#name));
            }
        }
    };
    gen.into()
}
```

hello_macro_derive/src/lib.rs

```rust
extern crate proc_macro;

use crate::proc_macro::TokenStream;
use quote::quote;
use syn;

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pub fn hello_macro_derive(input: TokenStream) -> TokenStream {
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fn impl_hello_macro(ast: &syn::DeriveInput) -> TokenStream {
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    let gen = quote! {
        impl HelloMacro for #name {
            fn hello_macro() {
                println!("Hello, Macro! My name is {}", stringify!(#name));
            }
        }
    };
    gen.into()
}
```

It's corresponding to the

`#[dervie(HellMacro)]` *in* `hello/src/main.rs`

hello_macro_derive/src/lib.rs

```rust
extern crate proc_macro;

use crate::proc_macro::TokenStream;
use quote::quote;
use syn;

#[proc_macro_derive(HelloMacro)]
pub fn hello_macro_derive(input: TokenStream) -> TokenStream {
    // Construct a representation of Rust code as a syntax tree
    // that we can manipulate
    let ast = syn::parse(input).unwrap();

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        impl HelloMacro for #name {
            fn hello_macro() {
                println!("Hello, Macro! My name is {}", stringify!(#name));
            }
        }
    };
    gen.into()
}
```

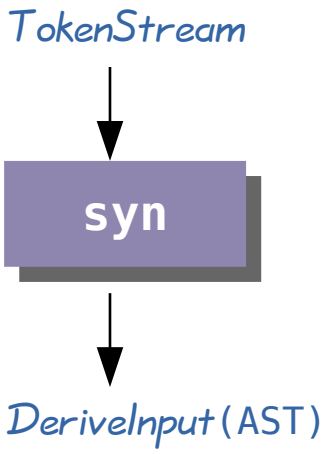

hello_macro_derive/src/lib.rs

```rust
extern crate proc_macro;

use crate::proc_macro::TokenStream;
use quote::quote;
use syn;

#[proc_macro_derive(HelloMacro)]
pub fn hello_macro_derive(input: TokenStream) -> TokenStream {
    // Construct a representation of Rust code as a syntax tree
    // that we can manipulate
    let ast = syn::parse(input).unwrap();

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    let gen = quote! {
        impl HelloMacro for #name {
            fn hello_macro() {
                println!("Hello, Macro! My name is {}", stringify!(#name));
            }
        }
    };
    gen.into()
}
```

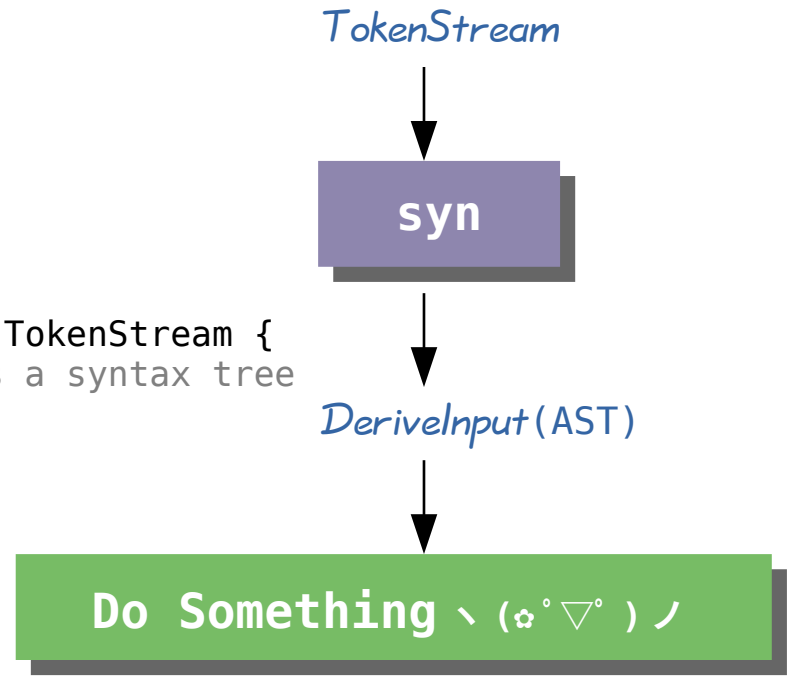

hello_macro_derive/src/lib.rs

```rust
extern crate proc_macro;

use crate::proc_macro::TokenStream;
use quote::quote;
use syn;

#[proc_macro_derive(HelloMacro)]
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    // Build the trait implementation
    impl_hello_macro(&ast)
}

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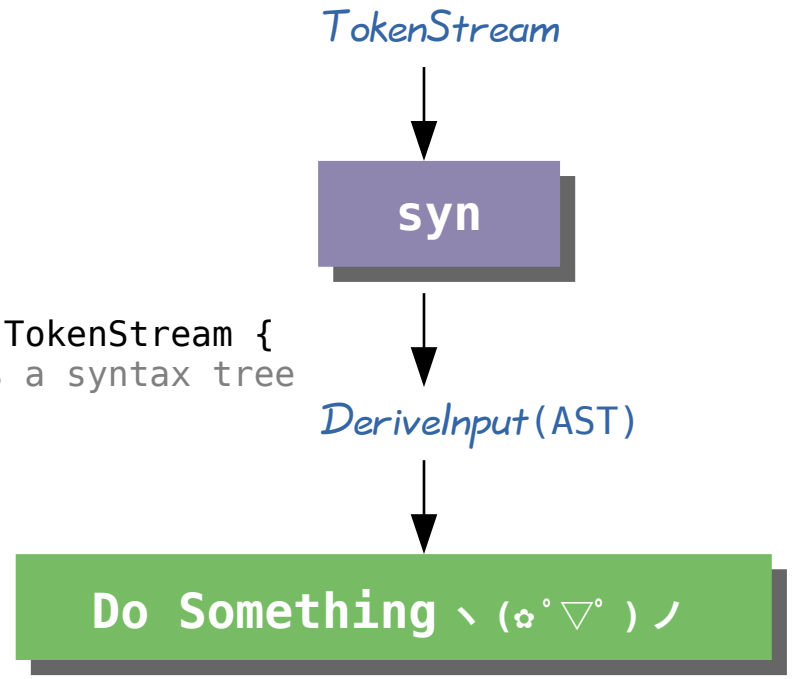
    let name = &ast.ident;
    let gen = quote! {
        impl HelloMacro for
            fn hello_macro() {
                println!("Hello, Macro! My name is {}", stringify!(#name));
            }
        }
    };
    gen.into()
}
```

Pancakes



hello_macro_derive/src/lib.rs

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extern crate proc_macro;

use crate::proc_macro::TokenStream;
use quote::quote;
use syn;

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pub fn hello_macro_derive(input: TokenStream) -> TokenStream {
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    // that we can manipulate
    let ast = syn::parse(input).unwrap();

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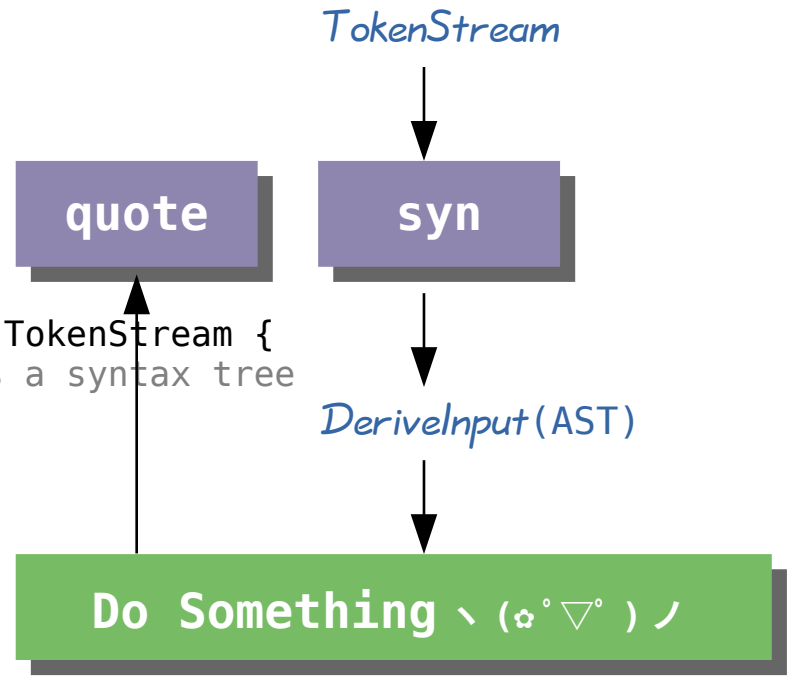
    let gen = quote! {
        impl HelloMacro for #name {
            fn hello_macro() {
                println!("Hello, Macro! My name is {}", stringify!(#name));
            }
        }
    };
    gen.into()
}
```



hello_macro_derive/src/lib.rs

```rust
extern crate proc_macro;

use crate::proc_macro::TokenStream;
use quote::quote;
use syn;

#[proc_macro_derive(HelloMacro)]
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}

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    let gen = quote! {
        impl HelloMacro for #name {
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            }
        }
    };
    gen.into()
}
```

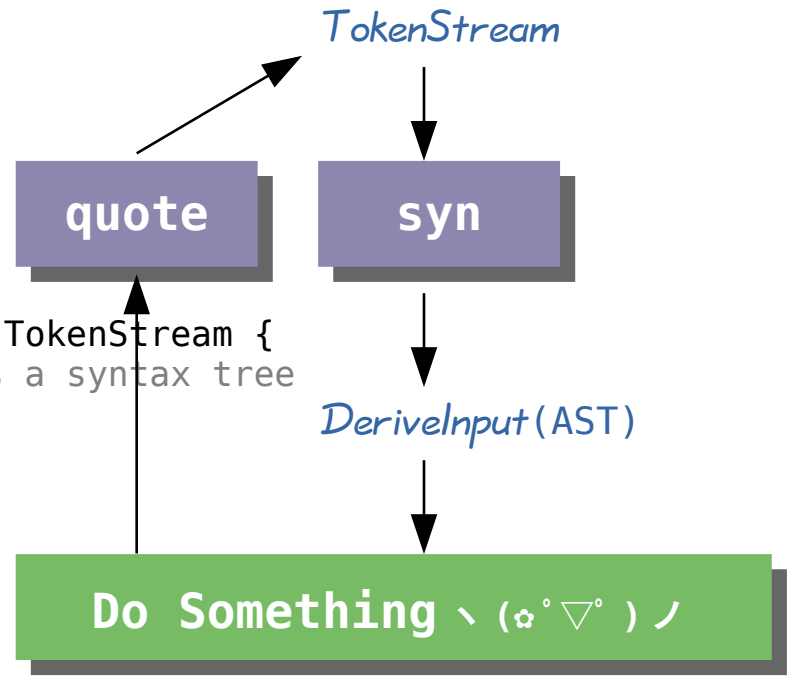

hello_macro_derive/src/lib.rs

Attribute-like Macro

```
#[route(GET, "/")]
fn index() { … }
```

```
#[proc_macro_attribute]
pub fn route(attr: TokenStream,
             item: TokenStream) -> TokenStream
{
```

Function-like Macro

Attribute-like Macro

```
#[route(GET, "/")]
fn index() { … }
```

```
#[proc_macro_attribute]
pub fn route(attr: TokenStream,
             item: TokenStream) -> TokenStream
{
```

Function-like Macro

Attribute-like Macro

```
#[route(GET, "/")]
fn index() { … }
```

```
#[proc_macro_attribute]
pub fn route(attr: TokenStream,
             item: TokenStream) -> TokenStream
{
```

Function-like Macro

Attribute-like Macro

```
#[route(GET, "/")]
fn index() { … }
```

```
#[proc_macro_attribute]
pub fn route(attr: TokenStream,
             item: TokenStream) -> TokenStream
{
```

Function-like Macro

Attribute-like Macro

```
#[route(GET, "/")]
fn index() { … }
```

```
#[proc_macro_attribute]
pub fn route(attr: TokenStream,
             item: TokenStream) -> TokenStream
{
```

Function-like Macro

```
let sql = sql!(
SELECT * FROM posts WHERE id=1
);
```

```
#[proc_macro]
pub fn sql(input: TokenStream) -> TokenStream
{
    …
```

Attribute-like Macro

```
#[route(GET, "/")]
fn index() { … }
```

```
#[proc_macro_attribute]
pub fn route(attr: TokenStream,
             item: TokenStream) -> TokenStream
{
```

Function-like Macro

```
let sql = sql!(
SELECT * FROM posts WHERE id=1
);
```

```
#[proc_macro]
pub fn sql(input: TokenStream) -> TokenStream
{
    …
```

Lifetimes 我們很好 ~

```
struct Context(&str);

struct Parser {
    context: &Context,
}

impl Parser {
    fn parse(&self) -> Result<(), &str> {
        Err(&self.context.0[1..])
    }
}
```

```
struct Context(&str);

struct Parser {
    context: &Context,
}

impl Parser {
    fn parse(&self) -> Result<(), &str> {
        Err(&self.context.0[1..])
    }
}
```

Can not compile ! Missing lifetime specifier

```rust
struct Context<'a>(&'a str);

struct Parser<'a> {
    context: &'a Context<'a>,
}

impl<'a> Parser<'a> {
    fn parse<'b>(&'b self) -> Result<(), &'b str> {
        Err(&self.context.0[1..])
    }
}
```

```rust
struct Context<'a>(&'a str);

struct Parser<'a> {
    context: &'a Context<'a>,
}

impl<'a> Parser<'a> {
    fn parse<'b>(&'b self) -> Result<(), &'b str> {
        Err(&self.context.0[1..])
    }
}
```

And we added this function :

```rust
fn parse_context(context: Context) -> Result<(), &str> {
    Parser { context: &context }.parse()
}
```

```rust
struct Context<'a>(&'a str);

struct Parser<'a> {
    context: &'a Context<'a>,
}

impl<'a> Parser<'a> {
    fn parse<'b>(&'b self) -> Result<(), &'b str> {
        Err(&self.context.0[1..])
    }
}
```

And we added this function :

```rust
fn parse_context(context: Context) -> Result<(), &str> {
    Parser { context: &context }.parse()
}
```

Can not compile ! Returns a value referencing data owned by the current function

```rust
struct Context<'a>(&'a str);

struct Parser<'a> {
    context: &'a Context<'a>,
}

impl<'a> Parser<'a> {
    fn parse<'b>(&'b self) -> Result<(), &'b str> {
        Err(&self.context.0[1..])
    }
}
```

Transfer the context's ownership into function

```rust
fn parse_context(context: Context) -> Result<(), &str> {
    Parser { context: &context }.parse()
}
```

```rust
struct Context<'a>(&'a str);

struct Parser<'a> {
    context: &'a Context<'a>,
}

impl<'a> Parser<'a> {
    fn parse<'b>(&'b self) -> Result<(), &'b str> {
        Err(&self.context.0[1..])
    }
}
```

```rust
fn parse_context(context: Context) -> Result<(), &str> {
    Parser { context: &context }.parse()
}
```

Create a Parser, and borrow the context

```rust
struct Context<'a>(&'a str);

struct Parser<'a> {
    context: &'a Context<'a>,
}

impl<'a> Parser<'a> {
    fn parse<'b>(&'b self) -> Result<(), &'b str> {
        Err(&self.context.0[1..])
    }
}
```

```rust
fn parse_context(context: Context) -> Result<(), &str> {
    Parser { context: &context }.parse()
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```

Create a Parser, and borrow the context

```
struct Context<'a>(&'a str);

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impl<'a> Parser<'a> {
    fn parse<'b>(&'b self) -> Result<(), &'b str> {
        Err(&self.context.0[1..])
    }
}
```
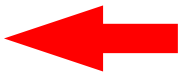
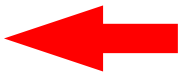



We just need to let str and Context has different lifetimes

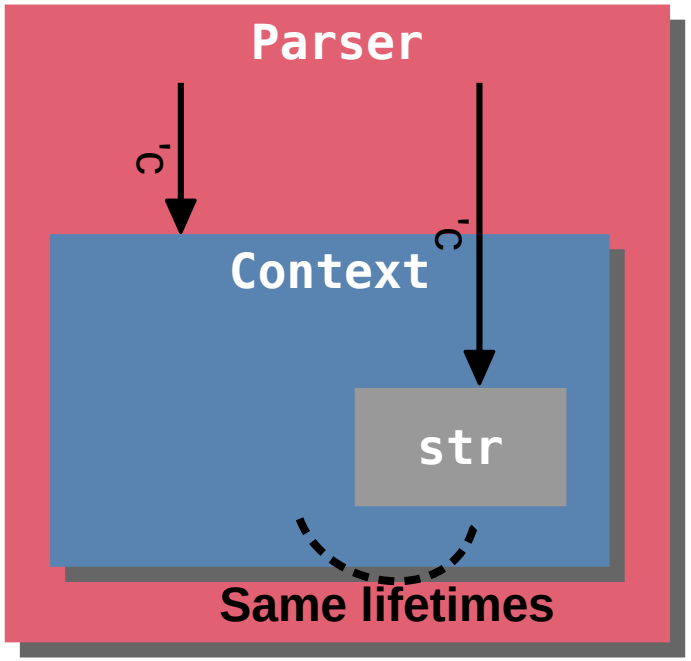
```
fn parse_context(context: Context) -> Result<(), &str> {
    Parser { context: &context }.parse()
}
```

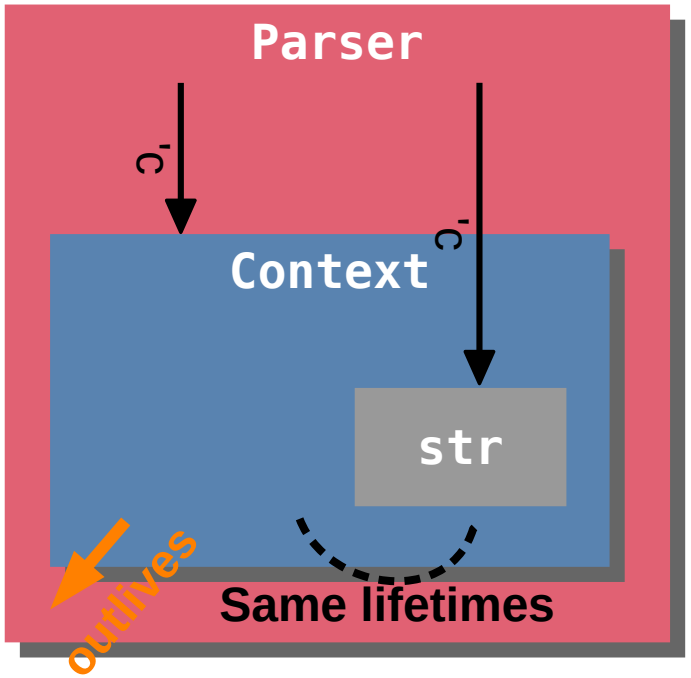
```
struct Context<'a>(&'a str);

struct Parser<'c, 's> {
    context: &'c Context<'s>,
}

impl<'c, 's> Parser<'c, 's> {
    fn parse<'b>(&'b self) -> Result<(), &'s str> {
        Err(&self.context.0[1..])
    }
}
```

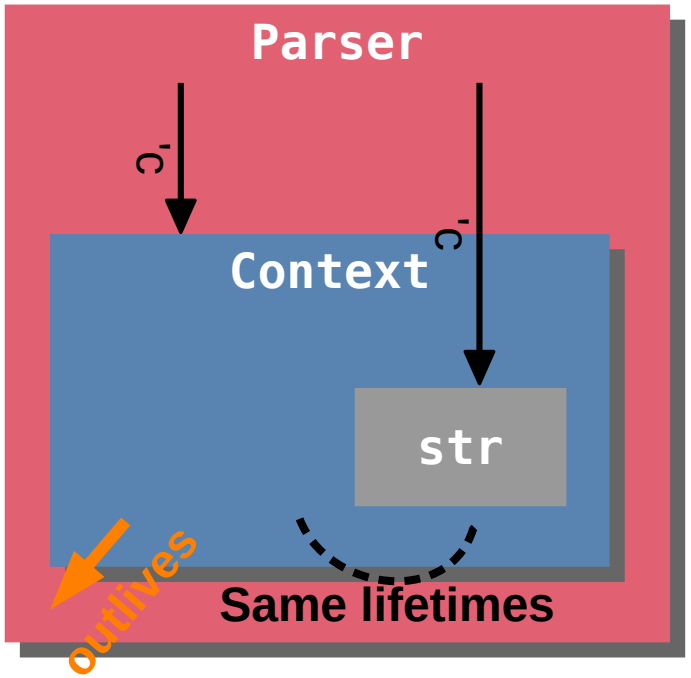


We just need to let &str and Context has different lifetimes

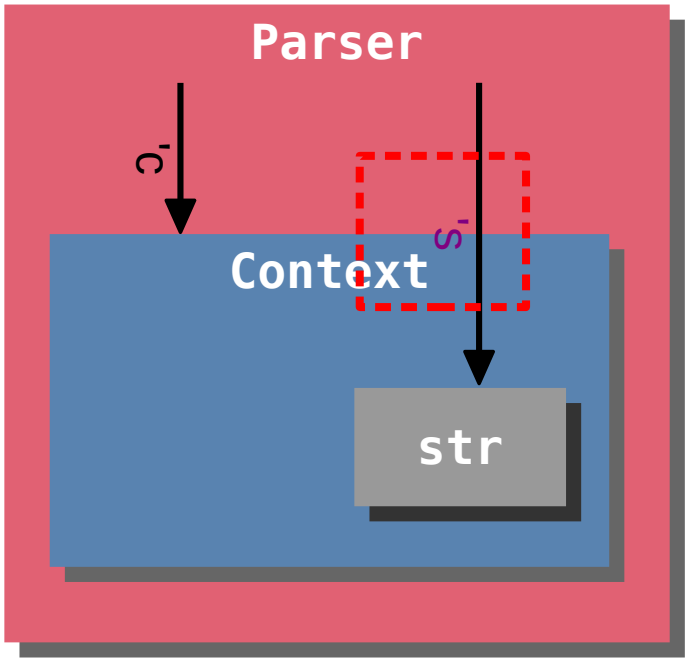
```
fn parse_context(context: Context) -> Result<(), &str> {
    Parser { context: &context }.parse()
}
```

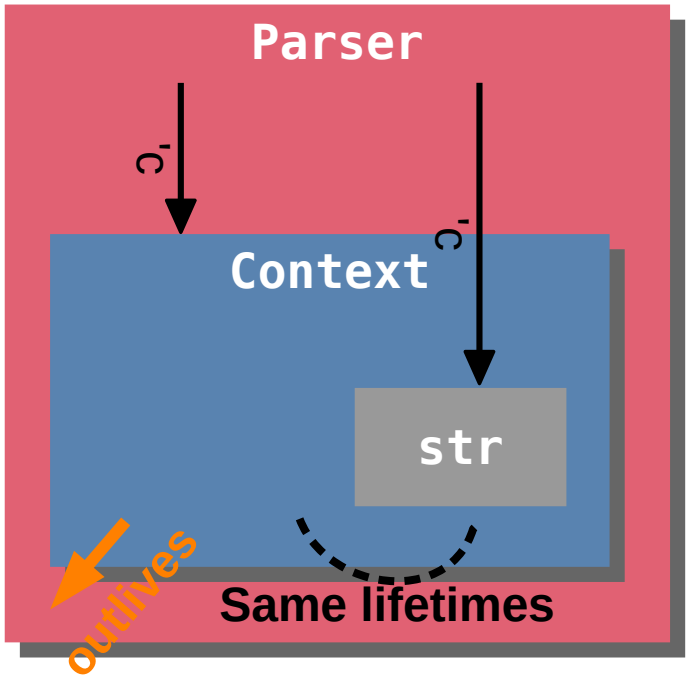

Parser
'c
'c
Context
str
Same lifetimes


Parser
'c
'c
Context
str
Same lifetimes
outlives

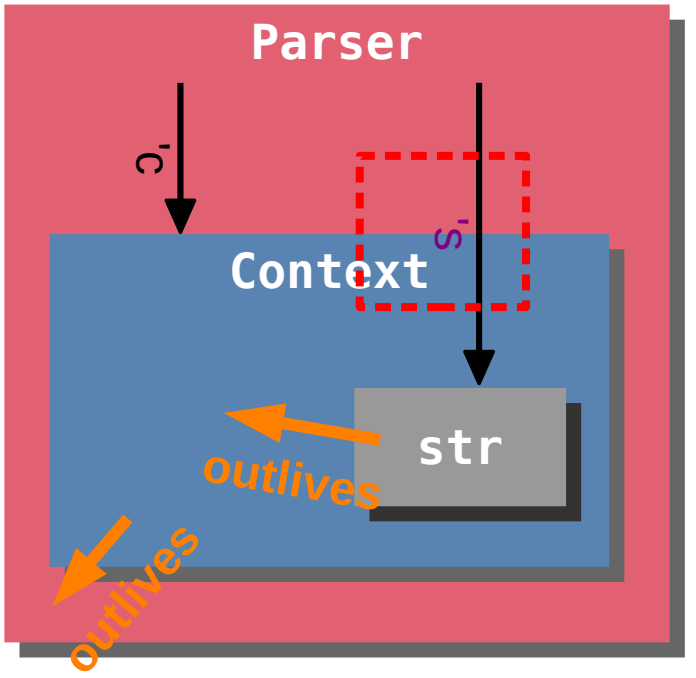


Specify the different lifetimes





Specify the different lifetimes



Problem 1 . Combine the Unsafe and Liftimes

```
struct Cell<T>{value: T}

impl<T> Cell<T> {
    fn set(&self, v: T) {
        use std::ptr;
        let p = &self.value as *const _ as *mut _;

        unsafe {
            ptr::write(p, v);
        }
    }
}

fn evil(c: &Cell<&i32>) {

    let drop_value = 42;

    c.set(&drop_value);
}
```

Problem 2. Combine the Unsafe and Liftimes

```
struct Cell<T>{value: T}

impl<T> Cell<T> {
    fn set(&self, v: T) {
        use std::ptr;
        let p = &self.value as *const _ as *mut _;

        unsafe {
            ptr::write(p, v);
        }
    }
}

fn evil(c: &Cell<&i32>) {

    let drop_value = 42;

    c.set(&drop_value);
}
```

Why this is accepted by the Compiler ?

drop_value dropped here

Another Problem

```
Use std::cell::Cell;

fn eat<'a>(x: &'a Cell::<&'a i32>) {}

fn main() {
    let x = Cell::new(&5);
    {
        eat(&x);
    }
    x;
}
```

Another Problem

```
Use std::cell::Cell;

fn eat<'a>(x: &'a Cell::<&'a i32>) {}

fn main() {
    let x = Cell::new(&5);
    {
        eat(&x);
    }       -- borrow of x occurs here
    x;
}   ^
    |
    move out of x occurs here
    borrow later used here

    error[E0505]: cannot move out of x because it is borrowed
```

Hint

Subtyping and Variance

Reference.

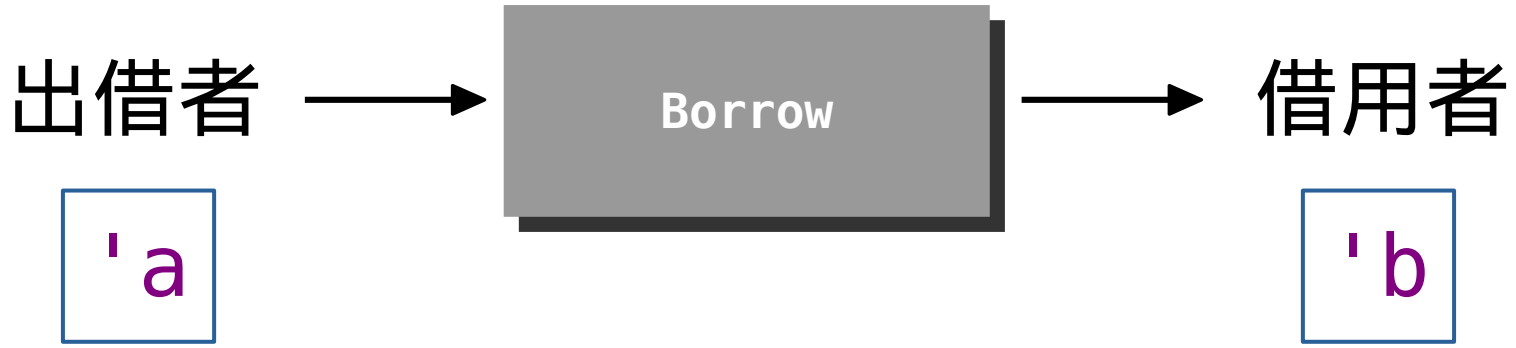
```
https://doc.rust-lang.org/nomicon/subtyping.html
```

Subtyping

- **寫法**：`'a : 'b`
- **意思**： Lifetimes `'a` is outlives Lifetimes `'b`

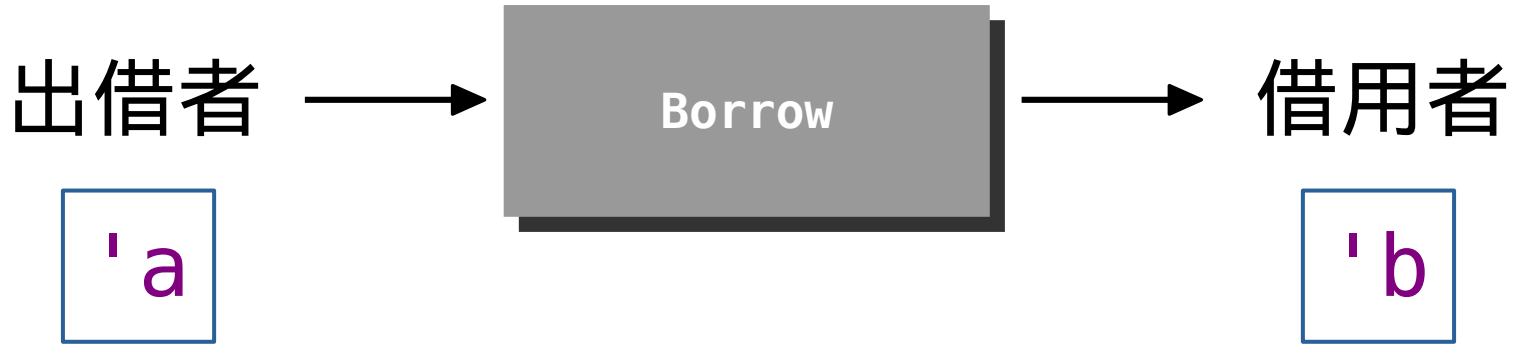
Subtyping

- 寫法：`'a : 'b`
- 意思： Lifetimes `'a` is outlives Lifetimes `'b`



Subtyping

- 寫法：`'a : 'b`
- 意思： Lifetimes `'a` is outlives Lifetimes `'b`



- 例子：

```
let p: &'p T = &'foo foo;
```

Then we say: `'foo : 'p`

```
struct Ref<'a, T: 'a>(&'a T);
```

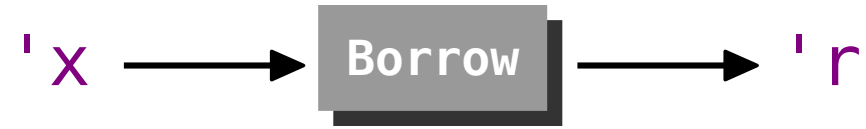
```
struct Ref<'a, T: 'a>(&'a T);
```

T can be any type, if it contains any reference then it must live at least as long as 'a

Or we say Lifetimes of &T must outlives lifetimes 'a

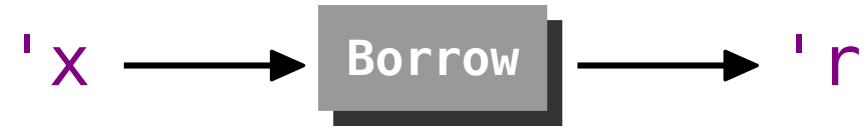
```
struct Ref<'a, T: 'a>(&'a T);

let x = 1;

let r = Ref(&x);




}
```

```
struct Ref<'a, T: 'a>(&'a T);

let x = 1;

let r: Ref(&'r T) = Ref(&'x x);
```




```
}
```

```
struct Ref<'a, T: 'a>(&'a T);

let x = 1;

let r: Ref(&'r T) = Ref(&'x x);
```




```
}
```

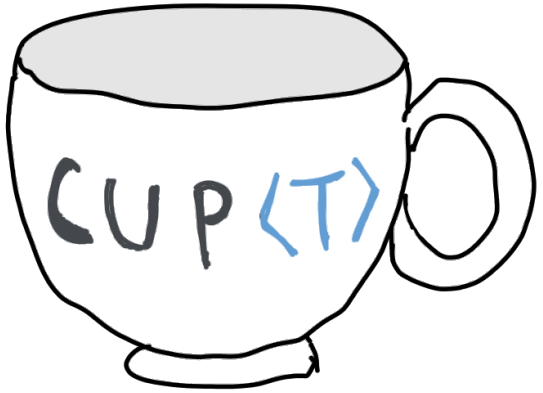
Lifetimes of x end here

The x is outlives r
So the Compiler accept this code

```
struct Ref<'a, T: 'a>(&'a T);
```

Actually, you don't need to specify this today

Types and Traits



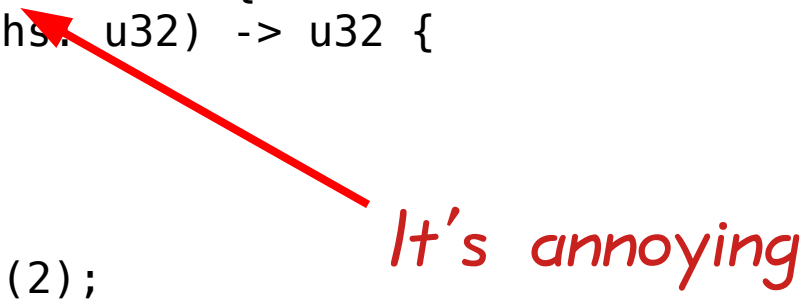
Associated Type

- **目的**：
    1. Readable
    2. Eliminate a bunch of Type annotation
- **用法**：

```
trait Add<RHS=Self> {
    type Output;
    fn add(self, rhs: RHS) -> Self::Output;
}
```

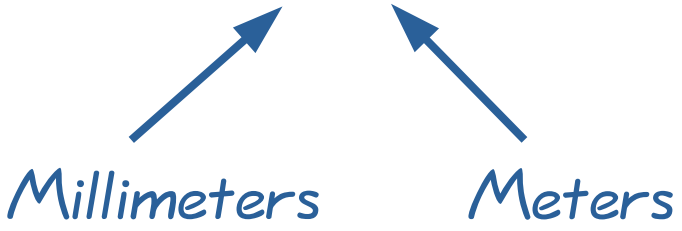
```
trait Add<RHS, Output> {
    fn add(self, rhs: RHS) -> Output;
}

impl Add<u32, u32> for u32 {
    fn add(self, rhs: u32) -> u32 {
        self + rhs
    }
}

let x: u32 = 1.add(2);
```

```
trait Add<RHS, Output> {
    fn add(self, rhs: RHS) -> Output;
}

impl Add<u32, u32> for u32 {
    fn add(self, rhs: u32) -> u32 {
        self + rhs
    }
}

let x: u32 = 1.add(2);
```



```
trait Add<RHS=Self> {
    type Output;
    fn add(self, rhs: RHS) -> Self::Output;
}

impl Add for u32 {
    type Output = u32;
    fn add(self, rhs: u32) -> u32 {
        self + rhs
    }
}

let x: u32 = 1.add(2);
```

```
struct Millimeters(u32);
struct Meters(u32);

impl Add<Meters> for Millimeters {

    type Output = Millimeters;

    fn add(self, other: Meters) -> Millimeters {
        Millimeters(self.0 + (other.0 * 1000))
    }
}


let a = Millimeters(200);

let b = Meters(1);

let sum = a + b;
```



UFCS

- **時機**： 通常發生在 Impl 多個 trait 時 , method 名子衝突時，
  Calling Methods with the Same Name

- **目的**： 可讀性更佳

- **方法**：

```
<Type as Trait>::function(receiver_if_method,
                          next_arg, … );
```

```
trait Pilot { fn fly(&self); }

trait Wizard { fn fly(&self); }

struct Human;

impl Pilot for Human {
    fn fly(&self) {
        println!("This is your captain speaking.");
    }
}

impl Wizard for Human {
    fn fly(&self) {
        println!("Up!");
    }
}

impl Human {
    fn fly(&self) {
        println!("*waving arms furiously*");
    }
}
```

```
trait Pilot { fn fly(&self); }

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struct Human;

impl Pilot for Human {
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        println!("Up!");
    }
}

impl Human {
    fn fly(&self) {
        println!("*waving arms furiously*");
    }
}
```

飛行員和魔法少女都會飛

```
trait Pilot { fn fly(&self); }

trait Wizard { fn fly(&self); }

struct Human;

impl Pilot for Human {
    fn fly(&self) {
        println!("This is your captain speaking.");
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}

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    fn fly(&self) {
        println!("Up!");
    }
}

impl Human {
    fn fly(&self) {
        println!("*waving arms furiously*");
    }
}
```

人可以是飛行員或是魔法少女

或什麼也不是

```
    let a = Human;
    a.fly();
```

1.

```
    Pilot::fly(&a);
    Wizard::fly(&a);
```

2.

```
    <Human as Pilot>::fly(&a);
    <Human as Wizard>::fly(&a);
```

```
let a = Human;
a.fly();
```

1.

```
Pilot::fly(&a);
Wizard::fly(&a);
```

2.

```
<Human as Pilot>::fly(&a);
<Human as Wizard>::fly(&a);
```

Better readability

Function and Closures

Fn and fn

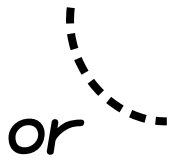
```
let list_of_numbers = vec![1, 2, 3];

let list_of_strings: Vec<String> = list_of_numbers
    .iter()
    .map(|i| i.to_string())
    .collect();
```

Fn and fn

```rust
let list_of_numbers = vec![1, 2, 3];

let list_of_strings: Vec<String> = list_of_numbers
    .iter()
    .map(|i| i.to_string())
    .collect();
```




```rust
ToString::to_string
```

Because fn also implement Fn, FnMut, FnOnce trait

Fn and fn

```
let list_of_numbers = vec![1, 2, 3];

let list_of_strings: Vec<String> = list_of_numbers
    .iter()
    .map(|i| i.to_string())
    .collect();
```

```
["1", "2", "3"]
```

```
fn returns_closure() -> Fn(i32) -> i32 {
    |x| x + 1
}
```

```
fn returns_closure() -> Fn(i32) -> i32 {
    |x| x + 1
}
```

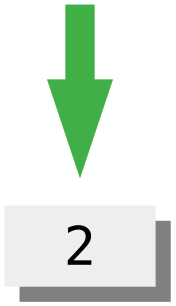
Because Closure is a Trait !

```
fn returns_closure() -> Box<dyn Fn(i32) -> i32> {
   Box::new(|x| x + 1)
}

let c = returns_closure();
println!("{}", c(1));
```

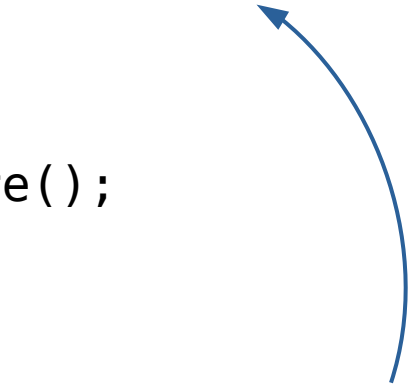
```
fn returns_closure() -> Box<dyn Fn(i32) -> i32> {
   Box::new(|x| x + 1)
}

let c = returns_closure();
println!("{}", c(1));
```



```
fn returns_closure() -> impl Fn(i32) -> i32 {
    |x| x + 1
}

let c = returns_closure();
println!("{}", c(1));
```



Actually, you can just use impl Trait

That's All

QA

github.com/rniczh