CS 241: Systems Programming
Lecture 20. Generics and Traits

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Generics

Similar to Java's generics

- e.g., ArrayList<Integer> and Vec<i32>

We can have generic

- structs
- enums
- functions/methods

Generic struct

```
struct Container<T> {
    x: T,
    y: T,
    z: T,
}

fn main() {
    let c1 = Container { x: 10, y: 20, z: 30 };
    let c2 = Container { x: 1.8, y: 2.3, z: -7.2};
    let c3 = Container { x: "abc", y: "def", z: "ghi" };
}
```

Each type we plug in for T gives a new type

```
c1: Container<i32>
c2: Container<f64>
c3: Container<&str>
```

Implementing methods

A generic impl block lists all type parameters in <> after impl

```
impl<T> Container<T> {
    fn new(x: T, y: T, z: T) -> Self {
        Self { x, y, z }
    }

    fn set_y(&mut self, y: T) {
        self.y = y;
    }
}
```

“For any type T, implement functions/methods for Container<T>”

Type parameters can have different names

```
struct Container<T> {
    x: T,
    y: T,
    z: T,
}

impl<Typ> Container<Typ> {
    fn new(x: Typ, y: Typ, z: Typ) -> Self {
        Self { x, y, z }
    }

    fn set_y(&mut self, y: Typ) {
        self.y = y;
    }
}
```

"For any type Typ, implement functions/methods for Container<Typ>"

Can implement methods for specific types

No generic parameter

```
impl Container<&str> {
    fn join(&self) -> String {
        format!("{}{}{}", self.x, self.y, self.z)
    }
}
```

.join() method can only be called on Container<&str>

How do we implement a max() method for the Container<T> struct that's only defined when T is an i32?

```
struct Container<T> {
    x: T,
    y: T,
    z: T,
}
```

```
// A
impl Container {
    fn max(&self) -> i32 { todo!() }
}
```

```
// B
impl<T> Container<T> {
    fn max(&self) -> i32 { todo!() }
}
```

```
// C
impl<T> Container<i32> {
    fn max(&self) -> i32 { todo!() }
}
```

```
// D
impl<i32> Container<T> {
    fn max(&self) -> i32 { todo!() }
}
```

```
// E
impl Container<i32> {
    fn max(&self) -> i32 { todo!() }
}
```

A generic version of join gives an error

```
impl<T> Container<T> {
    fn join(&self) -> String {
        format!("{}{}{}", self.x, self.y, self.z)
    }
}
error[E0277]: `T` doesn't implement `std::fmt::Display`
  --> generics.rs:21:27
   |
21 |         format!("{}{}{}", self.x, self.y, self.z)
   |                           ^^^^^^ `T` cannot be formatted with the
default formatter
   |
help: consider restricting type parameter `T`
   |
19 | impl<T: std::fmt::Display> Container<T> {
   |       ++++++++++++++++++++
```

Rustc doesn't know anything about type T

We'll return to this shortly!

Generic enums

We’ve seen this with Option<T> and Result<T, E>

```
enum Option<T> {
    None,
    Some(T),
}

enum Result<T, E> {
    Ok(T),
    Err(E),
}
```

Generic type aliases

```
type Result<T> = std::result::Result<T, Box<dyn std::error::Error>>;
```

Multiple generic parameters

```
enum Either<L, R> {
    Left(L),
    Right(R),
}

impl<L, R> Either<L, R> {
    fn left(&self) -> Option<&L> {
        match self {
            Either::Left(x) => Some(x),
            _ => None,
        }
    }

    fn unwrap_left_or(self, default: L) -> L {
        match self {
            Either::Left(x) => x,
            _ => default,
        }
    }
}
```

Returns a reference to an L or None

Always returns an L
Moves it out of self

Generic impl with fewer parameters

```
impl<T> Either<T, T> {
    fn unwrap(self) -> T {
        match self {
            Either::Left(x) => x,
            Either::Right(x) => x,
        }
    }
}
```

“For any type T, implement functions/methods for Either<T, T>”

Generic functions

Type parameters go after the function name but before parameter list

```
fn do_something<T>(x: T) -> T {
    todo!()
}
```

Generic arguments have limited functionality

There’s not a lot we can do with x; we cannot

1. Print x
2. Call methods on x (no methods defined for every type unlike Java)
3. Modify x (no way to modify a value that works for every type)

We cannot even create a new instance of T!

```
fn do_something<T>(x: T) -> T {
    todo!()
}
```

Given the following code, what can we say about val afterward

```
fn do_something<T>(x: T) -> T { /* … */ }

let val = do_something("hello");
```

A. val has type &str and can be any string

B. val has type &str and is exactly “hello”

C. val has some unknown type is an unknown value

D. It’s not possible to return a generic T so this is an error

Traits

Defining a trait

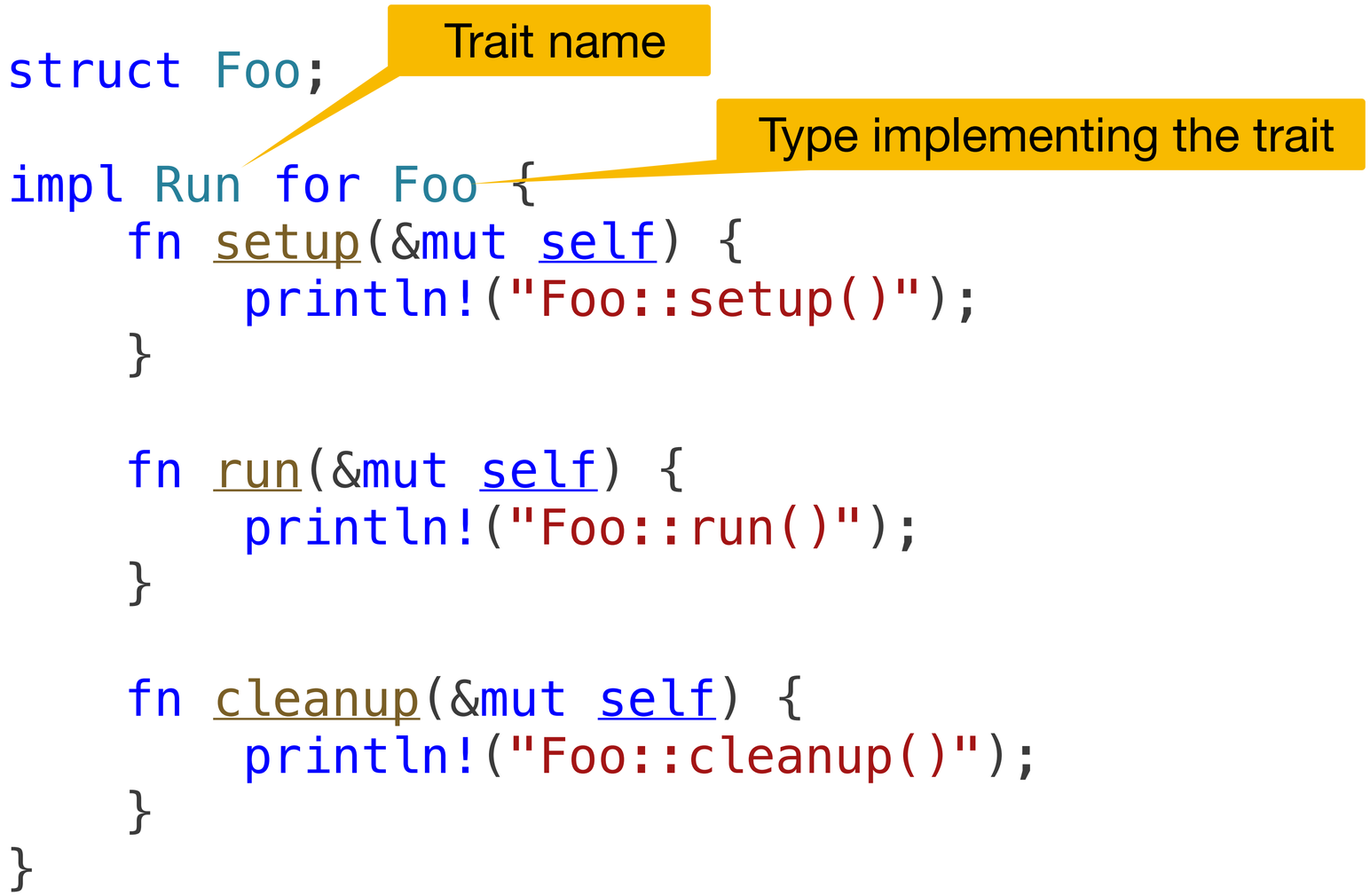
```
pub trait Run {
    fn setup(&mut self);

    fn run(&mut self);

    fn cleanup(&mut self);
}
```

Defines a public trait with three methods (that are public because the trait is)

Implementing a trait



Calling methods from the trait

To call a method from a trait, the trait must be in scope

- If it's in the same module, it's in scope
- If it's not in the same module, you need to use a use statement to bring it into scope like
  use std::io::Write;
  to bring the Write trait into scope

If the trait isn't in scope, we get an error

```
use std::{io, fs};

fn main() -> io::Result<()> {
    let mut file = fs::File::create("blarg.txt")?;
    writeln!(file, "Let's write some data!")?;
    Ok(())
}
```

writeln!() acts like println!() except it writes to something that implements std::io::Write
It returns an io::Result

A trait must be in scope to use its methods

```
error[E0599]: cannot write into `File`
    --> generics.rs:171:14
     |
171  |     writeln!(file, "Let's write some data!")?;
     |     ---------^^^^--------------------------- method not found in `File`
     |
    ::: /Users/steve/.rustup/toolchains/stable-aarch64-apple-darwin/lib/rustlib/src/
rust/library/std/src/io/mod.rs:1693:8
     |
1693 |     fn write_fmt(&mut self, fmt: fmt::Arguments<'_>) -> Result<()> {
     |        --------- the method is available for `File` here
     |
note: must implement `io::Write`, `fmt::Write`, or have a `write_fmt` method
    --> generics.rs:171:14
     |
171  |     writeln!(file, "Let's write some data!")?;
     |              ^^^^
     = help: items from traits can only be used if the trait is in scope
help: the following trait is implemented but not in scope; perhaps add a `use` for it:
     |
167  + use std::io::Write;
     |
```

And here's the fix

Default methods

```
pub trait Run {
    fn setup(&mut self) {
        println!("Default setup()");
    }

    fn run(&mut self);

    fn cleanup(&mut self) {
        println!("Default cleanup()");
    }
}
```

To implement Run, we have to implement at least the run() method

Implementing a trait with default methods

```
impl Run for Foo {
    fn setup(&mut self) {
        println!("Foo::setup()");
    }

    fn run(&mut self) {
        println!("Foo::run()");
    }
}

fn main() {
    let mut f = Foo;
    f.setup();
    f.run();
    f.cleanup();
}
```

```
Foo::setup()
Foo::run()
Default cleanup()
```

Trait bounds

Traits are used to constrain or **bound** the types of generic arguments

```
<T: TraitName>
```

The T type parameter is restricted to be some type that implements TraitName

A generic version of join gives an error

```
impl<T> Container<T> {
    fn join(&self) -> String {
        format!("{}{}{}", self.x, self.y, self.z)
    }
}
error[E0277]: `T` doesn't implement `std::fmt::Display`
  --> generics.rs:21:27
   |
21 |         format!("{}{}{}", self.x, self.y, self.z)
   |                           ^^^^^^ `T` cannot be formatted with the
default formatter
   |
help: consider restricting type parameter `T`
   |
19 | impl<T: std::fmt::Display> Container<T> {
   |       ++++++++++++++++++++
```

This is the issue: T doesn't implement the Display trait

This is suggesting we require T implement Display

impl with bound

```
struct Container<T> {
    x: T,
    y: T,
    z: T,
}

impl<Typ> Container<Typ> {
    fn new(x: Typ, y: Typ, z: Typ) -> Self { Self { x, y, z } }
    fn set_y(&mut self, y: Typ) { self.y = y; }
}

impl<D: std::fmt::Display>  Container<D> {
    fn join(&self) -> String {
        format!("{}{}{}", self.x, self.y, self.z)
    }
}
```

We can create Container<T> for any type T.

.join() is only defined for types that implement Display

The Clone trait defines a `fn clone(&self) -> Self` method

How do you specify the dup method's generic arguments?

```
fn dup(x: &T, n: usize) -> Vec<T> {
    let mut result: Vec<T> = Vec::new();
    for _ in 0..n {
        result.push(x.clone())
    }
    result
}
```

A. `fn<T> dup(x: &T, n: usize) -> Vec<T>`

B. `fn<T: Clone> dup(x: &T, n: usize) -> Vec<T>`

C. `fn dup<T: Clone>(x: &T: Clone, n: usize) -> Vec<T: Clone>`

D. `fn dup<T: Clone>(x: &T, n: usize) -> Vec<T>`

E. More than one of the above (which ones?)

A bunch of standard library traits

`std::fmt::Display` — data can be formatted via `{}` in `format!()`/`println!()`/etc

`Debug` — data can be formatted via `{:?}` in `format!()`/`println!()`/etc

`Clone` — defines `.clone()` method

`std::io::BufRead` — defines a bunch of methods, including read_line()

`std::io::Read` —
defines `.read()`, `.read_to_end()`, `.read_to_string()`, etc.

`std::io::Write` — defines `.write()` and `.write_all()` methods (and others)

Weird Read/Write trait behavior

If T implements Write, then &mut T implements Write

- `impl<W: Write> Write for &mut W { /* … */ }`

If T implements Read, then &mut T implements Read

- `impl<R: Read> Read for &mut R { /* … */ }`

For example, `File` implements `Read` and `Write` so `&mut File` implements them as well

- Functions often have generic arguments like
  `fn foo<W: Write>(writer: W)`
  You can pass a `File` or a `&mut File` (or anything else that implements `Write`)

Defining behavior in terms of generics

```
use std::io::{self, Write};

fn write_haiku<W: Write>(mut writer: W) -> io::Result<()> {
    writeln!(writer, "古池や蛙飛び込む水の音")?;
    writeln!(writer, "  ふるいけやかわずとびこむみずのおと")?;
    Ok(())
}

fn main() -> io::Result<()> {
    let mut v: Vec<u8> = Vec::new();
    write_haiku(&mut v)?; // Write into v

    write_haiku(io::stdout())?; // Write to stdout

    let mut file = std::fs::File::create("haiku.txt")?;
    write_haiku(&mut file)?; // Write once
    write_haiku(file)?; // Write a second time, and take ownership!
    Ok(())
}
```