



Polymorphism in Rust

Traits and Big Lambda

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2 (Unbounded) Parametric Polymorphism

3 Ad-hoc Polymorphism and Traits

4 Bounded Parametric Polymorphism

- Trait Objects

5 Existential Types

Generic Code

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void *id(void *x) {  
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```

Issues:

- Can only portably use pointers (often violated)
- Normal pointer-related issues in C: null pointers, alignment issues etc...
- No type-safety


```
void increment(void *n) {  
    *(int*)n += 1;  
}
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}
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... but what if I wanted a version for shorts, longs, and so on?

```
#define increment(x) _Generic((x),  
                               \br/>                               short: incr_short, \br/>                               int:  incr_int,    \br/>                               long:  incr_long,   \br/>                               float: incr_f,     \br/>                               long double: incr_ld)(x)
```

Another try

```
fun 'a (x : 'a) : 'a = x
```

Now, properly generic.

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```

Now, properly generic. (and we only had to switch languages)

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In Rust

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What about this?

```
fn double<T>(x: T) -> T {  
    x + x  
}  
  
fn main() {  
    println!("{}", double(7));  
}
```

Aside: C++ Templates

```
template<typename T>
T id(T x) {
    return x;
}
```

Similar, but not the same.

- Both languages will “monomorphise” this, making a separate version of the function for all of the types it’s used on.
- But in Rust, we typecheck the whole function, not just instances.

Ownership Semantics with Generic Functions

These are still the same as before:

- If the type is `Copy`, then its copied.
- Otherwise, its moved.

```
fn main() {  
    let x = 7;  
    let y = String::from("Hello!");  
    let z = id(x);  
    let w = id(y);  
    println!("{}", {}, {}, {}, x, y, z, w);  
}
```

Generic Data Structures

So we can be generic over data in our functions, but what about elsewhere?

```
struct Queue<T> {  
    in_stack: Vec<T>,  
    out_stack: Vec<T>,  
}
```

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

Aside: Common Parametric Enums

```
enum Option<T> {  
    Some(T),  
    None,  
}  
  
enum Result<T, E> {  
    Ok(T),  
    Err(E),  
}
```

Lifetime Genericity: Functions

Recall from last time that we can do the same with lifetimes

```
fn saxpy<'a, 'b>(
    a: f32, x: &'a [f32], y: &'b mut [f32]
) -> &'b mut [f32] {
    for (yi, xi) in y.iter_mut().zip(x) {
        *yi = a * xi + *yi;
    }
    y
}
```

Lifetime Genericity: Data

We can also do this with our data, and don't benefit from lifetime elision here.

```
enum CopyOnWrite<'a, T> {  
    Borrowed(&'a T),  
    Owned(T),  
}
```


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```
enum CopyOnWrite<'a, T> {  
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    Owned(T),  
}
```

```
struct Token<'a> {  
    range: (usize, usize),  
    text: &'a str,  
}
```

Lifetime Genericity: Data

```
enum CopyOnWrite<'a, T> { Borrowed(&'a T), Owned(T), }

impl<'a, T> CopyOnWrite<'a, T> {
    fn to_mut(&mut self) -> &mut T {
        match self {
            Self::Borrowed(&b) => {
                *self = Self::Owned(b);
                self.to_mut()
            }
            Self::Owned(b) => b,
        }
    }
}
```

Trait Bound Preview

```
enum CopyOnWrite<'a, T> { Borrowed(&'a T), Owned(T), }

impl<'a, T: Copy> CopyOnWrite<'a, T> {
    fn to_mut(&mut self) -> &mut T {
        match self {
            Self::Borrowed(&b) => {
                *self = Self::Owned(b);
                self.to_mut()
            }
            Self::Owned(b) => b,
        }
    }
}
```

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Genericity with Behaviour?

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- Java, C#—interfaces
- Plenty of things—abstract classes
- C++20—concepts
- Haskell—typeclasses
- ML—modules

Traits

In Rust, we use a Trait for this.

```
trait Eq {  
    fn eq(&self, other: &Self) -> bool;  
}  
  
trait Bounds {  
    fn min() -> Self; // Note the capitalisation!  
  
    fn max() -> Self;  
}
```

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```

Implementing a Trait

Types can then implement traits:

```
impl PartialEq for (i32, i32) {  
    fn eq(&self, other: &foo) -> bool {  
        self.0 == other.0 && self.1 == other.1  
    }  
}  
  
impl Bounds for u8 {  
    fn min() -> u8 { 0 }  
    fn max() -> u8 { 255 }  
}
```

Aside: Derive for Implementing Traits

Oftentimes we avoid this for common, boilerplate heavy traits using an “attribute macro”¹.

```
#[derive(Debug, PartialEq, Eq)]
struct Person {
    name: String,
    age: u8,
}
```

Derivable traits include: `Debug`, `PartialEq`, `Eq`, `PartialOrd`, `Ord`, `Clone`, `Copy`, `Hash`, and more.

¹we'll revisit this in more depth in 6 weeks or so

Using Trait Implementations

Using a trait implementations is as simple as ensuring the trait is in scope, and just calling the method.

```
trait ToString { fn to_string(&self) -> String; }
impl ToString for i32 { /* omitted */ }

fn main() {
    let s = 7.to_string();
    println!("{}", s);
}
```


Default Implementations

Traits can also include default implementations for their items

```
enum SeekFrom { Start(u64), End(i64), Current(i64), }

/// This trait provides a cursor which can be moved
/// within a stream of bytes.
trait Seek {
    fn seek(&mut self, pos: SeekFrom) -> Result<(), u64>;
    fn rewind(&mut self) -> Result<(), ()> {
        match self.seek(SeekFrom::Start(0)) {
            Err(e) => Err(e),
            Ok(_) => Ok(()),
        }
    }
}
```

Type Parameters for Traits

And much like types, Traits can have type parameters

```
trait From<T> {  
    fn from(T) -> Self;  
}
```

```
impl From<u8> for i32 { fn from(x: u8) -> i32 { x as i32 } }  
impl From<u16> for i32 { fn from(x: u16) -> i32 { x as i32 } }  
impl From<i8> for i32 { fn from(x: i8) -> i32 { x as i32 } }  
impl From<i16> for i32 { fn from(x: i16) -> i32 { x as i32 } }
```

Associated Types

```
trait Iterator {  
    type Item;  
  
    fn next(&mut self) -> Option<Self::Item>;  
  
    fn nth(&mut self, n: usize) -> Option<Self::Item> {  
        for _ in 0..n {  
            self.next()?;  
        }  
        self.next()  
    }  
}
```

Note that we can only implement this once for a given type, with some fixed type for `Item`—if many possible types make sense, we should use a type parameter.

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Genericity with Trait Bounds

We can use traits as bounds for our type parameters!

```
fn find_diff<'a, 'b, T: Eq>(
    xs: &'a [T], ys: &'b [T]
) -> Option<(&'a T, &'b T)> {
    for (x, y) in xs.iter().zip(ys) {
        if x != y { return Some((x, y)); }
    }
    None
}
```

Aside: Lifetime Subtyping

```
fn find_same<'a, T: Eq>(xs: &'a [T], ys: &'a [T]) -> Option<&'a T> {  
    for (x, y) in xs.iter().zip(ys) {  
        if x == y {  
            return Some(x);  
        }  
    }  
    None  
}
```

Can I use this on any two slices? Do they have to have the exact same lifetime?

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    for (x, y) in xs.iter().zip(ys) {  
        if x == y {  
            return Some(x);  
        }  
    }  
    None  
}
```

Can I use this on any two slices? Do they have to have the exact same lifetime?
No—they can have different ones, and 'a will be the “shared” lifetime.

Verbose Bounds

Sometimes there can be quite a few constraints, or some complex combination:

```
fn double<T>(x: T) -> T
where
    T: Add<T, Output = T> + Copy,
{
    x + x
}
```


Trait Objects: `dyn`

When we use traits in a type parameter bound, we're still monomorphising. What if we want dynamic dispatch?

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```
trait Button {  
    fn on_click(&self, s: State) -> State;  
}  
  
fn handle_click_events(  
    clicked: &[Box<dyn Button>], mut s: State  
) -> State {  
    for b in clicked {  
        s = b.on_click(b);  
    }  
    s  
}
```

Sized and Unsized Types

Most of the types we've seen so far are “sized”, meaning we statically know how large they are.

Some types are “unsized”, meaning we don't know their size!

Some examples:

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- `[T]`
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Most of the types we've seen so far are “sized”, meaning we statically know how large they are.

Some types are “unsized”, meaning we don't know their size!

Some examples:

- `[T]`
- `dyn Trait`
- `str` (like `[u8]` but UTF-8)

If we want to use these, they should be through a level of indirection: `&T`, `Box<T>`, etc...

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As a return type

Sometimes we might want to return a specific type which implements a trait, but don't want users of our function to know:

```
enum Tree<T> { Leaf(T), Node(Box<Tree<T>, T, Box<Tree<T>>) }

struct Leaves { /* omitted */ }
impl Iterator for Leaves { /* omitted */ }

fn leaf_values<T>(tree: &Tree<T>) -> impl Iterator<Item = &T> {
    Leaves { tree, current: tree.leftmost() };
}
```


As a argument's type

This will end up being equivalent to a bound on a type parameter:

```
fn use_fn<T, U>(x: T, f: impl Fn(T) -> U) -> U {  
    f(x)  
}
```

is the same as

```
fn use_fn<T, U, F: Fn (T) -> U>(x: T, f: F) -> U {  
    f(x)  
}
```

$$((\exists x. P(x)) \rightarrow Q) \iff (\forall x. (P(x) \rightarrow Q))$$