

Zero-Cost Abstractions

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Types and Operations

- Rust custom types are new types defined by the user
- A data type defined by:
 - Set of possible values the variable can contain
 - Operations such values
- Until now, we only saw how to define the possible values (`struct` and `enum`)
- Let's define the operations for a custom type!
 - `impl` block: methods and associated functions
 - Applied to `struct`, recalls concepts from OO design...
 - Applied to `enum`, is a less known concept

Methods

- Method: function associated to a custom type (`struct` or `enum`)
- Always bound to a variable (of the method's custom type)
 - First parameter of the method: `self` value (or reference to it)
 - It is the variable (of the custom type) used to invoke the method
 - Note: it can be a value, a reference, or a mutable reference!
- If the custom type is a struct, looks like a class method in C++, Java or similar
- But `impl` blocks can be used for enum types too...

Methods — Example

```
struct Point {  
    x: f64,  
    y: f64  
}  
  
impl Point {  
    fn display(&self) {  
        println!("({}, {})", self.x, self.y)  
    }  
}  
  
fn main()  
{  
    let p = Point{x:1.0,y:1.0};  
    p.display();  
}
```

Methods on Enumerations

```
enum Colore {
    Bianco,
    Nero
}

impl Colore {
    fn stampa(&self) {
        match self {
            Colore::Bianco => println!("Bianco!"),
            Colore::Nero   => println!("Nero!")
        }
    }
}

fn main() {
    let v = Colore::Nero;

    v.stampa()
}
```

More on `impl` Blocks

- Multiple `impl` blocks can be added to the same data type
- An `impl` block can contain definition of functions that are not methods
 - Associated functions: do not have `self`
 - Associated to the type, but not bound to any particular variable
- Example: “`new`” function
 - It is not a method or a constructor

```
impl Point {  
    fn new(v: f64) -> Point {  
        Point{x:v, y:v}  
    }  
}
```

Abstractions and Overhead

- Zero cost abstractions (from C++): what you do not use, you do not pay for
 - Introduce only the overhead of the abstractions that are really used
 - How?
- Rust approach (once again): resolve as much as possible at build time!
 - Avoid dynamic method dispatch
 - Avoid duck typing
 - ...
- In general, specify the types behaviour so that the compiler knows it!

Specifying the Types Behaviour

- Mechanism used by Rust: **traits**
 - Mechanism used to define shared behaviours in an abstract way
 - Similar to interfaces, but with some **important differences**
- Behaviour of a type: set of methods invocable on the type, + some other properties...
 - For example, the fact that for this type assignments have a copy behaviour!!!
- Trait syntax: “`trait`” keyword followed by a “`{}`” block
 - Can contain declarations (an maybe definitions...) or methods and associated functions

Differences between Traits and Interfaces

- An interface is generally specified for new data types when defining them
 - The interface of pre-defined types cannot be modified/extended
- Traits can be implemented for existing types after they are defined
 - First I define a new structure `struct S`...
 - ...Then I define a trait `trait Display`...
 - ...And finally I implement `Display` for `S`!
- Traits can be implemented even for pre-defined types...
 - I can implement `Display` even for `i32`!

Trait Example

```
struct S {
    v1: f64, v2: f64
}
trait Display {
    fn display(&self);
}
impl Display for S {
    fn display(&self) {
        println!("This_is_an_S({}, {})", self.v1, self.v2)
    }
}
impl Display for i64 {
    fn display(&self) {
        println!("This_is_a_64_bit_integer: {}", self)
    }
}

fn main()
{
    let s = S{v1:1.1,v2:1.1};
    let n1 = 2;

    s.display();
    n1.display()
}
```

More on Traits

- A trait generally declares some methods/functions to be implemented for the type...
- ...But in some cases it can also **define** the methods/functions!
 - Provide default implementation...
- The default implementation is used when “`impl` . . .” is used for a type without specifying the method implementations (empty “`impl`” block, etc...)
- In some cases, empty traits also make sense
 - We will see later...

Using Traits

- Interesting concept, but... What are traits useful for?
 - Defining/extending the interface of a type
 - Declaring the properties of a type
 - All done at build time!
- The real power of traits becomes clear only when considering generic functions and types
 - Will see later
- Can be used to define functions that accept different types as input
 - Defining some properties of the input types
 - Example: `fn f(v: impl Display) {`
`...`

Trait Parameters...

```
fn f(v: impl Display) {  
    println! ("Going_to_invoke_display()");  
    v.display()  
}
```

- For the parameter “v”, no concrete type is specified
- “impl Display” here denotes a generic type for which the “Display” trait is implemented
 - Hence, “f ()” can invoke “v.display ()”
- The compiler knows how “f ()” is invoked...
 - ...And can generate different versions of the function (one for “S”, one for “i64”, ...)
 - There is no runtime cost/overhead!

...And Generic Functions!

- In the previous example, “ $f()$ ” is a *generic function*
 - Can receive multiple types for the input parameter
 - One single function definition, using the trait interface of a generic type
- Monomorphized by the compiler at build time
 - A different version of the function is generated, for each type used to invoke it
- Similar to C++ templates
- This is just a special case of generic function (generic types exist too!!!)

Generic Functions and Types

- Functions like `fn f(v: impl Display)` are generic
 - The code describes *a classes* of functions, all with the same structure but operating on different concrete types
- Here, the generic nature of the function is hidden...
- ...But it can be made more explicit
- `fn f<T: Display>(v: T)`
 - See? The function is parametric respect to type “T”!
 - Similar to C++ templates...
- Parametric types (**generic types**) exist too...

Generics Syntax

- Inspired by the C++ templates syntax:
 - The “type parameter” is part of the function/type name
 - Enclosed in angle brackets
- So, “`id<T> (v: T) -> T`” is a generic function with type parameter “T”
- Multiple (comma-separated) type parameters are of course possible

```
struct S<T, V> {  
    v1: T,  
    v2: V  
}
```


Remember the Option Type?

- Sum type, previously introduced to avoid NULL pointers...

- Values “Nothing” or “Just (p)”

- Can be more generic, not only for pointers
- Here is a possible definition in Rust:

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

- Why “None” and “Some ()” instead of “Nothing” and “Just ()”?
 - Because these are the names actually used by Rust

Predefined Generic Types

- Rust provides some useful generic types like “`Option<T>`”
 - Not really predefined, they are part of a Rust standard library
- Other important type (another generic sum type): “`Result`”

```
enum Result<T, E> {  
    Ok (T) ,  
    Err (E)  
}
```
- Used by all the standard functions that can potentially fail
- Two type parameters: “`T`” (the wrapped result) and “`E`” (describing a possible error)

Monomorphization

- As usual, Rust tries to minimize the abstractions' overhead
- Done through *monomorphization* at build time (as for traits)
 - The generic code/type is transformed in specific instances of the function/type by replacing type parameters with concrete types
 - Again, the compiler knows the concrete values of type parameters when the generic function is called (or the generic type is used)
- Example: “ $f < T > (v : T) \rightarrow T$ ” invoked as “ $f(3)$ ” and “ $f(3.14)$ ”...
 - The compiler generates 2 functions: one working on integers and one on floating points

Scope and Lifetime

- Scope of an “entity” (value or variable): part of the code where an entity can be referenced
 - A binding between a name and the entity is in the environment
- Lifetime of an entity: time interval in which the entity exists
- There must be a precise relationship between lifetime and scope
 - If an entity is destroyed when it is in scope, dangling reference!

Rust and Dangling References

- Rust avoids dangling references/pointers by destroying a value when it is not owned by any variable
 - The variable owning it goes out of scope
 - The (mutable) variable is assigned a new value
- However, a value can be borrowed (references)...
 - The compiler must ensure that a value is not destroyed when it is borrowed
 - Restrictions on borrowing/references
- How can the compiler enforce this?
- Other way to see it: references are variables → every reference has a lifetime
 - End of value lifetime $>$ end of reference lifetime

Enforcing the Validity of References

- For nested blocks, it is simple
- What about function invocations?
 - Passing a reference as an argument to a function
→ borrowing
 - The function might return such a reference...
 - ...And in some cases the borrow checker might be in trouble!
- Some help is needed \Rightarrow explicit lifetime annotations
 - Lifetime: similar to a type parameter
 - Lowercase and starting with '
 - Example: `fn f<'a, 'b> (v: &'a i32, b: &'b i32) -> &'a i32`
- The issue exists for custom data types too...

Lifetime Annotations

- When are lifetime annotations needed?
 - In general, every time a function returns a reference...
 - ...Or every time a custom type contains/wraps a reference
- Can lifetime annotations be omitted some times?
 - When the lifetime of the return value (or wrapped/contained) reference is univoque, the compiler can infer it
 - Lifetime inference \rightarrow lifetime elision

```
fn f(v: (&i32, i32)) -> &i32 {  
    let (a, b) = v;  
    a  
}
```