

Rust Programming Language(Part I)

- Rust Basics
- Ownership & Lifetime
- Error Handling(Option & Result)
- Object Oriented Programming

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목차(Table of Contents)

Part I.

1. Rust 개발 환경 구축
2. Rust 기초 - 변수, 상수, 제어 흐름, 함수 등
3. 소유권(Ownership) - 이동(Move), 복사(Copy), 빌림(Borrowing)과 참조(Reference), 수명(Lifetime)
4. Composite Type과 Collections - 구조체, 열거형, 튜플, Vector, HashMap
5. Error Handling - Option과 Result
6. 다형성과 OOP - 트레이트(Trait)과 제네릭스(Generics)

Part II.

7. Functional Programming - 반복자(Iterator)와 클로저(Closure)
8. 스마트 포인터
9. Concurrency - 쓰레드(Thread)와 채널(Channel)
10. Package, Crate, Module
11. File and Network I/O
12. 고급 기능 - unsafe, macro, FFI 등

소유권(Ownership)

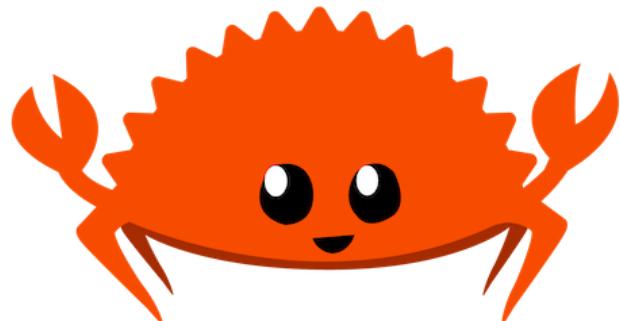
Error Handling
(Option<T>, Result<T, E>)

Part I

Struct + Generics + Trait =>
OOP

Iterator + Closure =>
Functional Programming

Rust의 6가지 주요 항목



Part II

Smart Pointer

Thread, Async
Concurrent Programming

취지(Purpose)

- [1] 어려운 Rust language의 개념을 쉽게 요약 & 정리한다.
- [2] Rust language의 주요 concept를 빠르게 훑어 봄으로써, 이후 관련 서적을 읽을 때 도움이 될 수 있도록 한다.
- [3] 따라서 Rust를 구성하는 모든 내용을 세세히 소개하는 것 보다는, 실제로 필드에서 자주 사용하게 되는 개념을 중심으로 예제와 함께 소개한다.

Let's make a Rust Router!



1. Rust 개발 환경 구축

Windows, MacOS and Linux

1. Rust 개발 환경 구축(1) - Windows 환경

<https://rustup.rs/>
=> rustup-init.exe



Welcome to Rust!

This will download and install the official compiler for the Rust programming language, and its package manager, Cargo.

Rustup metadata and toolchains will be installed into the Rustup home directory, located at:

```
C:\Users\chung\.rustup
```

This can be modified with the RUSTUP_HOME environment variable.

The Cargo home directory is located at:

```
C:\Users\chung\.cargo
```

This can be modified with the CARGO_HOME environment variable.

The cargo, rustc, rustup and other commands will be added to Cargo's bin directory, located at:

```
C:\Users\chung\.cargo\bin
```

This path will then be added to your PATH environment variable by modifying the PATH registry key at HKEY_CURRENT_USER\Environment.

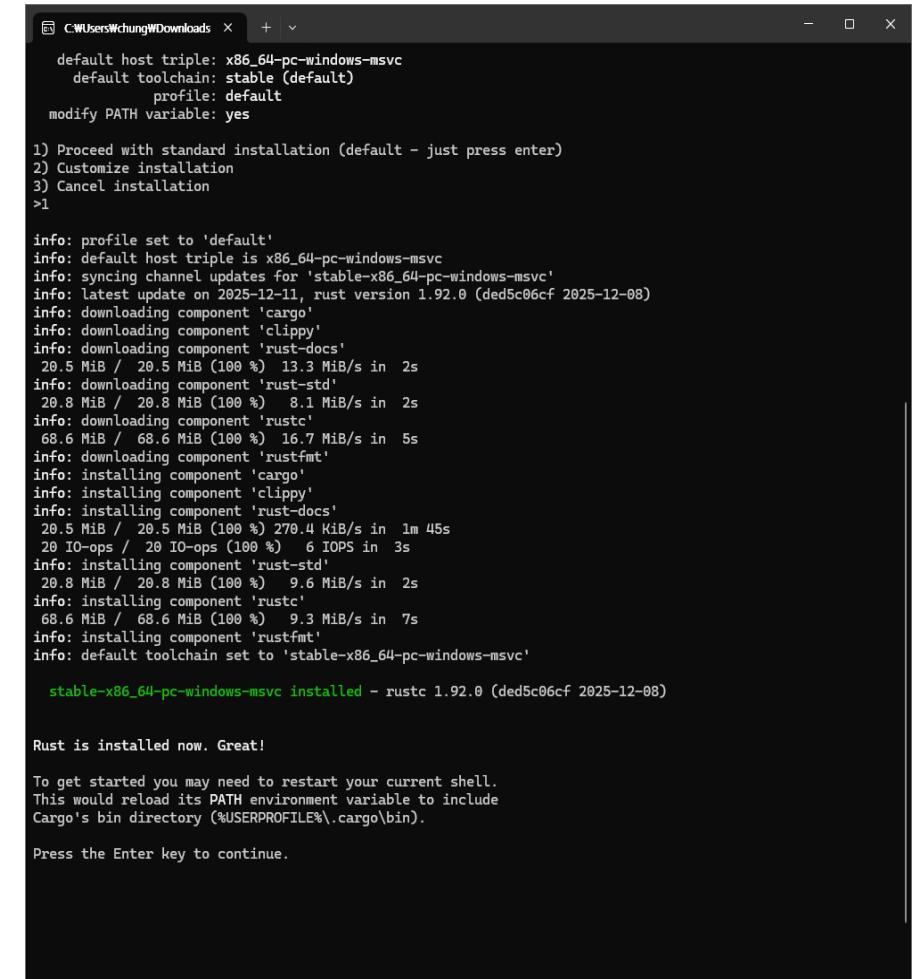
You can uninstall at any time with `rustup self uninstall` and these changes will be reverted.

Current installation options:

```
default host triple: x86_64-pc-windows-msvc
  default toolchain: stable (default)
    profile: default
  modify PATH variable: yes
```

1) Proceed with standard installation (default - just press enter)
2) Customize installation
3) Cancel installation
>1

```
info: profile set to 'default'
info: default host triple is x86_64-pc-windows-msvc
info: syncing channel updates for 'stable-x86_64-pc-windows-msvc'
info: latest update on 2025-12-11, rust version 1.92.0 (ded5c06cf 2025-12-08)
info: downloading component 'cargo'
info: downloading component 'clippy'
info: downloading component 'rust-docs'
20.5 MiB / 20.5 MiB (100%) 13.3 MiB/s in 2s
info: downloading component 'rustc'
20.8 MiB / 20.8 MiB (100%) 8.1 MiB/s in 2s
info: downloading component 'rustc'
68.6 MiB / 68.6 MiB (100%) 16.7 MiB/s in 5s
info: downloading component 'rustfmt'
info: installing component 'cargo'
info: installing component 'clippy'
info: installing component 'rust-docs'
20.5 MiB / 20.5 MiB (100%) 270.4 KiB/s in 1m 45s
20 IO-ops / 20 IO-ops (100%) 6 IOPS in 3s
info: installing component 'rustc'
20.8 MiB / 20.8 MiB (100%) 9.6 MiB/s in 2s
info: installing component 'rustc'
68.6 MiB / 68.6 MiB (100%) 9.3 MiB/s in 7s
info: installing component 'rustfmt'
info: default toolchain set to 'stable-x86_64-pc-windows-msvc'
```



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default host triple: x86_64-pc-windows-msvc
  default toolchain: stable (default)
    profile: default
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1) Proceed with standard installation (default - just press enter)
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info: default toolchain set to 'stable-x86_64-pc-windows-msvc'
```

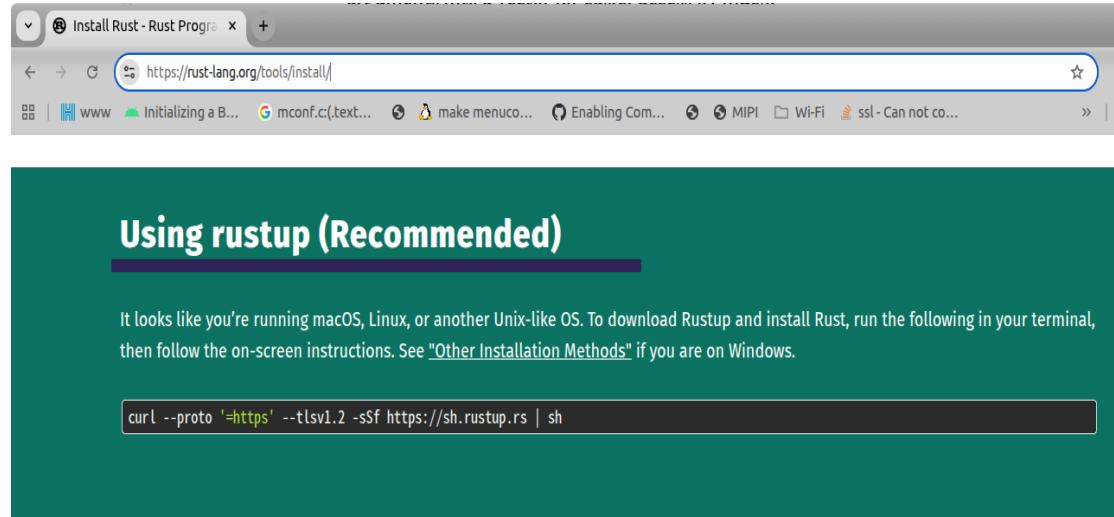
stable-x86_64-pc-windows-msvc installed - rustc 1.92.0 (ded5c06cf 2025-12-08)

Rust is installed now. Great!

To get started you may need to restart your current shell.
This would reload its PATH environment variable to include
Cargo's bin directory (%USERPROFILE%\cargo\bin).

Press the Enter key to continue.

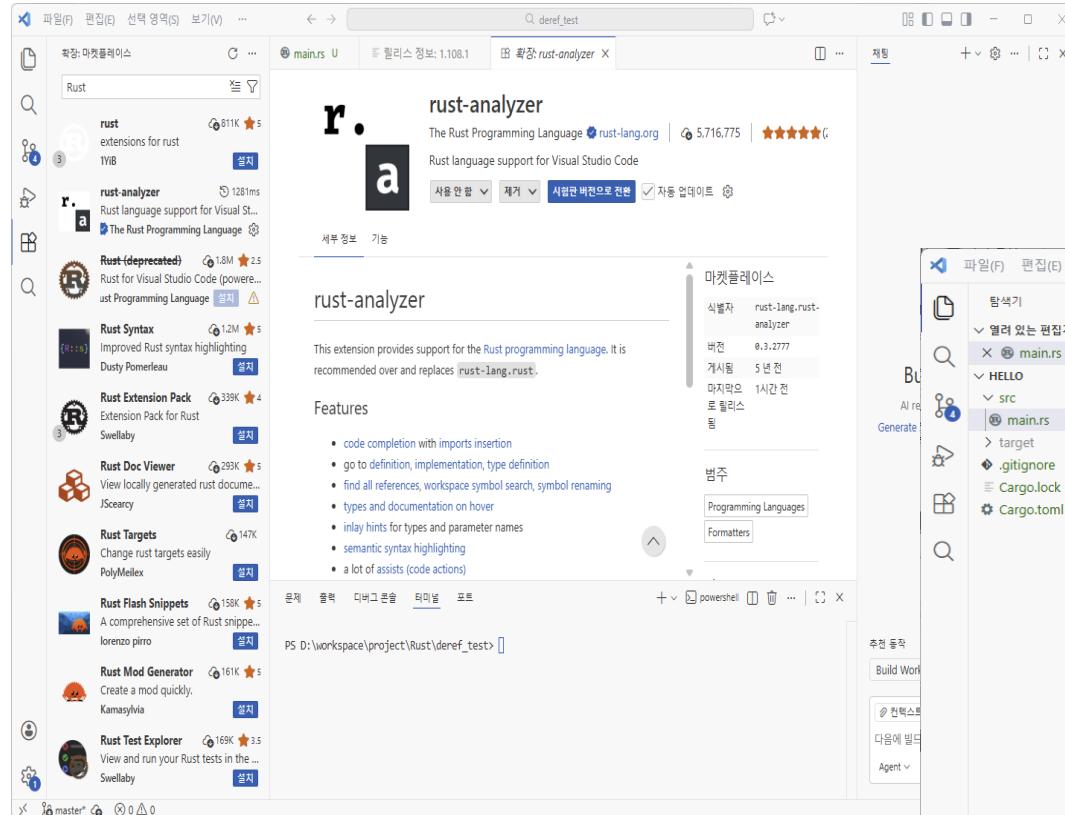
1. Rust 개발 환경 구축(2) - Linux 환경



<How to install Rust on Ubuntu>

```
$ sudo apt update && sudo apt upgrade -y  
$ sudo apt install build-essential -y  
$ sudo apt install curl -y  
  
$ curl --proto '=https' --tlsv1.2 -sSf https://sh.rustup.rs | sh  
  
$ source $HOME/.cargo/env  
$ rustc --version  
$ cargo --version
```

1. Rust 개발 환경 구축(3) - Visual Studio Code



- Visual Studio Code
- RustRover by IntelliJ IDEA
- Neovim

The screenshot shows a Visual Studio Code workspace for a 'Hello, Rust' example. The left sidebar shows a file tree with 'main.rs' as the active file. The code in 'main.rs' is:fn main() {
 println!("Hello, Rust!");
}The right side of the screen has a terminal window showing the build and run process:PS D:\workspace\project\Rust\hello>
PS D:\workspace\project\Rust\hello>
PS D:\workspace\project\Rust\hello> cargo build
Compiling hello v0.1.0 (D:\workspace\project\Rust\hello)
 Finished `dev` profile [unoptimized + debuginfo] target(s) in 0.49s
PS D:\workspace\project\Rust\hello>
PS D:\workspace\project\Rust\hello>
PS D:\workspace\project\Rust\hello> cargo run
 Finished `dev` profile [unoptimized + debuginfo] target(s) in 0.01s
 Running `target\debug\hello.exe`
Hello, Rust!
PS D:\workspace\project\Rust\hello>
PS D:\workspace\project\Rust\hello>A red dashed circle highlights the terminal output area. The status bar at the bottom right shows '줄 2, 열 27' and other standard terminal information.

Hello, Rust example



Build with Agent

AI responses may be inaccurate.
Generate Agent Instructions to onboard AI onto your codebase.

주전 풀작
Build Workspace Show Config
+ main.rs
다음에 빌드할 내용 설명
Agent Auto

1. Rust 개발 환경 구축(4) - Hello Rust

main.rs

```
fn developer_mood(caffeine_level: u8) -> &'static str {
    match caffeine_level {
        0 => "I can't work without coffee! ☕",
        1..=2 => "Alright, I can write a few functions.",
        3..=5 => "Productivity mode: ON! 🚀",
        _ => "Too much coffee! I'm rewriting the entire project in
Rust! ☕"
    }
}

fn main() {
    println!("{}", developer_mood(4));
    // Output: Productivity mode: ON! 🚀
}
```

<How to create a project and build>

\$ cargo new hello

Edit src/main.rs

\$ cargo build

or

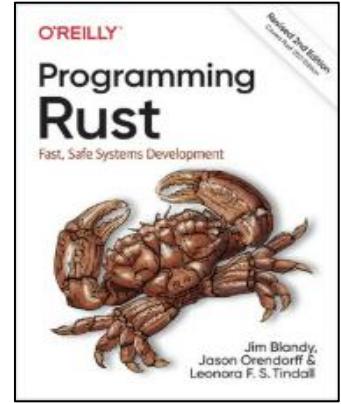
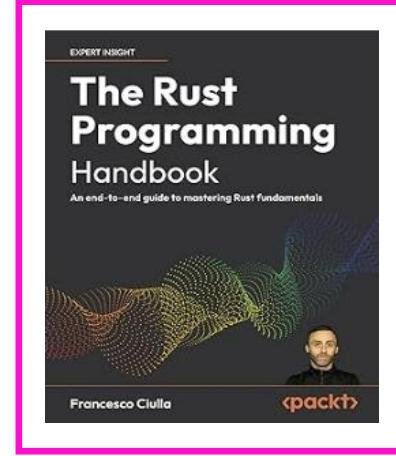
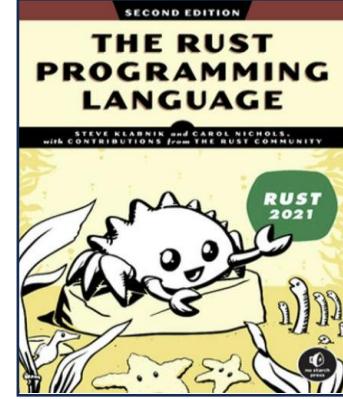
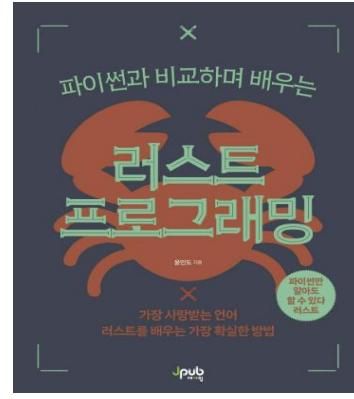
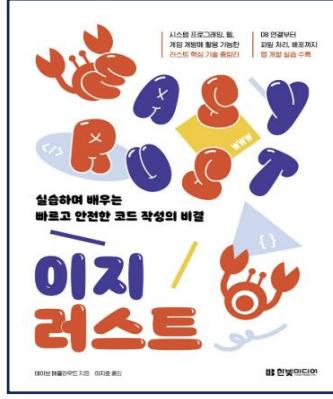
\$ cargo build --release

\$ cargo run

\$ cd target/debug

\$ ls -l hello

1. Rust 개발 환경 구축(5) - Reference Books



<https://slowbootkernelhacks.blogspot.com/2026/02/howaboutlearningrustprogramminglanguage.html>

2. Rust 기초

변수, 상수, 함수, 제어

2. Rust 기초(1) – Variable Types(1)

```
fn main() {  
    let signed_int: i32 = -42;  
    let unsigned_int: u32 = 42;  
    println!("Signed integer: {}, Unsigned integer: {}", signed_int,  
           unsigned_int);  
}
```

정수 변수 i32, u32 사용 예

```
fn main() {  
    let float_num: f64 = 3.14;  
    println!("Floating-point number: {}", float_num);  
}
```

실수 변수 사용 예

```
fn main() {  
    let is_rust_fun: bool = true;  
    println!("Is Rust fun? {}", is_rust_fun);  
}
```

Boolean 변수 사용 예

```
fn main() {  
    let letter: char = 'R';  
    let emoji: char = '😊';  
    println!("Letter: {}, Emoji: {}", letter, emoji);  
}
```

Character 변수 사용 예

2. Rust 기초(1) – Variable Types(2)

```
fn main() {  
    // A tuple holding an integer, a float, and a character.  
    let my_tuple: (i32, f64, char) = (500, 6.4, 'R');  
  
    // Method 1: Destructuring with a `let` binding.  
    // This is a form of pattern matching that breaks the tuple into  
    // separate variables.  
    let (x, y, z) = my_tuple;  
    let first_element = my_tuple.0;  
    let second_element = my_tuple.1;
```

Tuple 변수 사용 예

```
fn main() {  
    let array: [i32; 3] = [1, 2, 3];  
    println!("Array values: {} {} {}", array[0], array[1], array[2]);  
}
```

Array 변수 사용 예

2. Rust 기초(1) – Variable Types(3)

```
fn main() {  
    let array = [10, 20, 30, 40, 50];  
    // Create a slice that references elements from index 1 up to (but not  
    // including) index 3.  
    // The type of `slice` is `&[i32]`.  
    let slice = &array[1..3];  
    println!("Original array: {:?}", array);  
    println!("Slice (a view into the array): {:?}", slice); // Output:  
    [20, 30]  
}
```

Slice 변수 사용 예

```
fn main() {  
    let mut s = String::from("Hello");  
    s.push_str(", world!");  
    println!("{}", s);  
}
```

String 변수 사용 예

```
fn main() {  
    let s = "Hello, world!"; // string literal  
    println!("{}", s);  
}
```

&str 변수 사용 예

2. Rust 기초(2) - Immutable & Mutable Variable

```
fn main() {  
    let x = 5;  
  
    println!("The value of x is: {}", x);  
  
    // x = 6; // This line would cause a compile-time error because x is  
    immutable  
}
```

Immutable 변수는 수정할 수 없음.



```
fn main() {  
    let mut x = 5;  
  
    println!("The value of x is: {}", x);  
  
    x = 6; // This is allowed because x is mutable  
  
    println!("The value of x is: {}", x);  
}
```

Mutable 변수는 수정할 수 있음.

```
fn main() {  
    let x = 5;  
  
    let x = x + 1; // This shadows the previous x  
  
    println!("The value of x is: {}", x);  
}
```

변수 Shadowing

2. Rust 기초(3) - 구조체 Struct

```
struct User {  
    username: String,  
    email: String,  
    sign_in_count: u64,  
    active: bool,  
}  
  
fn main() {  
    let user1 = User {  
        username: String::from("someusername123"),  
        email: String::from("someone@example.com"),  
        sign_in_count: 1,  
        active: true,  
    };  
  
    println!("Username: {}", user1.username);  
    println!("Email: {}", user1.email);  
    println!("Sign in count: {}", user1.sign_in_count);  
    println!("Active: {}", user1.active);  
}
```

struct 변수 사용 예

2. Rust 기초(4) - 열거형 Enum

```
#[derive(Debug)]
enum Color {
    // A variant that holds a tuple of three 8-bit unsigned integers
    Rgb(u8, u8, u8), Rust의 enum의 각 variant는 type을 가질 수 있음.
    // A variant that holds a single String
    Named(String),
}

fn main() {
    let red = Color::Rgb(255, 0, 0);
    let custom_color = Color::Named(String::from("Forest Green"));

    println!("An RGB color: {:?}", red);
    println!("A named color: {:?}", custom_color);
}
```

enum 변수 사용 예

2. Rust 기초(5) - 함수 Function(1)

Function 사용 예

```
fn main() {
    println!("Hello, world!");
}

fn greet(name: &str) {
    println!("Hello, {}!", name);
}

fn add(a: i32, b: i32) -> i32 {
    a + b
}
```

fn 함수명 (인수 선언) -> 반환 값 타입 {
}

Call by value 예

```
fn takes_value_copy(mut some_integer: i32) {
    some_integer += 1;
    println!("Value inside function: {}", some_integer);
}

fn main() {
    let x = 5;
    takes_value_copy(x);
    println!("Original value of x after function call: {}", x); // x is
still 5
}
```

2. Rust 기초(5) - 함수 Function(2)

Call by reference 예

```
// This function borrows a String and calculates its length.  
fn calculate_length(s: &String) -> usize {  
    s.len()  
} // `s` goes out of scope here, but since it doesn't have ownership, the  
// data is not dropped.  
  
fn main() {  
    let s1 = String::from("hello");  
  
    // We pass a reference to s1 using the `&` operator.  
    // s1 is borrowed, not moved.  
    let len = calculate_length(&s1);  
  
    println!("The length of '{}' is {}.", s1, len);  
    // `s1` is still valid here because its ownership was never  
    // transferred.  
}
```

Call by mutable reference 예

```
fn main() {  
    let mut s = String::from("hello");  
    takes_mutable_reference(&mut s);  
    println!("s in main: {}", s); // s is modified by the function  
}  
  
fn takes_mutable_reference(some_string: &mut String) {  
    some_string.push_str(", world");  
}
```

2. Rust 기초(7) - if else 문과 loop 문

if and else문 예

```
fn main() {  
    let number = 7;  
  
    if number < 5 {  
        println!("The number is less than 5");  
    } else if number > 5 {  
        println!("The number is greater than 5");  
    } else {  
        println!("The number is exactly 5");  
    }  
}
```

loop문 예

```
fn main() {  
    let mut counter = 0;  
  
    loop {  
        counter += 1;  
        println!("Counter is now: {}", counter);  
        if counter == 5 {  
            break; // Exits the Loop  
        }  
    }  
    println!("Loop finished.");  
}
```

(*) while loop문은 C와 동일하여 생략함.

2. Rust 기초(8) - for loop 문

for loop문 예

```
fn main() {
    for number in 1..=10 {
        // If the number is odd, skip the println! and go to the next
        // iteration.
        if number % 2 != 0 {
            continue;
        }
        // This line only runs for even numbers.
        println!("Found an even number: {}", number);
    }
}
```

for keyword문 예

```
fn main() {
    let a = [10, 20, 30, 40, 50];

    for element in a.iter() {
        println!("The value is: {}", element);
    }
}
```

2. Rust 기초(9) - match 문(1)

```
enum Message {  
    Quit,  
    Move { x: i32, y: i32 },  
    Write(String),  
    ChangeColor(i32, i32, i32),  
}
```

```
fn main() {  
    let msg = Message::Move { x: 10, y: 20 };  
  
    match msg {  
        Message::Quit => println!("Quit message"),  
        Message::Move { x, y } => println!("Move to x: {}, y: {}", x, y),  
        Message::Write(text) => println!("Write message: {}", text),  
        Message::ChangeColor(r, g, b) => println!("Change color to red:  
{}, green: {}, blue: {}", r, g, b),  
    }  
}
```

match 문 예#2

```
fn main() {  
    let x = 1;  
  
    match x {  
        1 | 2 => println!("The number is one or two"),  
        3 => println!("The number is three"),  
        _ => println!("It's some other number"),  
    }  
}
```

match 문 예#1

Rust에는 Switch case문이 없음.

2. Rust 기초(9) - match 문(2)

match 문 예#3

```
fn main() {
    let some_number = Some(5);
    let absent_number: Option<i32> = None;

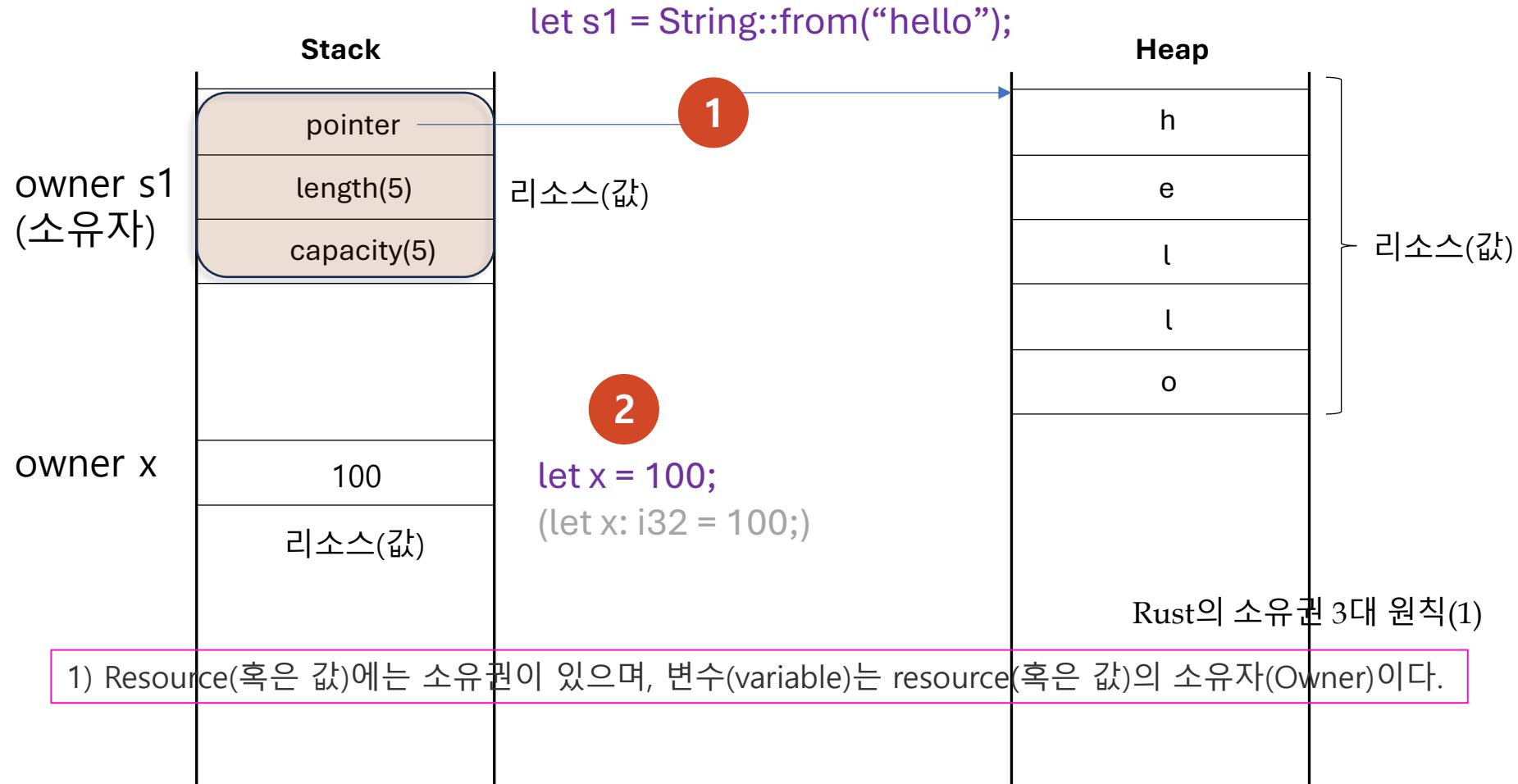
    match some_number {
        Some(x) => println!("The number is: {}", x),
        None => println!("No number"),
    }

    match absent_number {
        Some(x) => println!("The number is: {}", x),
        None => println!("No number"),
    }
}
```

3. 소유권(Ownership)

이동(Move), 복사(Copy), 빌림(Borrowing) & 참조(Reference)

3. 소유권(1) - 소유권 3대 원칙(1)



3. 소유권(1) - 소유권 3대 원칙(2)

Rust의 소유권 3대 원칙(2)

2) 소유권(Ownership)은 이동(move)할 수 있으며, 특정 시점에서의 소유자(Owner)는 오직 1개(1개의 변수) 뿐이다.

소유권 이동

```
let pasta = String::from("Carbonara");
let dinner = pasta; // ownership moves from `pasta` to `dinner`

// println!("{}", pasta); // ✗ Error! `pasta` no longer owns the
// data
println!("{}", dinner); // ✓ "Carbonara"
```

3. 소유권(1) - 소유권 3대 원칙(3)

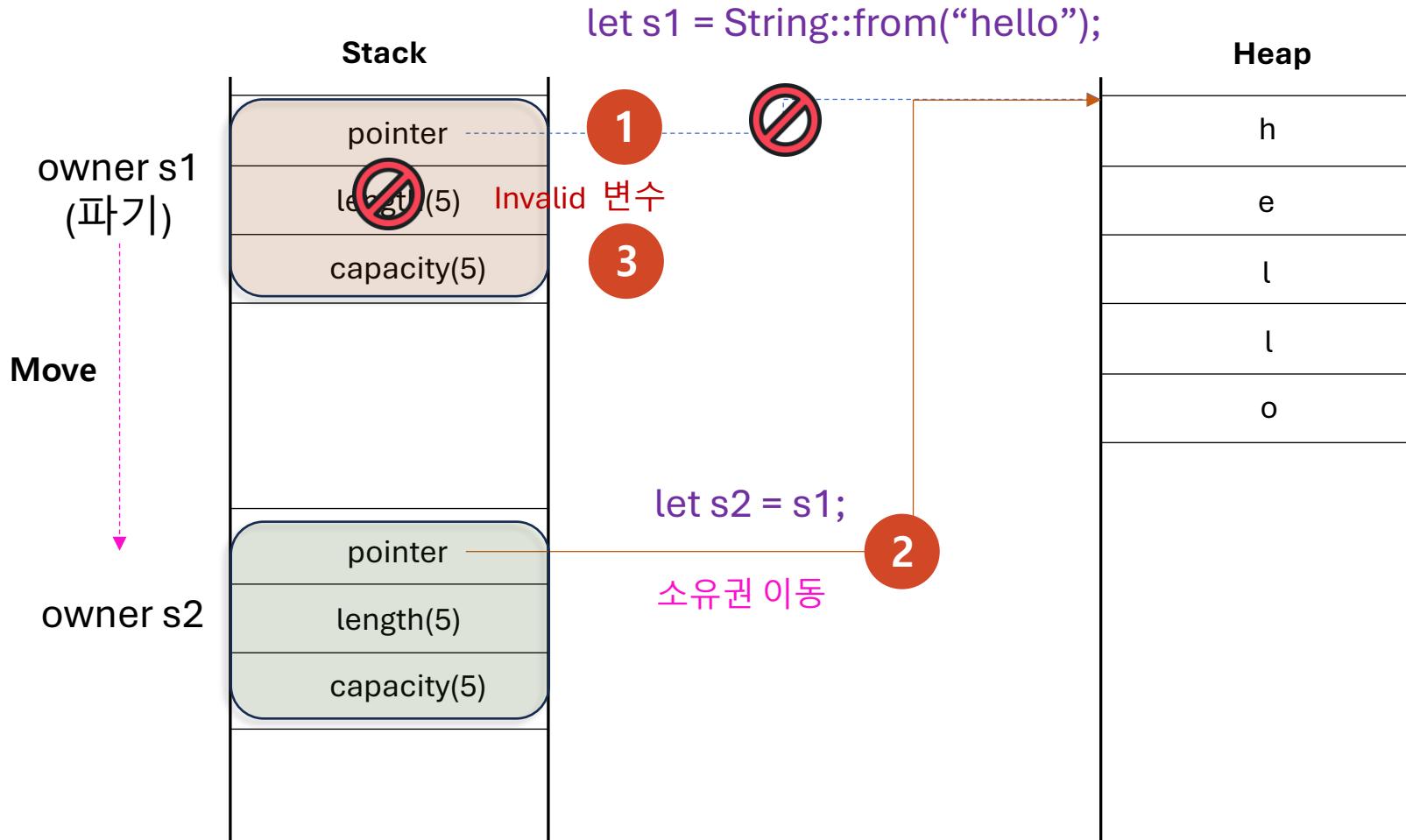
소유자가 소유한 리소스 자동 파기

```
fn main() {
    {
        let espresso = String::from("Delicious");
        println!("{}", espresso); // ✓ "Delicious"
    } // `espresso` goes out of scope here; Rust automatically drops
      its value
    // println!("{}", espresso); // ✗ Error! `espresso` doesn't
      exist anymore
}
```

Rust의 소유권 3대 원칙(3)

3) 소유자가 유효한 범위(scope)를 벗어나면, 소유자가 소유한 값은 자동으로 파기된다. 이는 memory leak을 방지해주는 효과가 있다.

3. 소유권(2) – 이동 Move(1)

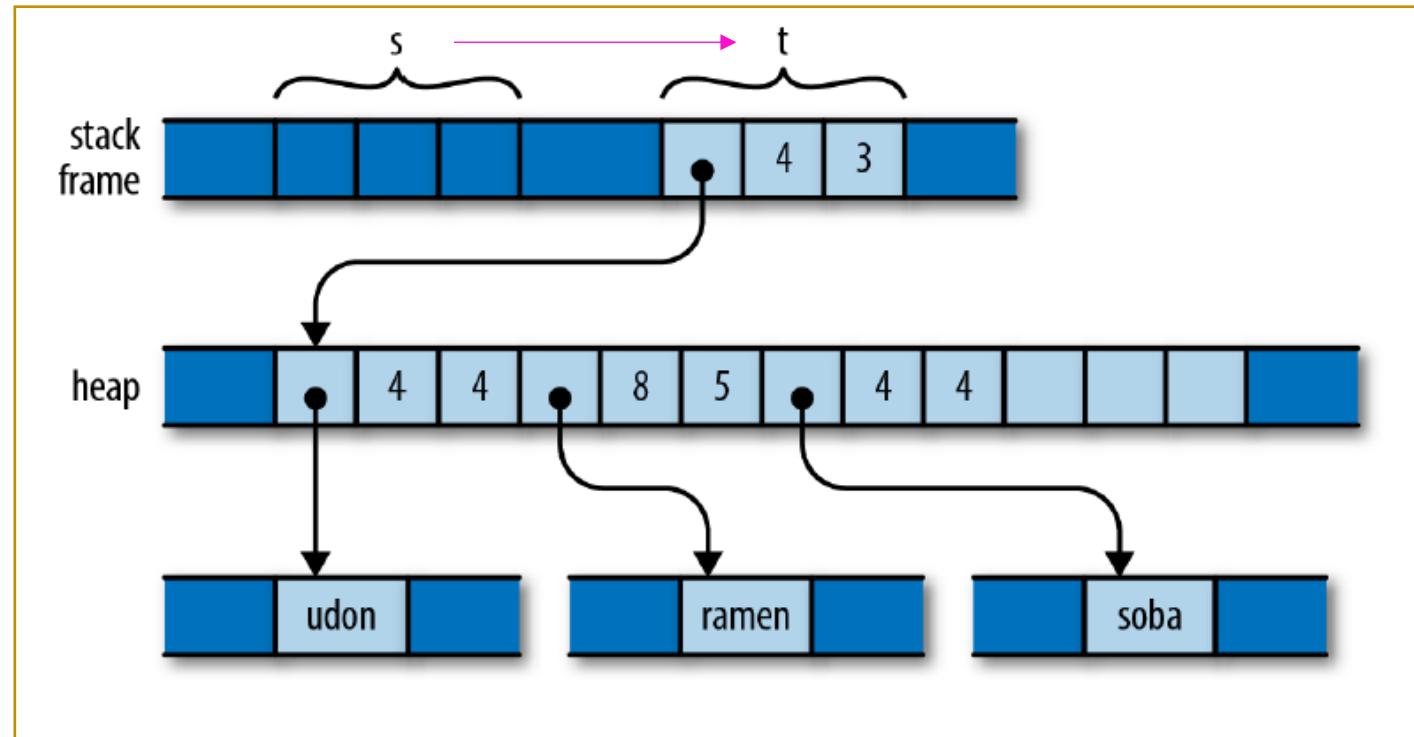


- Heap 영역에 resource가 할당되는 type의 경우, 대입문을 수행하면 값이 복사되지 않고 이동한다.
- Move는 Stack 정보만 이동하므로 빠르다.

3. 소유권(2) – 이동 Move(2)

```
let s = vec!["udon".to_string(), "ramen".to_string(), "soba".to_string()];
let t = s;
```

Vector 변수의 이동 예



3. 소유권(2) - 이동 Move(3)

변수 대입문 사용시 이동

```
fn main() {  
    // s1 is on the stack and owns the "hello" data on the heap.  
    let s1 = String::from("hello");  
  
    // The `let s2 = s1;` line performs a move.  
    // The pointer, length, and capacity from s1 are copied to s2.  
    // Ownership of the heap data is transferred to s2.  
    let s2 = s1;  
  
    // After the move, s1 is no longer considered valid by the compiler.  
    // Uncommenting the line below would cause a compile-time error.  
    // println!("This will not compile: {}", s1);  
  
    println!("s2 holds the value: {}", s2);  
}
```

함수 파라미터 전달 시 이동

```
fn main() {  
    let my_string = String::from("Hello, world!");  
  
    take_ownership(my_string);  
  
    // This line would cause a compile-time error  
    // println!("{}", my_string);  
}  
  
fn take_ownership(s: String) {  
    println!("Taking ownership: {}", s);  
}
```

3. 소유권(2) - 이동 Move(4)

함수 결과 전달 시 이동

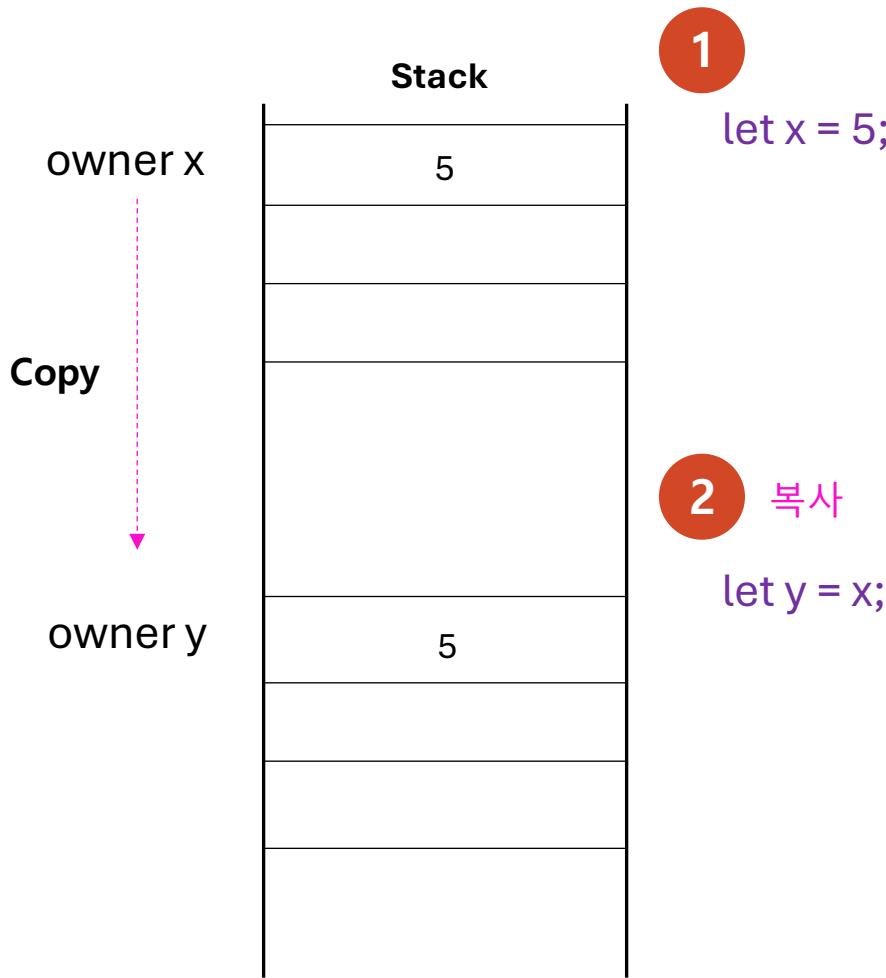
```
fn main() {
    let my_string = String::from("Hello, Rust!");

    let my_string = return_ownership(my_string);

    println!("{}", my_string); // Now this is valid
}

fn return_ownership(s: String) -> String {
    s
}
```

3. 소유권(3) - 복사 Copy



Stack에 할당되는 기본 Type(정수, 실수, Boolean 등)은 이동 대신 복사가 일어남.

```
fn main() {
    // `x` is an i32 which implements the `Copy` trait.
    let x = 5;

    // Because `x`'s type is `Copy`, a bit-for-bit copy of the value 5
    // is made and assigned to `y`. `x` is not moved or invalidated.
    let y = x;

    println!("x = {}, y = {}", x, y); // Both x and y are valid and can be
    used.

    // Let's look at a non-Copy type for contrast.
    let s1 = String::from("hello");
    // `String` does not implement `Copy`, so this is a move.
    let s2 = s1;

    // The line below would cause a compile-time error because s1 was
    moved.
    // println!("s1 = {}, s2 = {}", s1, s2);
    // error[E0382]: borrow of moved value: `s1`
}
```

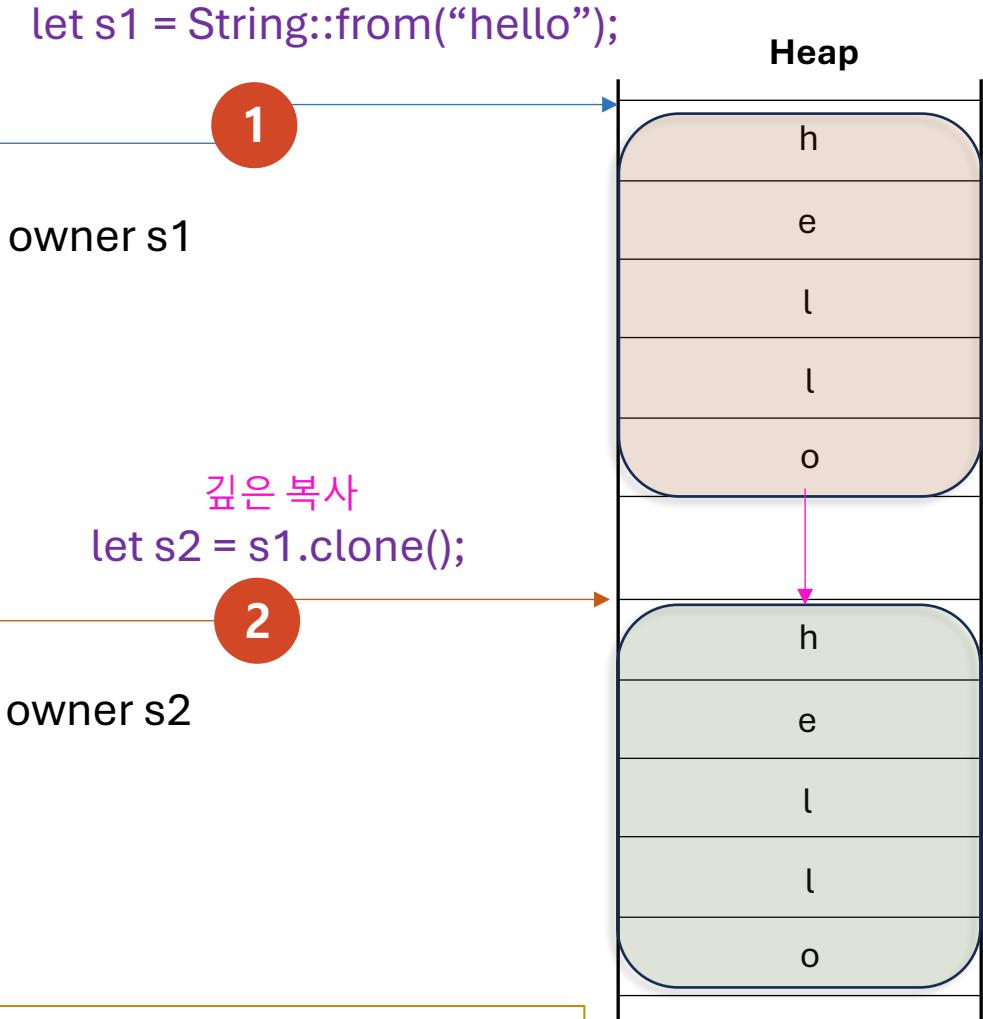
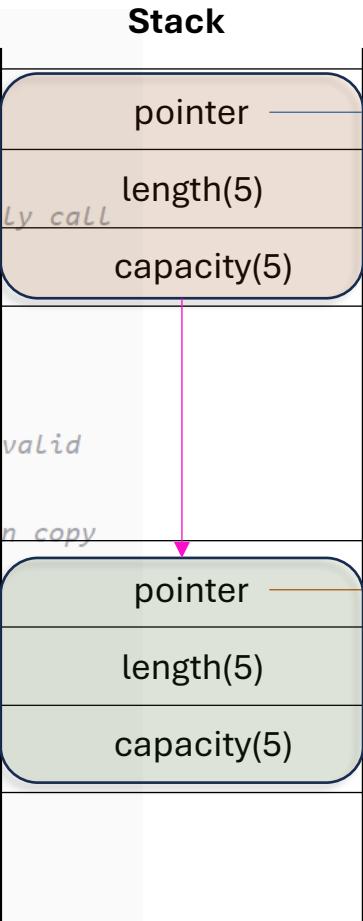
3. 소유권(4) - 깊은 복사 Clone

```
fn main() {
    // `s1` is a String, which does not implement the `Copy` trait.
    let s1 = String::from("hello");

    // To create an independent duplicate of `s1`, we must explicitly call
    .clone().
    // This performs a deep copy of the string data on the heap.
    let s2 = s1.clone();

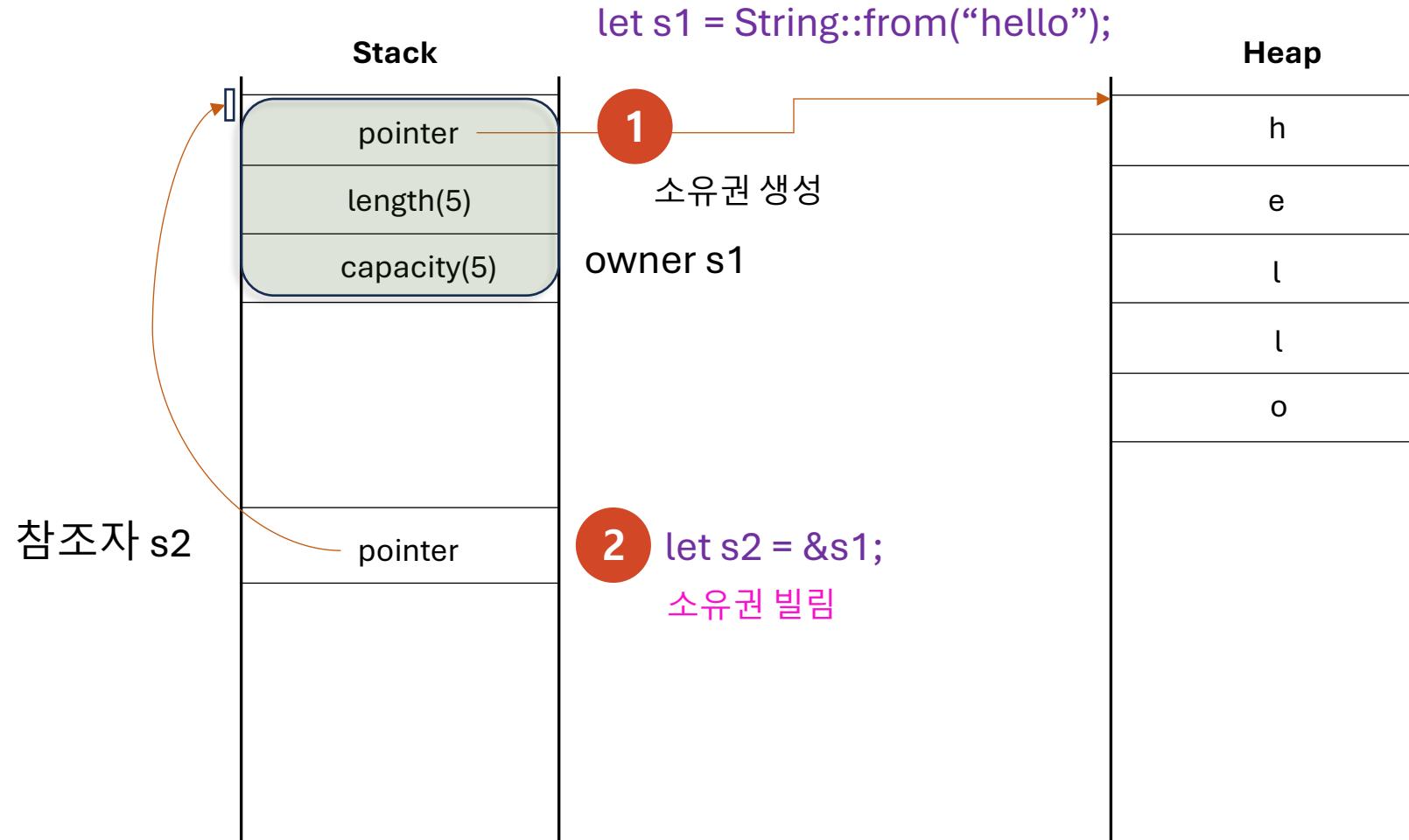
    // Because we cloned `s1`, the original variable `s1` is still valid
    and retains ownership
    // of its own data. `s2` is a brand new String that owns its own copy
    // of the data.
    println!("s1 = {}, s2 = {}", s1, s2);

    // We can modify one without affecting the other.
    // Let mut s3 = s1.clone();
    // s3.push_str(", world!");
    // println!("s1 = {}, s3 = {}", s1, s3);
}
```



Heap에 할당되는 Type(String, Vector, Box 등)에 대해 깊은 복사(Clone)을 하면, Heap 영역도 복사된다.

3. 소유권(5) - 빌림 Borrowing(1)



빌림(Borrowing)은 소유권을 이동시키지 않고, 해당 Resource를 사용하는 방법으로, 참조자(Reference)를 이용하여 실현한다.

3. 소유권(5) - 빌림 Borrowing(2)

Immutable Borrowing

```
fn main() {
    let book = String::from("Rust Programming");

    let len = calculate_length(&book); // Borrow book immutably
    println!("The length of {} is {}", book, len);

    // book is still valid here
}

fn calculate_length(s: &String) -> usize {
    s.len()
}
```

Mutable Borrowing

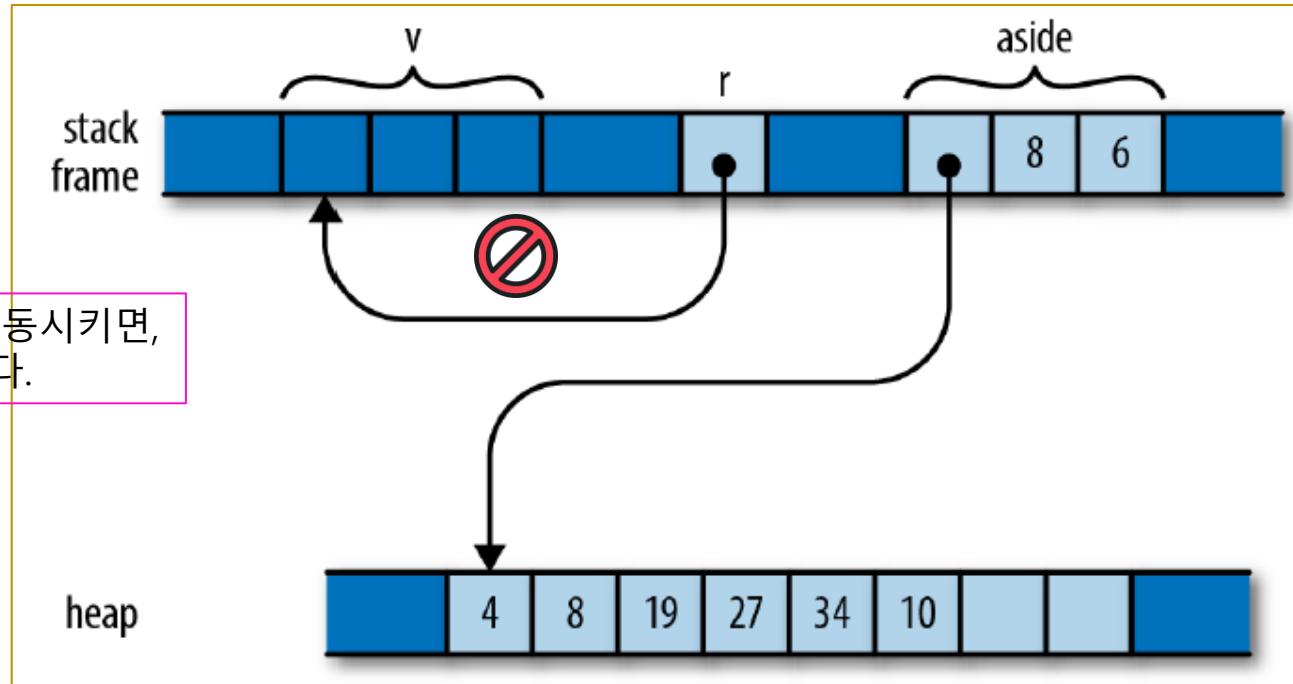
```
fn main() {
    let mut article = String::from("Rust is awesome");
    update_article(&mut article); // Borrow article mutably
    println!("Updated article: {}", article);
    // article is still valid here
}

fn update_article(s: &mut String) {
    s.push_str(" for system programming!");
}
```

3. 소유권(5) - 빌림 Borrowing(3)

```
let v = vec![4, 8, 19, 27, 34, 10];
let r = &v;
let aside = v; // move vector to aside
r[0]; // bad: uses `v` , which is now uninitialized
```

Vector 변수의 참조 예



참조하고 있는 중에, 다른 변수로 이동시키면,
Dangling Reference 문제가 발생한다.

3. 소유권(6) - 빌림 규칙(1)

1) 특정 시점에 1개의 mutable reference(&mut T)와 여러 개의 immutable reference(&T)를 동시에 사용해서는 안된다.
즉, 한 놈이 수정하고 있는데, 다른 녀석들이 그 값을 읽어가는 상황이 벌어져서는 안된다.
이는 data races, dangling pointers, unsafe memory access 등을 (compile 시점에) 찾아내기 위해 반드시 필요하다.

```
fn main() {
    let mut note = String::from("Rust is fast");

    let r1 = &note; // Immutable borrow
    let r2 = &note; // Immutable borrow
    // let r3 = &mut note; // Error: cannot borrow as mutable
    // because it is also borrowed as immutable

    println!("Note: {}, {}", r1, r2);

    let r3 = &mut note; // Mutable borrow is allowed here because no
    // immutable borrows are active
    r3.push_str(" and safe");
    println!("Updated note: {}", r3);
}
```

3. 소유권(6) - 빌림 규칙(2)

2) 모든 reference는 유효(valid)해야 한다. 즉, 모든 reference는 할당 해제된 resource나 scope를 벗어난 resource를 참조하면 안된다. 이는 dangling pointer or reference issue를 막기 위해 반드시 필요하다.

```
// This function attempts to return a reference to data that will be
// deallocated.
// Rust's compiler will prevent this with a lifetime error.
fn get_dangling_reference() -> &String {
    let s = String::from("hello");
    &s // We are trying to return a reference to `s`.
} // But `s` goes out of scope and is dropped here, so the memory is
   freed.
   // The returned reference would be "dangling" - pointing to invalid
   memory.
fn main() {
    // Let reference_to_nothing = get_dangling_reference();
    // If the code above were allowed to compile, `reference_to_nothing`
    // would be a dangling reference, and using it would be undefined
    behavior.
}
```

3. 소유권(7) - Lifetime(1)

Reference Lifetime의 정의

- Rust의 라이프타임(Lifetime)은 참조자(&T)가 유효한 범위를 의미하며, 맹글링 참조(dangling reference)를 방지하여 메모리 안전성을 보장하는 핵심 개념이다.
- 컴파일러가 유효성을 분석하며, 대부분 암묵적으로 추론되지만, 복잡한 경우 'a와 같은 제네릭 라이프타임 파라미터를 사용해 명시'해야 한다.

맹글링 참조 방지: 소유권이 해제된 데이터에 대한 참조를 컴파일 시점에 막아 에러를 발생시킨다.

컴파일 타임 검증: 라이프타임 체크는 런타임 성능에 영향을 주지 않으며, 모든 참조자는 컴파일러가 수명을 분석한다.

Lifetime Annotation: 함수의 입력 참조자와 반환 참조자의 라이프타임이 연관될 때,
fn longest<'a>(x: &'a str, y: &'a str) -> &'a str와 같이 어퍼스트로피(')를 사용하여 명시적으로 표시한다.

Lifetime은 Generic과 함께 소개되어야 하지만, 소유권 관계가 있으므로, 미리 소개하기로 함.

3. 소유권(7) - Lifetime(2)

Dangling reference issue

```
fn main() {
    let reference_to_nothing;
    {
        let x = 5;
        // Error: 'x' only lives inside this block
        reference_to_nothing = &x;
    } // 'x' is dropped here
    // This would crash if Rust allowed it!
    println!("r: {}", reference_to_nothing);
}
```

Lifetime은 Reference의 유효기간을 지정하는 기능

Lifetime의 정의

```
// src/main.rs
fn main() {
    let r; // -----+-- 'a (Outer scope: Long duration)
    {
        let x = 5; // +-+ 'b | (Inner scope: Short duration)
        r = &x; // | |
    } // --+ | <--- 'b ends here (x is dropped)

    println!("r: {}", r); // |
} // -----+ <--- 'a ends here

// Error: The reference 'r' has lifetime 'a', but refers to 'x' which has
// lifetime 'b'.
// Because the scope 'b' is shorter (ends earlier) than 'a', 'r' is left
// pointing to invalid memory.
```

```
&i32 // a reference
&'a i32 // a reference with an explicit lifetime 'a
&'a mut i32 // a mutable reference with an explicit lifetime 'a
```

3. 소유권(7) - Lifetime(3)

<조건>

- 2개의 입력 reference
- 1개의 출력 reference

<대응>

- 동일한 'a lifetime annotation' 입력
 - 2개의 입력 reference의 intersection(교집합) 즉, 더 작은 lifetime으로 지정함을 의미

```
// We declare generic lifetime 'a.  
// We tell the compiler: "x, y, and the return value must all live at least as long as 'a'.  
// Practically, 'a' becomes the intersection (the smaller) of the lifetimes of x and y.  
fn longest<'a>(x: &'a str, y: &'a str) -> &'a str {  
    if x.len() > y.len() {  
        x  
    } else {  
        y  
    }  
  
fn main() {  
    let string1 = String::from("long string");  
    let string2 = "xyz";  
  
    // We pass references to both strings.  
    // The compiler sees that both live until the end of main, so the result is valid.  
    let result = longest(string1.as_str(), string2);  
    println!("The longest string is {}", result);  
  
    // DEMO: Nested scopes  
    {  
        let string3 = String::from("tiny");  
        // Here, 'result2' is valid because 'string3' is still alive inside this block.  
        let result2 = longest(string1.as_str(), string3.as_str());  
        println!("The longest inner string is {}", result2);  
    }  
}
```

3. 소유권(7) - Lifetime(4)

구조체와 Lifetime

```
// src/main.rs
// This struct holds a reference, so it needs a lifetime 'a
struct ImportantExcerpt<'a> {
    part: &'a str,
}

fn main() {
    let novel = String::from("Call me Ishmael. Some years ago...");

    // The instance 'first_sentence' cannot outlive 'novel'
    let first_sentence = ImportantExcerpt {
        part: &novel[0..15],
    };
}

// If 'novel' were dropped here, 'first_sentence' would become
invalid.
}
```

Struct내에 reference field가 있는 경우,
Lifetime를 표시해 주어야 함.

```
struct Highlight<'a> {
    part: &'a str,
}

// 1. impl<'a>: We DECLARE the Lifetime parameter here so the compiler
// knows it exists.
// 2. Highlight<'a>: We USE it here to select the specific struct type.
impl<'a> Highlight<'a> {
    fn announce(&self) {
        println!("Attention to: {}", self.part);
    }
}
```

4. Composite Type과 Collections

구조체(struct), 열거형(enum), 튜플
&
Vector, HashMap and etc.

4. Composite Type과 Collections(1) - 구조체 Struct(1)

C++ Class

```
class Person {
```

data

methods

```
}
```

Rust Struct

```
struct Person {
```

data

```
}
```

```
impl Person {
```

methods

Associated funcs

vs

4. Composite Type과 Collections(1) - 구조체 Struct(2)

```
struct User {  
    username: String,  
    email: String,  
    sign_in_count: u64,  
    active: bool,  
}
```

```
fn main() {  
    let user1 = User {  
        username: String::from("someusername123"),  
        email: String::from("someone@example.com"),  
        sign_in_count: 1,  
        active: true,  
    };  
  
    println!("Username: {}", user1.username);  
    println!("Email: {}", user1.email);  
    println!("Sign in count: {}", user1.sign_in_count);  
    println!("Active: {}", user1.active);  
}
```

struct 변수 사용 예

```
struct Color(i32, i32, i32);  
fn main() {  
    let black = Color(0, 0, 0);  
  
    println!("Black: {}, {}, {})", black.0, black.1, black.2);  
}
```

Tuple struct 변수 사용 예

Unit struct 변수 사용 예

```
struct AlwaysEqual;  
  
fn main() {  
    let _subject = AlwaysEqual;  
}
```

4. Composite Type과 Collections(1) - 구조체 Struct(3)

```
struct Rectangle {  
    width: u32,  
    height: u32,  
}
```

struct와 method 구현 예

```
impl Rectangle {  
    fn area(&self) -> u32 {  
        self.width * self.height  
    }  
  
    fn can_hold(&self, other: &Rectangle) -> bool {  
        self.width > other.width && self.height > other.height  
    }  
}
```

```
fn main() {  
    let rect1 = Rectangle {  
        width: 30,  
        height: 50,  
    };  
  
    let rect2 = Rectangle {  
        width: 10,  
        height: 40,  
    };  
  
    let rect3 = Rectangle {  
        width: 60,  
        height: 45,  
    };  
  
    println!("The area of rect1 is {} square pixels.", rect1.area());  
    println!("Can rect1 hold rect2? {}", rect1.can_hold(&rect2));  
    println!("Can rect1 hold rect3? {}", rect1.can_hold(&rect3));  
}
```

4. Composite Type과 Collections(1) - 구조체 Struct(4)

```
impl Rectangle {  
    fn square(size: u32) -> Rectangle {  
        Rectangle {  
            width: size,  
            height: size,  
        }  
    }  
  
    fn main() {  
        let sq = Rectangle::square(3);  
        println!("The area of the square is {} square pixels.", sq.area());  
    }  
}
```

self가 없음.

struct와 연관 함수(associated function) 구현 예

4. Composite Type과 Collections(1) - 구조체 Struct(5)

```
// Define tuple structs
struct Color(u8, u8, u8); // RGB
struct Point(i32, i32);   // 2D coordinates

fn main() {
    // Instantiate like tuples, but with the type name
    let red = Color(255, 0, 0);
    let origin = Point(0, 0);

    // Access fields using dot notation and index
    println!("Red's green component: {}", red.1); // Accesses the second
field (index 1)

    // They define distinct types
    // Let point_tuple: (i32, i32) = origin; // Error: mismatched types
Point != (i32, i32)

    // Can be destructured
    let Point(x, y) = origin;
    println!("Origin coordinates: x={}, y={}", x, y);
}
```

Struct로 Tuple을 구현한 예

Tuple type을 사용한 예

```
fn main() {
    let tuple: (i32, f64, bool) = (42, 6.7, true);

    let int_value = tuple.0;
    let float_value = tuple.1;
    let bool_value = tuple.2;

    println!("Integer value: {}", int_value);
    println!("Float value: {}", float_value);
    println!("Boolean value: {}", bool_value);
}
```

4. Composite Type과 Collections(1) - 구조체 Struct(6)

소유권 이동(Move) 발생

```
struct User {  
    username: String,  
    email: String,  
    sign_in_count: u64,  
    active: bool,  
}  
  
fn main() {  
    let user1 = User {  
        username: String::from("someusername123"),  
        email: String::from("someone@example.com"),  
        sign_in_count: 1,  
        active: true,  
    };  
  
    let user2 = user1; // Moves ownership of user1 to user2  
  
    // println!("Username: {}", user1.username); // This would cause a  
    // compile-time error  
    println!("Username: {}", user2.username); // Accessing user2 is fine  
}
```

구조체의 소유권 이동 구현 예

4. Composite Type과 Collections(1) - 구조체 Struct(7)

```
fn main() {
    let user1 = User {
        username: String::from("someusername123"),
        email: String::from("someone@example.com"),
        sign_in_count: 1,
        active: true,
    };

    let user_ref = &user1; // Borrowing user1
    println!("Username: {}", user_ref.username); // Reading borrowed data
    // user1 can still be used because user_ref is just a reference
    println!("Email: {}", user1.email);
}
```

구조체의 소유권 빌림 구현 예

4. Composite Type과 Collections(1) - 구조체 Struct(8)

```
#[derive(Debug)]
struct User {
    username: String,
    email: String,
    sign_in_count: u64,
    active: bool,
}

fn main() {
    let user1 = User {
        username: String::from("someusername123"),
        email: String::from("someone@example.com"),
        sign_in_count: 1,
        active: true,
    };
    println!("{:?}", user1);
}
```

구조체의 Debug 트레이트 사용 예

4. Composite Type과 Collections(2) - 열거형 Enum(1)

Rust Enum

```
enum Color {
```

variants

```
}
```

```
impl Color {
```

methods

```
}
```

```
#[derive(Debug)]  
enum Color {  
    // A variant that holds a tuple of three 8-bit unsigned integers  
    Rgb(u8, u8, u8),  
    // A variant that holds a single String  
    Named(String),  
}  
  
fn main() {  
    let red = Color::Rgb(255, 0, 0);  
    let custom_color = Color::Named(String::from("Forest Green"));  
  
    println!("An RGB color: {:?}", red);  
    println!("A named color: {:?}", custom_color);  
}
```

enum 변수 사용 예

Rust의 enum의 각 variant는 type을 가질 수 있음.

4. Composite Type과 Collections(2) - 열거형 Enum(2)

```
enum Message {
    Quit,
    Move { x: i32, y: i32 },
    Write(String),
    ChangeColor(i32, i32, i32),
}

impl Message{
    fn call(&self) {
        match self {
            Message::Quit => println!("Quit message"),
            Message::Move { x, y } => println!("Move to x: {}, y: {}", x, y),
            Message::Write(text) => println!("Write message: {}", text),
            Message::ChangeColor(r, g, b) => println!("Change color to red: {}, green: {}, blue: {}", r, g, b),
        }
    }
}
```

enum method 구현 예

4. Composite Type과 Collections(3) - Vector(1)

```
fn main() {
    let mut i32_vec = Vec::<i32>::new(); // 자료형 명시

    i32_vec.push(1); // 자료형 추가
    i32_vec.push(2);
    i32_vec.push(3);

    println!("{:?}", i32_vec);

    let mut float_vec = Vec::new(); // 자료형 추론

    float_vec.push(1.3);
    float_vec.push(2.3);
    float_vec.push(3.4);

    println!("{:?}", float_vec);

    float_vec.pop(); // 마지막 요소 제거

    println!("{:?}", float_vec);

    let string_vec = vec![String::from("Hello"), String::from("World")];

    for word in string_vec.iter() { // 반복자 사용
        println!("{}", word);
    }
}
```

Vec<T>

```
fn main() {
    let v = vec![1,2,3];

    for n in &v {
        println!("{}", n);
    }

    let mut v = vec![1,2,3];

    for n in &mut v {
        *n = *n + 1;
        println!("{}", n);
    }
}
```

```
fn main() {
    let numbers = vec![1, 2, 3, 4, 5];

    for (index, number) in numbers.iter().enumerate() {
        println!("Index: {}, Value: {}", index, number);
    }
}
```

4. Composite Type과 Collections(3) - Vector(2)

```
fn main() {
    // 3x3 2차원 벡터 생성
    let rows = 3;
    let cols = 3;
    let mut matrix: Vec<Vec<i32>> = vec![vec![0; cols]; rows];

    // 값 할당
    for i in 0..rows {
        for j in 0..cols {
            matrix[i][j] = i as i32 + j as i32; // 간단한 값 할당
        }
    }

    // 출력
    for row in &matrix {
        for value in row {
            print!("{} ", value);
        }
        println!();
    }
}
```

```
fn main() {
    // 2x2x2 크기의 3차원 벡터 생성
    let x_size = 2;
    let y_size = 2;
    let z_size = 2;
    let mut cube: Vec<Vec<Vec<i32>>> = vec![vec![vec![0; z_size]; y_size]; x_size];

    // 값 할당
    for x in 0..x_size {
        for y in 0..y_size {
            for z in 0..z_size {
                cube[x][y][z] = x as i32 + y as i32 + z as i32; // 간단한 값 할당
            }
        }
    }

    // 출력
    for x in &cube {
        for y in x {
            for value in y {
                print!("{} ", value);
            }
            println!();
        }

        println!("---"); // 끝 구분
    }
}
```

4. Composite Type과 Collections(4) - HashMap

```
use std::collections::HashMap;

fn main() {
    let mut scores = HashMap::new();
    let name = String::from("Alice");

    scores.insert(name, 10); // name의 소유권이 HashMap으로 이동

    //println!("{}: {}", name, scores); // ✗ 오류! name의 소유권이 이동되었음

    // 키가 없으면 기본값 삽입
    scores.insert(String::from("Bob"), 30);

    println!("{}: {}", "scores", scores);
}
```

HashMap<T>

```
use std::collections::HashMap;

fn main() {
    let mut scores = HashMap::new();

    scores.insert("Alice", 10);
    scores.insert("Bob", 20);
    scores.insert("Charlie", 30);

    // HashMap 순회
    for (key, value) in &scores {
        println!("{}: {}", key, value);
    }
}
```

```
use std::collections::HashMap;

fn main() {
    let mut scores = HashMap::new();

    scores.insert("Alice", 10);

    // 기존 키가 존재하면 값을 변경하지 않을
    scores.entry("Alice").or_insert(20); // 기존 값 유지
    scores.entry("Bob").or_insert(30); // 새로운 값 추가

    println!("{}: {}", "scores", scores);

    // 키가 없을 때 기본값을 삽입하고, 값을 변경
    let charlie = scores.entry("Charlie").or_insert(30);

    *charlie += 10; // Charlie의 값 증가
    println!("{}: {}", "scores", scores);

    // 값을 계산해서 넣는다.
    scores.entry("Dave").or_insert_with(|| {
        let computed_value = 50;
        computed_value
    });

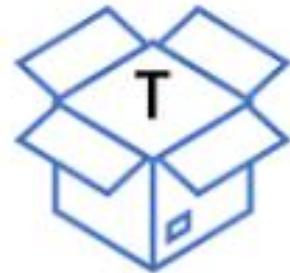
    println!("{}: {}", "scores", scores);
}
```

5. Error Handling

열거형(Enum) Option<T> and Result<T, E>

5. Error Handling(1) - Option과 Result 열거형(Enum)

- Option<T>는 함수 실행 결과, 원하는 값이 없을 수도 있는 경우에 주로 사용함.
- 이 경우, 값이 존재하는 이유는 중요하지 않을 경우에 주로 사용함.



Option<T>
Some(T) or
None

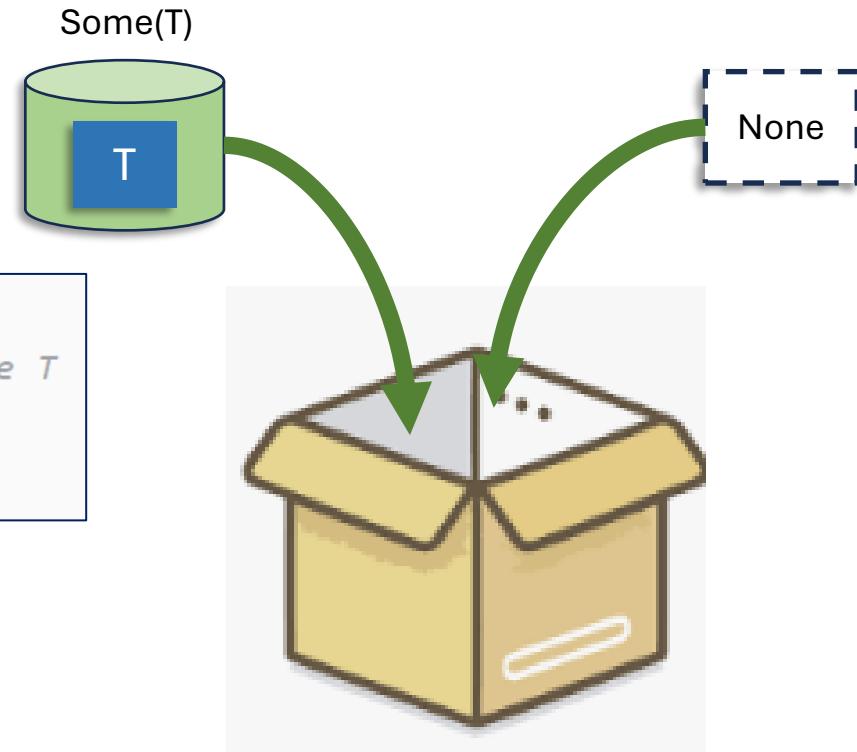


Result<T,E>
Ok(T) or
Err(E)

- Result<T, E>는 함수 실행 결과, 성공과 실패로 나뉘는 경우에 주로 사용함.
- 또한, 함수 호출자에서 실패의 이유를 알리고자 할 경우에 주로 사용함.

5. Error Handling(2) - Option<T> (1)

```
enum Option<T> {  
    Some(T), // Value is present: contains a value of type T  
    None,    // Value is absent  
}
```



Option<T>

T는 제네릭(Generics) 타입을 의미함.

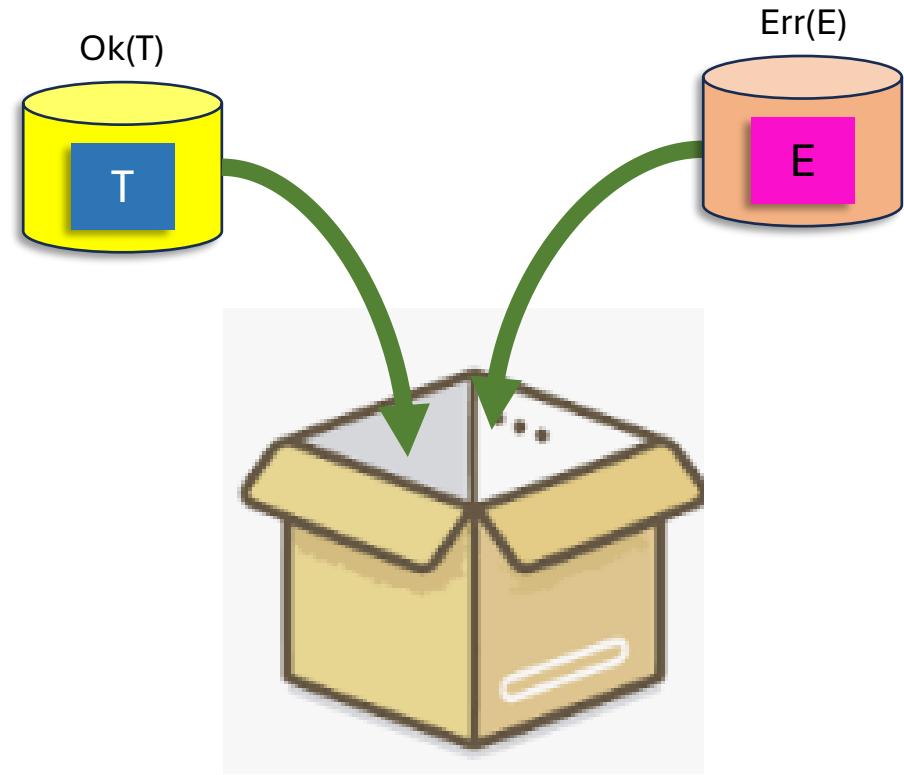
5. Error Handling(2) - Option<T> (2)

```
// This function searches for a word in a sentence.  
// It returns Option<usize>: Some(index) if the word is found, or None  
otherwise.  
  
fn find_word_index(haystack: &str, needle: &str) -> Option<usize> {  
    // The built-in .find() method on string slices already returns  
Option<usize>,  
    // which is very convenient.  
    haystack.find(needle)  
}  
  
fn main() {  
    let famous_phrase = "The quick brown fox jumps over the lazy dog.";  
    let word_to_find = "fox";  
    let word_not_present = "cat";  
  
    // --- Test Case 1: Word is found ---  
    println!("Searching for '{}'", word_to_find);  
    match find_word_index(famous_phrase, word_to_find) {
```

```
        Some(index) => println!("Success! Found at index {}.", index),  
        None => println!("Failure: Word not found."),  
    }  
  
    println!("---");  
  
    // --- Test Case 2: Word is NOT found ---  
    println!("Searching for '{}'", word_not_present);  
    match find_word_index(famous_phrase, word_not_present) {  
        Some(index) => println!("Success! Found at index {}.", index),  
        None => println!("Correctly determined that the word was not  
found."),  
    }
```

5. Error Handling(3) – Result<T, E> (1)

```
enum Result<T, E> {  
    Ok(T), // Success: contains a value of type T  
    Err(E), // Failure: contains an error value of type E  
}
```



T와 E는 제네릭(Generics) 타입을 의미함.

5. Error Handling(3) - Result<T, E> (2)

```
// Function returning a Result: Ok with an f64 result, or Err with a
String error message.

fn divide(numerator: f64, denominator: f64) > Result<f64, String> {
    if denominator == 0.0 {
        // If denominator is zero, return an error (Err)
        Err(String::from("Error: division by zero!"))
    } else {
        // Otherwise, return the result successfully (Ok)
        Ok(numerator / denominator)
    }
}

fn main() {
    let result1 = divide(10.0, 2.0); // Successful call
    let result2 = divide(5.0, 0.0); // Failing call

    // Use 'match' to handle both cases of the Result
    match result1 {
        Ok(value) => println!("Division 10/2 succeeded: {}", value),
        Err(message) => println!("Error in division 10/2: {}", message),
    }
}
```

Output: 5.0

5. Error Handling(4) - Unwrapping(1)

.unwrap() method 사용 예

```
// A simple function that returns a Result, for context.  
fn divide(a: f64, b: f64) -> Result<f64, String> {  
    if b == 0.0 {  
        Err("Division by zero".to_string())  
    } else {  
        Ok(a / b)  
    }  
}
```

.unwrap()은 실패(Err)시, panic이 발생한다.

```
fn main() {  
    // --- Success Case ---  
    let ok_result = divide(10.0, 5.0);  
  
    // Print the Result before unwrapping to show its Ok(value)  
    // state.  
    println!("The Result before unwrap: {:?}", ok_result); // Prints: Ok(2.0)  
  
    // .unwrap() extracts the value from the Ok variant.  
    let value = ok_result.unwrap();  
    println!("The value after unwrap: {}", value); // Prints: 2.0  
  
    // --- Panic Case ---  
    // let err_result = divide(10.0, 0.0); // This would be  
    // Err("Division by zero")  
    // println!("The Result before panic: {:?}", err_result);  
    //  
    // Calling .unwrap() on an Err variant will cause the program  
    // to panic.  
    // let value_panic = err_result.unwrap(); // This line would  
    // PANIC!  
}
```

5. Error Handling(4) - Unwrapping(2)

.expect() method 사용 예

```
let non_existent_file: Result<String, std::io::Error> =
    std::fs::read_to_string("file_no_exist.txt");
// This will panic with the specified message
// non_existent_file.expect("Expected the file to definitely exist!");
```

.expect()는 실패(Err)시, 파라미터 값을 출력하면서, panic이 발생한다.

.unwrap_or() method 사용 예

```
let err_result = divide(10.0, 0.0); // This is Err(...)
let value_or_default = err_result.unwrap_or(0.0); // Doesn't panic,
                                                 returns 0.0
println!("Value or default: {}", value_or_default);

let none_option: Option<i32> = None;
let option_value = none_option.unwrap_or(100); // Returns 100
println!("Option or default: {}", option_value);
```

.unwrap_or()는 실패(Err)시, 파라미터 전달한다(panic은 발생하지 않음).

5. Error Handling(4) - Unwrapping(3)

.unwrap_or_else() method 사용 예

```
let err_result = divide(10.0, 0.0); // Err(...)

let value_or_computed = err_result.unwrap_or_else(|err_msg| {
    println!("Error during division: {}. Using fallback value.", err_msg);
    -1.0 // Value computed/returned by the closure
});

println!("Value or computed: {}", value_or_computed);
```

.unwrap_or_else()는 실패(Err)시, 파라미터로 넘긴 closure를 실행한다.

5. Error Handling(4) - Unwrapping(4-1)

? Operator 사용 예(1)

```
1  use std::fs;
2  use std::io;
3  use std::num::ParseFloatError;
4
5  // 1. Define a custom error type for our function
6  // Suppress the spurious 'dead_code' warning related to the derived Debug implementation
7  #[allow(dead_code)]
8  #[derive(Debug)]
9  enum ReadDivideError {
10     Io(io::Error),
11     Format(ParseFloatError),
12     Math(String),
13 }
14
15 // 2. Implement 'From' trait to allow '?' to automatically convert io::Error
16 impl From<io::Error> for ReadDivideError {
17     fn from(err: io::Error) -> ReadDivideError {
18         ReadDivideError::Io(err)
19     }
20 }
21
22 // 3. Implement 'From' trait to allow '?' to automatically convert ParseFloatError
23 impl From<ParseFloatError> for ReadDivideError {
24     fn from(err: ParseFloatError) -> ReadDivideError {
25         ReadDivideError::Format(err)
26     }
27 }
28
29 // 4. Implement 'From' trait to allow '?' to automatically convert String (from divide)
30 impl From<String> for ReadDivideError {
31     fn from(err: String) -> ReadDivideError {
32         ReadDivideError::Math(err)
33     }
34 }
```

```
36  // 5. Our original 'divide' function
37  fn divide(numerator: f64, denominator: f64) -> Result<f64, String> {
38      if denominator == 0.0 {
39          Err(String::from("Division by zero!"))
40      } else {
41          Ok(numerator / denominator)
42      }
43  }
44
45  // Function using '?'
46  fn read_then_divide_with_qmark(file_path: &str, divisor: f64) -> Result<f64, ReadDivideError> {
47      // The '?' operator automatically converts and propagates errors
48      let content = fs::read_to_string(file_path)?;
49      let number = content.trim().parse::<f64>()?;
50      let result = divide(number, divisor)?;
51      Ok(result)
52  }
53
54
55  fn main() {
56      // --- Setup and Tests ---
57      let filename = "number.txt";
58      fs::write(filename, "100.5").expect("Cannot write file");
59
60      println!("--- 1. Success Case ---");
61      match read_then_divide_with_qmark(filename, 2.0) {
62          Ok(r) => println!("Result with '?': {}", r),
63          Err(e) => println!("Error with '?': {:?}", e),
64      }
65
66      println!("\\n--- 2. Division by Zero Error ---");
67      match read_then_divide_with_qmark(filename, 0.0) {
68          Ok(_) => (),
69          Err(e) => println!("Error with '?': {:?}", e),
70      }
71
72      // Clean up dummy file
73      fs::remove_file(filename).ok();
74 }
```

5. Error Handling(4) - Unwrapping(4-2)

? Operator 사용 예(2)

```
// Function using '?' - Note it now returns our custom error type
fn read_then_divide_with_qmark(file_path: &str, divisor: f64) ->
Result<f64, ReadDivideError> {
    // '?' handles io::Error, converting it via From into
    ReadDivideError::Io
    let content = fs::read_to_string(file_path)?; [ ]

    // '?' handles ParseFloatError, converting it via From into
    ReadDivideError::Format
    let number = content.trim().parse::<f64>()?;
[ ]

    // '?' handles the String error from divide, converting via From into
    ReadDivideError::Math
    let result = divide(number, divisor)?;
[ ]

    Ok(result) // If all OK, return Ok...
}
```

6. 다형성(Polymorphism)과 OOP

구조체(Struct), 트레이트(Trait) and 제네릭스(Generics)

6. 다형성과 OOP(1) - 구조체 Struct

Struct + Generics + Trait

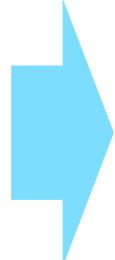
```
struct Rectangle<T> {  
    data  
}
```

```
Impl<T> Rectangle<T>  
where  
    T: Display + Copy,  
{
```

Associated funcs

methods

}



```
use std::ops::Mul;  
use std::fmt::Display;  
  
struct Rectangle<T> {  
    width: T,  
    height: T,  
}  
  
impl<T> Rectangle<T>  
where  
    T: Display + Mul<Output = T> + Copy, // 곱셈과 출력이 가능하도록 제약 추가  
{  
    fn area(&self) -> T {  
        println!("Rectangle: {}x{}", self.width, self.height);  
        self.width * self.height  
    }  
}  
  
fn main() {  
    let rect = Rectangle { width: 5, height: 10 };  
  
    println!("Area: {}", rect.area());  
}
```

6. 다형성과 OOP(2) - 제네릭스(Generics)(1)

```
// we are forced to write two functions with identical logic
fn largest_i32(list: &[i32]) -> i32 {
    let mut largest = list[0];
    for &item in list {
        if item > largest {
            largest = item;
        }
    }
    largest
}

fn largest_char(list: &[char]) -> char {
    let mut largest = list[0];
    for &item in list {
        if item > largest {
            largest = item;
        }
    }
    largest
}
```

```
// we read this as: "largest is a function generic over some type T"
fn largest<T>(list: &[T]) -> T {
    let mut largest = list[0];
    for &item in list {
        // NOTE: This specific line will cause a compiler error right now!
        // We will explain why and fix it in the next section.
        if item > largest {
            largest = item;
        }
    }
    largest
}
```

<T>, <T, U>, <T, U, V> ...

6. 다형성과 OOP(2) - 제네릭스(Generics)(2)

Generics for function

```
fn largest<T: PartialOrd + Copy>(list: &[T]) -> T {
    let mut largest = list[0];

    for &item in list.iter() {
        if item > largest {
            largest = item;
        }
    }
    largest
}
```

```
struct Point<T, U> {
    x: T,
    y: U,
}

fn main() {
    let p = Point { x: 5, y: 4.0 }; // T는 i32, U는 f64

    println!("Point: ({}, {})", p.x, p.y);
}
```

Generics for struct#2

Generics for struct#1

```
struct Point<T> {
    x: T,
    y: T,
}

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

```
fn main() {
    let p1 = Point::new(5, 10); // 정수 타입
    let p2 = Point::new(1.0, 4.0); // 부동소수점 타입

    println!("p1: ({}, {})", p1.x, p1.y);
    println!("p2: ({}, {})", p2.x, p2.y);
}
```

6. 다형성과 OOP(2) - 제네릭스(Generics)(3)

Generics for enum

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

Generics + Trait bound

```
use std::ops::Mul;  
use std::fmt::Display;  
  
struct Rectangle<T> {  
    width: T,  
    height: T,  
}  
  
impl<T> Rectangle<T>  
where  
    T: Display + Mul<Output = T> + Copy, // 곱셈과 출력이 가능하도록 제약 추가  
{  
    fn area(&self) -> T {  
        println!("Rectangle: {}x{}", self.width, self.height);  
        self.width * self.height  
    }  
}  
  
fn main() {  
    let rect = Rectangle { width: 5, height: 10 };  
  
    println!("Area: {}", rect.area());  
}
```

6. 다형성과 OOP(2) - 제네릭스(Generics)(4)

```
// We define a lifetime 'a so the returned Self can hold references to
// 'input'
trait Parse<'a>{
    fn parse(input: &'a str) -> Self;
}

// This function works for ANY type T that implements Parse
// The <'a> ensures that the returned T cannot outlive the input string.
fn load_configuration<'a, T>(input: &'a str) -> T
where
    T: Parse<'a>,
{
    println!("Loading configuration...");
    T::parse(input)
}
```

Generics + lifetime

<'a, 'b', 'c>, <'static>

```
// src/lib.rs

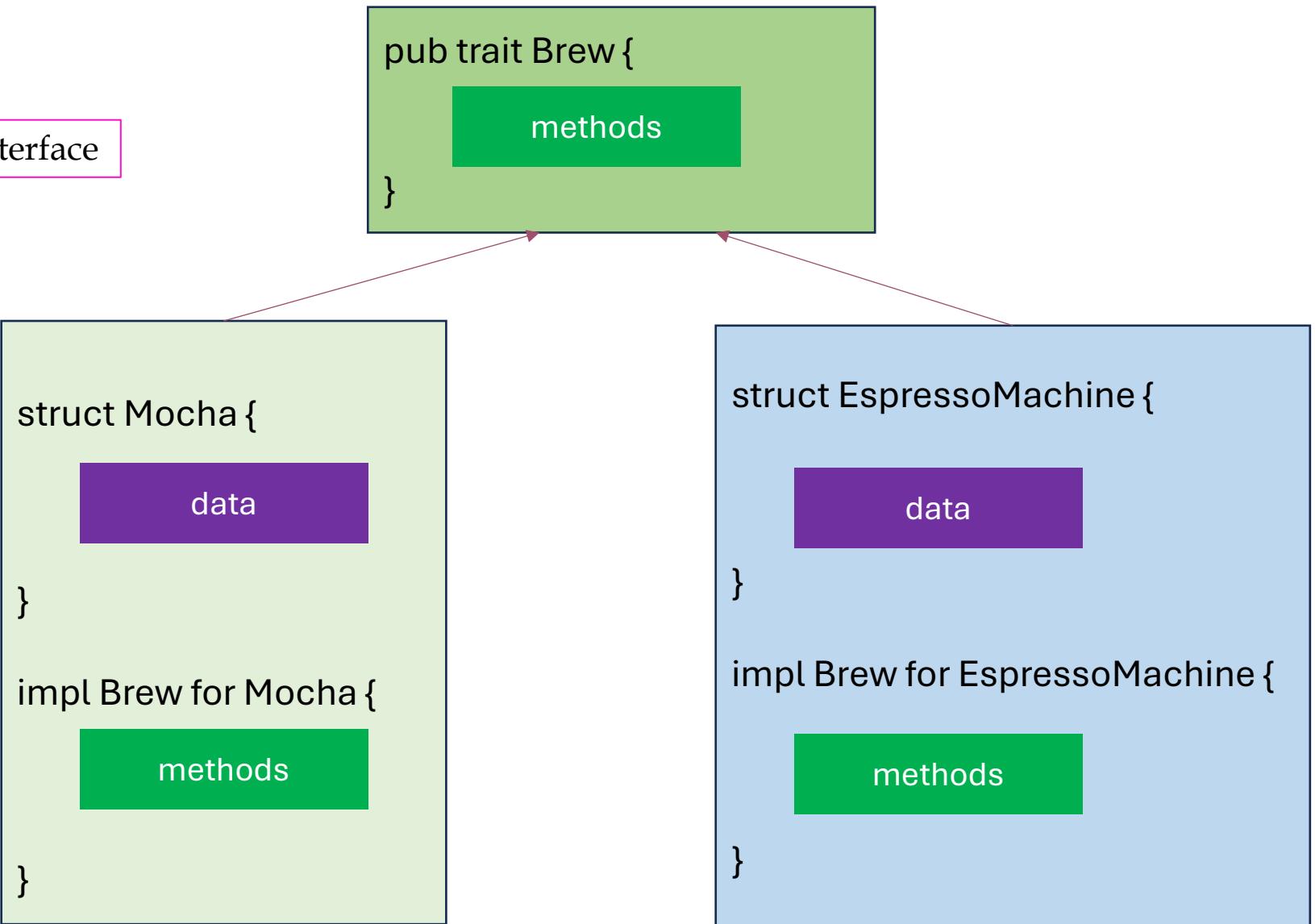
struct ServerConfig<'a> {
    address: &'a str,
    port: &'a str,
}

impl<'a> Parse<'a> for ServerConfig<'a> {
    fn parse(input: &'a str) -> Self {
        // We look for a space to separate the address and port.
        // Example Input: "localhost 8080"
        let index = input.find(' ').unwrap_or(input.len());

        // ZERO-COPY MAGIC:
        // We use slicing syntax to create references that point directly
        // into the original 'input' memory buffer.
        // No new strings are allocated here!
        ServerConfig {
            address: &input[..index],           // Borrow the first part
            port: &input[index + 1..],          // Borrow the second part
        }
    }
}
```

6. 다형성과 OOP(3) - Trait(1)

Rust Trait = Java, Golang's Interface



6. 다형성과 OOP(3) - Trait(2)

```
// src/lib.rs
pub trait Brew {
    fn extract(&self) -> String;
    // This is a default implementation.
    // If a type doesn't define this method, it gets this version
    // automatically.
    fn clean(&self) -> String {
        String::from("Cleaning with a simple hot water rinse.")
    }
}
```

```
pub struct Moka;
pub struct EspressoMachine;

impl Brew for Moka {
    fn extract(&self) -> String {
        String::from("Bubbling up some coffee...")
    }
    // We don't implement clean() here.
    // Moka automatically uses the default "hot water rinse".
}

impl Brew for EspressoMachine {
    fn extract(&self) -> String {
        String::from("Pressurizing water...")
    }
    // We override the default because this machine is complex.
    fn clean(&self) -> String {
        String::from("Running automatic descaling program.")
    }
}
```

6. 다형성과 OOP(3) - Trait(3)

```
pub trait SimpleIterator {
    type Item; ← Associated Type
    fn next(&mut self) -> Option<Self::Item>;
}

struct Counter {
    current: u32,
    max: u32,
}

impl SimpleIterator for Counter {
    type Item = u32;
    fn next(&mut self) -> Option<Self::Item> {
        if self.current < self.max {
            let val = self.current;
            self.current += 1;
            Some(val)
        } else {
            None
        }
    }
}

fn main() {
    let mut counter = Counter {
        current: 0,
        max: 3
    };
    for _i in 0..=3 {
        println!("{}:", counter.next());
    }
}
```

6. 다형성과 OOP(4) - Debug and Display Trait

Derived Macro

```
use std::fmt::Display;

trait PrintableSummary: Display {
    fn print_summary(&self);
}

#[derive(Debug)]
struct Report {
    title: String,
    content: String,
}

impl Display for Report {
    fn fmt(&self, f: &mut std::fmt::Formatter<'_>) -> std::fmt::Result {
        write!(f, "Report: '{}'", self.title)
    }
}
```

```
impl PrintableSummary for Report {
    fn print_summary(&self) {
        println!("--- Summary ---");
        println!("###1 -> {:?}", self);
        println!("###2 -----> {}", self);
        println!("Content length: {}", self.content.len());
        println!("--- -----");
    }
}

fn main() {
    let report = Report {
        title: "Q1 Results".into(),
        content: "Sales were strong...".into(),
    };
    report.print_summary();
}
```

6. 다형성과 OOP(5) - Trait Orphan Rule

```
// src/lib.rs
use std::fmt;

// --- ALLOWED SCENARIOS ---
외부 type에 대해 사용자 정의 Trait를 적용하는 것은 허용

// 1. Implementing a LOCAL trait (Brew) on an EXTERNAL type (String).
// This is allowed because we own the trait "Brew".
impl Brew for String {
    fn extract(&self) -> String {
        String::from("Pour-over coffee")
    }
}

사용자 정의 type에 대해 외부 Trait를 적용하는 것은 허용

// 2. Implementing an EXTERNAL trait (Display) on a LOCAL type (Moka).
// This is allowed because we own the type "Moka".
impl fmt::Display for Moka {
    fn fmt(&self, f: &mut fmt::Formatter) -> fmt::Result {
        write!(f, "Moka pot size {}", self.size)
    }
}
```

외부 type에 대해 외부 Trait를 적용하는 것은 금지!!

```
// --- FORBIDDEN SCENARIO (The Orphan Rule) ---
/*
// ⚠️ ERROR: Implementing an EXTERNAL trait on an EXTERNAL type.
// You cannot implement Display for Vec<i32> because you own neither!
impl fmt::Display for Vec<i32> {
    fn fmt(&self, f: &mut fmt::Formatter) -> fmt::Result {
        write!(f, "Vector content...")
    }
}

// --- THE SOLUTION (Newtype Pattern) ---
외부 type에 대해 외부 Trait를 적용하기 위한 Trick!!

// We wrap the external type in a local struct.
pub struct MyIntList(pub Vec<i32>);

// Now MyIntList is LOCAL, so we can implement Display!
impl fmt::Display for MyIntList {
    fn fmt(&self, f: &mut fmt::Formatter) -> fmt::Result {
        // We access the wrapped Vec using .0
        write!(f, "List: {:?}", self.0)
    }
}
```

6. 다형성과 OOP(6) - Trait Bounds(1)

```
// src/main.rs
// We restrict T: It must be comparable (PartialOrd) and copyable (Copy)
// We return Option<T> to handle the case where the list is empty.
fn largest<T: PartialOrd + Copy>(list: &[T]) -> Option<T> {
    if list.is_empty() {
        return None;
    }
    let mut largest = list[0];
    for &item in list {
        if item > largest {
            largest = item;
        }
    }
    Some(largest)
}
```

PartialOrd 트레이트 사용

Copy 트레이트 사용

6. 다형성과 OOP(6) - Trait Bounds(2)

```
use std::fmt::{Debug, Display};

// Hard to read: The bounds clutter the function name
fn compare_prints<T: Display + Clone, U: Clone + Debug>(t: &T, u: &U) { }

// Easier to read: The bounds are moved to the 'where' clause
fn compare_prints<T, U>(t: &T, u: &U)
where
    T: Display + Clone,
    U: Clone + Debug,
{
    // Function body...
}
```

6. 다형성과 OOP(7) - 정적 Binding: Impl Trait

```
trait TreasureBox {
    fn open(&self, key_no: i32) -> bool;
    fn check(&self);
}

struct JewelryBox {
    price: i32,
    key_no: i32,
}

struct TrapBox {
    damage: i32,
}

impl TreasureBox for JewelryBox {
    fn open(&self, key_no: i32) -> bool {
        self.key_no == key_no
    }

    fn check(&self) {
        println!("보석 상자였다. {} 골드 입수.", self.price);
    }
}

impl TreasureBox for TrapBox {
    fn open(&self, _key_no: i32) -> bool {
        return true;
    }

    fn check(&self) {
        println!("함정이었다. HP가 {} 감소했다.", self.damage);
    }
}
```

```
fn open_box(tbox: &impl TreasureBox, key_no: i32) {
    if !tbox.open(key_no) {
        println!("열쇠가 맞지 않아 상자가 열리지 않는다.");
        return;
    }
    tbox.check();
}

fn main() {
    let box1 = JewelryBox {
        price: 30,
        key_no: 1,
    };

    let box2 = TrapBox { damage: 3 };

    let box3 = JewelryBox {
        price: 20,
        key_no: 2,
    };

    let my_key = 2;
    open_box(&box1, my_key);
    open_box(&box2, my_key);
    open_box(&box3, my_key);
}
```

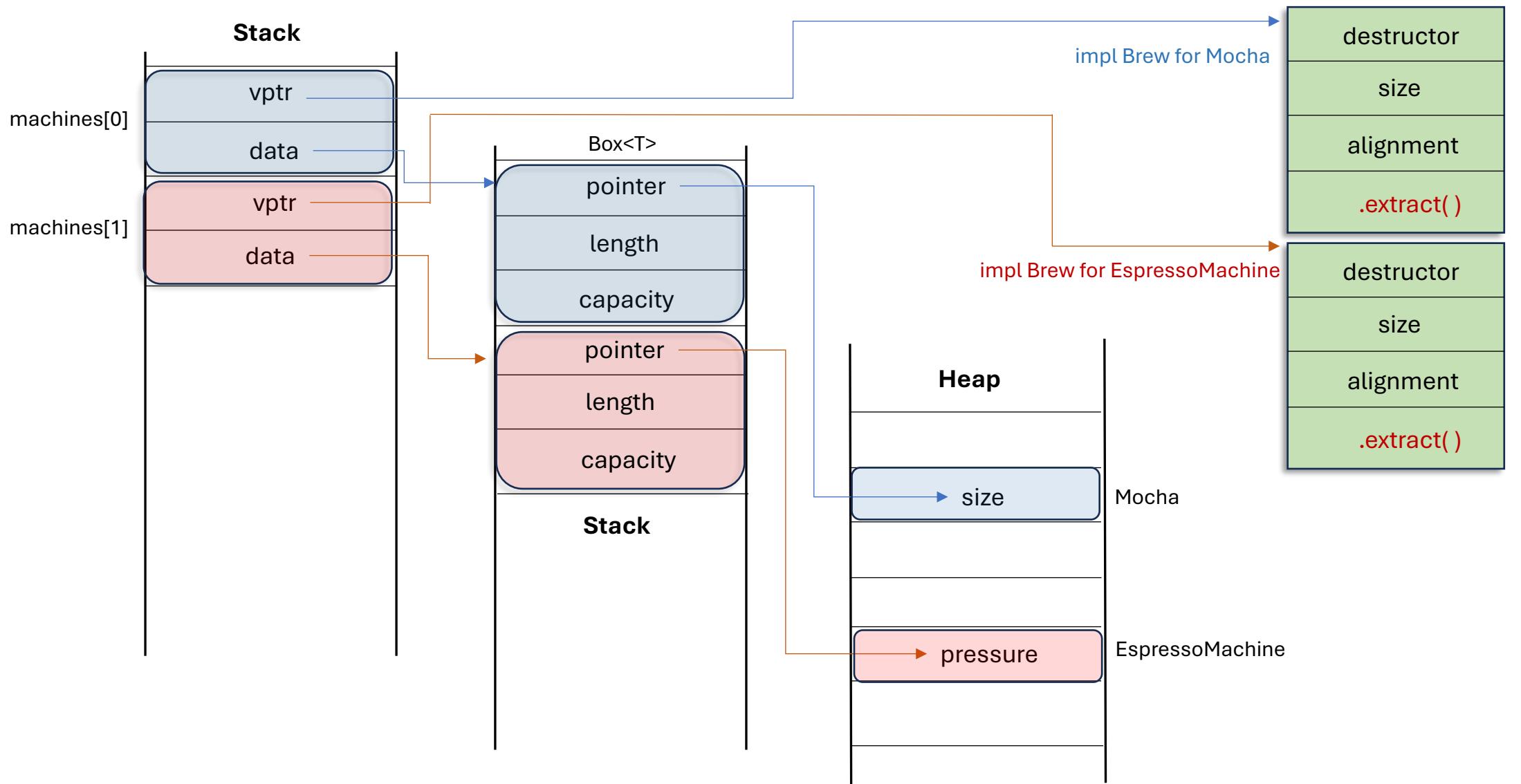
6. 다형성과 OOP(8) - 동적 Binding : Trait Object(1)

```
// 1. Setup: Let's define the types and implementations first.  
// (Moka was defined previously, but we define EspressoMachine here).  
  
pub struct Moka { pub size: u8 }  
  
impl Brew for Moka {  
    fn extract(&self) -> String {  
        format!("Bubbling up {} cups.", self.size)  
    }  
}  
  
pub struct EspressoMachine { pub pressure: u8 }  
  
impl Brew for EspressoMachine {  
    fn extract(&self) -> String {  
        format!("Extracting at {} bars of pressure.", self.pressure)  
    }  
}
```

Dynamic Dispatch

```
// 2. The Main Event: Storing mixed types using Trait Objects.  
fn main() {  
    // We can store mixed types because they both satisfy 'dyn Brew'.  
    // 'Box' puts the data on the heap, so the vector just stores pointers  
    // of the same size  
    let machines: Vec<Box<dyn Brew>> = vec![  
        Box::new(Moka { size: 6 }),  
        Box::new(EspressoMachine { pressure: 9 }),  
    ];  
  
    for machine in machines {  
        println!("Coffee shop says: {}", machine.extract());  
    }  
}
```

6. 다형성과 OOP(8) - 동적 Binding : Trait Object(2)



6. 다형성과 OOP(9) - 표준 Trait(1)

```
use std::borrow::Borrow;
use std::convert::TryFrom;
use std::ops::{Deref, DerefMut};
use std::rc::Rc;

// =====
// 1. Default
// 기본값을 정의하는 트레이트입니다.
// =====
#[derive(Debug)]
struct GameConfig {
    volume: i32,
    resolution: String,
}

impl Default for GameConfig {
    fn default() -> Self {
        Self {
            volume: 50,
            resolution: String::from("1920x1080"),
        }
    }
}

// =====
// 2. Clone & Copy
// Clone: 명시적인 복사 (.clone()) / 힙 메모리 데이터 복사 가능
// Copy: 암묵적인 비트 단위 복사 (stack-only), 소유권 이동이 일어나지 않음
// =====
#[derive(Debug, Clone, Copy)]
struct Point {
    x: i32,
    y: i32,
}

#[derive(Debug, Clone)] // String을 포함하므로 Copy 불가능
struct Person {
    name: String,
}
```

```
// 3. Drop
// 스코프를 벗어날 때 실행되는 소멸자 로직을 정의합니다.
// =====
struct CustomSmartPointer {
    data: String,
}

impl Drop for CustomSmartPointer {
    fn drop(&mut self) {
        println!(">>> [Drop] 메모리 해제됨: {}", self.data);
    }
}

// =====
// 4. Deref & DerefMut
// 스마트 포인터가 내부 데이터의 메서드에 접근할 수 있게 해줍니다 (* 연산자 오버로딩).
// =====
struct MyBox<T>(T);

impl<T> Deref for MyBox<T> {
    type Target = T;
    fn deref(&self) -> &Self::Target {
        &self.0
    }
}

impl<T> DerefMut for MyBox<T> {
    fn deref_mut(&mut self) -> &mut Self::Target {
        &mut self.0
    }
}
```

```
// =====
// 5. From & Into
// 타입 변환을 위한 트레이트입니다. From을 구현하면 Into는 자동으로 구현됩니다.
// =====
#[derive(Debug)]
struct NumberWrapper(i32);

impl From<i32> for NumberWrapper {
    fn from(item: i32) -> Self {
        NumberWrapper(item)
    }
}

// =====
// 6. TryFrom & TryInto
// 실패할 수 있는 타입 변환입니다. Result를 반환합니다.
// =====
#[derive(Debug)]
struct EvenNumber(i32);

impl TryFrom<i32> for EvenNumber {
    type Error = &'static str;

    fn try_from(value: i32) -> Result<Self, Self::Error> {
        if value % 2 == 0 {
            Ok(EvenNumber(value))
        } else {
            Err("짝수가 아닙니다!")
        }
    }
}
```

6. 다형성과 OOP(9) - 표준 Trait(2)

```
// =====
// 7. AsRef & AsMut
// 비용이 적게 드는 참조 변환(Reference-to-Reference conversion)을 수행합니다.
// =====
fn print_length<T: AsRef<str>>(s: T) {
    // T가 String이든 &str이든 상관없이 &str로 취급
    println!("길이: {}", s.as_ref().len());
}

// =====
// 8. Borrow & BorrowMut
// 데이터 구조(HashMap 등)에서 키를 조회할 때 유용합니다.
// 소유한 데이터(String)를 참조 형태(&str)로 빌릴 수 있게 해줍니다.
// Eq, Hash, Ord가 원본과 빌린 형태에서 동일하게 동작해야 한다는 계약이 있습니다.
// =====
fn check_key<K, Q>(key: &K, query: &Q)
where
    K: Borrow<Q>, // K 타입을 Q 타입으로 빌릴 수 있어야 함
    Q: PartialEq + ?Sized,
{
    if key.borrow() == query {
        println!("키가 일치합니다!");
    } else {
        println!("키가 다릅니다.");
    }
}
```

```
// =====
// 9. ToOwned
// Borrow된 데이터(예: &str)에서 소유권이 있는 데이터(예: String)를 생성합니다.
// Clone의 일반화된 형태입니다.
// =====
fn make_owned(s: &str) -> String {
    s.to_owned() // &str -> String 변환 (내부적으로 복사 발생)
}

// =====
// 10. Sized
// 컴파일 타임에 크기가 알려진 타입을 나타내는 마커 트레이트입니다.
// ?Sized는 크기가 알려지지 않을 수도 있음(DST)을 나타냅니다.
// =====
fn generic_sized<T: Sized>(t: T) {
    println!("이 타입은 컴파일 타임에 크기가 정해져 있습니다.");
    // std::mem::size_of_val(&t); // 가능
}

fn generic_maybe_unsized<T: ?Sized>(t: &T) {
    println!("이 타입은 크기가 동적일 수 있으므로 참조로만 다릅니다.");
}
```

6. 다형성과 OOP(9) - 표준 Trait(3)

```
fn main() {
    println!("== Rust Utility Traits Demo ==\n");

    // 1. Default
    let conf = GameConfig::default();
    println!("[Default] 기본 설정: {:?}", conf);

    // 2. Clone & Copy
    let p1 = Point { x: 10, y: 20 };
    let p2 = p1; // Copy 발생 (p1 여전히 사용 가능)
    println!("[Copy] p1: {:?}, p2: {:?}", p1, p2);

    let person1 = Person { name: "Alice".into() };
    let person2 = person1.clone(); // Clone (깊은 복사)
    // let person3 = person1; // 이 줄을 활성화하면 person1은 소유권 이동으로 사용 불가
    println!("[Clone] {:?} 복제됨", person2);

    // 3. Drop
    {
        let _ptr = CustomSmartPointer { data: String::from("중요한 데이터") };
        println!("[Drop] 스코프 내부");
    } // 여기서 Drop 호출됨
    println!("[Drop] 스코프 외부");

    // 4. Deref & DerefMut
    let mut my_box = MyBox(String::from("Hello"));
    // MyBox에는 len()이 없지만, Deref를 통해 String의 len() 호출 가능
    println!("[Deref] 길이: {}", my_box.len());
    // DerefMut를 통해 내부 String 수정 가능
    my_box.push_str(" World");
    println!("[DerefMut] 내용: {}", *my_box);
}
```

```
// 5. From & Into
let num = NumberWrapper::from(100);
let num2: NumberWrapper = 200.into();
println!("[From/Into] {:?}, {:?}", num, num2);

// 6. TryFrom & TryInto
let even = EvenNumber::try_from(4);
let odd: Result<EvenNumber, _> = 5.try_into();
println!("[TryFrom] 짝수 성공: {:?}", even);
println!("[TryInto] 홀수 실패: {:?}", odd);

// 7. AsRef
println!("[AsRef] String 전달:");
print_length(String::from("Rust"));
println!("[AsRef] &str 전달:");
print_length("Programming");

// 8. Borrow
let owner = String::from("key_value");
// String을 소유하고 있지만 &str로 비교 가능 (Borrow 트레이트 덕분)
print!("[Borrow] ");
check_key(&owner, "key_value");

// 9. ToOwned
let borrowed_str: &str = "im borrowed";
let owned_string: String = make_owned(borrowed_str);
println!("[ToOwned] 소유권 생성: {:?}", owned_string);

// 10. Sized vs ?Sized
let x = 10;
generic_sized(x);

let slice: &str = "Dynamic Size";
generic_maybe_unsized(slice); // str은 Sized가 아니지만 ?Sized로 허용
}
```

Thank You

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