Rust Programming Language(Part II)

- Functional Programming(Iterator & Closure)
- Smart Pointer
- Concurrent Programming
- Package, Crate, Module

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목차(Table of Contents)

소유권(Ownership)

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

Struct + Generics + Trait =>
OOP

Iterator + Closure =>
Functional Programming

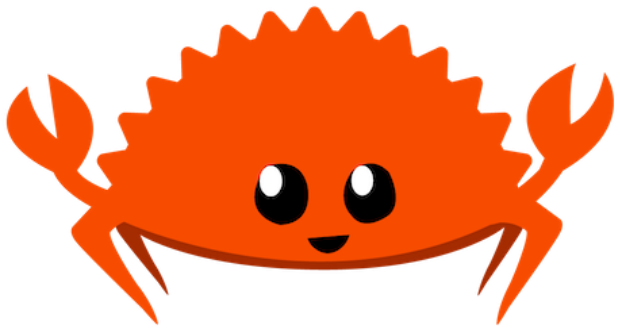
Smart Pointer

Thread, Async
Concurrent Programming

Part I

Part II

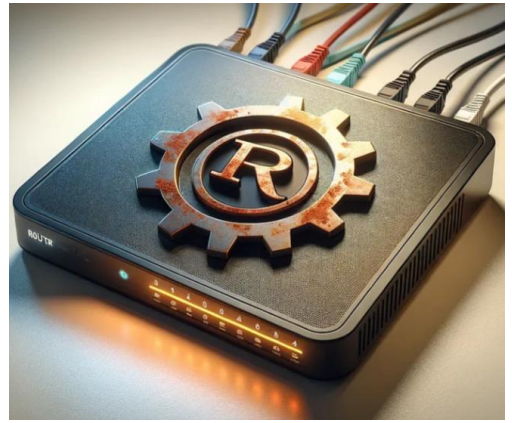
Rust의 6가지 주요 항목



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.

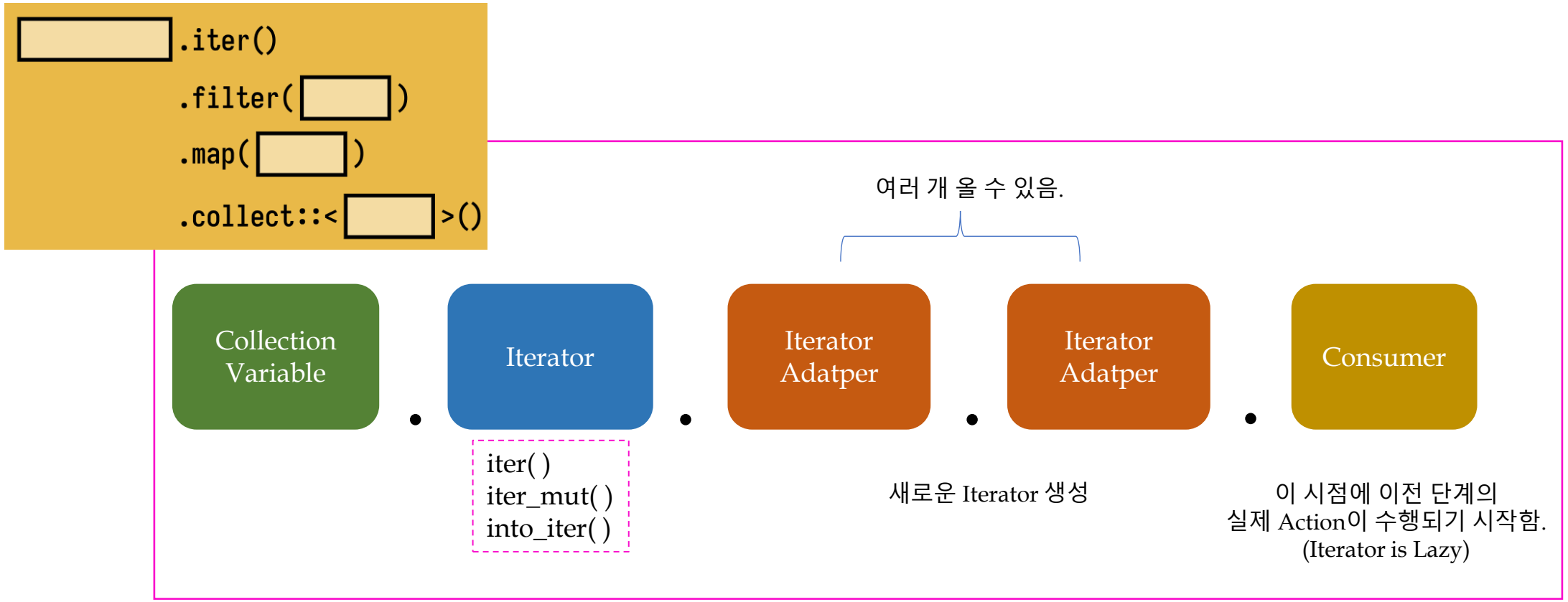
Let's make a Rust Router!



7. Functional Programming

반복자(Iterator)와 클로져(Closure)

7. Functional Programming(1) – Function Call Chain




```
let numbers = vec![1, 2, 3, 4, 5, 6, 7, 8, 9, 10];
let evens: Vec<i32> = numbers.iter().filter(|&&x| x % 2 == 0).copied().collect();
```

7. Functional Programming(2) – Iterator(1)

<Iterator의 정의>

이터레이터(Iterator, 반복자)는 컬렉션(배열, 벡터 등)의 요소를 순차적으로 처리하는 std::iter::Iterator 트레잇(trait)을 구현한 객체이다.

지연 평가(Lazy Evaluation)

- iter(), iter_mut()나 into_iter()로 이터레이터를 생성해도 즉시 요소를 순회하지 않는다. collect(), sum() 같은 소비(consumer) 메서드가 호출될 때만 비로소 동작한다.

Iterator/IntoIterator Trait

- 핵심은 **next()** 메서드이다. 요소를 차례로 반환하고 끝에 도달하면 None을 반환하여 반복을 멈춘다.

반복자 어댑터(Iterator Adapter)

- map, filter 등으로, 또 다른 이터레이터를 반환하여 체이닝(chaining)을 가능하게 한다

소비자(Consumer)

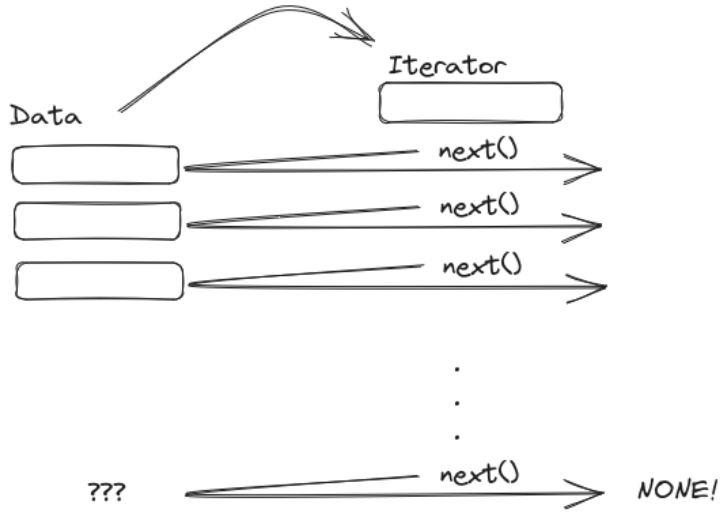
- collect(), sum(), fold() 등으로, 데이터를 처리하여 최종 결과를 반환한다(lazy 방식).

7. Functional Programming(2) – Iterator(2)

Iterator & IntoIterator 트레잇

```rust
pub trait Iterator {
    type Item;

    // Required method
    fn next(&mut self) -> Option<Self::Item>;

    // Provided methods
    fn next_chunk<const N: usize>(
        &mut self,
    ) -> Result<[Self::Item; N], IntoIter<Self::Item, N>>
       where Self: Sized { ... }

    fn size_hint(&self) -> (usize, Option<usize>) { ... }

    fn count(self) -> usize
       where Self: Sized { ... }

    fn last(self) -> Option<Self::Item>
       where Self: Sized { ... }
```

```rust
pub trait IntoIterator {
    type Item;
    type IntoIter: Iterator<Item = Self::Item>;

    // Required method
    fn into_iter(self) -> Self::IntoIter;
}
```

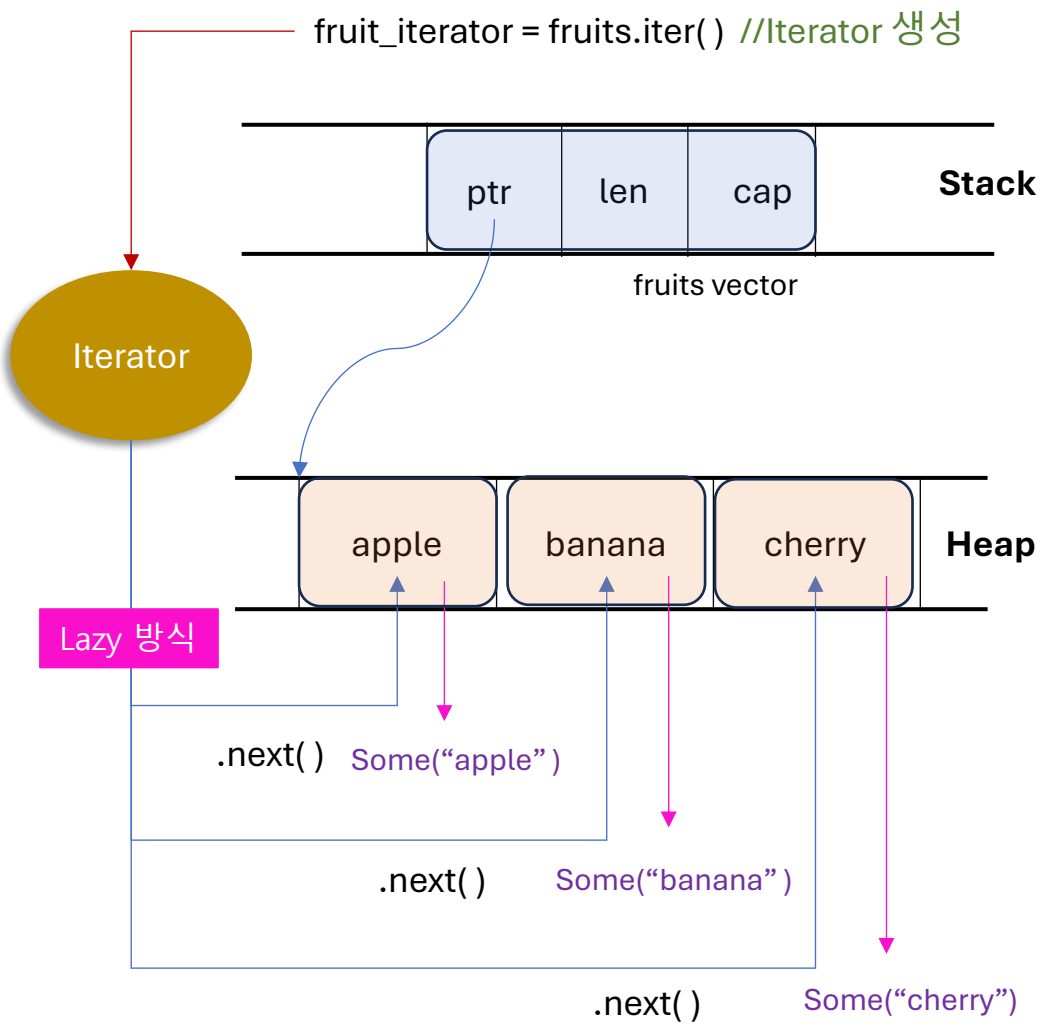


iter(), iter_mut() metho는 Iterator Trait의 metho가 아니라, Collection type의 metho이다.

7. Functional Programming(2) – Iterator(3)

Iterator와 next( ) method

```rust
fn main() {
    let fruits = vec!["apple", "banana", "cherry"];

    // Create an iterator over references to the elements in the vector.
    // The iterator variable must be `mut` because calling `.next()`
advances
    // the iterator and changes its internal state.
    let mut fruit_iterator = fruits.iter();

    // Call next() manually
    println!("First call: {:?}", fruit_iterator.next()); // Some("apple")
    println!("Second call: {:?}", fruit_iterator.next()); //
Some("banana")
    println!("Third call: {:?}", fruit_iterator.next()); // Some("cherry")
    println!("Fourth call: {:?}", fruit_iterator.next()); // None
(sequence finished)

    // Note: Once an iterator returns None, it will always return None
afterwards.
    println!("Fifth call: {:?}", fruit_iterator.next()); // None
}
```



7. Functional Programming(2) – Iterator(4-1)

<Iterator를 만드는 3가지 방법>

iter( )

```
fn iter(&self);
```

- Collection의 각 항목에 대해 immutable reference를 결과로 던져주는 Iterator 생성
- Collection(예: Vector)의 각 항목을 빌려와 사용하지만, 각 항목을 수정하지는 않는다. 따라서 원본 Collection은 그대로 보존된다.

iter_mut( )

```
fn iter_mut(&mut self);
```

- Collection의 각 항목에 대해 Mutable reference를 결과로 던져주는 Iterator 생성
- Collection(예: Vector)의 각 항목을 mutable 속성으로 빌려와 수정한다. 따라서 원본 Collection은 수정된 상태로 보존된다.

into_iter( )

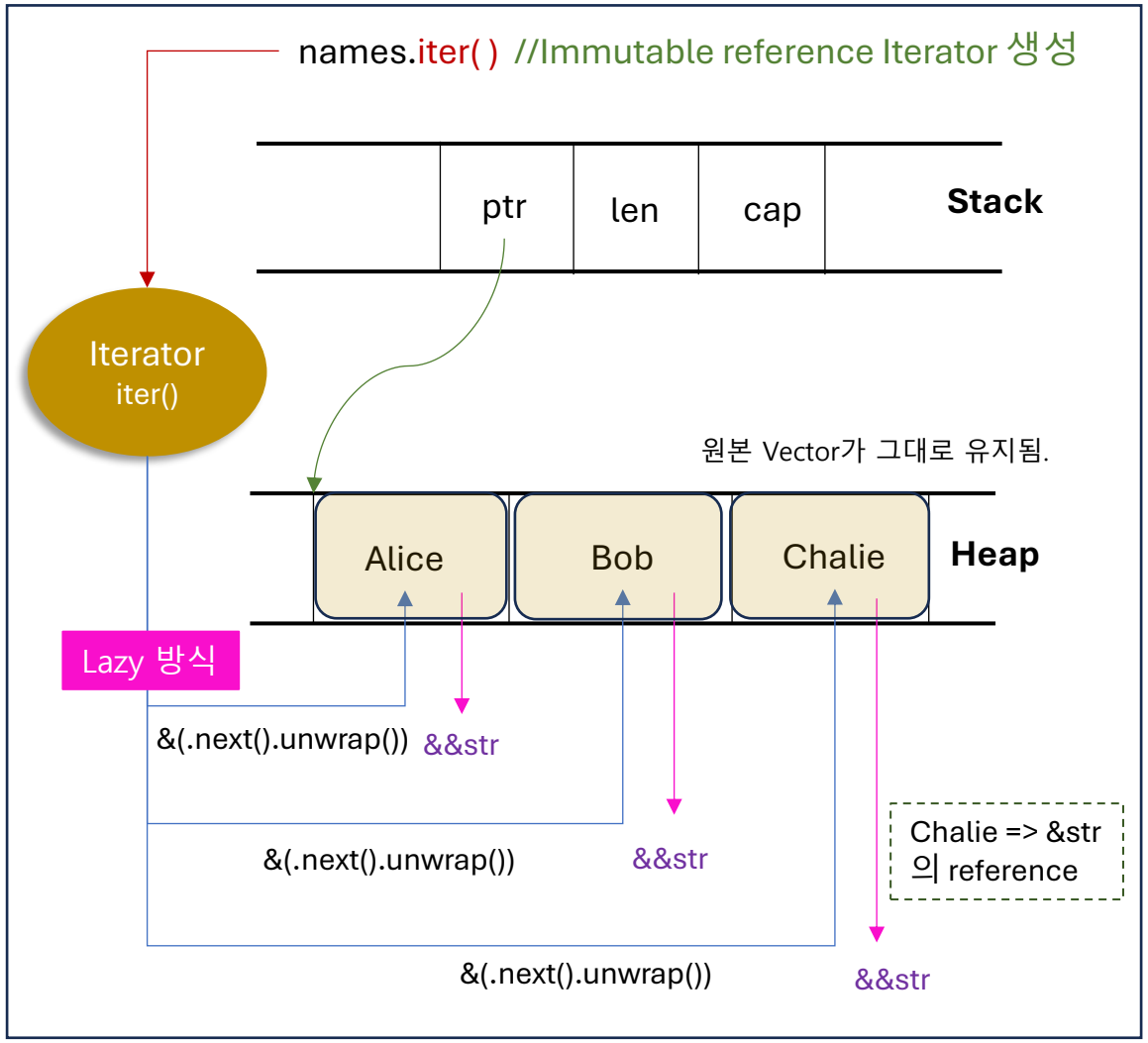
```
fn into_iter(self);
```

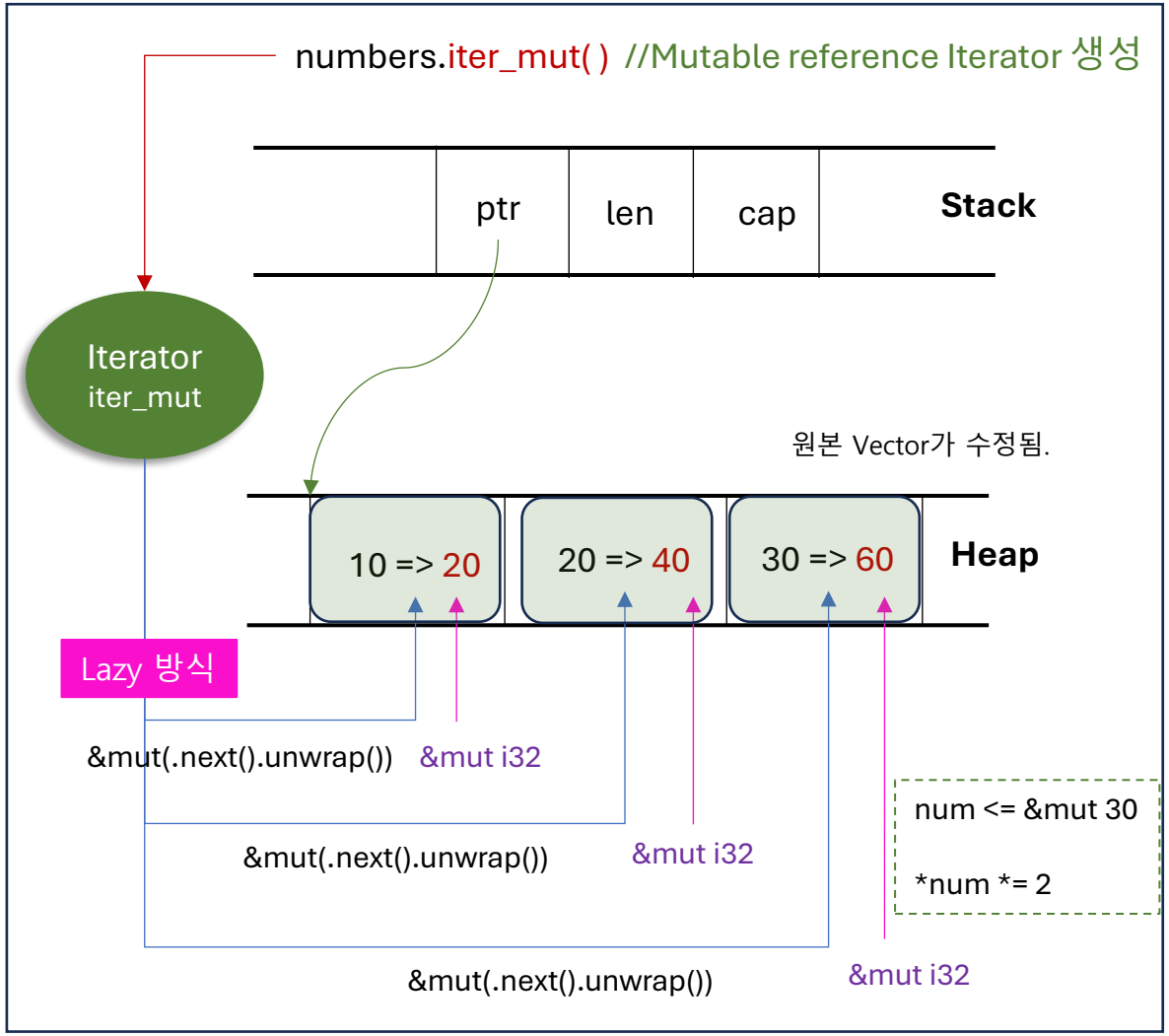
- Collection의 각 항목에 대해 소유권 이동(Move)이 발생하도록 하는 Iterator 생성
- Collection(예: Vector)의 각 항목의 소유권을 가져와 사용한다. 따라서 반복 후 원본은 사라진다.

7. Functional Programming(2) – Iterator(4-2)

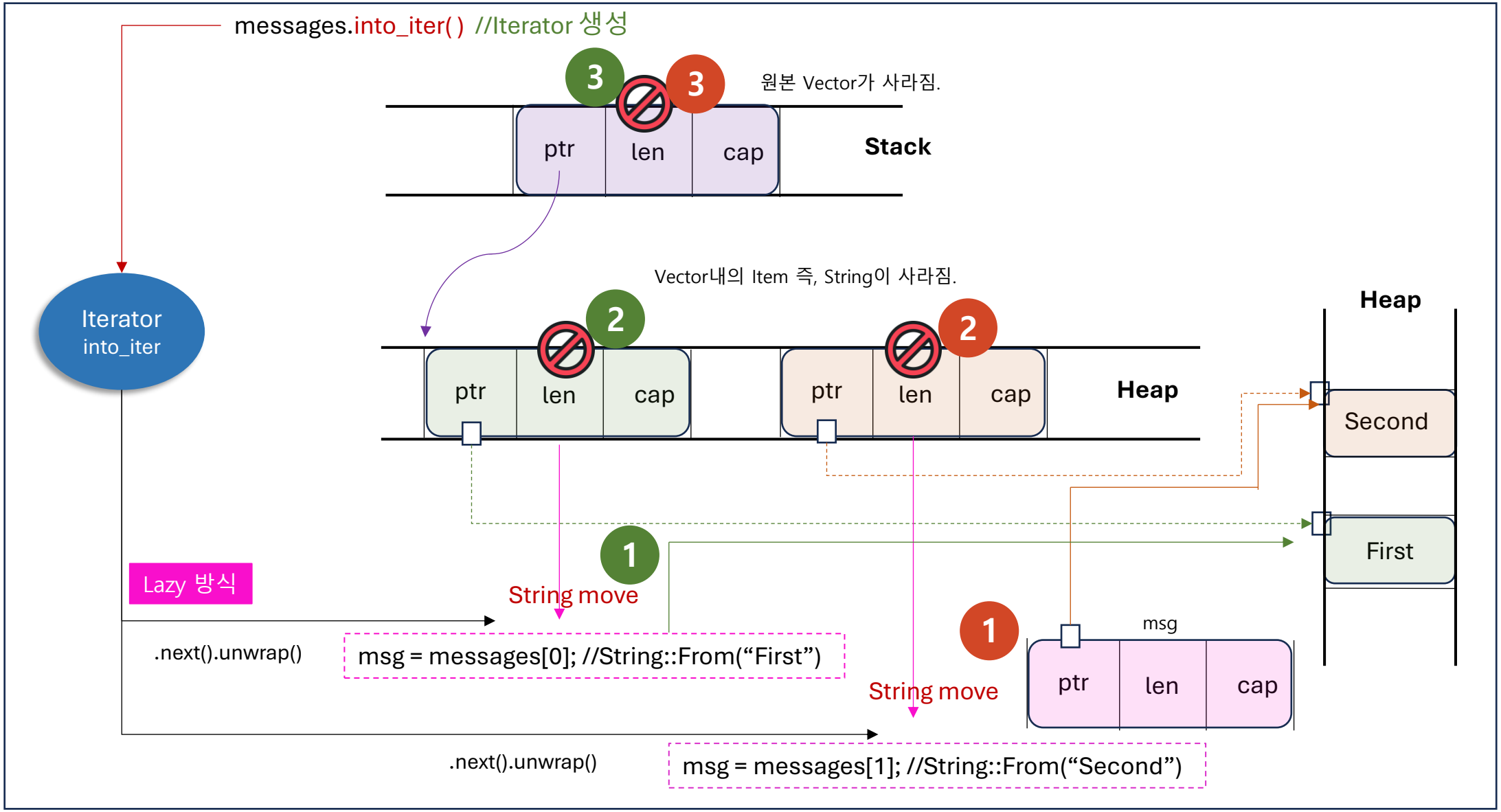
```rust
fn main() {
    // --- 1. iter() - Immutable Borrows ---
    let names = vec!["Alice", "Bob", "Charlie"];
    for name in names.iter() {
        // `name` here is of type `&&str` (a reference to a string slice)
        println!("Hello, {}!", name);
    }
    // `names` is still valid and can be used here.
    println!("The names vector is still available: {:?}\n", names);


    // --- 2. iter_mut() - Mutable Borrows ---
    let mut numbers = vec![10, 20, 30];
    for num in numbers.iter_mut() {
        // `num` here is of type `&mut i32` (a mutable reference)
        *num *= 2; // We dereference `num` to modify the value it points
to
    }
    // `numbers` has been modified in place.
    println!("The numbers vector has been modified: {:?}\n", numbers);



    // --- 3. into_iter() - Taking Ownership ---
    let messages = vec![String::from("First"), String::from("Second")];
    for msg in messages.into_iter() {
        // `msg` here is of type `String` (the owned value)
        println!("Processing message: {}", msg);
    }
    // The `messages` vector has been moved and is no longer valid.
    // The line below would cause a compile-time error.
    // println!("Can we use messages again? No: {:?}", messages);
}
```

7. Functional Programming(2) – Iterator(4-3)





7. Functional Programming(2) – Iterator(4-4)



7. Functional Programming(3) – Consumer

Collect( ), sum( ), fold( ) consumer method

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

    // --- Using collect() ---
    // Here, we filter for numbers greater than 2 and collect them into a new Vec.
    // We use a type annotation `Vec<_>` to tell collect what to build.
    let greater_than_two: Vec<_> = numbers
        .iter()
        .filter(|&&n| n > 2)
        .collect();
    println!("Numbers greater than 2: {:?}", greater_than_two); // Output: [3, 4, 5]
```

```rust
    // --- Using sum() ---
    // We can sum the numbers in a range.
    let total: i32 = (1..=10).sum(); // The iterator is the range (1..=10)
    println!("The sum of numbers from 1 to 10 is: {}", total); // Output: 55

    // --- Using fold() ---
    // Let's calculate the product of the numbers in our vector.
    // We start with an initial accumulator value of 1.
    let product = numbers
        .iter()
        .fold(1, |accumulator, &item| accumulator * item);
    println!("The product of the numbers is: {}", product); // Output: 120
}
```

Consumer는 최종 단계에서 실행되는 metho로 Iterator로 부터 소유권을 가져간다.
Iterator는 lazy해서, consumer method가 호출되는 시점에야 비로소 실제 원하는 action이 이루어진다.

7. Functional Programming(4) – Iterator Adapter(1)

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

    // Create an iterator, map a closure to square each number,
    // and then collect the results.
    let squares: Vec<i32> = numbers.iter() // Iterator yields &i32
                                   .map(|x| x * x) // Closure takes &i32,
squares it, returns i32
                                   .collect(); // Collects the i32 results

    println!("Original: {:?}", numbers);   // Output: [1, 2, 3, 4]
    println!("Squares: {:?}", squares); // Output: [1, 4, 9, 16]

    // Example with Strings
    let names = vec!["alice", "bob", "charlie"];
    let upper_names: Vec<String> = names.iter() // Iterator yields &str
                                        .map(|name| name.to_uppercase())
// Closure returns String
                                        .collect(); // Collects the
Strings

    println!("Upper names: {:?}", upper_names); // Output: ["ALICE",
"BOB", "CHARLIE"]
}
```

map() Iterator Adapter
(또 다른 Iterator를 만드는 method)

실제로 이 closure 내부의 동작은 아래 .collect( ) consumer method가 호출되는 시점에 이루어짐.

7. Functional Programming(4) – Iterator Adapter(2)

```rust
fn main() {
    let numbers = vec![1, 2, 3, 4, 5, 6, 7, 8, 9, 10];

    // Create an iterator, filter for even numbers, and collect.
    let evens: Vec<i32> = numbers.iter() // Iterator yields &i32
                                 // Closure takes &i32, returns true if
even.
                                 // We need *x because filter gets a
reference (&i32)
                                 .filter(|&&x| x % 2 == 0) // Note the
double reference `&&x`
                                 .copied() // Convert the iterator of &i32
to i32
                                 .collect(); // Collects the i32 results

    println!("Original: {:?}", numbers); // Output: [1, 2, ..., 10]
    println!("Evens: {:?}", evens);   // Output: [2, 4, 6, 8, 10]
    // Chaining map and filter
    let scores = vec![85, 42, 95, 60, 77];
    // Get scores above 70, and add a 5-point bonus
    let adjusted_high_scores: Vec<i32> = scores.iter()
                                               .filter(|&&score| score >
70) // Keep scores > 70
                                               .map(|&score| score + 5) //
Add 5 to the filtered scores
                                               .collect();

    println!("Adjusted high scores: {:?}", adjusted_high_scores); //
Output: [90, 100, 82]
}
```

filter() Iterator Adapter
(또 다른 Iterator를 만드는 method)

<TODO>

이 밖에도 유용한 iterator adapter 존재함

- take, skip, rev, zip, enumerate, flat_map

7. Functional Programming(4) – Iterator Adapter(3)

filter( )의 Closure 파라미터 Reference 사용 방법에 대한 분석

```
case#1) numbers.iter().filter(|&&x| { })
                &&x = n: &&i32 => x
case#2) numbers.iter().filter(|x| { })
                x = n: &&i32 => **x
```

[1] iter( ) method는 Collection 변수 각 항목(예: i32 type)에 대해 Reference 값(예: n: &i32)을 return 한다. 그리고, iterator adapter인 filter method는 argument type으로 Reference를 전달 받도록 정의하고 있다. 따라서, case1과 같이 closure 파라미터로 &&x를 지정한 상태에서 argument n: &&i32를 넘기게 되면,

&&x = n: &&i32 => **x = n: i32** //양변의 && 상쇄

와 같은 형태가 되어, 실제 closure 내부에서는 x를 곧 바로 사용할 수가 있게 된다.

[2] 한편, case2와 같이 closure 파라미터로 x를 지정하게 될 경우에는

x = n: &&i32 => **x

형태가 되어, closure 내부에서 실제 값에 접근하려면 두번의 역참조 즉, **x를 해 주어야만 한다.

7. Functional Programming(5) – Closure(1)

<Closure의 정의>

클로저(Closure)는 주변 환경(scope)의 변수를 캡처하여 사용할 수 있는 익명 함수이다. 변수에 저장하거나 다른 함수의 인자로 전달 가능하며, 불변(Immutable)/가변 참조(Mutable) 또는 소유권 이동 방식(Move)으로 외부 값을 캡처할 수 있다.

환경 캡처 (Capture Environment): 정의된 스코프 내의 변수를 클로저 내부에서 자유롭게 사용할 수 있다.
익명성 (Anonymous): 이름을 정의하지 않고 바로 변수에 대입하거나 인자로 넘긴다.
타입 추론 (Type Inference): 대부분의 경우 컴파일러가 매개변수와 반환 타입을 추론하므로 명시하지 않아도 된다.

Closure는 환경 capture 방식에 따라 아래와 같이 3가지 Closure 트레잇(Fn, FnMut, FnOnce)을 지원한다.

```rust
fn main() {
    // The compiler infers that `x` is an i32 and the return type is i32.
    let add_one = |x| x + 1;
    println!("5 + 1 = {}", add_one(5));

    // You can also add explicit type annotations for clarity.
    let multiply = |a: i32, b: i32| -> i32 {
        a * b
    };
    println!("3 * 4 = {}", multiply(3, 4));
}
```

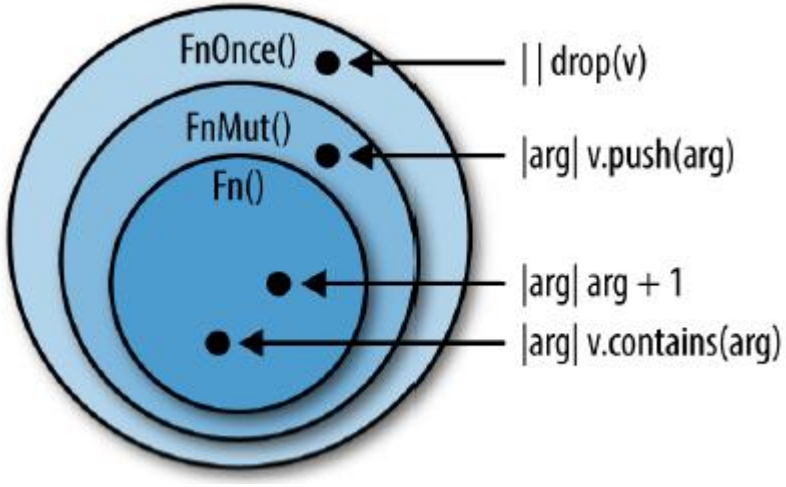
7. Functional Programming(5) – Closure(2)

```rust
fn main() {
    let my_name = String::from("Alice");
    let mut counter = 0;
    let data = vec![1, 2, 3];

    // 1. Captures `my_name` by immutable reference (&String) because it only reads it.
    let greet = || println!("Hello, {}!", my_name);
    greet();
    // `my_name` is still valid here.
    println!("`my_name` can still be used: {}", my_name);

    // 2. Captures `counter` by mutable reference (&mut i32) because it modifies it.
    let mut increment = || {
        counter += 1;
        println!("Counter is now: {}", counter);
    };
    increment();
    increment();
    // `counter` has been modified.
    println!("Final counter value: {}", counter);

    // 3. Captures `data` by taking ownership (Vec<i32>) because of the `move` keyword.
    // We'll discuss `move` next.
    let consume_data = move || {
        println!("Consumed data: {:?}", data);
        // `data` is dropped when this closure ends.
    };
    consume_data();
    // The line below would cause a compile error because `data` was moved.
    // println!("Can we use data after move? No: {:?}", data);
}
```

Capture & Move

7. Functional Programming(5) – Closure(3-1)

Closure 관련 3가지 트레잇



Trait	How it captures variables	How many times it can be called
`Fn`	Borrows captured variables immutably (`&self`)	Multiple times, potentially concurrently
`FnMut`	Borrows captured variables mutably (`&mut self`)	Multiple times, but not concurrently
`FnOnce`	Takes ownership of captured variables (`self`)	Exactly once, consuming the closure

7. Functional Programming(5) – Closure(3-2)

```rust
// This function accepts closures that only need immutable access (`Fn`).
fn call_reporter<F>(reporter: F)
where
    F: Fn() -> String, // Trait bound: must implement Fn
{
    println!("Report: {}", reporter());
}

// This function accepts closures that might mutate their environment
(`FnMut`).
fn call_mutator<F>(mut mutator: F) // Note the `mut` here
where
    F: FnMut(), // Trait bound: must implement FnMut
{
    // We can call it multiple times.
    mutator();
    mutator();
}

// This function accepts any closure but consumes it (`FnOnce`).
fn call_once<F>(consumer: F)
where
    F: FnOnce(), // Trait bound: must implement FnOnce
{
    consumer();
    // Calling `consumer()` again here would cause a compile error.
}
```

```rust
fn main() {
    let message = String::from("System status OK");
    // This closure captures `message` by reference, so it implements
`Fn`.
    let report_closure = || message.clone();
    call_reporter(report_closure);

    let mut counter = 0;
    // This closure captures `counter` by mutable reference, so it
implements `FnMut`.
    let mut increment_closure = || {
        counter += 1;
        println!("Counter is now: {}", counter);
    };
    // We pass ownership of the closure to `call_mutator`.
    call_mutator(increment_closure);

    let data = String::from("Consume me");
    // This closure moves `data`, so it implements `FnOnce`.
    let consume_closure = || {
        println!("Consumed: {}", data);
    };
    call_once(consume_closure);
}
```

Fn 트레잇 사용

FnMut 트레잇 사용

FnOne 트레잇 사용

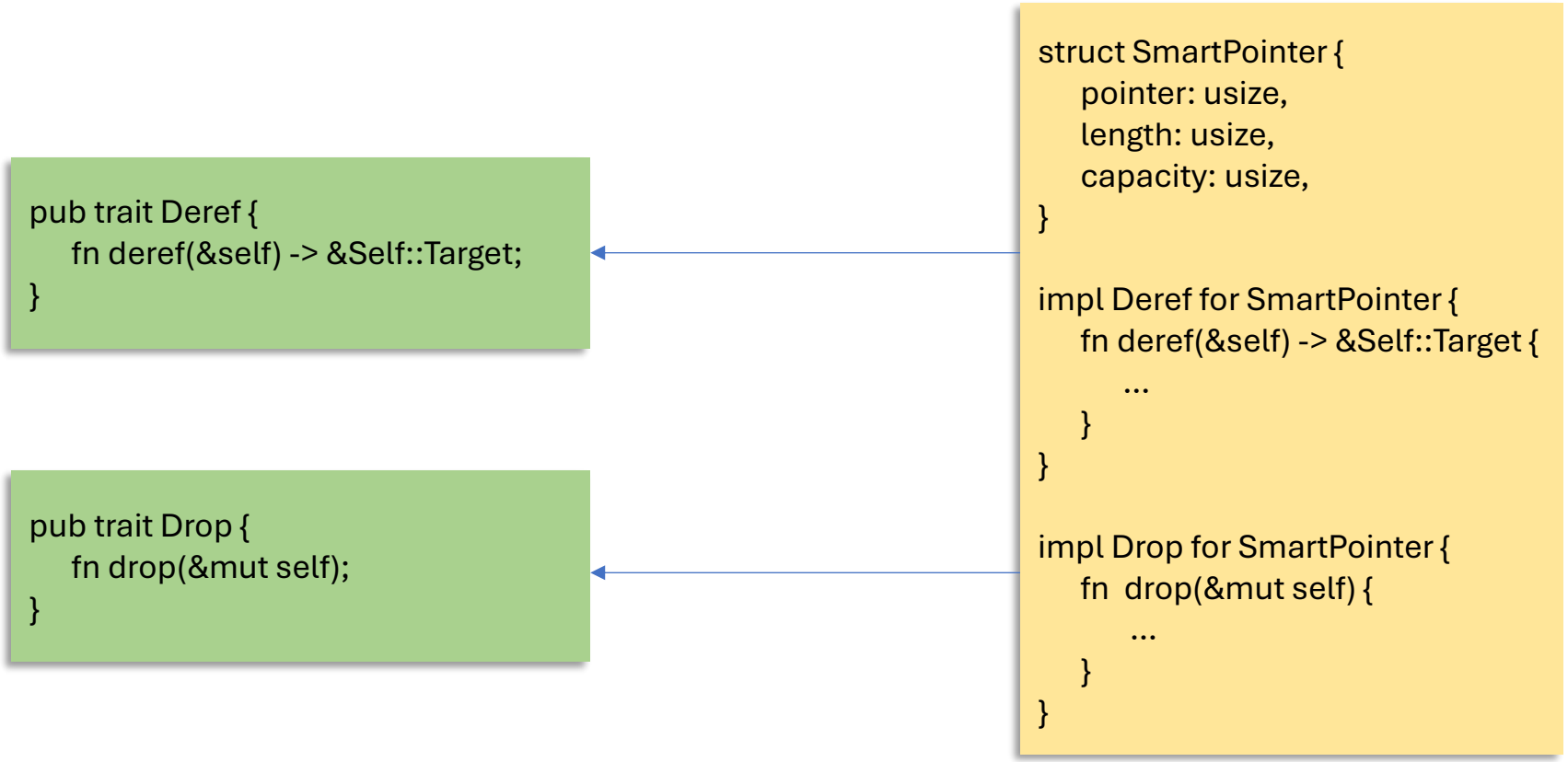
8. 스마트 포인터(Smart Pointer)

Box<T>, Rc<T>/Arc<T>, RefCell<T>/Mutex<T>

8. 스마트 포인터(1) – What is Smart Pointer ?(1)

"Smart pointers are essentially structs that implement the Deref and Drop traits."

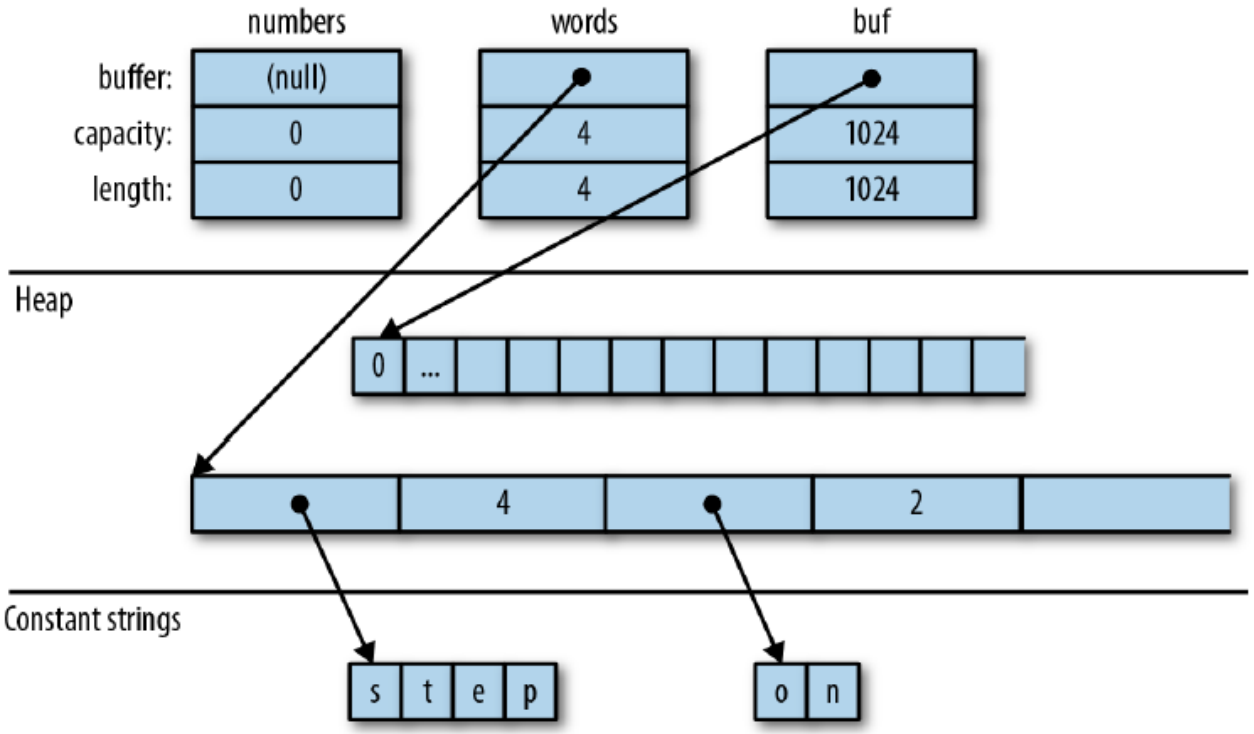
(스마트 포인터는 Deref 트레잇과 Drop 트레잇을 구현한 struct 이다)



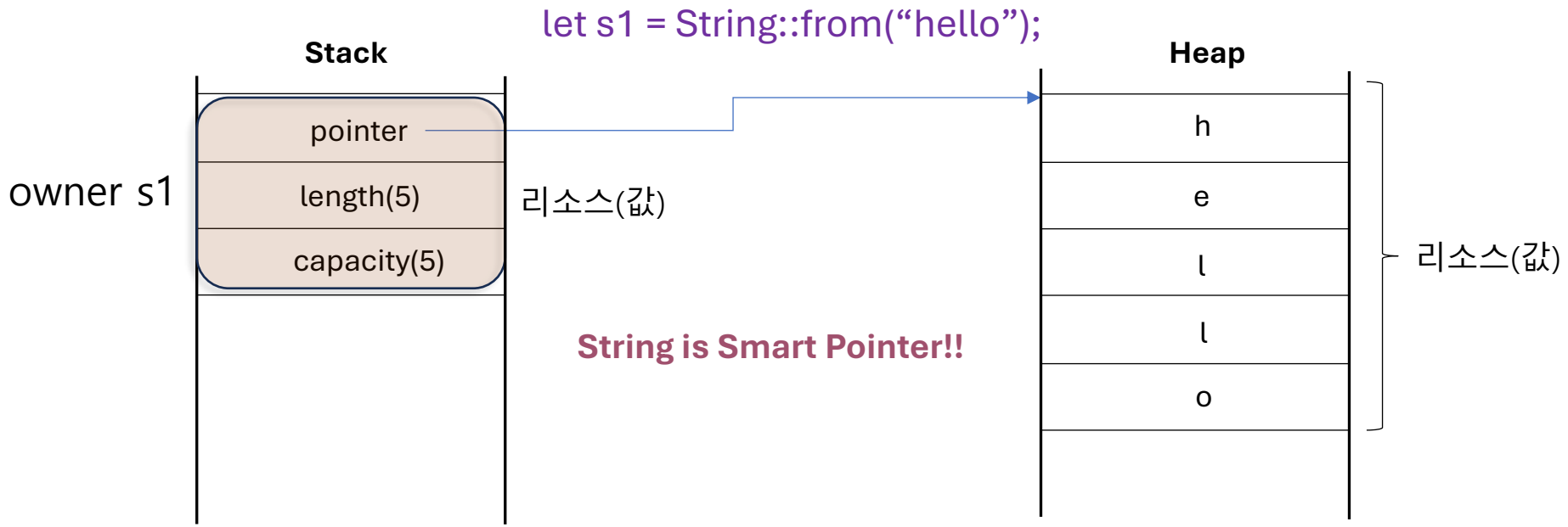
8. 스마트 포인터(1) – What is Smart Pointer ?(2)

```
// Create an empty vector
let mut numbers: Vec<i32> = vec![];
// Create a vector with given contents
let words = vec!["step", "on", "no", "pets"];
let mut buffer = vec![0u8; 1024]; // 1024 zeroed-out bytes
```

Vector is Smart Pointer!!



8. 스마트 포인터(1) – What is Smart Pointer ?(3)



Rust의 소유권 3대 원칙

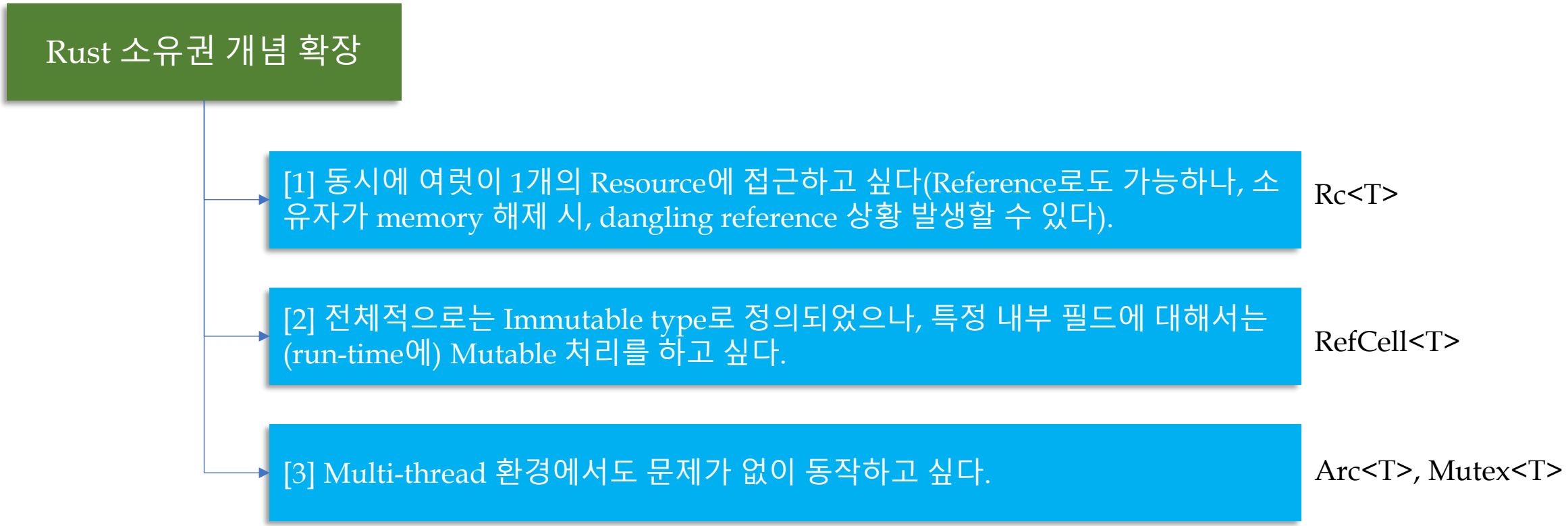
1) Resource(혹은 값)에는 소유권이 있으며, 변수(variable)는 resource(혹은 값)의 소유자(Owner)이다.

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

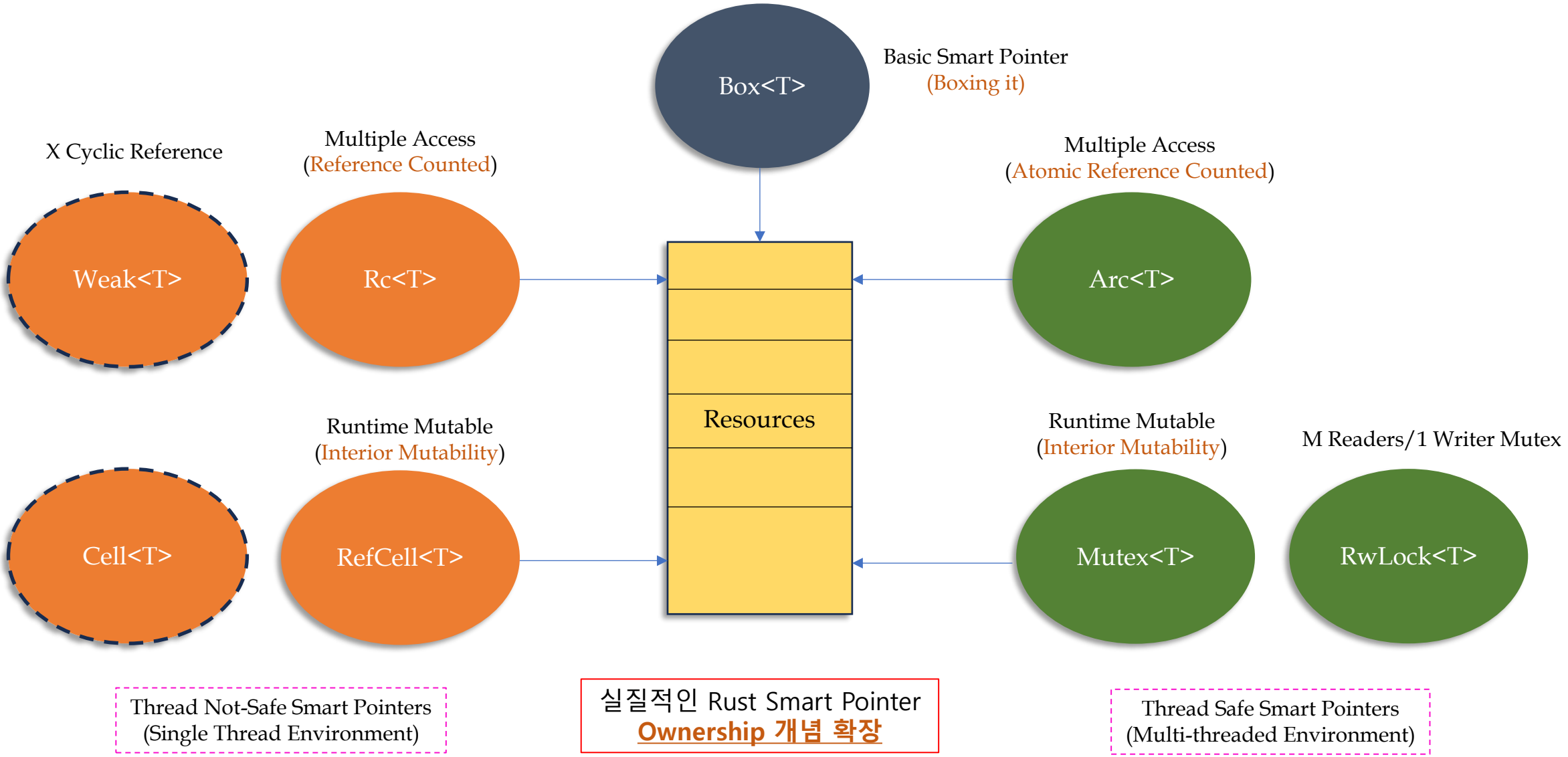
3) 소유자가 유효한 범위(scope)를 벗어나면, 소유자가 소유한 값은 자동으로 파기된다. 이는 memory leak을 방지해주는 효과가 있다.

매우 제한적임

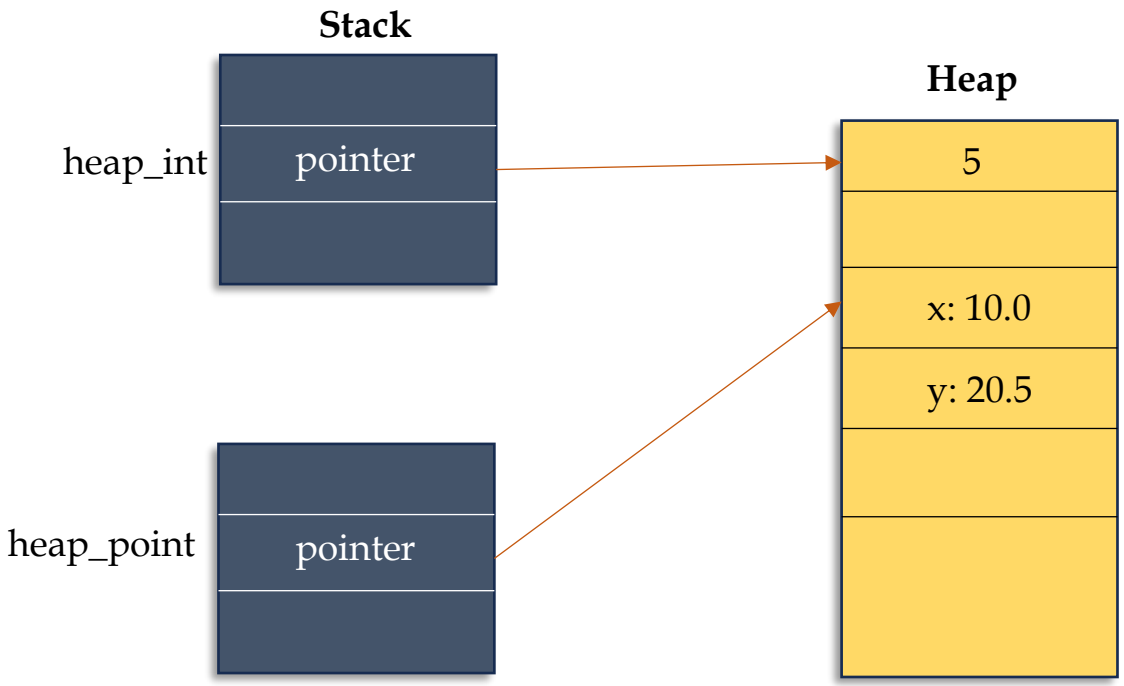
8. 스마트 포인터(1) – What is Smart Pointer ?(4)



8. 스마트 포인터(1) – What is Smart Pointer ?(5)



8. 스마트 포인터(2) – Box<T>(1)




```rust
// It's standard practice to define structs outside the main function.
#[derive(Debug)]
struct Point {
    x: f64,
    y: f64,
}

fn main() {
    // Create a Box<i32> to store an integer on the heap.
    let heap_int = Box::new(5);
    println!("Value in a Box: {}", heap_int);

    // Create a Box<Point> to store a struct on the heap.
    let heap_point = Box::new(Point { x: 10.0, y: 20.5 });
    println!("Struct in a Box: {:?}", heap_point);

    // Explicitly dereference the Box to access the value.
    let value_from_box = *heap_int;
    println!("Explicitly dereferenced value: {}", value_from_box);

    // Access a field directly thanks to automatic dereferencing (Deref
coercion).
    println!("Accessing field via deref coercion: heap_point.x = {}",
heap_point.x);

    // When `heap_int` and `heap_point` go out of scope here, the memory
they manage
    // on the heap is automatically freed via the Drop trait.
}
```

Box<T>가 주로 사용되는 예

- Trait Object 구현 시 – Box<dyn MyTrait>
- Recursive Type 선언 시
- Large data를 전달하는 경우 – Box<MyLargeStruct>

8. 스마트 포인터(2) – Box<T>(2)

```rust
use std::fmt;

// A recursive enum representing a simple arithmetic expression.
// `Box<T>` is used to give the recursive variants a known size.
#[derive(Debug)]
enum Expression {
    Value(i32),
    Add(Box<Expression>, Box<Expression>),
    Multiply(Box<Expression>, Box<Expression>),
    Negate(Box<Expression>),
}

// A custom error type for our evaluation function.
#[derive(Debug)]
pub enum EvaluationError {
    Overflow,
}

// Implement Display for user-friendly error messages.
impl fmt::Display for EvaluationError {
    fn fmt(&self, f: &mut fmt::Formatter) -> fmt::Result {
        match self {
            EvaluationError::Overflow => write!(f, "Arithmetic overflow
occurred during evaluation"),
        }
    }
}
```

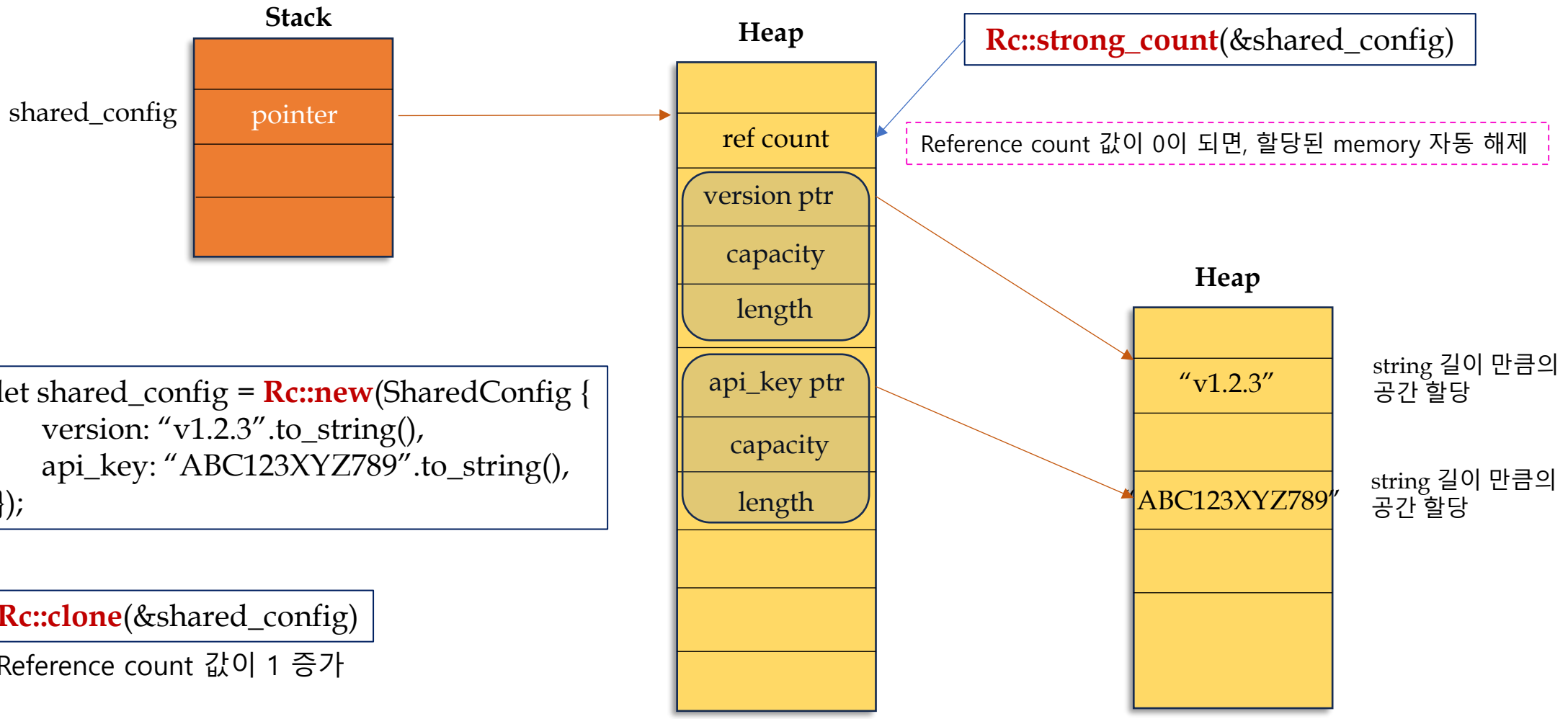
Recursive type 선언 예

```rust
// Helper functions for building the expression tree ergonomically.
fn val(v: i32) -> Box<Expression> {
    Box::new(Expression::Value(v))
}
fn add(left: Box<Expression>, right: Box<Expression>) -> Box<Expression> {
    Box::new(Expression::Add(left, right))
}
fn multiply(left: Box<Expression>, right: Box<Expression>) ->
Box<Expression> {
    Box::new(Expression::Multiply(left, right))
}
fn negate(expr: Box<Expression>) -> Box<Expression> {
    Box::new(Expression::Negate(expr))
}
```

8. 스마트 포인터(3) – Rc<T>(1)

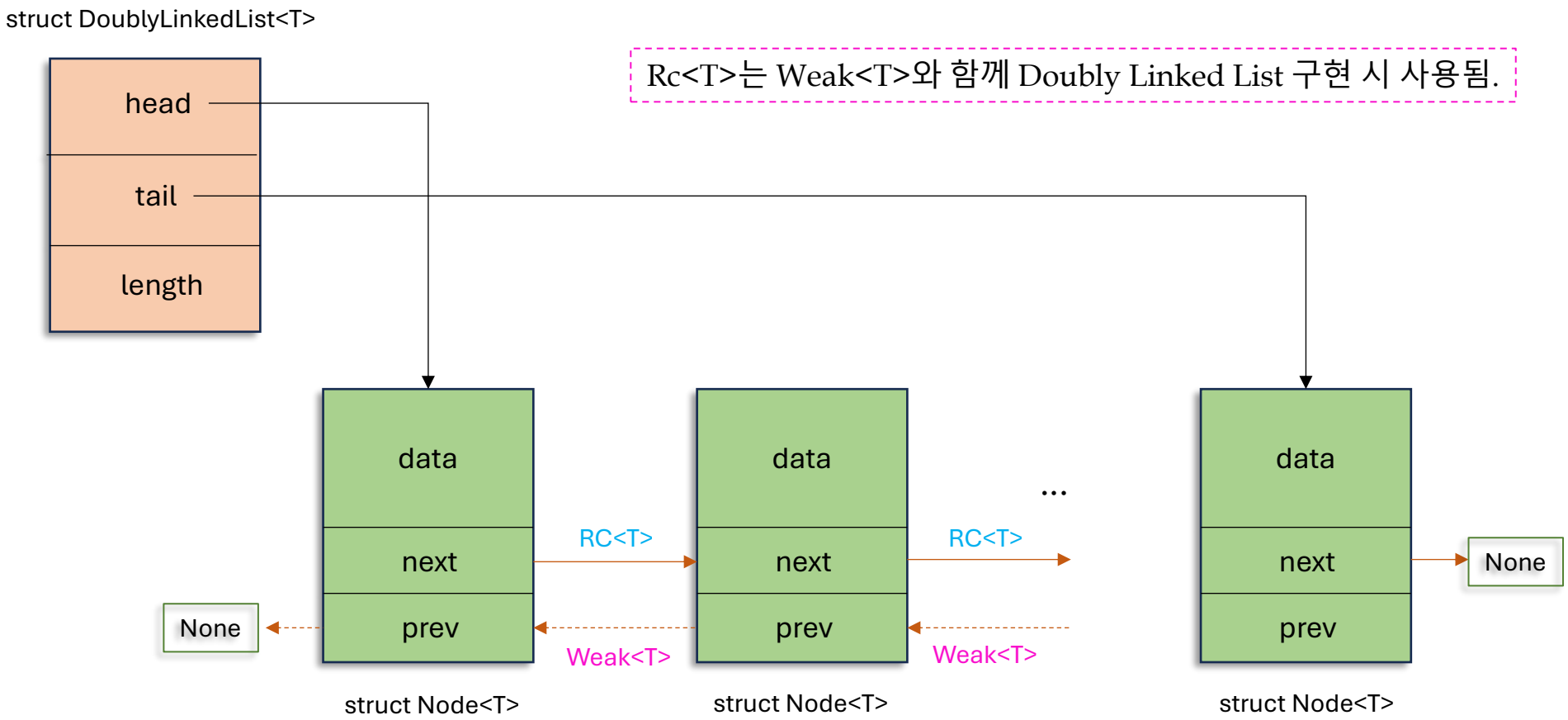
```rust
use std::rc::Rc;

#[derive(Debug)]
struct SharedConfig {
    version: String,
    api_key: String,
}
struct ServiceA {
    id: u32,
    config: Rc<SharedConfig>,
}
struct ServiceB {
    name: String,
    config: Rc<SharedConfig>,
}

fn main() {
    // Create the shared configuration data wrapped in an Rc.
    let shared_config = Rc::new(SharedConfig {
        version: "v1.2.3".to_string(),
        api_key: "ABC123XYZ789".to_string(),
    });
    println!("Initial strong count: {}", Rc::strong_count(&shared_
config));
    // Create clones of the Rc to share ownership.
    // This only increments the reference count; it does not deep copy the
data.
    let service_a = ServiceA {
        id: 101,
        config: Rc::clone(&shared_config),
    };
    println!("After ServiceA created: strong count = {}", Rc::strong_
count(&shared_config));
    let service_b = ServiceB {
        name: "LoggerService".to_string(),
        config: Rc::clone(&shared_config),
    };
    println!("After ServiceB created: strong count = {}", Rc::strong_
count(&shared_config));
    println!("---");
    println!("Service A accesses config version: {}", service_a.config.
version);
    println!("Service B accesses API key: {}", service_b.config.api_key);
    println!("---");

    // Explicitly drop service_a to see the reference count decrease.
    drop(service_a);
    println!("After ServiceA is dropped: strong count = {}", Rc::strong_
count(&shared_config)); // Output: 2
    // Explicitly drop service_b.
    drop(service_b);
    println!("After ServiceB is dropped: strong count = {}", Rc::strong_
count(&shared_config)); // Output: 1
    // The final Rc (`shared_config`) will be dropped at the end of main's
scope.
    // At that point, the count will become 0, and the SharedConfig data
will be deallocated.
}
```

8. 스마트 포인터(3) – Rc<T>(2)



Rc<T>와 multi-thread 환경에서는 사용할 수가 없다. 즉, 여러 thread에서 사용 시, reference count 값이 뒤죽박죽 된다.

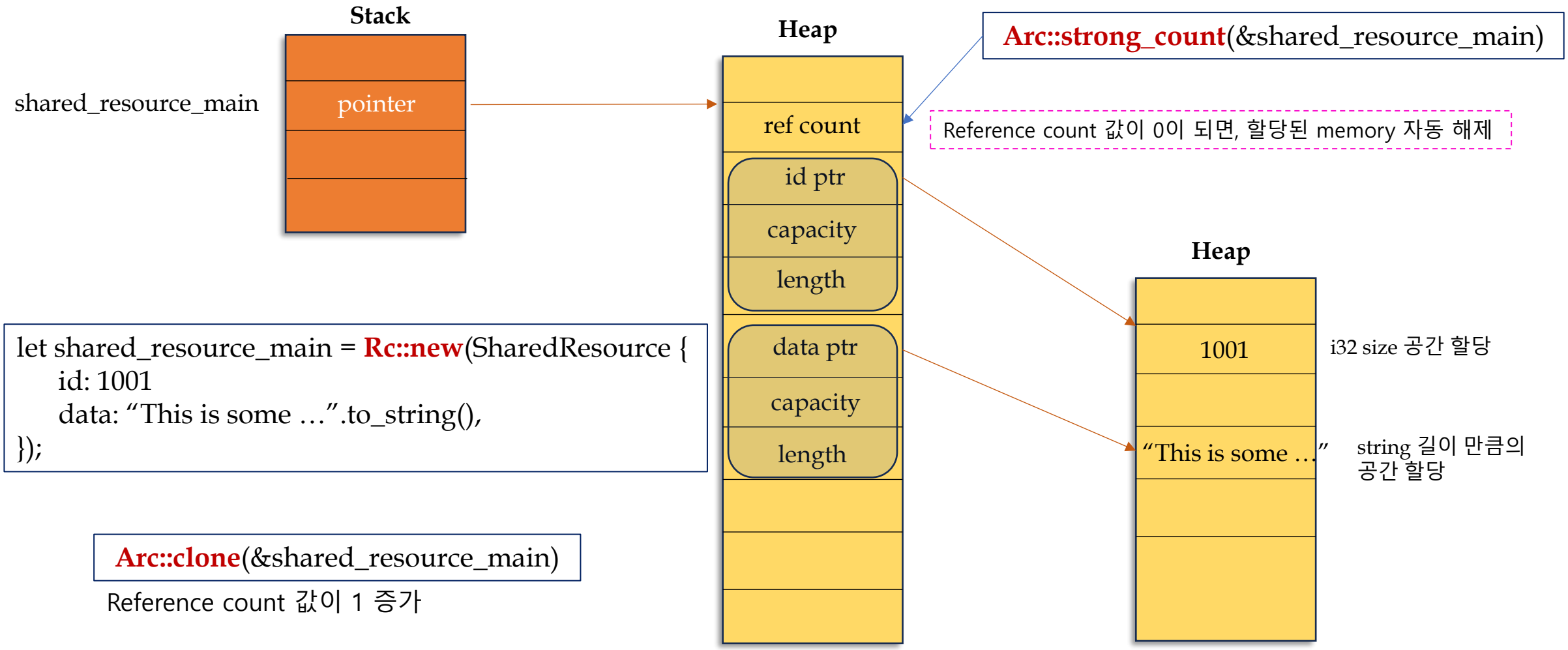
8. 스마트 포인터(3) – Rc<T>(3)



8. 스마트 포인터(4) – Arc<T>(1)

```rust
use std::sync::Arc;
use std::thread;
use std::time::Duration;
#[derive(Debug)]
struct SharedResource {
    id: u32,
    data: String,
}

fn main() {
    // Create shared data wrapped in an Arc
    let shared_resource_main = Arc::new(SharedResource {
        id: 1001,
        data: "This is some important data shared across threads.".to_
string(),
    });

    println!("Main thread: Initial strong count = {}", Arc::strong_
count(&shared_resource_main)); // Output: 1

    let mut thread_handles = vec![];

    for i in 0..3 { // Spawn 3 threads
        // Clone the Arc for each thread. This is crucial.
        // The cloned Arc is moved into the thread's closure.
        let shared_resource_for_thread = Arc::clone(&shared_resource_
main);
        println!("Main thread: Count before spawning thread {} = {}", i,
Arc::strong_count(&shared_resource_main));

        let handle = thread::spawn(move || {
            // This thread now has its own Arc pointing to the shared data
            println!("Thread {}: Started. Accessing resource ID: {}, Data:
'{}'. Strong count here: {}",
                     i,
                     shared_resource_for_thread.id,
                     shared_resource_for_thread.data,
                     Arc::strong_count(&shared_resource_for_thread) //
Count might be higher due to other clones
            );
            thread::sleep(Duration::from_millis(50)); // Simulate some
work
            println!("Thread {}: Finished.", i);
            // When shared_resource_for_thread goes out of scope here, the
count is decremented.
        });
        thread_handles.push(handle);
    }

    // The main thread still has its reference
    println!("Main thread: After spawning threads, strong count = {}",
Arc::strong_count(&shared_resource_main));
    println!("Main thread: Resource data: {}", shared_resource_main.data);

    // Wait for all threads to complete
    for handle in thread_handles {
        handle.join().unwrap();
    }

    println!("Main thread: All threads finished. Final strong count
(before shared_resource_main drops): {}", Arc::strong_count(&shared_
resource_main)); // Should be 1
    // When shared_resource_main drops, the count goes to 0, and
SharedResource is deallocated.
}
```

8. 스마트 포인터(4) – Arc<T>(2)



Arc<T>는 Rc<T>와 달리 Atomic 동작을 하므로, multi-thread 환경에 적합하다(즉, reference count가 일관되게 유지된다).

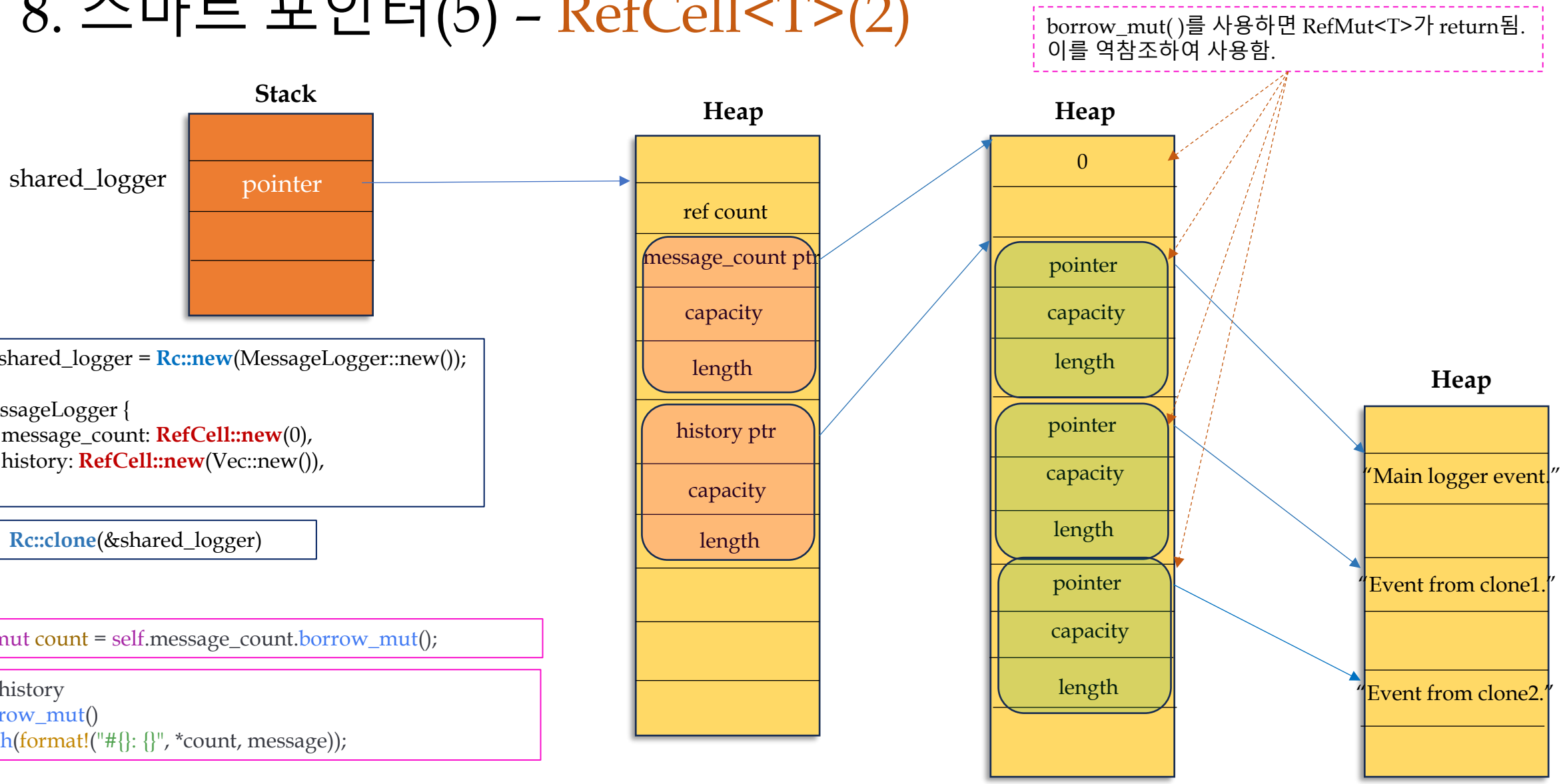
8. 스마트 포인터(5) – RefCell<T>(1)

Rc<RefCellM<T>> 예제

```rust
use std::cell::RefCell;
use std::rc::Rc;

// A logger that uses interior mutability to track its state.
struct MessageLogger {
    message_count: RefCell<usize>,
    history: RefCell<Vec<String>>,
}

impl MessageLogger {
    fn new() -> Self {
        MessageLogger {
            message_count: RefCell::new(0),
            history: RefCell::new(Vec::new()),
        }
    }

    // This method takes &self but can modify internal state via RefCell.
    fn log(&self, message: &str) {
        let mut count = self.message_count.borrow_mut();
        *count += 1;

        self.history
            .borrow_mut()
            .push(format!("#{}: {}", *count, message));
    }
    fn get_count(&self) -> usize {
        *self.message_count.borrow()
    }
    fn print_history(&self) {
        println!("--- Log History ---");
        for entry in self.history.borrow().iter() {
            println!("{}", entry);
        }
        println!("--------------------");
    }
}
fn main() {
    // Wrap the MessageLogger in Rc to allow shared ownership.
    let shared_logger: Rc<MessageLogger> = Rc::new(MessageLogger::new());
    // Create multiple references to the same logger instance.
    let logger_clone1 = Rc::clone(&shared_logger);
    let logger_clone2 = Rc::clone(&shared_logger);

    // Log messages from different references.
    // Each call will mutate the same underlying MessageLogger instance.
    shared_logger.log("Main logger event.");
    logger_clone1.log("Event from clone 1.");
    logger_clone2.log("Event from clone 2.");
    // Check the final state from any of the references.
    println!("\nTotal messages logged: {}", shared_logger.get_count());
    shared_logger.print_history();
}
```

RefCell<T>는 대게 Rc<T>와 함께 사용(Rc<RefCell<T>>)되므로, 코드가 매우 복잡해 보임.

8. 스마트 포인터(5) – RefCell<T>(2)




```
let shared_logger = Rc::new(MessageLogger::new());

MessageLogger {
    message_count: RefCell::new(0),
    history: RefCell::new(Vec::new()),
}
```

```
Rc::clone(&shared_logger)
```

```
let mut count = self.message_count.borrow_mut();
```

```
self.history
.borrow_mut()
.push(format!("#{}: {}", *count, message));
```

RefCell<T>로 선언된 field는 runtime에 borrow_mut() 함수로 빌려와 수정 가능함.

8. 스마트 포인터(5) – RefCell<T>(3)

RefCell<T> 사용 방법 요약

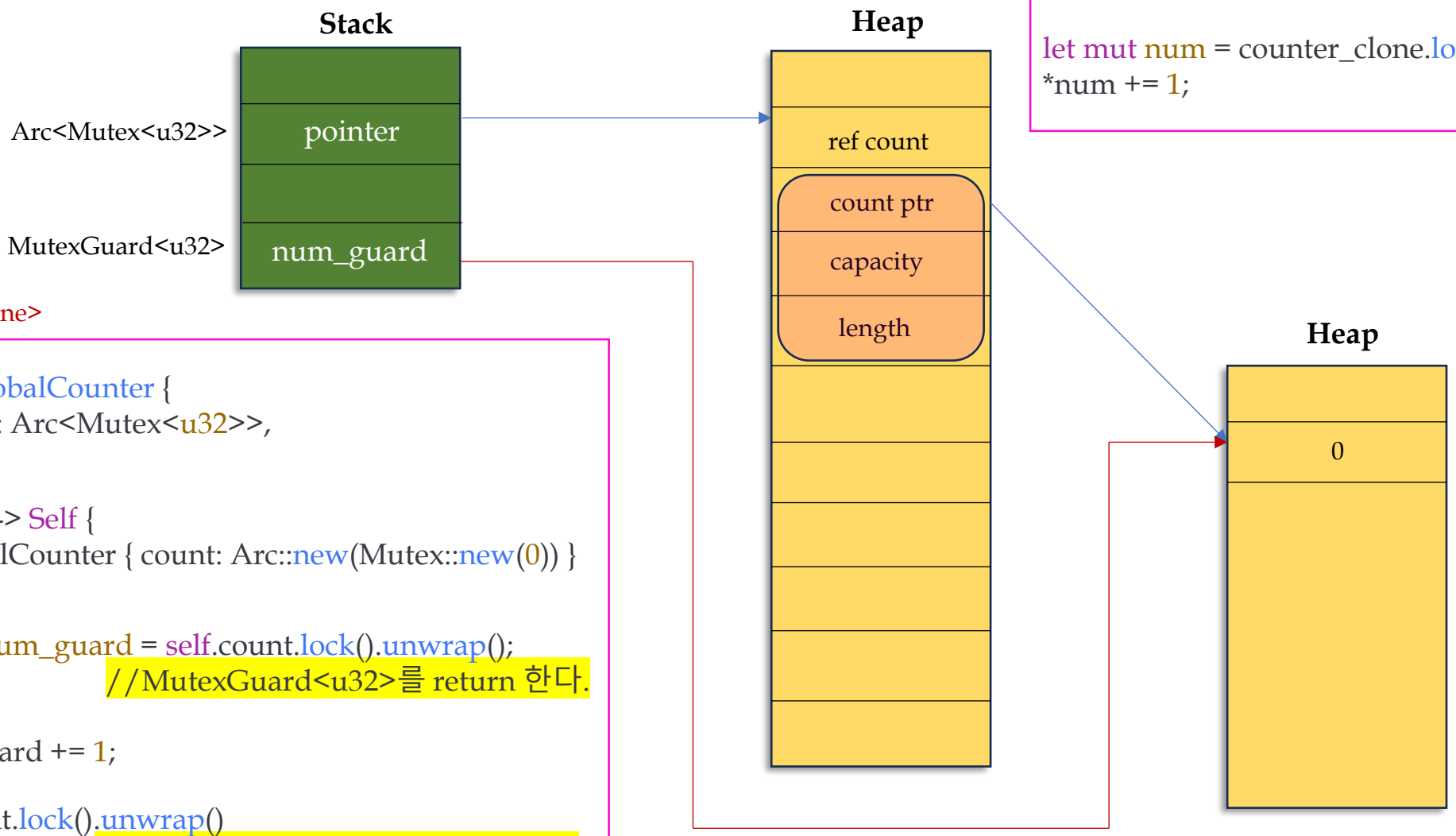
```
struct MessageLogger {
    message_count: RefCell<usize>,
    history: RefCell<Vec<String>>,
}

let m = MessageLogger {
    message_count: RefCell::new(0),
    history: RefCell::new(Vec::new()),
}

//MessageLogger 자체는 Immutable로 선언되었으나, 내부 field를 수정하기 위하여, RefCell을 이용함.
let mut count = m.message_count.borrow_mut();  //RefMut<usize>가 return 된다.

*count += 1;

...
```

8. 스마트 포인터(6) – Mutex<T>(1)

```rust
use std::sync::{Arc, Mutex};
use std::thread;
use std::time::Duration;

struct GlobalCounter {
    count: Arc<Mutex<u32>>, // Shared, mutable counter
}

impl GlobalCounter {
    fn new() -> Self {
        GlobalCounter { count: Arc::new(Mutex::new(0)) }
    }

    fn increment(&self) {
        // Acquire the lock. This blocks if another thread has the lock.
        // unwrap() here will panic if the mutex is poisoned.
        let mut num_guard = self.count.lock().unwrap();
        *num_guard += 1; // Mutate the data through the MutexGuard
        // Lock is released when num_guard goes out of scope
    }

    fn get_value(&self) -> u32 {
        *self.count.lock().unwrap() // Lock, get value, unlock
    }
}
```

```rust
fn main() {
    let global_counter = GlobalCounter::new();
    let mut handles = vec![];

    println!("Initial count: {}", global_counter.get_value()); // Output: 0

    // Spawn multiple threads that all increment the same counter
    for i in 0..5 {
        // Clone the Arc to give ownership to the new thread
        let counter_clone = Arc::clone(&global_counter.count);

        let handle = thread::spawn(move || {
            // This is a different way to use the Arc<Mutex<T>> directly
            // without the GlobalCounter struct, for illustration.
            for _ in 0..100 {
                let mut num = counter_clone.lock().unwrap();
                *num += 1;
                // Slight delay to make interleaving more likely
                thread::sleep(Duration::from_micros(1));
            }
            println!("Thread {} finished incrementing.", i);
        });
        handles.push(handle);
    }

    // Using the methods on our GlobalCounter struct from the main thread
    // (This is a bit contrived here as the struct methods would also contend for the same lock
    //  if called concurrently with the threads above, but demonstrates method usage)
    global_counter.increment(); // Main thread also increments

    // Wait for all spawned threads to finish
    for handle in handles {
        handle.join().unwrap();
    }

    println!("Final count: {}", global_counter.get_value()); // Expected: 5 * 100 + 1 = 501
}
```

8. 스마트 포인터(6) – Mutex<T>(2)



<Thread routine>

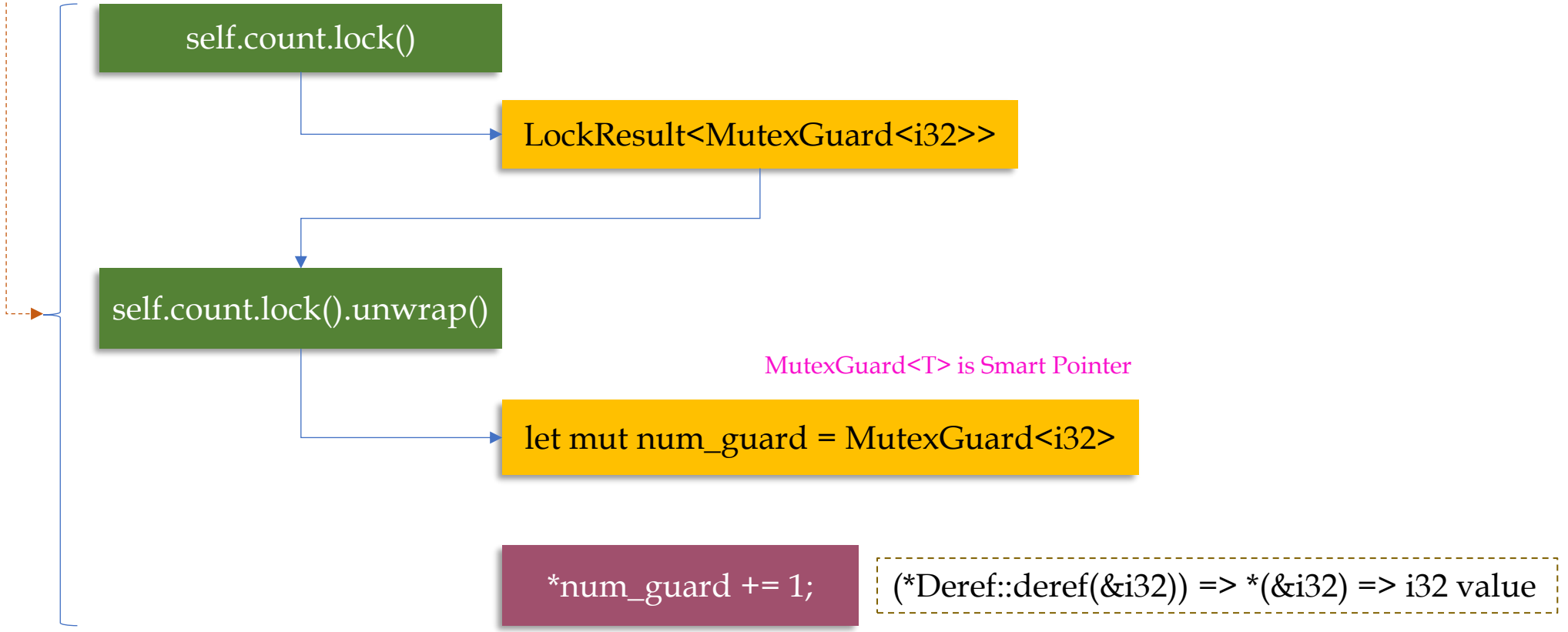
```
let counter_clone = Arc::clone(&global_counter.count);

let mut num = counter_clone.lock().unwrap();
*num += 1;
```

<Main routine>

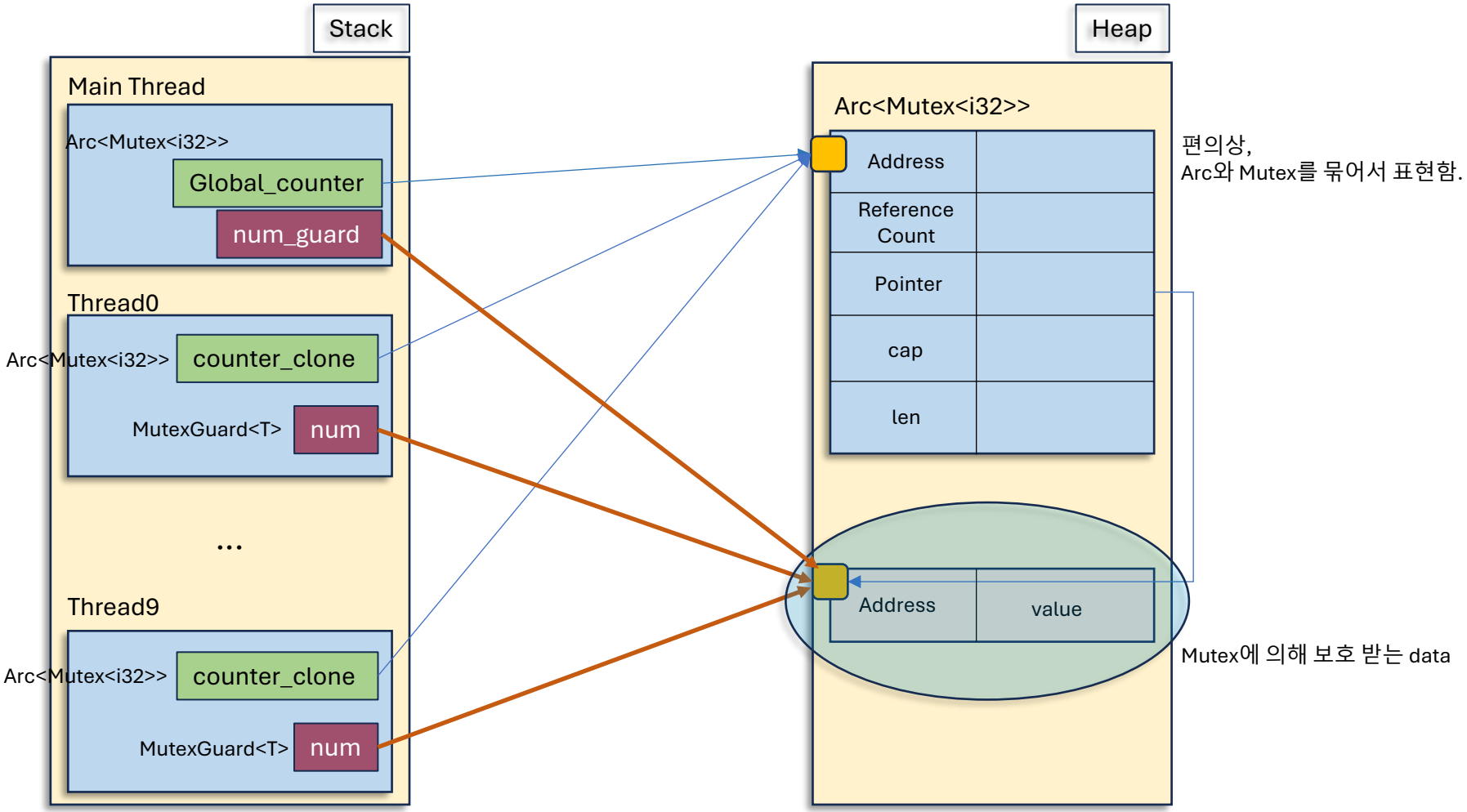
```
struct GlobalCounter {
    count: Arc<Mutex<u32>>,
}

fn new() -> Self {
    GlobalCounter { count: Arc::new(Mutex::new(0)) }
}

let mut num_guard = self.count.lock().unwrap();
                    //MutexGuard<u32>를 return 한다.

*num_guard += 1;

*self.count.lock().unwrap()
                    //MutexGuard<u32>를 return 한다.
```

8. 스마트 포인터(6) – Mutex<T>(3)

```
let mut num_guard = self.count.lock().unwrap();

*num_guard += 1;
```



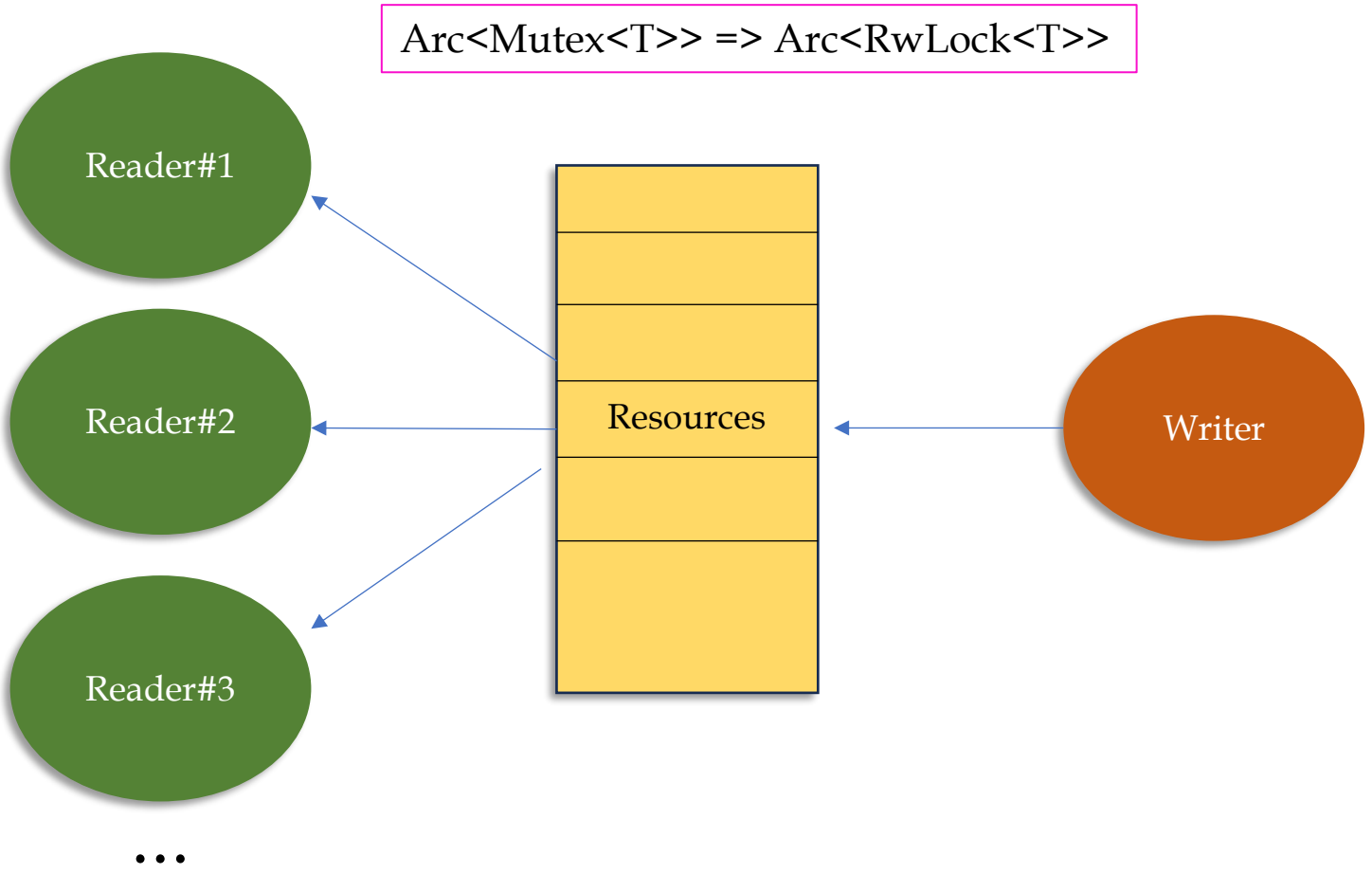
8. 스마트 포인터(6) – Mutex<T>(4)



num = counter_clone.lock().unwrap()

*num MutexGuard로 i32 value에 direct access

8. 스마트 포인터(7) – RwLock<T>(1)



8. 스마트 포인터(7) – RwLock<T>(2)

```rust
use std::sync::{Arc, RwLock};
use std::thread;

fn main() {
    // A shared configuration that many threads will read, but one will update.
    let config = Arc::new(RwLock::new("Initial Config".to_string()));

    let mut handles = vec![];

    // --- Spawn multiple READER threads ---
    for i in 0..5 {
        let config_clone = Arc::clone(&config);
        handles.push(thread::spawn(move || {
            // Acquire a read lock. Multiple threads can hold this at the same time.
            let config_guard = config_clone.read().unwrap();
            println!("Reader {}: sees config: '{}'", i, *config_guard);
        }));
    }
```

```rust
    // --- Spawn one WRITER thread ---
    let config_clone = Arc::clone(&config);
    handles.push(thread::spawn(move || {
        // Simulate some work before writing
        thread::sleep(std::time::Duration::from_millis(10));

        // Acquire a write lock. This will wait until all readers are done.
        // Once held, no new readers or writers can get a lock.
        let mut config_guard = config_clone.write().unwrap();
        *config_guard = "Updated Config".to_string();
        println!("--- Writer: Updated config! ---");
    }));

    // Wait for all threads to finish
    for handle in handles {
        handle.join().unwrap();
    }

    println!("\nFinal config value: '{}'", *config.read().unwrap());
}
```

8. 스마트 포인터(8) – Todo!

- **Cow<'a T>**
- **NonNull<T>**
- **OnceCell<T>**
- **OnceLock<T>**
- **LazyLock<T>**
- **UnsafeCell<T>***

9. Concurrency

Thread and Channel, Async Programming

9. Concurrency(1) – Thread Spawn & Join(1)

```rust
use std::thread;
use std::time::Duration;

fn main() {
    println!("Main thread: Starting up!");

    // Spawn a new thread
    let handle = thread::spawn(|| {
        // This code runs in the new thread
        for i in 1..=5 {
            println!("New thread: count {}", i);
            thread::sleep(Duration::from_millis(500)); // Pause for 0.5 seconds
        }
        println!("New thread: I'm done!");
    });

    // The main thread continues its work immediately
    for i in 1..=3 {
        println!("Main thread: working... {}", i);
        thread::sleep(Duration::from_millis(300)); // Pause for 0.3 seconds
    }

    println!("Main thread: Waiting for the new thread to finish...");
    // We'll see how to properly wait for the handle next.
    // For now, if main exits, the spawned thread might be killed.
    // To ensure the spawned thread finishes in this example, we can add a longer sleep here,
    // but using join() is the correct way.
    // thread::sleep(Duration::from_secs(3)); // Temporary, to see spawned thread output

    // The correct way to wait for the spawned thread:
    handle.join().unwrap(); // We'll explain join() shortly

    println!("Main thread: All done!");
}
```

9. Concurrency(1) – Thread Spawn & Join(2)

```rust
use std::thread;
use std::time::Duration;

fn main() {
    let message = String::from("Hello from the main thread!");
    let important_number = 42;

    // The `move` keyword forces the closure to take ownership of
`message` and `important_number`
    let handle = thread::spawn(move || {
        println!("Spawned thread received message: '{}'", message);
        println!("Spawned thread received number: {}", important_number);
        // `message` and `important_number` are now owned by this
closure's environment.
        // The original variables in main are no longer accessible if they
were moved (like String).
        // For Copy types like i32, a copy is moved.
    });
    // Attempting to use `message` here would cause a compile error:
    // println!("Main thread still has message: {}", message); // ERROR!
value borrowed here after move
    // `important_number` was an i32, which is Copy, so a copy was moved.
    // The original `important_number` in main is still valid.
    println!("Main thread still has important_number: {}", important_
number);

    // Wait for the thread to finish
    handle.join().unwrap();
    println!("Main thread: Spawned thread finished.");
}
```

9. Concurrency(2) – Advanced Threads(1)

Thread function

```rust
use std::thread;

fn thread_function(start: u32, end: u32) {
    for i in start..end {
        println!("스레드: {}", i);
        std::thread::sleep(std::time::Duration::from_millis(100));
    }
}

fn main() {
    // thread::spawn 호출 시, 함수 포인터를 전달
    let handle = thread::spawn(|| thread_function(1, 10));

    // 메인 스레드 작업
    for i in 1..5 {
        println!("메인 스레드: {}", i);
        std::thread::sleep(std::time::Duration::from_millis(100));
    }

    // 스레드 종료 대기
    handle.join().unwrap();
}
```

```rust
use std::thread;

// 스레드에서 실행할 함수
fn thread_function() {
    for i in 1..10 {
        println!("스레드: {}", i);
        std::thread::sleep(std::time::Duration::from_millis(100));
    }
}

fn main() {
    // thread::spawn에 함수 포인터 전달
    let handle = thread::spawn(thread_function);

    // 메인 스레드 작업
    for i in 1..5 {
        println!("메인 스레드: {}", i);
        std::thread::sleep(std::time::Duration::from_millis(100));
    }

    // 스레드 종료 대기
    handle.join().unwrap();
}
```

9. Concurrency(2) – Advanced Threads(2)

std::thread::Builder

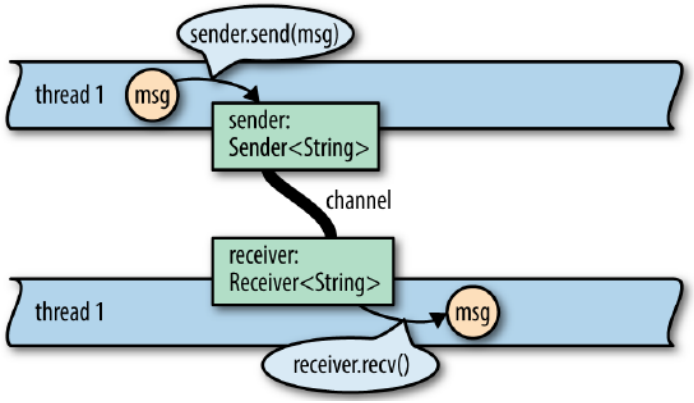
```rust
use std::thread;

fn main() {
    let builder = thread::Builder::new()
        .stack_size(4 * 1024 * 1024) // 4MB 스택 설정
        .name("CustomThread".into());

    let handle = builder.spawn(|| {
        println!("스레드 이름: {:?}", thread::current().name());
    }).unwrap();

    handle.join().unwrap();
}
```

```rust
use std::thread;
use std::time::Duration;

fn main() {
    let handle = thread::spawn(|| {
        println!("스레드 대기 중...");
        thread::park(); // 여기서 중단됨
        println!("스레드가 다시 실행됨!");
    });

    thread::sleep(Duration::from_secs(1));
    handle.thread().unpark(); // 중단된 스레드를 다시 실행
    handle.join().unwrap();
}
```

9. Concurrency(3) – Arc<Mutex<T>>

```rust
use std::sync::{Arc, Mutex};
use std::thread;

fn main() {
    // Create a counter, protected by a Mutex, and wrapped in an Arc for sharing
    let counter = Arc::new(Mutex::new(0u32)); // Start with 0

    let mut handles = vec![];

    println!("Main: Initial counter value = {}", *counter.lock().unwrap());

    for i in 0..5 { // Spawn 5 threads
        let counter_clone_for_thread = Arc::clone(&counter); // Clone Arc for the thread

        let handle = thread::spawn(move || {
            // Each thread will try to increment the counter 10 times
            for _ in 0..10 {
                // Acquire the lock. This blocks if another thread has it.
                let mut num_guard = counter_clone_for_thread.lock().unwrap();
                // We now have exclusive mutable access to the u32 inside the Mutex.
                *num_guard += 1;
                // The lock is released automatically when num_guard goes out of scope here.
            }
            println!("Thread {}: Finished incrementing.", i);
        });
        handles.push(handle);
    }

    // Wait for all threads to complete their work
    for handle in handles {
        handle.join().unwrap();
    }

    // Lock the mutex in the main thread to read the final value
    let final_value = *counter.lock().unwrap();
    println!("Main: All threads finished. Final counter value = {}", final_value); // Expected: 50
}
```

9. Concurrency(4) – Thread Channel(1)




```
let (tx, rx) = (mpsc::Sender<String>, mpsc::Receiver<String>) = mpsc::channel();
```

Multiple Senders

send(), recv() 결과도 Result<T, E>임
보내는 data(변수)에 대한 소유권이 이동함

Sender Thread

Owernership

```
tx.send(String::from"hello1").unwrap();
```

Sender Thread

```
tx.send(String::from"hello2").unwrap();
```

...

Sender Thread

```
tx.send(String::from"helloN").unwrap();
```

Channel

Single Receiver

Owernership

Receiver Thread

```
for message in rx {
  process_received_messages(message);
}
```

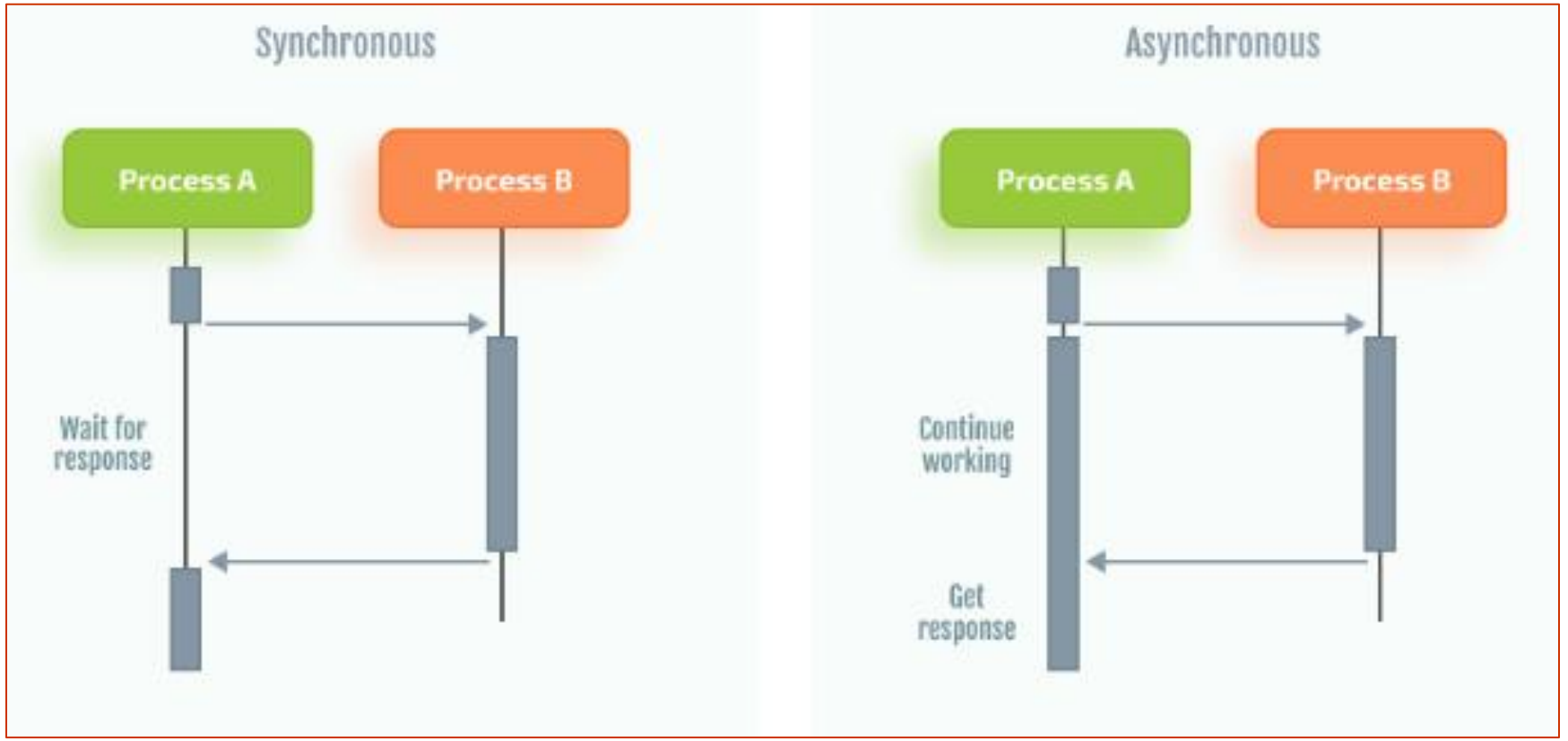
9. Concurrency(4) – Thread Channel(2)

```rust
use std::sync::mpsc;
use std::thread;
use std::time::Duration;

fn main() {
    let (tx, rx): (mpsc::Sender<String>, mpsc::Receiver<String>) =
mpsc::channel();

    // Spawn a thread that will send messages
    let sender_thread_handle = thread::spawn(move || {
        let messages_to_send = vec![
            String::from("Greetings"),
            String::from("from"),
            String::from("the producer"),
            String::from("thread!"),
        ];

        for msg_content in messages_to_send {
            println!("Sender Thread: Preparing to send '{}'", msg_
content);
            // Send the message. send() takes ownership of msg_content.
            if tx.send(msg_content).is_err() {
                eprintln!("Sender Thread: Receiver has disconnected,
unable to send further messages.");
                break; // Exit the loop if we can't send
            }
            println!("Sender Thread: Message sent successfully.");
            thread::sleep(Duration::from_millis(200)); // Simulate some
work
        }
        println!("Sender Thread: All messages dispatched or receiver
gone.");
    });

    // Main thread will now try to receive.
    // The receiver (rx) is still in scope here.
    println!("Main Thread: Waiting for messages from sender thread...");
    for received_message in rx { // rx can be used as an iterator
        println!("Main Thread: Received: '{}'", received_message);
    }
    println!("Main Thread: Channel disconnected (all senders dropped).");

    // Wait for the sender thread to finish its execution completely
    sender_thread_handle.join().expect("Sender thread panicked!");
    println!("Main Thread: Sender thread has joined.");
}
```

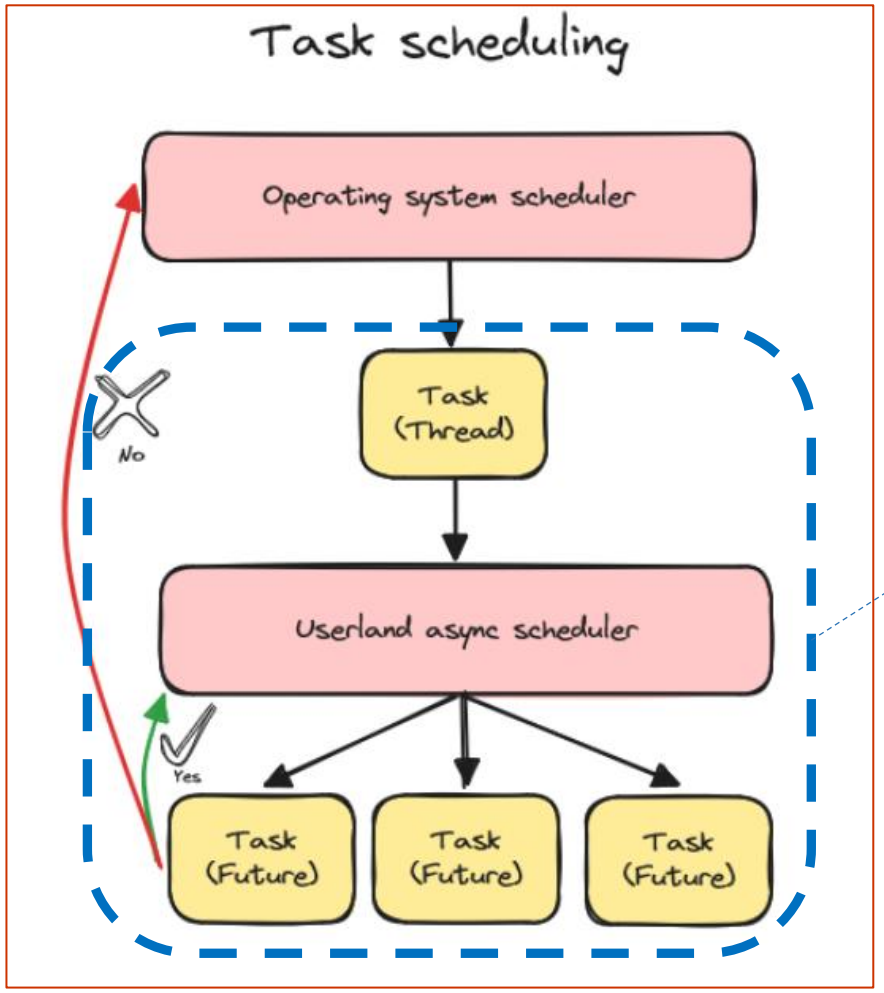
9. Concurrency(4) – Thread Channel(3)

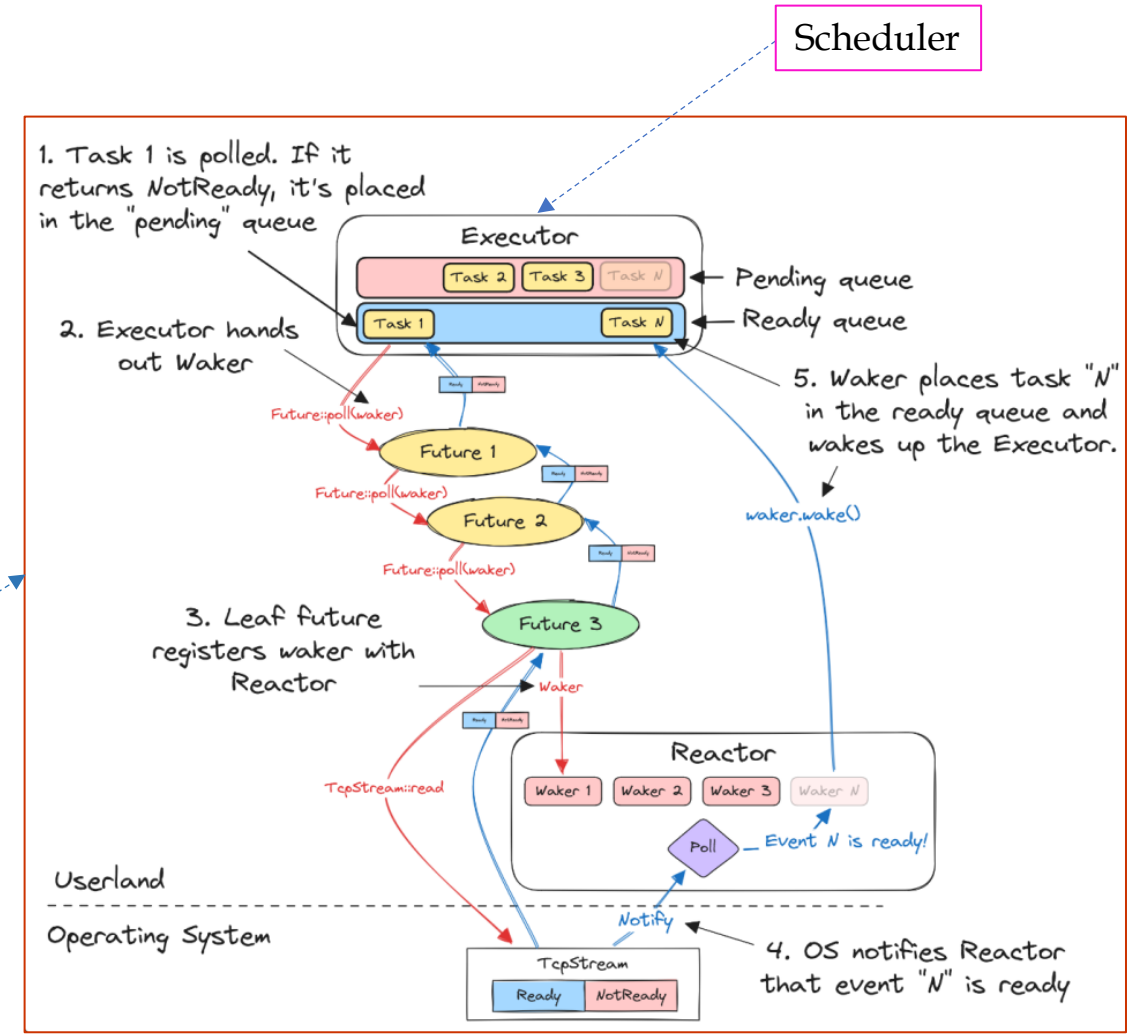
```rust
use std::sync::mpsc;
use std::thread;
use std::time::Duration;

fn main() {
    // Channel for the main thread to signal the worker to start
    let (start_tx, start_rx) = mpsc::channel::<()>(); // Using unit type for a pure signal

    // Channel for the worker to send its result back to the main thread
    let (result_tx, result_rx) = mpsc::channel::<String>();

    let worker_handle = thread::spawn(move || {
        println!("Worker Thread: Initialized and waiting for the green light...");
        // Block until a () signal is received on start_rx
        start_rx.recv().expect("Failed to receive start signal from main thread.");

        println!("Worker Thread: Green light received! Performing complex task...");
        thread::sleep(Duration::from_secs(1)); // Simulate some work
        let computation_result = "Task completed successfully by worker!".to_string();

        // Send the result back to the main thread
        result_tx.send(computation_result).expect("Failed to send result to main thread.");
        println!("Worker Thread: Result sent, finishing up.");
    });

    println!("Main Thread: Performing some setup before signaling worker...");
    thread::sleep(Duration::from_millis(500)); // Simulate setup work

    println!("Main Thread: Setup complete. Sending start signal to worker...");
    start_tx.send(()).expect("Failed to send start signal to worker."); // Send the () signal

    // Block and wait for the worker thread to send back its result
    println!("Main Thread: Waiting for result from worker...");
    let worker_output = result_rx.recv().expect("Failed to receive result from worker.");
    println!("Main Thread: Received from worker: '{}'", worker_output);

    // Ensure the worker thread has fully completed its execution
    worker_handle.join().expect("Worker thread panicked during execution!");
    println!("Main Thread: Worker thread has joined. Program exiting.");
}
```

9. Concurrency(5) – Async Programming(1)



9. Concurrency(5) – Async Programming(2)





9. Concurrency(5) – Async Programming(3)

Tokio(runtime) async/await

```rust
use tokio::time::{sleep, Duration};

/// This is an async function. When called, it returns a `Future`
/// that will resolve to a String.
async fn fetch_simulated_data(task_id: u32) -> String {
    println!("Task {}: Starting fetch...", task_id);

    // This is an async-aware sleep.
    // Unlike `std::thread::sleep`, this does NOT block the whole thread.
    // It yields control back to the tokio runtime,
    // allowing other async tasks to run.
    sleep(Duration::from_secs(1)).await;

    println!("Task {}: Finished fetch.", task_id);
    format!("Data from task {}", task_id)
}
```

```rust
/// This function contains our main async logic.
async fn process_tasks_sequentially() {
    println!("Starting sequential processing...");

    // We call and .await the first task.
    // Our function's execution pauses here (non-blockingly)
    // until `fetch_simulated_data(1)` completes.
    let data1 = fetch_simulated_data(1).await;
    println!("Main: Received first data: '{}'", data1);

    // Only *after* the first task is complete, we call and .await the
second.
    let data2 = fetch_simulated_data(2).await;
    println!("Main: Received second data: '{}'", data2);

    println!("Sequential processing finished.");
}

/// The #[tokio::main] macro automatically:
/// 1. Creates a new Tokio runtime instance.
/// 2. Runs the `async fn main` on that runtime.
#[tokio::main]
async fn main() {
    // We .await the future returned by our main logic function.
    process_tasks_sequentially().await;
}
```

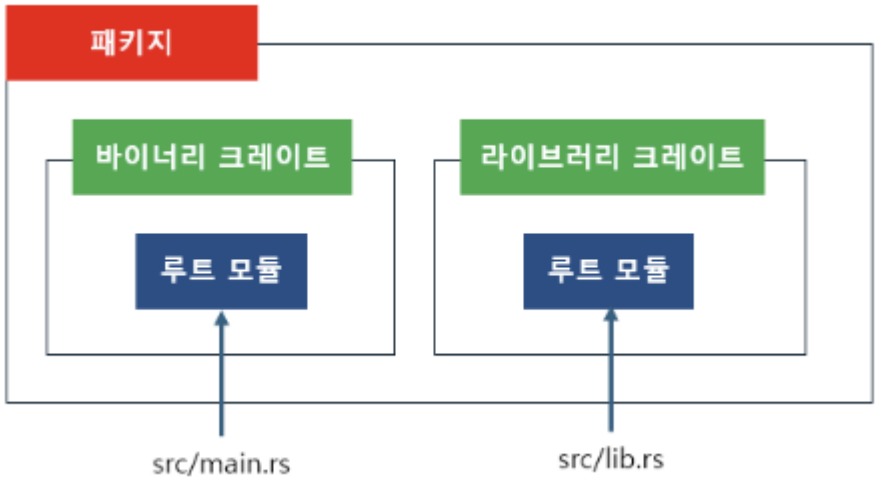
9. Concurrency(5) – Async Programming(4)

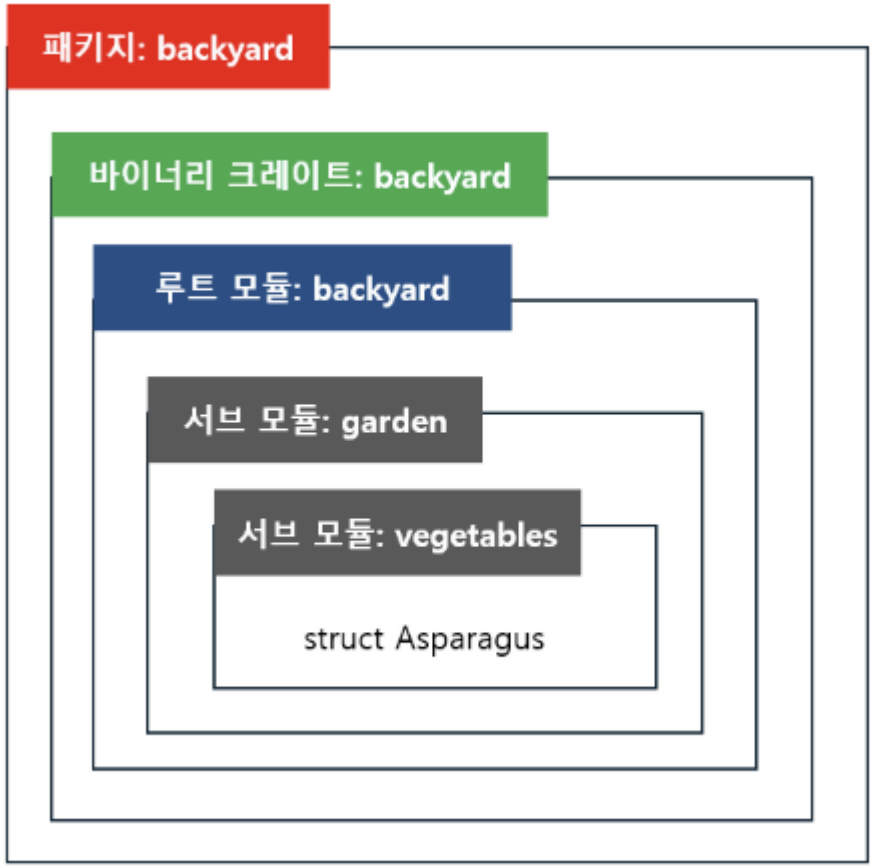
```rust
// This is a "handler" function.
// It's an async function that returns something that can be
// converted into an HTTP response. A simple &str works!
async fn hello_world_handler() -> &'static str {
    "Hello, Web!"
}

// We need the tokio::main macro to run our async main function
#[tokio::main]
async fn main() {
    // Build our application with a single route
    let app = Router::new().route("/", get(hello_world_handler));

    // run it
    let listener = tokio::net::TcpListener::bind("127.0.0.1:8080")
        .await
        .expect("Failed to bind to address 127.0.0.1:8080");

    println!("🚀 Server listening on http://{}", listener.local_addr().
unwrap());

    axum::serve(listener, app)
        .await
        .expect("Failed to start server");
}
```

10. Package, Crate, Module

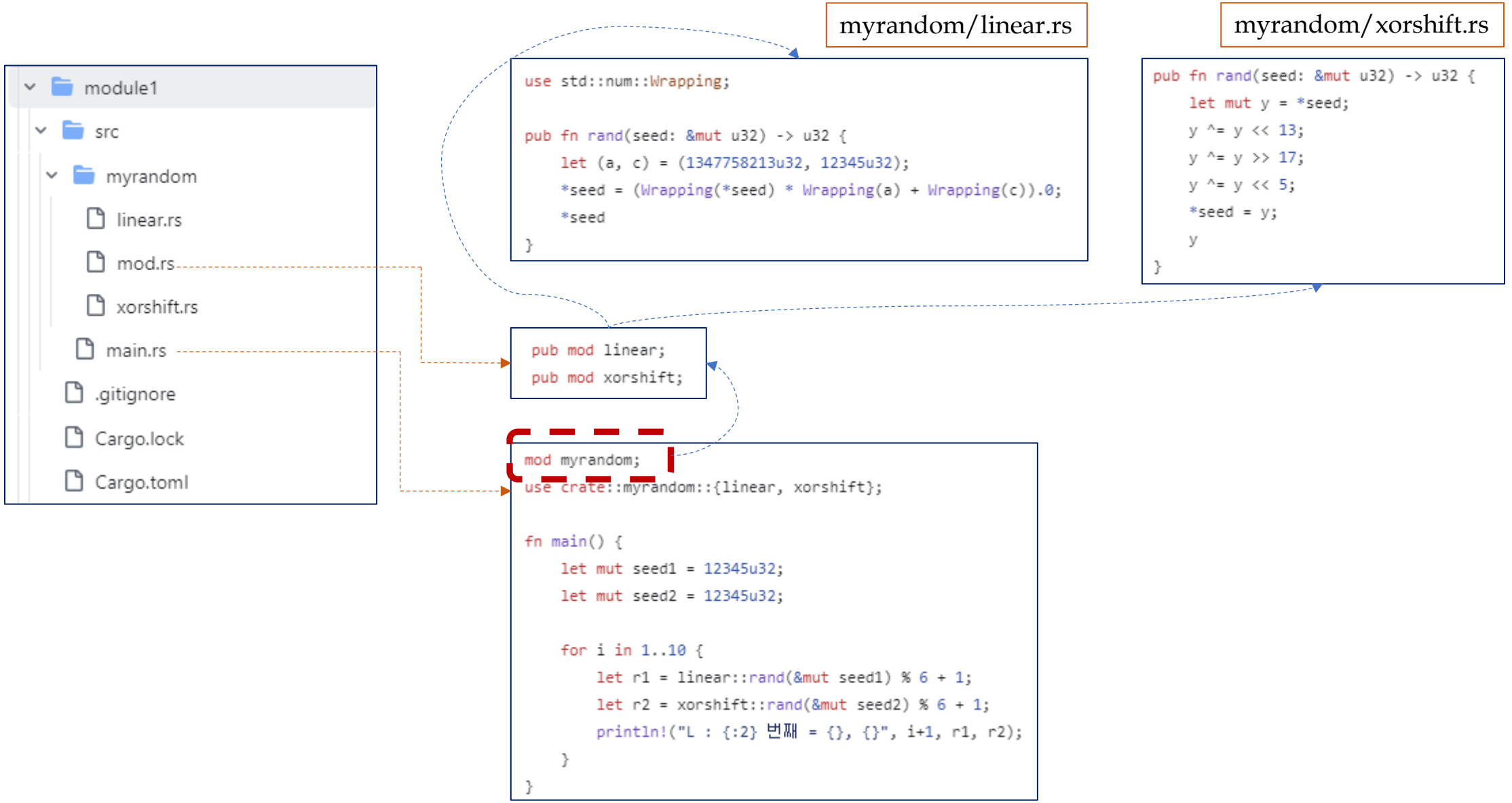
Package, Crate, Module

10. Package, Crate, Module(1)

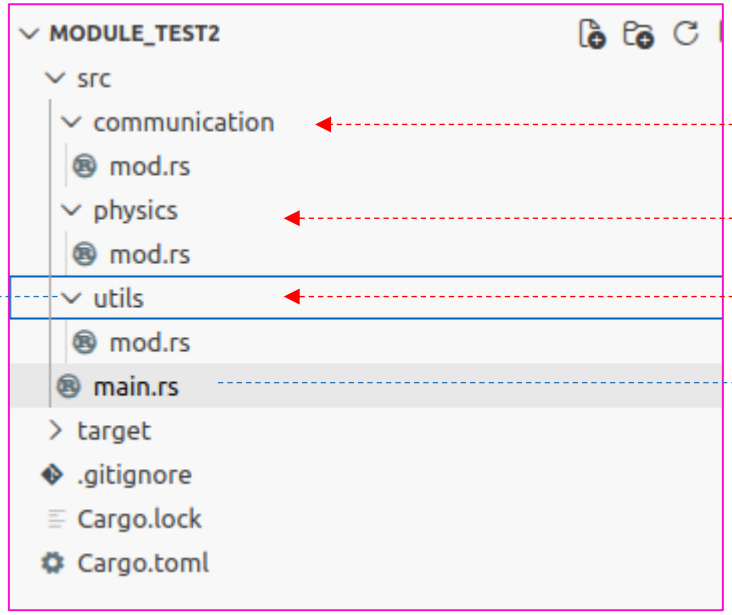




10. Package, Crate, Module(2)



10. Package, Crate, Module(3-1)



utils/mod.rs

```rust
// 이 파일 자체가 'utils' 모듈의 본체가 됩니다.

// 하위 모듈 1: 문자열 도구
pub mod string_tools {
    pub fn to_uppercase(s: &str) {
        println!("[StringTools] Result: {}", s.to_uppercase());
    }
}

// 하위 모듈 2: 수학 도구
pub mod math_tools {
    pub fn add(a: i32, b: i32) -> i32 {
        a + b
    }
}
```

```rust
mod communication;
mod physics;
mod utils;

// ============================================================
// [2] Main 함수
// 사용 코드는 이전과 거의 동일합니다.
// ============================================================
fn main() {
    println!("--- Rust Multi-File Module Demo ---\n");

    // 1. 절대 경로 사용
    crate::communication::radio::broadcast("Hello via Absolute Path!");
    crate::physics::gravity::calculate_drop();

    // 2. 상대 경로 사용 (main과 communication은 같은 레벨)
    communication::network::connect();
    communication::network::check_status();

    // 3. use 키워드 사용
    use crate::utils::string_tools;
    string_tools::to_uppercase("hello use keyword");

    // 4. 별칭(Alias) 사용
    use crate::utils::math_tools::add as sum;
    println!("[Math alias] 10 + 20 = {}", sum(10, 20));

    // 5. 구조체 사용
    use crate::physics::thermodynamics::Temperature;
    let mut temp = Temperature::new(36.5);
    temp.degrees = 37.2;
    temp.show();

    // 6. 중첩 경로 import
    use crate::communication::radio::{self, broadcast};
    radio::broadcast("Nested path works!");
    broadcast("Direct function works!");
}
```

10. Package, Crate, Module(3-2)

communication/mod.rs

```rust
// 이 파일 자체가 'communication' 모듈의 본체가 됩니다.

// 하위 모듈 1: 라디오
pub mod radio {
    pub fn broadcast(message: &str) {
        println!("[Radio] Broadcasting: {}", message);
    }
}

// 하위 모듈 2: 네트워크
pub mod network {
    pub fn connect() {
        println!("[Network] Connected to server.");
    }

    // 상대 경로 테스트
    pub fn check_status() {
        print!("[Network Status] ");
        // 여기서 super는 이 파일(mod.rs), 즉 communication 모듈을 가리킵니다.
        // 따라서 같은 파일 내에 있는 radio 모듈에 접근 가능합니다.
        super::radio::broadcast("Internal Check OK");
    }
}
```

physics/mod.rs

```rust
// 이 파일 자체가 'physics' 모듈의 본체가 됩니다.

// 하위 모듈 1: 중력
pub mod gravity {
    pub fn calculate_drop() {
        println!("[Gravity] Calculating drop speed...");
    }
}

// 하위 모듈 2: 열역학
pub mod thermodynamics {
    pub struct Temperature {
        pub degrees: f64,
        unit: String,
    }

    impl Temperature {
        pub fn new(degrees: f64) -> Temperature {
            Temperature {
                degrees,
                unit: String::from("Celsius"),
            }
        }

        pub fn show(&self) {
            println!("[Thermodynamics] Temp: {} {}", self.degrees, self.unit);
        }
    }
}
```

10. Package, Crate, Module(4)

```rust
mod outer {
    pub mod inner {
        pub fn greet() {
            println!("Hello from inner module");
        }

        pub fn call_self_greet() {
            // self 키워드 사용하여 현재 모듈의 함수 호출
            self::greet();
        }

        pub fn call_super_greet() {
            // super 키워드를 사용하여 부모 모듈로 이동
            super::outer_greet();
        }
    }

    pub fn outer_greet() {
        println!("Hello from outer module");
    }
}

fn main() {
    // 내부 모듈에서 자신과 부모 모듈의 함수 호출
    outer::inner::call_self_greet();
    outer::inner::call_super_greet();
}
```

11. File and Network I/O

File Read/Write, Socket Programming

11. File and Network I/O(1) – File Read/Write(1)

```rust
use std::fs::File;
use std::io::{self, BufRead, BufReader};
use std::path::Path;
use std::process; // For process::exit

// This function attempts to read and print lines from a file.
// It's similar to what our mini_grep will need to do before searching.
fn read_and_print_file_lines(file_path_str: &str) {
    let path = Path::new(file_path_str);

    // Attempt to open the file
    let file = match File::open(&path) {
        Ok(f) => f,
        Err(e) => {
            eprintln!("Error: Could not open file '{}': {}", path.
display(), e);
            process::exit(1); // Exit with error code
        }
    };
```

```rust
    // Use BufReader for efficient line-by-line reading
    let reader = BufReader::new(file);

    println!("--- Contents of '{}' ---", path.display());
    for (index, line_result) in reader.lines().enumerate() {
        match line_result {
            Ok(line_content) => {
                println!("Line {}: {}", index + 1, line_content);
            }
            Err(e) => {
                // Log error for a specific line but continue if possible,
                // or decide to exit if line read errors are critical.
                eprintln!("Error reading line {} from '{}': {}", index +
1, path.display(), e);
                // For a grep tool, we might want to skip unreadable lines
                // or halt. For now, we'll just report and continue.
            }
        }
    }
    println!("--- End of '{}' ---", path.display());
}
```

11. File and Network I/O(1) – File Read/Write(2)

```rust
fn main() {
    // Simulate getting a file path from command-line arguments
    // In a real CLI, this would come from std::env::args() or a parsing crate.
    let args: Vec<String> = std::env::args().collect();

    if args.len() < 2 {
        eprintln!("Usage: {} <file_path>", args.get(0).unwrap_or(&"program_name".into()));
        process::exit(1);
    }
    let file_to_read = &args[1];
```

```rust
    // Create a dummy file for testing if it doesn't exist
    if !Path::new(file_to_read).exists() {
        if file_to_read == "sample_cli_read.txt" { // Only create if it's our expected test file
            std::fs::write(file_to_read, "First line for CLI test.\nSecond line, with a keyword.\nThird and final line.").expect("Failed to create sample file.");
            println!("Created sample file: {}", file_to_read);
        } else {
            eprintln!("Specified file '{}' does not exist and won't be auto-created for this generic example.", file_to_read);
            process::exit(1);
        }
    }

    read_and_print_file_lines(file_to_read);

    // Clean up the dummy file if we created it for the test
    if file_to_read == "sample_cli_read.txt" {
        std::fs::remove_file(file_to_read).ok();
    }
}
```

11. File and Network I/O(2) – Socket Programming(1-1)

TCP Socket Server

```rust
use std::net::{TcpListener, TcpStream};
use std::io::{Read, Write};

/// Handles a single client connection by reading from the stream and
echoing back.
fn handle_client(mut stream: TcpStream) -> std::io::Result<()> {
    println!("Accepted connection from: {}", stream.peer_addr()?);

    // A buffer to hold incoming data.
    // 1024 bytes (1KB) is a common size for simple examples. In a real
    // application, buffer size is a trade-off:
    // - Too small (e.g., 64 bytes) can lead to many system calls, which
is inefficient.
    // - Too large (e.g., 1MB) wastes memory, especially if you have many
    //   concurrent connections.
    // Common sizes for I/O buffers are often 4KB (4096) or 8KB (8192).
    let mut buffer = [0u8; 1024]; // A buffer to hold incoming data
```

```rust
    // Loop to read data and echo it back
    loop {
        // Read data from the client into the buffer
        let bytes_read = stream.read(&mut buffer)?;

        // If read() returns 0 bytes, the client has closed the connection
        if bytes_read == 0 {
            println!("Client disconnected.");
            return Ok(());
        }

        // Echo the received data back to the client
        stream.write_all(&buffer[..bytes_read])?;
        println!("Echoed {} bytes.", bytes_read);
    }
}
```

11. File and Network I/O(2) – Socket Programming(1-2)

```rust
fn main() -> std::io::Result<()> {
    let listener_address = "127.0.0.1:8080";
    let listener = TcpListener::bind(listener_address)?;

    println!("Simple Echo Server listening on {}", listener_address);
    println!("Waiting for connections...");

    // listener.incoming() is an iterator that blocks until a new
connection arrives.
    // This loop processes one client connection fully before accepting
the next.
```

```rust
    for stream_result in listener.incoming() {
        match stream_result {
            Ok(stream) => {
                // A new client has connected successfully.
                if let Err(e) = handle_client(stream) {
                    eprintln!("Error handling client: {}", e);
                }
            }
            Err(e) => {
                // An error occurred while accepting a new connection.
                eprintln!("Failed to accept incoming connection: {}", e);
            }
        }
    }
    Ok(())
}
```

11. File and Network I/O(2) – Socket Programming(2)

TCP Socket Client

```rust
use std::net::TcpStream;
use std::io::{self, Write, BufRead, BufReader};

fn main() -> io::Result<()> {
    let server_address = "127.0.0.1:8080";
    println!("Connecting to echo server at {}...", server_address);

    // 1. Connect to the server. The '?' operator handles connection errors concisely.
    let mut stream = TcpStream::connect(server_address)?;
    println!("Connected! Type a message and press Enter. Type 'quit' to exit.");

    // 2. Prepare for reading and writing.
    //    We can clone the stream to have separate handles for reading and writing.
    //    This is a common pattern for more complex I/O.
    let mut reader = BufReader::new(stream.try_clone()?);
    loop {
        // Read a line of input from the user's keyboard.
        let mut input_line = String::new();
        io::stdin().read_line(&mut input_line)?;

        let message_to_send = input_line.trim(); // Trim whitespace and newline
        if message_to_send == "quit" || message_to_send.is_empty() {
            break; // Exit loop if user types 'quit' or just presses Enter
        }

        // 3. Send the message to the server.
        // We add a newline so the server's `read_line` can process it.
        writeln!(stream, "{}", message_to_send)?;
        stream.flush()?; // Ensure the buffered data is sent immediately.

        // 4. Read the echo back from the server.
        let mut echoed_response = String::new();
        reader.read_line(&mut echoed_response)?
        print!("Server echoed: {}", echoed_response); // `read_line` includes the newline
    }

    println!("Disconnecting from server.");
    Ok(())
}
```

11. File and Network I/O(3) – Command Line Parser

```
use clap::Parser; // Import the Parser trait

/// A simple program to greet a person, demonstrating clap.
#[derive(Parser, Debug)]
#[command(author = "Your Name", version = "0.1.0", about = "Greets a
person - clap example", long_about = None)]
struct CliArgs {
    /// The name of the person to greet
    #[arg(short, long)] // Allows -n <NAME> or --name <NAME>
    name: String,

    /// Number of times to greet
    #[arg(short, long, default_value_t = 1)] // Allows -c <COUNT> or
--count <COUNT>, defaults to 1
    count: u8,

    /// Optional message to include in the greeting
    #[arg(long)] // Allows --message <MESSAGE>
    message: Option<String>,

    // For our mini_grep example, it might look more like:
    // query: String,
    // file_path: std::path::PathBuf,
    // #[arg(short, long, action = clap::ArgAction::SetTrue)] // for a
flag like -i
    // ignore_case: bool,
}
```

```
[dependencies]
clap = { version = "4.5", features = ["derive"] } # Check crates.io for
the latest version
```

```
fn main() {
    // CliArgs::parse() will parse arguments from std::env::args(),
    // handle errors, and provide help/version messages automatically.
    let args = CliArgs::parse();

    for _ in 0..args.count {
        if let Some(ref msg) = args.message {
            println!("Hello, {}! Here's your message: {}", args.name,
msg);
        } else {
            println!("Hello, {}!", args.name);
        }
    }

    // If --help or --version was passed, clap handles it and exits before
this point.
    // If parsing failed, clap prints an error and exits.
}
```

12. 고급 기능

Unsafe, Macro 등

12. 고급 기능(1) – Unsafe Raw Pointer(1)

```rust
fn main() {
    let mut num = 5;

    // Create raw pointers from references. This part is safe.
    // r1 is an immutable raw pointer to num.
    let r1: *const i32 = &num as *const i32;
    // r2 is a mutable raw pointer to num.
    let r2: *mut i32 = &mut num as *mut i32;

    // --- WARNING: DANGEROUS OPERATION ---
    // The following code creates a raw pointer from an arbitrary memory address.
    // This is NOT something you should do in normal application code.
    // Accessing random memory addresses is undefined behavior and will
    // almost certainly crash your program with a segmentation fault.
    // This is only done in very specific low-level programming, like
    // interacting with known, fixed hardware addresses.
    let arbitrary_address = 0x012345usize;
    let r3_arbitrary_ptr = arbitrary_address as *const i32;
    // --- END WARNING ---
```

```rust
    unsafe {
        // Dereferencing r1 to read the value of num
        // This is safe because we know r1 was created from a valid reference.
        println!("Value via r1 (immutable raw pointer): {}", *r1); // Output: 5

        // Dereferencing r2 to write a new value to the memory location of num.
        // This is safe because r2 was also created from a valid reference.
        *r2 = 10; // Modifies `num` through the raw pointer

        println!("`num` has been changed via r2 to: {}", num); // Output: 10

        // r1 still points to `num`, so it will now see the new value.
        println!("Value via r1 after change via r2: {}", *r1); // Output: 10

        // --- DANGER: DO NOT DO THIS ---
        // Uncommenting the line below would attempt to dereference r3_arbitrary_ptr.
        // This is EXTREMELY DANGEROUS because r3_arbitrary_ptr points to an arbitrary,
        // likely invalid, memory location. It would almost certainly crash your program.
        // println!("Attempting to read from arbitrary address r3: {}", *r3_arbitrary_ptr);
        // --- END DANGER ---
    }
```

12. 고급 기능(1) – Unsafe Raw Pointer(2)

```
    // Creating a null pointer.
    let null_pointer: *const i32 = std::ptr::null();
    let mut_null_pointer: *mut i32 = std::ptr::null_mut();

    // It's crucial to check if a raw pointer is null before attempting to
dereference it.
    if !null_pointer.is_null() {
        // This block will not execute because null_pointer is indeed
null.
        unsafe {
            println!("This line should not be reached: {}", *null_
pointer);
        }
    } else {
        println!("null_pointer is confirmed to be null, not
dereferencing.");
    }
}
```

12. 고급 기능(2) – Macro(1)

Standard macro

format!(fmt, args...)

fmt 문자열을 이용해 String 객체를 생성한다.

```
let s = format!("Hello, {}!", "world");
println!("{}", s); // 출력: Hello, world!
```

print!(fmt, args...)

표준 출력에 포맷팅 된 문자열을 줄 바꿈 없이 출력한다.

```
print!("Hello, {}!", "world"); // 출력: Hello, world!
```

println!(fmt, args...)

표준 출력에 포맷팅 된 문자열을 출력하고 줄 바꿈을 추가한다.

```
println!("Hello, {}!", "world"); // 출력: Hello, world!\n
```

https://wikidocs.net/blog/@laniakea/1939/

eprint!(fmt, args...)

표준 오류 스트림에 포맷팅 된 문자열을 줄 바꿈 없이 출력한다.

```
eprint!("Error: {}", "Something went wrong!"); // 표준 오류 출력
```

eprintln!(fmt, args...)

표준 오류 스트림에 포맷팅 된 문자열을 출력하고 줄 바꿈을 추가한다.

```
eprintln!("Error: {}", "Something went wrong!"); // 표준 오류 출력 + 줄바꿈
```

write!(dst, fmt, args...)

지정된 출력 버퍼(예: 파일, 문자열 버퍼)에 포맷팅 된 문자열을 쓴다. std::io::Write 트레잇이 구현된 대상이 필요하다.

```
use std::io::Write;

let mut buf = Vec::new();

write!(&mut buf, "Hello, {}!", "world").unwrap();
println!("{:?}", buf);
// 출력: [72, 101, 108, 108, 111, 44, 32, 119, 111, 114, 108, 100, 33]
```

12. 고급 기능(2) – Macro(2)

Derived macro

```
// enable `Foo` to be Debug-printed and
// implicitly copied if needed
#[derive(Debug, Clone, Copy)]
struct Foo(usize);

fn hi(f: Foo) {}
let foo = Foo(1);

hi(foo); // moved
hi(foo); // implicit copy
hi(foo); // implicit copy
hi(foo); // implicit copy

// enable `Name` to be used as a key in a HashMap
#[derive(Eq, PartialEq, Hash)]
struct Name(String);

let name = Name("cheat sheet".into());
let mut names = std::collections::HashMap::new();

names.insert(name, ());

// enable `Letters` to be used with comparison operators
#[derive(PartialEq, PartialOrd)]

enum Letters {
    A,
    B,
    C,
}

if Letters::A < Letters::B { \* ... */ }
```

12. 고급 기능(2) – Macro(3)

```
macro_rules! my_macro {
    // 패턴 => 결과
    ($x:expr) => {
        println!("Value: {}", \$x);
    };
}

fn main() {
    my_macro!(5);
    my_macro!("Hello, world!");
}
```

```
macro_rules! multiple_print {
    ($($x:expr),*) => {
        $(println!("Value: {}", $x);)\*
    };
}

fn main() {
    multiple_print!(1, 2, 3);
    multiple_print!("Rust", "is", "awesome!");
}
```

사용자 정의 macro

```
[features]
default = []      # 기본적으로 활성화할 기능 (없으면 빈 배열)
feature_flag = [] # 새로운 기능 추가
```

$ cargo run –bin example1 –features feature_flag

선택적 코드 Compile 하기

```
macro_rules! conditional_compile {
    () => {
        #[cfg(feature = "feature_flag")]
        fn conditional_function_enabled() {
            println!("Feature flag is enabled!");
        }

        #[cfg(not(feature = "feature_flag"))]
        fn conditional_function_disabled() {
            println!("Feature flag is not enabled!");
        }
    };
}

fn main() {
    conditional_compile!();

    // 기능 플래그가 활성화되었을 때 호출되는 함수
    #[cfg(feature = "feature_flag")]
    conditional_function_enabled();

    // 기능 플래그가 비활성화되었을 때 호출되는 함수
    #[cfg(not(feature = "feature_flag"))]
    conditional_function_disabled();
}
```

12. 고급 기능(3) – Todo!

- FFI(Foreign Function Interface)
- Linux kernel programming

Thank You