RUST异步编程-透过表象看本质

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Async/await 异步编程模式

内存安全

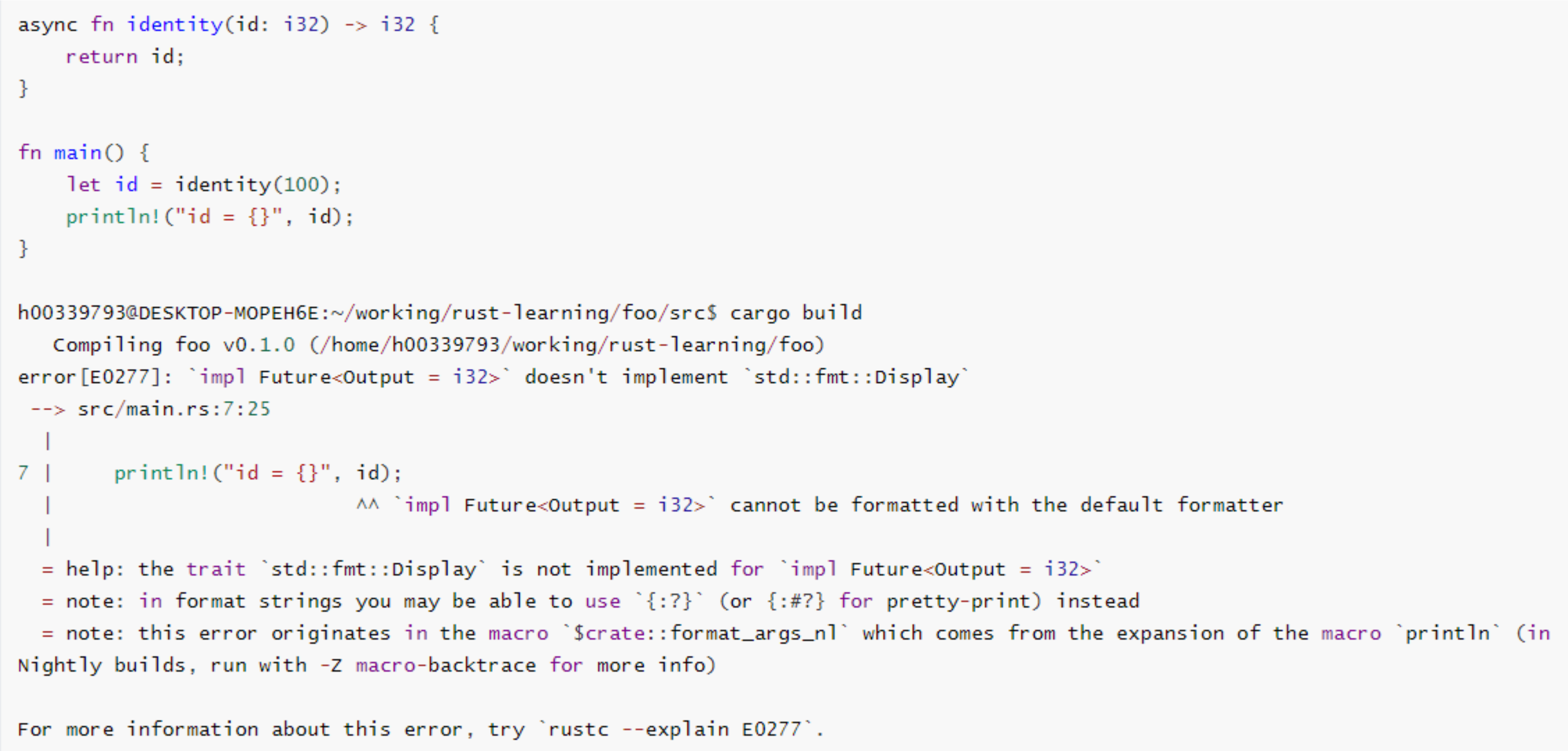
并发安全

无栈协程

无畏并发

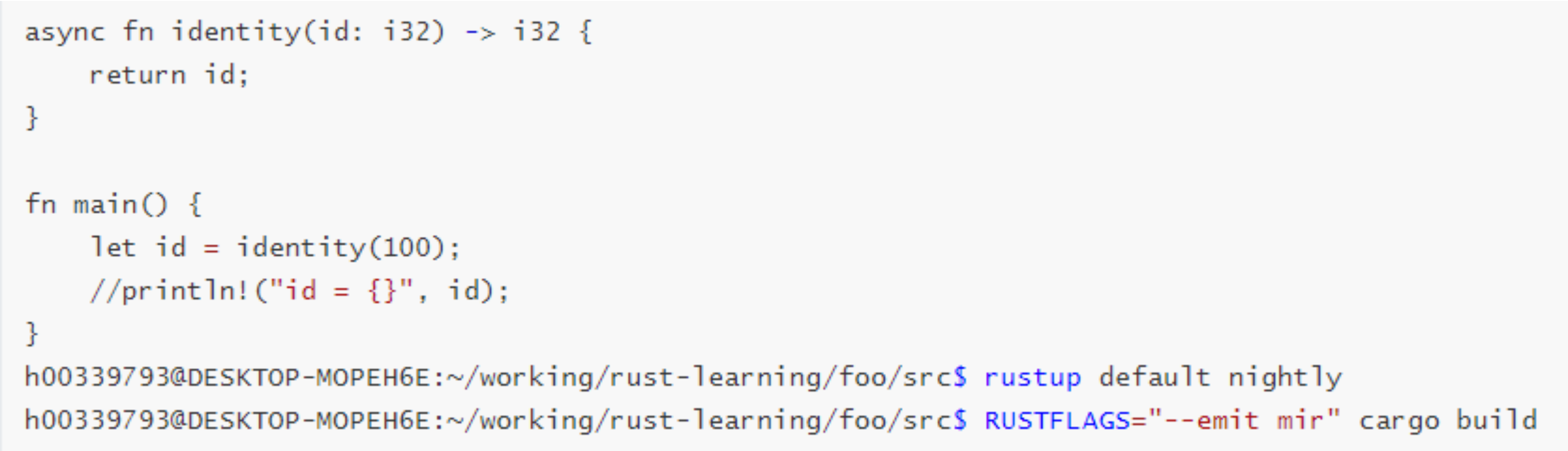
地表最强？

Async表象之下是什么？

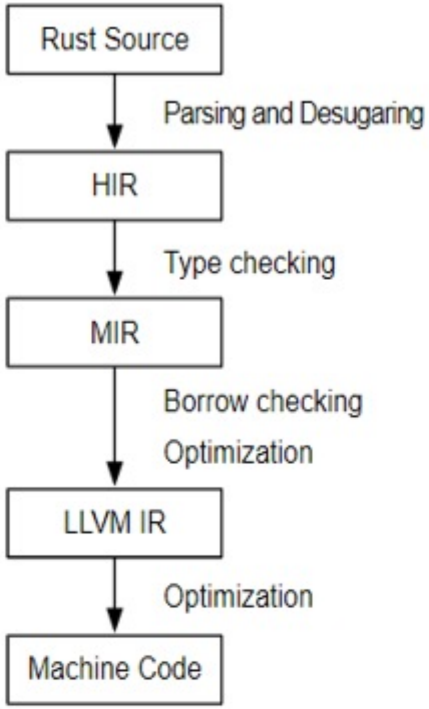


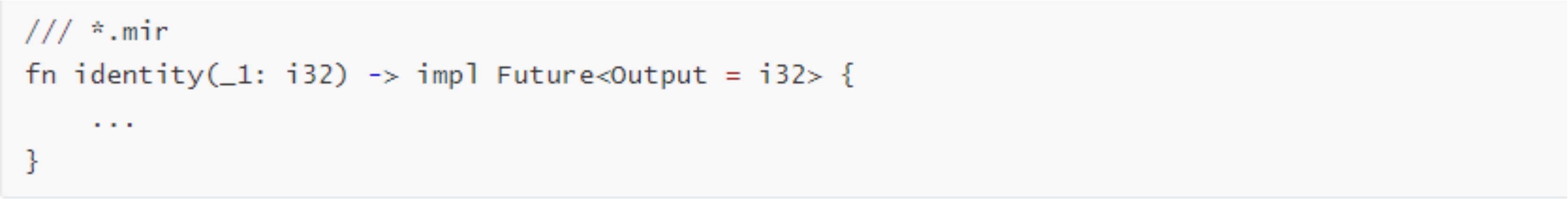
```
async fn identity(id: i32) -> i32 {
    return id;
}

fn main() {
    let id = identity(100);
    println!("id = {}", id);
}

h00339793@DESKTOP-MOPEH6E:~/working/rust-learning/foo/src$ cargo build
   Compiling foo v0.1.0 (/home/h00339793/working/rust-learning/foo)
error[E0277]: `impl Future<Output = i32>` doesn't implement `std::fmt::Display`
 --> src/main.rs:7:25
  |
7 |     println!("id = {}", id);
  |                         ^^ `impl Future<Output = i32>` cannot be formatted with the default formatter
  |
  = help: the trait `std::fmt::Display` is not implemented for `impl Future<Output = i32>`
  = note: in format strings you may be able to use `{:?}` (or {:#?} for pretty-print) instead
  = note: this error originates in the macro `$crate::format_args_nl` which comes from the expansion of the macro `println` (in
Nightly builds, run with -Z macro-backtrace for more info)

For more information about this error, try `rustc --explain E0277`.
```

Async == Future构造

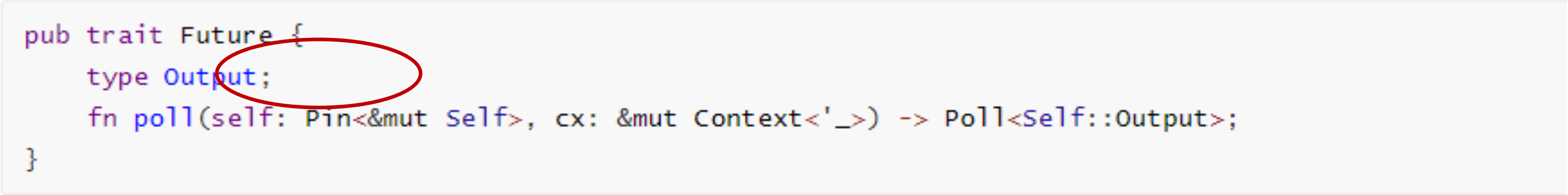


```
async fn identity(id: i32) -> i32 {
    return id;
}

fn main() {
    let id = identity(100);
    //println!("id = {}", id);
}
h00339793@DESKTOP-MOPEH6E:~/working/rust-learning/foo/src$ rustup default nightly
h00339793@DESKTOP-MOPEH6E:~/working/rust-learning/foo/src$ RUSTFLAGS="--emit mir" cargo build
```



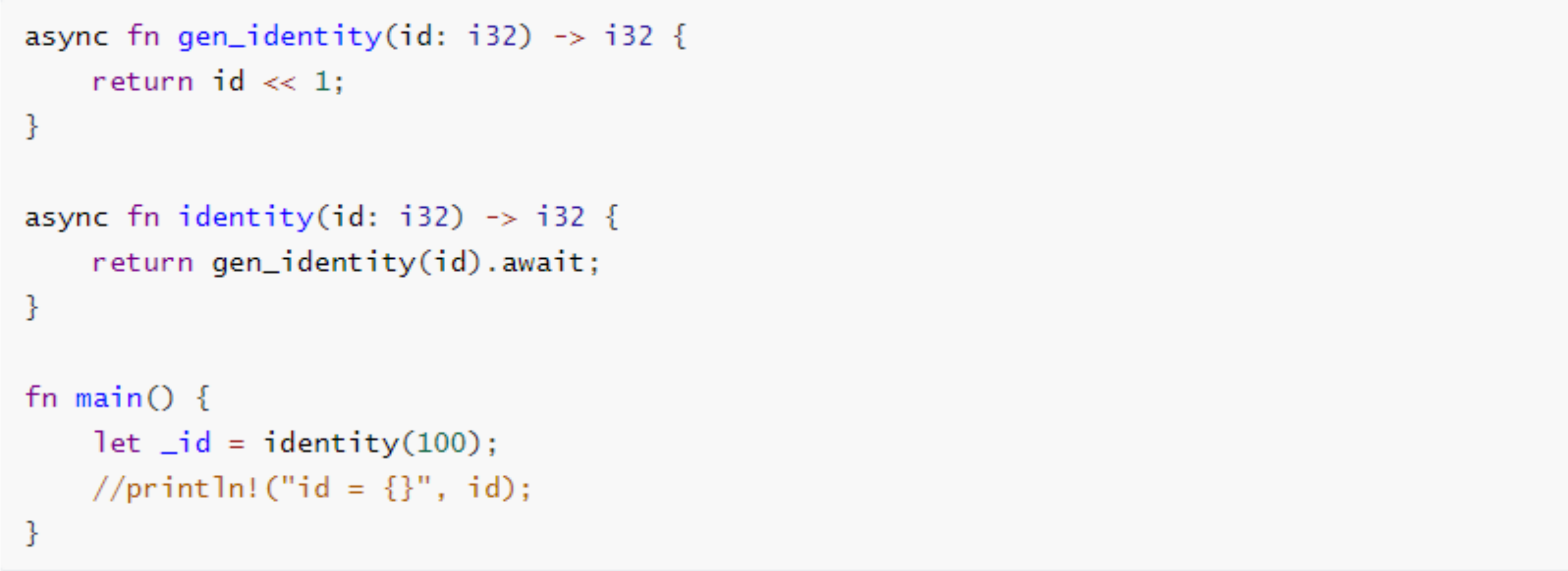


```
/// *.mir
fn identity(_1: i32) -> impl Future<Output = i32> {
    ...
}
```



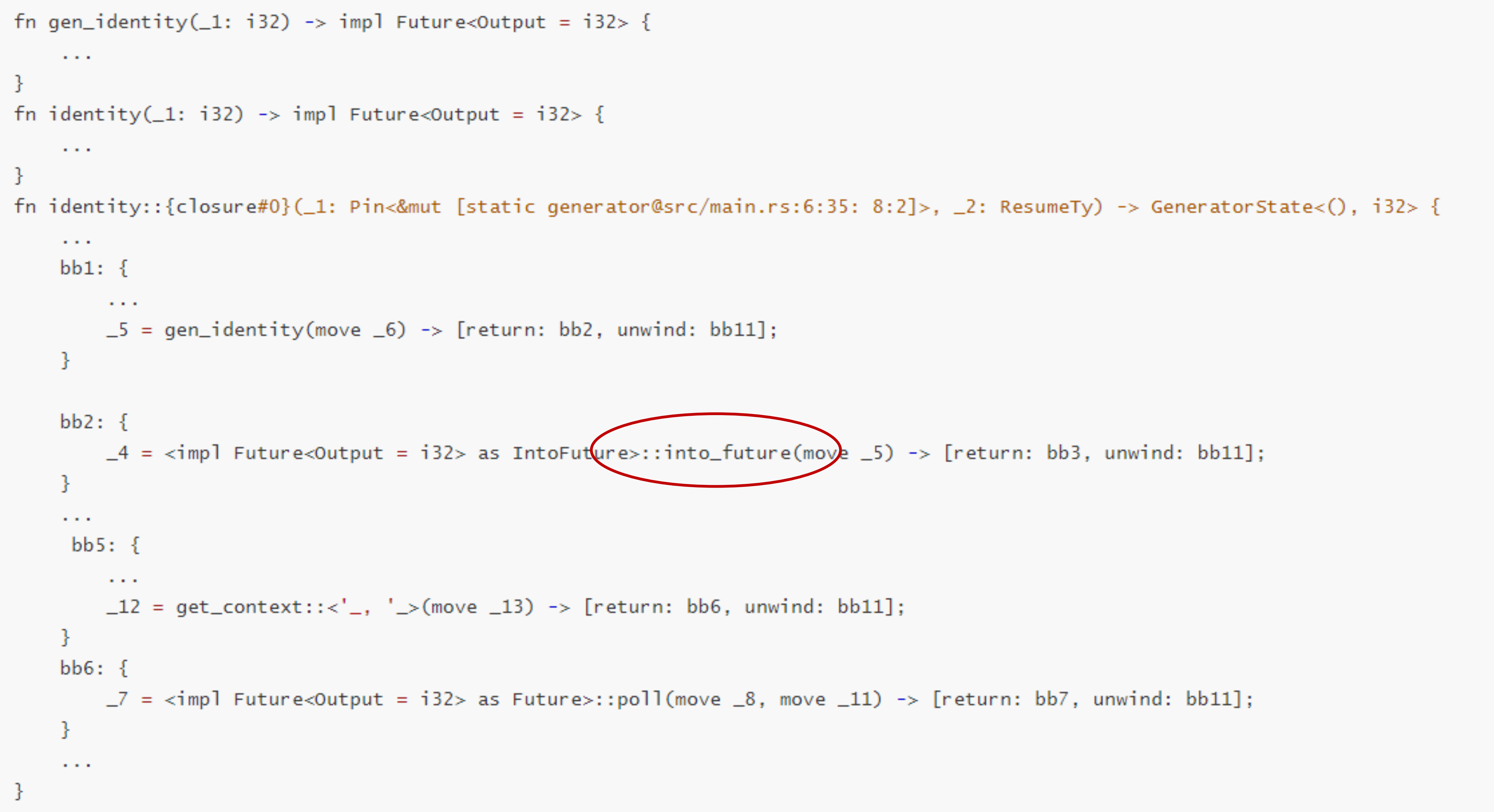
```
pub trait Future {
    type Output;
    fn poll(self: Pin<&mut Self>, cx: &mut Context<'_>) -> Poll<Self::Output>;
}
```

Await表象之下是什么？



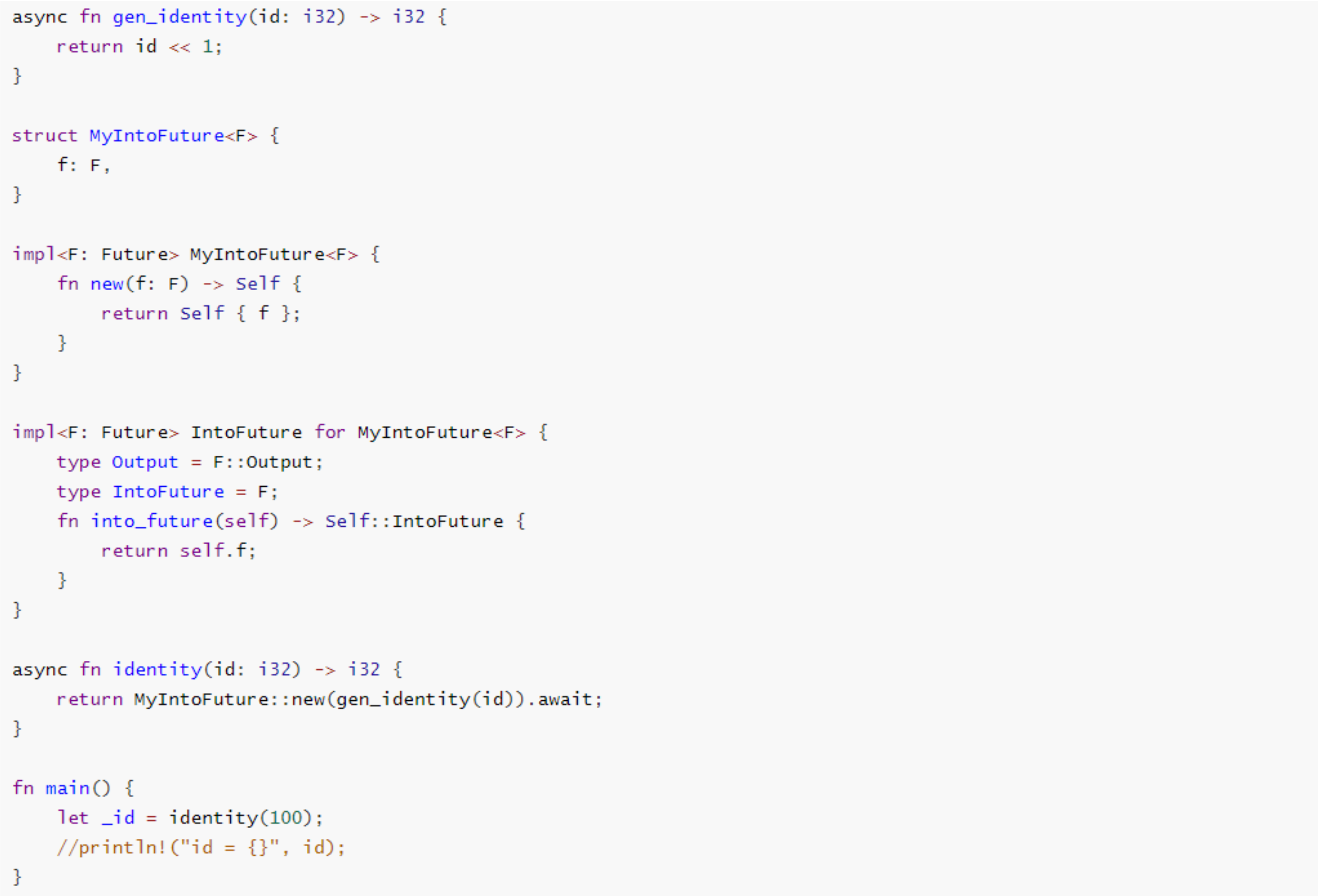
```
async fn gen_identity(id: i32) -> i32 {
    return id << 1;
}

async fn identity(id: i32) -> i32 {
    return gen_identity(id).await;
}

fn main() {
    let _id = identity(100);
    //println!("id = {}", id);
}
```

Await表象之下是什么？



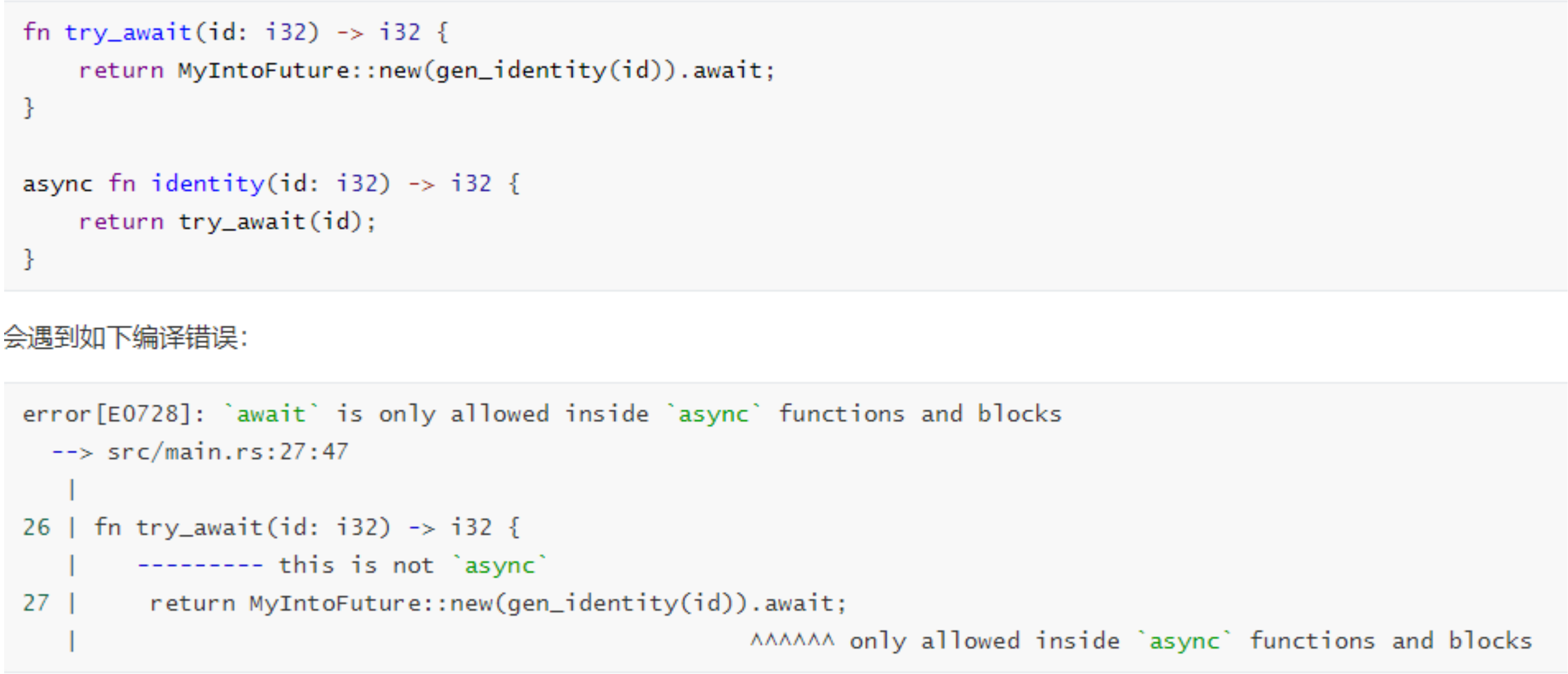
```
fn gen_identity(_1: i32) -> impl Future<Output = i32> {
    ...
}
fn identity(_1: i32) -> impl Future<Output = i32> {
    ...
}
fn identity::{closure#0}(_1: Pin<&mut [static generator@src/main.rs:6:35: 8:2]>, _2: ResumeTy) -> GeneratorState<(), i32> {
    ...
    bb1: {
        ...
        _5 = gen_identity(move _6) -> [return: bb2, unwind: bb11];
    }

    bb2: {
        _4 = <impl Future<Output = i32> as IntoFuture>::into_future(move _5) -> [return: bb3, unwind: bb11];
    }
    ...
     bb5: {
        ...
        _12 = get_context::<'_, '_>(move _13) -> [return: bb6, unwind: bb11];
    }
    bb6: {
        _7 = <impl Future<Output = i32> as Future>::poll(move _8, move _11) -> [return: bb7, unwind: bb11];
    }
    ...
}
```

Await表象之下是什么？



```rust
async fn gen_identity(id: i32) -> i32 {
    return id << 1;
}

struct MyIntoFuture<F> {
    f: F,
}

impl<F: Future> MyIntoFuture<F> {
    fn new(f: F) -> Self {
        return Self { f };
    }
}

impl<F: Future> IntoFuture for MyIntoFuture<F> {
    type Output = F::Output;
    type IntoFuture = F;
    fn into_future(self) -> Self::IntoFuture {
        return self.f;
    }
}

async fn identity(id: i32) -> i32 {
    return MyIntoFuture::new(gen_identity(id)).await;
}

fn main() {
    let _id = identity(100);
    //println!("id = {}", id);
}
```

Await表象之下是什么？

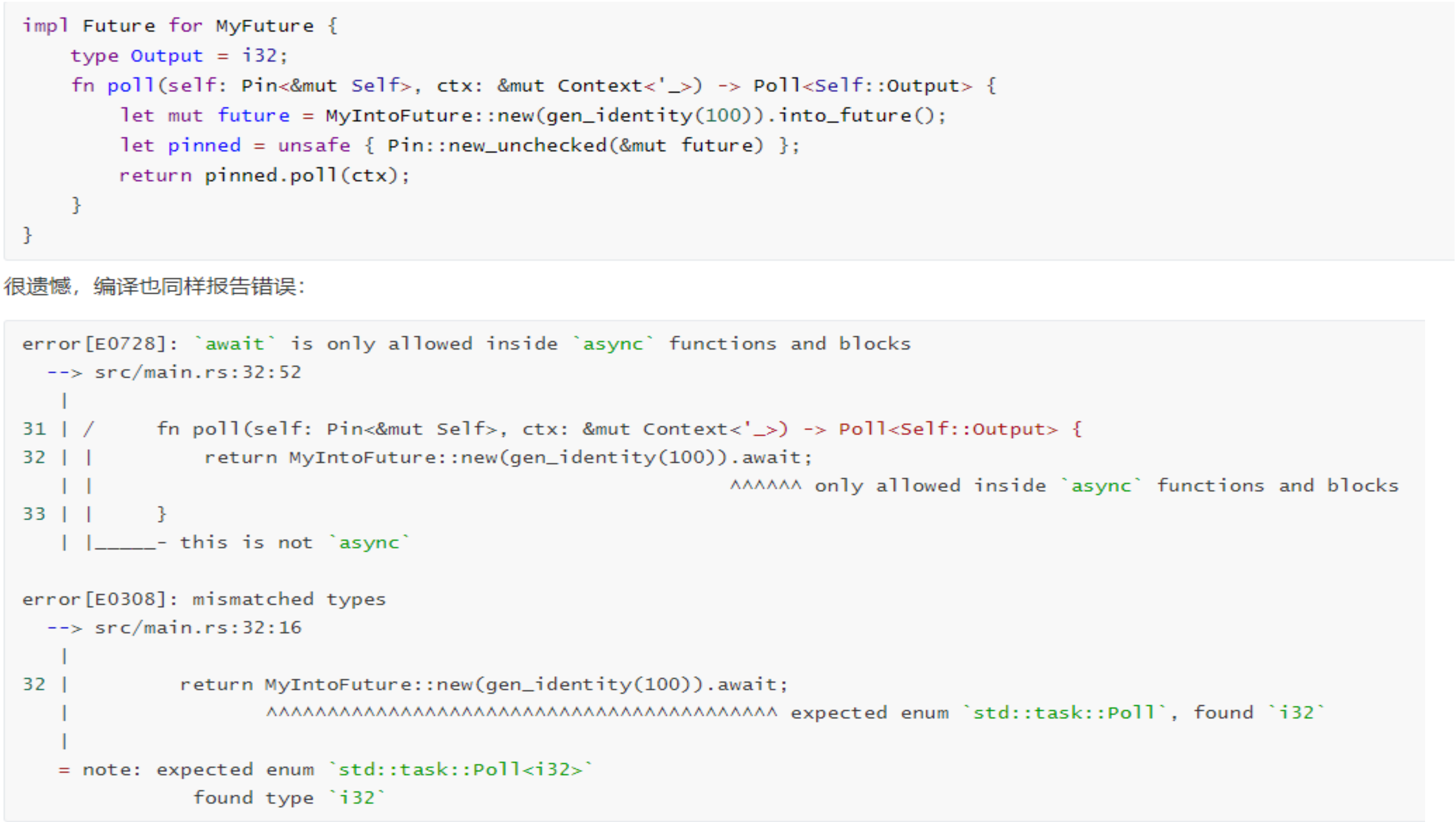


```
fn try_await(id: i32) -> i32 {
    return MyIntoFuture::new(gen_identity(id)).await;
}

async fn identity(id: i32) -> i32 {
    return try_await(id);
}
```

会遇到如下编译错误:

```
error[E0728]: `await` is only allowed inside `async` functions and blocks
  --> src/main.rs:27:47
   |
26 | fn try_await(id: i32) -> i32 {
   |    --------- this is not `async`
27 |     return MyIntoFuture::new(gen_identity(id)).await;
   |                                               ^^^^^^ only allowed inside `async` functions and blocks
```

Await表象之下是什么？

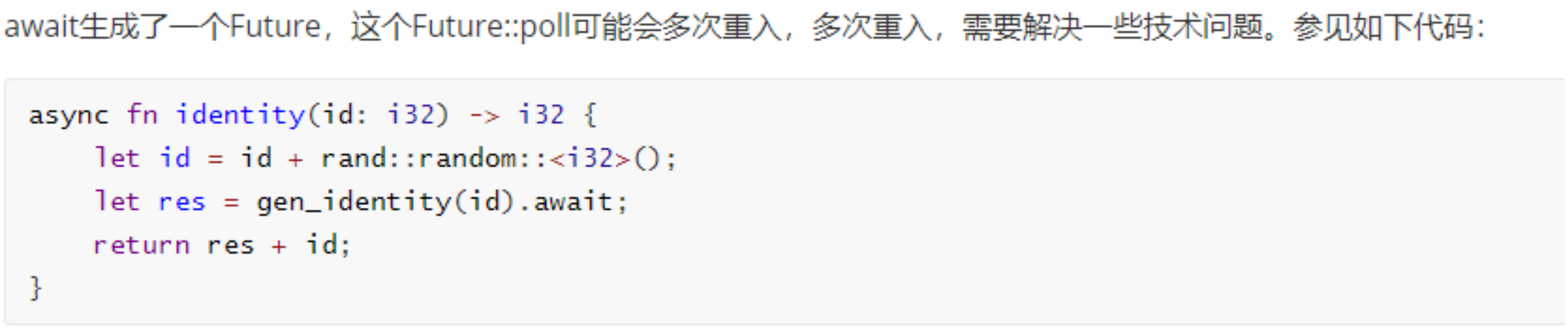


```rust
impl Future for MyFuture {
    type Output = i32;
    fn poll(self: Pin<&mut Self>, ctx: &mut Context<'_>) -> Poll<Self::Output> {
        let mut future = MyIntoFuture::new(gen_identity(100)).into_future();
        let pinned = unsafe { Pin::new_unchecked(&mut future) };
        return pinned.poll(ctx);
    }
}
```

很遗憾，编译也同样报告错误：

```
error[E0728]: `await` is only allowed inside `async` functions and blocks
  --> src/main.rs:32:52
   |
31 | /     fn poll(self: Pin<&mut Self>, ctx: &mut Context<'_>) -> Poll<Self::Output> {
32 | |         return MyIntoFuture::new(gen_identity(100)).await;
   | |                                                    ^^^^^^ only allowed inside `async` functions and blocks
33 | |     }
   | |_____- this is not `async`

error[E0308]: mismatched types
  --> src/main.rs:32:16
   |
32 |         return MyIntoFuture::new(gen_identity(100)).await;
   |                ^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^ expected enum `std::task::Poll`, found `i32`
   |
   = note: expected enum `std::task::Poll<i32>`
              found type `i32`
```

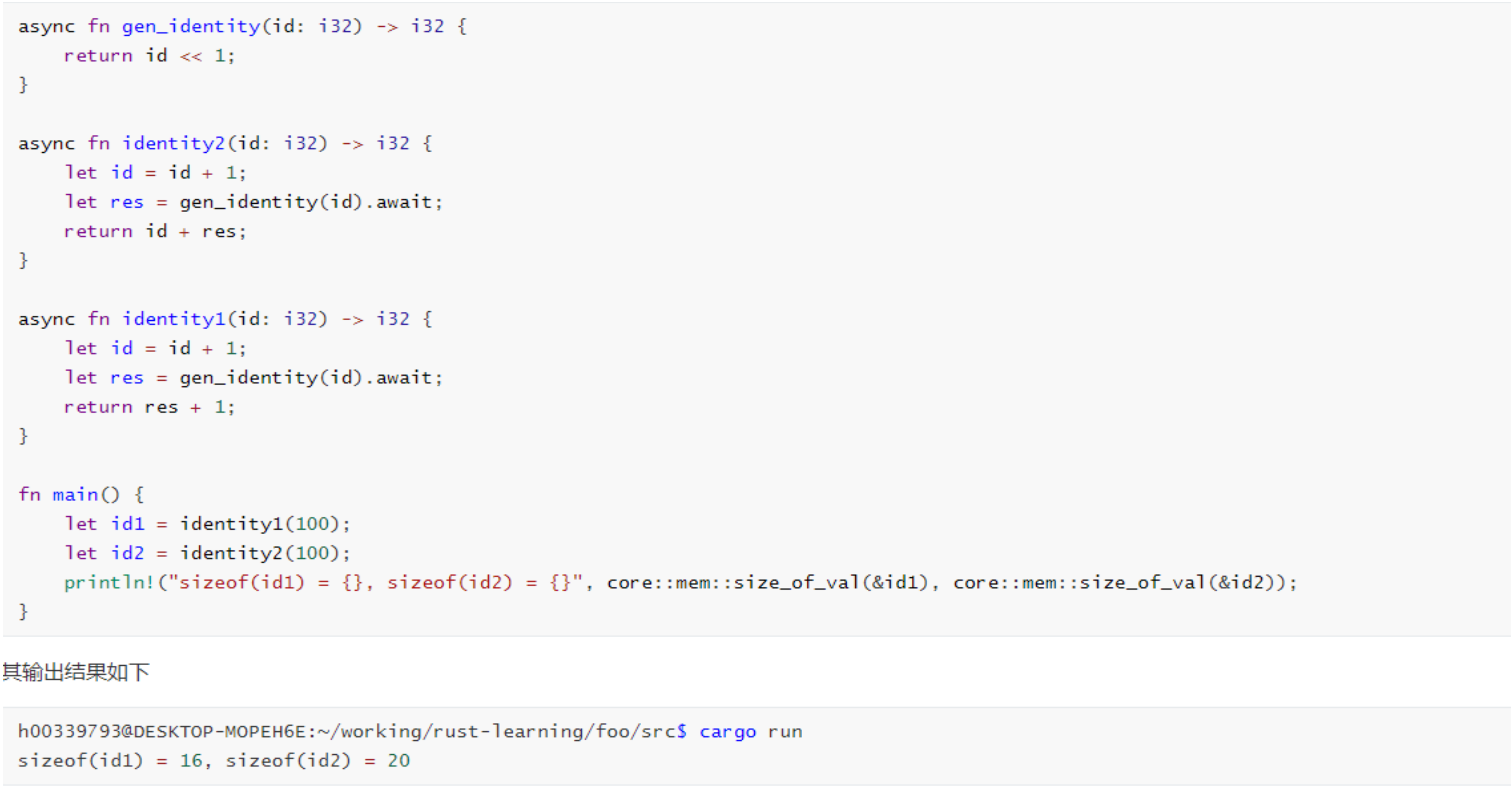
Await和无栈协程



await生成了一个Future，这个Future::poll可能会多次重入，多次重入，需要解决一些技术问题。参见如下代码：

```
async fn identity(id: i32) -> i32 {
    let id = id + rand::random::<i32>();
    let res = gen_identity(id).await;
    return res + id;
}
```

Await和无栈协程

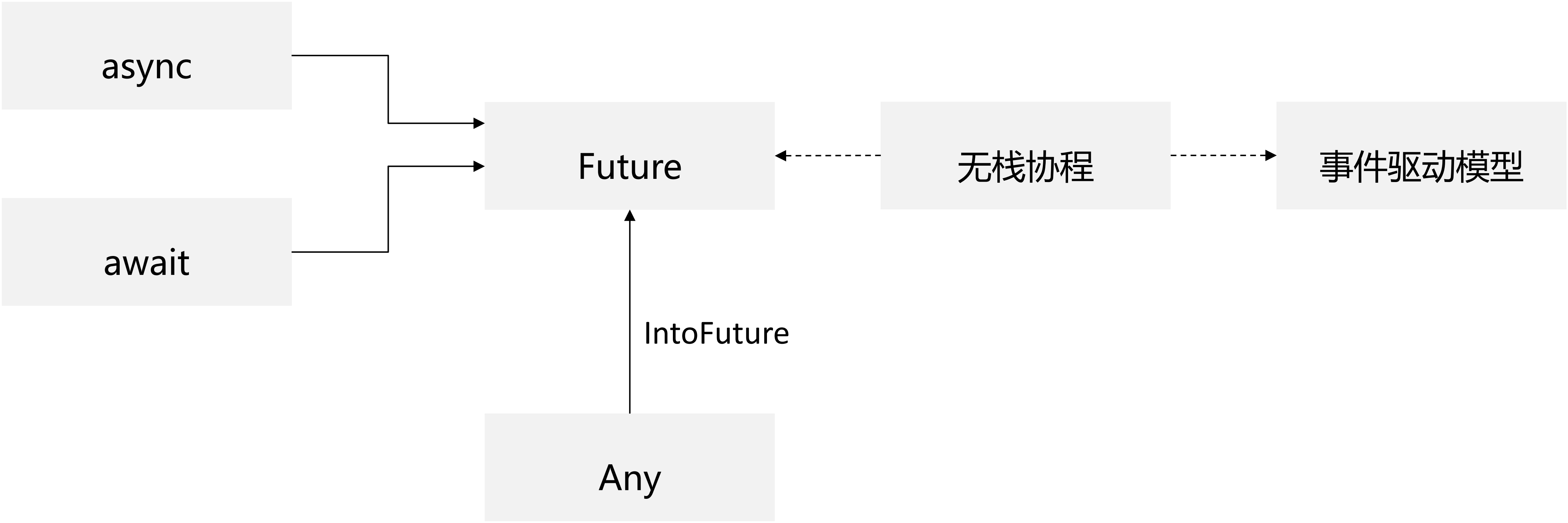


```rust
async fn gen_identity(id: i32) -> i32 {
    return id << 1;
}

async fn identity2(id: i32) -> i32 {
    let id = id + 1;
    let res = gen_identity(id).await;
    return id + res;
}

async fn identity1(id: i32) -> i32 {
    let id = id + 1;
    let res = gen_identity(id).await;
    return res + 1;
}

fn main() {
    let id1 = identity1(100);
    let id2 = identity2(100);
    println!("sizeof(id1) = {}, sizeof(id2) = {}", core::mem::size_of_val(&id1), core::mem::size_of_val(&id2));
}
```

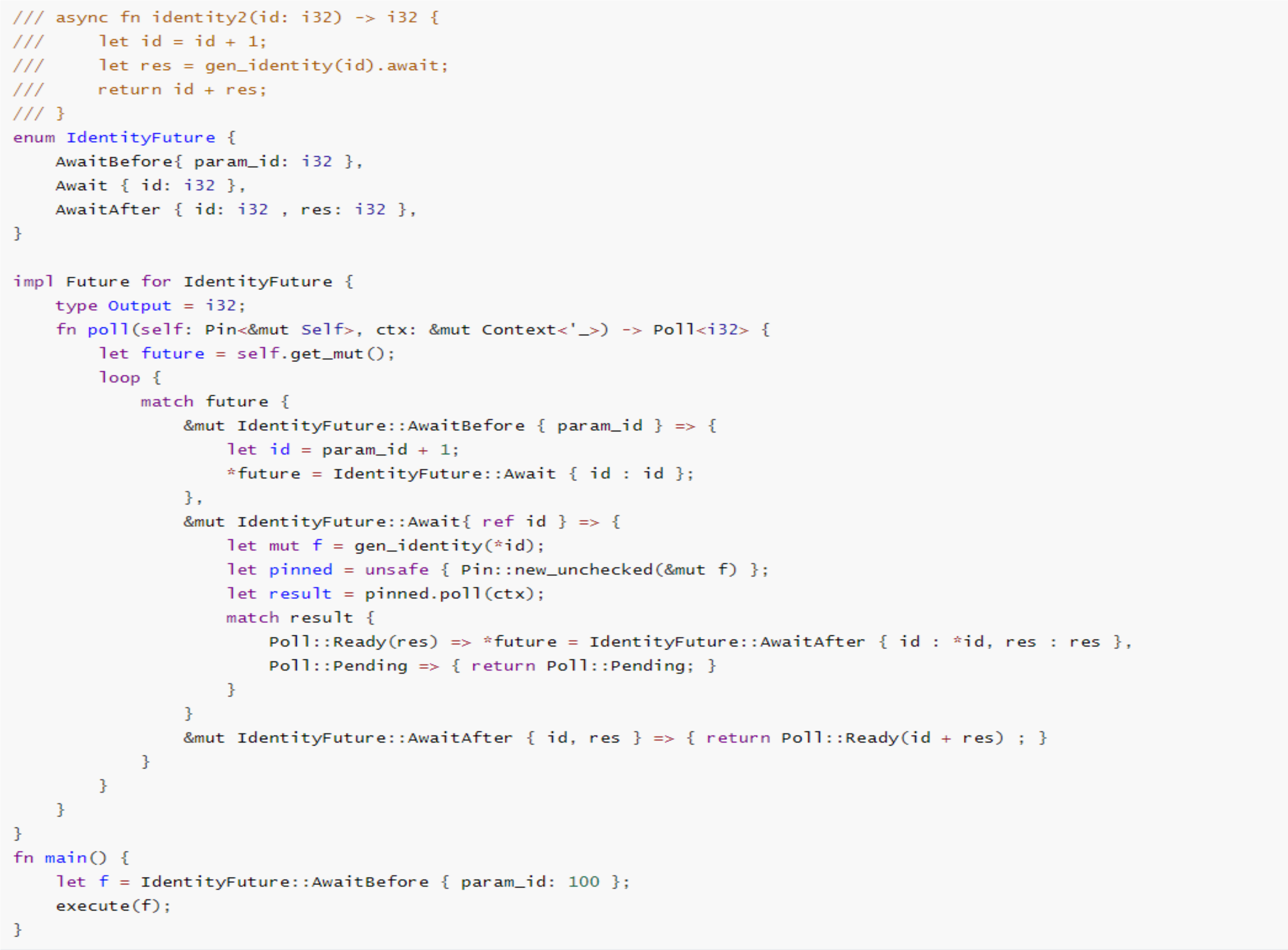
其输出结果如下

```
h00339793@DESKTOP-MOPEH6E:~/working/rust-learning/foo/src$ cargo run
sizeof(id1) = 16, sizeof(id2) = 20
```

初步印象：无栈协程 == 事件驱动模型

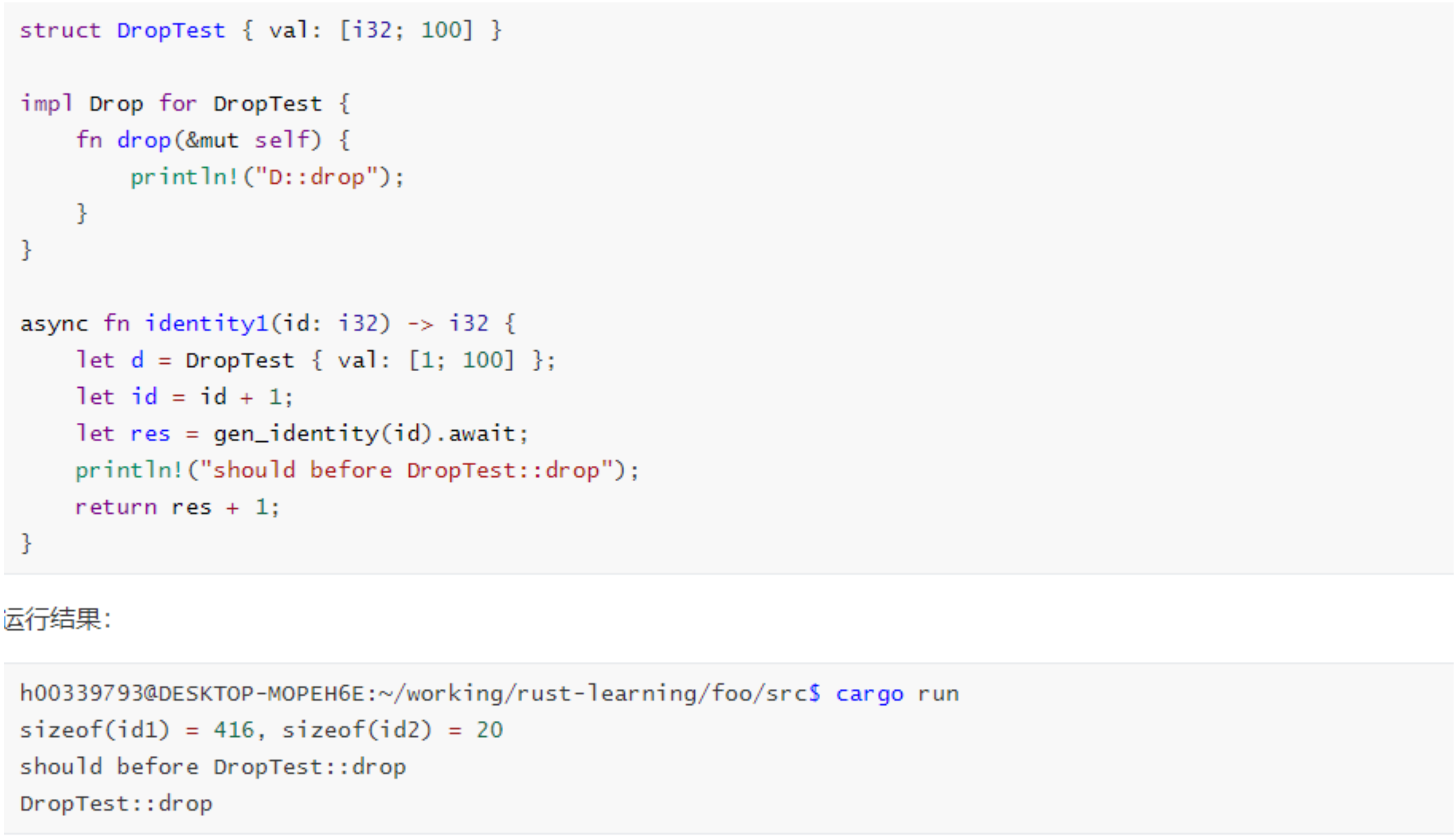


Future状态机版本



```
/// async fn identity2(id: i32) -> i32 {
///     let id = id + 1;
///     let res = gen_identity(id).await;
///     return id + res;
/// }
enum IdentityFuture {
    AwaitBefore{ param_id: i32 },
    Await { id: i32 },
    AwaitAfter { id: i32 , res: i32 },
}

impl Future for IdentityFuture {
    type Output = i32;
    fn poll(self: Pin<&mut Self>, ctx: &mut Context<'_>) -> Poll<i32> {
        let future = self.get_mut();
        loop {
            match future {
                &mut IdentityFuture::AwaitBefore { param_id } => {
                    let id = param_id + 1;
                    *future = IdentityFuture::Await { id : id };
                },
                &mut IdentityFuture::Await{ ref id } => {
                    let mut f = gen_identity(*id);
                    let pinned = unsafe { Pin::new_unchecked(&mut f) };
                    let result = pinned.poll(ctx);
                    match result {
                        Poll::Ready(res) => *future = IdentityFuture::AwaitAfter { id : *id, res : res },
                        Poll::Pending => { return Poll::Pending; }
                    }
                }
                &mut IdentityFuture::AwaitAfter { id, res } => { return Poll::Ready(id + res) ; }
            }
        }
    }
}
fn main() {
    let f = IdentityFuture::AwaitBefore { param_id: 100 };
    execute(f);
}
```

Drop对Future的影响

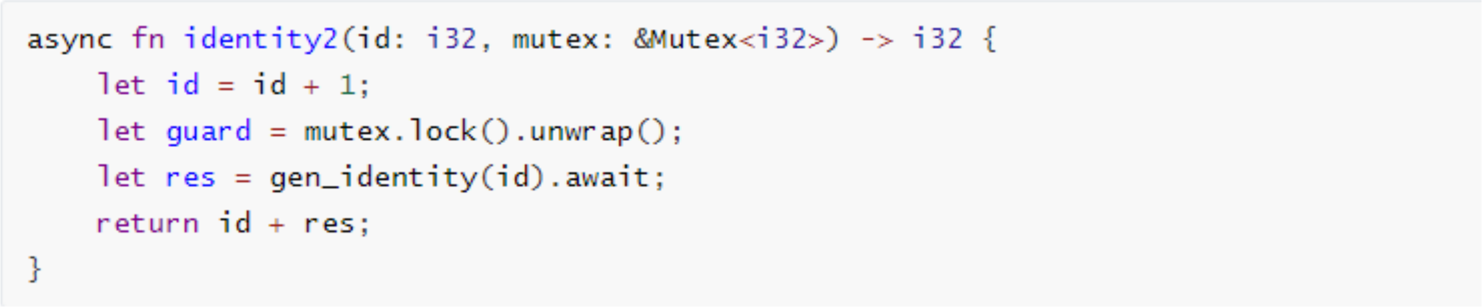


```
struct DropTest { val: [i32; 100] }

impl Drop for DropTest {
    fn drop(&mut self) {
        println!("D::drop");
    }
}

async fn identity1(id: i32) -> i32 {
    let d = DropTest { val: [1; 100] };
    let id = id + 1;
    let res = gen_identity(id).await;
    println!("should before DropTest::drop");
    return res + 1;
}
```

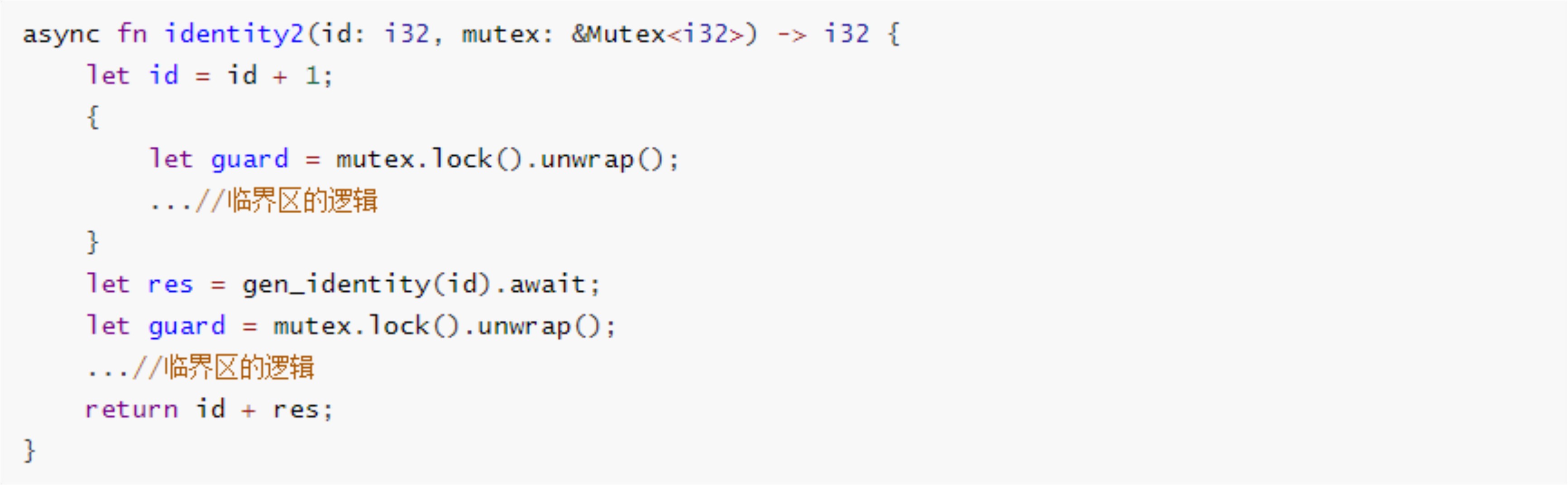
运行结果：

```
h00339793@DESKTOP-MOPEH6E:~/working/rust-learning/foo/src$ cargo run
sizeof(id1) = 416, sizeof(id2) = 20
should before DropTest::drop
DropTest::drop
```

Mutex作用范围

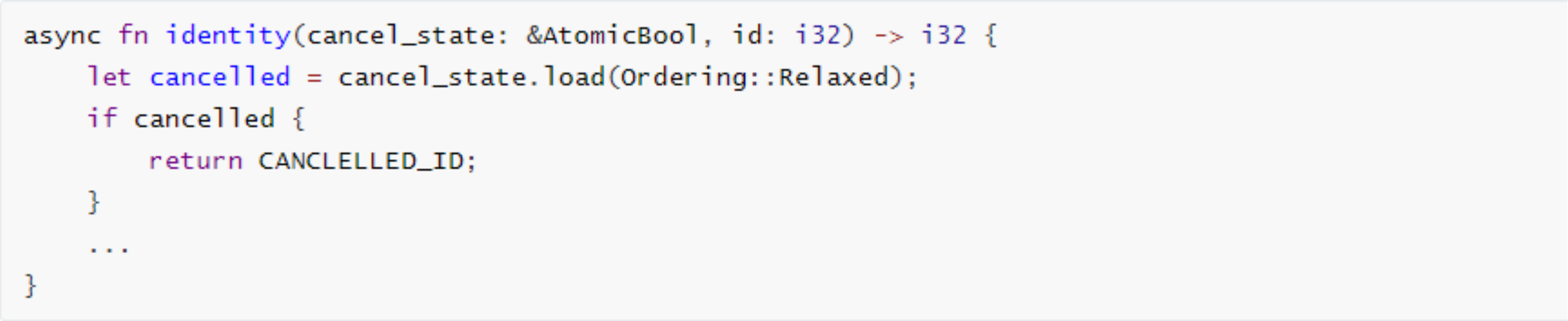


```
async fn identity2(id: i32, mutex: &Mutex<i32>) -> i32 {
    let id = id + 1;
    let guard = mutex.lock().unwrap();
    let res = gen_identity(id).await;
    return id + res;
}
```



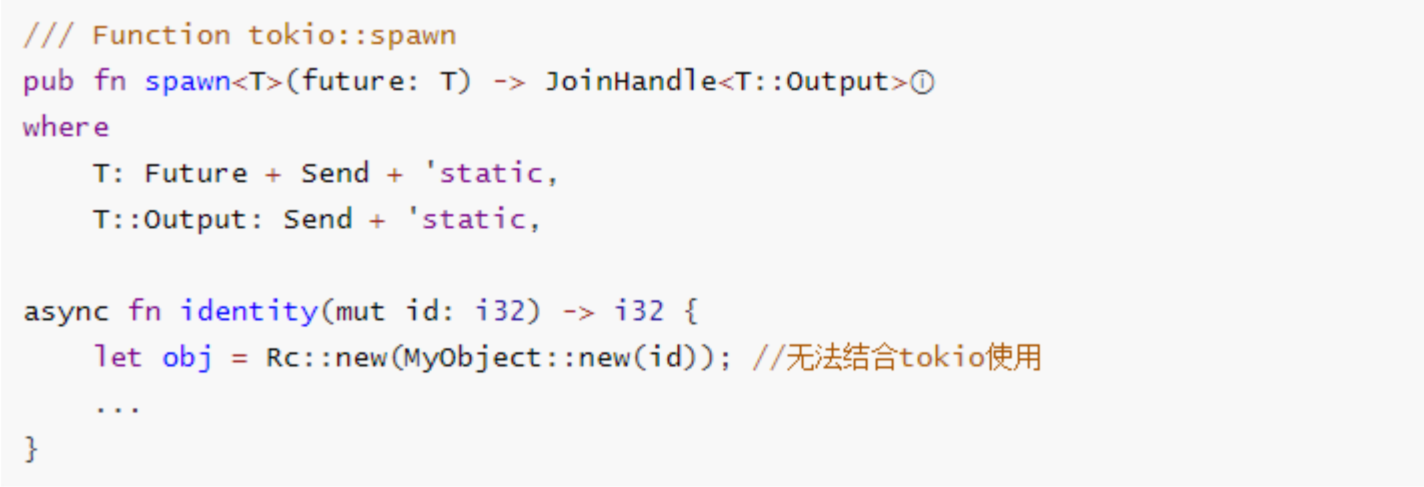
```
async fn identity2(id: i32, mutex: &Mutex<i32>) -> i32 {
    let id = id + 1;
    {
        let guard = mutex.lock().unwrap();
        ...//临界区的逻辑
    }
    let res = gen_identity(id).await;
    let guard = mutex.lock().unwrap();
    ...//临界区的逻辑
    return id + res;
}
```

Future取消



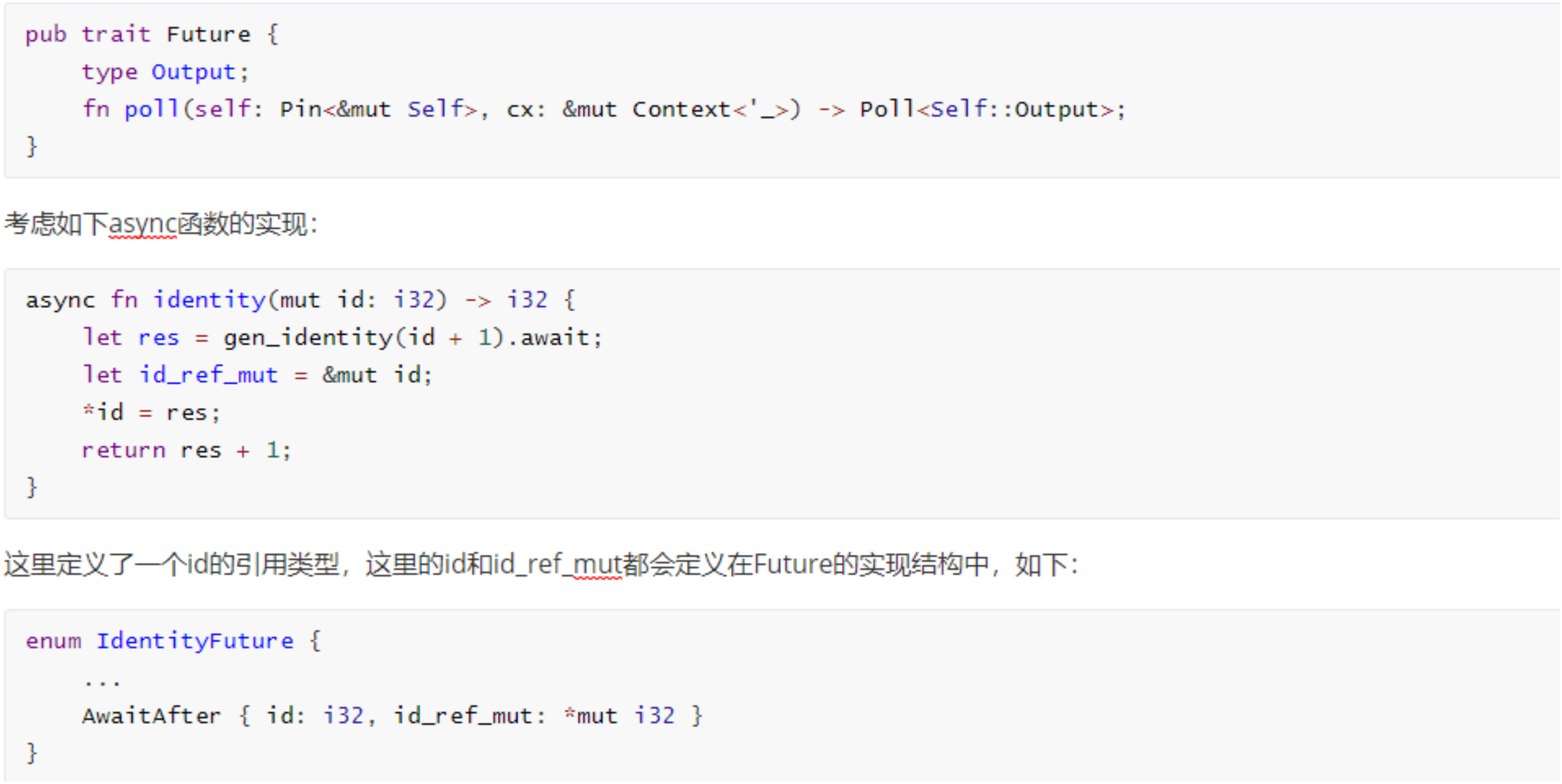
```
async fn identity(cancel_state: &AtomicBool, id: i32) -> i32 {
    let cancelled = cancel_state.load(Ordering::Relaxed);
    if cancelled {
        return CANCLELLED_ID;
    }
    ...
}
```

运行时库的附加约束



```
/// Function tokio::spawn
pub fn spawn<T>(future: T) -> JoinHandle<T::Output>ⓘ
where
    T: Future + Send + 'static,
    T::Output: Send + 'static,

async fn identity(mut id: i32) -> i32 {
    let obj = Rc::new(MyObject::new(id)); //无法结合tokio使用
    ...
}
```

Future和Pin



```
pub trait Future {
    type Output;
    fn poll(self: Pin<&mut Self>, cx: &mut Context<'_>) -> Poll<Self::Output>;
}
```

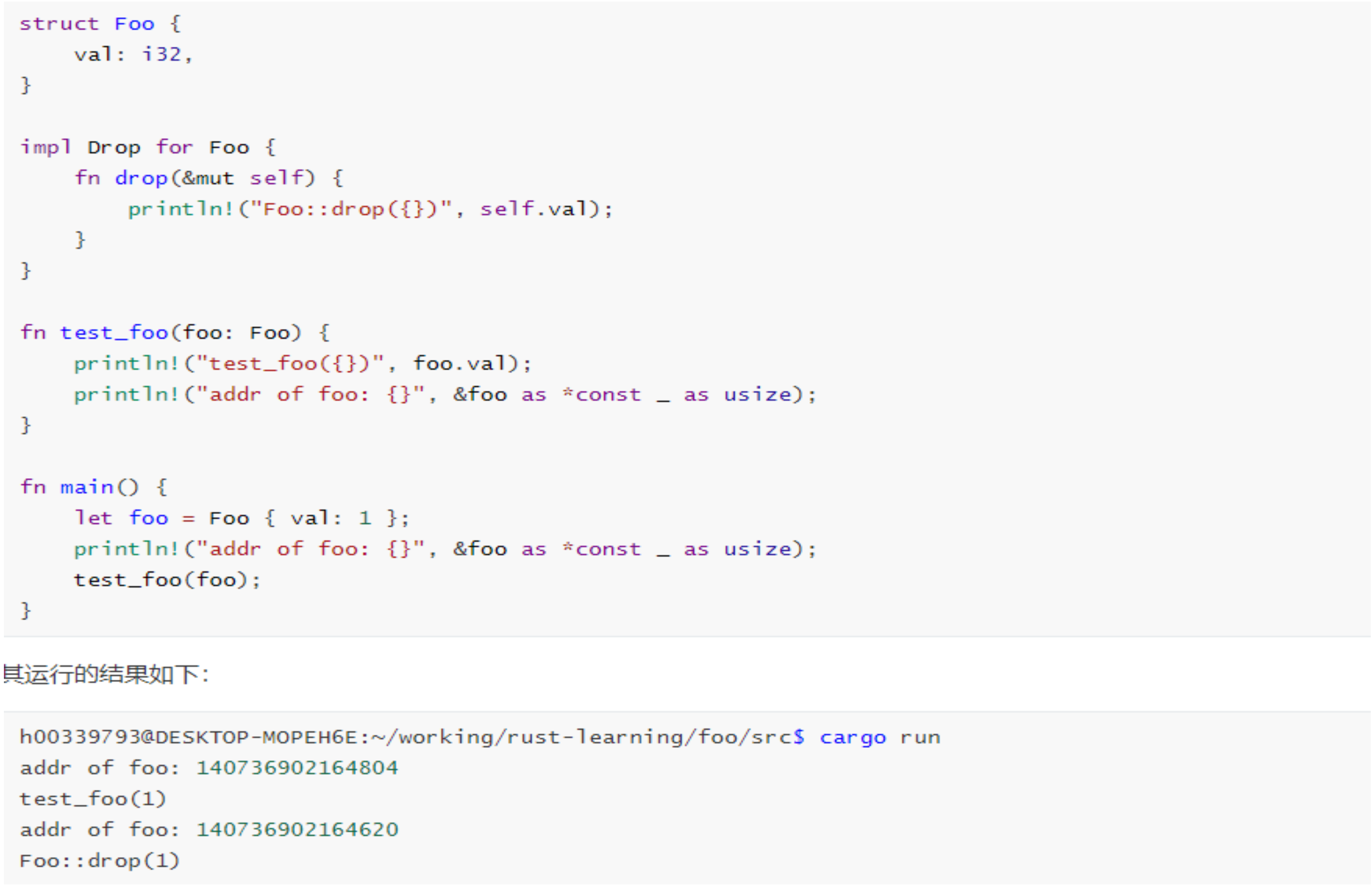
考虑如下async函数的实现：

```
async fn identity(mut id: i32) -> i32 {
    let res = gen_identity(id + 1).await;
    let id_ref_mut = &mut id;
    *id = res;
    return res + 1;
}
```

这里定义了一个id的引用类型，这里的id和id_ref_mut都会定义在Future的实现结构中，如下：

```
enum IdentityFuture {
    ...
    AwaitAfter { id: i32, id_ref_mut: *mut i32 }
}
```

所有权转移：隐式的内存拷贝

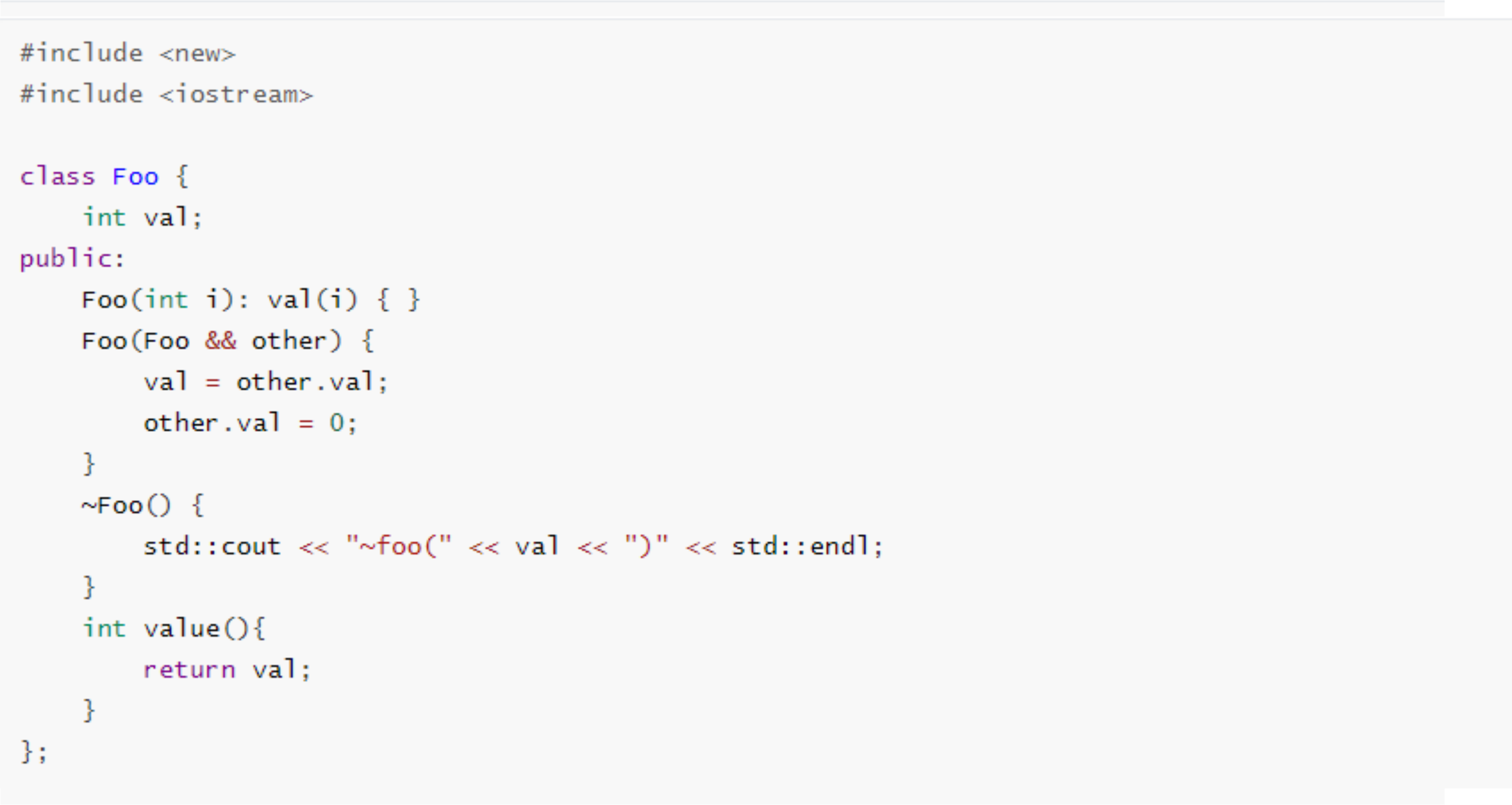


```rust
struct Foo {
    val: i32,
}

impl Drop for Foo {
    fn drop(&mut self) {
        println!("Foo::drop({})", self.val);
    }
}

fn test_foo(foo: Foo) {
    println!("test_foo({})", foo.val);
    println!("addr of foo: {}", &foo as *const _ as usize);
}

fn main() {
    let foo = Foo { val: 1 };
    println!("addr of foo: {}", &foo as *const _ as usize);
    test_foo(foo);
}
```

其运行的结果如下：

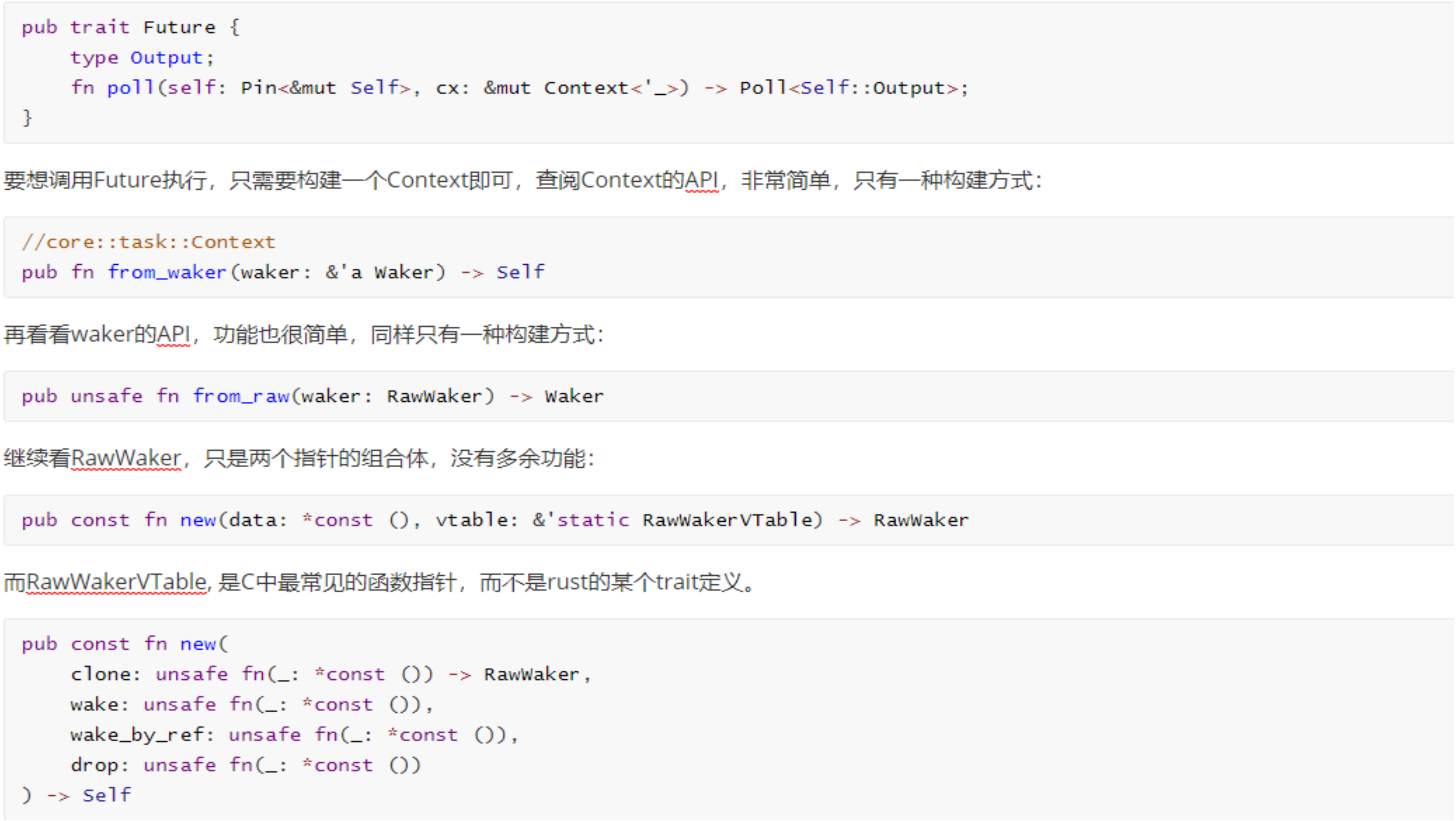
```
h00339793@DESKTOP-MOPEH6E:~/working/rust-learning/foo/src$ cargo run
addr of foo: 140736902164804
test_foo(1)
addr of foo: 140736902164620
Foo::drop(1)
```

Pin：缓解所有权转移的功能缺陷



```cpp
#include <new>
#include <iostream>

class Foo {
    int val;
public:
    Foo(int i): val(i) { }
    Foo(Foo && other) {
        val = other.val;
        other.val = 0;
    }
    ~Foo() {
        std::cout << "~foo(" << val << ")" << std::endl;
    }
    int value(){
        return val;
    }
};
```

Waker和调度框架



```
pub trait Future {
    type Output;
    fn poll(self: Pin<&mut Self>, cx: &mut Context<'_>) -> Poll<Self::Output>;
}
```

要想调用Future执行，只需要构建一个Context即可，查阅Context的API，非常简单，只有一种构建方式：

```
//core::task::Context
pub fn from_waker(waker: &'a Waker) -> Self
```

再看看waker的API，功能也很简单，同样只有一种构建方式：

```
pub unsafe fn from_raw(waker: RawWaker) -> Waker
```

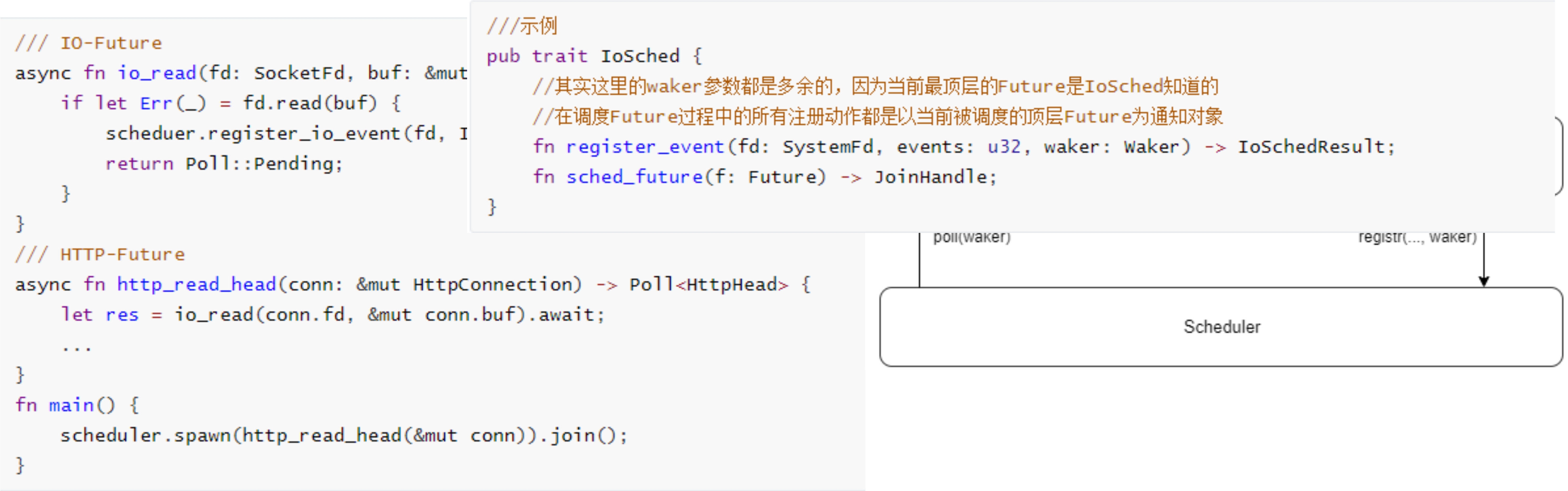
继续看RawWaker，只是两个指针的组合体，没有多余功能：

```
pub const fn new(data: *const (), vtable: &'static RawWakerVTable) -> RawWaker
```

而RawWakerVTable, 是C中最常见的函数指针，而不是rust的某个trait定义。

```
pub const fn new(
    clone: unsafe fn(_: *const ()) -> RawWaker,
    wake: unsafe fn(_: *const ()),
    wake_by_ref: unsafe fn(_: *const ()),
    drop: unsafe fn(_: *const ())
) -> Self
```

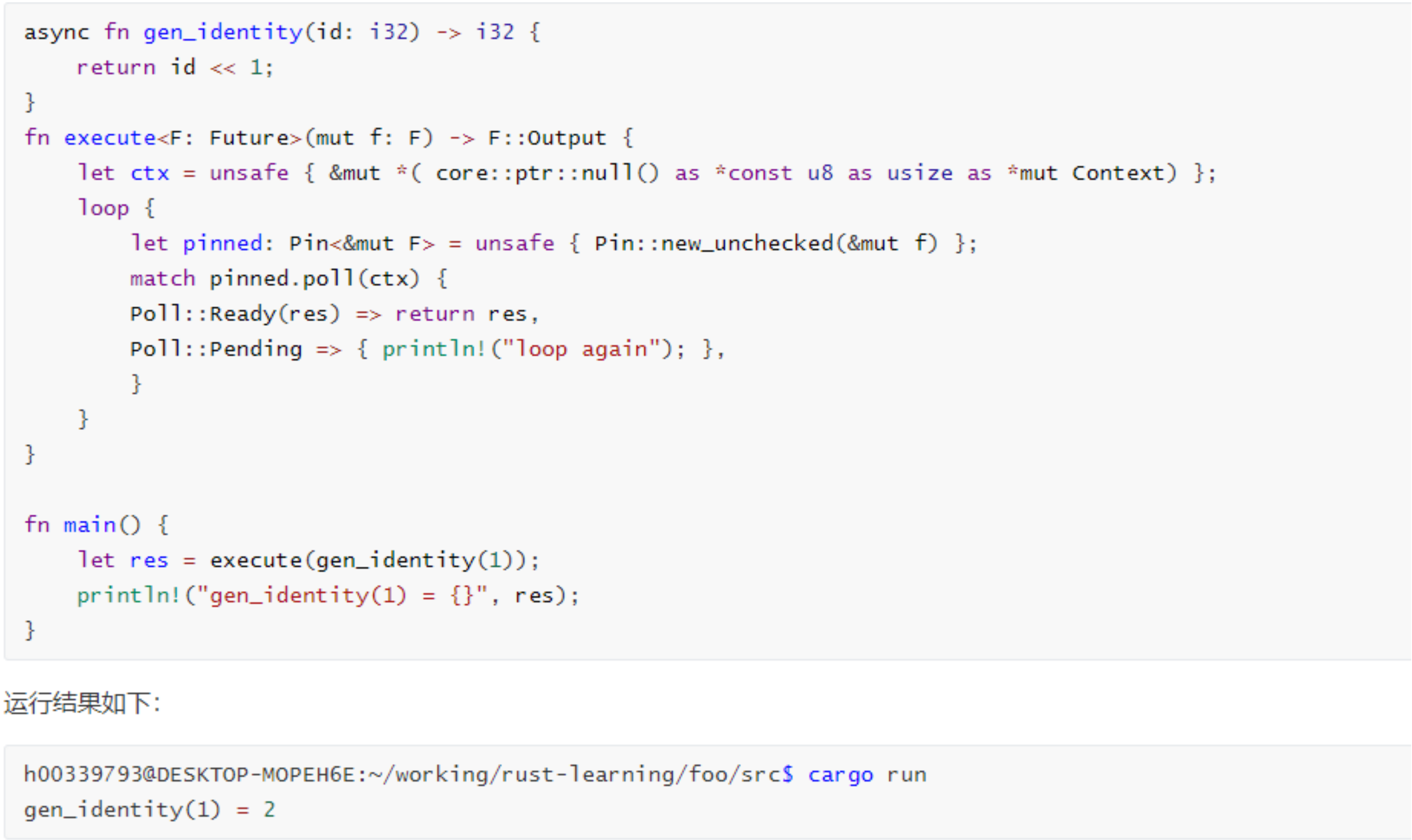
Waker的设计意图



```
/// IO-Future
async fn io_read(fd: SocketFd, buf: &mut
    if let Err(_) = fd.read(buf) {
        scheduer.register_io_event(fd, I
        return Poll::Pending;
    }
}
/// HTTP-Future
async fn http_read_head(conn: &mut HttpConnection) -> Poll<HttpHead> {
    let res = io_read(conn.fd, &mut conn.buf).await;
    ...
}
fn main() {
    scheduler.spawn(http_read_head(&mut conn)).join();
}
```

```
///示例
pub trait IoSched {
    //其实这里的waker参数都是多余的，因为当前最顶层的Future是IoSched知道的
    //在调度Future过程中的所有注册动作都是以当前被调度的顶层Future为通知对象
    fn register_event(fd: SystemFd, events: u32, waker: Waker) -> IoSchedResult;
    fn sched_future(f: Future) -> JoinHandle;
}
```

最简调度器



```
async fn gen_identity(id: i32) -> i32 {
    return id << 1;
}
fn execute<F: Future>(mut f: F) -> F::Output {
    let ctx = unsafe { &mut *( core::ptr::null() as *const u8 as usize as *mut Context) };
    loop {
        let pinned: Pin<&mut F> = unsafe { Pin::new_unchecked(&mut f) };
        match pinned.poll(ctx) {
        Poll::Ready(res) => return res,
        Poll::Pending => { println!("loop again"); },
        }
    }
}

fn main() {
    let res = execute(gen_identity(1));
    println!("gen_identity(1) = {}", res);
}
```

运行结果如下:

```
h00339793@DESKTOP-MOPEH6E:~/working/rust-learning/foo/src$ cargo run
gen_identity(1) = 2
```

观点总结：不神话不贬低，扬其所长，避其所短

- □ 无栈协程即事件驱动模型，async/await开发效率更胜一筹
- □ 运行性能的关键取决于运行时框架的实现，所有语言面临同样挑战
  - ✓ 减少内存拷贝
  - ✓ 提升Cache命中率
  - ✓ 减少上下文切换
  - ✓ 提升内存分配效率
  - ✓ 高性能线程同步机制
  - ✓ …
- □ RUST异步框架的约束
  - ✓ 解耦设计待完善：Waker设计值得商榷，运行时框架接口缺失
  - ✓ 性能隐患：所有权转移带来的隐式内存拷贝，堆数据初始化效率
  - ✓ 功能约束：具体运行时功能接口约束
  - ✓ …

Thank you

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