Calling Unsafe Functions

Failing to uphold the safety requirements breaks memory safety!

```
#[derive(Debug)]
#[repr(C)]
struct KeyPair {
    pk: [u16; 4], // 8 bytes
    sk: [u16; 4], // 8 bytes
}

const PK_BYTE_LEN: usize = 8;

fn log_public_key(pk_ptr: *const u16) {
    let pk: &[u16] = unsafe { std::slice::from_raw_parts(pk_ptr, PK_BYTE_LEN) };
    println!("{pk:?}");
}

fn main() {
    let key_pair = KeyPair { pk: [1, 2, 3, 4], sk: [0, 0, 42, 0] };
    log_public_key(key_pair.pk.as_ptr());
}
```

Always include a safety comment for each `unsafe` block. It must explain why the code is actually safe. This example is missing a safety comment and is unsound.

▼ *Speaker Notes*

Key points:

- The second argument to `slice::from_raw_parts` is the number of *elements*, not bytes! This example demonstrates unexpected behavior by reading past the end of one array and into another.
- This is undefined behavior because we're reading past the end of the array that the pointer was derived from.
- `log_public_key` should be unsafe, because `pk_ptr` must meet certain prerequisites to avoid undefined behaviour. A safe function which can cause undefined behaviour is said to be `unsound`. What should its safety documentation say?
- The standard library contains many low-level unsafe functions. Prefer the safe alternatives when possible!
- If you use an unsafe function as an optimization, make sure to add a benchmark to demonstrate the gain.

Implementing Unsafe Traits

Like with functions, you can mark a trait as `unsafe` if the implementation must guarantee particular conditions to avoid undefined behaviour.

For example, the `zerocopy` crate has an unsafe trait that looks something like this:

```
use std::{mem, slice};

/// ...
/// # Safety
/// The type must have a defined representation and no padding.
pub unsafe trait IntoBytes {
    fn as_bytes(&self) -> &[u8] {
        let len = mem::size_of_val(self);
        let slf: *const Self = self;
        unsafe { slice::from_raw_parts(slf.cast::<u8>(), len) }
    }
}

// SAFETY: `u32` has a defined representation and no padding.
unsafe impl IntoBytes for u32 {}
```

▼ *Speaker Notes*

This slide should take about 5 minutes.

There should be a `# Safety` section on the Rustdoc for the trait explaining the requirements for the trait to be safely implemented.

The actual safety section for `IntoBytes` is rather longer and more complicated.

The built-in `Send` and `Sync` traits are unsafe.

Safe FFI Wrapper

Rust has great support for calling functions through a *foreign function interface* (FFI). We will use this to build a safe wrapper for the `libc` functions you would use from C to read the names of files in a directory.

You will want to consult the manual pages:

- `opendir(3)`
- `readdir(3)`
- `closedir(3)`

You will also want to browse the `std::ffi` module. There you find a number of string types which you need for the exercise:

Types	Encoding	Use
`str` and `String`	UTF-8	Text processing in Rust
`CStr` and `CString`	NUL-terminated	Communicating with C functions
`OsStr` and `OsString`	OS-specific	Communicating with the OS

You will convert between all these types:

- `&str` to `CString`: you need to allocate space for a trailing `\0` character,
- `CString` to `*const i8`: you need a pointer to call C functions,
- `*const i8` to `&CStr`: you need something which can find the trailing `\0` character,
- `&CStr` to `&[u8]`: a slice of bytes is the universal interface for "some unknown data",
- `&[u8]` to `&OsStr`: `&OsStr` is a step towards `OsString`, use `OsStrExt` to create it,
- `&OsStr` to `OsString`: you need to clone the data in `&OsStr` to be able to return it and call `readdir` again.

The Nomicon also has a very useful chapter about FFI.

Copy the code below to https://play.rust-lang.org/ and fill in the missing functions and methods:

```rust
// TODO: remove this when you're done with your implementation.
#![allow(unused_imports, unused_variables, dead_code)]

mod ffi {
    use std::os::raw::{c_char, c_int};
    #[cfg(not(target_os = "macos"))]
    use std::os::raw::{c_long, c_uchar, c_ulong, c_ushort};

    // Opaque type. See https://doc.rust-lang.org/nomicon/ffi.html.
    #[repr(C)]
    pub struct DIR {
        _data: [u8; 0],
        _marker: core::marker::PhantomData<(*mut u8, core::marker::PhantomPinned)>,
    }

    // Layout according to the Linux man page for readdir(3), where ino_t and
    // off_t are resolved according to the definitions in
    // /usr/include/x86_64-linux-gnu/{sys/types.h, bits/typesizes.h}.
    #[cfg(not(target_os = "macos"))]
    #[repr(C)]
    pub struct dirent {
        pub d_ino: c_ulong,
        pub d_off: c_long,
        pub d_reclen: c_ushort,
        pub d_type: c_uchar,
        pub d_name: [c_char; 256],
    }

    // Layout according to the macOS man page for dir(5).
    #[cfg(all(target_os = "macos"))]
    #[repr(C)]
    pub struct dirent {
        pub d_fileno: u64,
        pub d_seekoff: u64,
        pub d_reclen: u16,
        pub d_namlen: u16,
        pub d_type: u8,
        pub d_name: [c_char; 1024],
    }

    unsafe extern "C" {
        pub unsafe fn opendir(s: *const c_char) -> *mut DIR;

        #[cfg(not(all(target_os = "macos", target_arch = "x86_64")))]
        pub unsafe fn readdir(s: *mut DIR) -> *const dirent;

        // See https://github.com/rust-lang/libc/issues/414 and the section on
        // _DARWIN_FEATURE_64_BIT_INODE in the macOS man page for stat(2).
        //
        // "Platforms that existed before these updates were available" refers
        // to macOS (as opposed to iOS / wearOS / etc.) on Intel and PowerPC.
        #[cfg(all(target_os = "macos", target_arch = "x86_64"))]
        #[link_name = "readdir$INODE64"]
        pub unsafe fn readdir(s: *mut DIR) -> *const dirent;

        pub unsafe fn closedir(s: *mut DIR) -> c_int;
    }
}

use std::ffi::{CStr, CString, OsStr, OsString};
use std::os::unix::ffi::OsStrExt;

#[derive(Debug)]
struct DirectoryIterator {
    path: CString,
    dir: *mut ffi::DIR,
}

impl DirectoryIterator {
    fn new(path: &str) -> Result<DirectoryIterator, String> {
```

```
    }
}

impl Iterator for DirectoryIterator {
    type Item = OsString;
    fn next(&mut self) -> Option<OsString> {
        // Keep calling readdir until we get a NULL pointer back.
        todo!()
    }
}

impl Drop for DirectoryIterator {
    fn drop(&mut self) {
        // Call closedir as needed.
        todo!()
    }
}

fn main() -> Result<(), String> {
    let iter = DirectoryIterator::new(".")?;
    println!("files: {:#?}", iter.collect::<Vec<_>>());
    Ok(())
}
```

▼ *Speaker Notes*

This slide and its sub-slides should take about 30 minutes.

FFI binding code is typically generated by tools like bindgen, rather than being written manually as we are doing here. However, bindgen can't run in an online playground.

Solution

```rust
mod ffi {
    use std::os::raw::{c_char, c_int};
    #[cfg(not(target_os = "macos"))]
    use std::os::raw::{c_long, c_uchar, c_ulong, c_ushort};

    // Opaque type. See https://doc.rust-lang.org/nomicon/ffi.html.
    #[repr(C)]
    pub struct DIR {
        _data: [u8; 0],
        _marker: core::marker::PhantomData<(*mut u8, core::marker::PhantomPinned)>
    }

    // Layout according to the Linux man page for readdir(3), where ino_t and
    // off_t are resolved according to the definitions in
    // /usr/include/x86_64-linux-gnu/{sys/types.h, bits/typesizes.h}.
    #[cfg(not(target_os = "macos"))]
    #[repr(C)]
    pub struct dirent {
        pub d_ino: c_ulong,
        pub d_off: c_long,
        pub d_reclen: c_ushort,
        pub d_type: c_uchar,
        pub d_name: [c_char; 256],
    }

    // Layout according to the macOS man page for dir(5).
    #[cfg(all(target_os = "macos"))]
    #[repr(C)]
    pub struct dirent {
        pub d_fileno: u64,
        pub d_seekoff: u64,
        pub d_reclen: u16,
        pub d_namlen: u16,
        pub d_type: u8,
        pub d_name: [c_char; 1024],
    }

    unsafe extern "C" {
        pub unsafe fn opendir(s: *const c_char) -> *mut DIR;

        #[cfg(not(all(target_os = "macos", target_arch = "x86_64")))]
        pub unsafe fn readdir(s: *mut DIR) -> *const dirent;

        // See https://github.com/rust-lang/libc/issues/414 and the section on
        // _DARWIN_FEATURE_64_BIT_INODE in the macOS man page for stat(2).
        //
        // "Platforms that existed before these updates were available" refers
        // to macOS (as opposed to iOS / wearOS / etc.) on Intel and PowerPC.
        #[cfg(all(target_os = "macos", target_arch = "x86_64"))]
        #[link_name = "readdir$INODE64"]
        pub unsafe fn readdir(s: *mut DIR) -> *const dirent;

        pub unsafe fn closedir(s: *mut DIR) -> c_int;
    }
}

use std::ffi::{CStr, CString, OsStr, OsString};
use std::os::unix::ffi::OsStrExt;

#[derive(Debug)]
struct DirectoryIterator {
    path: CString,
    dir: *mut ffi::DIR,
}

impl DirectoryIterator {
    fn new(path: &str) -> Result<DirectoryIterator, String> {
```

```
        let path =
            CString::new(path).map_err(|err| format!("Invalid path: {err}"))?;
        // SAFETY: path.as_ptr() cannot be NULL.
        let dir = unsafe { ffi::opendir(path.as_ptr()) };
        if dir.is_null() {
            Err(format!("Could not open {path:?}"))
        } else {
            Ok(DirectoryIterator { path, dir })
        }
    }
}

impl Iterator for DirectoryIterator {
    type Item = OsString;
    fn next(&mut self) -> Option<OsString> {
        // Keep calling readdir until we get a NULL pointer back.
        // SAFETY: self.dir is never NULL.
        let dirent = unsafe { ffi::readdir(self.dir) };
        if dirent.is_null() {
            // We have reached the end of the directory.
            return None;
        }
        // SAFETY: dirent is not NULL and dirent.d_name is NUL
        // terminated.
        let d_name = unsafe { CStr::from_ptr((*dirent).d_name.as_ptr()) };
        let os_str = OsStr::from_bytes(d_name.to_bytes());
        Some(os_str.to_owned())
    }
}

impl Drop for DirectoryIterator {
    fn drop(&mut self) {
        // Call closedir as needed.
        // SAFETY: self.dir is never NULL.
        if unsafe { ffi::closedir(self.dir) } != 0 {
            panic!("Could not close {:?}", self.path);
        }
    }
}

fn main() -> Result<(), String> {
    let iter = DirectoryIterator::new(".")?;
    println!("files: {:#?}", iter.collect::<Vec<_>>());
    Ok(())
}

#[cfg(test)]
mod tests {
    use super::*;
    use std::error::Error;

    #[test]
    fn test_nonexisting_directory() {
        let iter = DirectoryIterator::new("no-such-directory");
        assert!(iter.is_err());
    }

    #[test]
    fn test_empty_directory() -> Result<(), Box<dyn Error>> {
        let tmp = tempfile::TempDir::new()?;
        let iter = DirectoryIterator::new(
            tmp.path().to_str().ok_or("Non UTF-8 character in path")?,
        )?;
        let mut entries = iter.collect::<Vec<_>>();
        entries.sort();
        assert_eq!(entries, &[".", ".."]);
        Ok(())
    }

    #[test]
```

```
143         std::fs::write(tmp.path().join("bar.png"), "<PNG>\n")?;
144         std::fs::write(tmp.path().join("crab.rs"), "//! Crab\n")?;
145         let iter = DirectoryIterator::new(
146             tmp.path().to_str().ok_or("Non UTF-8 character in path")?,
147         )?;
148         let mut entries = iter.collect::<Vec<_>>();
149         entries.sort();
150         assert_eq!(entries, &[".", "..", "bar.png", "crab.rs", "foo.txt"]);
151         Ok(())
152     }
153 }
```

Welcome to Rust in Android

Rust is supported for system software on Android. This means that you can write new services, libraries, drivers or even firmware in Rust (or improve existing code as needed).

▼ *Speaker Notes*

The speaker may mention any of the following given the increased use of Rust in Android:

- Service example: DNS over HTTP.
- Libraries: Rutabaga Virtual Graphics Interface.
- Kernel Drivers: Binder.
- Firmware: pKVM firmware.

Setup

We will be using a Cuttlefish Android Virtual Device to test our code. Make sure you have access to one or create a new one with:

```
source build/envsetup.sh
lunch aosp_cf_x86_64_phone-trunk_staging-userdebug
acloud create
```

Please see the Android Developer Codelab for details.

The code on the following pages can be found in the `src/android/` directory of the course material. Please `git clone` the repository to follow along.

▼ *Speaker Notes*

Key points:

- Cuttlefish is a reference Android device designed to work on generic Linux desktops. MacOS support is also planned.
- The Cuttlefish system image maintains high fidelity to real devices, and is the ideal emulator to run many Rust use cases.

Build Rules

The Android build system (Soong) supports Rust via a number of modules:

Module Type	Description
`rust_binary`	Produces a Rust binary.
`rust_library`	Produces a Rust library, and provides both `rlib` and `dylib` variants.
`rust_ffi`	Produces a Rust C library usable by `cc` modules, and provides both static and shared variants.
`rust_proc_macro`	Produces a `proc-macro` Rust library. These are analogous to compiler plugins.
`rust_test`	Produces a Rust test binary that uses the standard Rust test harness.
`rust_fuzz`	Produces a Rust fuzz binary leveraging `libfuzzer`.
`rust_protobuf`	Generates source and produces a Rust library that provides an interface for a particular protobuf.
`rust_bindgen`	Generates source and produces a Rust library containing Rust bindings to C libraries.

We will look at `rust_binary` and `rust_library` next.

▼ *Speaker Notes*

Additional items speaker may mention:

- Cargo is not optimized for multi-language repos, and also downloads packages from the internet.
- For compliance and performance, Android must have crates in-tree. It must also interop with C/C++/Java code. Soong fills that gap.
- Soong has many similarities to Bazel, which is the open-source variant of Blaze (used in google3).
- Fun fact: Data from Star Trek is a Soong-type Android.

Rust Binaries

Let us start with a simple application. At the root of an AOSP checkout, create the following files:

hello_rust/Android.bp:

```
rust_binary {
    name: "hello_rust",
    crate_name: "hello_rust",
    srcs: ["src/main.rs"],
}
```

hello_rust/src/main.rs:

```
//! Rust demo.

/// Prints a greeting to standard output.
fn main() {
    println!("Hello from Rust!");
}
```

You can now build, push, and run the binary:

```
m hello_rust
adb push "$ANDROID_PRODUCT_OUT/system/bin/hello_rust" /data/local/tmp
adb shell /data/local/tmp/hello_rust
```

```
Hello from Rust!
```

▼ *Speaker Notes*

- Go through the build steps and demonstrate them running in your emulator.
- Notice the extensive documentation comments? The Android build rules enforce that all modules have documentation. Try removing it and see what error you get.
- Stress that the Rust build rules look like the other Soong rules. This is on purpose to make it as easy to use Rust as C++ or Java.

Rust Libraries

You use `rust_library` to create a new Rust library for Android.

Here we declare a dependency on two libraries:

- `libgreeting`, which we define below,
- `libtextwrap`, which is a crate already vendored in `external/rust/android-crates-io/crates/`.

hello_rust/Android.bp:

```
rust_binary {
    name: "hello_rust_with_dep",
    crate_name: "hello_rust_with_dep",
    srcs: ["src/main.rs"],
    rustlibs: [
        "libgreetings",
        "libtextwrap",
    ],
    prefer_rlib: true, // Need this to avoid dynamic link error.
}

rust_library {
    name: "libgreetings",
    crate_name: "greetings",
    srcs: ["src/lib.rs"],
}
```

hello_rust/src/main.rs:

```
//! Rust demo.

use greetings::greeting;
use textwrap::fill;

/// Prints a greeting to standard output.
fn main() {
    println!("{}", fill(&greeting("Bob"), 24));
}
```

hello_rust/src/lib.rs:

```
//! Greeting library.

/// Greet `name`.
pub fn greeting(name: &str) -> String {
    format!("Hello {name}, it is very nice to meet you!")
}
```

You build, push, and run the binary like before:

```
m hello_rust_with_dep
adb push "$ANDROID_PRODUCT_OUT/system/bin/hello_rust_with_dep" /data/local/tmp
adb shell /data/local/tmp/hello_rust_with_dep
```

```
Hello Bob, it is very
nice to meet you!
```

▼ *Speaker Notes*

- Go through the build steps and demonstrate them running in your emulator.
- A Rust crate named `greetings` must be built by a rule called `libgreetings`. Note how the Rust code uses the crate name, as is normal in Rust.
- Again, the build rules enforce that we add documentation comments to all public items.

AIDL

The Android Interface Definition Language (AIDL) is supported in Rust:

- Rust code can call existing AIDL servers,
- You can create new AIDL servers in Rust.

<details>
<summary>Speaker Notes</summary>

- AIDL is what enables Android apps to interact with each other.
- Since Rust is supported as a first-class citizen in this ecosystem, Rust services can be called by any other process on the phone.
</details>

Birthday Service Tutorial

To illustrate how to use Rust with Binder, we're going to walk through the process of creating a Binder interface. We're then going to both implement the described service and write client code that talks to that service.

AIDL Interfaces

You declare the API of your service using an AIDL interface:

birthday_service/aidl/com/example/birthdayservice/IBirthdayService.aidl:

```
package com.example.birthdayservice;

/** Birthday service interface. */
interface IBirthdayService {
    /** Generate a Happy Birthday message. */
    String wishHappyBirthday(String name, int years);
}
```

birthday_service/aidl/Android.bp:

```
aidl_interface {
    name: "com.example.birthdayservice",
    srcs: ["com/example/birthdayservice/*.aidl"],
    unstable: true,
    backend: {
        rust: { // Rust is not enabled by default
            enabled: true,
        },
    },
}
```

▼ *Speaker Notes*

- Note that the directory structure under the `aidl/` directory needs to match the package name used in the AIDL file, i.e. the package is `com.example.birthdayservice` and the file is at `aidl/com/example/IBirthdayService.aidl`.

Generated Service API

Binder generates a trait for each interface definition.

birthday_service/aidl/com/example/birthdayservice/IBirthdayService.aidl:

```
/** Birthday service interface. */
interface IBirthdayService {
    /** Generate a Happy Birthday message. */
    String wishHappyBirthday(String name, int years);
}
```

out/soong/.intermediates/.../com_example_birthdayservice.rs:

```
trait IBirthdayService {
    fn wishHappyBirthday(&self, name: &str, years: i32) -> binder::Result<String>;
}
```

Your service will need to implement this trait, and your client will use this trait to talk to the service.

▼ *Speaker Notes*

- Point out how the generated function signature, specifically the argument and return types, correspond the interface definition.
  - `String` for an argument results in a different Rust type than `String` as a return type.

Service Implementation

We can now implement the AIDL service:

birthday_service/src/lib.rs:

```
//! Implementation of the `IBirthdayService` AIDL interface.
use
com_example_birthdayservice::aidl::com::example::birthdayservice::IBirthdayService::IB
irthdayService;
use com_example_birthdayservice::binder;

/// The `IBirthdayService` implementation.
pub struct BirthdayService;

impl binder::Interface for BirthdayService {}

impl IBirthdayService for BirthdayService {
    fn wishHappyBirthday(&self, name: &str, years: i32) -> binder::Result<String> {
        Ok(format!("Happy Birthday {name}, congratulations with the {years} years!"))
    }
}
```

birthday_service/Android.bp:

```
rust_library {
    name: "libbirthdayservice",
    crate_name: "birthdayservice",
    srcs: ["src/lib.rs"],
    rustlibs: [
        "com.example.birthdayservice-rust",
    ],
}
```

▼ *Speaker Notes*

- Point out the path to the generated `IBirthdayService` trait, and explain why each of the segments is necessary.
- Note that `wishHappyBirthday` and other AIDL IPC methods take `&self` (instead of `&mut self`).
  - This is necessary because binder responds to incoming requests on a thread pool, allowing for multiple requests to be processed in parallel. This requires that the service methods only get a shared reference to `self`.
  - Any state that needs to be modified by the service will have to be put in something like a `Mutex` to allow for safe mutation.
  - The correct approach for managing service state depends heavily on the details of your service.
- TODO: What does the `binder::Interface` trait do? Are there methods to override? Where source?

AIDL Server

Finally, we can create a server which exposes the service:

birthday_service/src/server.rs:

```
//! Birthday service.
use birthdayservice::BirthdayService;
use
com_example_birthdayservice::aidl::com::example::birthdayservice::IBirthdayService::Bn
BirthdayService;
use com_example_birthdayservice::binder;

const SERVICE_IDENTIFIER: &str = "birthdayservice";

/// Entry point for birthday service.
fn main() {
    let birthday_service = BirthdayService;
    let birthday_service_binder = BnBirthdayService::new_binder(
        birthday_service,
        binder::BinderFeatures::default(),
    );
    binder::add_service(SERVICE_IDENTIFIER, birthday_service_binder.as_binder())
        .expect("Failed to register service");
    binder::ProcessState::join_thread_pool();
}
```

birthday_service/Android.bp:

```
rust_binary {
    name: "birthday_server",
    crate_name: "birthday_server",
    srcs: ["src/server.rs"],
    rustlibs: [
        "com.example.birthdayservice-rust",
        "libbirthdayservice",
    ],
    prefer_rlib: true, // To avoid dynamic link error.
}
```

▼ *Speaker Notes*

The process for taking a user-defined service implementation (in this case the `BirthdayService` type, which implements the `IBirthdayService`) and starting it as a Binder service has multiple steps, and may appear more complicated than students are used to if they've used Binder from C++ or another language. Explain to students why each step is necessary.

1. Create an instance of your service type (`BirthdayService`).
2. Wrap the service object in corresponding `Bn*` type (`BnBirthdayService` in this case). This type is generated by Binder and provides the common Binder functionality that would be provided by the `BnBinder` base class in C++. We don't have inheritance in Rust, so instead we use composition, putting our `BirthdayService` within the generated `BnBinderService`.
3. Call `add_service`, giving it a service identifier and your service object (the `BnBirthdayService` object in the example).
4. Call `join_thread_pool` to add the current thread to Binder's thread pool and start listening for connections.

Deploy

We can now build, push, and start the service:

```
m birthday_server
adb push "$ANDROID_PRODUCT_OUT/system/bin/birthday_server" /data/local/tmp
adb root
adb shell /data/local/tmp/birthday_server
```

In another terminal, check that the service runs:

```
adb shell service check birthdayservice
```

```
Service birthdayservice: found
```

You can also call the service with `service call`:

```
adb shell service call birthdayservice 1 s16 Bob i32 24
```

```
Result: Parcel(
  0x00000000: 00000000 00000036 00610048 00700070 '....6...H.a.p.p.'
  0x00000010: 00200079 00690042 00740072 00640068 'y. .B.i.r.t.h.d.'
  0x00000020: 00790061 00420020 0062006f 0020002c 'a.y. .B.o.b.,. .'
  0x00000030: 006f0063 0067006e 00610072 00750074 'c.o.n.g.r.a.t.u.'
  0x00000040: 0061006c 00690074 006e006f 00200073 'l.a.t.i.o.n.s. .'
  0x00000050: 00690077 00680074 00740020 00650068 'w.i.t.h. .t.h.e.'
  0x00000060: 00320020 00200034 00650079 00720061 ' .2.4. .y.e.a.r.'
  0x00000070: 00210073 00000000                   's.!.....       ')
```

AIDL Client

Finally, we can create a Rust client for our new service.

birthday_service/src/client.rs:

```
use
com_example_birthdayservice::aidl::com::example::birthdayservice::IBirthdayService::IB
irthdayService;
use com_example_birthdayservice::binder;

const SERVICE_IDENTIFIER: &str = "birthdayservice";

/// Call the birthday service.
fn main() -> Result<(), Box<dyn Error>> {
    let name = std::env::args().nth(1).unwrap_or_else(|| String::from("Bob"));
    let years = std::env::args()
        .nth(2)
        .and_then(|arg| arg.parse::<i32>().ok())
        .unwrap_or(42);

    binder::ProcessState::start_thread_pool();
    let service = binder::get_interface::<dyn IBirthdayService>(SERVICE_IDENTIFIER)
        .map_err(|_| "Failed to connect to BirthdayService")?;

    // Call the service.
    let msg = service.wishHappyBirthday(&name, years)?;
    println!("{msg}");
}
```

birthday_service/Android.bp:

```
rust_binary {
    name: "birthday_client",
    crate_name: "birthday_client",
    srcs: ["src/client.rs"],
    rustlibs: [
        "com.example.birthdayservice-rust",
    ],
    prefer_rlib: true, // To avoid dynamic link error.
}
```

Notice that the client does not depend on `libbirthdayservice`.

Build, push, and run the client on your device:

```
m birthday_client
adb push "$ANDROID_PRODUCT_OUT/system/bin/birthday_client" /data/local/tmp
adb shell /data/local/tmp/birthday_client Charlie 60
```

```
Happy Birthday Charlie, congratulations with the 60 years!
```

▼ *Speaker Notes*

- `Strong<dyn IBirthdayService>` is the trait object representing the service that the client has connected to.
  - `Strong` is a custom smart pointer type for Binder. It handles both an in-process ref count for the service trait object, and the global Binder ref count that tracks how many processes have a reference to the object.
  - Note that the trait object that the client uses to talk to the service uses the exact same

generated that both client and server use.

- Use the same service identifier used when registering the service. This should ideally be defined in a common crate that both the client and server can depend on.

Changing API

Let us extend the API with more functionality: we want to let clients specify a list of lines for the birthday card:

```
package com.example.birthdayservice;

/** Birthday service interface. */
interface IBirthdayService {
    /** Generate a Happy Birthday message. */
    String wishHappyBirthday(String name, int years, in String[] text);
}
```

This results in an updated trait definition for `IBirthdayService`:

```
trait IBirthdayService {
    fn wishHappyBirthday(
        &self,
        name: &str,
        years: i32,
        text: &[String],
    ) -> binder::Result<String>;
}
```

▼ *Speaker Notes*

- Note how the `String[]` in the AIDL definition is translated as a `&[String]` in Rust, i.e. that idiomatic Rust types are used in the generated bindings wherever possible:
  - `in` array arguments are translated to slices.
  - `out` and `inout` args are translated to `&mut Vec<T>`.
  - Return values are translated to returning a `Vec<T>`.

Updating Client and Service

Update the client and server code to account for the new API.

birthday_service/src/lib.rs:

```
impl IBirthdayService for BirthdayService {
    fn wishHappyBirthday(
        &self,
        name: &str,
        years: i32,
        text: &[String],
    ) -> binder::Result<String> {
        let mut msg = format!(
            "Happy Birthday {name}, congratulations with the {years} years!",
        );

        for line in text {
            msg.push('\n');
            msg.push_str(line);
        }

        Ok(msg)
    }
}
```

birthday_service/src/client.rs:

```
let msg = service.wishHappyBirthday(
    &name,
    years,
    &[
        String::from("Habby birfday to yuuuuu"),
        String::from("And also: many more"),
    ],
)?;
```

▼ *Speaker Notes*

- TODO: Move code snippets into project files where they'll actually be built?

Working With AIDL Types

AIDL types translate into the appropriate idiomatic Rust type:

- Primitive types map (mostly) to idiomatic Rust types.
- Collection types like slices, `Vec`s and string types are supported.
- References to AIDL objects and file handles can be sent between clients and services.
- File handles and parcelables are fully supported.

Primitive Types

Primitive types map (mostly) idiomatically:

AIDL Type	Rust Type	Note
`boolean`	`bool`	
`byte`	`i8`	Note that bytes are signed.
`char`	`u16`	Note the usage of `u16`, NOT `u32`.
`int`	`i32`	
`long`	`i64`	
`float`	`f32`	
`double`	`f64`	
`String`	`String`	

Array Types

The array types (`T[]` , `byte[]` , and `List<T>`) get translated to the appropriate Rust array type depending on how they are used in the function signature:

Position	Rust Type
`in` argument	`&[T]`
`out` / `inout` argument	`&mut Vec<T>`
Return	`Vec<T>`

▼ *Speaker Notes*

- In Android 13 or higher, fixed-size arrays are supported, i.e. `T[N]` becomes `[T; N]` . Fixed-size arrays can have multiple dimensions (e.g. `int[3][4]`). In the Java backend, fixed-size arrays are represented as array types.
- Arrays in parcelable fields always get translated to `Vec<T>` .

Sending Objects

AIDL objects can be sent either as a concrete AIDL type or as the type-erased `IBinder` interface:

birthday_service/aidl/com/example/birthdayservice/IBirthdayInfoProvider.aidl:

```
package com.example.birthdayservice;

interface IBirthdayInfoProvider {
    String name();
    int years();
}
```

birthday_service/aidl/com/example/birthdayservice/IBirthdayService.aidl:

```
import com.example.birthdayservice.IBirthdayInfoProvider;

interface IBirthdayService {
    /** The same thing, but using a binder object. */
    String wishWithProvider(IBirthdayInfoProvider provider);

    /** The same thing, but using `IBinder`. */
    String wishWithErasedProvider(IBinder provider);
}
```

birthday_service/src/client.rs:

```
/// Rust struct implementing the `IBirthdayInfoProvider` interface.
struct InfoProvider {
    name: String,
    age: u8,
}

impl binder::Interface for InfoProvider {}

impl IBirthdayInfoProvider for InfoProvider {
    fn name(&self) -> binder::Result<String> {
        Ok(self.name.clone())
    }

    fn years(&self) -> binder::Result<i32> {
        Ok(self.age as i32)
    }
}

fn main() {
    binder::ProcessState::start_thread_pool();
    let service = connect().expect("Failed to connect to BirthdayService");

    // Create a binder object for the `IBirthdayInfoProvider` interface.
    let provider = BnBirthdayInfoProvider::new_binder(
        InfoProvider { name: name.clone(), age: years as u8 },
        BinderFeatures::default(),
    );

    // Send the binder object to the service.
    service.wishWithProvider(&provider)?;

    // Perform the same operation but passing the provider as an `SpIBinder`.
    service.wishWithErasedProvider(&provider.as_binder())?;
}
```

▼ *Speaker Notes*

- Note the usage of `BnBirthdayInfoProvider`. This serves the same purpose as `BnBirthdayService` that we saw previously.

Parcelables

Binder for Rust supports sending parcelables directly:

birthday_service/aidl/com/example/birthdayservice/BirthdayInfo.aidl:

```
package com.example.birthdayservice;

parcelable BirthdayInfo {
    String name;
    int years;
}
```

birthday_service/aidl/com/example/birthdayservice/IBirthdayService.aidl:

```
import com.example.birthdayservice.BirthdayInfo;

interface IBirthdayService {
    /** The same thing, but with a parcelable. */
    String wishWithInfo(in BirthdayInfo info);
}
```

birthday_service/src/client.rs:

```
fn main() {
    binder::ProcessState::start_thread_pool();
    let service = connect().expect("Failed to connect to BirthdayService");

    let info = BirthdayInfo { name: "Alice".into(), years: 123 };
    service.wishWithInfo(&info)?;
}
```

Sending Files

Files can be sent between Binder clients/servers using the `ParcelFileDescriptor` type:

birthday_service/aidl/com/example/birthdayservice/IBirthdayService.aidl:

```
interface IBirthdayService {
    /** The same thing, but loads info from a file. */
    String wishFromFile(in ParcelFileDescriptor infoFile);
}
```

birthday_service/src/client.rs:

```
fn main() {
    binder::ProcessState::start_thread_pool();
    let service = connect().expect("Failed to connect to BirthdayService");

    // Open a file and put the birthday info in it.
    let mut file = File::create("/data/local/tmp/birthday.info").unwrap();
    writeln!(file, "{name}")?;
    writeln!(file, "{years}")?;

    // Create a `ParcelFileDescriptor` from the file and send it.
    let file = ParcelFileDescriptor::new(file);
    service.wishFromFile(&file)?;
}
```

birthday_service/src/lib.rs:

```
impl IBirthdayService for BirthdayService {
    fn wishFromFile(
        &self,
        info_file: &ParcelFileDescriptor,
    ) -> binder::Result<String> {
        // Convert the file descriptor to a `File`. `ParcelFileDescriptor` wraps
        // an `OwnedFd`, which can be cloned and then used to create a `File`
        // object.
        let mut info_file = info_file
            .as_ref()
            .try_clone()
            .map(File::from)
            .expect("Invalid file handle");

        let mut contents = String::new();
        info_file.read_to_string(&mut contents).unwrap();

        let mut lines = contents.lines();
        let name = lines.next().unwrap();
        let years: i32 = lines.next().unwrap().parse().unwrap();

        Ok(format!("Happy Birthday {name}, congratulations with the {years} years!"))
    }
}
```

▼ *Speaker Notes*

- `ParcelFileDescriptor` wraps an `OwnedFd`, and so can be created from a `File` (or any other type that wraps an `OwnedFd`), and can be used to create a new `File` handle on the other side.
- Other types of file descriptors can be wrapped and sent, e.g. TCP, UDP, and UNIX sockets.

Testing in Android

Building on Testing, we will now look at how unit tests work in AOSP. Use the `rust_test` module for your unit tests:

testing/Android.bp:

```
rust_library {
    name: "libleftpad",
    crate_name: "leftpad",
    srcs: ["src/lib.rs"],
}

rust_test {
    name: "libleftpad_test",
    crate_name: "leftpad_test",
    srcs: ["src/lib.rs"],
    host_supported: true,
    test_suites: ["general-tests"],
}

rust_test {
    name: "libgoogletest_example",
    crate_name: "googletest_example",
    srcs: ["googletest.rs"],
    rustlibs: ["libgoogletest_rust"],
    host_supported: true,
}

rust_test {
    name: "libmockall_example",
    crate_name: "mockall_example",
    srcs: ["mockall.rs"],
    rustlibs: ["libmockall"],
    host_supported: true,
}
```

testing/src/lib.rs:

```
//! Left-padding library.

/// Left-pad `s` to `width`.
pub fn leftpad(s: &str, width: usize) -> String {
    format!("{s:>width$}")
}

#[cfg(test)]
mod tests {
    use super::*;

    #[test]
    fn short_string() {
        assert_eq!(leftpad("foo", 5), "  foo");
    }

    #[test]
    fn long_string() {
        assert_eq!(leftpad("foobar", 6), "foobar");
    }
}
```

You can now run the test with

```
atest --host libleftpad_test
```

The output looks like this:

```
INFO: Elapsed time: 2.666s, Critical Path: 2.40s
INFO: 3 processes: 2 internal, 1 linux-sandbox.
INFO: Build completed successfully, 3 total actions
//comprehensive-rust-android/testing:libleftpad_test_host            PASSED in 2.3s
    PASSED  libleftpad_test.tests::long_string (0.0s)
    PASSED  libleftpad_test.tests::short_string (0.0s)
Test cases: finished with 2 passing and 0 failing out of 2 test cases
```

Notice how you only mention the root of the library crate. Tests are found recursively in nested modules.

GoogleTest

The GoogleTest crate allows for flexible test assertions using *matchers*:

```
use googletest::prelude::*;

#[googletest::test]
fn test_elements_are() {
    let value = vec!["foo", "bar", "baz"];
    expect_that!(value, elements_are!(eq(&"foo"), lt(&"xyz"), starts_with("b")));
}
```

If we change the last element to `"!"`, the test fails with a structured error message pin-pointing the error:

```
---- test_elements_are stdout ----
Value of: value
Expected: has elements:
  0. is equal to "foo"
  1. is less than "xyz"
  2. starts with prefix "!"
Actual: ["foo", "bar", "baz"],
  where element #2 is "baz", which does not start with "!"
  at src/testing/googletest.rs:6:5
Error: See failure output above
```

▼ *Speaker Notes*

This slide should take about 5 minutes.

- GoogleTest is not part of the Rust Playground, so you need to run this example in a local environment. Use `cargo add googletest` to quickly add it to an existing Cargo project.
- The `use googletest::prelude::*;` line imports a number of commonly used macros and types.
- This just scratches the surface, there are many builtin matchers. Consider going through the first chapter of "Advanced testing for Rust applications", a self-guided Rust course: it provides a guided introduction to the library, with exercises to help you get comfortable with `googletest` macros, its matchers and its overall philosophy.
- A particularly nice feature is that mismatches in multi-line strings are shown as a diff:

```
#[test]
fn test_multiline_string_diff() {
    let haiku = "Memory safety found,\n\
                 Rust's strong typing guides the way,\n\
                 Secure code you'll write.";
    assert_that!(
        haiku,
        eq("Memory safety found,\n\
            Rust's silly humor guides the way,\n\
            Secure code you'll write.")
    );
}
```

shows a color-coded diff (colors not shown here):

```
    Value of: haiku
Expected: is equal to "Memory safety found,\nRust's silly humor guides the
way,\nSecure code you'll write."
Actual: "Memory safety found,\nRust's strong typing guides the way,\nSecure code
you'll write.",
  which isn't equal to "Memory safety found,\nRust's silly humor guides the
way,\nSecure code you'll write."
Difference(-actual / +expected):
 Memory safety found,
-Rust's strong typing guides the way,
+Rust's silly humor guides the way,
 Secure code you'll write.
  at src/testing/googletest.rs:17:5
```

- The crate is a Rust port of GoogleTest for C++.

Mocking

For mocking, Mockall is a widely used library. You need to refactor your code to use traits, which you can then quickly mock:

```
use std::time::Duration;

#[mockall::automock]
pub trait Pet {
    fn is_hungry(&self, since_last_meal: Duration) -> bool;
}

#[test]
fn test_robot_dog() {
    let mut mock_dog = MockPet::new();
    mock_dog.expect_is_hungry().return_const(true);
    assert!(mock_dog.is_hungry(Duration::from_secs(10)));
}
```

▼ *Speaker Notes*

This slide should take about 5 minutes.

- Mockall is the recommended mocking library in Android (AOSP). There are other mocking libraries available on crates.io, in particular in the area of mocking HTTP services. The other mocking libraries work in a similar fashion as Mockall, meaning that they make it easy to get a mock implementation of a given trait.
- Note that mocking is somewhat *controversial*: mocks allow you to completely isolate a test from its dependencies. The immediate result is faster and more stable test execution. On the other hand, the mocks can be configured wrongly and return output different from what the real dependencies would do.

  If at all possible, it is recommended that you use the real dependencies. As an example, many databases allow you to configure an in-memory backend. This means that you get the correct behavior in your tests, plus they are fast and will automatically clean up after themselves.

  Similarly, many web frameworks allow you to start an in-process server which binds to a random port on `localhost`. Always prefer this over mocking away the framework since it helps you test your code in the real environment.
- Mockall is not part of the Rust Playground, so you need to run this example in a local environment. Use `cargo add mockall` to quickly add Mockall to an existing Cargo project.
- Mockall has a lot more functionality. In particular, you can set up expectations which depend on the arguments passed. Here we use this to mock a cat which becomes hungry 3 hours after the last time it was fed:

```
#[test]
fn test_robot_cat() {
    let mut mock_cat = MockPet::new();
    mock_cat
        .expect_is_hungry()
        .with(mockall::predicate::gt(Duration::from_secs(3 * 3600)))
        .return_const(true);
    mock_cat.expect_is_hungry().return_const(false);
    assert!(mock_cat.is_hungry(Duration::from_secs(5 * 3600)));
    assert!(!mock_cat.is_hungry(Duration::from_secs(5)));
}
```

- You can use `.times(n)` to limit the number of times a mock method can be called to `n` — the mock will automatically panic when dropped if this isn't satisfied.

Logging

You should use the `log` crate to automatically log to `logcat` (on-device) or `stdout` (on-host):

hello_rust_logs/Android.bp:

```
rust_binary {
    name: "hello_rust_logs",
    crate_name: "hello_rust_logs",
    srcs: ["src/main.rs"],
    rustlibs: [
        "liblog_rust",
        "liblogger",
    ],
    host_supported: true,
}
```

hello_rust_logs/src/main.rs:

```
//! Rust logging demo.

use log::{debug, error, info};

/// Logs a greeting.
fn main() {
    logger::init(
        logger::Config::default()
            .with_tag_on_device("rust")
            .with_max_level(log::LevelFilter::Trace),
    );
    debug!("Starting program.");
    info!("Things are going fine.");
    error!("Something went wrong!");
}
```

Build, push, and run the binary on your device:

```
m hello_rust_logs
adb push "$ANDROID_PRODUCT_OUT/system/bin/hello_rust_logs" /data/local/tmp
adb shell /data/local/tmp/hello_rust_logs
```

The logs show up in `adb logcat`:

```
adb logcat -s rust
```

```
09-08 08:38:32.454  2420  2420 D rust: hello_rust_logs: Starting program.
09-08 08:38:32.454  2420  2420 I rust: hello_rust_logs: Things are going fine.
09-08 08:38:32.454  2420  2420 E rust: hello_rust_logs: Something went wrong!
```

▼ *Speaker Notes*

- The logger implementation in `liblogger` is only needed in the final binary, if you're logging from a library you only need the `log` facade crate.

Interoperability

Rust has excellent support for interoperability with other languages. This means that you can:

- Call Rust functions from other languages.
- Call functions written in other languages from Rust.

When you call functions in a foreign language we say that you're using a *foreign function interface*, also known as FFI.

▼ *Speaker Notes*

- This is a key ability of Rust: compiled code becomes indistinguishable from compiled C or C++ code.
- Technically, we say that Rust can be compiled to the same ABI (application binary interface) as C code.

Interoperability with C

Rust has full support for linking object files with a C calling convention. Similarly, you can export Rust functions and call them from C.

You can do it by hand if you want:

```
unsafe extern "C" {
    safe fn abs(x: i32) -> i32;
}

fn main() {
    let x = -42;
    let abs_x = abs(x);
    println!("{x}, {abs_x}");
}
```

We already saw this in the Safe FFI Wrapper exercise.

> This assumes full knowledge of the target platform. Not recommended for production.

We will look at better options next.

▼ *Speaker Notes*

- The `"C"` part of the `extern` block tells Rust that `abs` can be called using the C ABI (application binary interface).
- The `safe fn abs` part tells that Rust that `abs` is a safe function. By default, extern functions are considered unsafe, but since `abs(x)` is valid for any `x`, we can declare it safe.

A Simple C Library

Let's first create a small C library:

interoperability/bindgen/libbirthday.h:

```
typedef struct card {
  const char* name;
  int years;
} card;

void print_card(const card* card);
```

interoperability/bindgen/libbirthday.c:

```
#include <stdio.h>
#include "libbirthday.h"

void print_card(const card* card) {
  printf("+--------------\n");
  printf("| Happy Birthday %s!\n", card->name);
  printf("| Congratulations with the %i years!\n", card->years);
  printf("+--------------\n");
}
```

Add this to your `Android.bp` file:

interoperability/bindgen/Android.bp:

```
cc_library {
    name: "libbirthday",
    srcs: ["libbirthday.c"],
}
```

Using Bindgen

The bindgen tool can auto-generate bindings from a C header file.

Create a wrapper header file for the library (not strictly needed in this example):

interoperability/bindgen/libbirthday_wrapper.h:

```
#include "libbirthday.h"
```

interoperability/bindgen/Android.bp:

```
rust_bindgen {
    name: "libbirthday_bindgen",
    crate_name: "birthday_bindgen",
    wrapper_src: "libbirthday_wrapper.h",
    source_stem: "bindings",
    static_libs: ["libbirthday"],
}
```

Finally, we can use the bindings in our Rust program:

interoperability/bindgen/Android.bp:

```
rust_binary {
    name: "print_birthday_card",
    srcs: ["main.rs"],
    rustlibs: ["libbirthday_bindgen"],
    static_libs: ["libbirthday"],
}
```

interoperability/bindgen/main.rs:

```
//! Bindgen demo.

use birthday_bindgen::{card, print_card};

fn main() {
    let name = std::ffi::CString::new("Peter").unwrap();
    let card = card { name: name.as_ptr(), years: 42 };
    // SAFETY: The pointer we pass is valid because it came from a Rust
    // reference, and the `name` it contains refers to `name` above which also
    // remains valid. `print_card` doesn't store either pointer to use later
    // after it returns.
    unsafe {
        print_card(&card);
    }
}
```

▼ *Speaker Notes*

- The Android build rules will automatically call `bindgen` for you behind the scenes.
- Notice that the Rust code in `main` is still hard to write. It is good practice to encapsulate the output of `bindgen` in a Rust library which exposes a safe interface to caller.

Running Our Binary

Build, push, and run the binary on your device:

```
m print_birthday_card
adb push "$ANDROID_PRODUCT_OUT/system/bin/print_birthday_card" /data/local/tmp
adb shell /data/local/tmp/print_birthday_card
```

Finally, we can run auto-generated tests to ensure the bindings work:

interoperability/bindgen/Android.bp:

```
rust_test {
    name: "libbirthday_bindgen_test",
    srcs: [":libbirthday_bindgen"],
    crate_name: "libbirthday_bindgen_test",
    test_suites: ["general-tests"],
    auto_gen_config: true,
    clippy_lints: "none", // Generated file, skip linting
    lints: "none",
}
```

```
atest libbirthday_bindgen_test
```

A Simple Rust Library

Exporting Rust functions and types to C is easy. Here's a simple Rust library:

interoperability/rust/libanalyze/analyze.rs

```rust
//! Rust FFI demo.
#![deny(improper_ctypes_definitions)]

use std::os::raw::c_int;

/// Analyze the numbers.
// SAFETY: There is no other global function of this name.
#[unsafe(no_mangle)]
pub extern "C" fn analyze_numbers(x: c_int, y: c_int) {
    if x < y {
        println!("x ({x}) is smallest!");
    } else {
        println!("y ({y}) is probably larger than x ({x})");
    }
}
```

interoperability/rust/libanalyze/Android.bp

```
rust_ffi {
    name: "libanalyze_ffi",
    crate_name: "analyze_ffi",
    srcs: ["analyze.rs"],
    include_dirs: ["."],
}
```

▼ *Speaker Notes*

`#[unsafe(no_mangle)]` disables Rust's usual name mangling, so the exported symbol will just be the name of the function. You can also use `#[unsafe(export_name = "some_name")]` to specify whatever name you want.

Calling Rust

We can now call this from a C binary:

interoperability/rust/libanalyze/analyze.h

```
#ifndef ANALYZE_H
#define ANALYZE_H

void analyze_numbers(int x, int y);

#endif
```

interoperability/rust/analyze/main.c

```
#include "analyze.h"

int main() {
  analyze_numbers(10, 20);
  analyze_numbers(123, 123);
  return 0;
}
```

interoperability/rust/analyze/Android.bp

```
cc_binary {
    name: "analyze_numbers",
    srcs: ["main.c"],
    static_libs: ["libanalyze_ffi"],
}
```

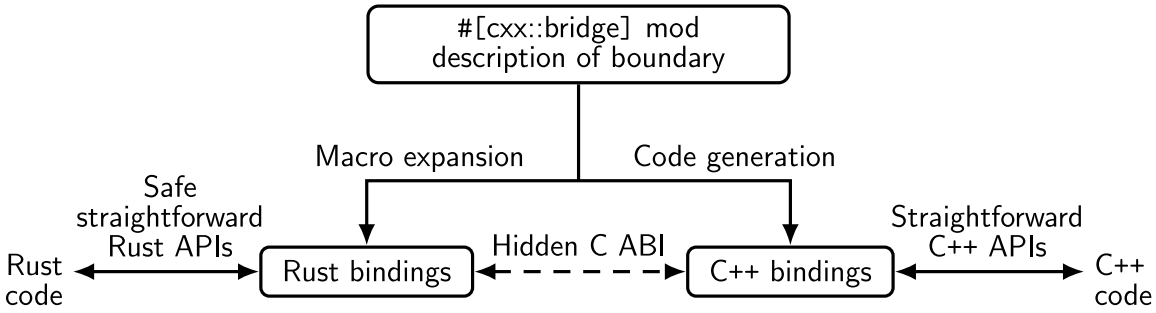
Build, push, and run the binary on your device:

```
m analyze_numbers
adb push "$ANDROID_PRODUCT_OUT/system/bin/analyze_numbers" /data/local/tmp
adb shell /data/local/tmp/analyze_numbers
```

With C++

The CXX crate makes it possible to do safe interoperability between Rust and C++.

The overall approach looks like this:



The Bridge Module

CXX relies on a description of the function signatures that will be exposed from each language to the other. You provide this description using extern blocks in a Rust module annotated with the `#[cxx::bridge]` attribute macro.

```
#[allow(unsafe_op_in_unsafe_fn)]
#[cxx::bridge(namespace = "org::blobstore")]
mod ffi {
    // Shared structs with fields visible to both languages.
    struct BlobMetadata {
        size: usize,
        tags: Vec<String>,
    }

    // Rust types and signatures exposed to C++.
    extern "Rust" {
        type MultiBuf;

        fn next_chunk(buf: &mut MultiBuf) -> &[u8];
    }

    // C++ types and signatures exposed to Rust.
    unsafe extern "C++" {
        include!("include/blobstore.h");

        type BlobstoreClient;

        fn new_blobstore_client() -> UniquePtr<BlobstoreClient>;
        fn put(self: Pin<&mut BlobstoreClient>, parts: &mut MultiBuf) -> u64;
        fn tag(self: Pin<&mut BlobstoreClient>, blobid: u64, tag: &str);
        fn metadata(&self, blobid: u64) -> BlobMetadata;
    }
}
```

▼ *Speaker Notes*

- The bridge is generally declared in an `ffi` module within your crate.
- From the declarations made in the bridge module, CXX will generate matching Rust and C++ type/function definitions in order to expose those items to both languages.
- To view the generated Rust code, use cargo-expand to view the expanded proc macro. For most of the examples you would use `cargo expand ::ffi` to expand just the `ffi` module (though this doesn't apply for Android projects).
- To view the generated C++ code, look in `target/cxxbridge`.

Rust Bridge Declarations

```
#[cxx::bridge]
mod ffi {
    extern "Rust" {
        type MyType; // Opaque type
        fn foo(&self); // Method on `MyType`
        fn bar() -> Box<MyType>; // Free function
    }
}

struct MyType(i32);

impl MyType {
    fn foo(&self) {
        println!("{}", self.0);
    }
}

fn bar() -> Box<MyType> {
    Box::new(MyType(123))
}
```

▼ *Speaker Notes*

- Items declared in the `extern "Rust"` reference items that are in scope in the parent module.
- The CXX code generator uses your `extern "Rust"` section(s) to produce a C++ header file containing the corresponding C++ declarations. The generated header has the same path as the Rust source file containing the bridge, except with a .rs.h file extension.

Generated C++

```
#[cxx::bridge]
mod ffi {
    // Rust types and signatures exposed to C++.
    extern "Rust" {
        type MultiBuf;

        fn next_chunk(buf: &mut MultiBuf) -> &[u8];
    }
}
```

Results in (roughly) the following C++:

```
struct MultiBuf final : public ::rust::Opaque {
  ~MultiBuf() = delete;

private:
  friend ::rust::layout;
  struct layout {
    static ::std::size_t size() noexcept;
    static ::std::size_t align() noexcept;
  };
};

::rust::Slice<::std::uint8_t const> next_chunk(::org::blobstore::MultiBuf &buf)
noexcept;
```