Lesson 4 - Rust continued / Solana Command Line

Lesson 1 - Blockchain / Solana architecture

Lesson 2 - Solana architecture / Rust

Lesson 3 - Rust / Solana command line tools

Lesson 4 - Rust / Solana development

Rust continued

Lifetime constraints on references

```
let x;
{
        let a = 2;
        ...
        x = &a;
        ...
}
```

```
assert_eq!(*x,2);
```

This is a problem because

1. For a variable `a` , any reference to `a` must not outlive `a` itself.
   The variable's lifetime must enclose that of the reference.
   => how *large* a reference's lifetime can be
   The lifetime of &a must not be outside the dots
2. If you store a reference in a variable `x` the reference's type must be good for the lifetime of the variable.
   The reference's lifetime must enclose that of the variable.
   => how *small* a reference's lifetime can be.

We should have

```
let a = 2;
{
```

```
        let x = &a;
        assert_eq!(*x,2);
}
```

Slices

Slices are similar to arrays, but their length is not known at compile time. Instead, a slice is a two-word object, the first word is a pointer to the data, and the second word is the length of the slice.
The word size is the same as usize, determined by the processor architecture eg 64 bits on an x86-64.
Slices can be used to borrow a section of an array, and have the type signature `&[T]`."

```
use std::mem;

// This function borrows a slice
fn analyze_slice(slice: &[i32]) {
    println!("first element of the slice: {}", slice[0]);
    println!("the slice has {} elements", slice.len());
}
```

```
fn main() {
    // Fixed-size array (type signature is superfluous)
    let xs: [i32; 5] = [1, 2, 3, 4, 5];

    // All elements can be initialized to the same value
    let ys: [i32; 500] = [0; 500];

    // Indexing starts at 0
    println!("first element of the array: {}", xs[0]);
    println!("second element of the array: {}", xs[1]);

    // `len` returns the count of elements in the array
    println!("number of elements in array: {}", xs.len());

    // Arrays are stack allocated
    println!("array occupies {} bytes", mem::size_of_val(&xs));
```

```
    // Arrays can be automatically borrowed as slices
    println!("borrow the whole array as a slice");
    analyze_slice(&xs);

    // Slices can point to a section of an array
    // They are of the form [starting_index..ending_index]
    // starting_index is the first position in the slice
    // ending_index is one more than the last position in the
slice
    println!("borrow a section of the array as a slice");
    analyze_slice(&ys[1 .. 4]);

    // Out of bound indexing causes compile error
    println!("{}", xs[5]);
}
```

See

[Arrays - TutorialsPoint]

[Arrays and Slices - RustBook]

Printing / Outputting

See Docs

There are many options

- `format!`: write formatted text to `String`
- `print!`: same as `format!` but the text is printed to the console (io::stdout).
- `println!`: same as `print!` but a newline is appended.
- `eprint!`: same as `print!` but the text is printed to the standard error (io::stderr).
- `eprintln!`: same as `eprint!` but a newline is appended.

We commonly use `println!`

The braces `{}` are used to format the output and will be replaced by the arguments
For example

```
println!("{} days", 31);
```

You can have positional or named arguments

For *positional* specify an index

For example

```
println!("{0}, this is {1}. {1}, this is {0}", "Alice", "Bob");
```

For *named* add the name of the argument within the braces

```
println!("{subject} {verb} {object}",
                 object="the lazy dog",
                 subject="the quick brown fox",
                 verb="jumps over");
```

A `crate` is a binary or library, a. number of these (plus other resources) can form. a `package` , which will contain a *Cargo.toml* file that describes how to build those crates.
A crate is meant to group together some functionality in a way that can be easily shared with other projects.
A package can contain at most one library crate, but. any number of binary crates.
There can be further refinement with the use of `modules` which organise code within a crate and can specify the privacy (public or private) of the code.
Module code is private by default, but you can make definitions public by adding the `pub` keyword.

Macros

see Docs

Macros allow us to avoid code duplication, or define syntax for DSLs.
Examples of Macros we have seen are

`vec!` to create a Vector

```
let names = vec!["Bob", "Frank", "Ferris"];
```

`println!` to output a line

```
println!("The value of number is: {}", number);
```

Hashmaps

See Docs
and examples

Where vectors store values by an integer index, `HashMap`s store values by key. `HashMap` keys can be booleans, integers, strings, or any other type that implements the `Eq` and `Hash` traits.

Like vectors, `HashMap`s are growable, but HashMaps can also shrink themselves when they have excess space.
You can create a HashMap with a certain starting capacity using `HashMap::with_capacity(uint)`, or use `HashMap::new()` to get a HashMap with a default initial capacity (recommended).

An example inserting values

```
use std::collections::HashMap;
let mut scores = HashMap::new();
scores.insert(String::from("Blue"), 10);
scores.insert(String::from("Yellow"), 50);
```

You can use an iterator to get values from the hashmap

```
let mut balances = HashMap::new();

balances.insert("132681", 12);
balances.insert("234987", 9);


for (address, balance) in balances.iter() {

```

```
        ...
}
```

Using the get method

The get method on a hashmap returns an `Option<&V>` where V is the type of the value

```
fn main() {
    use std::collections::HashMap;

    let mut scores = HashMap::new();

    scores.insert(String::from("Blue"), 10);
    scores.insert(String::from("Yellow"), 50);

    let team_name = String::from("Blue");
    let score = scores.get(&team_name).copied().unwrap_or(0);
}
```

This program handles the `Option` by calling `copied` to get an `Option<i32>` rather than an `Option<&i32>`, then `unwrap_or` to set `score` to zero if `scores` doesn't have an entry for the key.

Rust - (more) pattern matching

See Docs

Ignoring values and matching literals

We can use `_` to show we are ignoring a value, or to show a default match, where we don't care about the actual value.

```
    let x = ...;

    match x {
        1 => println!("one"),
        3 => println!("three"),
        5 => println!("five"),
        _ => println!("some other value"),
    }
```

Ranges

Use `..=`

For example

```
let x = 5;
match x {
        1..=5 => println!("one through five"),
        _ => println!("something else"),
}
```

Variables

Be aware the match starts a new scope, so if you use a variable it may shadow an existing variable.

```
let x = Some(5);
let y = 10;
match x {
```

```
        Some(50) => println!("Got 50"),
        Some(y) => println!("Matched, y = {y}"),
        _ => println!("Default case, x = {:?}", x),
}
println!("at the end: x = {:?}, y = {y}", x);
```

What we get printed out is

`Matched, y = 5`.

`x = Some(5), y = 10`.

Destructuring

We can destructure structs and match on their constituent parts

For example

```
fn main() {
let p = Point { x: 0, y: 7 };
match p {
        Point { x, y: 0 } => println!("On the x axis at {}",
```

```
x),
        Point { x: 0, y } => println!("On the y axis at {}",
y),
        Point { x, y } => println!("On neither axis: ({}, {})",
x, y), }
}
```

Adding further expressions

```
let num = Some(4);
match num {
        Some(x) if x % 2 == 0 => println!("The number {} is
even", x),
        Some(x) => println!("The number {} is odd", x),
        None => (),
}
```

Writing tests in Rust

See Docs
See examples

A test in Rust is a function that's annotated with the `test` attribute

To change a function into a test function, add `#[test]` on the line before `fn`.
When you run your tests with the `cargo test` command, Rust builds a test runner binary that runs the annotated functions and reports on whether each test function passes or fails.

```
#[cfg(test)] mod tests {
#[test]
fn simple_example() {
        let result = 3 + 5;
        assert_eq!(result, 8);
```

```
        }
}
```

The `#[cfg(test)]` annotation on the tests module tells Rust to compile and run the test code only when you run `cargo test`, not when you run `cargo build`.

Rust Errors etc.

Rust distinguishes between recoverable and un recoverable errors, we will handle these errors differently

1. Recoverable errors
   With these we will probably want to notify the user, but there is a clear structured way to proceed. We handle these using the type
   `Result<T, E>`
   `enum Result<T, E> { Ok(T), Err(E), }`
   Many standard operations will return a type of `Result` to allow for an error
   A good pattern to handle this is to use matching

```
let f = File::open("foo.txt"); // returns a Result
let f = match f {
        Ok(file) => file,
```

```
                Err(error) => // some error. handling
                }
```

You can propagate the error back up the stack if that is appropriate

```
let mut f = match f {
        Ok(file) => file,
        Err(e) => return Err(e),
};
```

The ? Operator

A shortcut for propagating errors is to use the ? operator

```
let mut f = File::open("hello.txt")?;
```

The `?` placed after a `Result` value works in almost the same way as the `match` expressions.
If the value of the `Result` is an `Ok`, the value inside the `Ok` will get returned from this expression, and the program will continue.
If the value is an `Err`, the `Err` will be returned from the whole function as if we had used the `return` keyword so the error value gets propagated to the calling code.

2. Un recoverable errors
   In this case, we have probably come across a bug in the code and there is no safe way to proceed. We handle these with the `panic!` macro
   For a discussion of when to use `panic!` see the docs

When the `panic!` macro executes, your program will print an error message, unwind and clean up the stack, and then quit.
We can specify the error message to be produced as follows

```
panic!("Bug found ....");
```

Traits examples in Solana

A trait tells the Rust compiler about the functionality of a generic type and defines shared behaviour. Traits are often called interfaces in other languages, although with some differences.

A `trait` is a collection of methods defined for an unknown type: `Self`. Trait methods can access other trait methods.

```
trait Details {
    fn get_owner(&self) -> &Pubkey;
    fn get_admin(&self) -> &Pubkey;
    fn set_owner(&self) -> &Pubkey;
    fn set_admin(&self) -> &Pubkey;
    fn get_amount(&self) -> u64;
    fn set_amount(&self);
    fn print_details(&self) {
            println!("Owner is {:?}", self.get_owner())
```

```
            println!("Admin is {:?}", self.set_admin())
            println!("Amount is {}", self.get_amount())
    }
}
```

If certain methods are frequently reused between structs, it makes sense to define a trait.

Implementations

Implementations are defined with the `impl` keyword and contain functions that belong to an instance of a type, statically, or to an instance that is being implemented.

For a struct `AccountA` representing the layout of data on chain:

```
pub struct AccountA {
        pub admin: Pubkey,
        pub owner: Pubkey,
```

```
        pub amount: u64,
}
```

To implement previously defined abstract functions of the trait `Details`:

```
impl Details for AccountA {
        fn get_owner(&self) -> &Pubkey {
                        &self.owner
        }
        fn get_admin(&self) -> &Pubkey {
                        &self.admin
        }
        ...
}
```

In Solana this is often used for instructions relating to serialisation of the data stored under a given account:

```
impl AccountA {
        fn unpack(input: &[u8]) -> Result<Self, ProgramError> {
                ...
        }

        fn pack(&self, dst: &mut [u8]) {
                ...
        }
}
```

Then in the processor bare bytes can be converted to a usable struct as simply as

```
let mut account_temp = AccountA::unpack(ADDRESS)?;
```

Solana Development

Solana Programs overview

See Docs

- Programs process instructions from both end users and other programs
- All programs are *stateless*: any data they interact with is stored in separate accounts that are passed in via instructions
- Programs themselves are stored in accounts marked as `executable`
- All programs are owned by the BPF Loader and executed by the Solana Runtime
- Developers most commonly write programs in Rust or C++, but can choose any language that targets the LLVM's BPF backend
- All programs have a single entry point where instruction processing takes place (i.e. `process_instruction`); parameters

always include:

- `program_id`: `pubkey`
- `accounts`: `array`,
- `instruction_data`: `byte array`

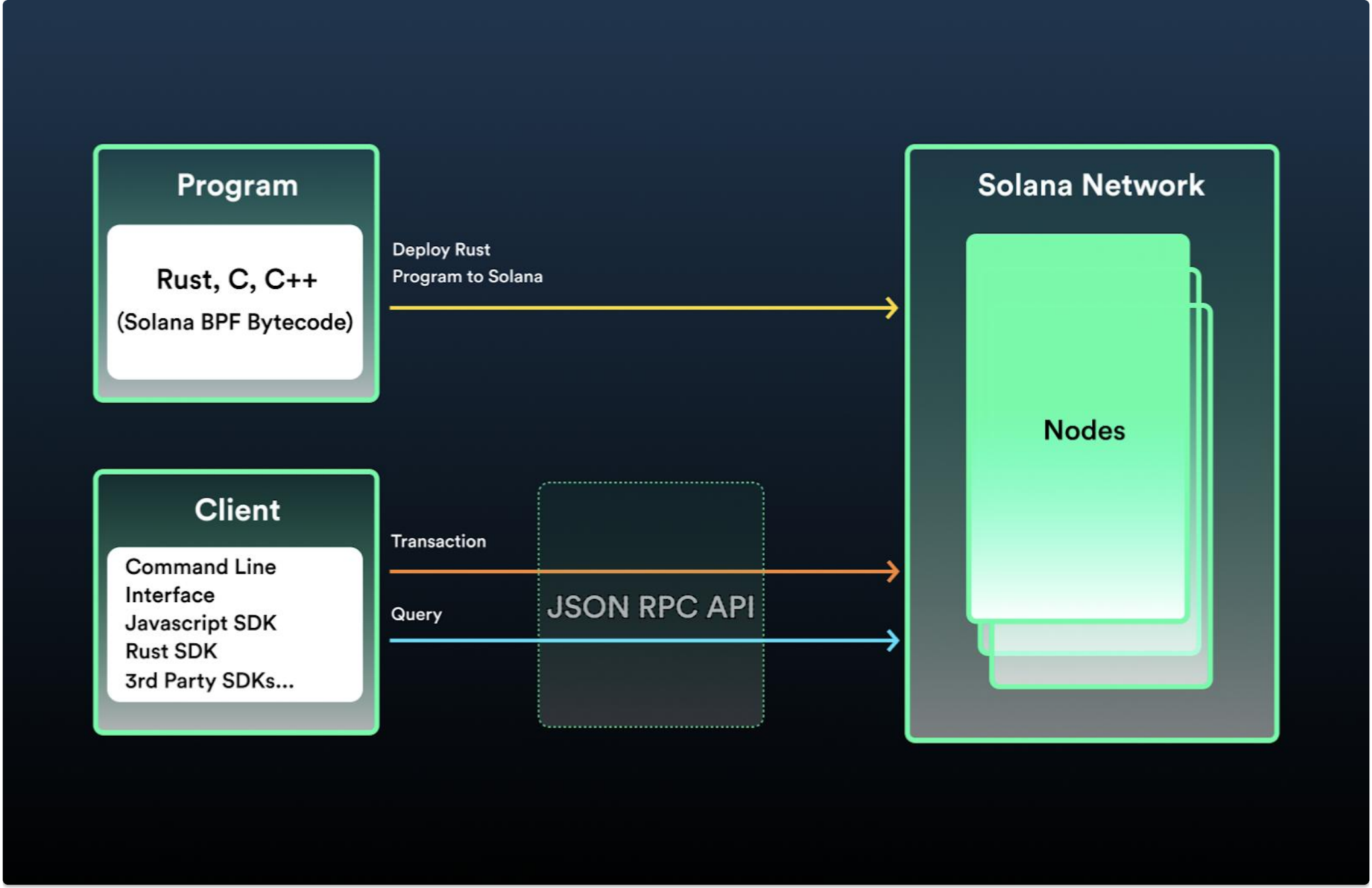
From Cookbook

Clients can invoke programs by submitting a transaction to a cluster. A single transaction can include multiple instructions, each targeting its own program. When a transaction is submitted, the Solana Runtime will process its instructions in order and atomically. If any part of an instruction fails, the entire transaction will fail.

dApp architecture

dApps on Solana have the following parts:

- accounts on Solana chain, which store program binaries and state data
- client that interacts with on-chain accounts using RPC nodes
- additional components such as storage (Arweave/IPFS), task scheduler (Cronos) or input from outside world (Chainlink)

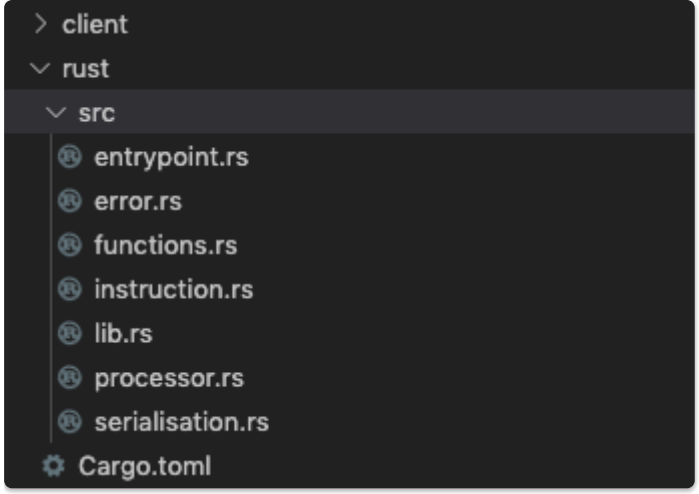


On-chain program architecture

Solana programs (ie a smart contracts) are generally composed of distinct modules, with each module represented by an individual Rust file:

- entrypoint
- instruction
- processor
- state
- error

This is to make reading, maintaining and testing code easier, for smaller projects it is fine to encapsulate total program functionality within a single file. It's up to the designer to break down intended business logic into sensible module layout.



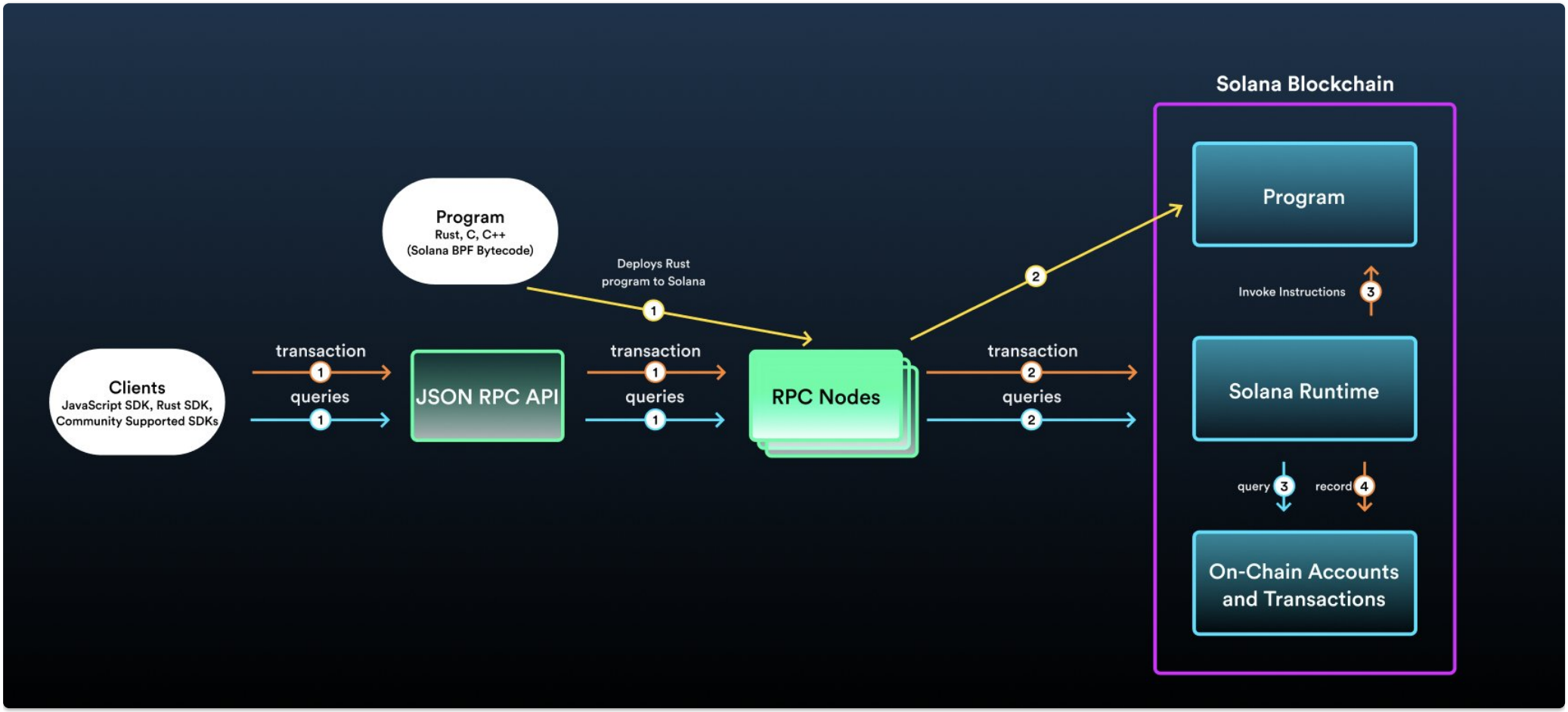
Cargo project architecture

Project set-up will look slightly differently depending on whether Anchor is used or not and whether you are developing the front end or only the smart contracts. Further deviations can come from customisation of the `Cargo.toml` which can be configured in different ways such as where `target` directory is located.

Rust project set-up (including Solana development) generally has the following directories:
- src: logic of the program that will be deployed on chain
- target: binary for deployment and files needed for compilation
- tests: tests for the smart contract

- Cargo.toml: Rust manifest file containting dependencies
- Cargo.lock: autogenerated dependency file

Details about RPC



All client interaction with the Solana network happens through Solana's [JSON RPC API].

This means sending JSON object representing a program you want to call, method within that program and arguments to this method which includes list of utilised accounts.

Example of object that can be sent to an RPC node.

```
payload = {
  "jsonrpc": "2.0",
  "id": 1,
  "method": "getBalance",
  "params": [
    "KEY"
  ]
}
```

- `jsonrpc` - The JSON RPC version number. It needs to be `2.0`
- `id` - An identifier specified for this call, it can be a string or a whole number.

- `method` - The name of the method you want to invoke.
- `params` - An array containing the parameters to use during the method invocation.

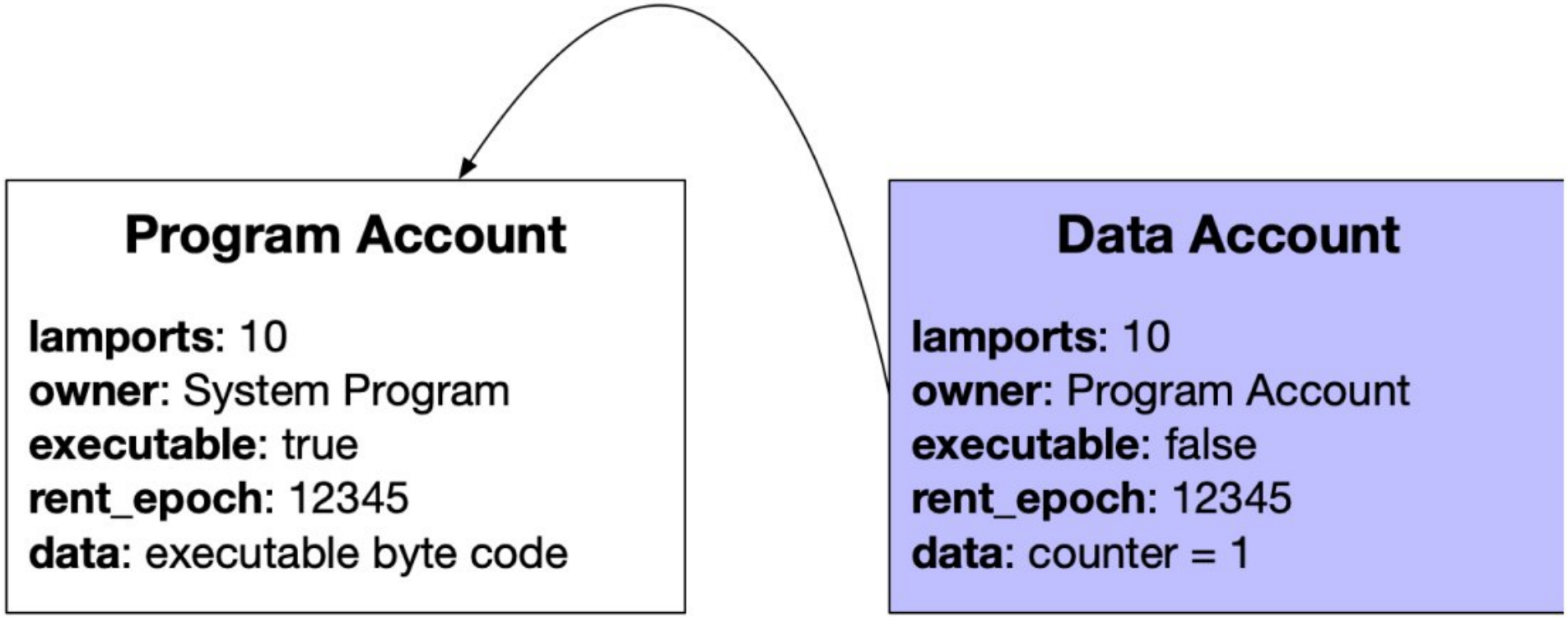
Interaction with RPC nodes is achieved using and SDK developed by solana labs.
This library (`@solana/web3.js`) abstracts away significant amount of boilerplate code meaning you can invoke functions rather than having to assemble each time JSON.

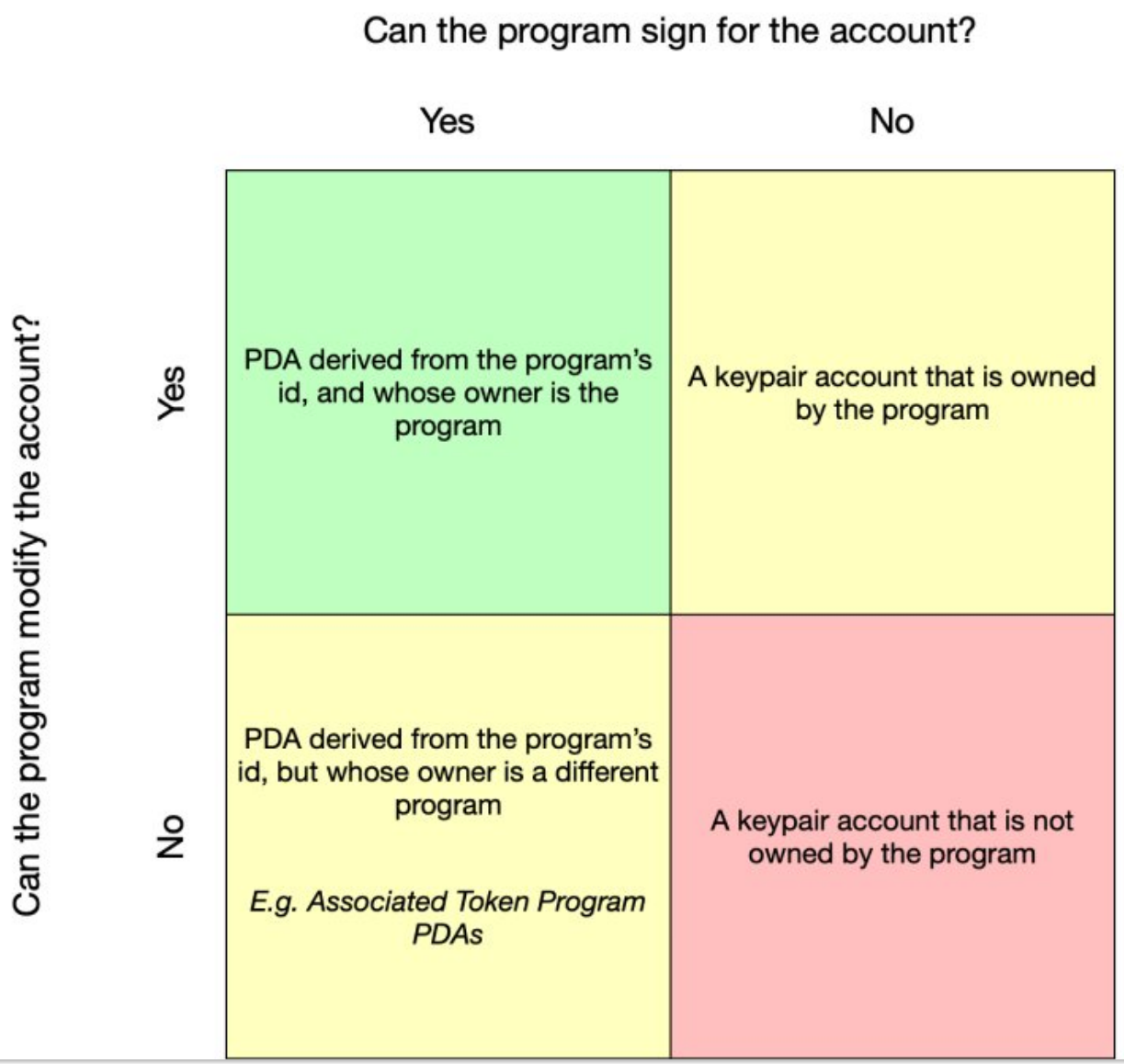
A list of available methods is here but these methods are not the same as the methods within a given program.
They are much broader and additional work including serialisation has to be done.
Thankfully there are libraries such as borsh or frameworks such as anchor to make it easier.

Programs in more detail

See Docs

Programs and accounts




Can the program sign for the account?
Yes
No
Can the program modify the account?
Yes
No
PDA derived from the program's id, and whose owner is the program
A keypair account that is owned by the program
PDA derived from the program's id, but whose owner is a different program
E.g. Associated Token Program PDAs
A keypair account that is not owned by the program

Programs are stateless so how do we handle state ?

We need to create other non-executable accounts and set the program as the owner of those accounts.
The program can then the update data of this 'storage' account.

A system account is one that was created by the Solana system program. It is typical that these are often considered a wallet conceptually.
This program is owned by the SystemProgram.

```
Public Key: 8wFGJ5ae5q2nGvcmwSrqxUy8MmHwKMejTV81Bm91RgNw
Balance: 499999997.75602299 SOL
Owner: 11111111111111111111111111111111
Executable: false
Rent Epoch: 0
```

This is an empty account owned by a program.

```
Public Key: 5WBMTK8B3g9b3fkFbS18WRWvxA52MjtDhpVPZF6Ti6zq
Balance: 0.00103008 SOL
Owner: 2pUPsC4tBLePhaX8XbU8hHRUMuZ4MGxhmBHDAWRAfapu
Executable: false
Rent Epoch: 0
Length: 20 (0x14) bytes
0000:   00 00 00 00  00 00 00 00  00 00 00 00  00 00 00 00
0010:   00 00 00 00
```

This is an on chain program owned by the BPFLoader.

```
Public Key: 2pUPsC4tBLePhaX8XbU8hHRUMuZ4MGxhmBHDAWRAfapu
Balance: 0.00114144 SOL
Owner: BPFLoaderUpgradeab1e11111111111111111111111
Executable: true
Rent Epoch: 0
Length: 36 (0x24) bytes
0000:   02 00 00 00  56 d7 56 a2  e0 d7 62 75  d4 0b f4 5e
0010:   e8 6e b9 ef  9d 30 fc fe  d2 aa 3e f0  d7 a4 eb e6
0020:   14 1f 8c ad
```

Program arguments

Every program has a single entry point and it receives instructions composed of three distinct parts:

- program id
- accounts
- instruction data

```
pub fn process_instruction(
    _program_id: &Pubkey,
    _accounts: &[AccountInfo],
    _instruction_data: &[u8],
) -> ProgramResult {
```

The program can return successfully, or with an error code. An error return causes the entire transaction to fail immediately.
On success you can not return any values, so in addition state has to be checked manually by the client.

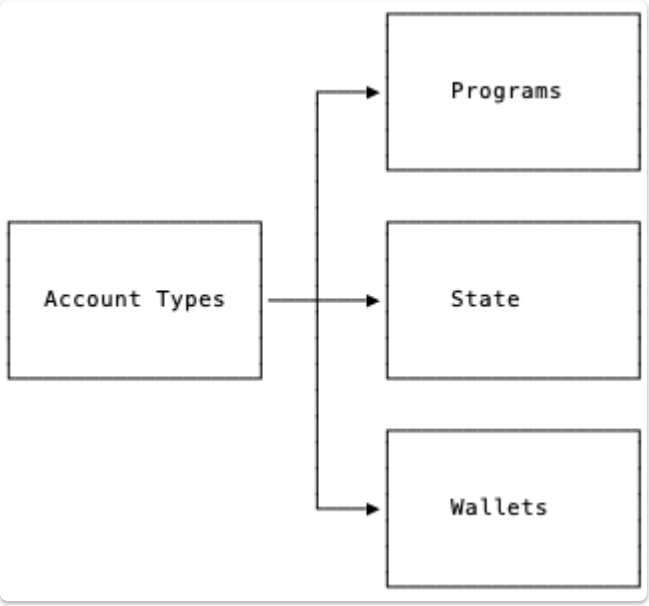
Program ID

The instruction's program_id specifies the Public key of the account being invoked. Though program's are statless they can inquire about

the ownership of a provided account that it is to attempt interacting with.

Accounts

The accounts referenced by an instruction represent all the on chain accounts that this program will interact with and serve as both the inputs and outputs of a program. Account can be either a program containing logic, data account containing state or users wallet.

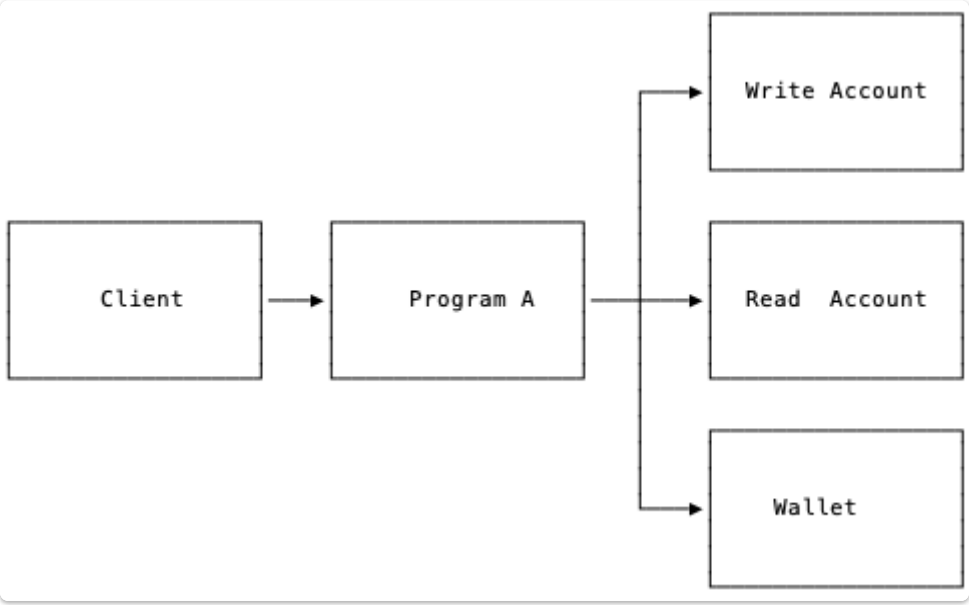


Account passed have to specify whether they will be read only or writeable.

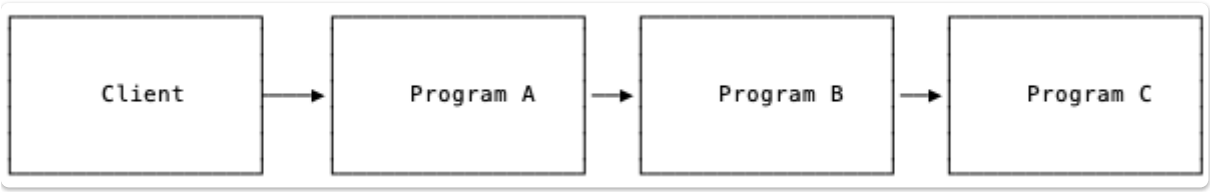
Account is a storage location on Solana blockchain. They store state like the amount of lamports, owner and state or logic data.

Each non-PDA account has a keypair with the public key being the address of that account.

Multiple accounts can be passed as the program might require them to accomplish it logic. It may require to read and modify state of other accounts or to transfer lamports.



Or it may require logic of other programs to supplement its own one.

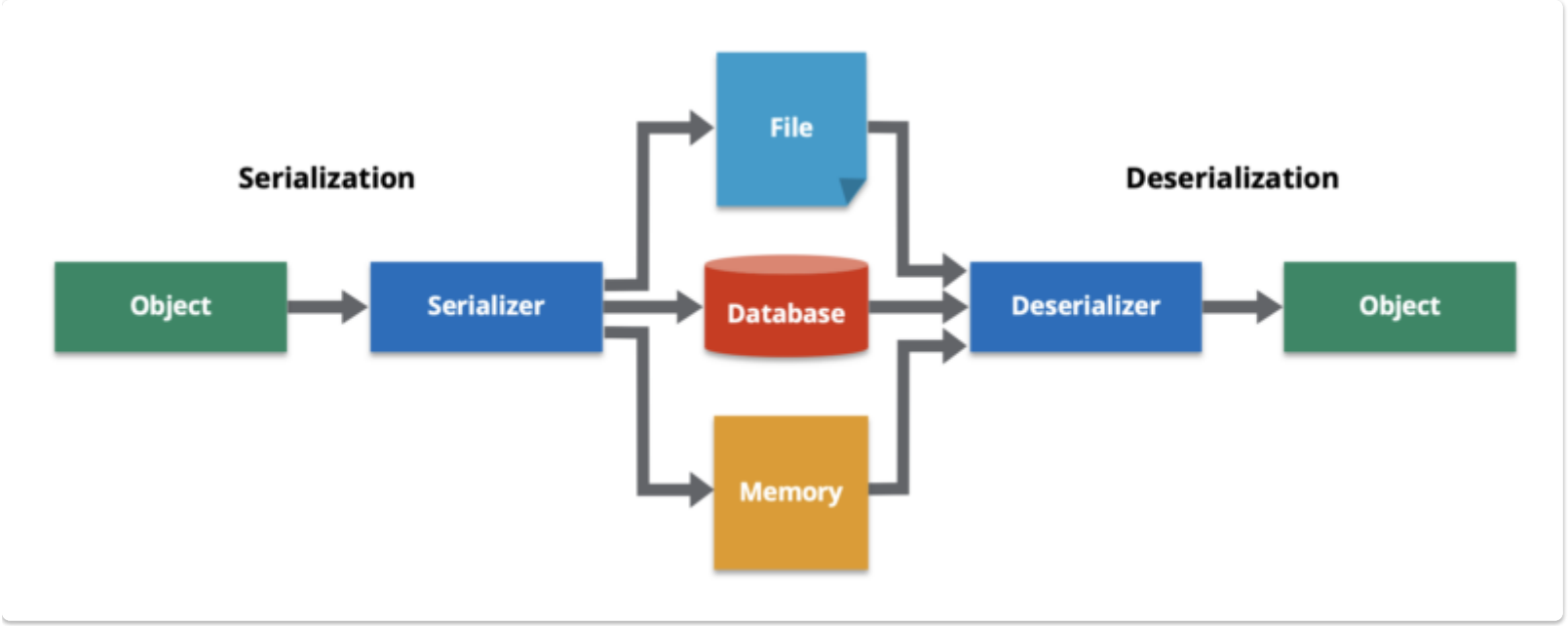


In future lessons we will look at Program Derived Addresses and how we use them when programs want to talk to each other.

Instruction data

Each instruction carries a general purpose byte array that is passed to the program along with the accounts. The contents of the instruction data is program specific and typically used to convey what operations the program should perform, and any additional information those operations may need above and beyond what the accounts contain.

Programs are free to specify how information is encoded into the instruction data byte array. The choice of how data is encoded should consider the overhead of decoding, since that step is performed by the program on-chain. It's been observed that some common encodings (Rust's bincode for example) are very inefficient.



A transaction can contain instructions in any order. This means a malicious user could craft transactions that may pose instructions in an order that the program has not been protected against. Programs should be hardened to properly and safely handle any possible instruction sequence.

Generic program flow

The basic program flow (excluding RPC call):

1. Serialised arguments (accounts, signatures, instruction) are received by the entrypoint
2. The entrypoint forwards the arguments to the processor module
3. The processor invokes the instruction module to decode the instruction argument
4. Using the decoded data, the processor will now decide which function to use to process this specific request
5. The processor may use the state module to encode state into or decode the state of an account which has been passed into the entrypoint or can be derived programatically
6. If error occurs at any point execution stops and program reverts with general or specific error code

Generic client flow

1. Load Interface Description Language (IDL)
2. Connect to the network
3. Assemble instruction
4. Submit instruction (RPC call)
5. Read modified account state (RPC call)

Development workflow

Developing a program involves iteration over the following steps:

1. Compilation of the Rust code to generate `.so` binary
2. Deployment of the `.so` binary to a cluster
3. Interaction with the program

Then re looping to add, modify, remove or test a given functionality.

Compilation

To compile a program the following command is run:

```
cargo build-bpf
```

`build-bpf` allows the Rust compiler to output Solana compatible Berkley Packet Filter bytecode.

This should be run from the program directory
using

`cd <PATH>`
to where there is `Cargo.toml` is located.

On the first compilation it will produce two files into the `/target/deploy directory`:

- `program_name.so` binary that can be deployed to the cluster
- `program_name-keypair.json` private key associated with this program

The name of the `program_name.so` and `program_name-keypair.json` files is set in `Cargo.toml` here:

```
[lib]
name = "program_name"
```

Deployment

The general format of the command to deploy a program is:

```
solana program deploy <PATH_TO_SO_BINARY>
```

You must have enough lamports in the network that the Solana client is connected to. Scripts can be written to automate deployment of multiple programs.

Interaction

Interacting with the program is dependent on what exactly the client is.
Language and libraries used will differ depending whether the client is a mobile application, a browser plugin or an embedded device.

Programs, State, Data, Rent, Fees

Solana stores only two things in on-chain accounts:

- program binary (and it's hash)
- arbitrary developer specified data

Any user data such as token balances, access rights can be stored in accounts.
Accounts is a bit of a confusing name and files would likely be more accurate. As a developer you chose what each account looks like and what kind of data it stores by defining the serialisation and deserialisation procedure.

We can look at the default example in the playground

Useful Solana Resources

Solana Cookbook - Accounts
Solana Docs - Accounts
Solana Wiki - Account model