Lesson13

This week

Monday - Stark theory / Circom
Tueday - Plonk Circuits, Noir, updates from Devcon
Wednesday - Identity applications
Thursday - Further cryptographic tools / review

STARK Theory, Circom

Polynomial Recap

A basic fact about polynomials and their roots is that if $p(x)$ is a polynomial, then $p(a) = 0$ for some specific value a,

if and only if there exists
a polynomial $q(x)$ such that
$(x - a)q(x) = p(x)$,

and therefore

$q(x) = \frac{p(x)}{(x-a)}$

and $deg(p) = deg(q) + 1$.

This is true for all roots

Process Overview

We are interested in Computational Integrity (CI), for example knowing that the Cairo program you wrote was computed correctly.

As with SNARKS we need to go through a number of transformations from the *trace* of our program, to the proof.
The first part of this is called arithmetisation, it involves taking our trace and turning it into a set of polynomials.

Our problem then becomes one where the prover that attempts to convince a verifier that the polynomial is of low degree (we will see why this is important later)

The verifier is convinced that the polynomial is of low degree if and only if the original computation is correct (except for an infinitesimally small probability).

Use of randomness

The prover uses randomness to achieve zero knowledge, the verifier uses randomness when generating queries to the prover, to detect cheating by the prover.

Succinctness and performance

Much of the work that is done in creating a proof is ensuring that it is succint and that it can be produced and verified in a reasonable time.

Arithmetisation

There are two steps

1. Generating an execution trace and polynomial constraints
2. Transforming these two objects into a single low-degree polynomial.

In terms of prover-verifier interaction, what really goes on is that the prover and the verifier agree on what the polynomial constraints are in advance.
The prover then generates an execution trace, and in the subsequent interaction, the prover tries to convince the verifier that the polynomial constraints are satisfied over this execution trace, unseen by the verifier.

The execution trace is a table that represents the steps of the underlying computation, where each row represents a single step

The type of execution trace that we're looking to generate must have the special trait of being succinctly testable — each row can be verified relying only on rows that are close to it in the trace, and the same verification procedure is applied to each pair of rows.

For example imagine our trace represents a running total, with each step as follows

Step	Amount	Total
0	0	0
1	5	5
2	2	7
3	2	9
4	3	12
5	6	18

If we represent the row as i , and the column as j , and the values as $A_{i,j}$
We could write some contraints about this as follows

$A_{0,2} = 0$

$\forall 1 >= i <= 5 : A_{i,2} - A_{i,1} - A_{i-1,2} = 0$

$A_{5,2} = 18$

These are linear polynomial constraints in $A_{i,j}$
Note that we are getting some succinctnesss here because we could represent a much larger number of rows with just these 3 constraints.

We want a verifier to ask a prover a very small number of questions, and decide whether to accept or reject the proof with a guaranteed high level of accuracy.
Ideally, the verifier would like to ask the prover to provide the values in a few (random) places in the execution trace, and check that the polynomial constraints hold for these places.
A correct execution trace will naturally pass this test.

However, it is not hard to construct a completely wrong execution trace (especially if we knew beforehand which points would be tested) , that violates the constraints only at a single place, and, doing so, reach a completely far and different outcome.
Identifying this fault via a small number of random queries is highly improbable.

But polynomials have some useful properties here
Two (different) polynomials of degree *d* evaluated on a domain that is considerably larger than *d* are different almost everywhere.
So if we have a dishonest prover, that creates a polynomial of low degree representing their trace (which is incorrect at some point) and evaluate it in a large domain, it will be easy to see that this is different to the *correct* polynomial.

Our plan is therefore to

1. Rephrase the execution trace as a polynomial
2. extend it to a large domain, and
3. transform that, using the polynomial constraints, into yet another polynomial that is guaranteed to be of low degree if and only if the execution trace is valid.

A more complex example

See article
Imagine our code calculates the first 512 Fibonacci sequence
1,1,2,3,5 ...

If we decide to operate on a finite field with max number 96769
And we have calculated that the 512th number is 62215.

Then our constraints are

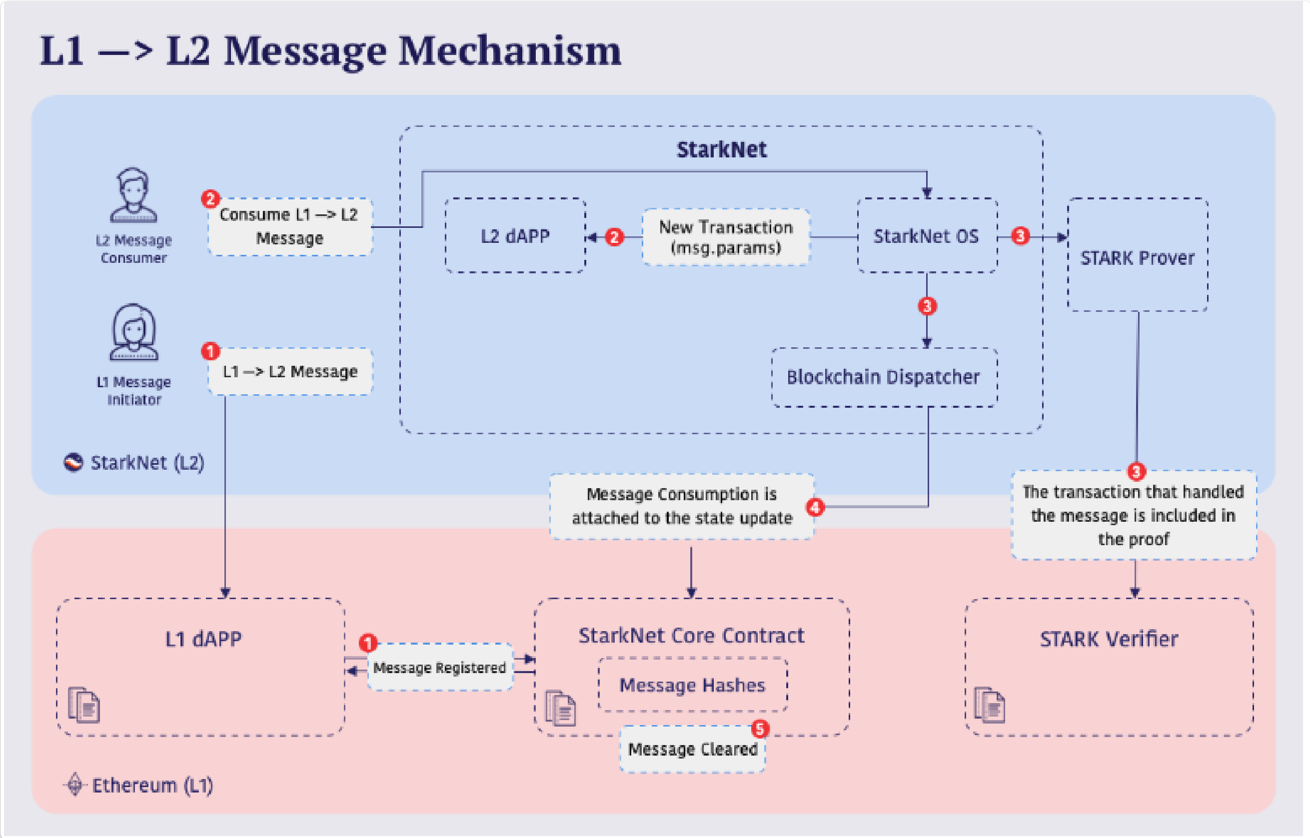
$A_{0,2} - 1 = 0$
$A_{1,2} - 1 = 0$

$\forall 0 >= i <= 510 : A_{i+2,2} = A_{i+1,2} + A_{i,2}$

$A_{511,2} - 62215 = 0$

Starknet Ecosystem

L1 to L2 Messaging

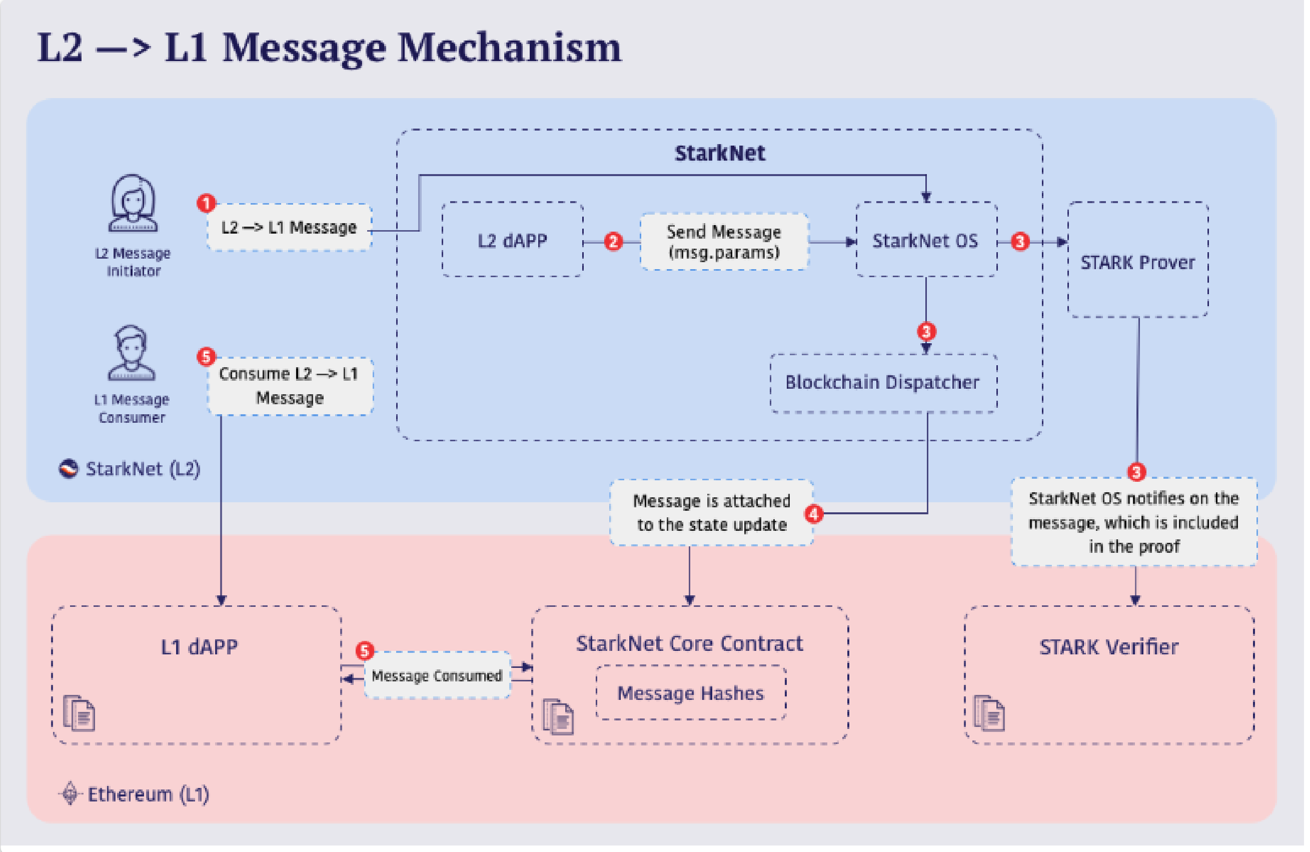


1. The L1 contract calls (on L1) the `send_message()` function of the StarkNet core contract, which stores the message. In this case the message includes an additional field - the "selector", which determines what function to call in the corresponding L2 contract.
2. The StarkNet Sequencer automatically consumes the message and invokes the requested L2 function of the contract designated by the "to" address.

This direction is useful, for example, for "deposit" transactions.

Note that while honest Sequencers automatically consume L1 -> L2 messages, it is not enforced by the protocol (so a Sequencer may choose to skip a message). This should be taken into account when designing the message protocol between the two contracts.

L2 to L1 Mesaging



Messages from L2 to L1 work as follows:

1. The StarkNet (L2) contract function calls the library function `send_message_to_l1()` in order to send the message. It specifies:
    1. The destination L1 contract (“to”),
    2. The data to send (“payload”)

    The StarkNet OS adds the “from” address, which is the L2 address of the contract sending the message.

2. Once a state update containing the L2 transaction is accepted on-chain, the message is stored on the L1 StarkNet core contract, waiting to be consumed.

3. The L1 contract specified by the “to” address invokes the `consumeMessageFromL2()` of the StarkNet core contract.

Note: Since any L2 contract can send messages to any L1 contract it is recommended that the L1 contract check the “from” address before processing the transaction.

Starkgate Token Bridge

There are bridges for each token type available

Steps for Deposit

1. Call The Deposit Function on L1
    - Transfers the funds from the user account to the StarkNet bridge
    - Emits a deposit event
    - Sends a message to the relevant L2 bridge with details. The sequencer will now be aware of this.
2. Deposit Triggered on StarkNet
    - Mints the relevant token on starknet
3. A proof of the state change is created and accepted on L1.

Steps for Withdraw

1. Call The Withdraw Function on L2
    1. Burns the tokens on starknet
    2. Informs the L1 bridge with the details
2. A proof of the state change is created and accepted on L1.
3. Transfer The funds On L1 by calling the withdraw function on the L1 core contract.

Transfer Limits

Token	Max deposit	Max total value locked
ETH	0.25 Eth	320 Eth
DAI	50 Dai	100,000 Dai

Flash Loans on Starknet

https://github.com/tohrnii/flashloan-starknet/blob/main/contracts/FlashLoanLender.cairo

Circom

See repo and documentation
Circom is DSL that can be used to create circuits, which can then be used in SNARK proofs.

You then compile this which gives you

1. An R1CS file
2. A C++ file needed to compute the witness
   This produced a `witness.wtns` file.

You can then use the `snarkjs` tool to generate and validate a proof for our input.

- Firstly you need to do the trusted setup
- You can then create proving and verification keys
- With the proving key you can generate a proof
  This has two files, the proof, and the public inputs
- With the verification key you can create a smart contract verifier.

One of the advantages of Circom is that it has templates for common circuits to allow you to quickly build more complex circuits.

Installing Circom

`git clone https://github.com/iden3/circom.git`

Enter the circom directory and build with cargo

`cargo build --release`

Install snarkjs

`npm install -g snarkjs`

Writing circuits

Taken from the documentation

Circom allows programmers to define the constraints that define the arithmetic circuit. All constraints must be of the form `A*B + C = 0`, where `A`, `B` and `C` are linear combinations of signals.

You can define contraints in this way

```
pragma circom 2.0.0;

```

```
/*This circuit template checks that c is the multiplication of a and b.*/

template Multiplier2 () {

   // Declaration of signals.
   signal input a;
   signal input b;
   signal output c;

   // Constraints.
   c <== a * b;
}
```

Signals

The arithmetic circuits built using circom operate on signals
Signals can be named with an identifier or can be stored in arrays and declared using the keyword signal.
Signals can be defined as input or output, and are considered intermediate signals otherwise.
Signals are by default private.
The programmer can distinguish between public and private signals only when defining the main component, by providing the list of public input signals.

```
pragma circom 2.0.0;

template Multiplier2(){
   //Declaration of signals
   signal input in1;
   signal input in2;
   signal output out;
   out <== in1 * in2;
}

component main {public [in1,in2]} = Multiplier2();
```

Circom data types

- Field Element
  Integers mod the max field value, these are the default type.
- Arrays
  These hold items of the same type

```
var x[3] = [2,8,4];
var z[n+1];  // where n is a parameter of a template
var dbl[16][2] = base;
var y[5] = someFunction(n);
```

Templates and components

The mechanism to create generic circuits in Circom is the so-called templates.

They are normally parametric on some values that must be instantiated when the template is used.
The instantiation of a template is a new circuit object, which can be used to compose other circuits, so as part of larger circuits.

```
template tempid ( param_1, ... , param_n ) {
 signal input a;
 signal output b;

 .....

}
```

The instantiation of a template is made using the keyword component and by providing the necessary parameters.

`component c = tempid(v1,...,vn);`
The values of the parameters should be known constants at compile time.

Components

A component defines an arithmetic circuit has input signals, output signals and intermediate signals, and can have a set of constraints.
Components are immutable once instantiated.

```

template A(N){
   signal input in;
   signal output out;
   out <== in;
}

template C(N){
```

```
    signal output out;
    out <== N;
}
template B(N){
  signal output out;
  component a;
  if(N > 0){
     a = A(N);
  }
  else{
     a = A(0);
  }
}

component main = B(1);
```

We can create arrays of components.

```
template MultiAND(n) {
    signal input in[n];
    signal output out;
    component and;
    component ands[2];
    var i;
    if (n==1) {
        out <== in[0];
    } else if (n==2) {
          and = AND();
        and.a <== in[0];
        and.b <== in[1];
        out <== and.out;
    } else {
        and = AND();
    var n1 = n\2;
        var n2 = n-n\2;
        ands[0] = MultiAND(n1);
        ands[1] = MultiAND(n2);
        for (i=0; i<n1; i++) ands[0].in[i] <== in[i];
        for (i=0; i<n2; i++) ands[1].in[i] <== in[n1+i];
        and.a <== ands[0].out;
        and.b <== ands[1].out;
        out <== and.out;
    }
```

```
}
```

The main component

In order to start the execution, an initial component has to be given. By default, the name of this component is “main”, and hence the component main needs to be instantiated with some template.

This is a special initial component needed to create a circuit and it defines the global input and output signals of a circuit. For this reason, compared to the other components, it has a special attribute: the list of public input signals. The syntax of the creation of the main component is:

```
component main {public [signal_list]} = tempid(v1,...,vn);
```

```
pragma circom 2.0.0;

template A(){
    signal input in1;
    signal input in2;
    signal output out;
    out <== in1 * in2;
}

component main {public [in1]}= A();
```

Circom -> Cairo

See repo and take note of the caveats

Allows circom projects to be verified on Ethereum by exporting to Cairo

First write and compile a circuit and compute the witness through circom, then generate a validation key through snarkjs (this process is properly explained at https://docs.circom.io/getting-started/installation/), this will yield a .zkey, which we can use to generate a solidity verifier through the command:

```
snarkjs zkey export solidityverifier [name of your key].zkey [nme of the verifier produced]
```