

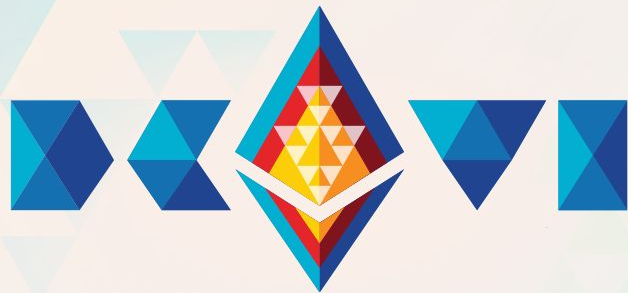


Modular rollup theory (through the lens of the OP Stack)

AKA you just watched Karl's talk and now you want to understand how this whole modular rollup architecture actually works

Kelvin Fichter

Building the Optimism Collective



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The background of the slide is a complex, abstract geometric pattern. It features a variety of triangles and lines in warm, muted colors including shades of orange, yellow, and light brown. These elements are arranged in a way that creates a sense of depth and movement, with some shapes appearing to overlap others. The overall effect is a textured, almost crystalline appearance that frames the central text.

Some context on this talk

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I'll be talking about the theory behind modular rollup architecture.



Some context on this talk

I'll be talking about the theory behind modular rollup architecture. The OP Stack is a software stack that turns this theory into practice.



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Also I'm going to use TypeScript types, TypeScript is a
tier don't @ me. I hope you enjoy!





Section 1

Modular rollups 101



The background features a complex geometric pattern of nested triangles, characteristic of fractals like the Sierpinski triangle. The pattern is composed of many small triangles that form larger triangular shapes. The colors transition from a warm orange-red on the left, through a pale yellow and light blue in the center, to a vibrant green and yellow on the right. The text "Some brief history" is centered in a dark, monospaced font.

Some brief history

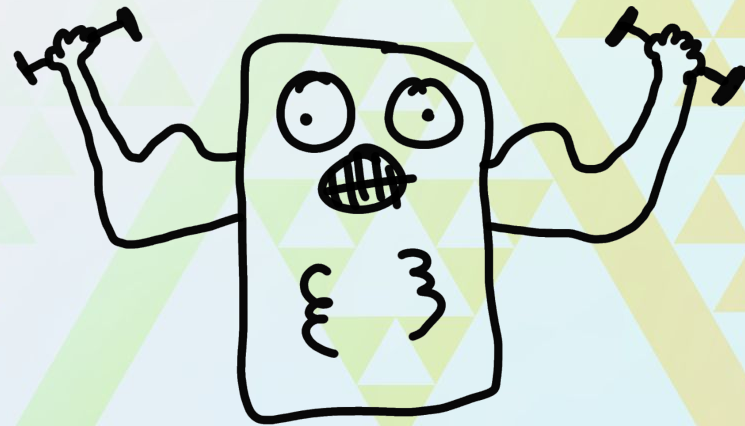
Some brief history

Back in 2020, everyone was building **monolithic rollups**.



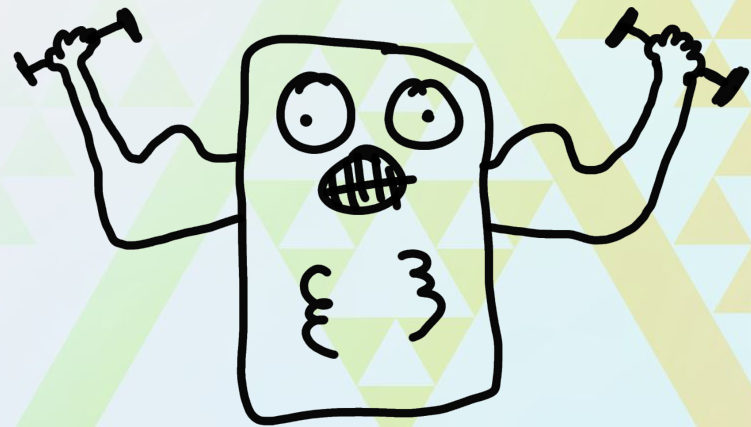
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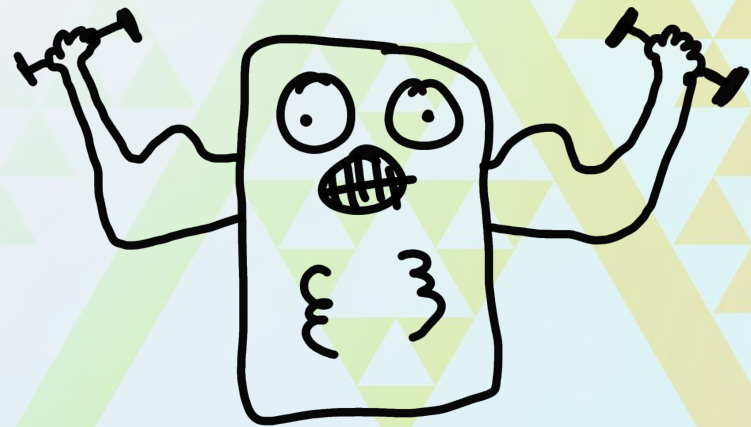
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Rollups were defined (and limited) by our proof systems.



Some brief history

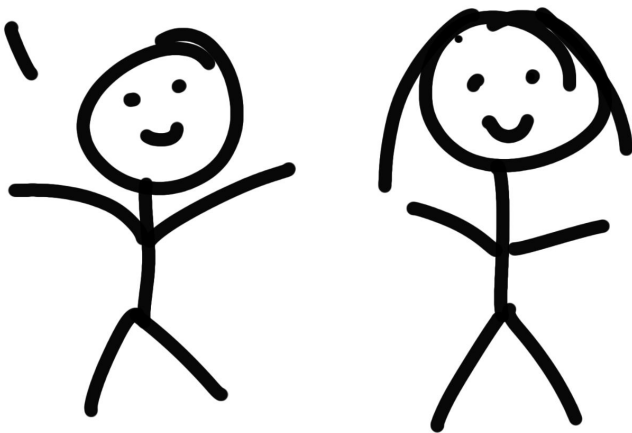
Back in 2020, everyone was building **monolithic rollups**. Rollups were defined (and limited) by our proof systems. We did this because we had no clue what we were actually building.



Some brief history

Back in 2020, everyone
Rollups were defined
We did this because
building.

how 2 rollup?



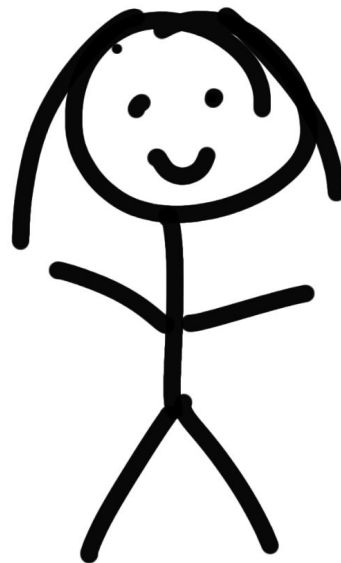
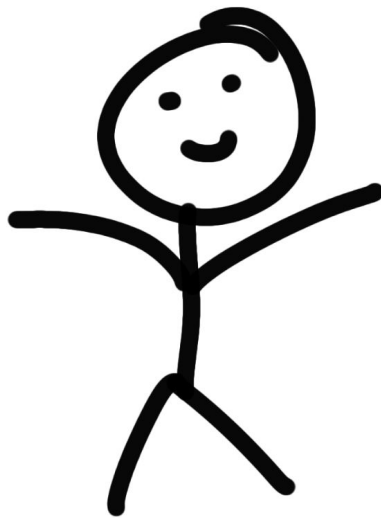
s.
s.
ally



Some history of history

Back in 2020, everyone
Rollups were defined
We did this because
building.

who knows



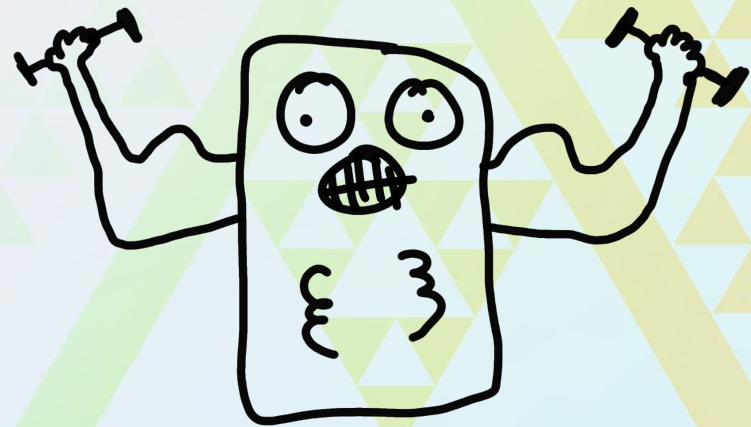
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Some brief history

Back in 2020, everyone was building **monolithic rollups**. Rollups were defined (and limited) by our proof systems. We did this because we had no clue what we were actually building.

Mental models are important!



Aside

Isn't that funny? We can work on things for a long time before we really start to understand what we're actually building.



Aside

Isn't that funny? We can work on things for a long time before we really start to understand what we're actually building. Anyway.



Then we finally kinda got it



Then we finally kinda got it

Between 2021 and 2022, we started to understand rollups more deeply.



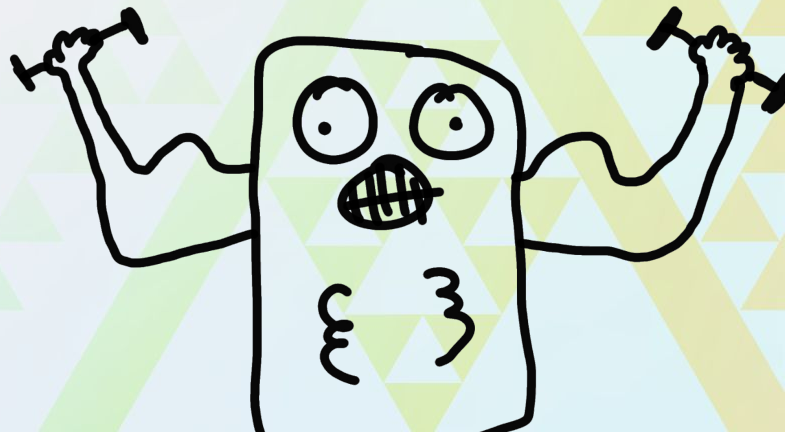
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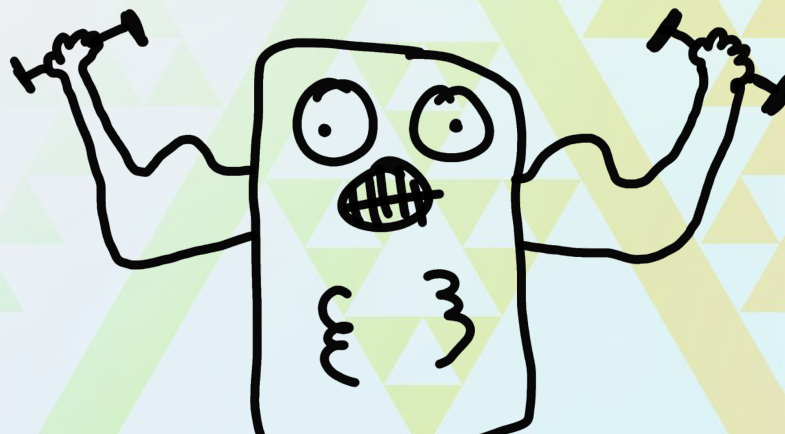
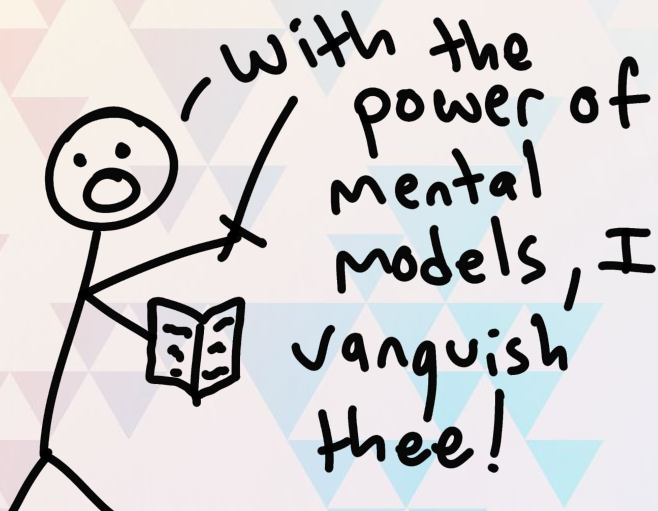
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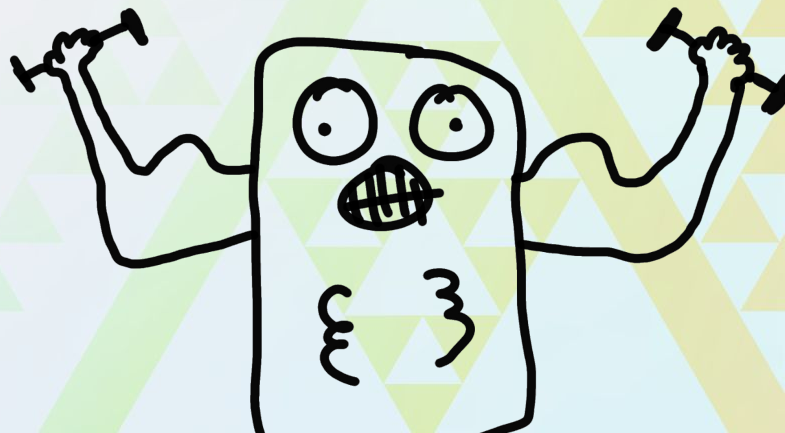
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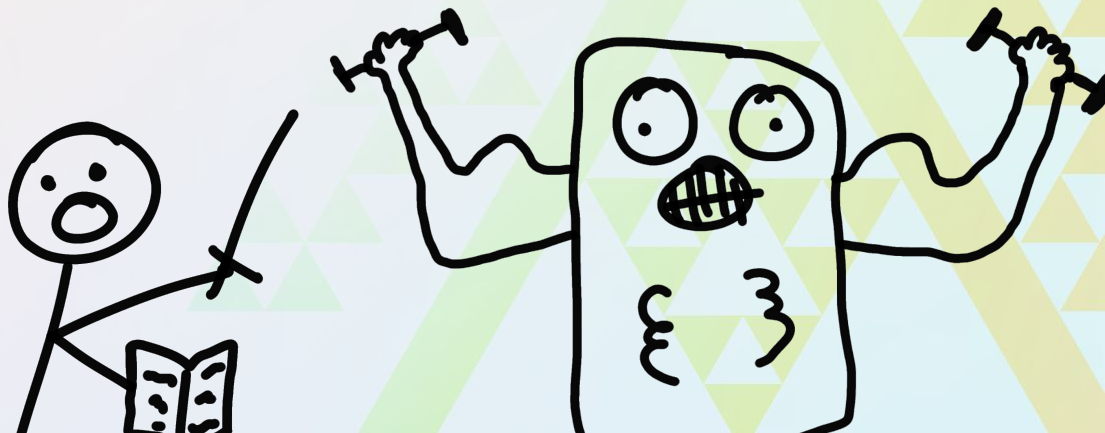
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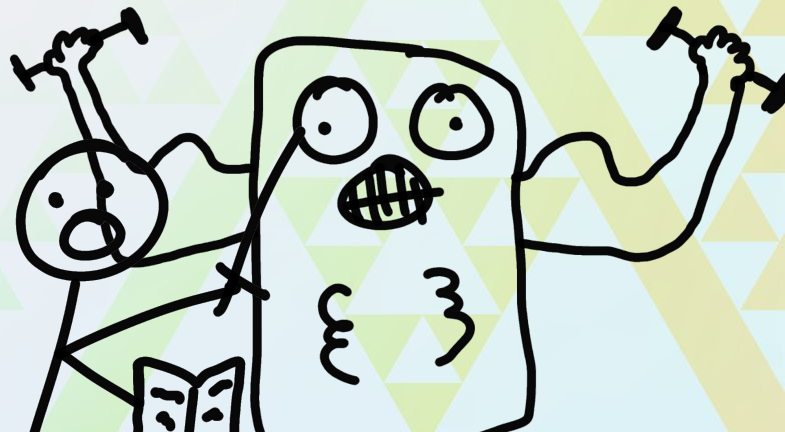
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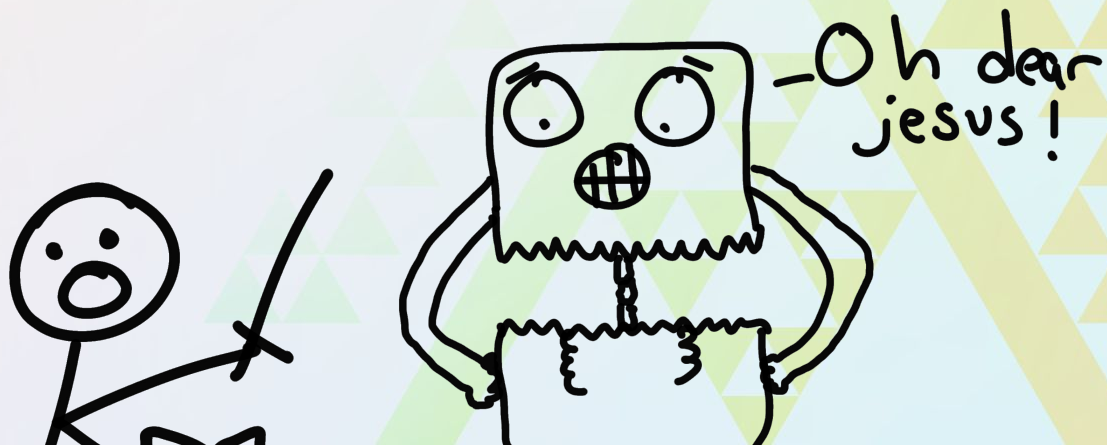
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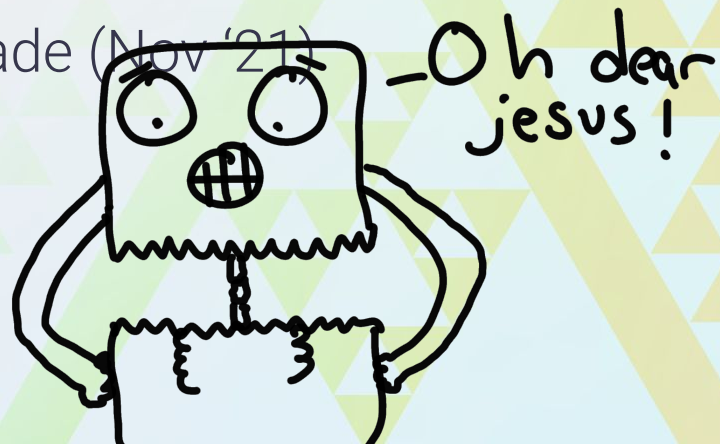
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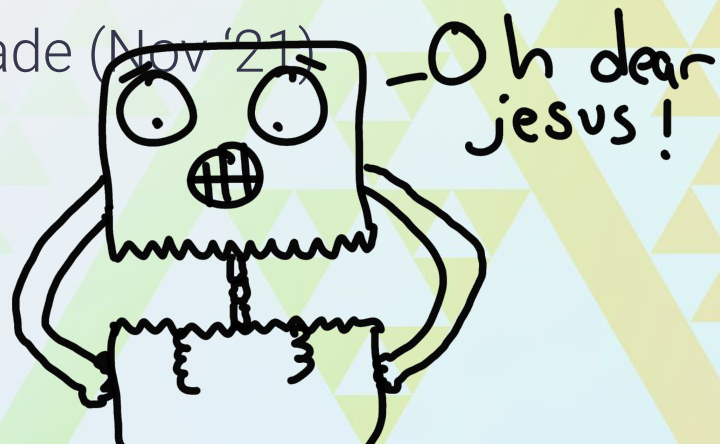
- Optimism's EVM Equivalence upgrade (Nov '21)



Then we finally kinda got it

Between 2021 and 2022, we started to understand rollups more deeply. We first came to realize that the proof should be fully separated from execution.

- Optimism's EVM Equivalence upgrade (Nov '21)
- Arbitrum's Nitro upgrade (Aug '22)

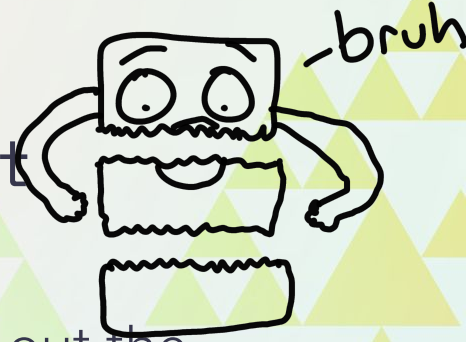


Then we finally kinda got it

We then also came to realize that we could break out the data availability layer.



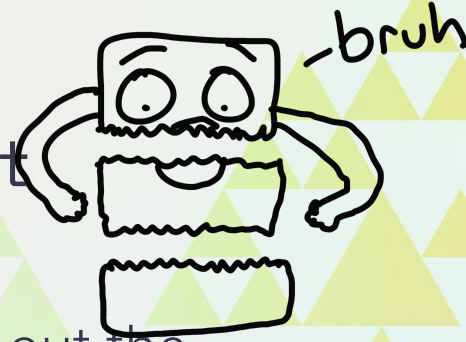
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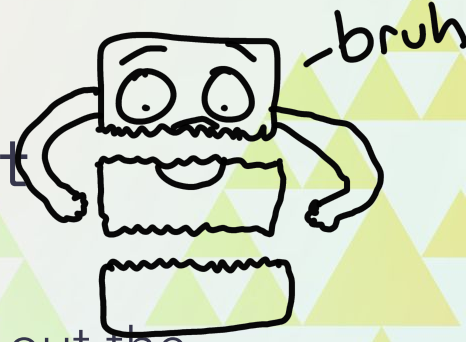


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- Metis forked Optimism and added a DA committee



Then we finally kinda got it



We then also came to realize that we could break out the data availability layer.

- Metis forked Optimism and added a DA committee
- Arbitrum releases Nova with a DA committee



Rollups were becoming modular!

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We generally saw rollups beginning to break down into three primary layers.



Rollups were becoming modular!

We generally saw rollups beginning to break down into three primary layers.

- Consensus



Rollups were becoming modular!

We generally saw rollups beginning to break down into three primary layers.

- Consensus
- Execution



Rollups were becoming modular!

We generally saw rollups beginning to break down into three primary layers.

- Consensus
- Execution
- Settlement



Isn't that just modular blockchains?

Isn't that just modular blockchains?

Yes.



Isn't that just modular blockchains?

Yes. But it was the theory of modular blockchains actually being put into practice.



Isn't that just modular blockchains?

Yes. But it was the theory of modular blockchains actually being put into practice. Instead of fun charts describing how different pieces might fit together, this was software actually fitting these pieces together!





It was time to make things official

It was time to make things official

This was modular blockchain design being put into practice, but it was messy and haphazard.



It was time to make things official

This was modular blockchain design being put into practice, but it was messy and haphazard.

You know what time it is!



It was time to make things official

This was modular blockchain design being put into practice, but it was messy and haphazard.

You know what time it is!

Formalization time!



It was time to make things official

This was modular blockchain design being put into practice, but it was messy and haphazard.

You know what time it is!

Formalization time!



Like, loosely formalized. I never graduated college.



Section 2

The Consensus Layer



The background is a complex geometric pattern. It features a large, faint, light-colored triangle in the center. Surrounding this are various smaller triangles and lines in shades of orange, yellow, and light blue. The overall effect is a modern, abstract design with a warm color palette.

Beep boop, bias warning

Beep boop, bias warning

I'm going to start using the abstractions that we defined as part of the OP Stack.



Beep boop, bias warning

I'm going to start using the abstractions that we defined as part of the OP Stack. I think these abstractions are good.



Beep boop, bias warning

I'm going to start using the abstractions that we defined as part of the OP Stack. I think these abstractions are good. Deal with it!



The background is a complex geometric pattern. It features large, faint triangles in shades of orange, yellow, and light blue. Overlaid on these are smaller, more vibrant triangles in red, purple, teal, and green. A series of parallel lines in orange, teal, and green also crisscross the composition, creating a layered, architectural feel.

The three primary layers

The three primary layers

- Consensus



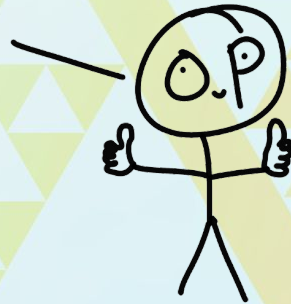
The three primary layers

- Consensus
 - Data Availability



The three primary layers

- Consensus
 - Data Availability
 - Derivation



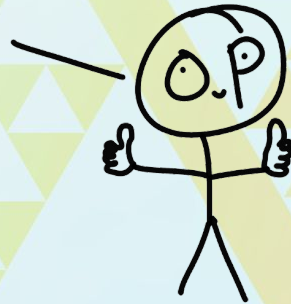
The three primary layers

- Consensus
 - Data Availability
 - Derivation
- Execution



The three primary layers

- Consensus
 - Data Availability
 - Derivation
- Execution
- Settlement



The three primary layers

- **Consensus**
 - **Data Availability**
 - **Derivation**
- Execution
- Settlement



The background is a complex, abstract geometric pattern. It features a large, light-colored triangle in the center, surrounded by smaller triangles and lines in various shades of orange, yellow, and light blue. The pattern is dense and layered, creating a sense of depth and movement.

We have two sub-components

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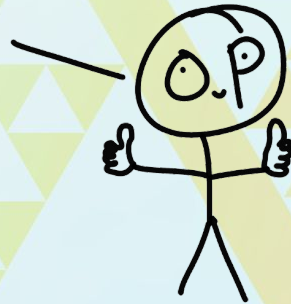
Data availability layer



We have two sub-components

Data availability layer

Derivation layer



What is the data availability layer even?

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It's where you post the data.



What is the data availability layer even?

It's where you post the data. Alright, fine, we can get slightly more formal.



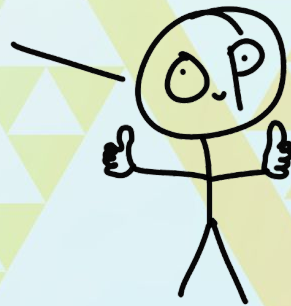
What is the data availability layer even?

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It's where you post the data. Alright, fine, we can get slightly more formal. It's an ordered list of blobs. Preferably an immutable append-only list, but that's an implementation detail.



What is the data availability layer even?

It's where you post the data. Alright, fine, we can get slightly more formal. It's an ordered list of blobs. Preferably an immutable append-only list, but that's an implementation detail.

type DA = bytes[]





Some examples of DA layers

Some examples of DA layers

- Ethereum (via calldata)



Some examples

```
// AdvanceL1Block advances the internal state of L1 Traversal
func (l1t *L1Traversal) AdvanceL1Block(ctx context.Context) error {
    origin := l1t.block
    nextL10origin, err := l1t.l1Blocks.L1BlockRefByNumber(ctx, origin.Number+1)
    if errors.Is(err, ethereum.NotFound) {
        l1t.log.Debug("can't find next L1 block info (yet)", "number", origin.Number+1, "origin", origin)
        return io.EOF
    } else if err != nil {
        return NewTemporaryError(fmt.Errorf("failed to find L1 block info by number, at origin %s next %d: %w", origin, origin.Number+1, err))
    }
    if l1t.block.Hash != nextL10origin.ParentHash {
        return NewResetError(fmt.Errorf("detected L1 reorg from %s to %s with conflicting parent %s", l1t.block, nextL10origin, nextL10origin.ParentHash))
    }
    l1t.block = nextL10origin
    l1t.done = false
    return nil
}
```



Some examples of DA layers

- Ethereum (via calldata)
- Ethereum (via 4844)



Some examples of DA layers

- Ethereum (via calldata)
- Ethereum (via 4844)
- Celestia



Some examples of DA layers

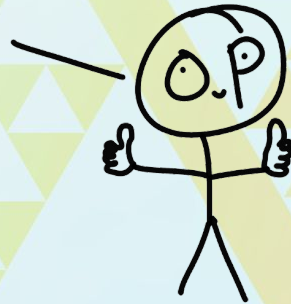
- Ethereum (via calldata)
- Ethereum (via 4844)
- Celestia
- A stack of post-its



Derivation is the more interesting one

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The derivation layer takes the data availability layer and the current state of the rollup and produces Engine API payloads.



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Why Engine API?



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The derivation layer takes the data availability layer and the current state of the rollup and produces Engine API payloads.

Why Engine API? One of those OP Stack opinionated things.




Derivation is the more interesting one

The derivation layer takes the data availability layer and the current state of the rollup and produces Engine API payloads.

Why Engine API? One of those OP Stack opinionated things. Already standard in Ethereum clients and makes block building easier.



The background of the slide is a complex geometric pattern of nested triangles, resembling a Sierpinski triangle. The pattern is composed of many small triangles in various shades of orange, yellow, green, and blue, arranged in a way that creates a sense of depth and movement. The text "Let's formalize it" is centered in the upper half of the image, rendered in a dark, monospaced font.

Let's formalize it

Let's formalize it

Derivation has a relatively simple function signature.



Let's formalize it

Derivation has a relatively simple function signature.

$$\text{derive}(S_{\text{prev}}, DA) \Rightarrow \left\{ \begin{array}{c} \text{payload} \\ \text{or} \\ \text{null} \end{array} \right\}$$



Derivation in Bedrock

The background of the slide is an abstract geometric pattern. It features large, faint, fractal-like structures composed of many small triangles, resembling the Sierpinski triangle. These structures are arranged diagonally across the slide. The left side has a warm color palette with shades of orange, yellow, and light purple. The right side has a cool color palette with shades of light blue, green, and yellow. The overall effect is a complex, layered geometric design.

Derivation in Bedrock

Optimism derives data from three locations:



Derivation in Bedrock

Optimism derives data from three locations:

1. Sequencer data posted to a specific address



De in Bedrock

Optimism de

1. Sequen

ess

```
go channel_bank_test.go
go channel_bank.go
go channel_in_reader.go
go channel_out_test.go
go channel_out.go
go channel.go
```



Derivation in Bedrock

Optimism derives data from three locations:

1. Sequencer data posted to a specific address
2. Deposits sent to the Portal contract



Derivation in Bedrock

```
// UserDeposits transforms the L2 block-height and L1 receipts into the transaction inputs for a full L2 block
func UserDeposits(receipts []*types.Receipt, depositContractAddr common.Address) ([]*types.DepositTx, error) {
    var out []*types.DepositTx
    var result error
    for i, rec := range receipts {
        if rec.Status != types.ReceiptStatusSuccessful {
            continue
        }
        for j, log := range rec.Logs {
            if log.Address == depositContractAddr && len(log.Topics) > 0 && log.Topics[0] == DepositEventABIHash {
                dep, err := UnmarshalDepositLogEvent(log)
                if err != nil {
                    result = multierror.Append(result, fmt.Errorf("malformatted L1 deposit log in receipt %d, log %d: %w", i, j, err))
                } else {
                    out = append(out, dep)
                }
            }
        }
    }
    return out, result
}
```



Derivation in Bedrock

Optimism derives data from three locations:

1. Sequencer data posted to a specific address
2. Deposits sent to the Portal contract
3. L1 block data itself



Deriving L1 Info in Bedrock

Optimism derives

1. Sequencer data
2. Deposits sent
3. L1 block data

```
// L1InfoDeposit creates a L1 Info deposit transaction based on the L1 block,  
// and the L2 block-height difference with the start of the epoch.  
func L1InfoDeposit(seqNumber uint64, block eth.BlockInfo) (*types.DepositTx, error) {  
    infoDat := L1BlockInfo{  
        Number:      block.NumberU64(),  
        Time:         block.Time(),  
        BaseFee:      block.BaseFee(),  
        BlockHash:    block.Hash(),  
        SequenceNumber: seqNumber,  
    }  
    data, err := infoDat.MarshalBinary()  
    if err != nil {  
        return nil, err  
    }  
    source := L1InfoDepositSource{  
        L1BlockHash: block.Hash(),  
        SeqNumber:    seqNumber,  
    }  
    // Set a very large gas limit with 'IsSystemTransaction' to ensure  
    // that the L1 Attributes Transaction does not run out of gas.  
    return &types.DepositTx{  
        SourceHash:    source.SourceHash(),  
        From:          L1InfoDepositerAddress,  
        To:            &L1BlockAddress,  
        Mint:          nil,  
        Value:         big.NewInt(0),  
        Gas:           150_000_000,  
        IsSystemTransaction: true,  
        Data:          data,  
    }, nil  
}
```

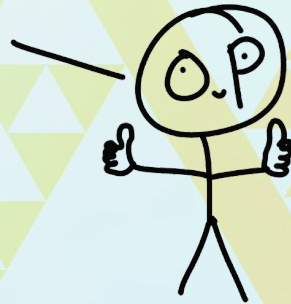


Derivation in Bedrock

Optimism derives data from three locations:

1. Sequencer data posted to a specific address
2. Deposits sent to the Portal contract
3. L1 block data itself

Each of these get translated into Engine payloads



This abstraction is ridiculously powerful.

This abstraction is ridiculously powerful.

Want to build a rollup?



This abstraction is ridiculously powerful.

Want to build a rollup?

- Read sequenced transactions directly from tx data



This abstraction is ridiculously powerful.

Want to build a rollup?

- Read sequenced transactions directly from tx data
- Read deposit transaction data from events



This abstraction is ridiculously powerful.

Want to build a rollup?

- Read sequenced transactions directly from tx data
- Read deposit transaction data from events
- Read block data and system generate transactions



This abstraction is ridiculously powerful.

But that's not all you can build.



This abstraction is ridiculously powerful.

Let's look at a toy example.



This abstraction is ridiculously powerful.

Let's look at a toy example.

Any time there's a Uniswap swap event, we derive an L2 transaction that includes the assets and amount swapped.



This abstraction is ridiculously powerful.

Let's look at a toy example.

Any time there's a Uniswap swap event, we derive an L2 transaction that includes the assets and amount swapped.

Each transaction updates a value in a smart contract that keeps a running tally of total volume. What does that kinda sound like?



This abstraction is ridiculously powerful.

An indexer!



This abstraction is ridiculously powerful.

An indexer!

Are indexers just rollups?



This abstraction is ridiculously powerful.

An indexer!

Are indexers just rollups?
Who knows.



This abstraction is ridiculously powerful.

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Are indexers just rollups?

Who knows.

Whatever.



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Are indexers just rollups?

Who knows.

Whatever.

Anyway, you get it.



This abstraction is ridiculously powerful.

An indexer!

Are indexers just rollups?

Who knows.

Whatever.

Anyway, you get it.

You can do a lot with this.

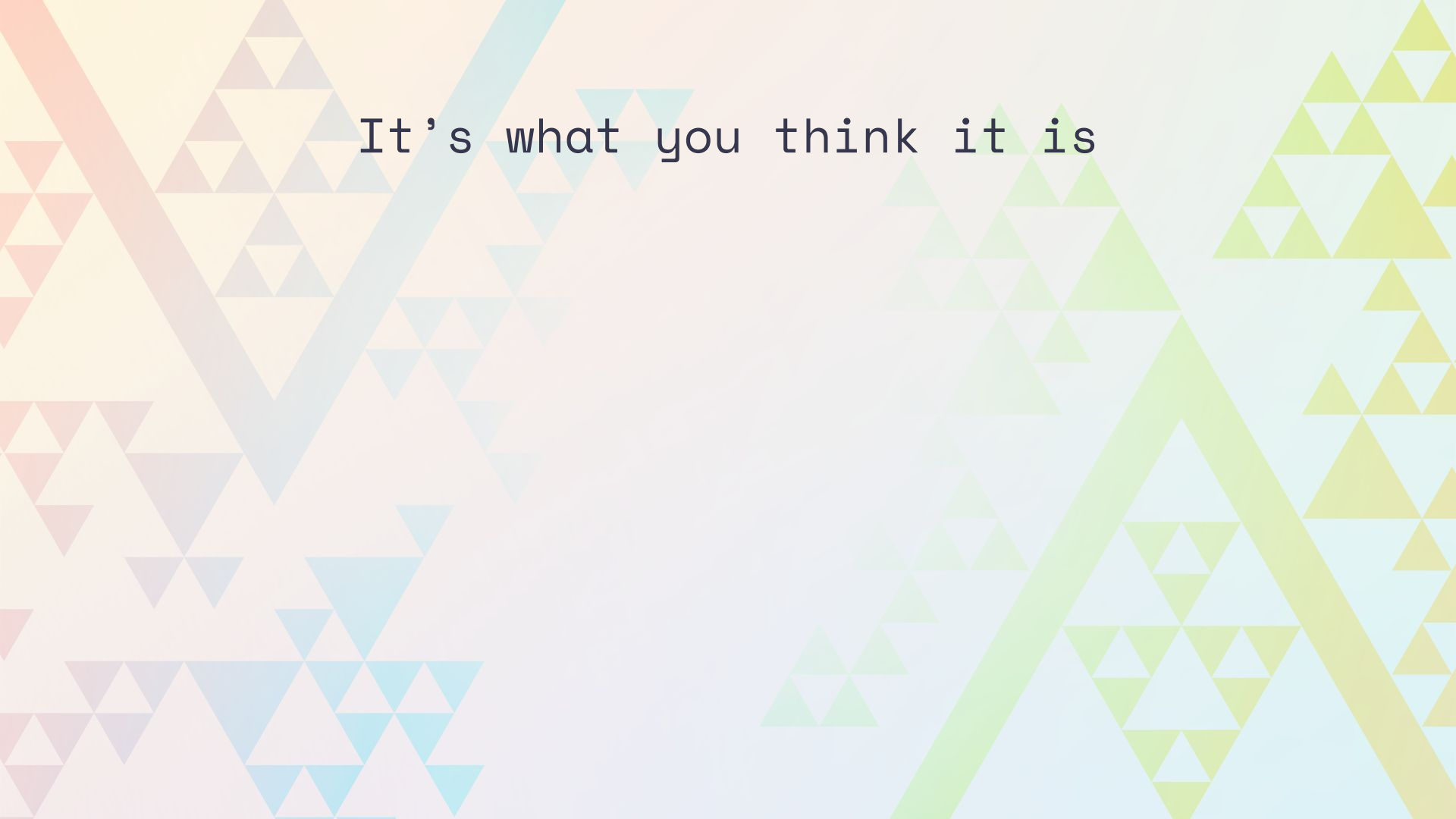




Section 4

The Execution Layer



The background is a complex geometric pattern. It features a large, faint, light-colored triangle in the center, composed of many smaller triangles. This central triangle is surrounded by various other geometric shapes, including lines and smaller triangles, in a range of colors from warm (peach, orange, yellow) to cool (light blue, green, teal). The overall effect is a layered, fractal-like design.

It's what you think it is

It's what you think it is

It's the interesting part of your state transition function.



Also represented as a function

Also represented as a function

$\text{execute}(S_{\text{prev}}, \text{payload}) \Rightarrow S_{\text{next}}$



The background features a complex geometric pattern. It consists of numerous small triangles in various colors (red, orange, yellow, green, blue, purple) arranged in a way that creates larger, faint triangular shapes. Overlaid on this are several thick, diagonal stripes in muted colors like light blue, light green, and light orange. The overall effect is a vibrant, abstract design.

Derivation and execution work together

Derivation and execution work together

These two layers work together to form the state transition function loop.



Derivation and execution work together

These two layers work together to form the state transition function loop.

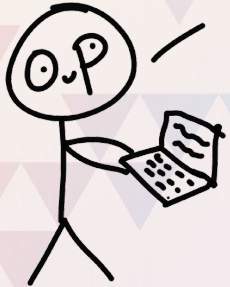
1. Wait for a new element in the DA layer list



Derivation and execution work together

These two layers work together to form the state transition function loop.

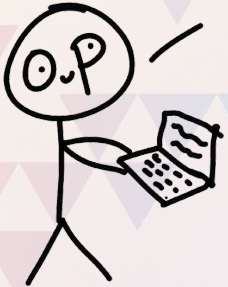
1. Wait for a new element in the DA layer list
2. Run derivation function



Derivation and execution work together

These two layers work together to form the state transition function loop.

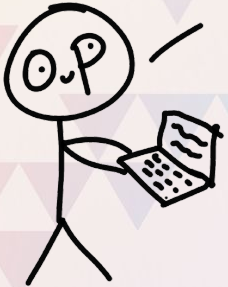
1. Wait for a new element in the DA layer list
2. Run derivation function
 - a. If it returns null, return to step 1



Derivation and execution work together

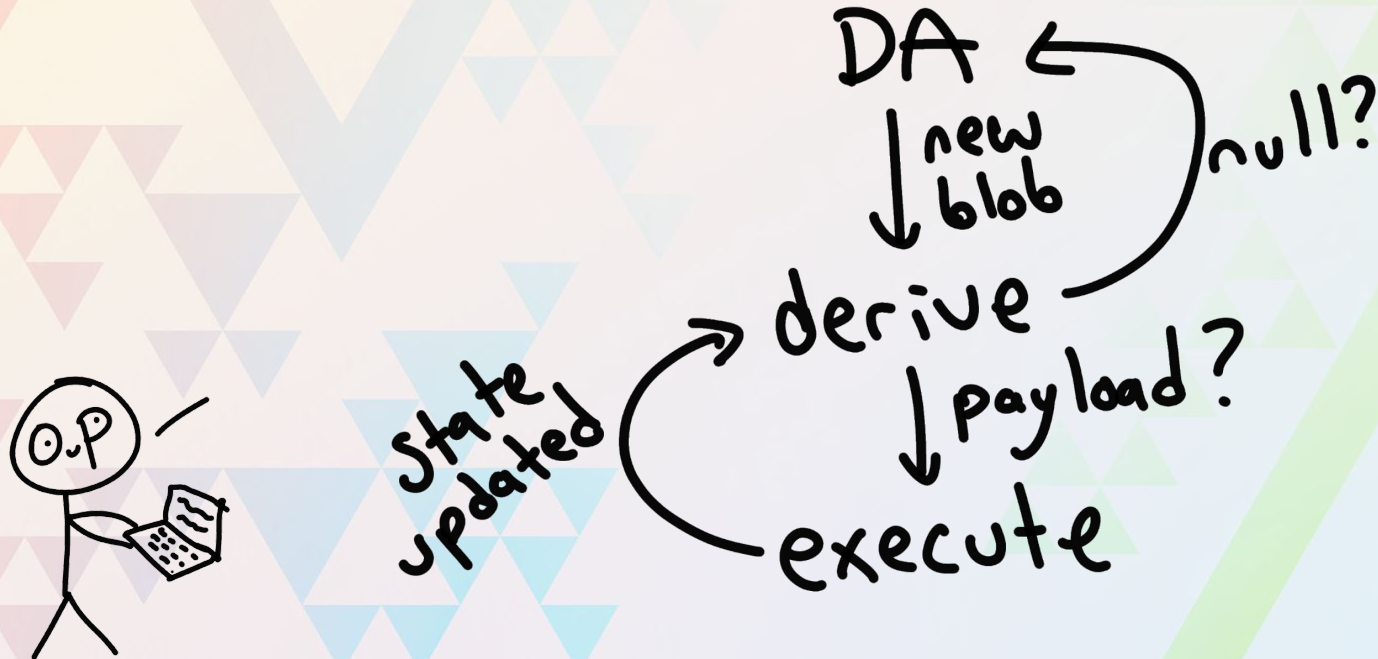
These two layers work together to form the state transition function loop.

1. Wait for a new element in the DA layer list
2. Run derivation function
 - a. If it returns null, return to step 1
 - b. If it returns a payload, pass it into the execution function, update the state, return to step 2



Derivation and execution work together

Here's that same loop drawn out:



Execution in Bedrock

The background of the slide is a complex, abstract geometric pattern. It features a variety of triangles of different sizes and orientations, some pointing up and some pointing down. These triangles are arranged in a way that creates a sense of depth and movement. The color palette is divided into two main sections: the left side is dominated by warm tones like orange, yellow, and light brown, while the right side is dominated by cool tones like light blue, green, and pale yellow. A prominent, thick, light blue diagonal line runs from the top left towards the bottom right, bisecting the composition. The overall effect is a modern, minimalist aesthetic that suggests a technical or architectural theme.

Execution in Bedrock

It's just the EVM!



Execution in Bedrock

It's just the EVM! Mostly.



Execution in Bedrock

It's just the EVM! Mostly.

- Smallest possible diff to make it rollup-compatible



Execution in Bedrock

It's just the EVM! Mostly.

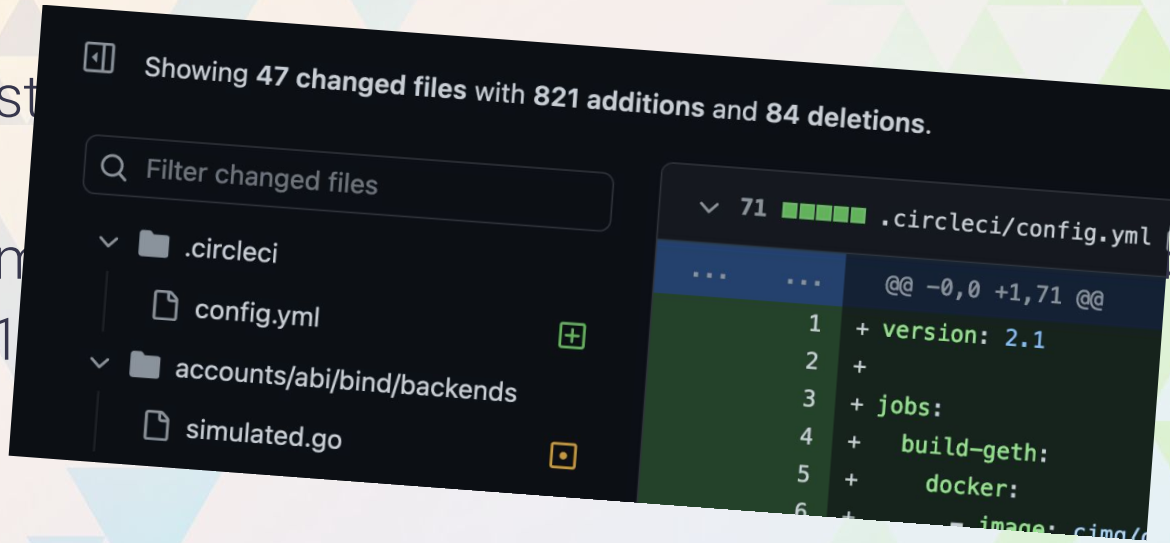
- Smallest possible diff to make it rollup-compatible
- <1k lines of code in a single commit



Execution in Bedrock

It's just

- Sm
- <1



Execution in Bedrock

It's just the EVM! Mostly.

- Smallest possible diff to make it rollup-compatible
- <1k lines of code in a single commit
- Support for multiple clients

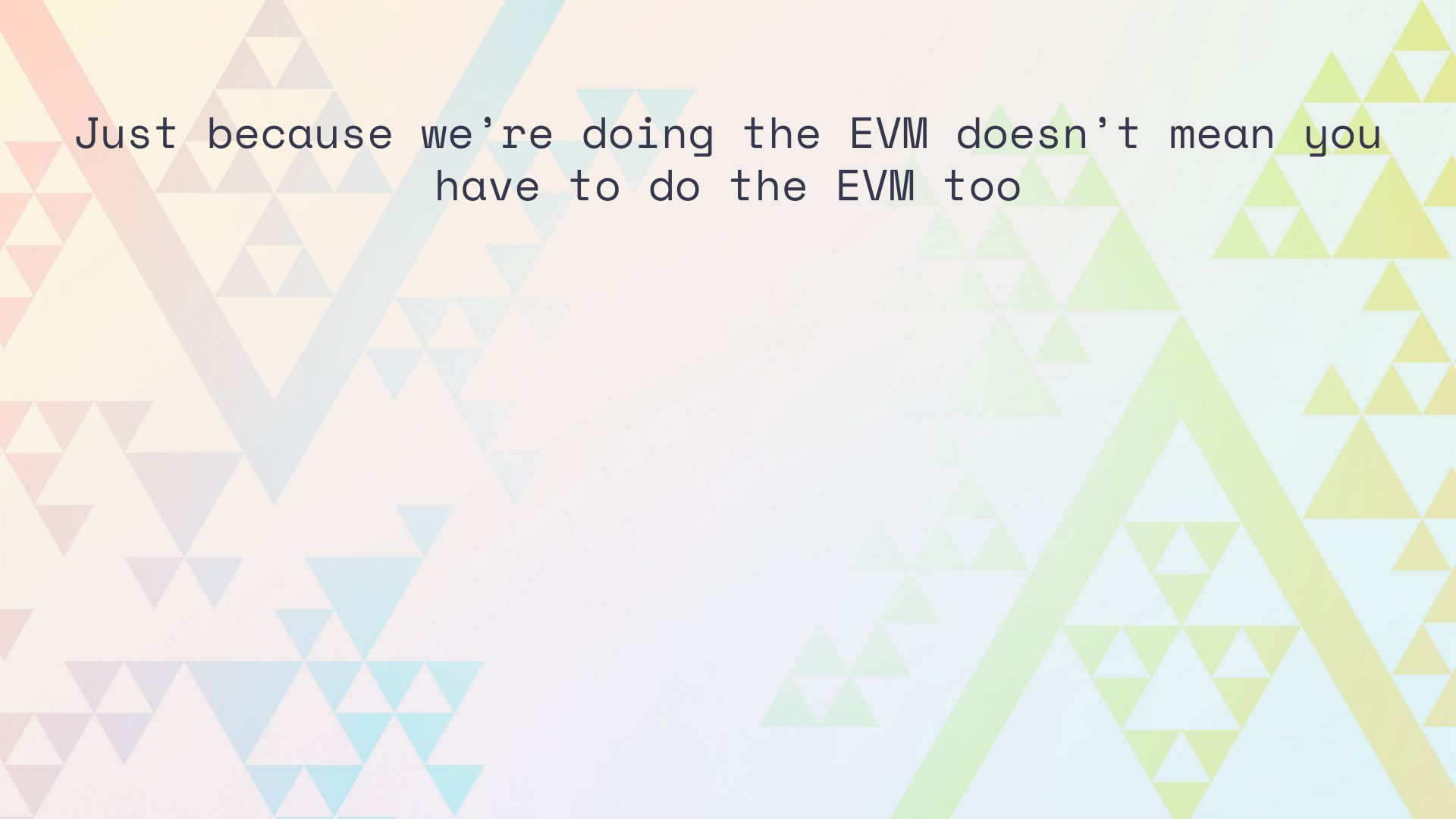


Execution in Beowulf

It's just the FvM! Mostly.

- Smallest possible difference in fully compatible
- <1k lines of code in a single component
- Support for multiple clients



The background of the slide is a complex, abstract geometric pattern. It features a variety of triangles and lines in warm, muted colors including shades of orange, yellow, light blue, and pale green. These elements are arranged in a way that creates a sense of depth and movement, with some shapes appearing to overlap others. The overall effect is a modern, artistic backdrop for the text.

Just because we're doing the EVM doesn't mean you
have to do the EVM too

Just because we're doing the EVM doesn't mean you
have to do the EVM too

You have an immense amount of flexibility with this design.



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You have an immense amount of flexibility with this design.

- Bitcoin?



Just because we're doing the EVM doesn't mean you have to do the EVM too

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- Bitcoin?
- Game Boy?



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- Bitcoin?
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- Python interpreter?



Just because we're doing the EVM doesn't mean you have to do the EVM too

You have an immense amount of flexibility with this design.

- Bitcoin?
- Game Boy?
- Python interpreter?



The sky's the limit.



Section 5

Settlement



Settlement

The background of the slide is an abstract geometric pattern. It features a central area with a soft, horizontal gradient from light pink to light blue. This central area is framed by large, stylized triangular shapes. On the left, a large triangle is composed of smaller triangles in shades of orange, red, and purple. On the right, a large triangle is composed of smaller triangles in shades of green and yellow. The overall aesthetic is modern and geometric.

Settlement

Is it even a real thing?



Settlement

Is it even a real thing? Yes.



Settlement

Is it even a real thing? Yes. Kinda.



Settlement

Here's how we'll define it for the sake of the OP Stack:



Settlement

Here's how we'll define it for the sake of the OP Stack:

Settlement is a view that another chain has of your chain.



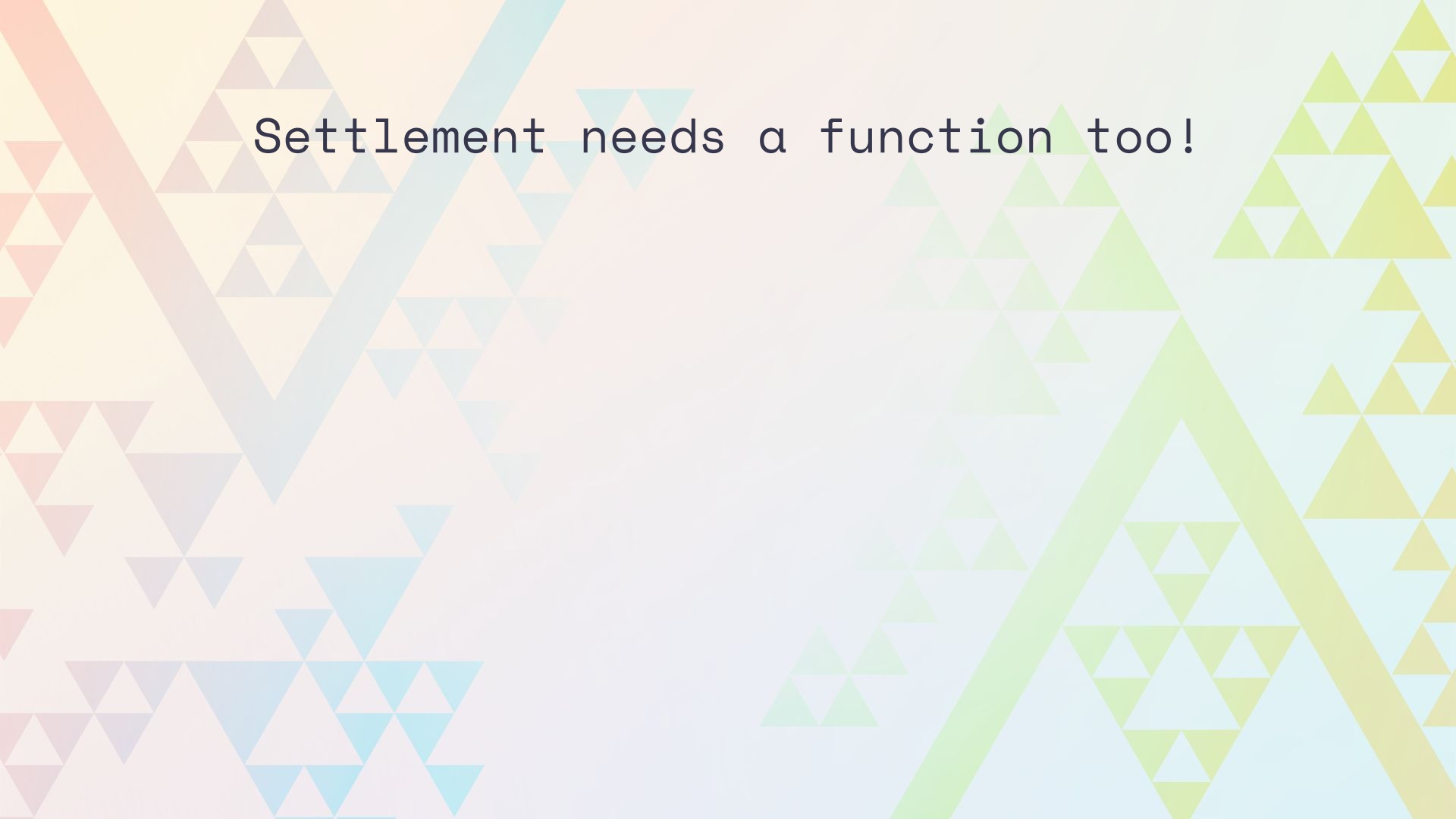
Settlement

Here's how we'll define it for the sake of the OP Stack:

Settlement is a view that another chain has of your chain.

It's about making claims about the state of your chain to another chain and being able to back those claims up.





Settlement needs a function too!

Settlement needs a function too!

You can make all sort of claims, but most commonly you'll make a claim about the "state root" of the L2.



Settlement needs a function too!

You can make all sort of claims, but most commonly you'll make a claim about the "state root" of the L2.

$\text{valid}(S_p, S_n, DA, \text{derive}, \text{execute})$
 $\Rightarrow \text{boolean}$



How do we make this function work?

$\text{valid}(S_p, S_n, DA, \text{derive}, \text{execute})$
 $\Rightarrow \text{boolean}$



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Look at this carefully.



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Look at this carefully. State is a given, so that's fine.



How do we make this function work?

$\text{valid}(S_p, S_n, DA, \text{derive}, \text{execute})$
 $\Rightarrow \text{boolean}$

Look at this carefully. State is a given, so that's fine.
Derivation and execution could be implemented on-chain,
but we bypass that with fault proofs or validity proofs.



How do we make this function work?

$\text{valid}(S_p, S_n, DA, \text{derive}, \text{execute})$
 $\Rightarrow \text{boolean}$

But how do we access the data availability layer?





It's another function!

It's another function!

Remember, our DA takes the form:

type DA = bytes[]



It's another function!

We want a function to access the DA:



It's another function!

We want a function to access the DA:

`getBlobByIndex(idx) ⇒ bytes`



Oooo important formalization

Oooo important formalization

`getBlobByIndex` formalizes something important.



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`getBlobByIndex` formalizes something important. First, the ability to resolve this function clearly depends on the actual availability of the DA.



Oooo important formalization

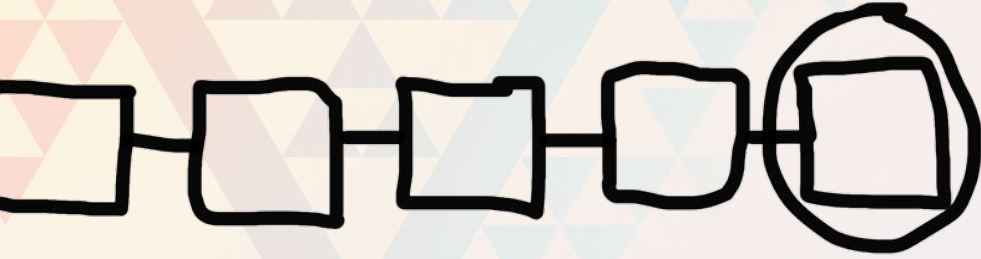
`getBlobByIndex` formalizes something important. First, the ability to resolve this function clearly depends on the actual availability of the DA. Second, this function also depends on the mechanism by which we prove that the blobs are correct.



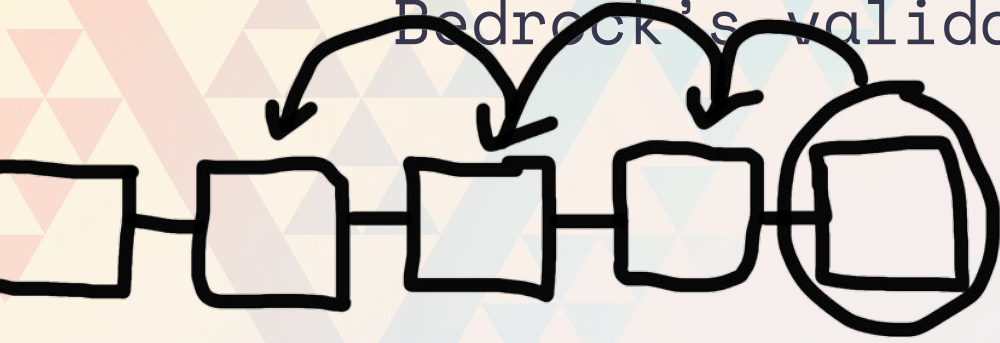
Bedrock's validation function



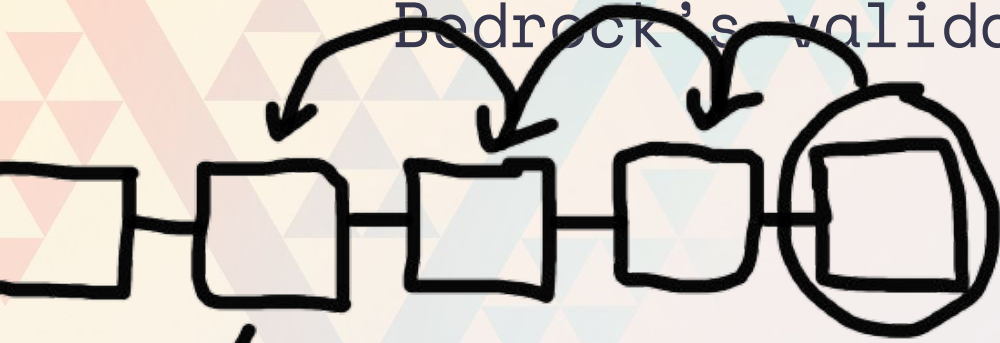
Bedrock's validation function



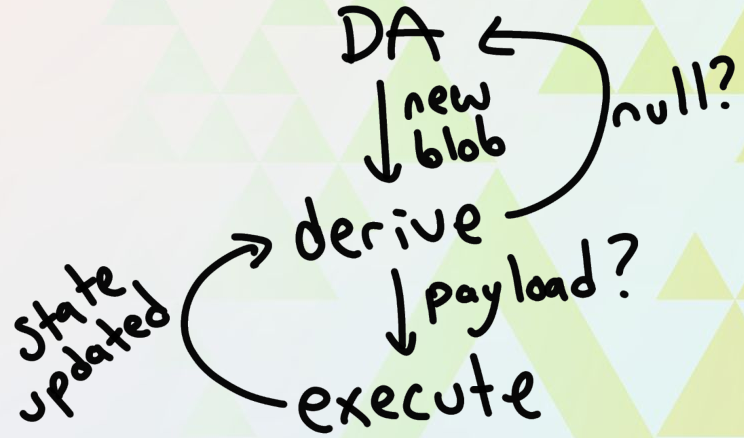
Bedrock's validation function



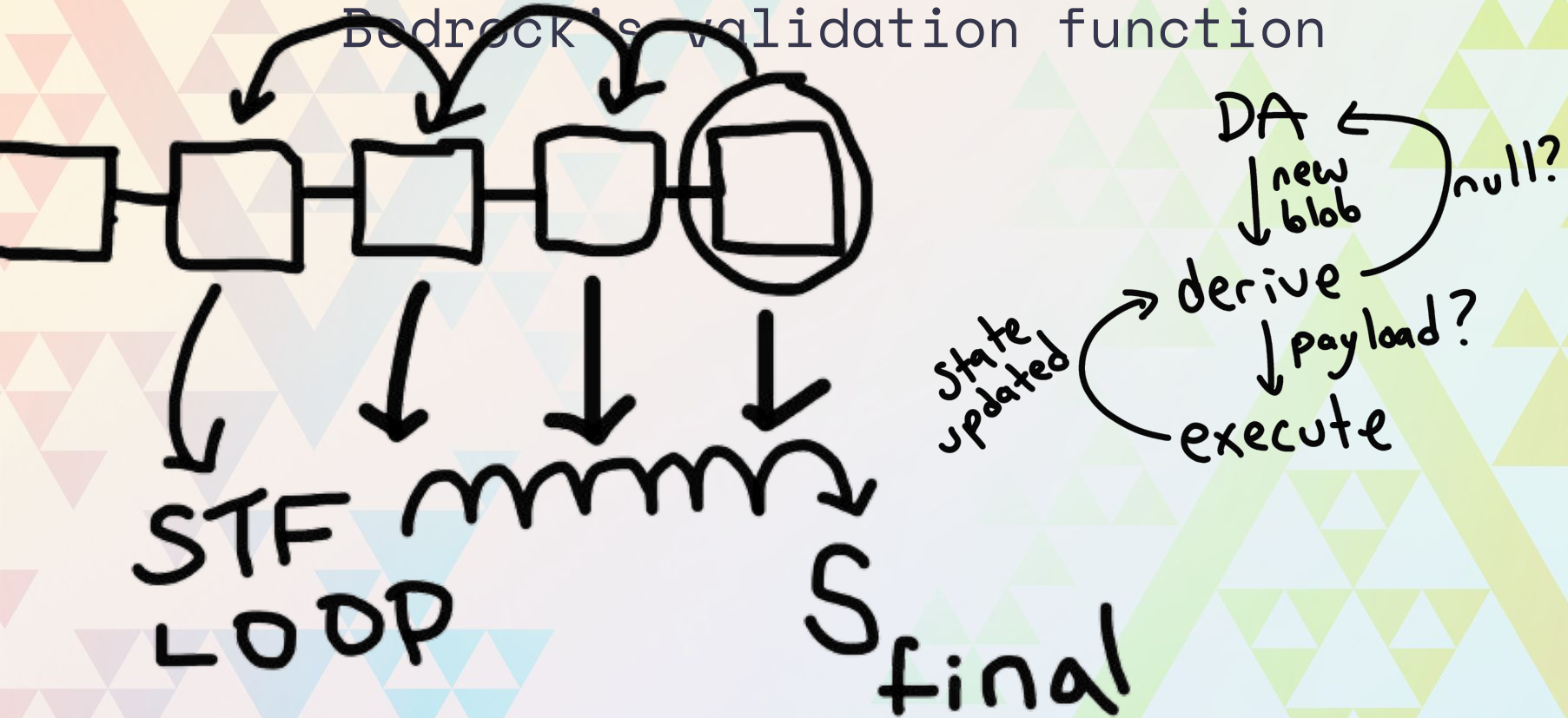
Bedrock's validation function



STF
LOOP



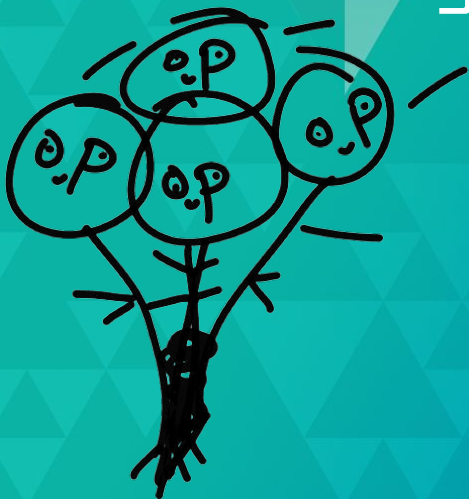
Bedrock's validation function





Section 2

Bringing it all back together

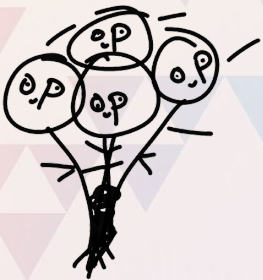




Whew.

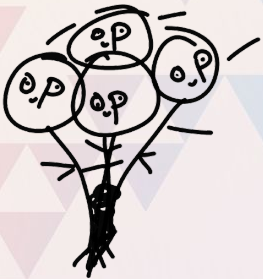
Whew .

Lot's of content there.



Whew .

Lot's of content there. But not too many components!

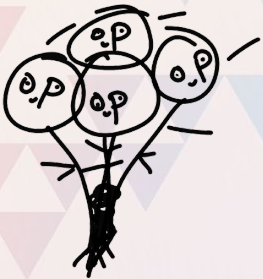


Recapping the components

The background of the slide is a complex, abstract geometric pattern. It features a variety of triangles and lines in warm, muted colors including shades of orange, yellow, light blue, and pale green. Some of these shapes are solid, while others are nested or layered, creating a sense of depth and complexity. The overall effect is a modern, artistic backdrop for the text.

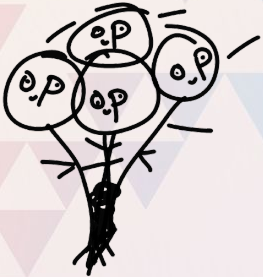
Recapping the components

type DA = bytes[]



Recapping the components

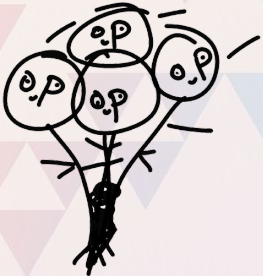
type DA = bytes[] $\text{derive}(S_{\text{prev}}, \text{DA}) \Rightarrow \begin{cases} \text{payload} \\ \text{or} \\ \text{null} \end{cases}$



Recapping the components

type DA = bytes[] $\text{derive}(S_{\text{prev}}, \text{DA}) \Rightarrow \begin{cases} \text{payload} \\ \text{or} \\ \text{null} \end{cases}$

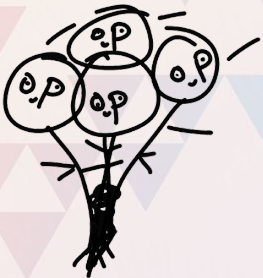
$\text{execute}(S_{\text{prev}}, \text{payload}) \Rightarrow S_{\text{next}}$



Recapping the components

type $DA = \text{bytes}[]$ $\text{derive}(S_{\text{prev}}, DA) \Rightarrow \begin{cases} \text{payload} \\ \text{or} \\ \text{null} \end{cases}$

$\text{execute}(S_{\text{prev}}, \text{payload}) \Rightarrow S_{\text{next}}$ $\text{valid}(S_p, S_n, DA, \text{derive}, \text{execute})$
 $\Rightarrow \text{boolean}$

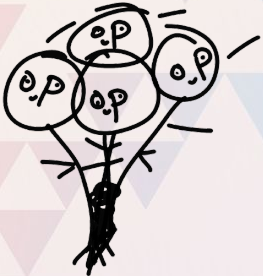


Recapping the components

type DA = bytes[] $\text{derive}(S_{\text{prev}}, \text{DA}) \Rightarrow \begin{cases} \text{payload} \\ \text{or} \\ \text{null} \end{cases}$

$\text{execute}(S_{\text{prev}}, \text{payload}) \Rightarrow S_{\text{next}}$ $\text{valid}(S_p, S_n, \text{DA}, \text{derive}, \text{execute}) \Rightarrow \text{boolean}$

$\text{getBlobByIndex}(\text{idx}) \Rightarrow \text{bytes}$

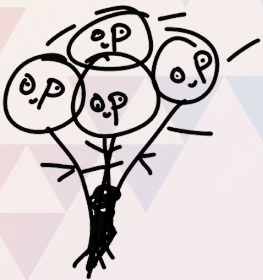


The background features a large, stylized Sierpinski triangle composed of smaller triangles in various pastel shades including orange, yellow, light blue, and green. A soft, multi-colored gradient transitions from light orange on the left to light green on the right, passing through a pale yellow center. The text is centered in a dark, monospaced font.

Build your dream chain

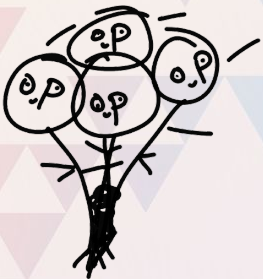
Build your dream chain

- Bitcoin Plasma?



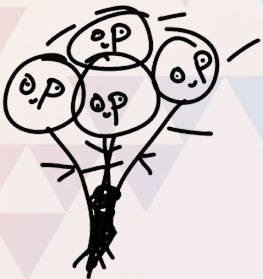
Build your dream chain

- Bitcoin Plasma?
- Bridge Rollup with multiple DAs and settlement layers?

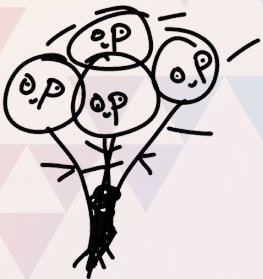


Build your dream chain

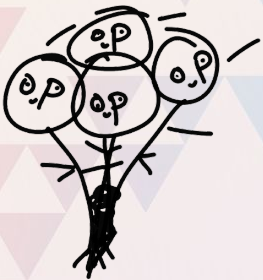
- Bitcoin Plasma?
- Bridge Rollup with multiple DAs and settlement layers?
- Another parallelized VM?

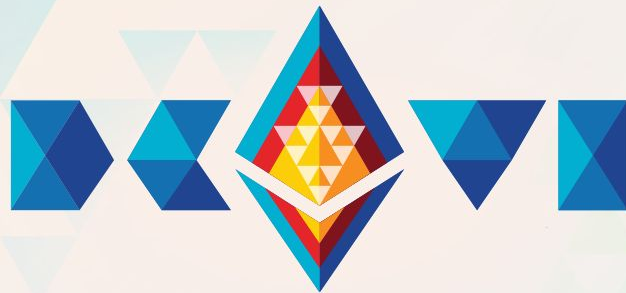


Literally build whatever, just fit
the APIS!



That's the whole talk





ty and remember to enjoy life

Kelvin Fichter

Building the Optimism Collective



@kelvinfichter

bedrock specs



y and remember to enjoy life



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get in touch

y and remember t



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