Non Custodial Sidechains for Bitcoin utilizing Plasma Cash and Covenants

(research in progress)

Scalingbitcoin

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Slides available: gakonst.com/scalingbitcoin2019.pdf

Related Work

Plasma: Autonomous Scalable Smart Contracts, Poon, Buterin

Plasma EthResearch Forum, too many contributors

NOCUST – A Securely Scalable Commit-Chain, Khalil, Gervais, Felley

CoinCovenants using SCIP signatures, an amusingly bad idea, Maxwell

Preventing Consensus Fraud with Commitments and Single-Use-Seals, Todd

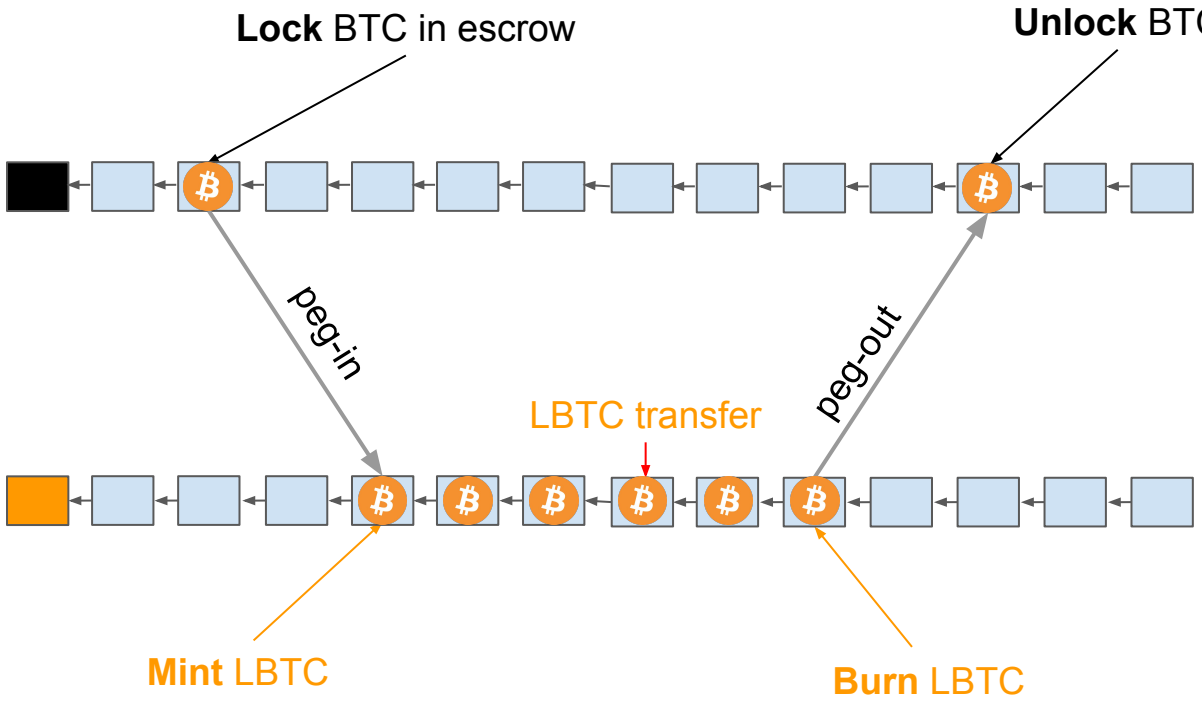
Minimal Viable Merged Consensus, Adler

...

How do we scale?

1. Increase semantic density of transactions
   (Segwit / MAST / Schnorr / Taproot / … / **Layer 2**)
2. ~~Bigger blocks~~

Sidechains considered harmful



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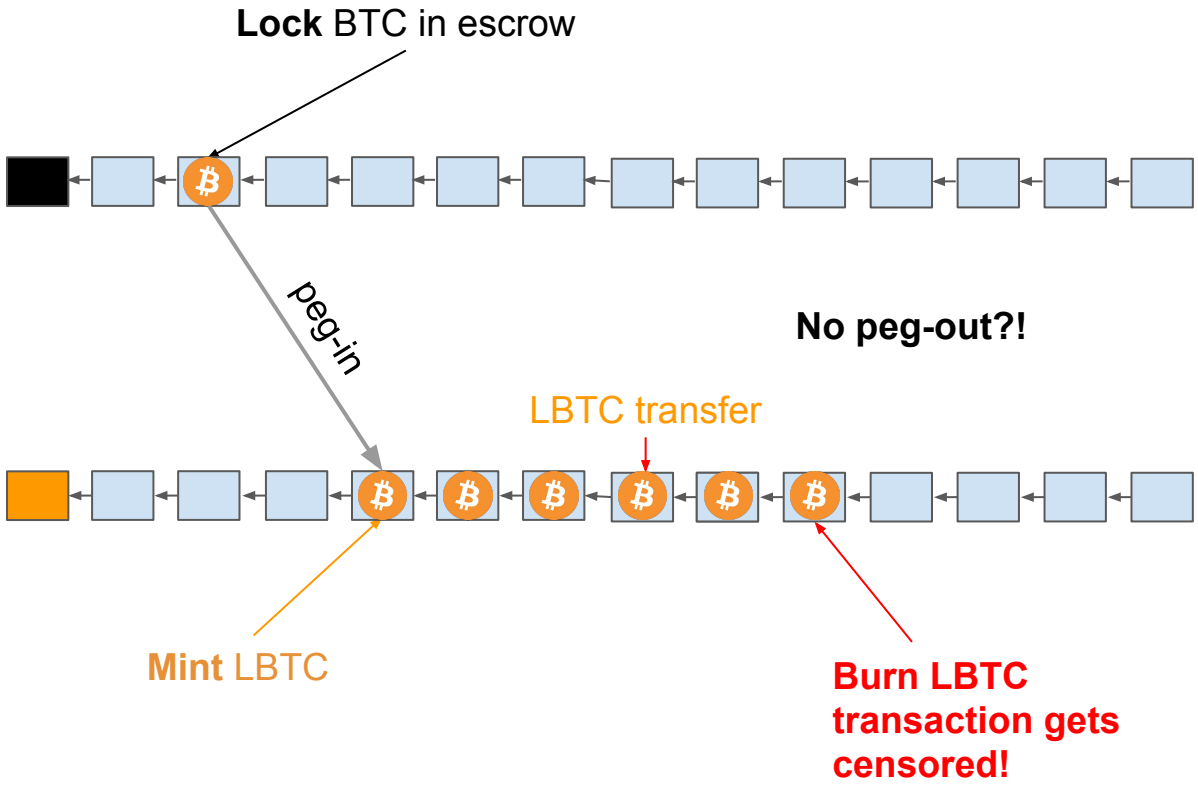

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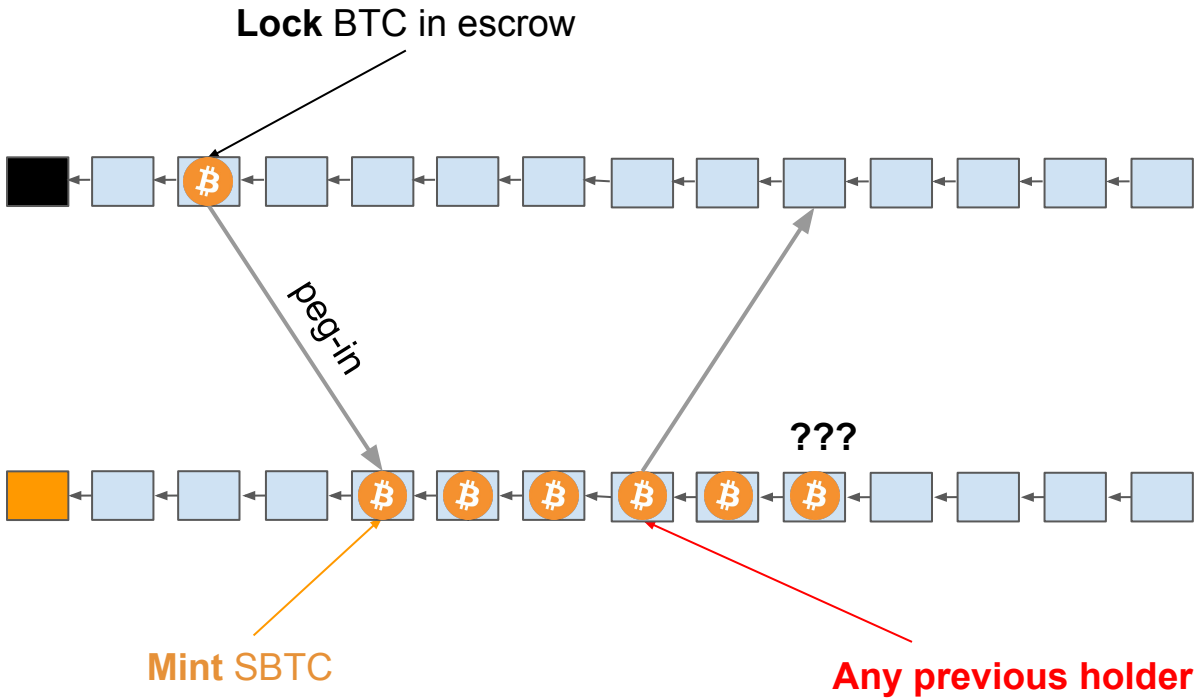

"Statechain entity"

Plasma Cash Tradeoffs

1. Operator cannot steal
2. “Finalize” arbitrary number of txs in one on-chain transaction
3. No overcollateralization requirements
4. No need to sign to receive a payment
5. Can receive funds without on-chain transaction (no notion of inbound liquidity)

https://docs.google.com/spreadsheets/d/1vHw3Rr7aFH1FXlyMjnhC0Wvro_IZ4S8hozpaWqMR1bc/

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1. Fixed denomination transfers
2. Safe only under liveness assumption (O(1) stale state fraud proof)
3. Requires high base chain quality (so that disputes can reliably get included)

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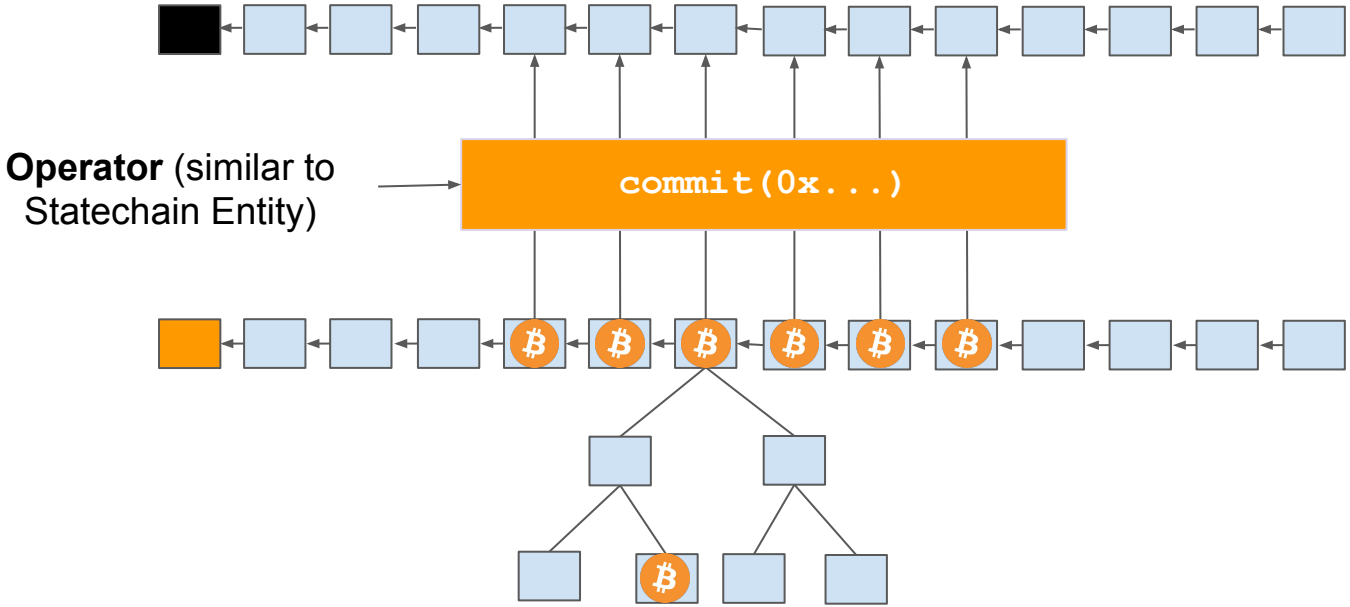
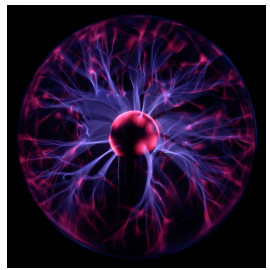
https://docs.google.com/spreadsheets/d/1vHw3Rr7aFH1FXlyMjnhC0Wvro_IZ4S8hozpaWqMR1bc/

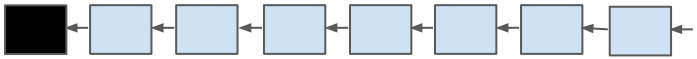
“Operator” commits* each block root to “parent chain”

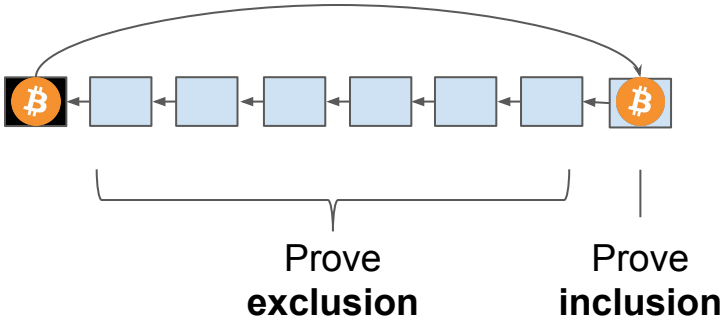


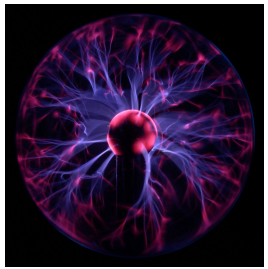


*uses accumulator that supports non-membership proofs e.g. ordered merkle tree

Users prove coin history per transfer (off-chain)







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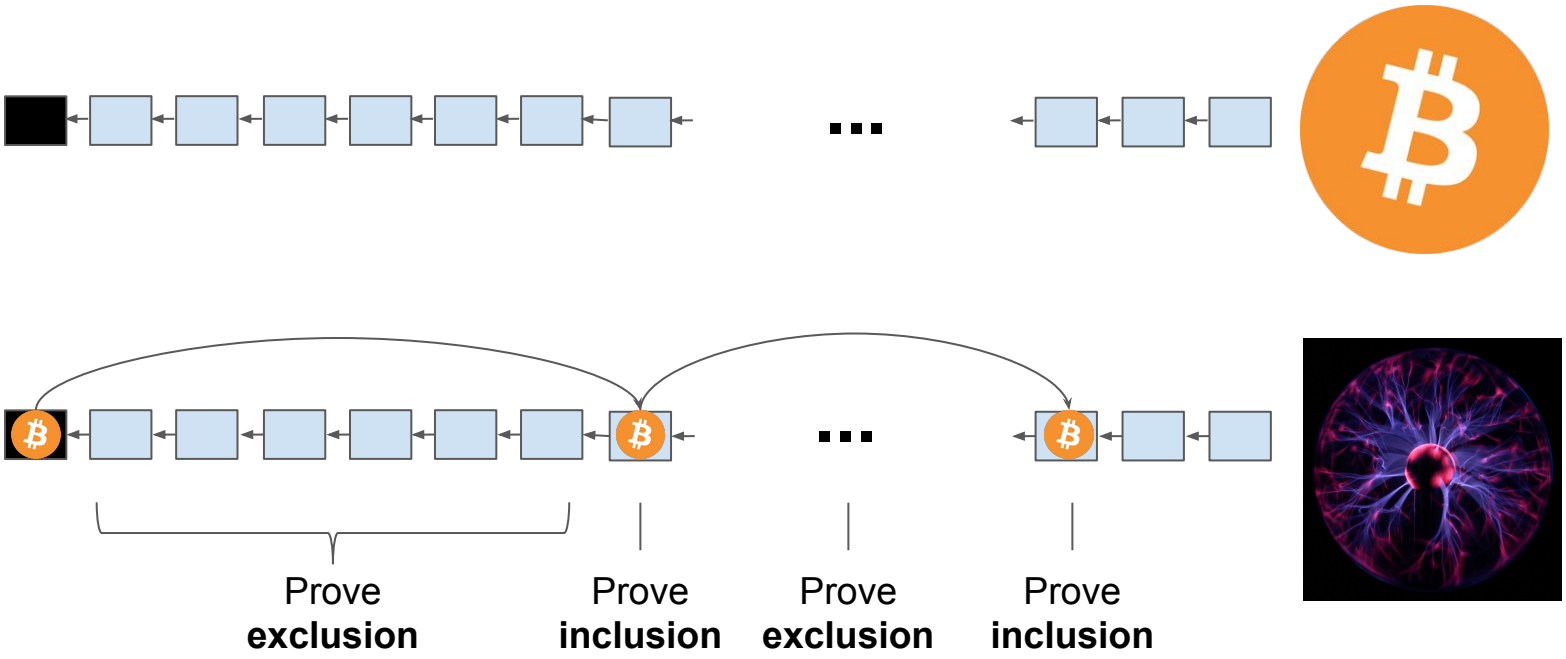
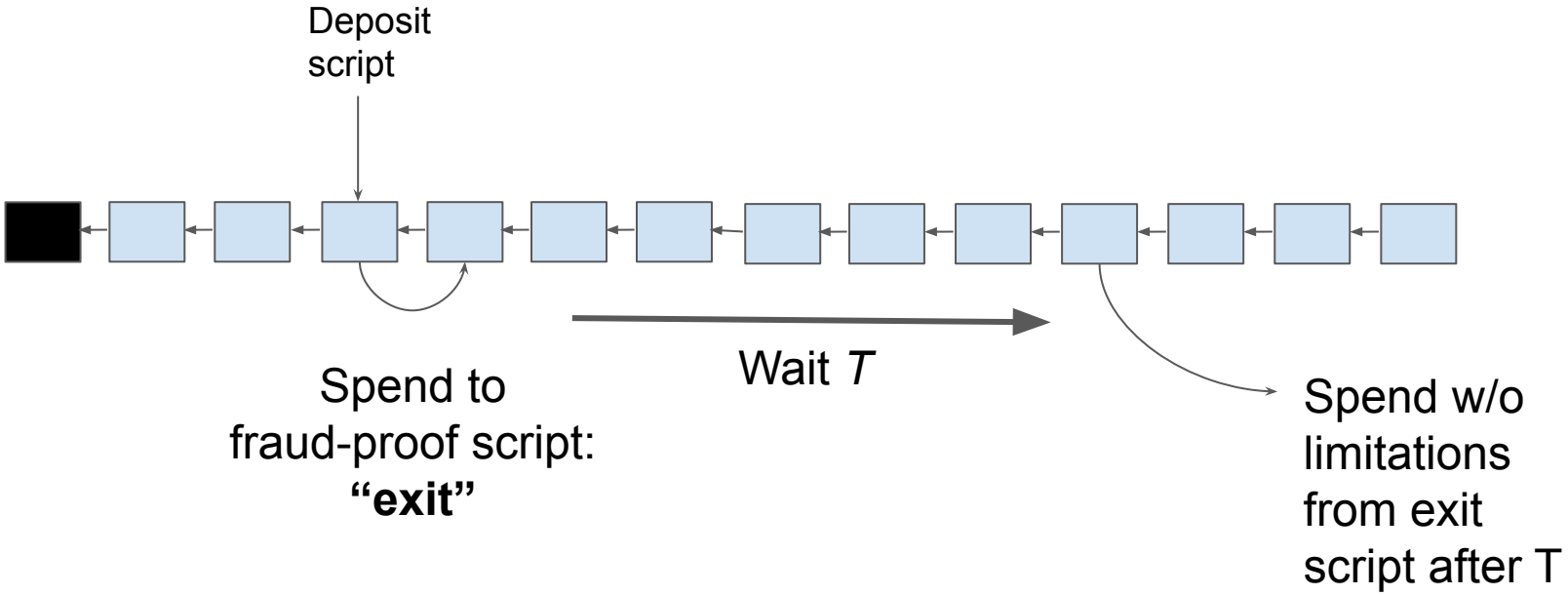
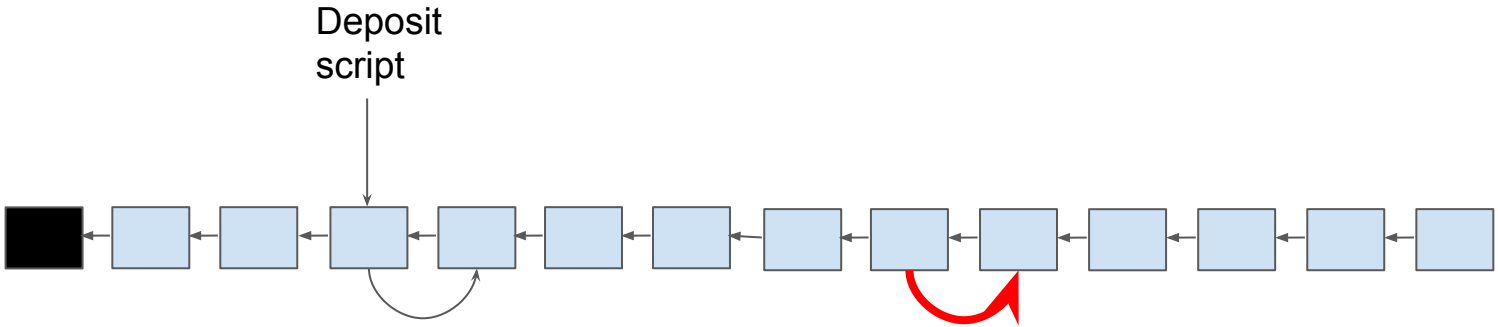


Coin history grows linearly with number of blocks
TXO Commitments? RSA Accumulators?

Exit Game: Delayed Withdrawals



Exit Game: Delayed Withdrawals



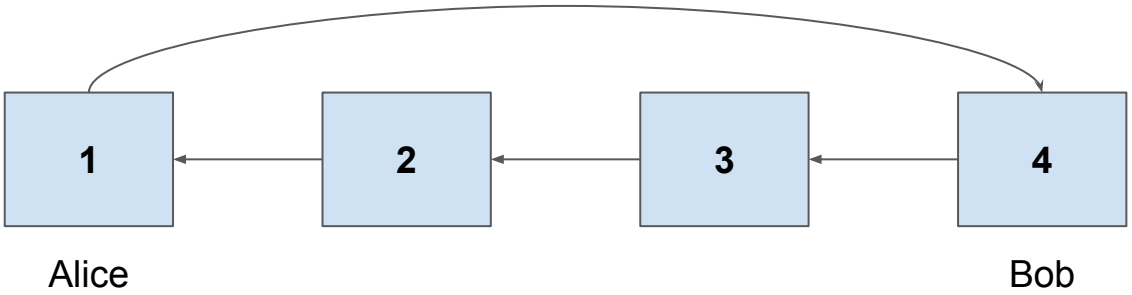
Spend to
fraud-proof script:
“exit”

CHALLENGE:
Spend back to
deposit script

Transaction Format: 1 input 1 output UTXO

(UTXO_ID, PARENT_BLOCK, NEW_OWNER, PREV_OWNER_SIG)

(0x123, 1, Bob, Alice_sig)

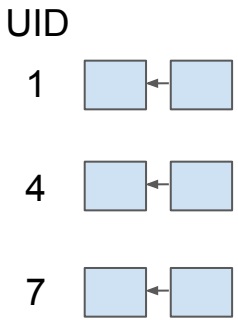


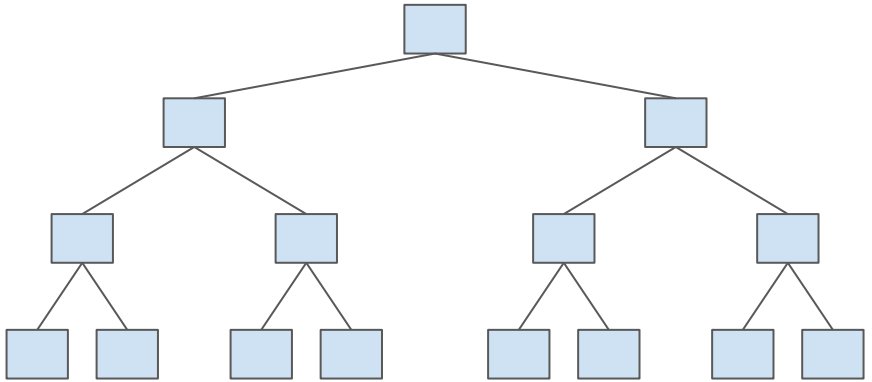
UTXO ID: 0x123

https://ethresear.ch/t/plasma-cash-was-a-transaction-format/4261

Merkle Tree: TxHash at each UTXO_ID index

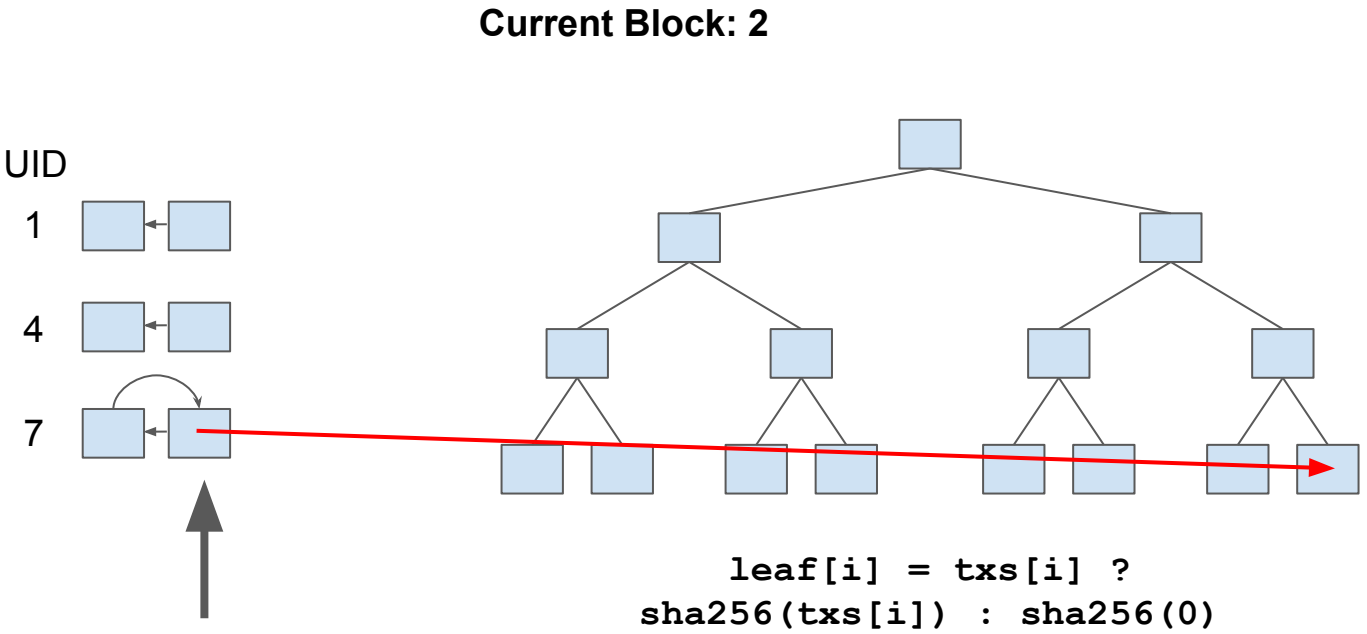
Current Block: 2





```
leaf[i] = txs[i] ?
sha256(txs[i]) : sha256(0)
```

Merkle Tree: TxHash at each UTXO_ID index



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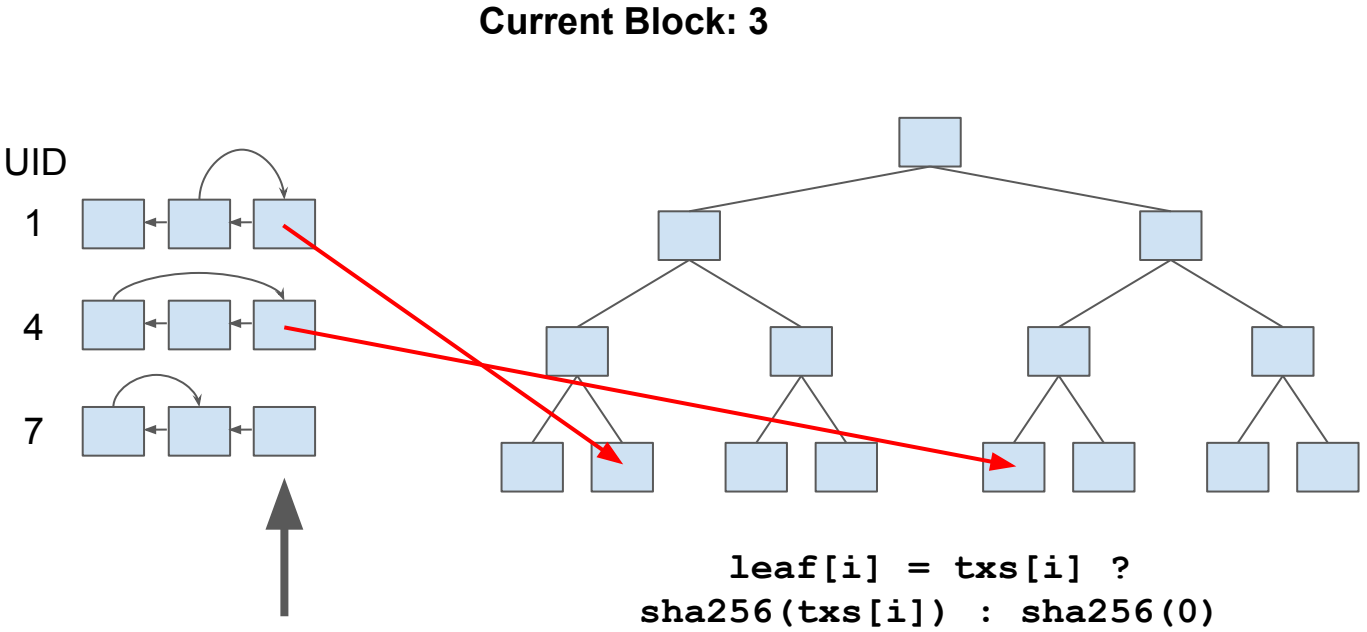
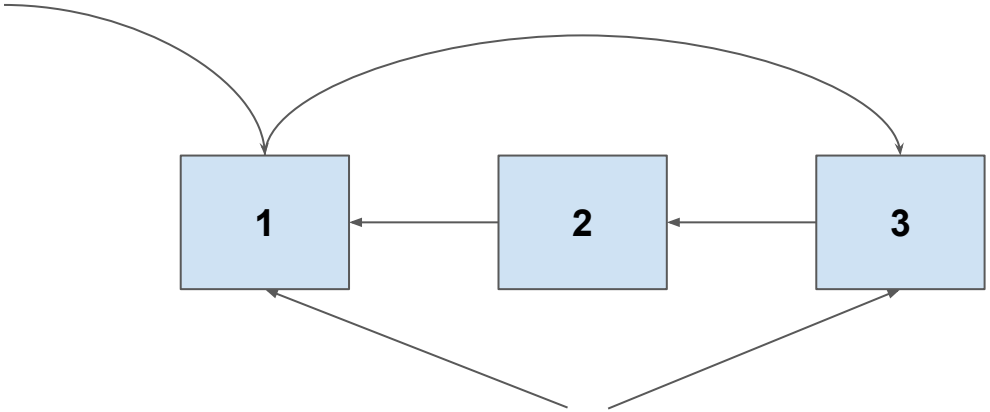
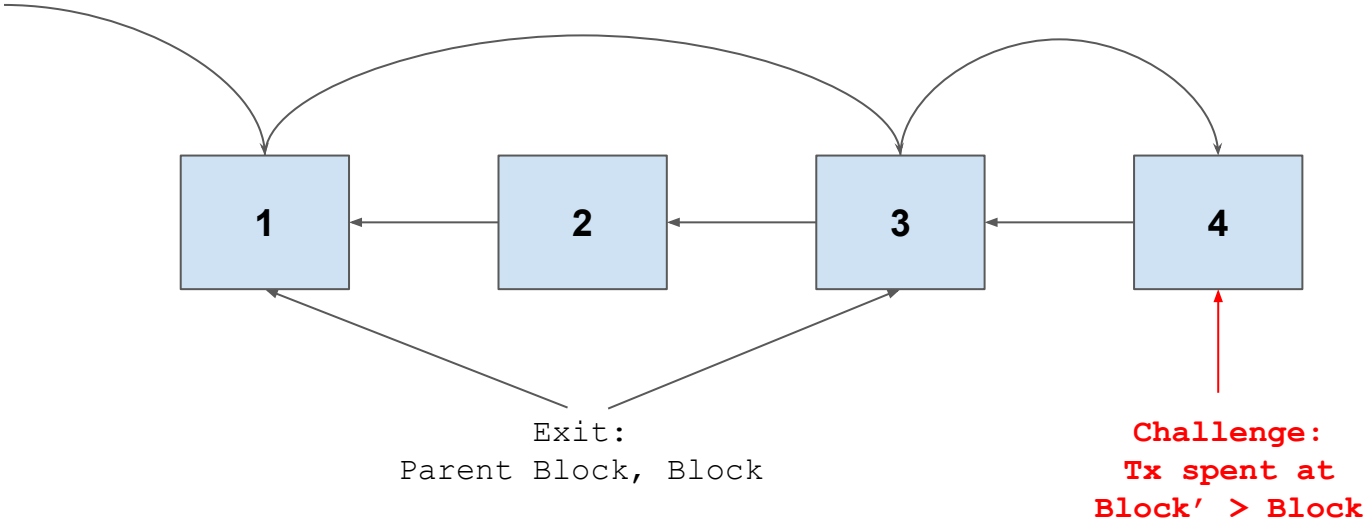


Exit

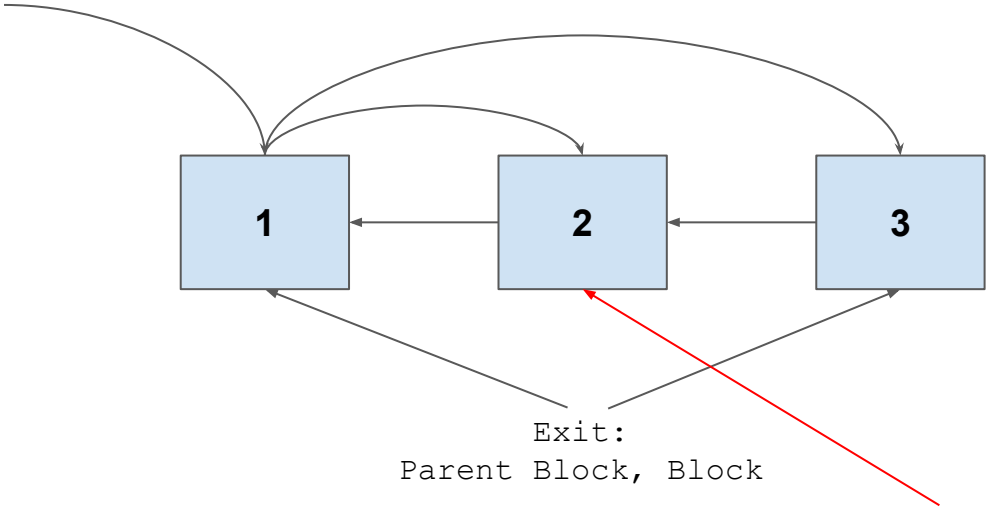



```
Exit:
Parent Block, Block
```

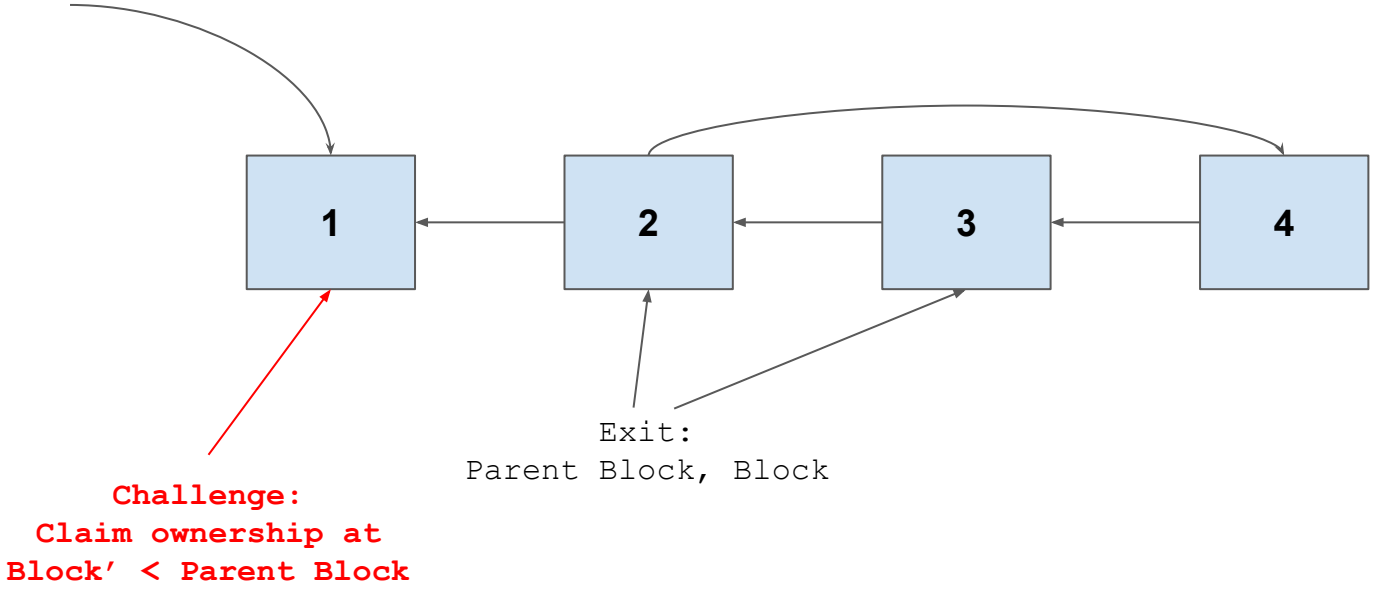
“Exit Spent Coin”



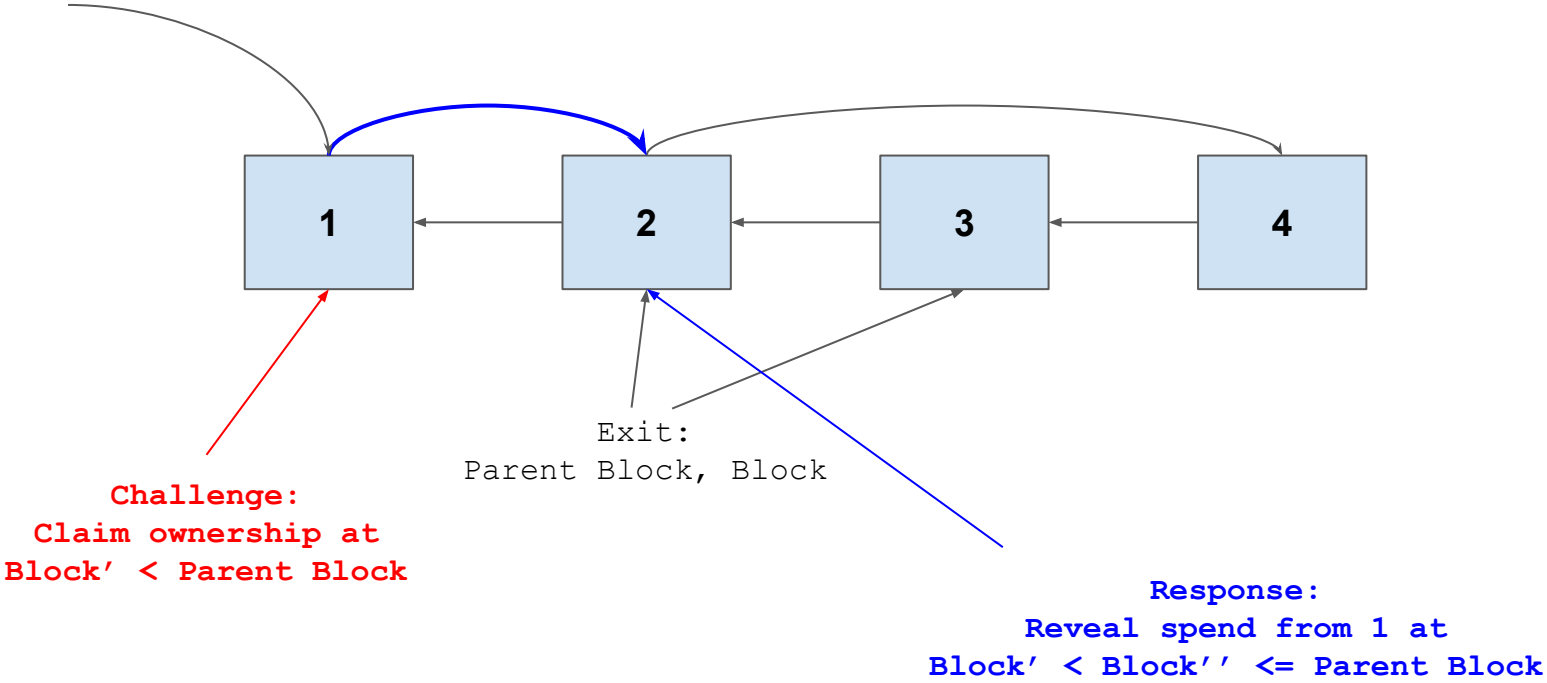
“Exit Double Spend”



“Invalid History Challenge”



Response to Invalid History Challenge



Background literature on covenants

What is a covenant?

Restriction on the outputs spending a UTXO.

O'Connor @ Bitcoin Workshop 2017:

- Digital signatures: **WHO** can spend Bitcoin
- Timelocks: **WHEN** Bitcoin can be spent

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Restriction on the outputs spending a UTXO.

O'Connor @ Bitcoin Workshop 2017:

- Digital signatures: **WHO** can spend Bitcoin
- Timelocks: **WHEN** Bitcoin can be spent
- Covenants: **HOW** and **WHERE** Bitcoin can be spent

Use Cases

- Vaults
- Paralysis Proofs
- Colored Coins (non-fungible tokens)
- Congestion Control
- **Fraud proofs → Sidechains with trust-minimized reverse peg**
- ...more in the mailing list

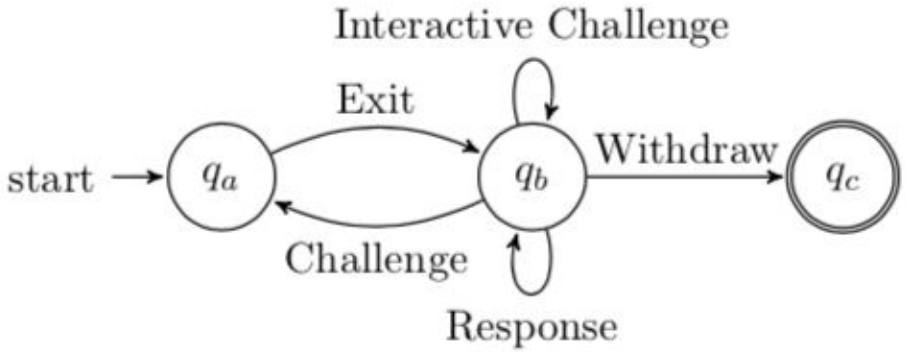
Covenant Designs

- OP_CHECKOUTPUT (MES'16)
- OP_CAT + OP_CHECKSIGFROMSTACK (O'Connor, Piekarska '17)
- OP_CHECKOUTPUTSHASHVERIFY / OP_SECURETHEBAG (Rubin '19)
- OP_PUSHTXDATA (Lau '17)
- Presigned Transactions (..? mailing list spec)

Implementing Plasma Cash on Bitcoin

< new opcodes trigger alert >

UTXO State Machine



Merkle Proof Verification

```
VerifyIncluded(UTXO_ID, ROOT, TX_HASH, PROOF):

    ROOT
    TX_HASH
    PROOF
    UTXO_ID
    MERKLEBRANCHVERIFY
```

Verify block root was signed by Operator

```
VerifySignedByOperator(BLOCK_NUM, ROOT, SIG):

    BLOCK_NUM
    ROOT
    CAT
    SIG
    <OPERATOR_ADDRESS>
    CHECKSIGFROMSTACKVERIFY
```

Verify transaction was signed by previous owner

```
VerifyTxSigned(TX)

    UTXO_ID
    PARENT_BLOCK_NUM
    NEW_OWNER
    CAT CAT SHA256
    SIG
    <PREV_OWNER_PUBKEY>
    CHECKSIGFROMSTACKVERIFY
```

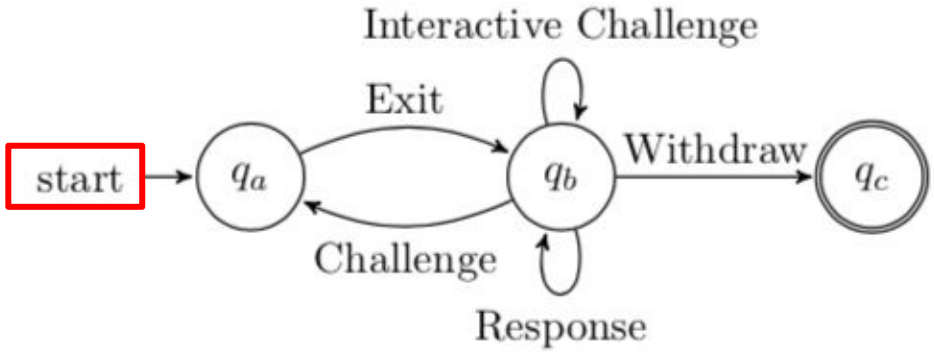
Enforce UTXO is spent to next state

```
EnforceSpentTo(ARGS, NEXT_STATE_PATTERN):
    ARGS
    NEXT_STATE_PATTERN
    CHECKOUTPUTVERIFY
```

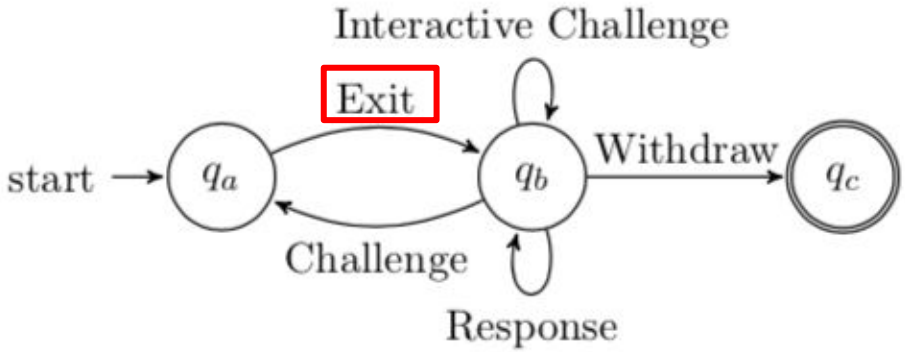
(use `PICK` to dynamically construct the covenant with scriptSig args)

Deposit = Spend to covenant

Spend to `EnforceSpentTo(EXIT)`



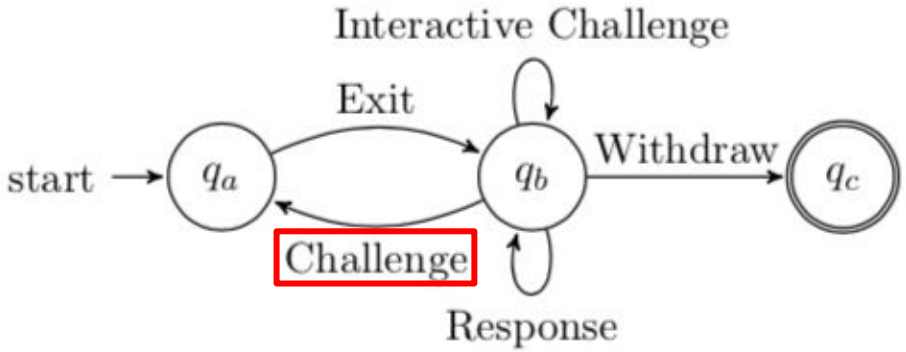
Exit = Spend from Deposit to Exit Script



Spend to

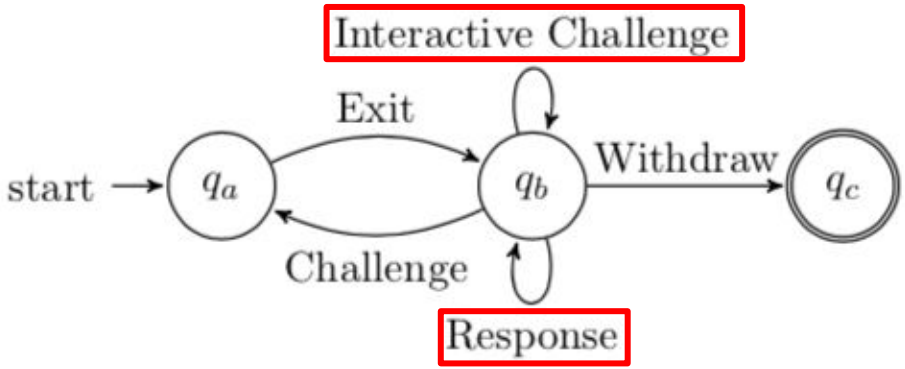
`EXIT(parentIncludedTx, includedTx)`

Challenge Spent Coin / Double Spend = Spend back to Deposit



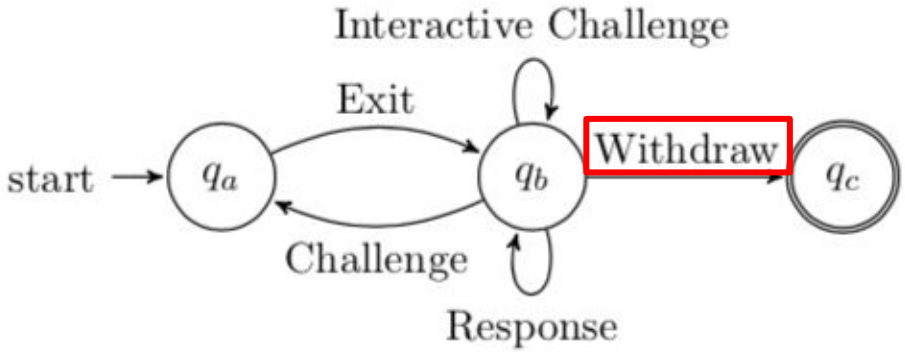
Spend to `DEPOSIT`, show `includedTx` according to exit game

Challenge Invalid History = Increment Counter, Response = Decrement Counter



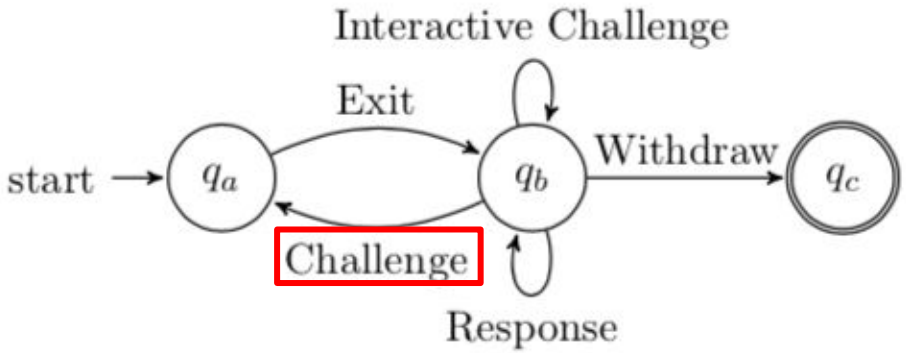
Spend to `EXIT'`, show `includedTx` according to exit game. New EXIT state = previous state with 1 extra IF condition for the Response.

Withdraw = Spend anywhere after T if counter = 0




```
CSV 1000 BENEFICIARY_ADDRESS CHECKSIG
```

Finalize Challenge = Spend to Deposit after T if counter > 0



Summary

- Off-chain fixed-denomination payments
- “Compress” any* amount of transactions to O(1) commitment on Layer 1
- Operator can censor, CANNOT steal under liveness assumption
- Requires:
  - Restrictions on spending outputs
  - Merkle proof verification
  - Signature checks on arbitrary message

Plasma Cash vs Lightning

- No on-chain transaction to transact
- Can receive payments when keys are cold
- Capital efficient

- Fixed denomination (Plasma Debit / Cashflow)
- Exploding History (Checkpoints / better accumulators)

Thank you for your attention

Q & A ?

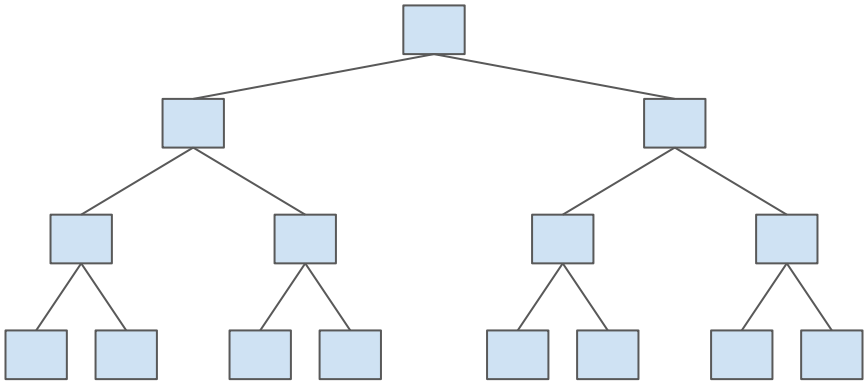
@gakonst / me@gakonst.com

gakonst.com/scalingbitcoin2019.pdf

gakonst.com/plasmacash.pdf

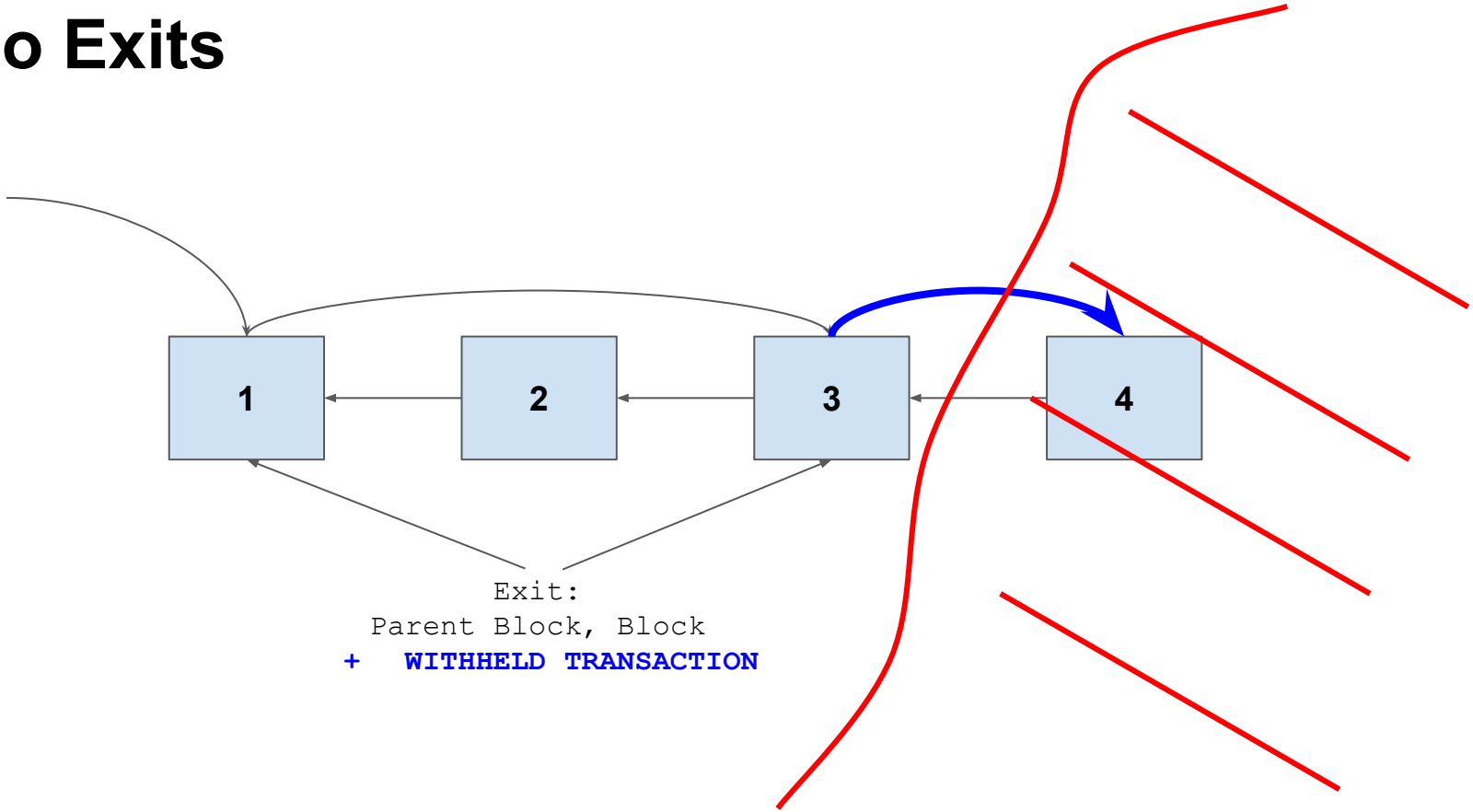
Appendix

Non Fungibility = Feature



Each coin is separate from another
There is no assymetric 1-to-N relationship where the operator can force N participants to go onchain with 1 transaction

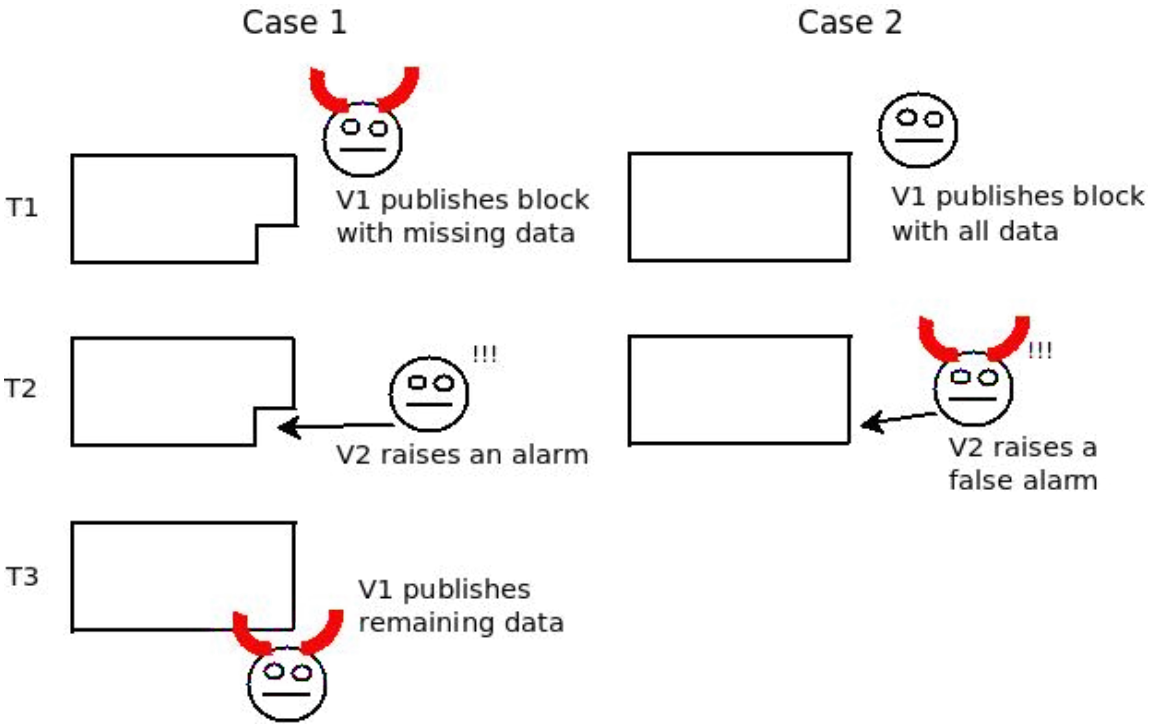
Limbo Exits



More general State Transitions?

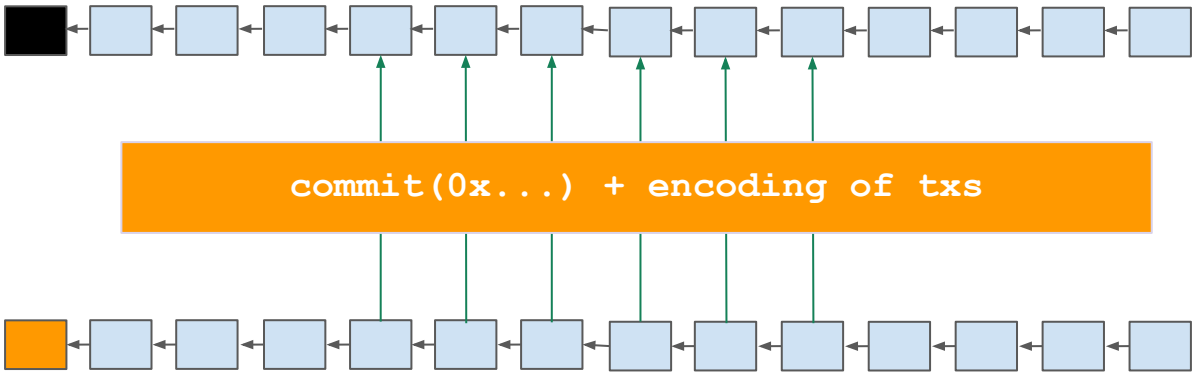
Data unavailability breaks safety…

NOCUST - Data unavailability challenge



https://github.com/ethereum/research/wiki/A-note-on-data-availability-and-erasure-coding

“Optimistic Rollup” - Put all the data on-chain



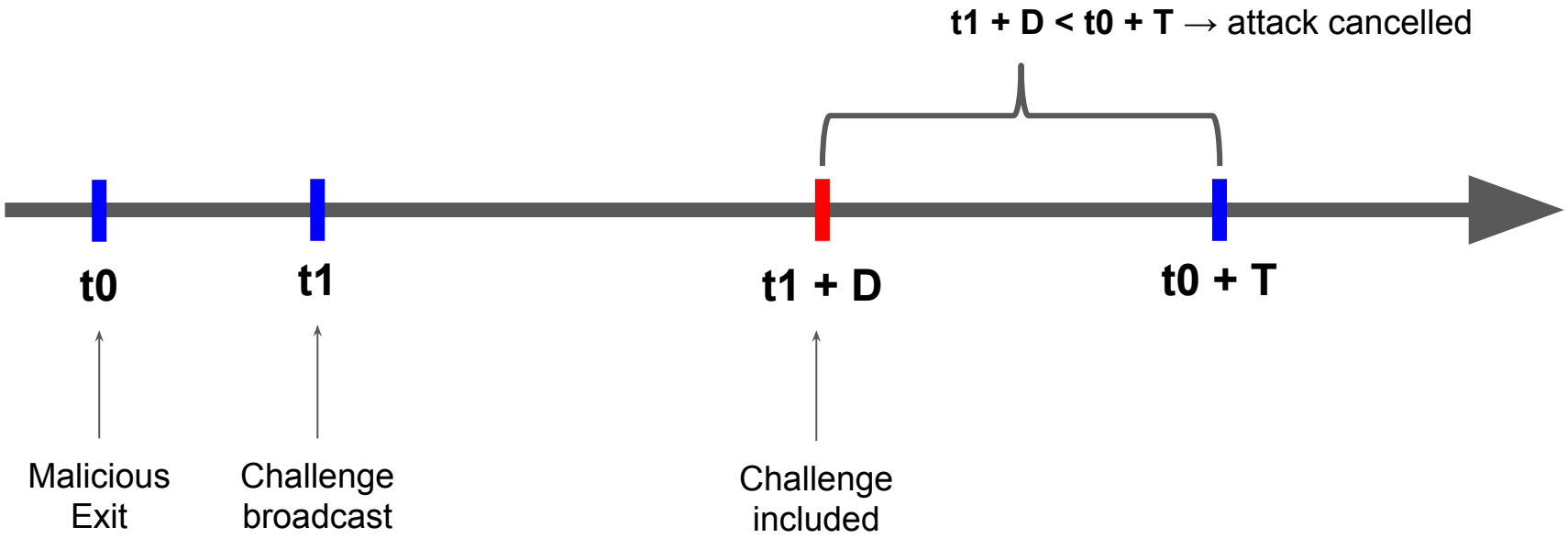
Use the Layer 1 as a data availability and dispute layer. Do not perform any computations on the txs themselves.

Security & Incentive Compatibility of Layer 2 games requirements*:

- **liveness (somebody must challenge)**
- **expected reward of attacker <=0**

*L2 games are implemented as deferred optimists: https://medium.com/@decanus/optimistic-contracts-fb75efa7ca84

Secure iff challenge included before t0 + T



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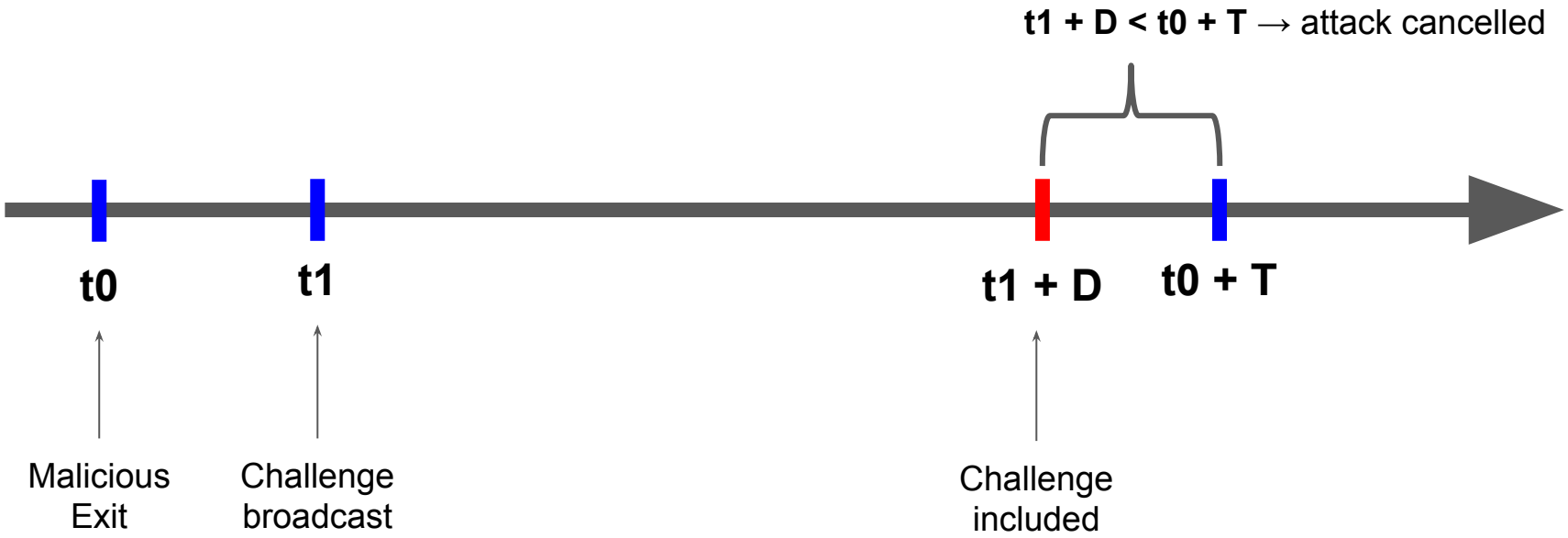
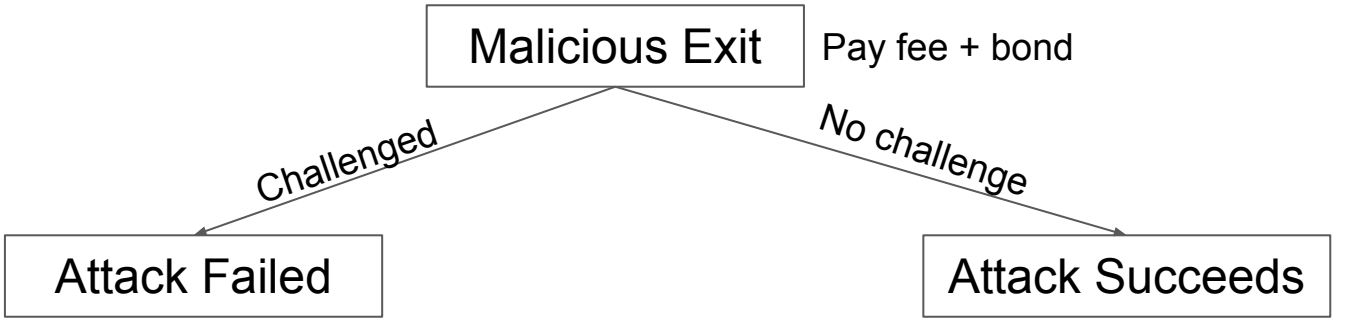


Insecure iff no challenge included before t0 + T

Insecure iff no challenge included before t0 + T

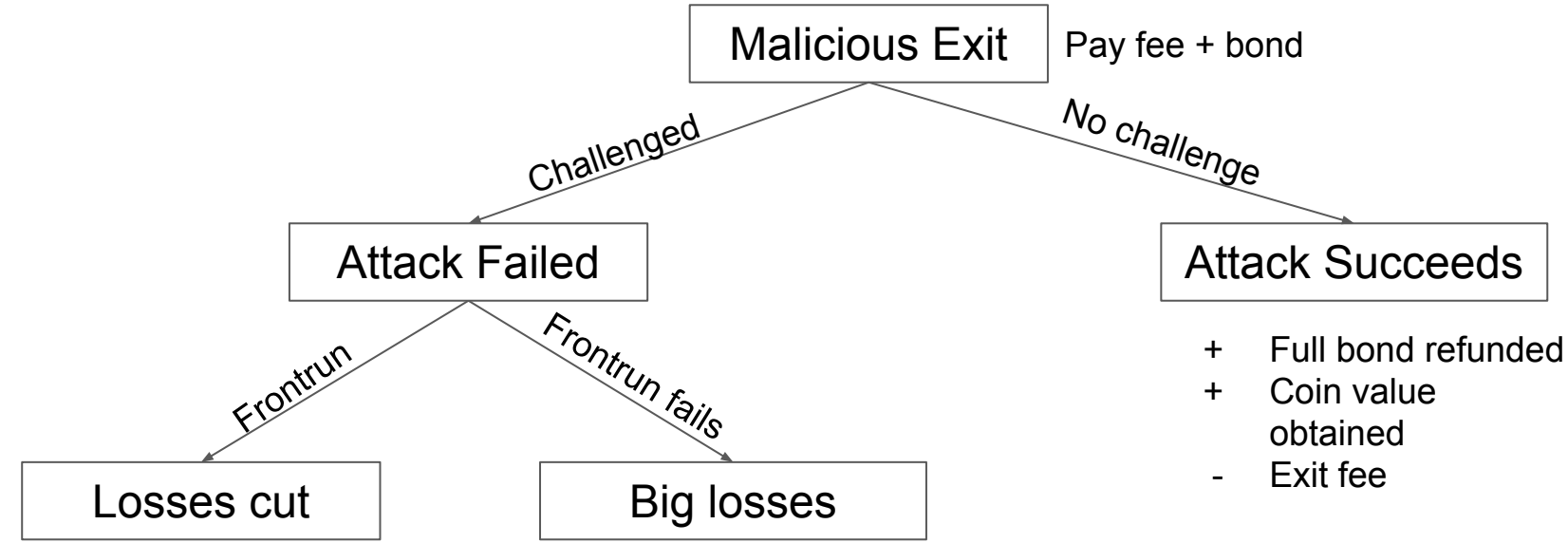
Safety condition: D <= T + t0 - t1 ← Liveness of observers

Attacker Decision Flow



\+ Full bond refunded
\+ Coin value obtained
\- Exit fee

Attacker Decision Flow



+ Full bond refunded
+ Coin value obtained
- Exit fee

- **a% of bond refunded**
- Exit fee
- Challenge fee

- **100% of bond lost**
- Exit fee
- Challenge fee

Incentive Compatibility of the Exit Game

$$E(R) = P(\overline{C})v \leq 0$$

No challenges = success:

- ↑ onchain congestion / censorship
- ↑ block withholding
- ↓ liveness of participants
- ↓ **challenge period *T***

Large T = Secure but bad UX!

Incentive Compatibility of the Exit Game

$$E(R) = P(\overline{C})v - \underbrace{[gas + P(C) * bond]}_{cost\ to\ attack} \leq 0$$

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Cost to Attack =

- Tx fees (constant)
- **Fidelity Bond**
  (goes to challenger)

Incentive Compatibility of the Exit Game

$$E(R) = P(\overline{C})v - \underbrace{[gas + P(C) * bond]}_{cost\ to\ attack} + \underbrace{P(C)P(F \mid C) * bond}_{reward\ from\ frontrunning} \leq 0$$

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Frontrunning removes bond from cost if successful

$$P(F \mid \overline{C}) = 0$$

Attacker won't frontrun if nobody challenged

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Frontrunning removes bond from cost if successful

Burn part of the bond.

Plasma Cash → Fixed-denomination. Arbitrary denomination payments?

Plasma Cash + Channels = Plasma Debit

- Each coin is a channel with the operator

Example:

A has a 5/5 coin. B has a 0/5 coin. A can pay B by atomically decreasing her coin by 1 and increasing B's coin by 1. Capped liquidity. Also receiver needs to sign the state update.

https://ethresear.ch/t/plasma-debit-arbitrary-denomination-payments-in-plasma-cash/2198

Plasma Cash + Fragmentation = Plasma Cashflow

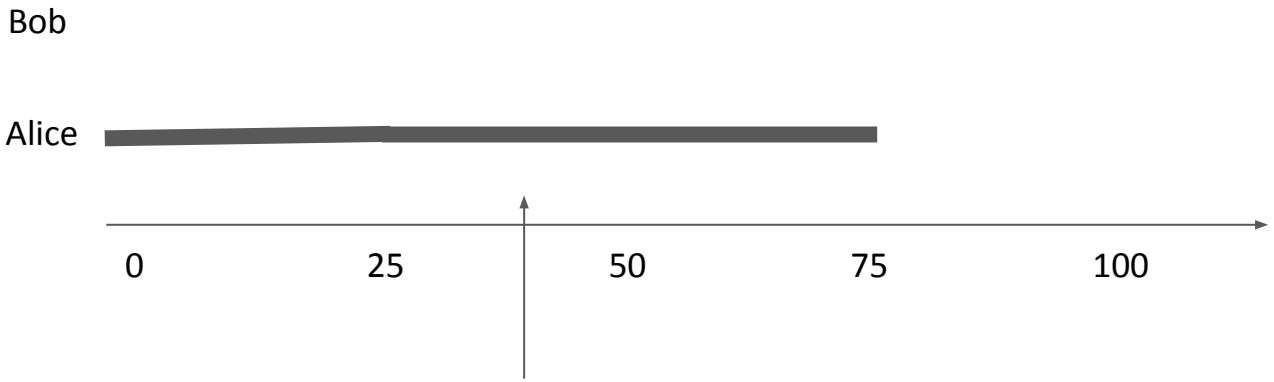
1 Euro

Plasma Cash + Fragmentation = Plasma Cashflow

1 Euro

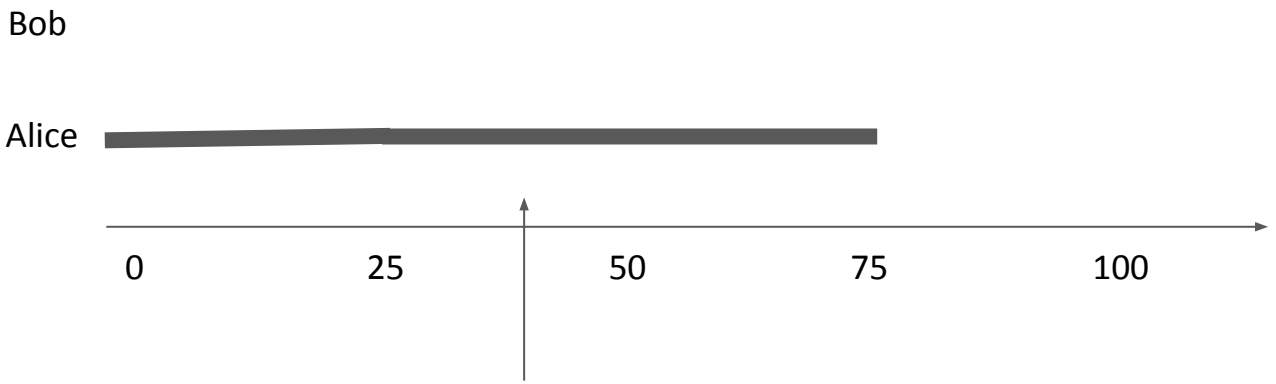
range of 10 x 10 cent **fragments**

A non-interrupted range can be transferred in 1 tx



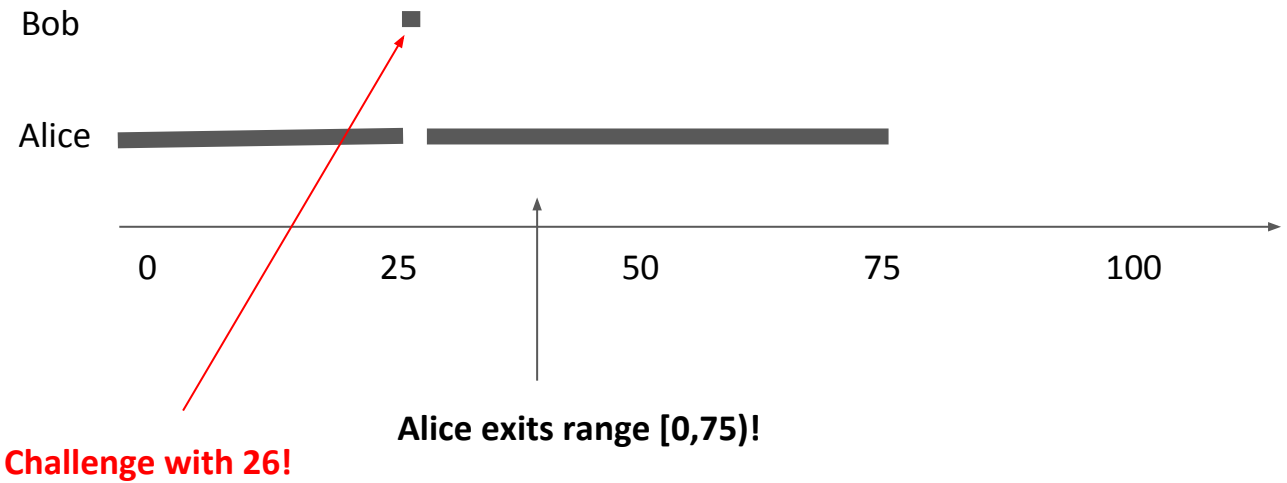
Alice transfers range [0,75) to Bob!

A non-interrupted range can be exited in 1 tx

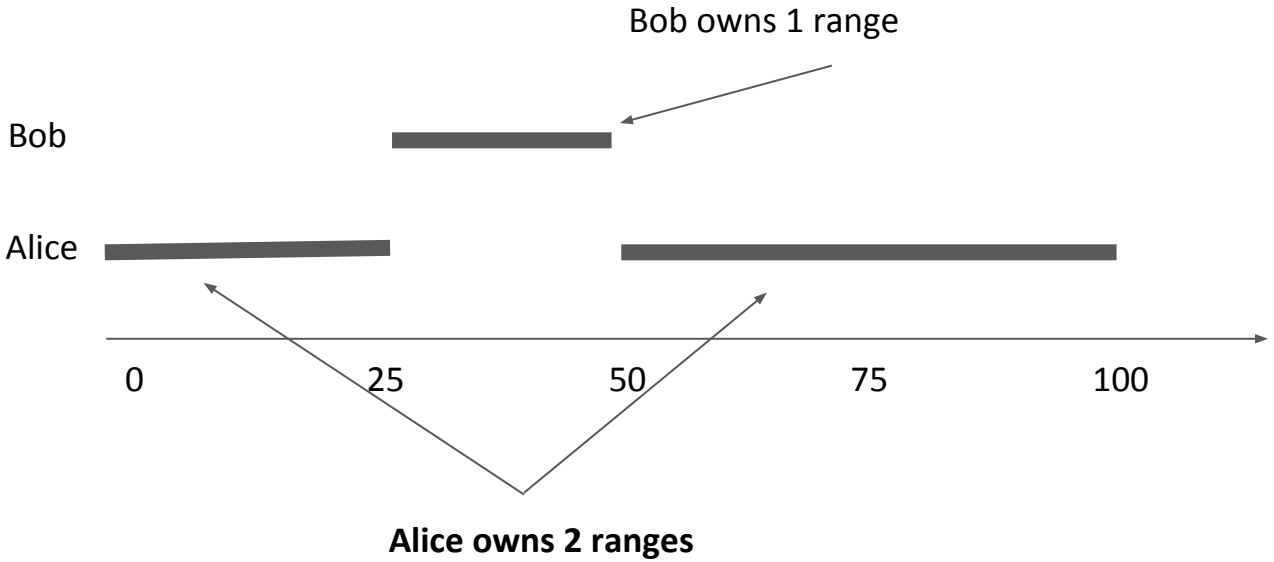


Alice exits range [0,75)!

Any 1 coin inside the range is a valid challenge!

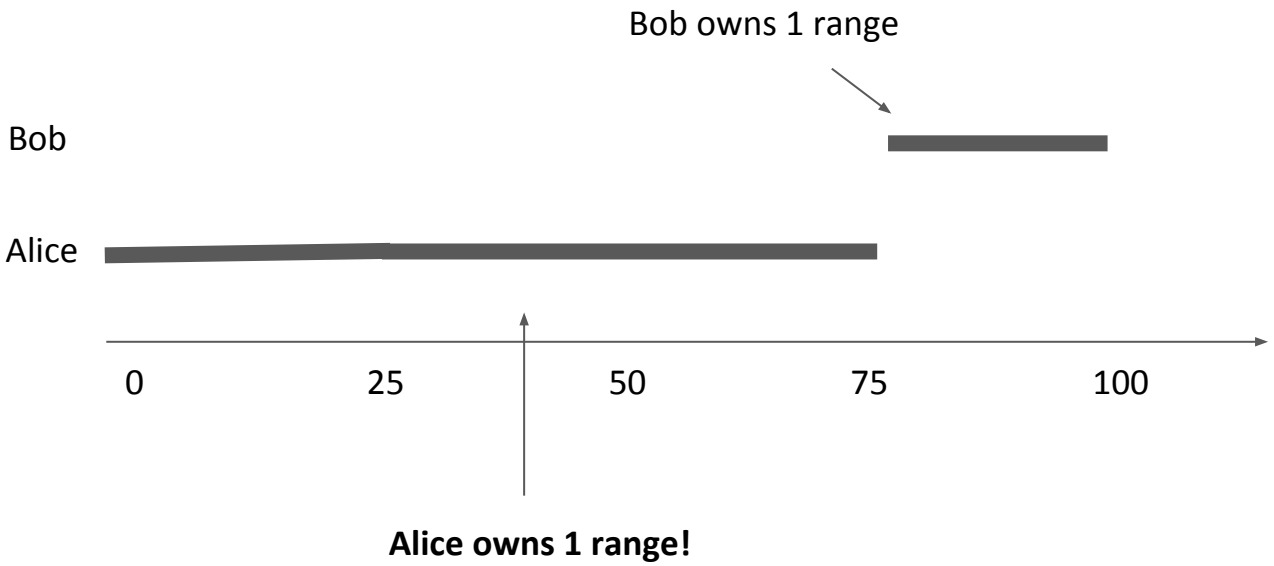


Defragmentation of ranges



https://twitter.com/_sgtn/status/1100357379760091137

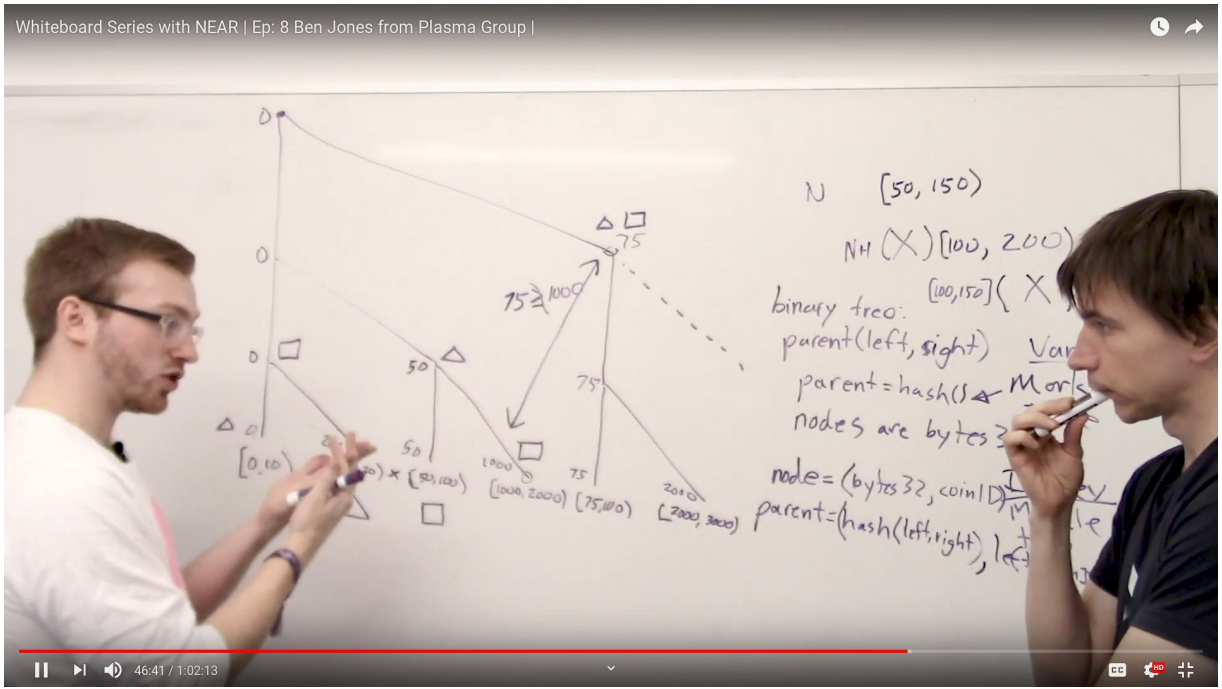
Defragmentation of ranges



https://ethresear.ch/t/plasma-cash-defragmentation/3410
https://ethresear.ch/t/plasma-cash-minimal-atomic-swap/3409

Merkle Interval Tree

Inclusion / exclusion proofs **for ranges w/ light client support!**



https://www.youtube.com/watch?v=-8Jp7VjspQE