Blockchain

Intro

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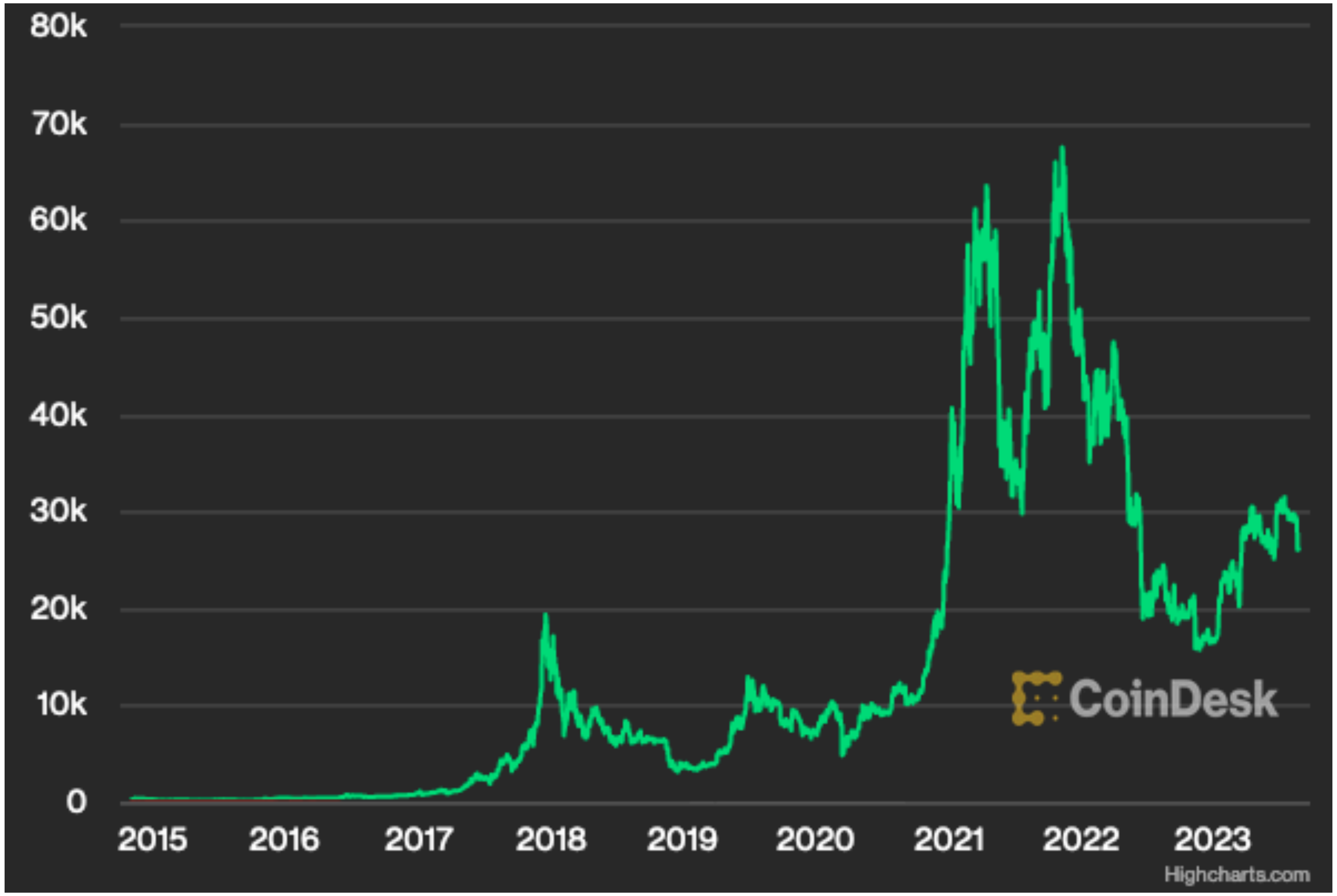
Blockchain

Motivation

Bitcoin

- running > 10 years
- 10.000 nodes



- not possible to buy a coffee

Blockchain

This lectures

Take a look at blockchain technology

- What works
- What does not work

Learning goal: Know how and when to use it.

Know when not to use it.

But: No investment tips

Blockchain 1

Hashlist and Mercle trees

Leander Jehl

Blockchain datastructure

What is a blockchain

A blockchain is an append only log secured against changed.

Typically a blockchain

- is stored on different nodes

Idea: Log all interactions

- Log enables anyone to reproduce/recreate state.

Cryptographic hash function

Idea

$$H(x) = y$$

- x string or byte array
- y fixed size byte array

looks random: hashing something new gives a random value

is deterministic: hashing something twice gives the same value

Cryptographic hash function

Properties

```
<script src="https://code.jquery.com/jquery-3.3.1.slim.min.js"
integrity="sha384-q8i/X+965DzO0rT7abK41JStQIAqVgRVzpbzo5smXKp4YfRvH+8abtTE1Pi6jizo">
</script>
```

Properties:

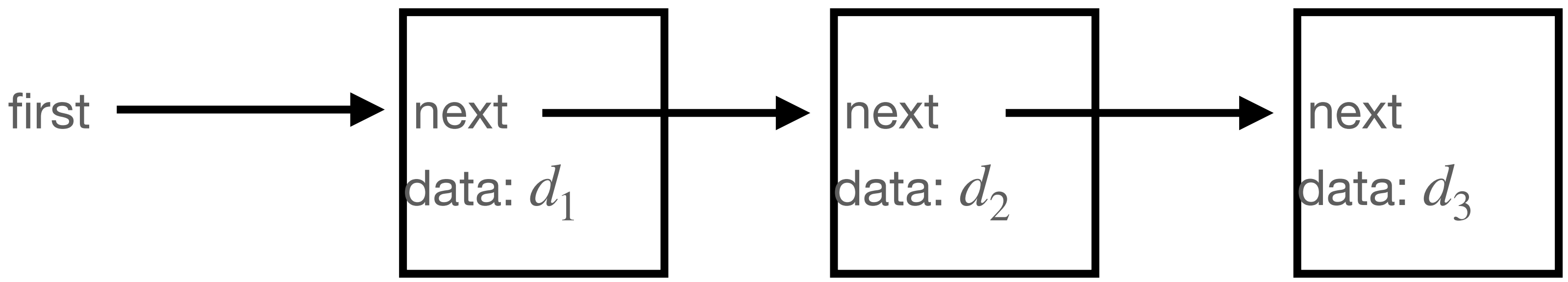
- **Pre-image resistance:**
  given y cannot find x s.t. $H(x) = y$
- **Weak collision resistance:**
  given x cannot find x' s.t. $H(x) = H(x')$
- **Strong collision resistance:**
  cannot find x and x' s.t. $H(x) = H(x')$

Use cases examples:
- Password hashes
- HTML5 integrity attribute

Hash chain

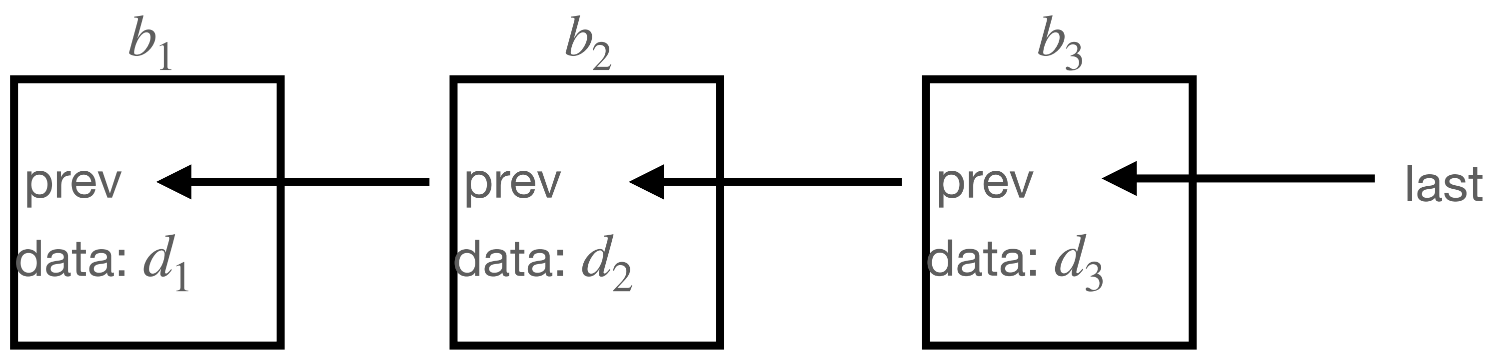
Hash chain

Linked list




```
type Node struct {
    next pointer
    data bytes
}
```

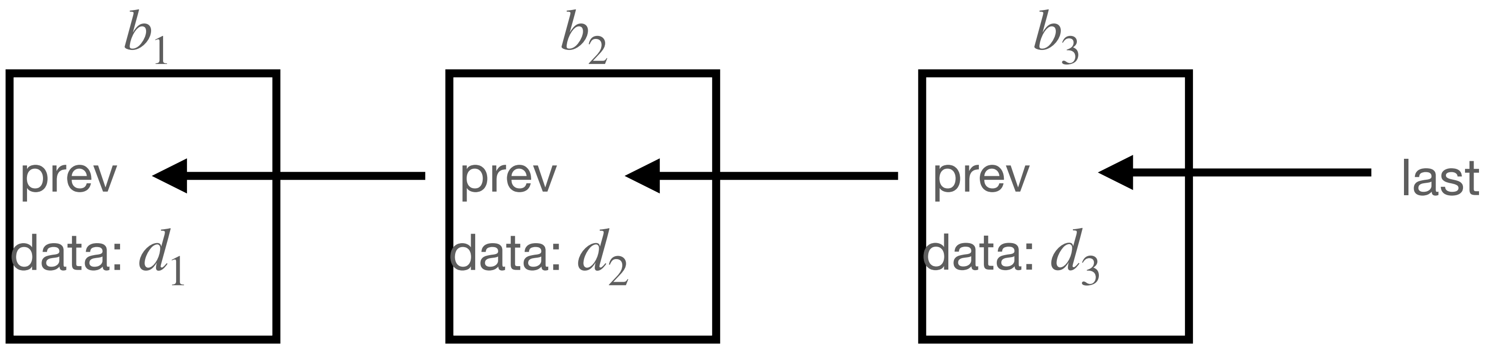
Hash chain




```
type Block struct {
    prev pointer
    data bytes
    prevhash hash
}
```

- Can hash a block by concatenating fields.
- Blockhash gives id: $id_b = H(b\,.\texttt{prevhash}\,||\,b\,.\texttt{data})$
- $b_2\,.\texttt{prevhash} = id_{b_1}$

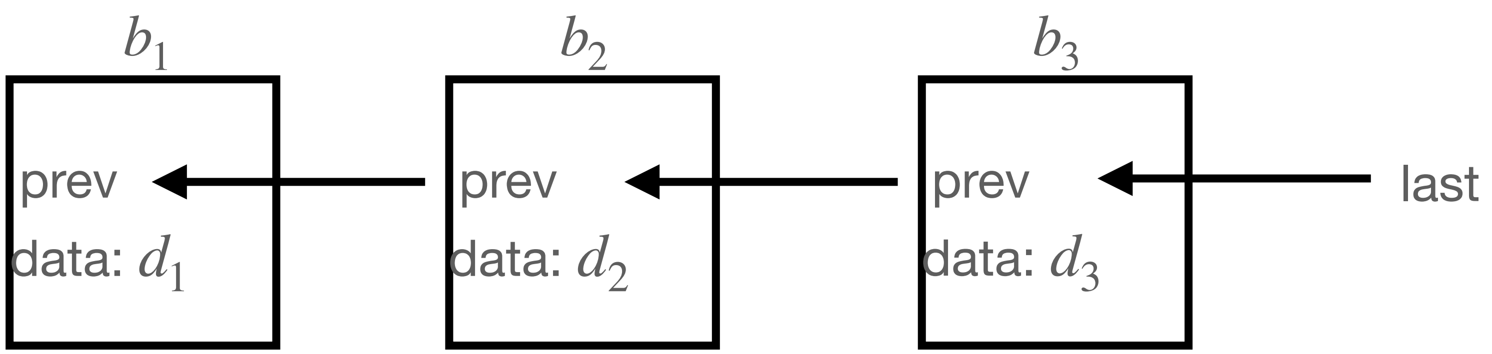
Hash chain



- $id_b = H(b\texttt{.prevhash}||b\texttt{.data})$
- Blockchain identified by id_{b_3}
- Changing d_1 changes id_{b_3}
- Removing b_2 changes id_{b_3}
- Adding b_2' changes id_{b_3}

secured against changes

Hash chain




```
type Block struct {
    prev pointer
    data bytes
    datahash hash
    prevhash hash
    timestamp
}
```

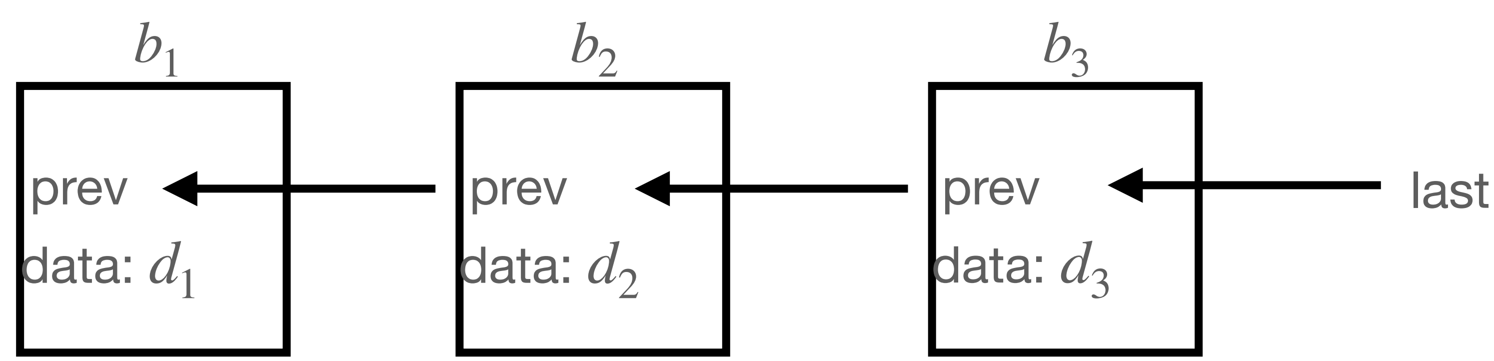
Reduce size:

- $id_b = H(b.\texttt{prevhash}||b.\texttt{datahash})$
- $b.\texttt{datahash} = H(b.\texttt{data})$

- easy to store
- can proof that data is included

Hash chain

Example: Linked timestamping



Trusted source collects data and publishes a new block, e.g. on newspaper.

Hash chain

Digital Signatures and trusted publishers

$$pk, sk \leftarrow setup(\kappa)$$

$$\sigma \leftarrow sign(sk, msg)$$

$$bool \leftarrow verify(\sigma, msg, pk)$$

Ideas:

- Require a trusted party to sign every new block
- Require m out of n trusted parties to sign a block

Permissioned blockchains!

Merkle trees

Merkle trees

Problem

```
type Block struct {
    prev pointer
    data bytes
    datahash hash
    prevhash hash
    timestamp
}
```

Idea:

- put multiple data items into one block

- **Is my item in the block?**

Merkle trees

Ideas

```
type Block struct {
    prev pointer
    data bytes
    datahash hash
    prevhash hash
    timestamp
}
```

Data items: $D_1, D_2, D_3, D_4, \ldots$

- `datahash` $= h$

Data as a hash

- $h = H(D_1 || D_2 || D_3 || \ldots)$

Data as a hashes

- $h = H(D_1) || H(D_2) || H(D_3) || \ldots$

Merkle trees

Design

Data items: $D_1, D_2, D_3, D_4, \ldots$

- `datahash` $= h$

$$h_{1,2,3,4} = H(h_{1,2} \,||\, h_{3,4})$$

$$h_{1,2} = H(h_1 \,||\, h_2) \qquad h_{3,4} = H(h_3 \,||\, h_4)$$

$$h_1 = H(D_1) \qquad h_2 = H(D_2) \qquad h_3 = H(D_3) \qquad h_4 = H(D_4)$$

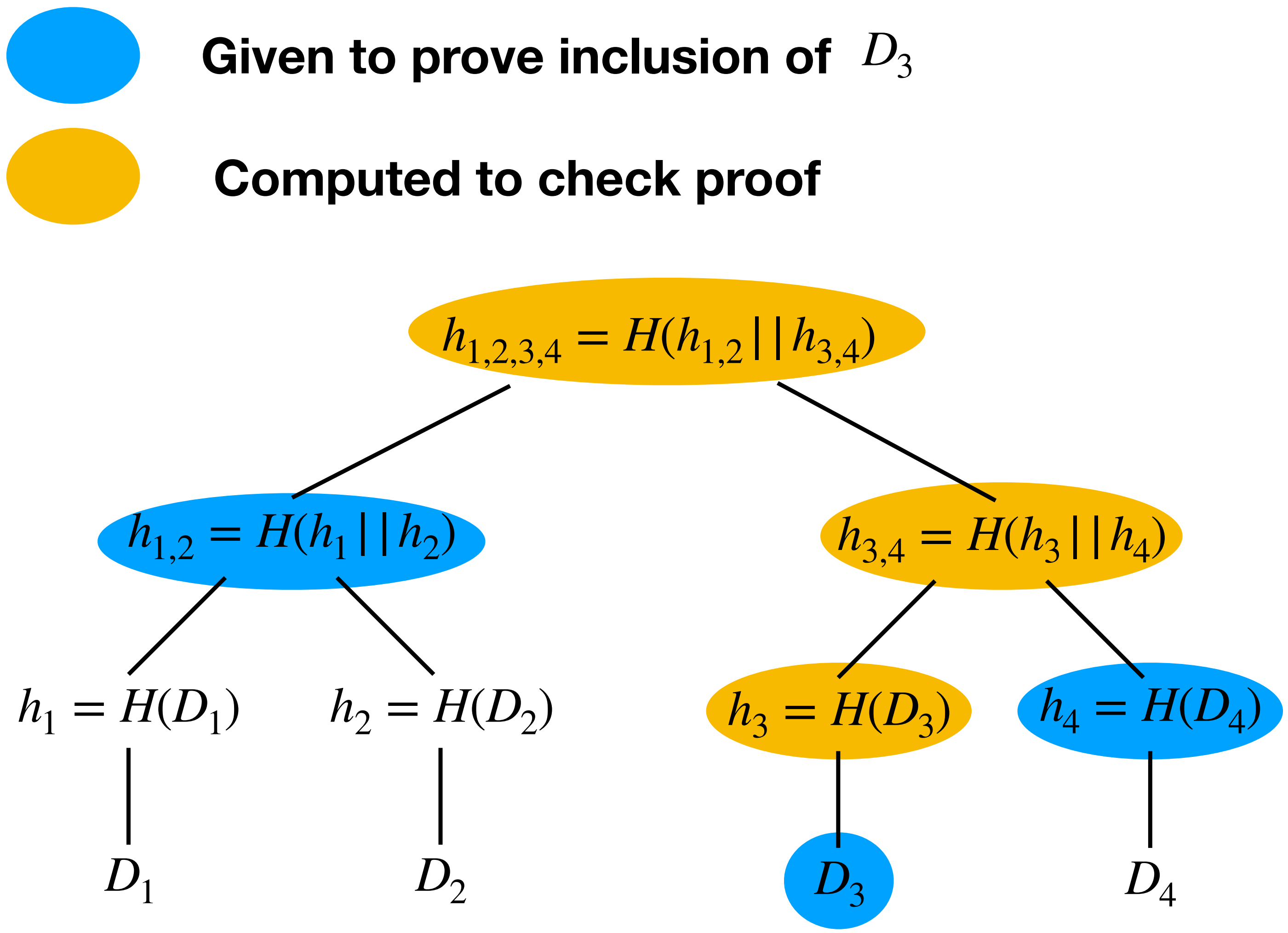
$$D_1 \qquad D_2 \qquad D_3 \qquad D_4$$

Merkle trees

Proofs

Data items: $D_1, D_2, D_3, D_4, \ldots$

- `datahash` $= h$



Merkle trees

Proofs

Data items: $D_1, D_2, D_3, D_4, ...$

- $\texttt{datahash} = h$

What if we have only 5 data items?

- **Duplicate D_5**
- **Add default element**

Signatures and Transactions

Transactions

How can we create an application/cryptocurrency on a blockchain?

- What is in the blocks?
- How to build a meaningful application from it?
- Assume anyone can submit data to the blockchain.

Transactions

Digital Signatures

$$pk, sk \leftarrow setup(\kappa)$$

$$\sigma \leftarrow sign(sk, msg)$$

$$bool \leftarrow verify(\sigma, msg, pk)$$

Ideas:

- Use public key as identity.
- Put signed messages on the blockchain. $\langle msg \rangle_\sigma$
- Signed messages are called *transactions.*

Transactions

Accounts

Transactions are: $\langle pk_{from}, pk_{to}, value \rangle_\sigma$

State is: balance for each public-key

Checks:

- Is signature correct?
- Does pk_{from} have enough money?

Transactions

Accounts

Transactions are: $\langle pk_{from}, pk_{to}, value \rangle_\sigma$

Algorithm 1 Account transactions

$balances := [pk]\text{uint}$
for $block$ **in** chain **do**
  for $\langle pk_{from}, pk_{to}, value \rangle_\sigma$ **in** $block$.data **do**
    if !verify$(pk_{to} || value, pk_{from}, \sigma)$ **then**
      continue
    if $balances[pk_{from}] < value$ **then**
      continue
    $balances[pk_{from}] - = value$
    $balances[pk_{to}] + = value$

Transactions

Accounts

Transactions are: $\langle pk_{from}, pk_{to}, value \rangle_\sigma$

State is: balance for each public-key

Checks:

- Is signature correct?
- Does pk_{from} have enough money?

Problems:

1. **How to deposit money?**
2. **Replay attack!**

Transactions

Accounts

Transactions are: $\langle pk_{from}, pk_{to}, value \rangle_\sigma$

Deposit:

- Give out some money
- Deposit with someone who has money

Replay attack:

- A signed transaction can be submitted multiple times.
- Sequence numbers!

Transactions

Accounts

Algorithm 2 Account transactions

$balances := [pk]\text{uint}$
$sqNrs := [pk]\text{uint}$
for $block$ **in** chain **do**
    for $\langle pk_{from}, pk_{to}, value, sqNr\rangle_\sigma$ **in** $block$.data **do**
        if $!\text{verify}(pk_{to}||value||sqNr, pk_{from}, \sigma)$ **then**
            continue
        if $balances[pk_{from}] < value$ **then**
            continue
        if $sqNrs[pk_{from}] = sqNr$ **then**
            $balances[pk_{from}] -= value$
            $balances[pk_{to}] += value$
            $sqNrs[pk_{from}]++$

Idea: do checks when adding transaction to chain.

Transactions
UTXO

UTXO: Unspent transaction output

Idea: *No balances but coins*

- For each coin store pk of owner and unique id
- Transaction spends some coints and creates new ones.

Transactions

UTXO

Transactions:

$$tx = \langle \underbrace{[(id_1, \sigma_1), (id_2, \sigma_2)]}_{\text{Inputs}}, \underbrace{[(pk_a, value_a), (pk_b, value_b)]}_{\text{Outputs}} \rangle$$

State is unspent outpus $map[id](pk, value)$

Transactions
UTXO

Transactions:

$$tx = \langle \underbrace{[(id_1, \sigma_1), (id_2, \sigma_2)]}_{\text{Inputs}}, \underbrace{[(pk_a, value_a), (pk_b, value_b)]}_{\text{Outputs}} \rangle$$

Valid if:

- Inputs refer to unspent outputs.
- Signatures are correct (with outputs public key)
- Value of all inputs larger or equal than all output values.

Transactions

UTXO

Algorithm 3 Transaction validation and maintenance of UTXO

$UTXO := map[id](value, pk)$
for $tx = \langle inputs, outputs \rangle$ **do**
    for $(id, \sigma) \in inputs$ **do**
        if $UTXO[id]$ does not exist **then**
            abort ▷ invalid transaction
        if verify$(tx, \sigma, UTXO[id].pk) ==$ **false then**
            abort ▷ invalid transaction
    if sum of values of inputs < sum of values of new outputs **then**
        abort ▷ invalid transaction
    for $((id, \sigma) \in inputs$ **do**
        remove$(UTXO[id])$ ▷ output spent
    for $((pk, value) \in inputs$ **do**
        $UTXO[newid] = (pk, value)$ ▷ add new outputs

Transactions

UTXO

Transactions:

$$tx = \langle \underbrace{[(id_1, \sigma_1), (id_2, \sigma_2)]}_{\text{Inputs}}, \underbrace{[(pk_a, value_a), (pk_b, value_b)]}_{\text{Outputs}} \rangle$$

- No replay attack
- What to sign: $\langle [id_1, id_2], [(pk_a, value_a), (pk_b, value_b)] \rangle$

Transactions

Accounts vs. UTXO

Assuming only valid transactions on chain,
how to verify that a pk has money.

Accounts: Check all received and sent transactions.

UTXO: Check received output and that it is unspent.

Transactions

Accounts vs. UTXO

Assuming only valid transactions on chain,
how to verify that a pk has money.

Accounts: Check all received and sent transactions.

UTXO: Check received output and that it is unspent.

Does UTXO provide anonymity/prevent tracing?

Transactions
Accounts vs. UTXO

Assuming only valid transactions on chain,
how to verify that a pk has money.

Accounts: Check all received and sent transactions.

UTXO: Check received output and that it is unspent.

Does UTXO provide anonymity/prevent tracing?

- Also in UTXO transactions from one sender can be traced.
- But most untracable solutions build on UTXO

Take away

A blockchain is an append only log secured against changed.

Transactions/state changes are recorded in the blockchain.

Application state can be recreated by applying all transactions.