Blockchain technology and applications

Intro

DAT655 Blockchain tech & app

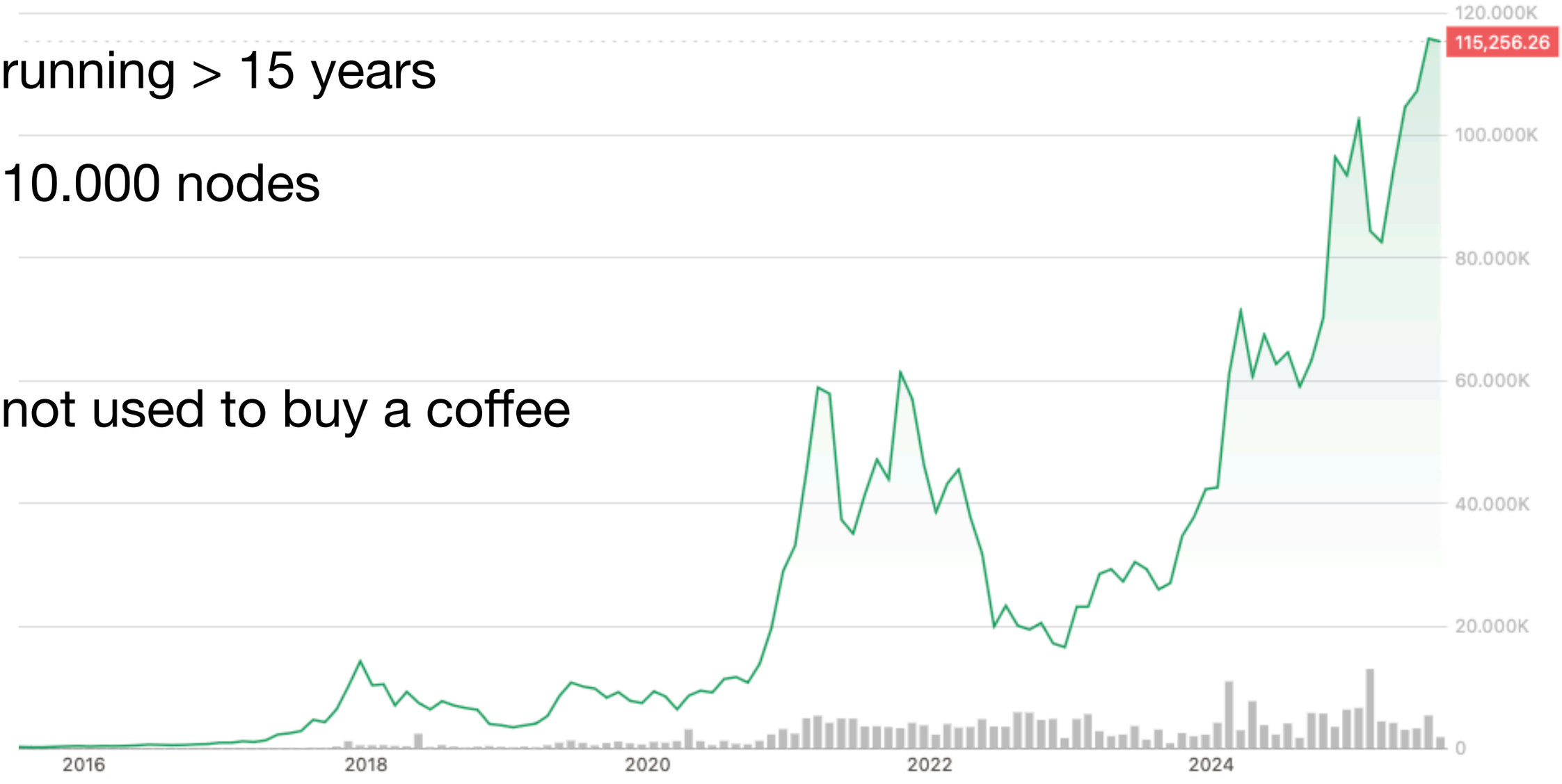
Leander Jehl

Blockchain

Motivation

Bitcoin

- running > 15 years
- 10.000 nodes
- not used to buy a coffee



https://www.coindesk.com/price/bitcoin

Blockchain and applications

Take a look at blockchain technology and applications

- 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 and applications

Where can many people, jointly store an important document?

- e.g. Will
- e.g. Ownership list
- Can changes be made?

Blockchain 1

Hashlist and Mercle trees

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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

$$H(x) = y$$

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:

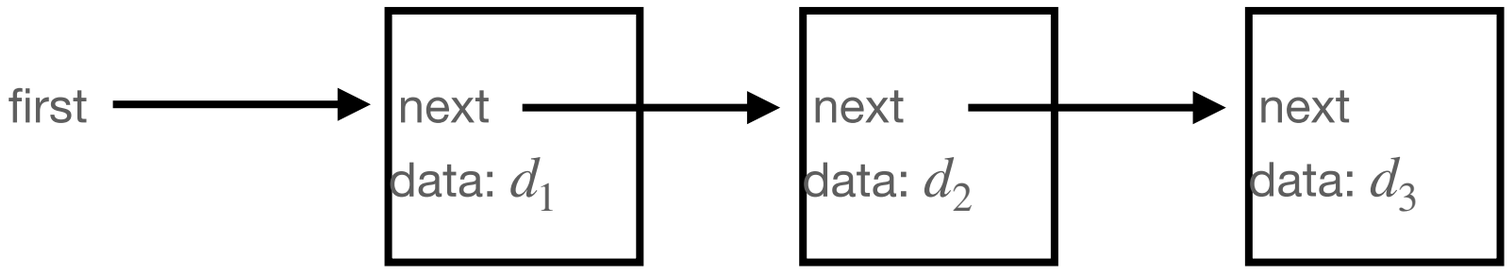
- **Pre-image resistance:**
  given y cannot find x s.t. $H(x) = y$
- **Weak collision resistance:**
  given x cannot find x' s.t. $H(x) = H(x')$
- **Strong collision resistance:**
  cannot find x and x' s.t. $H(x) = H(x')$

Use cases examples:
- **Password hashes**
- **HTML5 integrity attribute**

Hash chain

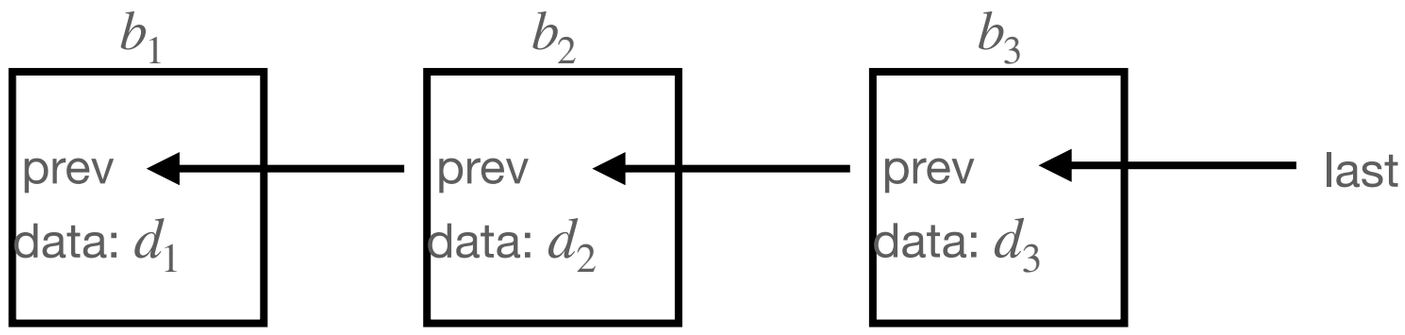
Hash chain

Linked list




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

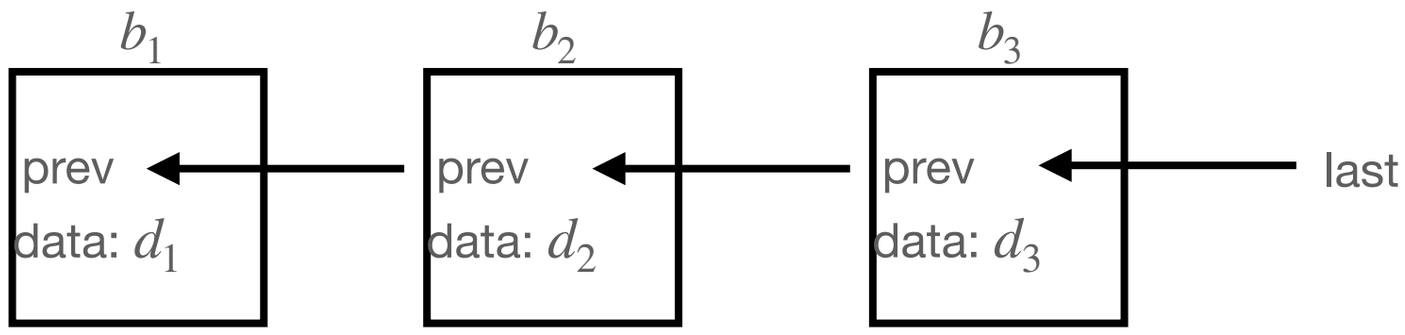
Hash chain




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

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

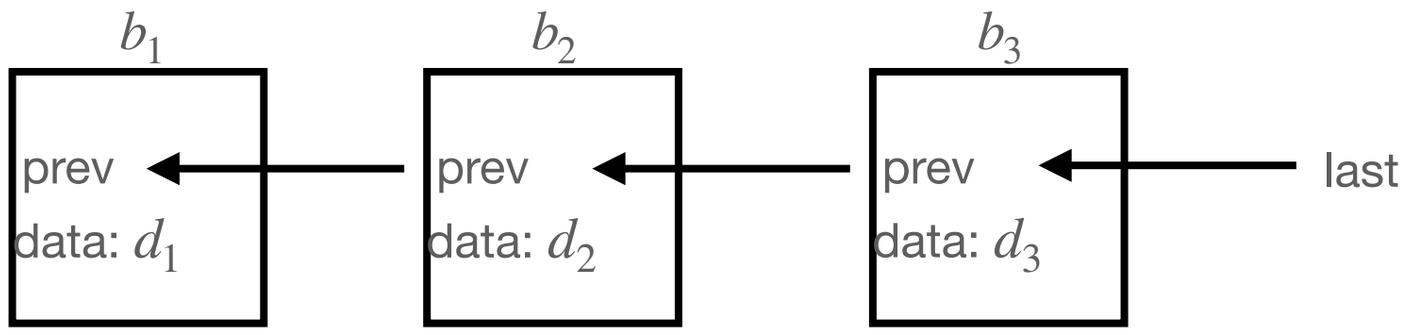
Hash chain



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

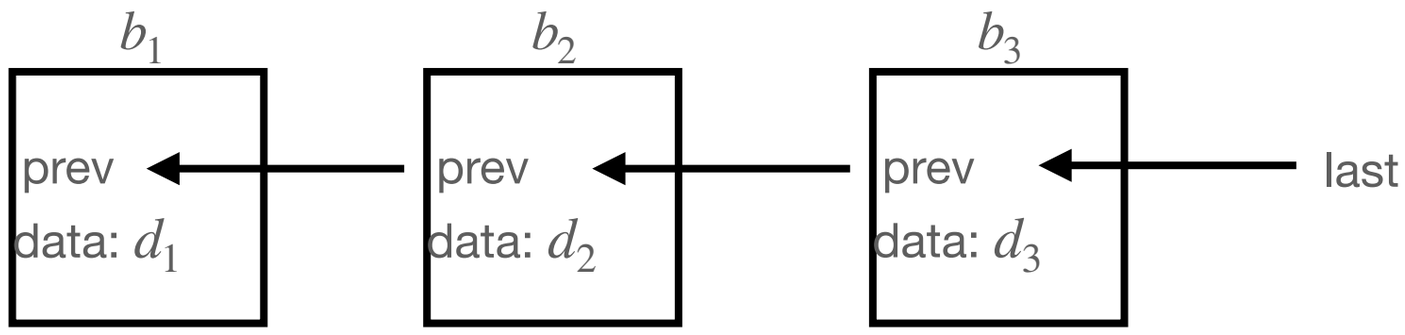
Reduce size:

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

- 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

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 list of hashes

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

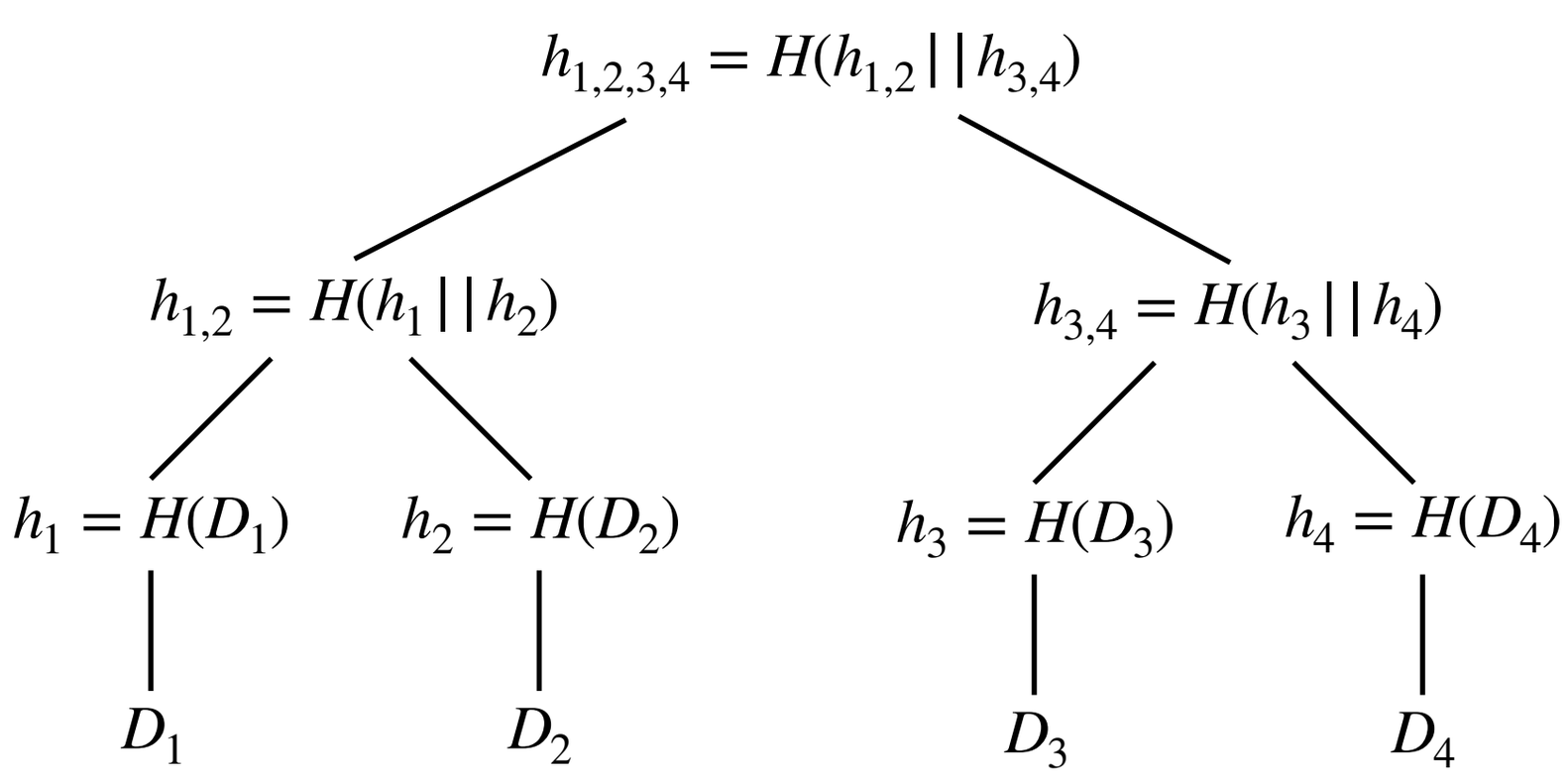
```
type Block struct {
    prev pointer
    data bytes
    datahash hash
    prevhash hash
    timestamp
}
```

Merkle trees

Design

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

- `datahash` $= h$

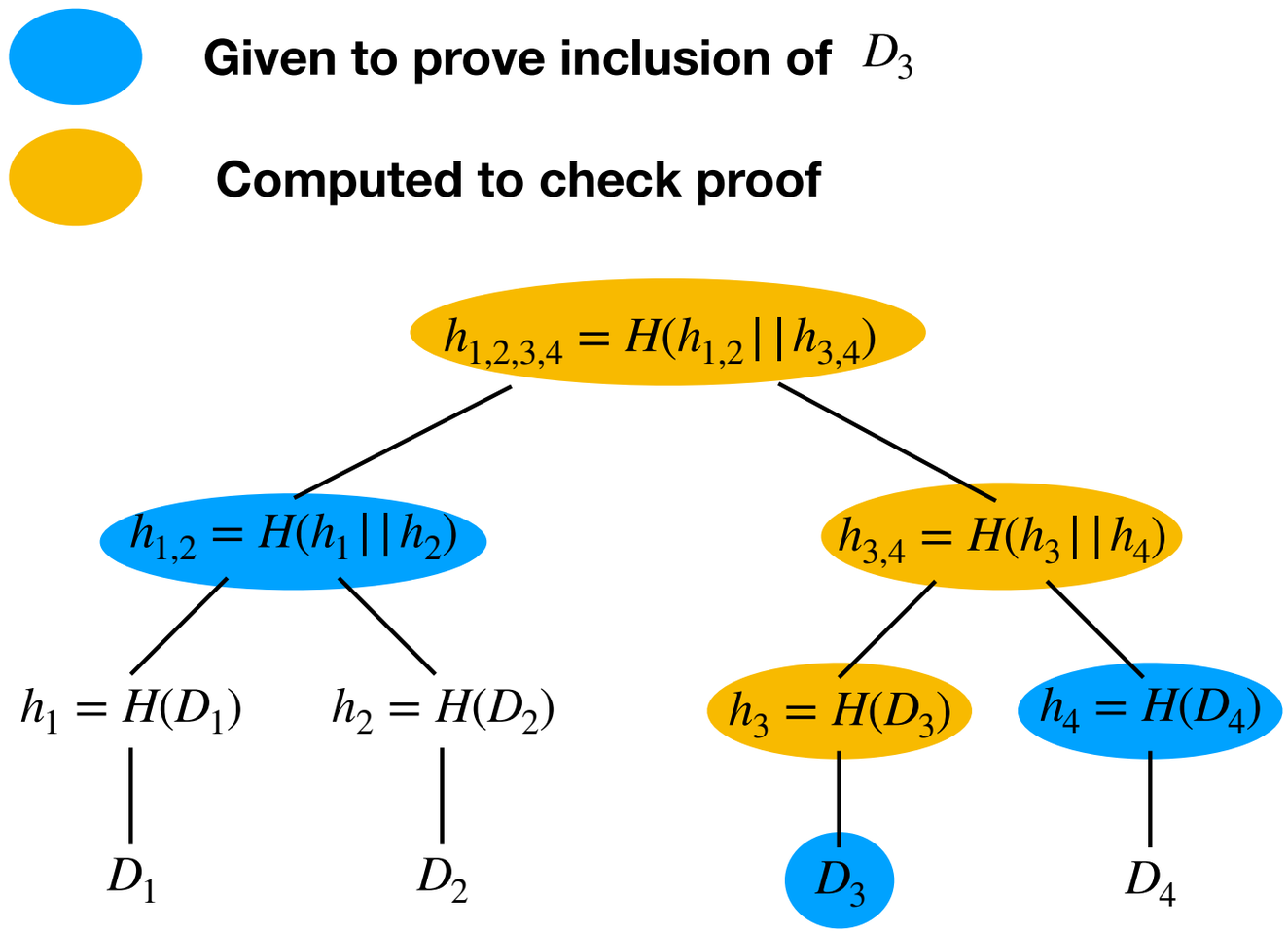


Merkle trees

Proofs

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

- `datahash` $= h$



Merkle trees

Proofs

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

- `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]uint
for block in chain do
    for ⟨pk_from, pk_to, value⟩_σ in block.data do
        if !verify(pk_to||value, pk_from, σ) 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

1: $balances := [pk]\text{uint}$
2: $sqNrs := [pk]\text{uint}$
3: **for** $block$ **in** chain **do**
4: **for** $\langle pk_{from}, pk_{to}, value, sqNr \rangle_\sigma$ **in** $block$.data **do**
5: **if** $!\text{verify}(pk_{to}||value||sqNr, pk_{from}, \sigma)$ **then**
6: **continue**
7: **if** $balances[pk_{from}] < value$ **then**
8: **continue**
9: **if** $sqNrs[pk_{from}] = sqNr$ **then**
10: $balances[pk_{from}] -= value$
11: $balances[pk_{to}] += value$
12: $sqNrs[pk_{from}]++$

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:

$$tx = \langle [(id_1, \sigma_1), (id_2, \sigma_2)], [(pk_a, value_a), (pk_b, value_b)] \rangle$$

Inputs — Outputs

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

Transactions

UTXO

Transactions:

$$tx = \langle [(id_1, \sigma_1), (id_2, \sigma_2)], [(pk_a, value_a), (pk_b, value_b)] \rangle$$

Inputs

Outputs

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:

$$tx = \langle [(id_1, \sigma_1), (id_2, \sigma_2)], [(pk_a, value_a), (pk_b, value_b)] \rangle$$

Inputs — Outputs

- 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.