Cryptography Basics for Understanding Bitcoin and Blockchain Technology

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Agenda

Crypto building blocks
- Hash functions
- Digital signatures

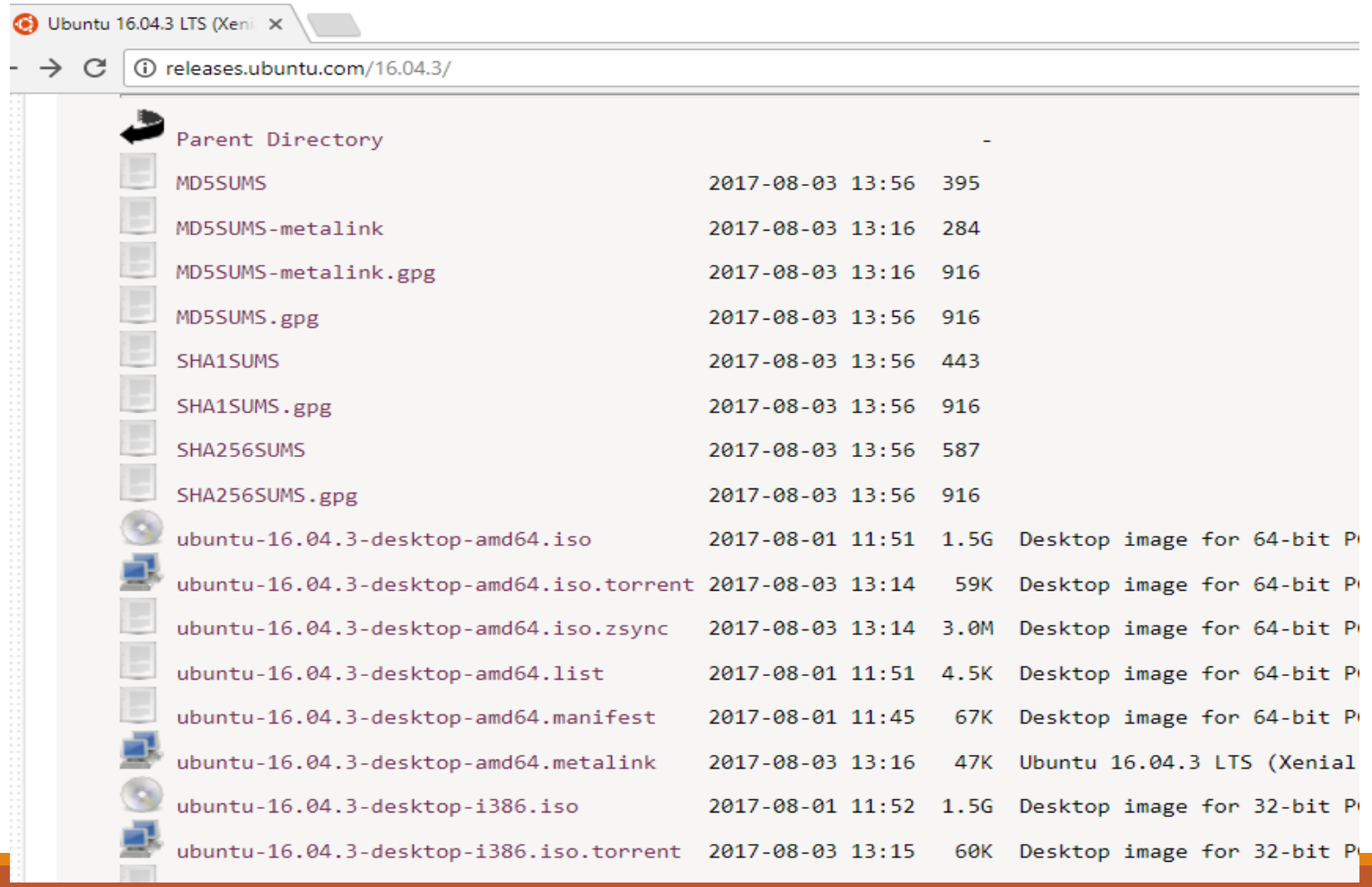
Relevant data structures
- Hash pointer
- Blockchain

Simple cryptocurrencies
- Goofycoin
- Scroogecoin

Bitcoin and blockchain

Hash functions: WHAT

Hash function = a function mapping inputs of any size to outputs of a fixed size

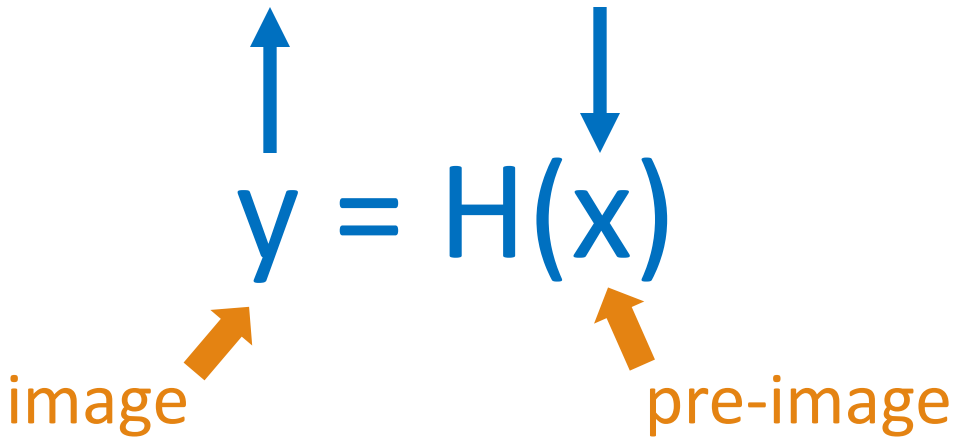


Hash functions: WHAT

Hash function = a function mapping inputs of any size to outputs of a fixed size

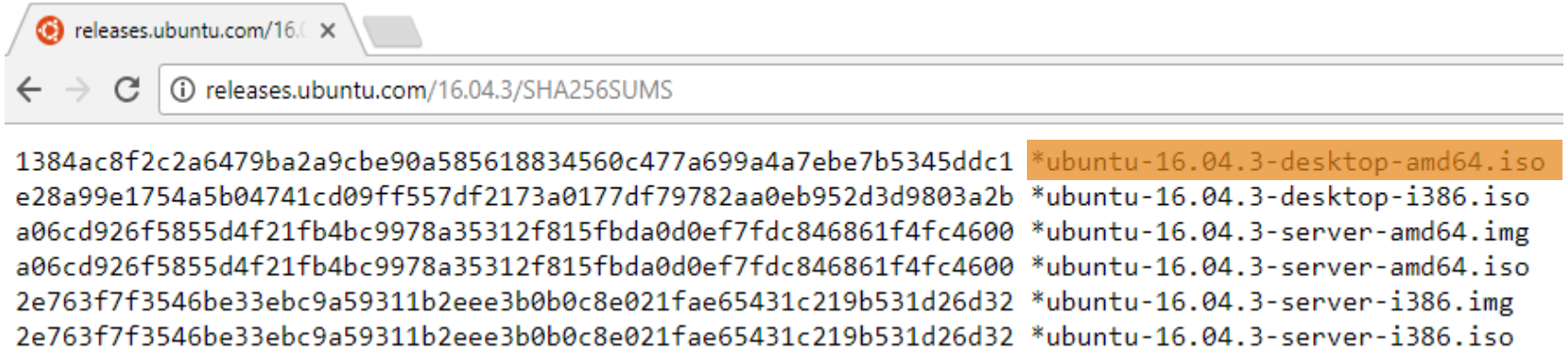
releases.ubuntu.com/16.04.3/SHA256SUMS

```
1384ac8f2c2a6479ba2a9cbe90a585618834560c477a699a4a7ebe7b5345ddc1 *ubuntu-16.04.3-desktop-amd64.iso
e28a99e1754a5b04741cd09ff557df2173a0177df79782aa0eb952d3d9803a2b *ubuntu-16.04.3-desktop-i386.iso
a06cd926f5855d4f21fb4bc9978a35312f815fbda0d0ef7fdc846861f4fc4600 *ubuntu-16.04.3-server-amd64.img
a06cd926f5855d4f21fb4bc9978a35312f815fbda0d0ef7fdc846861f4fc4600 *ubuntu-16.04.3-server-amd64.iso
2e763f7f3546be33ebc9a59311b2eee3b0b0c8e021fae65431c219b531d26d32 *ubuntu-16.04.3-server-i386.img
2e763f7f3546be33ebc9a59311b2eee3b0b0c8e021fae65431c219b531d26d32 *ubuntu-16.04.3-server-i386.iso
```



Hash functions: Collision resistance

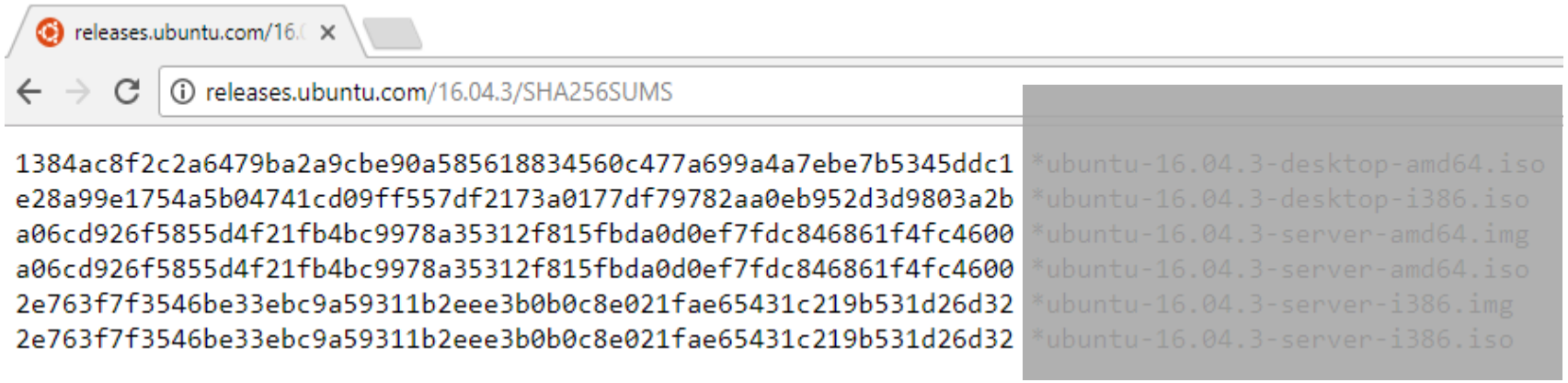
Hard to find x ≠ y such that
H(x) = H(y)



Hash functions: Hiding

If a secret value r is sampled from a probability distribution that has high min-entropy, then

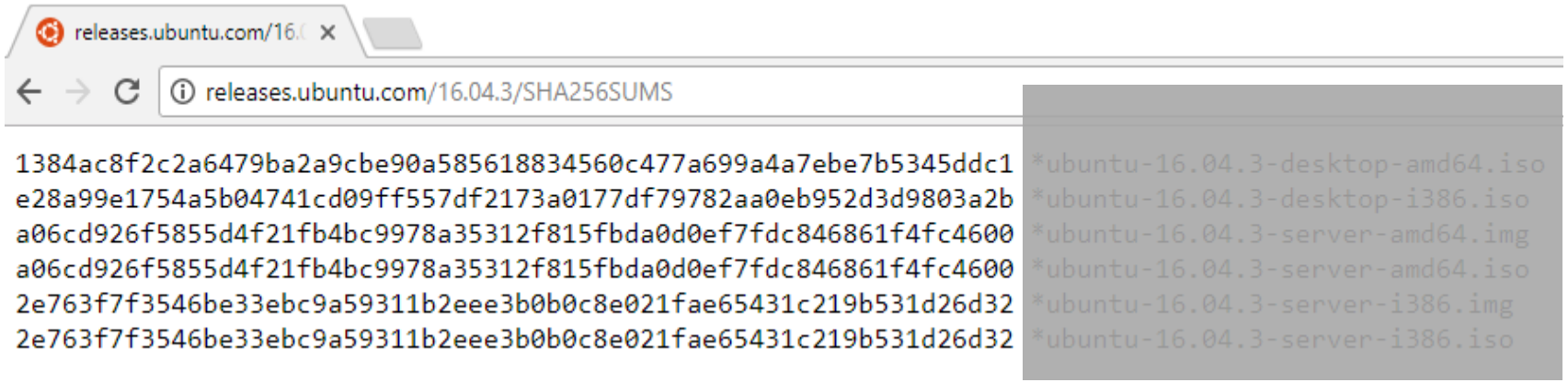
given $y = H(r \| x)$, it is hard to find x.



Hash functions: Puzzle friendliness

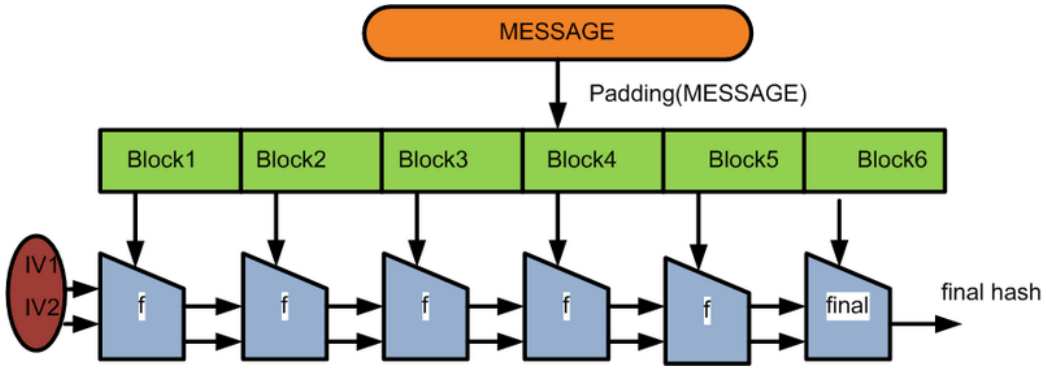
If a secret value r is chosen from a probability distribution that has high min-entropy, then for every n-bit output y

given $y = H(r \| x)$, it is hard to find x in time much less than 2^n.



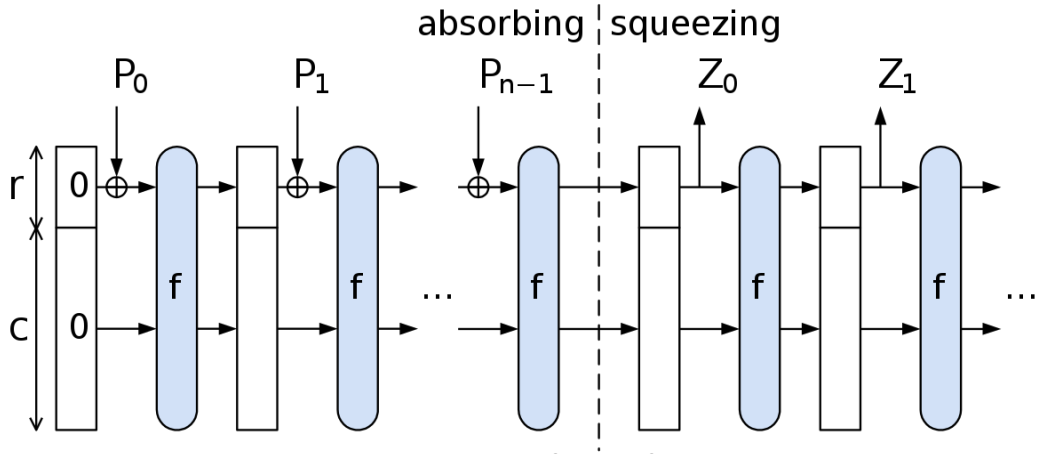
Hash functions: Examples

- SHA256



source: wikipedia

- Keccak



source: wikipedia

- Chacha
- Curl (!)
- etc

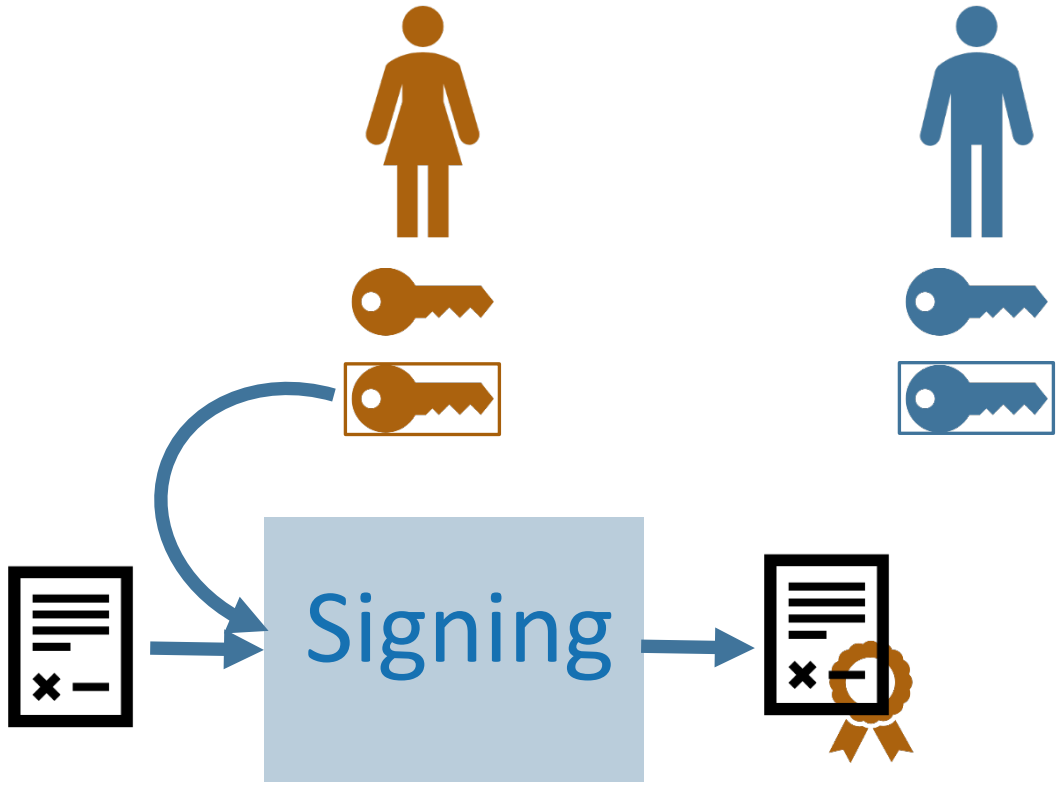
Digital signatures: WHAT

Key generation:
everyone in the system has a key pair

(public key, private key)

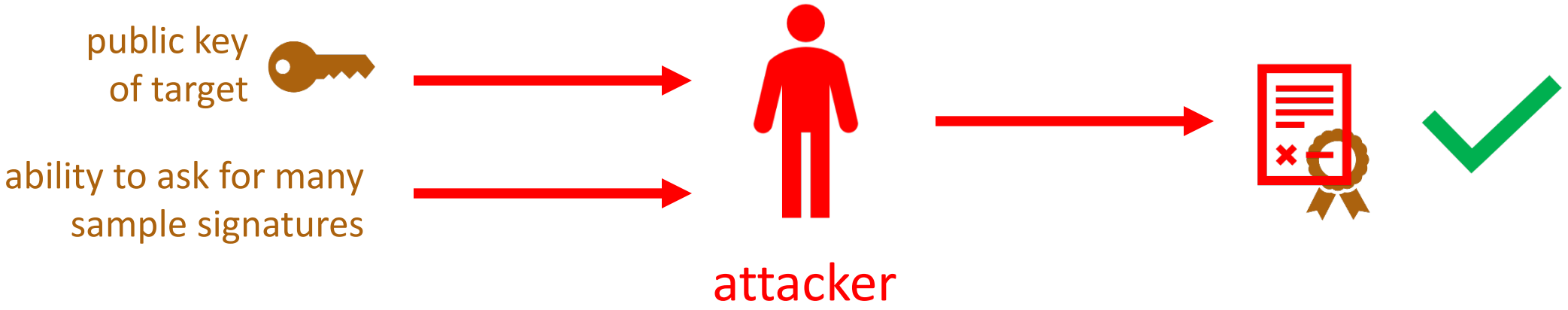
Signing: only the signer can sign (duh!)

Verification: “anyone” can verify

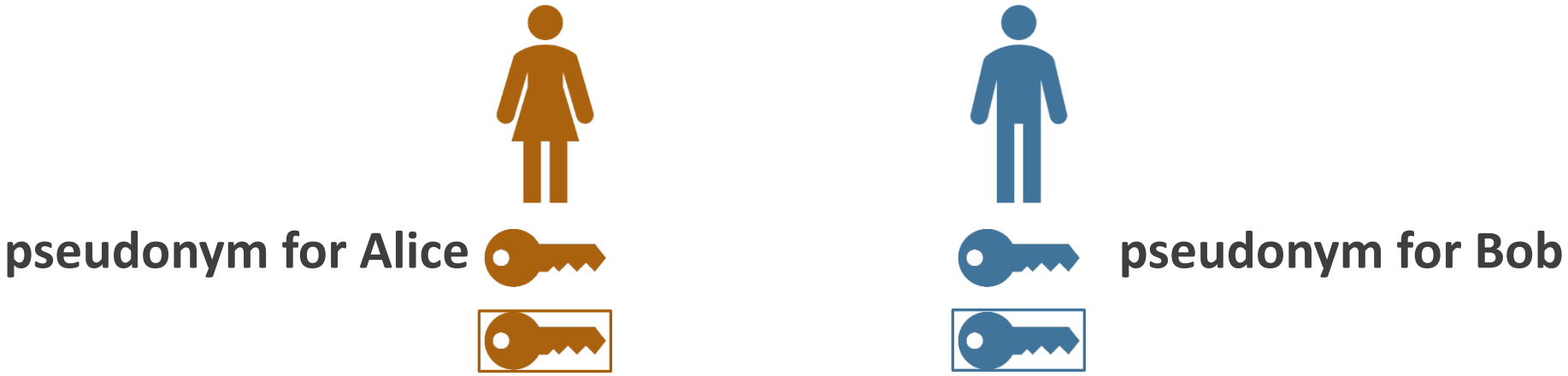


Digital signatures: unforgeability

Hard to forge signatures

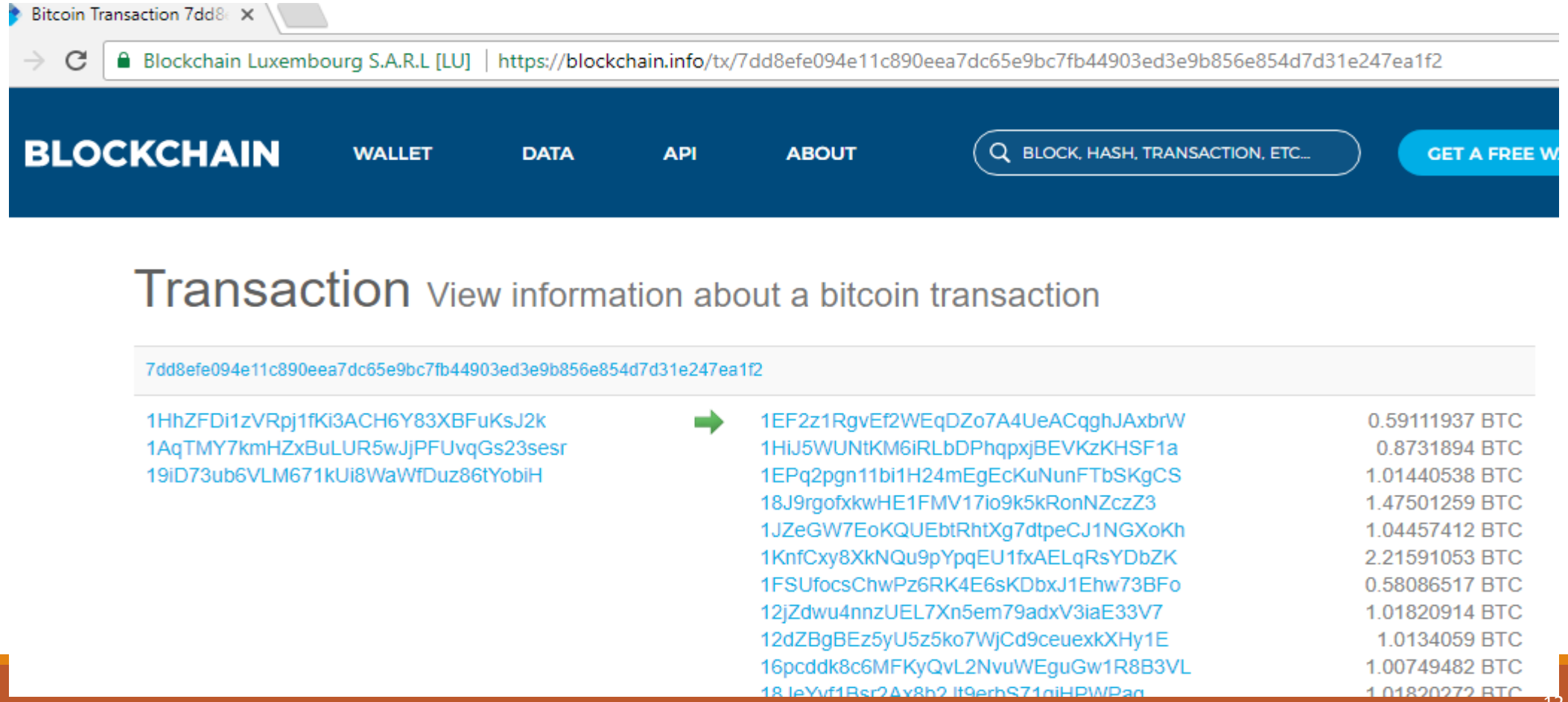


Digital signatures: Public keys as identities



Public key as identities in bitcoin system

https://blockchain.info/tx/7dd8efe094e11c890eea7dc65e9bc7fb44903ed3e9b856e854d7d31e247ea1f2



Digital signatures: Examples

- RSA
- ElGamal
- DSA
- etc.

- Bitcoin system uses ECDSA.

DSA (Digital Signature Algorithm)

- Fix primes p, q such that q divides $p-1$
- Let $G = \mathbf{Z}_p^* = \langle h \rangle$ and $g = h^{(p-1)/q}$ so that $g \in G$ has order q
- H: $\{0,1\}^* \to \mathbf{Z}_q$ a hash function
- Signer keys: $pk = X = g^x \in \mathbf{Z}_p^*$ and $sk = x \xleftarrow{\$} \mathbf{Z}_q$

Alg $\mathcal{S}_x(M)$

$m \leftarrow H(M)$
$k \xleftarrow{\$} \mathbf{Z}_q^*$
$r \leftarrow (g^k \mod p) \mod q$
$s \leftarrow (m + xr) \cdot k^{-1} \mod q$
Return (r, s)

Alg $\mathcal{V}_X(M, (r, s))$

$m \leftarrow H(M)$
$w \leftarrow s^{-1} \mod q$
$u_1 \leftarrow mw \mod q$
$u_2 \leftarrow rw \mod q$
$v \leftarrow (g^{u_1} X^{u_2} \mod p) \mod q$
If $(v = r)$ then return 1 else return 0

Details: Signature is regenerated if $s = 0$.

source: Bellare lecture slides.

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Relevant data structures
- Hash pointer
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Simple cryptocurrencies
- Goofycoin
- Scroogecoin

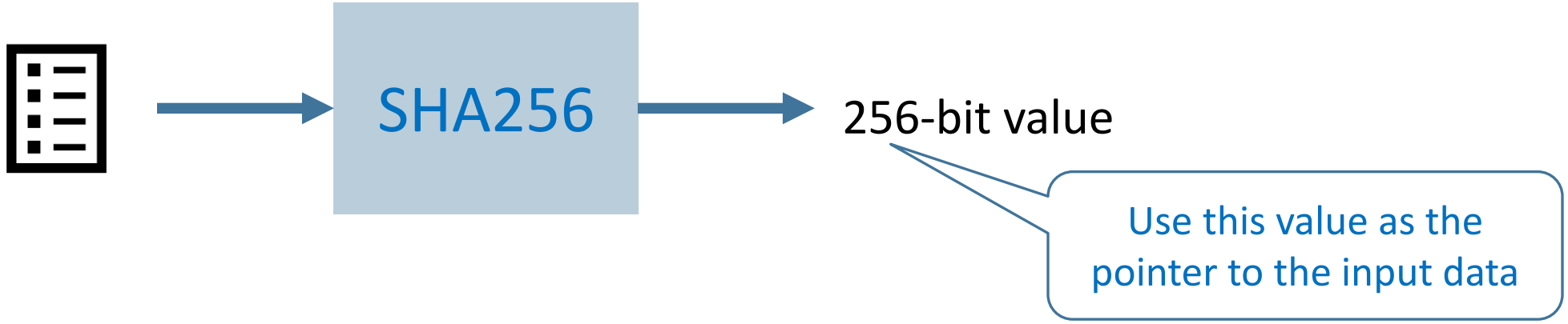
Bitcoin and blockchain

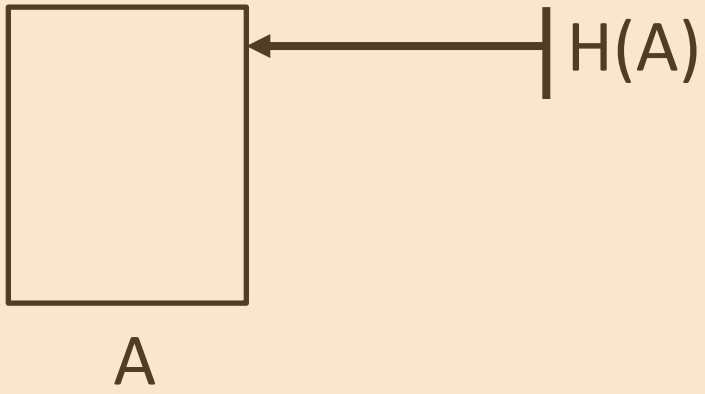
Relevant data structures

Hash pointer

Blockchain

Hash pointer

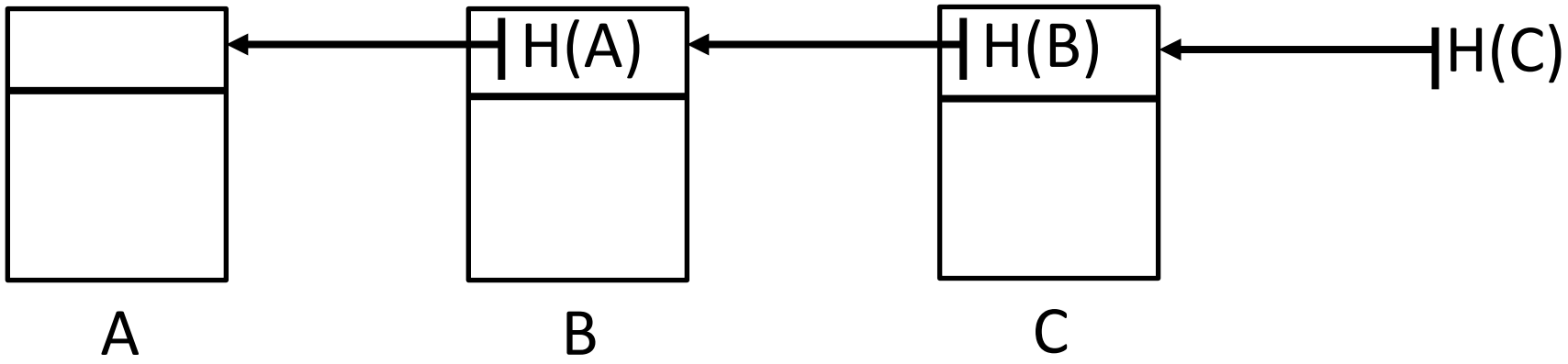




Notation for Hash pointer

Property: Lets us locate the data and verify the contents.

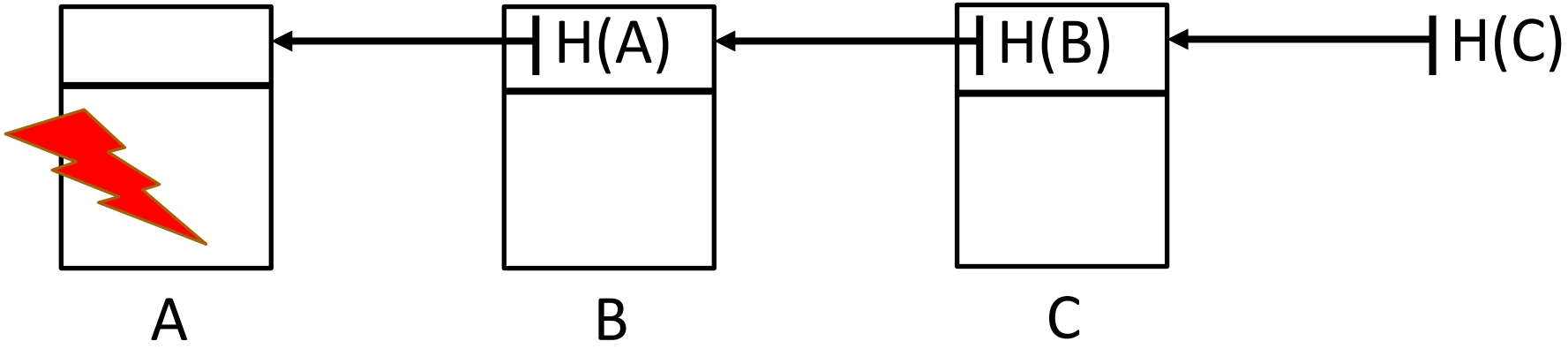
Blockchain (as a data structure)



In its simplest form, a blockchain is a linked list created by embedding hash pointers into the data blocks.

Verify data in the entire chain by verifying the hashes in the chain.

Blockchain (as a data structure)



- What if an attacker wants to modify data in block A?
- Compared to a normal, line-by-line ledger?

Example applications: append-only ledger, “timestamping” service

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Simple cryptocurrencies

Goofycoin

Scroogecoin

Reference:

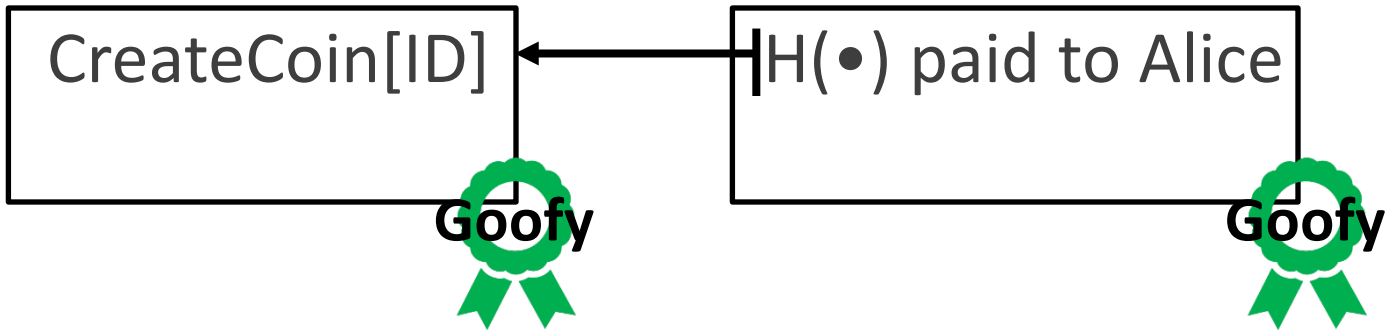
Bitcoin and Cryptocurrency Technologies, Narayanan, et. al. 2016

Goofycoin

Goofy is the central authority. He mints coins.

Goofycoin

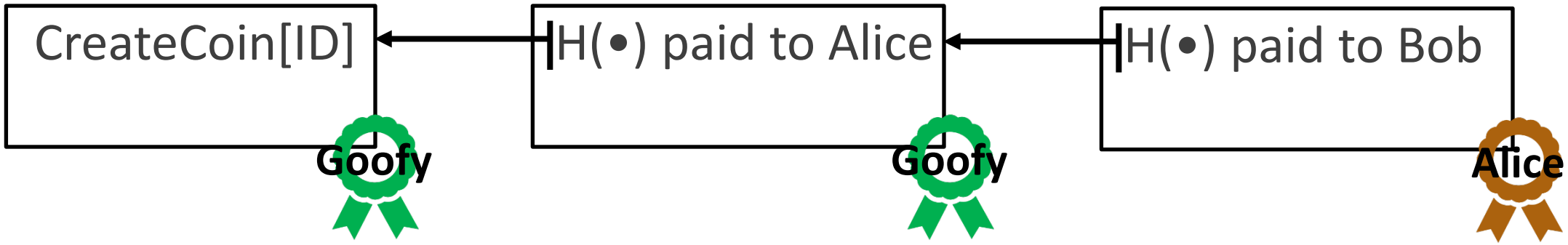
Goofy is the central authority. He pays people.



Simplification: one transaction per block.

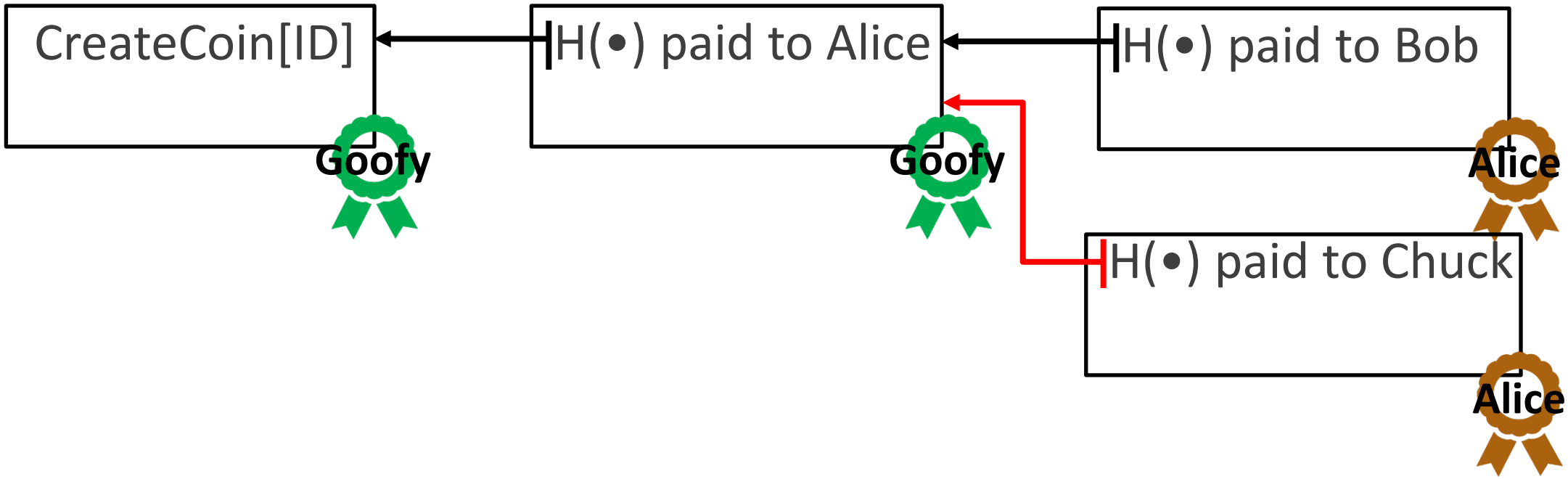
Goofycoin

People spend coins.



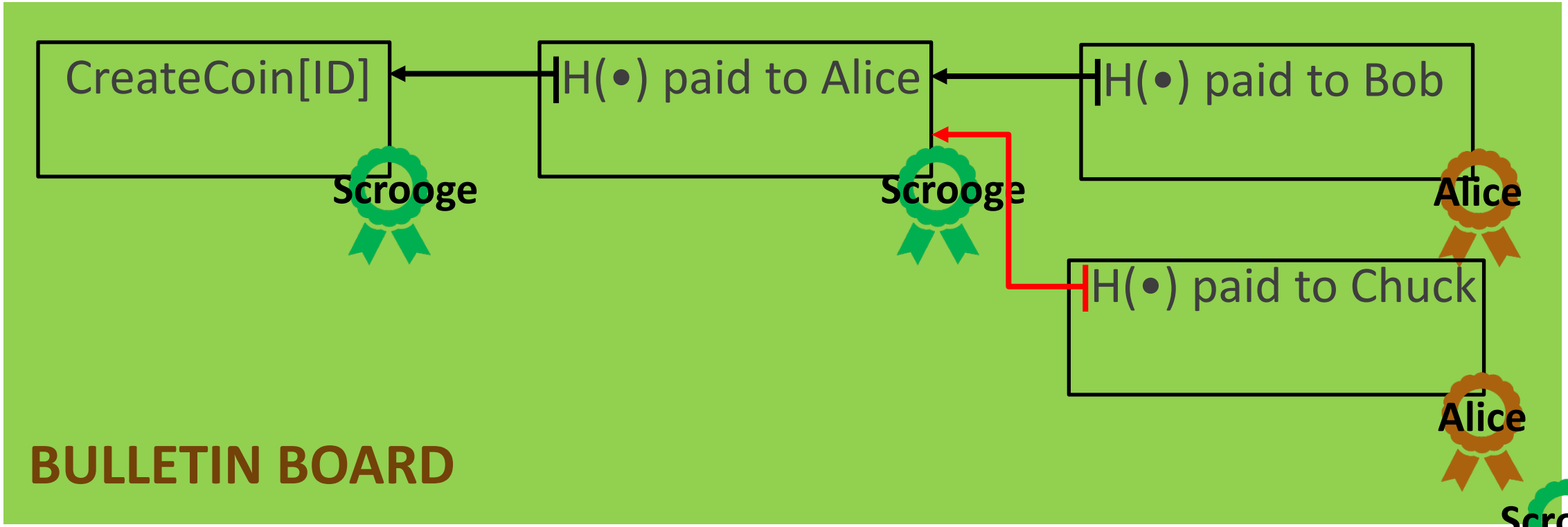
Goofycoin

But what if Alice tries to double-spend?



Scroogecoin

Scrooge acts like Goofy except that he publishes the history of all transactions.



Scroogecoin

Scrooge is the central authority.

Reasons we want to remove him:

- We don’t necessarily trust him
- He’s the single point of failure.
  - if he decides to quit this job or
  - if his secret key gets stolen or
  - if his computer crashes
  - etc etc, we’re toast!

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Bitcoin and blockchain

Bitcoin and blockchain

Bitcoin network

Bitcoin blocks

Adding blocks to the blockchain

Bitcoin transactions

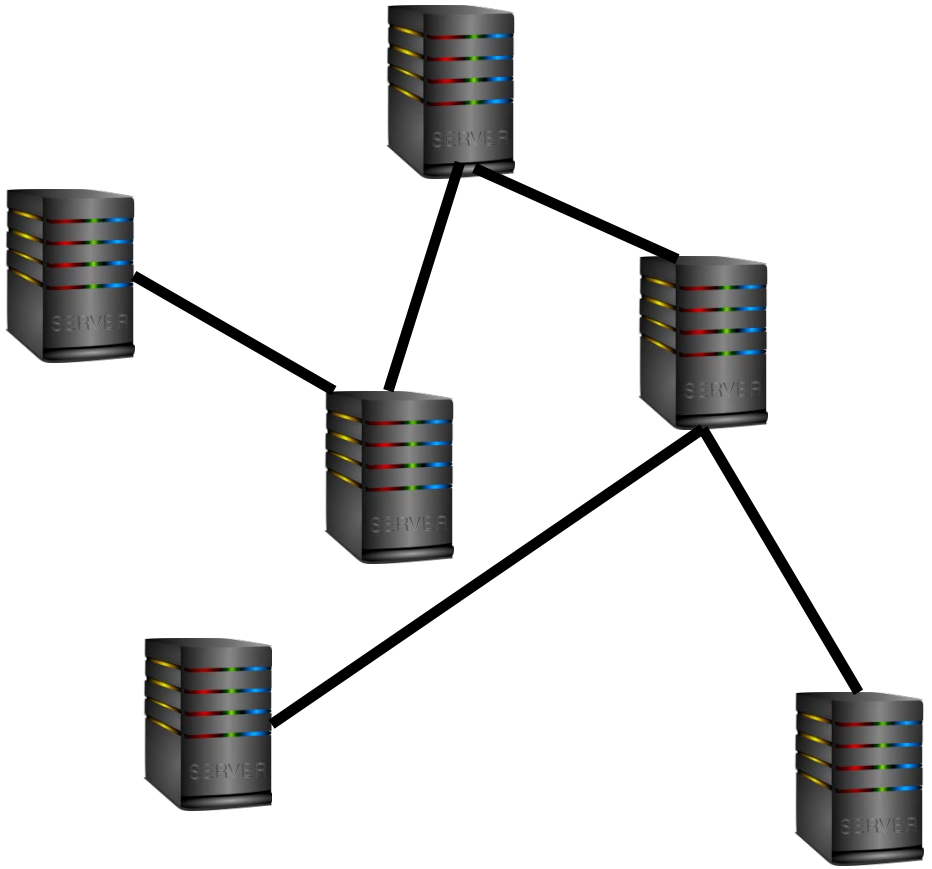
Attacks

- Fraudulent transactions
- Double spending attack

Discussions

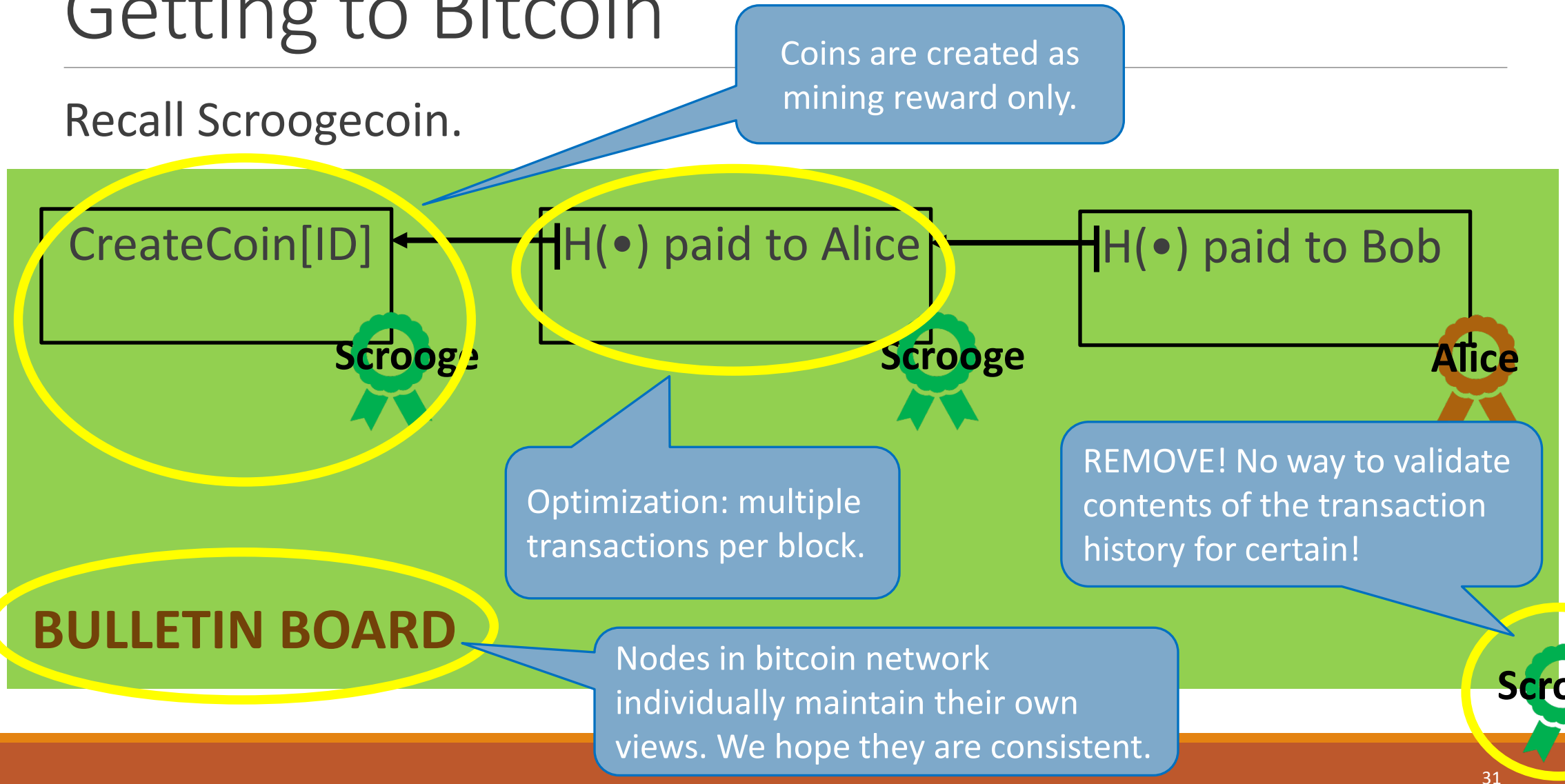
Bitcoin network

- Peer-to-peer
- No trusted authority
- Anyone can run a node
- Nodes execute distributed protocols
- Nodes potentially malicious



Getting to Bitcoin

Recall Scroogecoin.

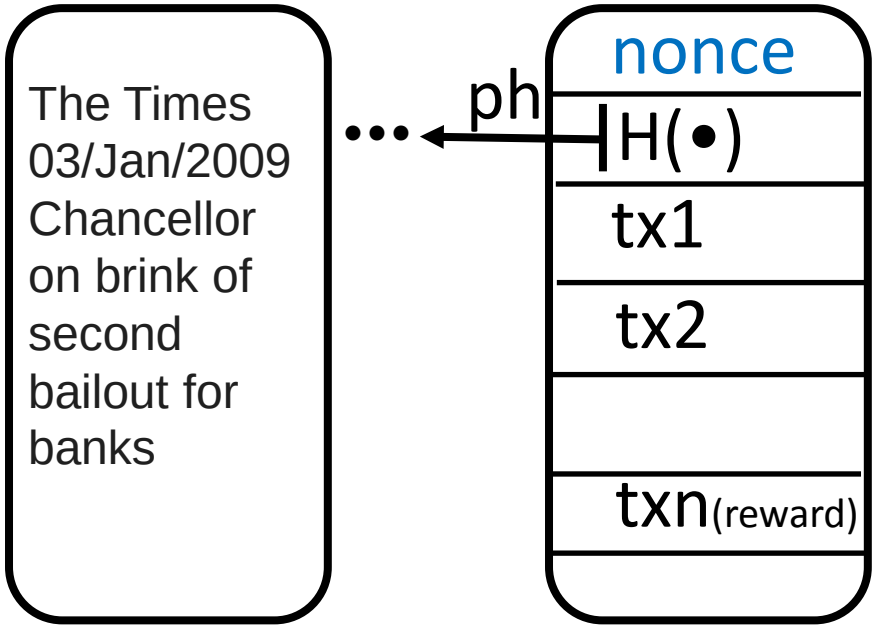


Bitcoin blockchain

The Times
03/Jan/2009
Chancellor
on brink of
second
bailout for
banks

Genesis
block

Bitcoin blockchain: appending a new block



Genesis block

Each bitcoin node

1. collects and validates transactions conducted by bitcoin users
2. tries to add the next block onto the blockchain to reap the block reward

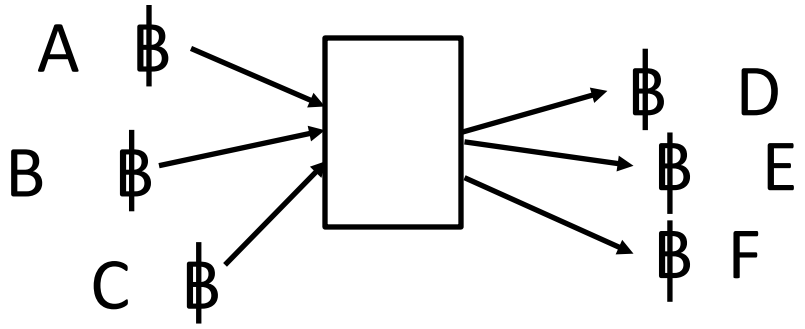
halved every 4 years

To add the next block, find "nonce" such that

00…..0xxxxxx…xxxx = H(nonce||ph||tx1||tx2 …)

re-configured every 2 weeks

Bitcoin transaction: money changing hands



Coins are immutable. (can only be created and consumed)

A transaction is valid if

- consumed coins were created in previous transaction
- total value out ≤ total value in, and
- entire transaction signed by owners of all consumed coins
- consumed coins not a double-spend

no guarantee!

transID: 73 type:PayCoins		
consumed coinIDs: 68(1), 42(0), 72(3)		
coins created		
num	*value*	*recipient*
0	3.2	0x...
1	1.4	0x...
2	7.1	0x...
signatures		

source: Bitcoin and Cryptocurrency Technologies, Narayanan, et. al. 2016

Bitcoin transaction

transID: 73 type:PayCoins		
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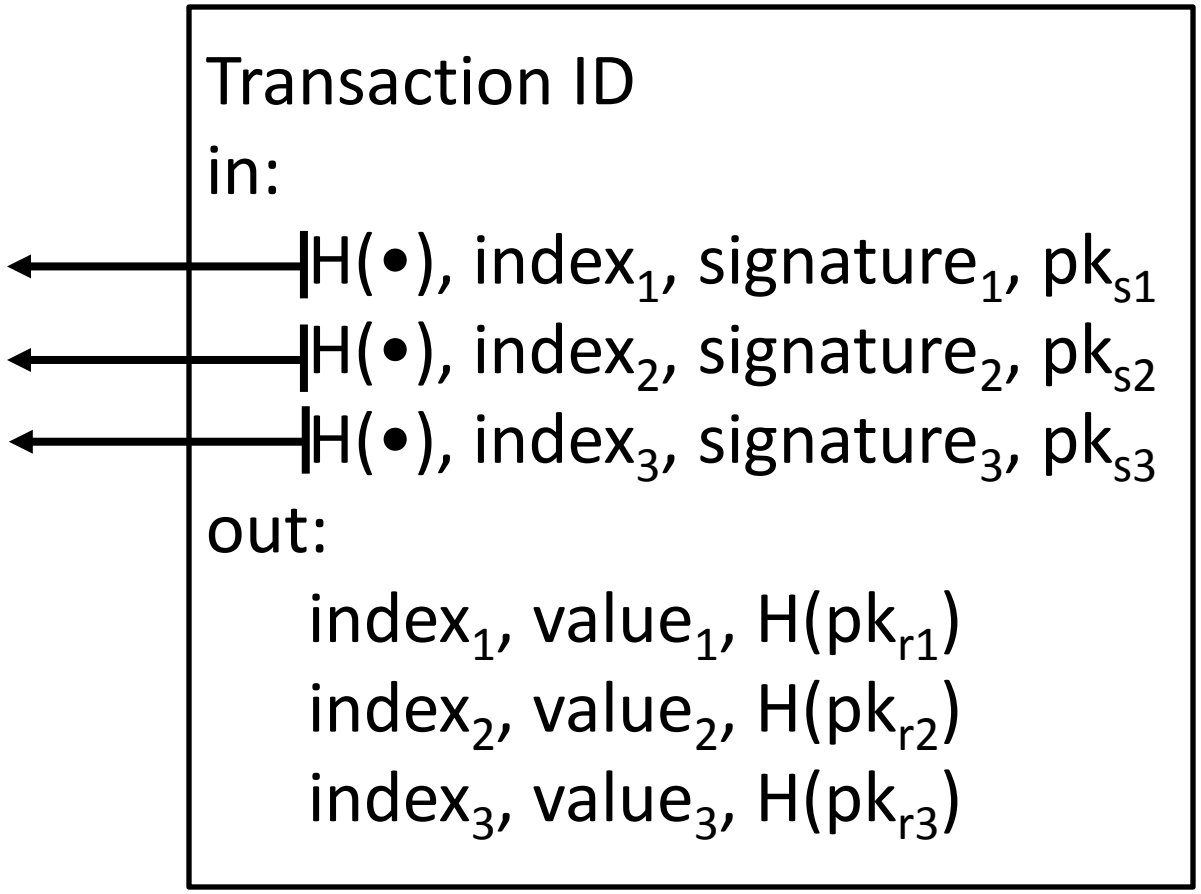
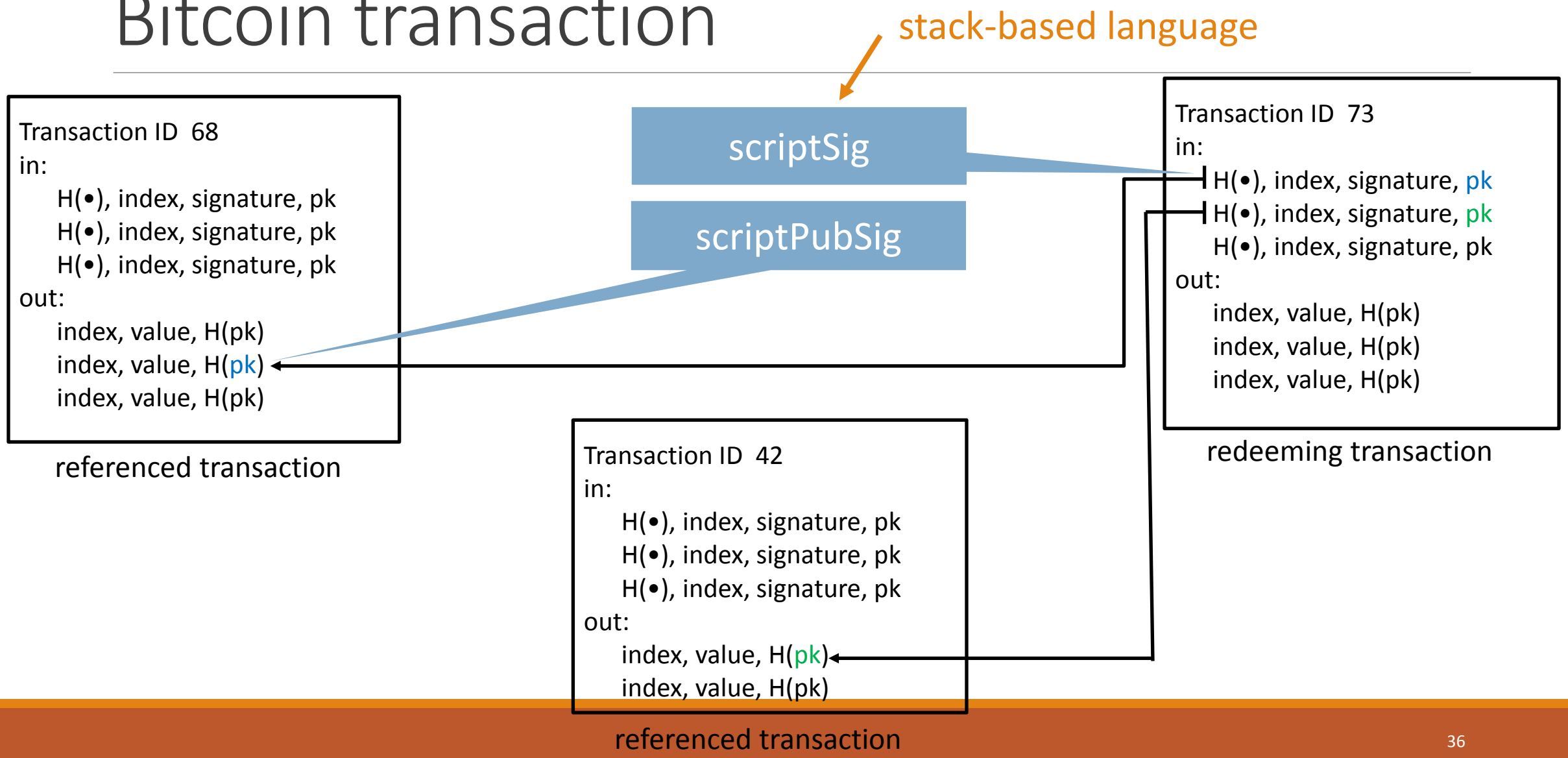
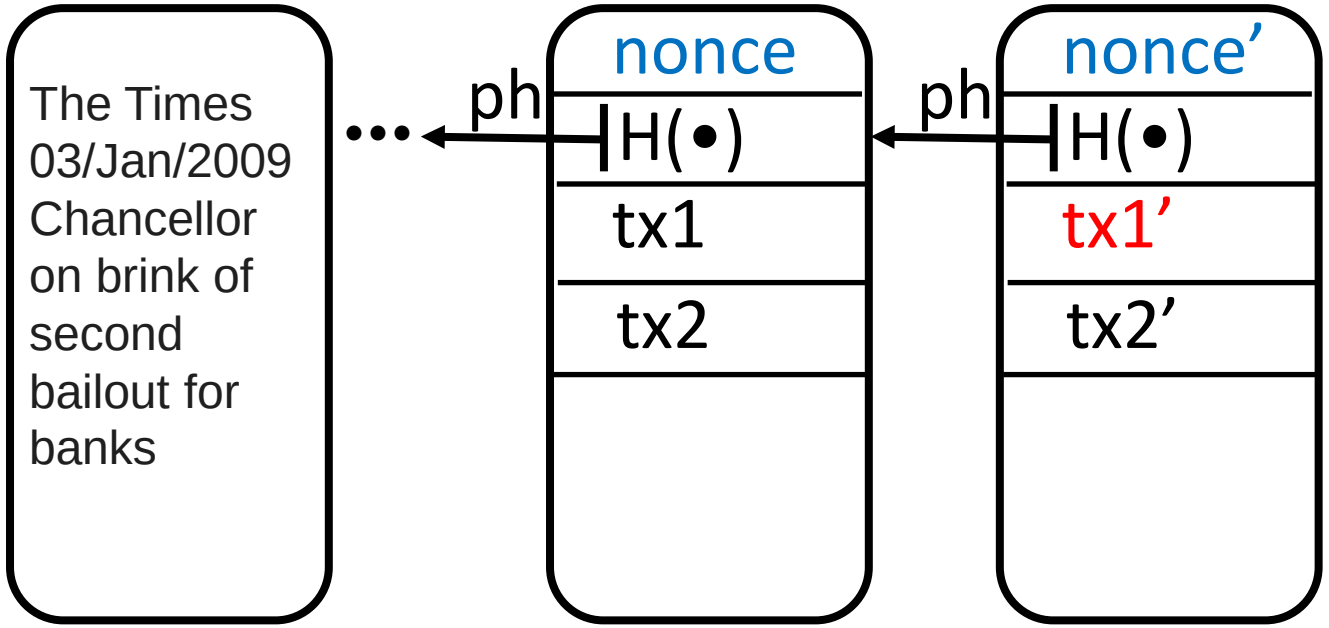


Bitcoin transaction

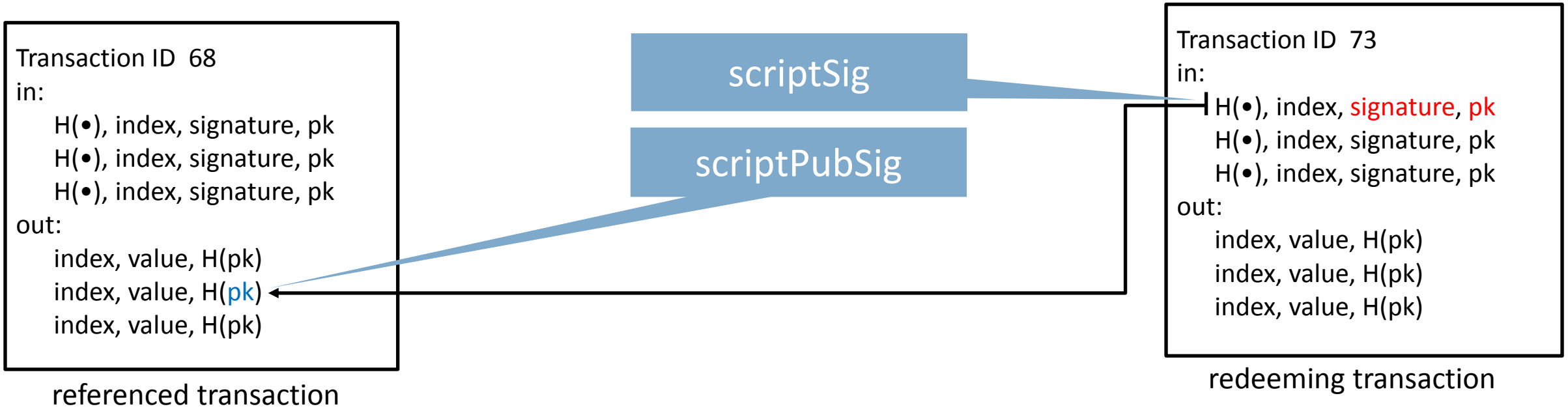


Fraudulent transactions?



Genesis block

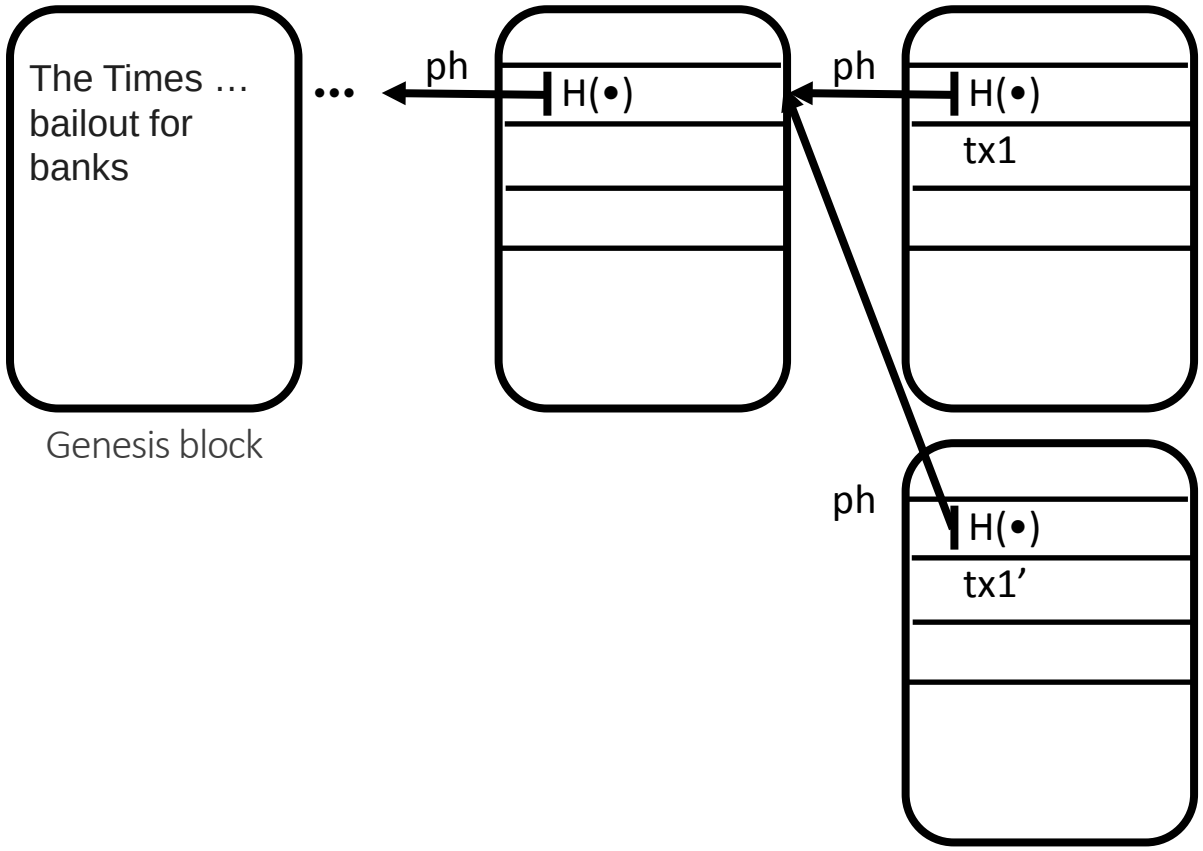
Fraudulent transaction?



Prevented through cryptography and enforced through consensus.

- Bitcoin nodes will detect fraudulent transactions when verifying signatures.
- If majority of nodes are honest, the blocks with invalid transactions will not be added to the blockchain.

Double-spending?

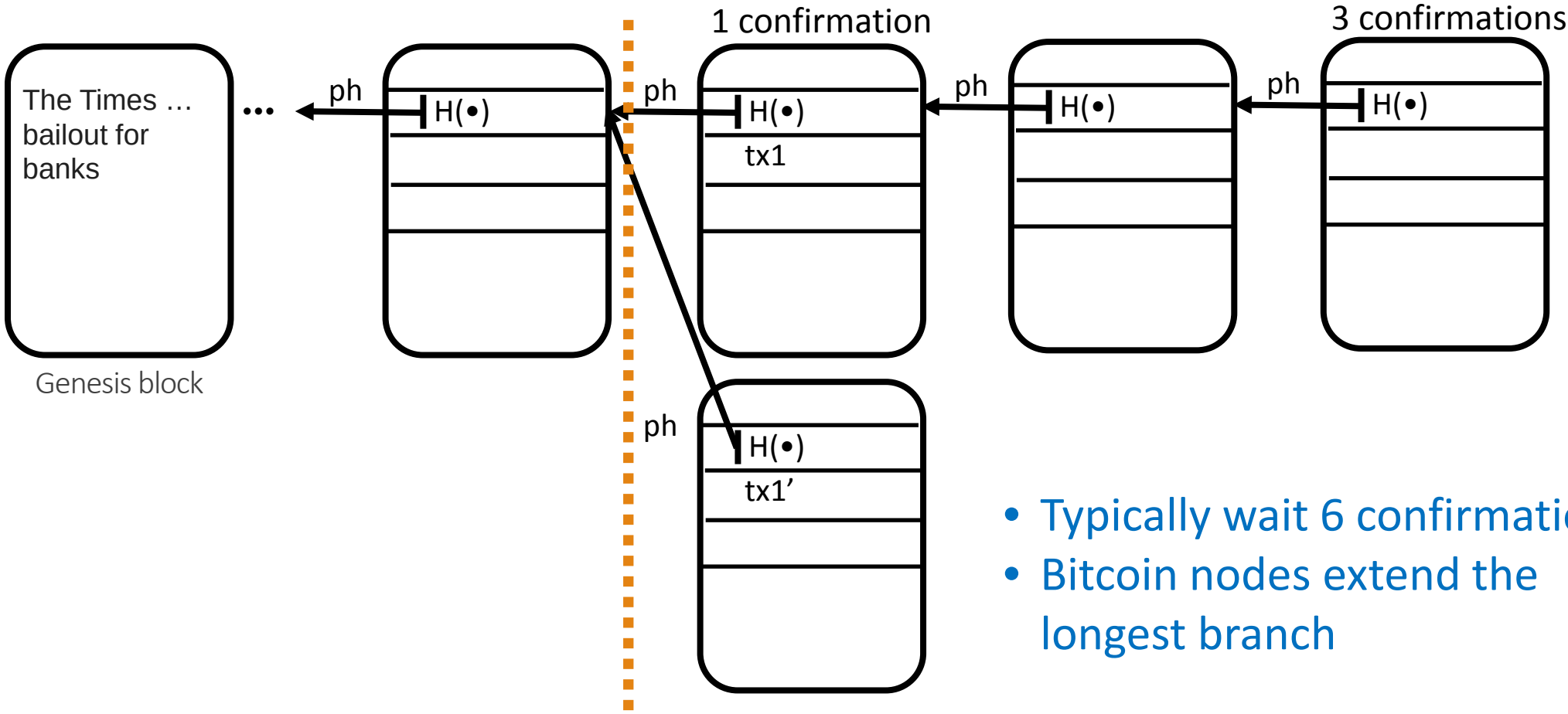


Suppose

- tx1 contains a transfer of a particular coin from A to B, and
- tx1' contains a transfer of the same coin from A to C

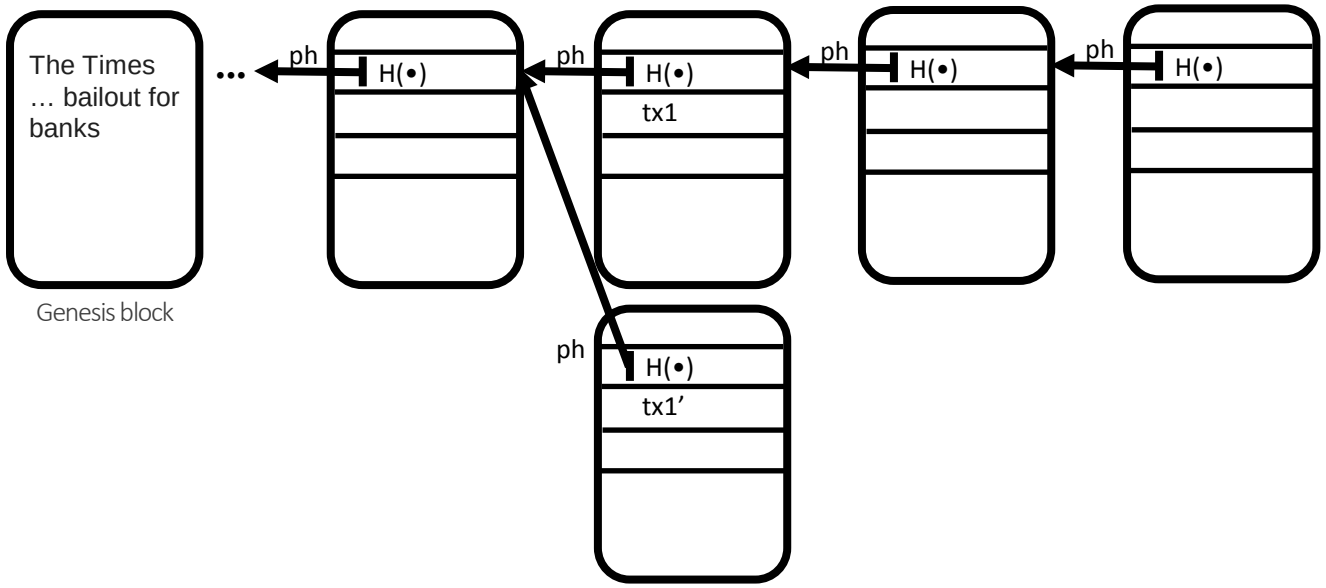
Which one is "legitimate"?

Double-spending?



- Typically wait 6 confirmations
- Bitcoin nodes extend the longest branch

Double spending?



- Prevented purely by consensus.
- Cryptography has nothing to do with it.

Discussions

- We have discussed
  - The bitcoin network
  - The bitcoin consensus protocol:
    - what the consensus is on
    - how it works

- Next time: Blockchain systems as Byzantine Fault-Tolerant (BFT) distributed systems!