# Blockchain

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**General:**

- Bitcoin: A Peer-to-Peer Electronic Cash System
- SoK: Research Perspectives and Challenges for Bitcoin and Cryptocurrencies

**Consensus:**

- The Bitcoin Backbone Protocol: Analysis and Applications.
- Bitcoin Backbone Protocol with Chains of Variable Difficulty.
- Analysis of the Blockchain Protocol in Asynchronous Networks. On Trees, Chains and Fast Transactions in the Blockchain.

# Tentative research areas/projects

**Cryptography:**

- On Bitcoin as a public randomness source.
- Distributed Cryptography Based on the Proofs of Work.
- Scalable, transparent, and post-quantum secure computational integrity

**Block generation parameters:**

- Bootstrapping the Blockchain - Directly.
- Speed-Security Tradeoffs in Blockchain Protocols.
- "GHOST": Secure High-Rate Transaction Processing in Bitcoin.
- "PHANTOM": A Scalable BlockDAG protocol.
- Inclusive Block Chain Protocols.
- On the Security and Performance of Proof of Work Blockchains.

# Tentative research areas/projects

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**Network:**

- The Bitcoin P2P network.
- Empirical Analysis of Denial-of-Service Attacks in the Bitcoin Ecosystem.
- Eclipse Attacks on Bitcoin's Peer-to-Peer Network.Hijacking Bitcoin: Routing Attacks on Cryptocurrencies.

**Smart Contracts:**

- "Ethereum": A next-generation smart contract and decentralized application platform.
- Fair Two-Party Computations via Bitcoin Deposits.
- Step by Step Towards Creating a Safe Smart Contract: Lessons and Insights from a Cryptocurrency Lab.
- EthIKS: Using Ethereum to audit a CONIKS key transparency log.

# Tentative research areas/projects

**Stake:**

- Ouroboros: A provably secure proof-of-stake blockchain protocol

- ALGORAND: The Efficient and Democratic Ledger
- "ByzCoin": Enhancing Bitcoin Security and Performance with Strong Consistency via Collective Signing.
- Cryptocurrencies without Proof of Work

**Attack:**

- "Selfish Mining": Majority Is Not Enough: Bitcoin Mining Is Vulnerable
- Theoretical Bitcoin Attacks with less than Half of the Computational Power
- Optimal Selfish Mining Strategies in Bitcoin
- Refund attacks on Bitcoin’s Payment Protocol
- Low-Resource Eclipse Attacks on Ethereum’s Peer-to-Peer Network

# Tentative research areas/projects

**Proof of work:**

- "Proof-of-work": Pricing via processing or combatting junk mail
- Hashcash - A Denial of Service Counter-Measure
- Cuckoo Cycle: a memory bound graph-theoretic proof-of-work
- PieceWork: Generalized Outsourcing Control for Proofs of Work

**Applications:**

- Blockstack Technical Whitepaper
- Storj A Peer-to-Peer Cloud Storage Network
- IPFS - Content Addressed, Versioned, P2P File System

# Books/ Marks Distribution

Books:

- Bitcoin and Cryptocurrency Technologies (Arvind Narayanan, Princeton University) book online link
- Mastering Bitcoin 2nd Ed( Andreas M. Antonopoulos) book online link

**Course Marks Distribution (Tentative):**

| | |
|---|---|
| **Midterm Exam** | **20%** |
| **Quizzes** | **15%** |
| **Assignments/Project(Phases)** | **30%** |
| **Final Exam** | **35%** |

# Lecture 1

## Intro to Crypto and Cryptocurrencies

Slide Credit: Joseph Bonneau (team), Princeton University, US

## This lecture

Crypto background

- hash functions
- digital signatures
- … and applications

# Intro to cryptocurrencies
## basic digital cash
### Lecture 1.1: Cryptographic

Hash Functions Hash

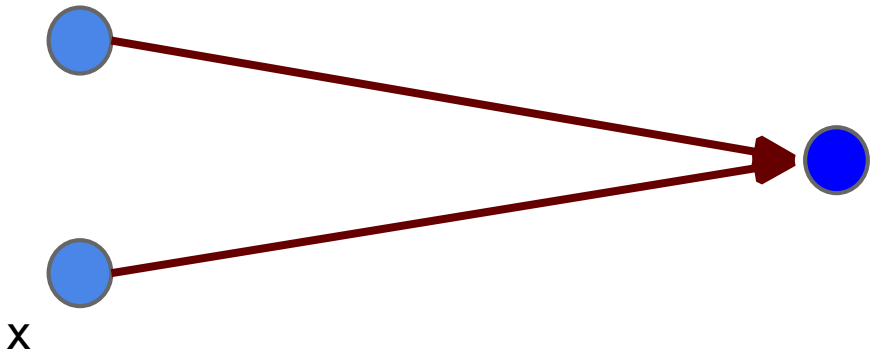
function:

takes any string as input fixed-size output (we'll use 256 bits) efficiently computable Security properties: collision-free hiding puzzle-friendly

# Hash property 1: Collision-free

Nobody can find x and y such that

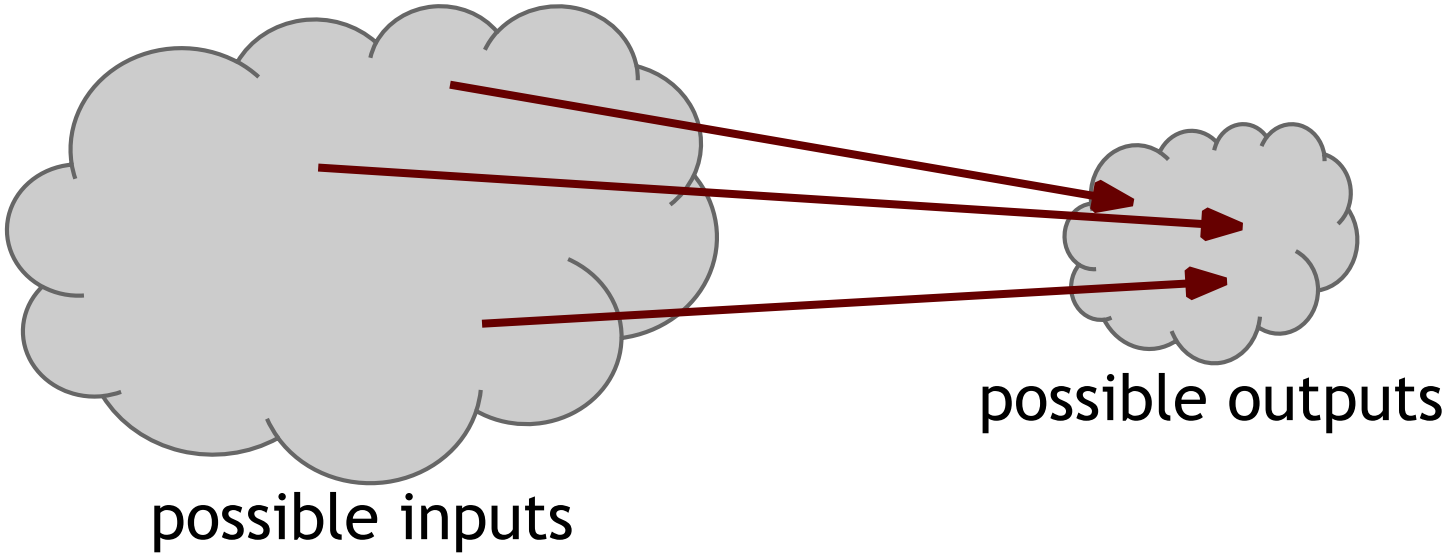
x != y and H(x)=H(y)



$H(x) = H(y)$

y

# Collisions do exist ...



… but can anyone find them?

How to find a collision

try $2^{130}$ randomly chosen inputs

99.8% chance that two of them will collide

This works no matter what H is …

… but it takes too long to matter

Is there a faster way to find collisions?

For some possible H's, yes.

For others, we don't know of one.

No H has been proven collision-free.

# Application: Hash as message digest

If we know H(x) = H(y), it's safe
to assume that x = y.

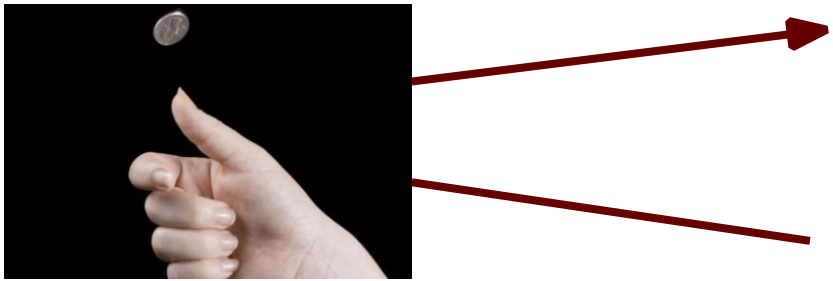
To recognize a file that we saw before,
just remember its hash.

Useful because the hash is small.

# Hash property 2: Hiding

We want something like this:

Given H(x), it is infeasible to find x.



H(“heads”)

easy to find x!

H(“tails”)

# Hash property 2: Hiding

Hiding property:

If r is chosen from a probability distribution that has *high min-entropy*, then given H(r | x), it is infeasible to find x.

High min-entropy means that the distribution is “very spread out”, so that no particular value is chosen with more than negligible probability.

# Application: Commitment

Want to “seal a value in an envelope”, and “open the envelope” later.

Commit to a value, reveal it later.

# Commitment API

(*com*, *key*) := commit(*msg*)

*match* := verify(*com*, *key*, *msg*)

To seal *msg* in envelope:

(*com*, *key*) := commit(*msg*) -- then publish *com*

To open envelope: publish *key*, *msg*

anyone can use verify() to check validity

# Commitment API

(*com*, *key*) := commit(*msg*)

*match* := verify(*com*, *key*, *msg*)

Security properties:

Hiding: Given *com*, infeasible to find *msg*.

Binding: Infeasible to find *msg != msg'* such that

verify(commit(*msg*), *msg'*) == true

# Commitment API

commit(*msg)* := ( H(*key* | *msg*), H(*key)* ) where *key* is a random 256-bit value

verify(*com*, *key*, *msg*) := ( H(*key* | *msg)* == *com* )

Security properties:

Hiding: Given H(*key* | *msg)*, infeasible to find *msg*.

Binding: Infeasible to find *msg != msg'* such that H(*key* | *msg)* == H(*key* | *msg')*

# Hash property 3: Puzzle-friendly

Puzzle-friendly:

For every possible output value y, if k is chosen from a distribution with high min-entropy, then it is infeasible to find x such that H(k | x) = y.

K or Id : puzzle id has to be random, otherwise some one could precompute and cheat.  Y as a set. Problem is easy. Y exact, problem maximally hard.

# Application: Search puzzle

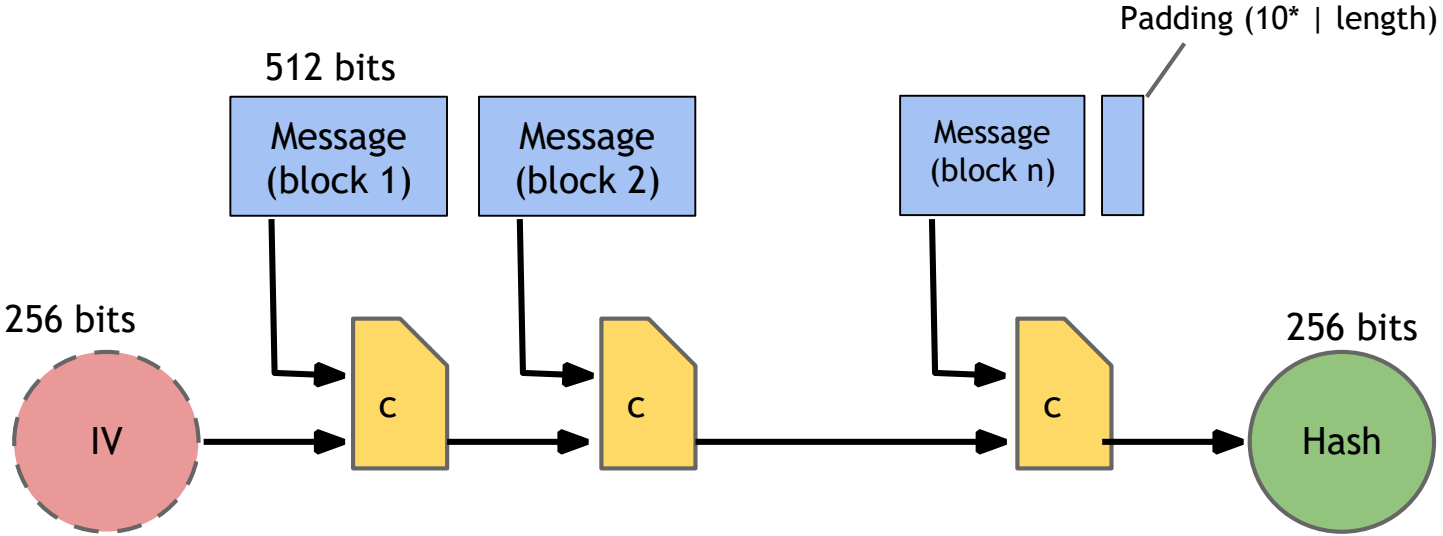
Given a “puzzle ID” *id* (from high min-entropy distrib.), and a target set *Y*:

Try to find a “solution” *x* such that

$$H(id \mid x) \in Y.$$

Puzzle-friendly property implies that no solving strategy is much better than trying random values of *x*.

# SHA-256 hash function



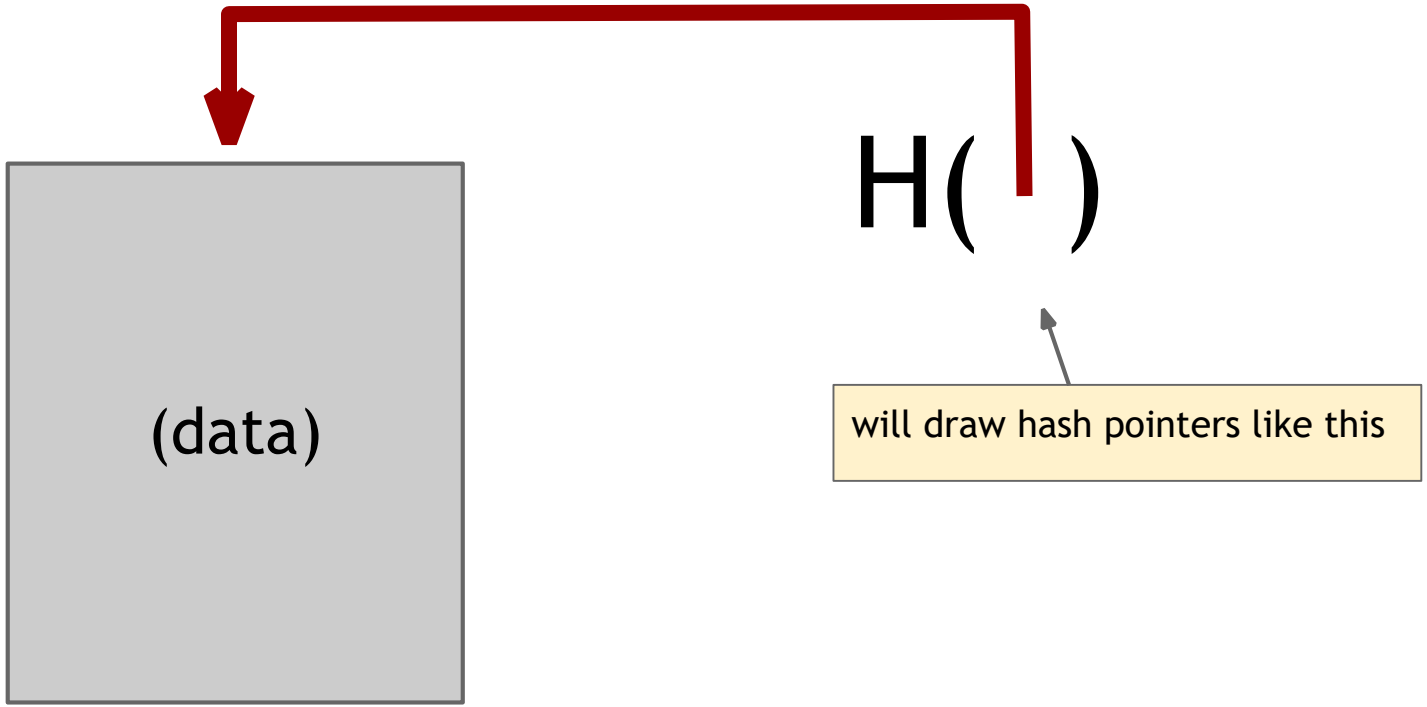

Theorem: If c is collision-free, then SHA-256 is collision-free.

# Lecture 1.2: Hash Pointers and Data Structures

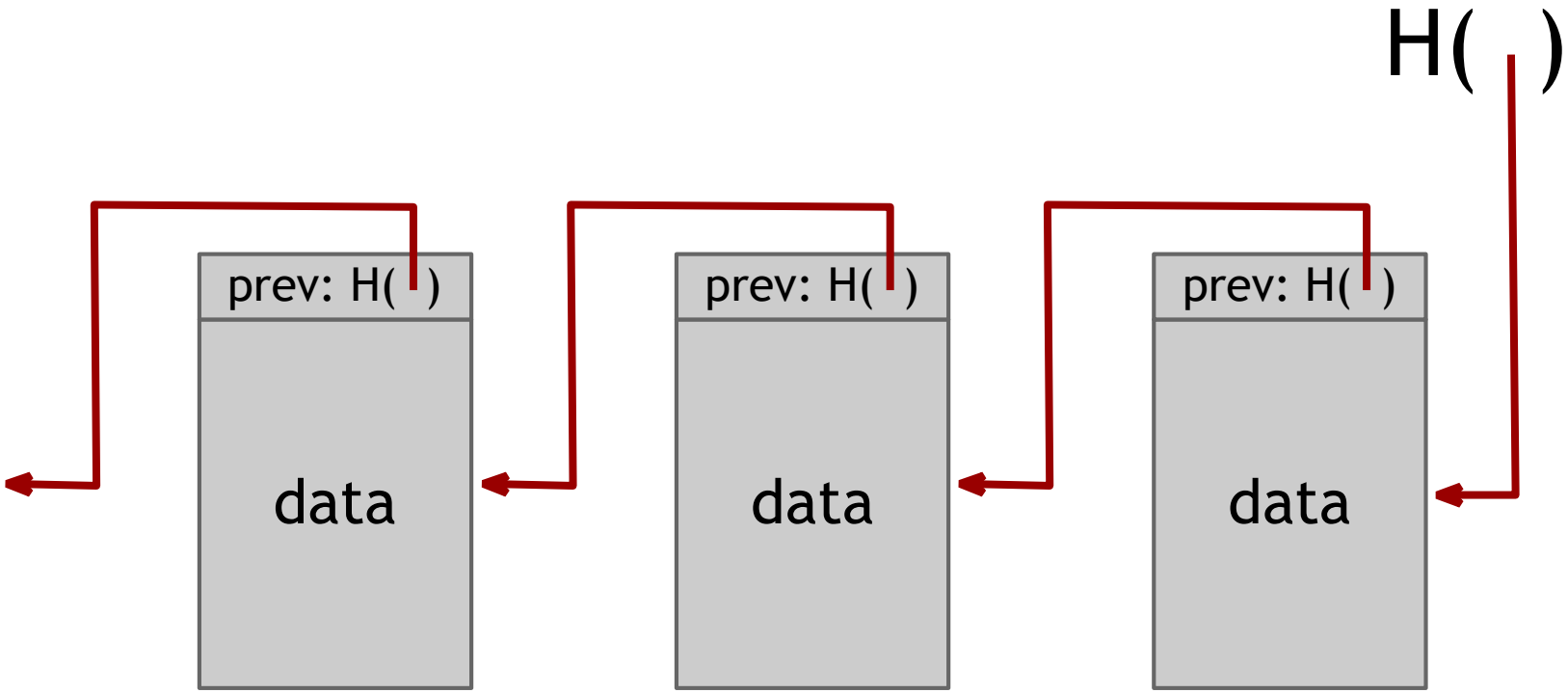
hash pointer is:

* pointer to where some info is stored, and
* (cryptographic) hash of the info if we have a hash pointer, we can
* ask to get the info back, and

* verify that it hasn't changed (compare with ordinary pointer)



# key idea:

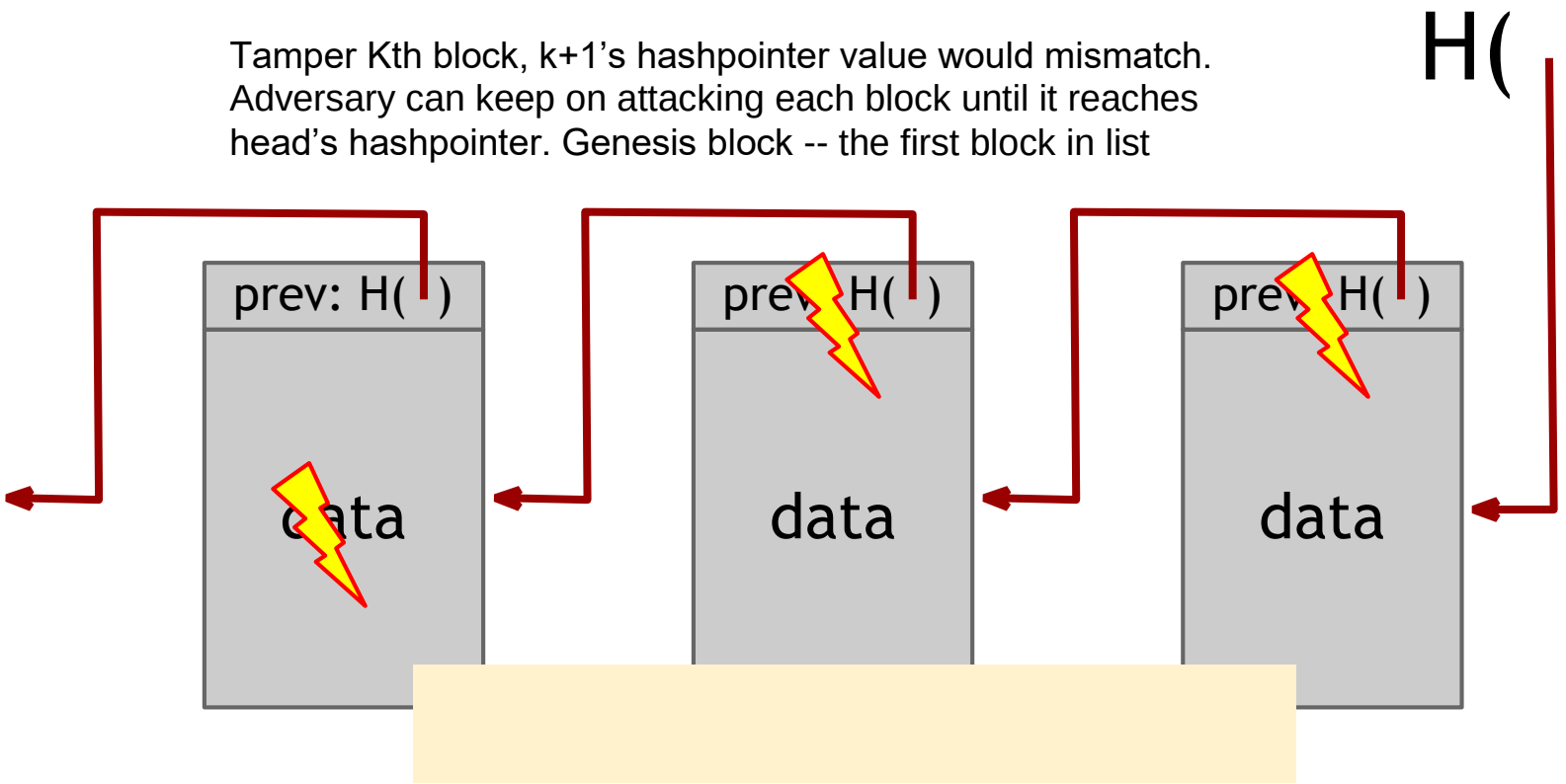



use case: tamper-evident log

linked list with hash pointers = “block chain”

# detecting tampering

Tamper Kth block, k+1's hashpointer value would mismatch. Adversary can keep on attacking each block until it reaches head's hashpointer. Genesis block -- the first block in list

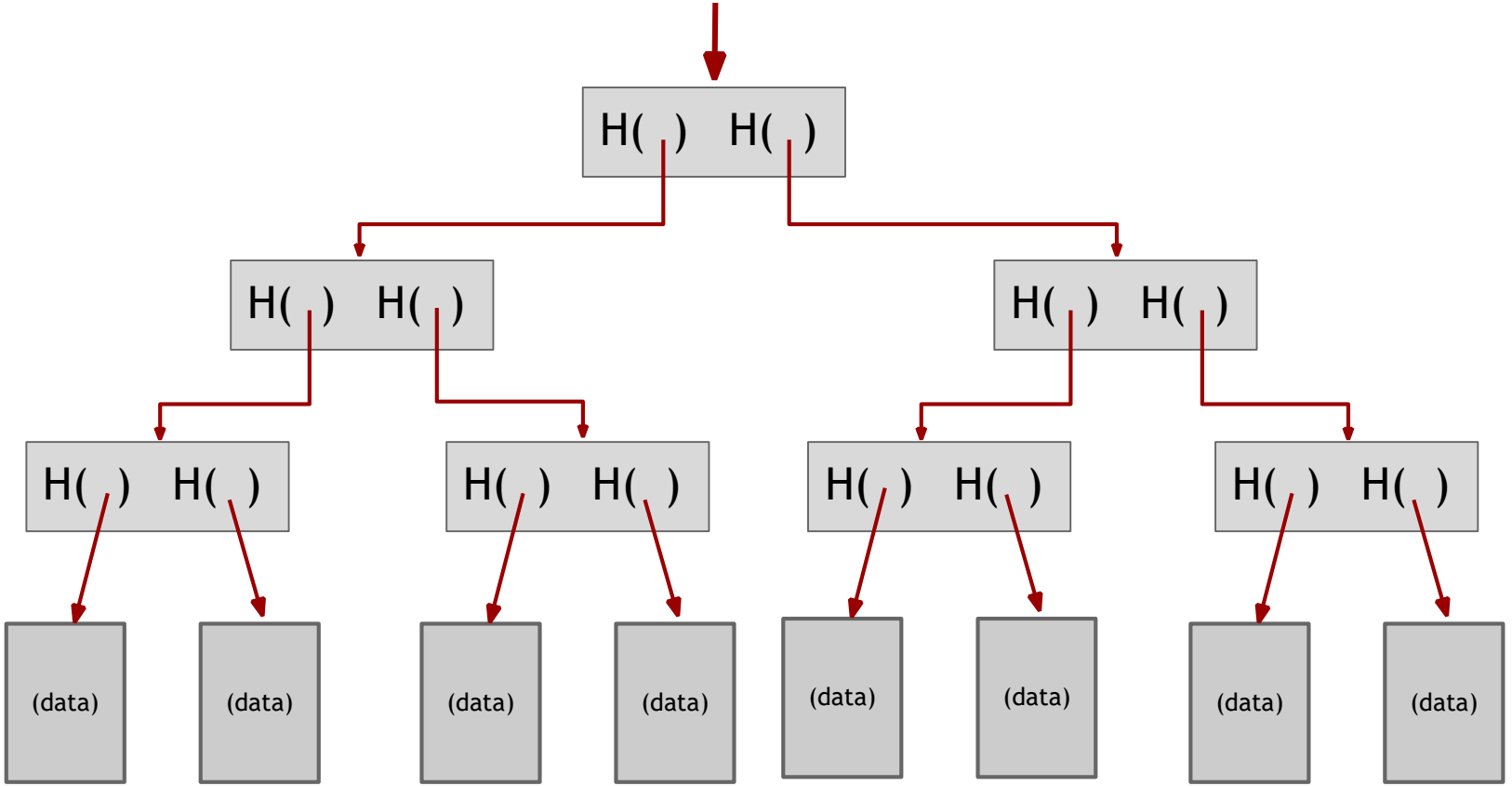



use

case: tamper-evident log

Just remember the last hashpointer to detect tampering

# binary tree with hash pointers = “Merkle tree”


H( ) H( )
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H( ) H( )
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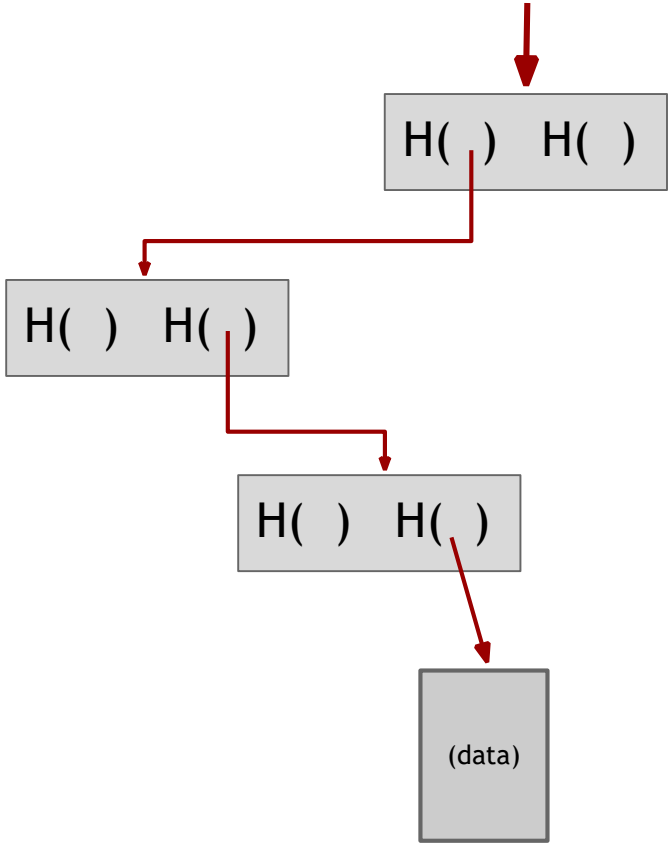
proving membership in a Merkle tree

show O(log n) items




Ignore rest of the tree. Logn items in logn time to verify.

# Advantages of Merkle trees

Tree holds many items but just need to remember the root hash

Can verify membership in O(log n) time/space

Variant: sorted Merkle tree can verify non-membership in O(log n)

(show items before, after the missing one)

# More generally ...

can use hash pointers in any pointer-based data structure that has no cycles

Lecture 1.3:

Digital Signatures

# What we want from signatures

Only you can sign, but anyone can verify

Signature is tied to a particular document

- can’t be cut-and-pasted to another doc

# API for digital signatures

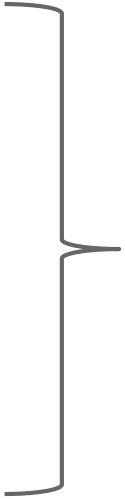
(sk, pk) := generateKeys(keysize)

sk: secret signing key

pk: public verification key

sig := sign(sk, message) isValid :=

verify(pk, message, sig)



algorithms can be randomized

# Requirements for signatures

“valid signatures verify”

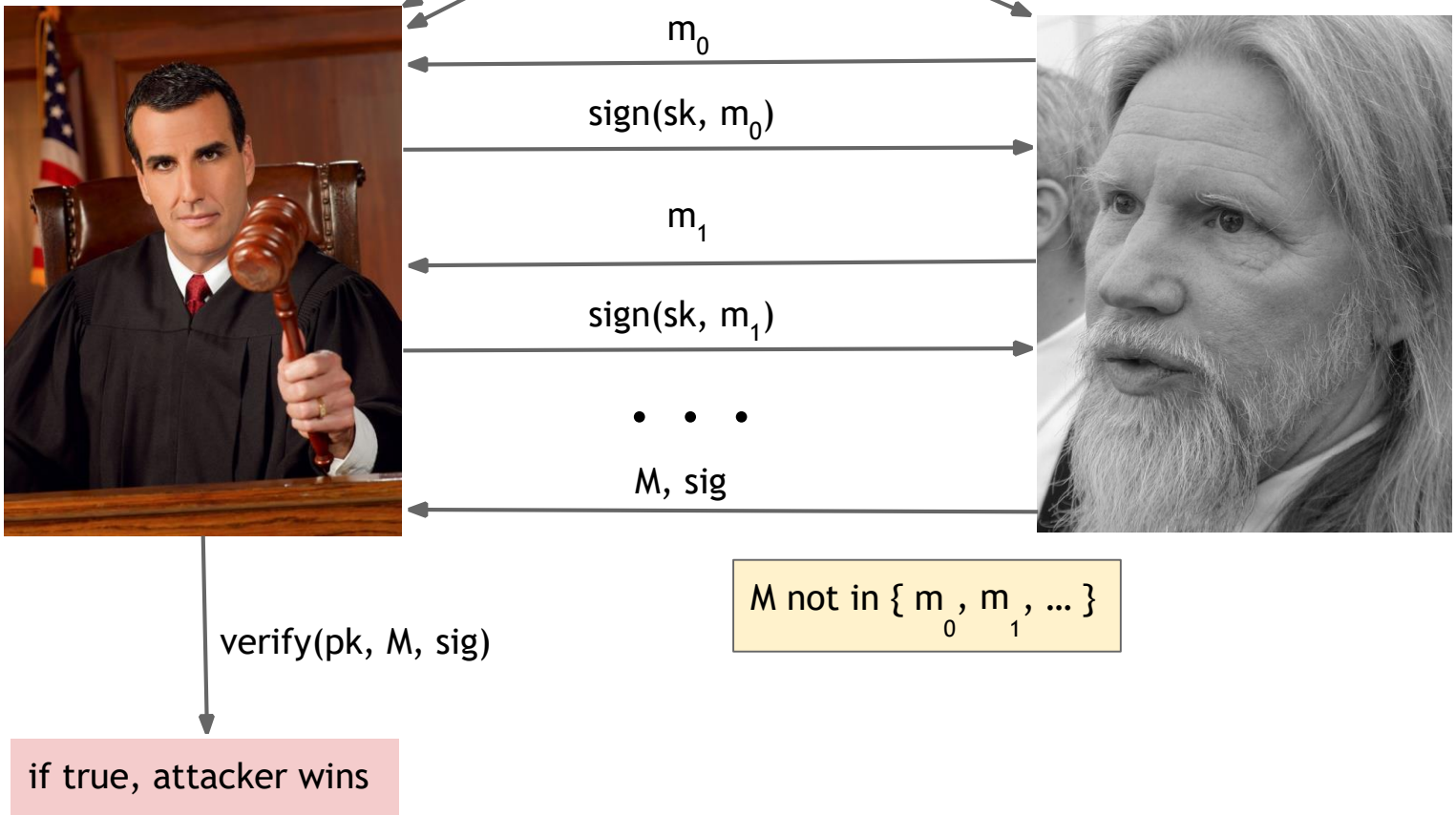
verify(pk, message, sign(sk, message)) == true

“can’t forge signatures”

adversary who:

knows pk

gets to see signatures on messages of his choice can’t produce a verifiable signature on another message


(sk, pk)
challenger
attacker
$m_0$
sign(sk, $m_0$)
$m_1$
sign(sk, $m_1$)
• • •
M, sig
verify(pk, M, sig)
M not in { $m_0$, $m_1$, … }
if true, attacker wins

# Practical stuff...

algorithms are randomized need
    good source of randomness

limit on message size fix: use Hash(message)
    rather than message

fun trick: sign a hash pointer signature
    “covers” the whole structure Bitcoin
    uses ECDSA standard

# Elliptic Curve Digital Signature Algorithm

relies on hairy math

- will skip the details here --- look it up if you care

good randomness is essential foul this up

- in generateKeys() or sign() ?
- probably leaked your private key

# Lecture 1.4: Public Keys as Identities

Useful trick: public key

== an identity

if you see *sig* such that *verify(pk, msg, sig)==true*, think of it as *pk* says, "*[msg]*".

to "speak for" *pk*, you must know matching secret key *sk*

## How to make a new identity

create a new, random key-pair *(sk, pk)*

*pk* is the public "name" you can use

[usually better to use Hash(pk)]

*sk* lets you "speak for" the identity

you control the identity, because only you know *sk* if *pk* “looks random”, nobody needs to know who you are

## Decentralized identity management

anybody can make a new identity at any time

make as many as you want! no central point

of coordination

These identities are called “addresses” in Bitcoin.

# Privacy

Addresses not directly connected to real-world identity.

But observer can link together an address’s activity over time, make inferences.

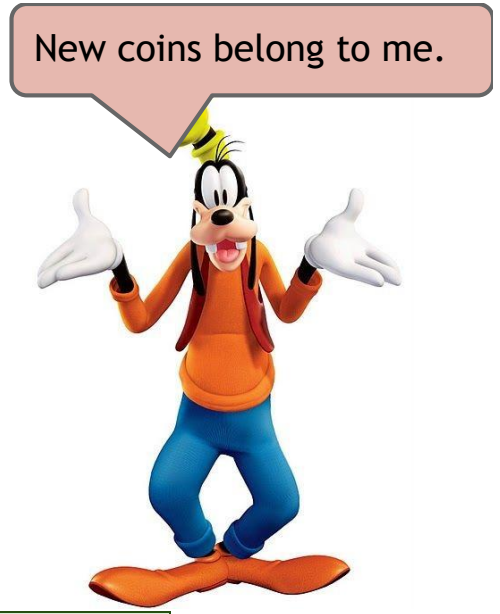
Later: a whole lecture on privacy in Bitcoin ...

# Lecture 1.5: Simple Cryptocurrencies

# GoofyCoin

Goofy can create new coins

| signed by $pk_{Goofy}$ |
| --- |
| CreateCoin [uniqueCoinID] |




A coin’s owner can spend it.

signed by $pk_{Goofy}$

Pay to $pk_{Alice}$ : H( )

signed by $pk_{Goofy}$

CreateCoin [uniqueCoinID]


The recipient can pass on the coin again.

signed by $pk_{Alice}$

Pay to $pk_{Bob}$ : H( )

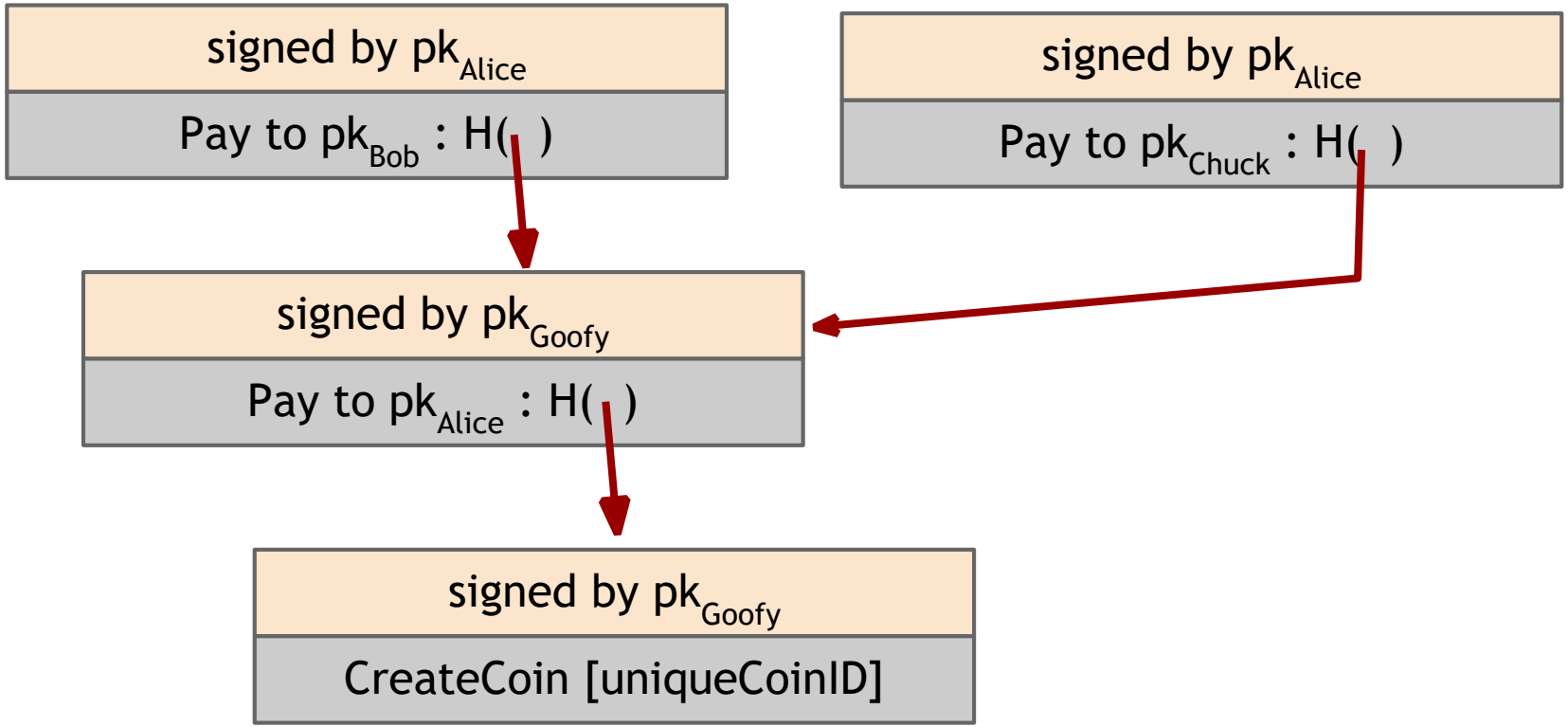
signed by $pk_{Goofy}$

Pay to $pk_{Alice}$ : H( )

signed by $pk_{Goofy}$

CreateCoin [uniqueCoinID]

# double-spending attack



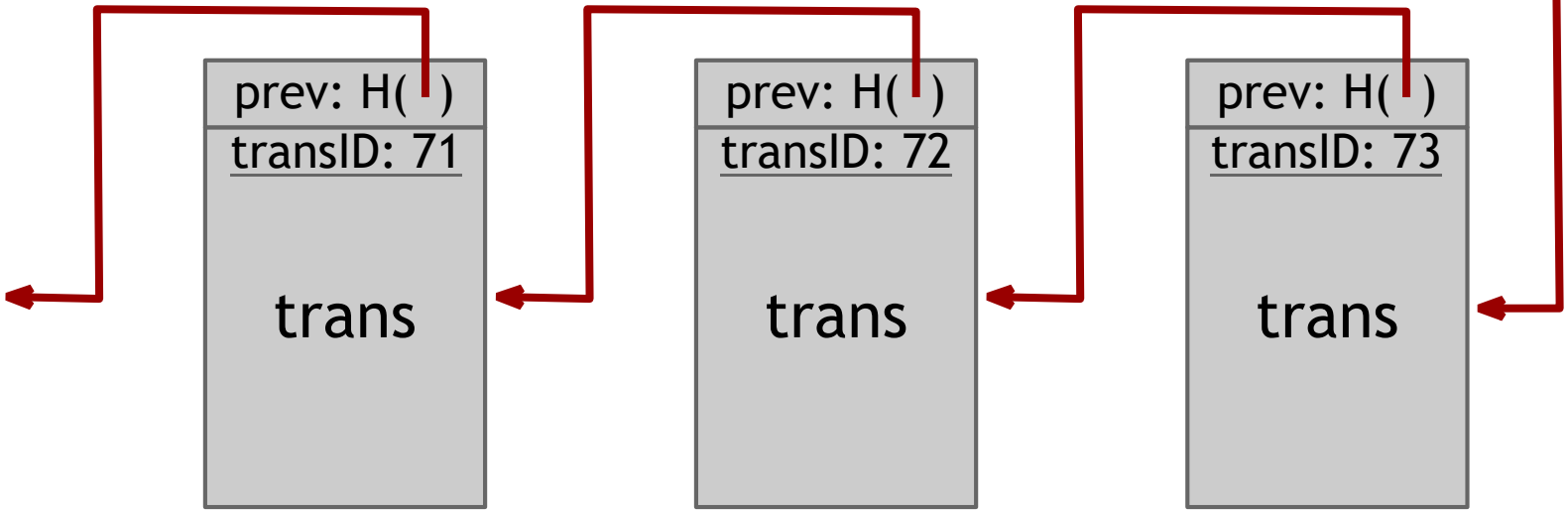
# double-spending attack

the main design challenge in digital currency

# ScroogeCoin

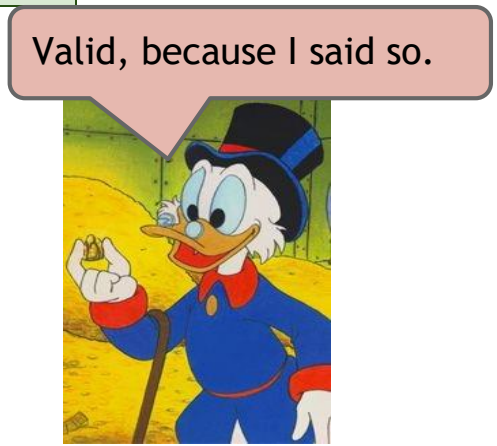
Scrooge publishes a history of all transactions
(a block chain, signed by Scrooge)

H( )



optimization: put multiple transactions in the same block

CreateCoins transaction creates new coins




| transID: 73 | type:CreateCoins | |
|---|---|---|
| coins created | | |
| *num* | *value* | *recipient* |
| 0 | 3.2 | 0x... |
| 1 | 1.4 | 0x... |
| 2 | 7.1 | 0x... |

coinID 73(0)

coinID 73(1)

coinID 73(2)

PayCoins transaction consumes (and destroys) some coins,
and creates new coins of the same total value

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

Valid if:
-- consumed coins valid,
-- not already consumed,
-- total value out = total value in, and
-- signed by owners of all consumed coins

# Immutable coins

Coins can’t be transferred, subdivided, or combined.

But: you can get the same effect by using transactions
to subdivide: create new trans consume your coin
pay out two new coins to yourself


Crucial question:

Can we descroogify the currency, and operate without any central, trusted party?

# Tentative learning Opportunities

- What is blockchain ?

- What are cryptocurrencies ?
- How bitcoin is developed ?
- How you can mine yourself ?
- Who to develop your own cryptocurrency ?
- How you can develop decentralized apps(Dapps) ?
- Writing smart contracts
- Research