Catena: Efficient Non-equivocation via 

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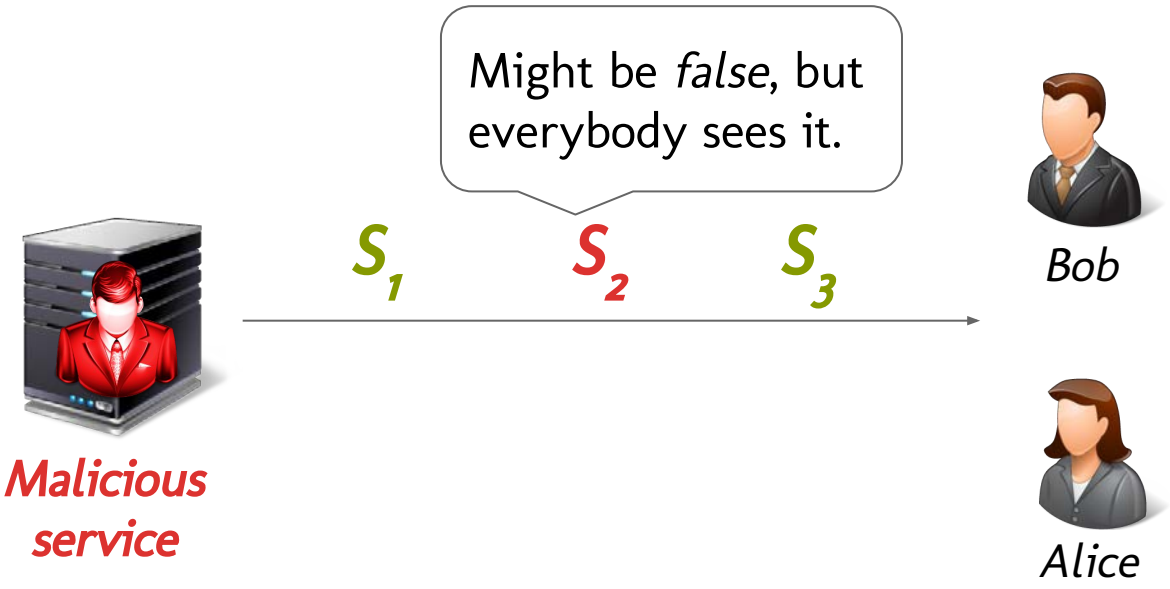
Overview

1. **What?**
2. How?
3. Why?

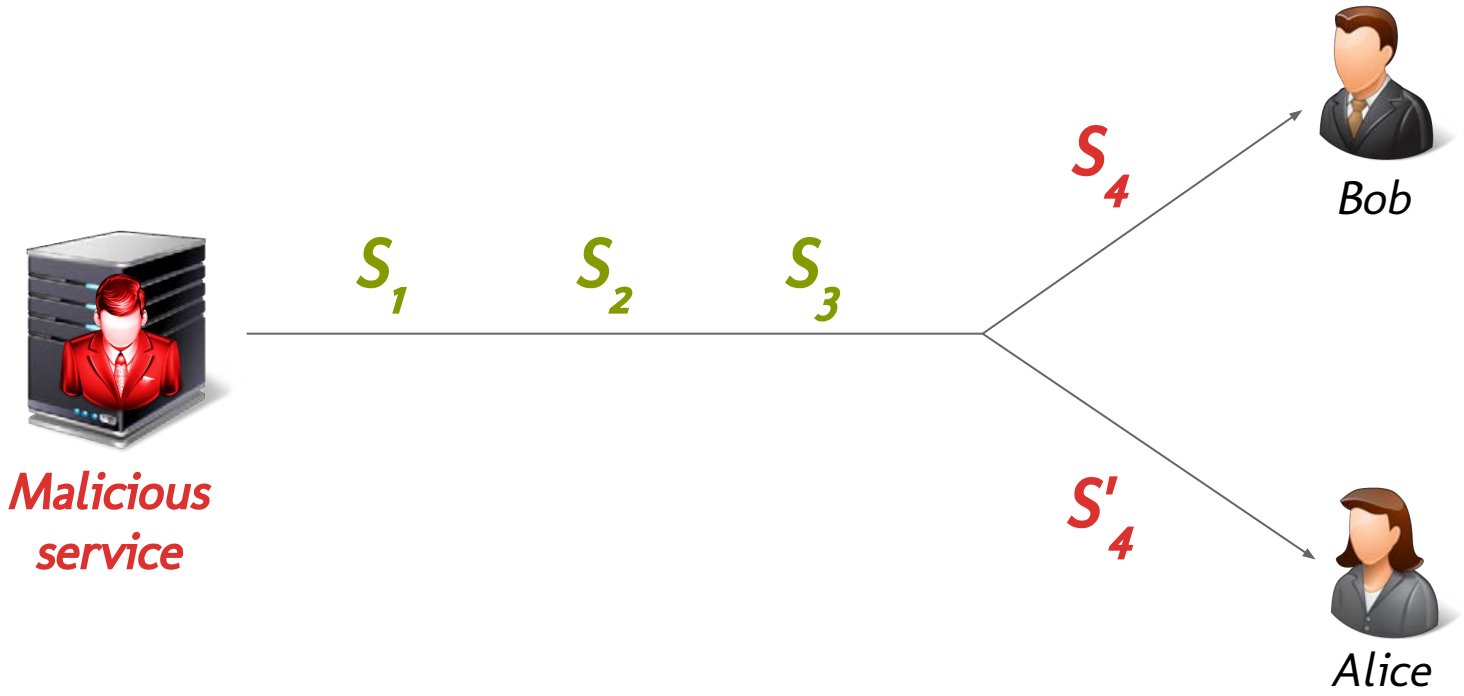
The equivocation problem

Non-equivocation: *"Saying the same thing to everybody."*



The equivocation problem

Equivocation: *"Saying different things to different people."*



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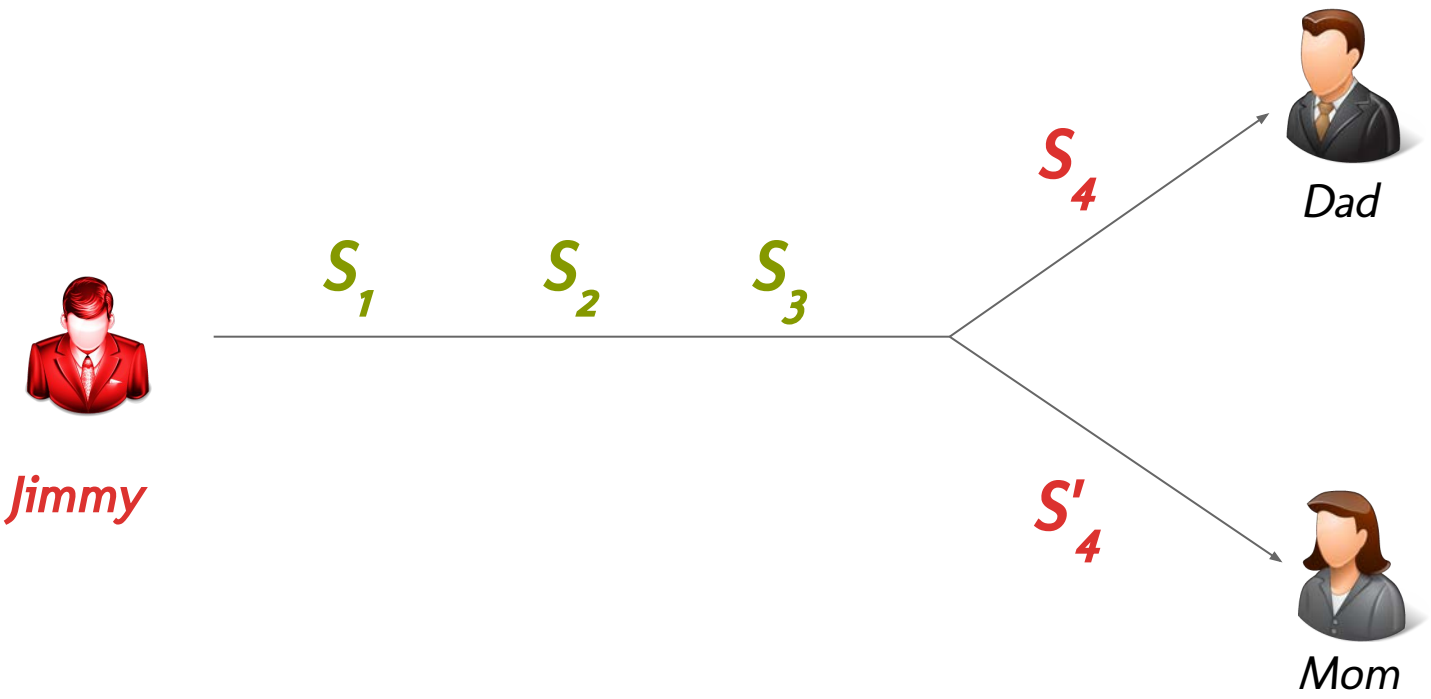

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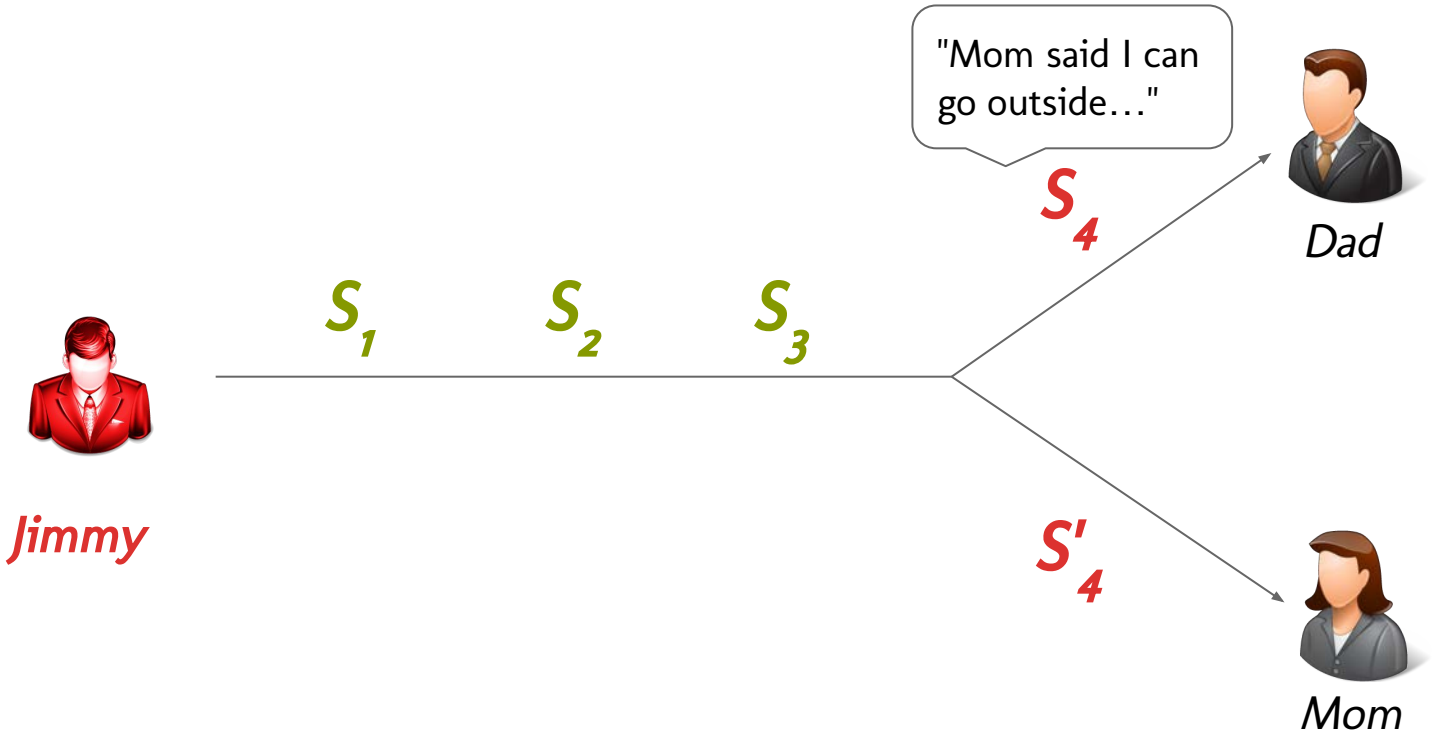

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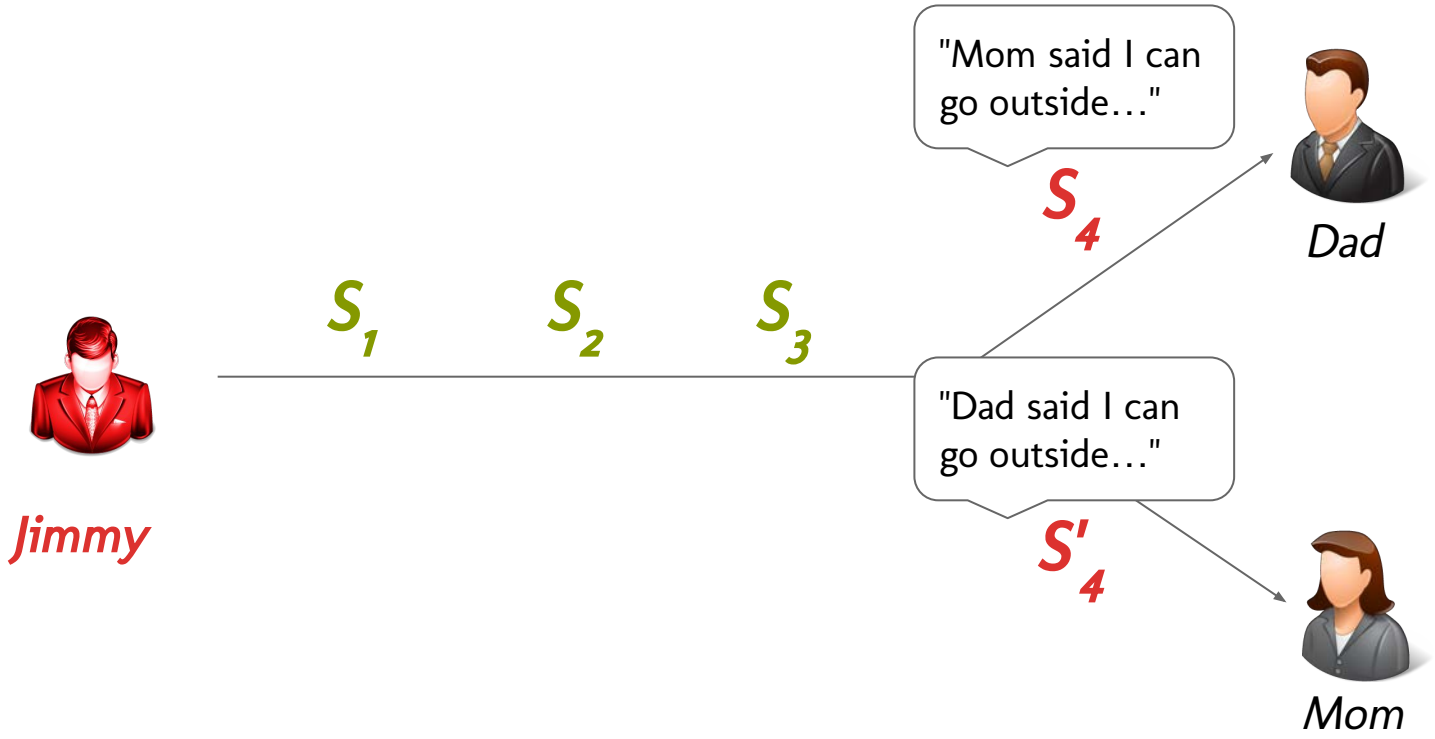
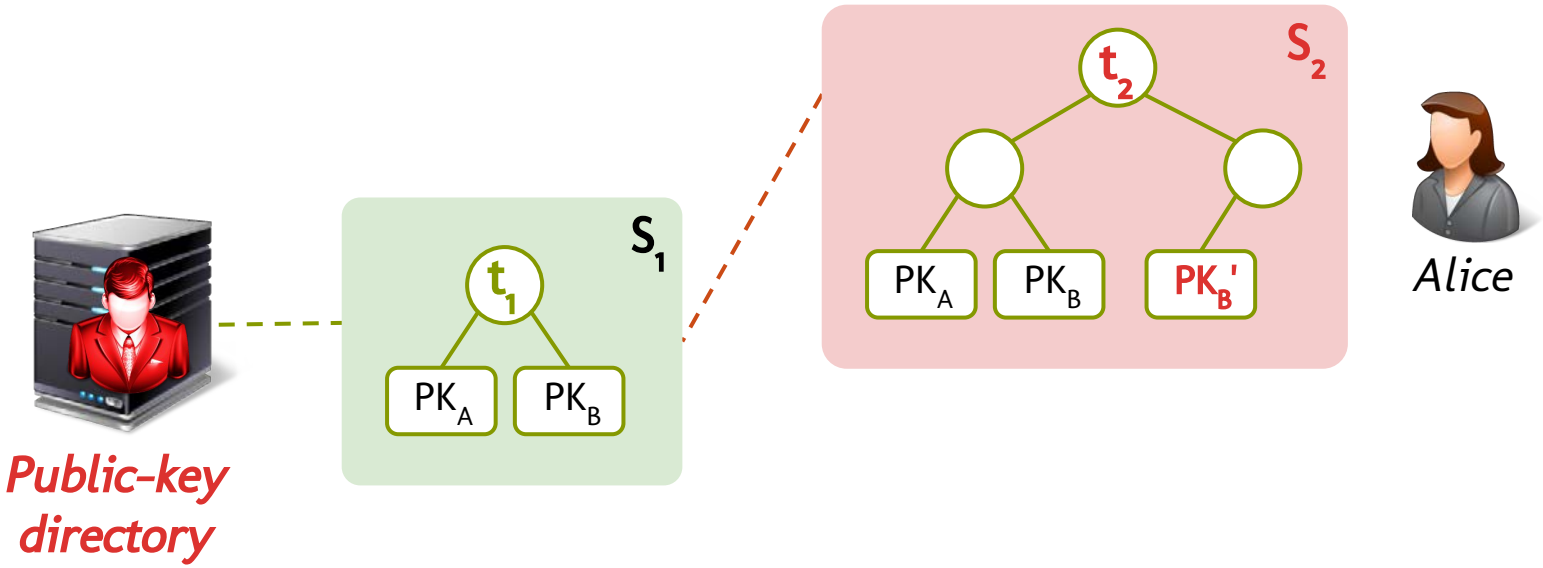


What is equivocation?

- s_2: Leave Alice's key intact, add fake PK_B' for Bob



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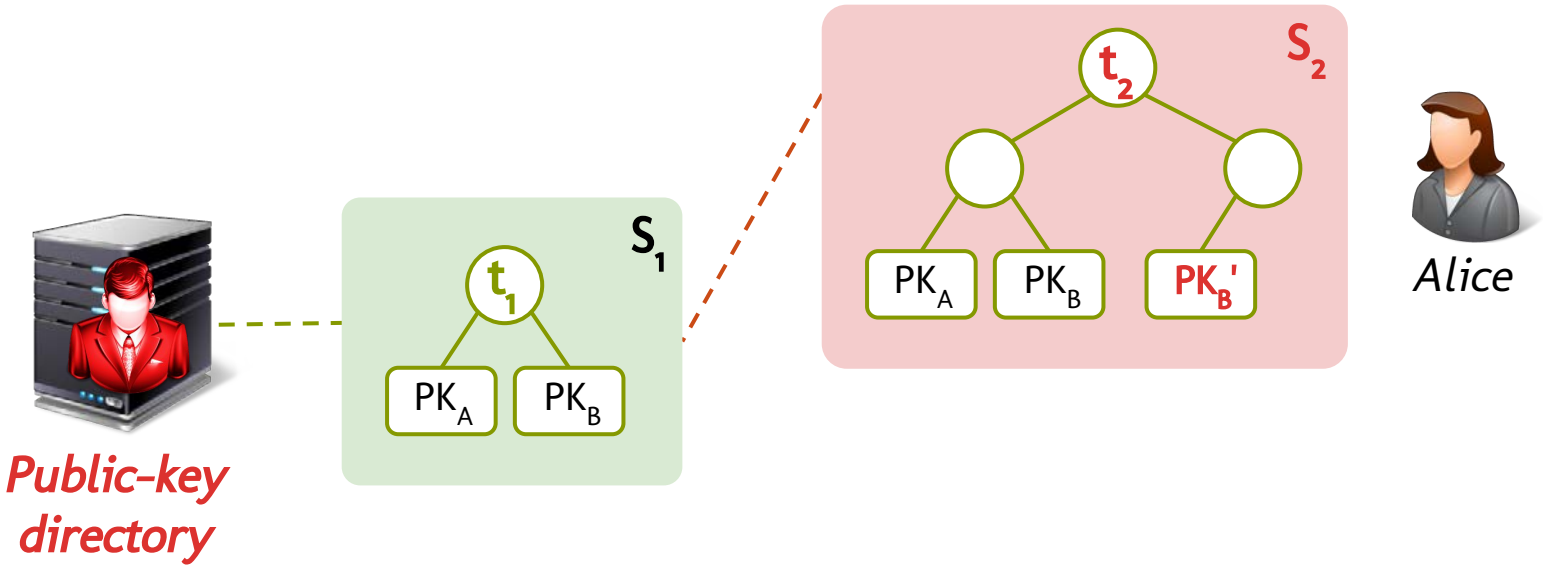
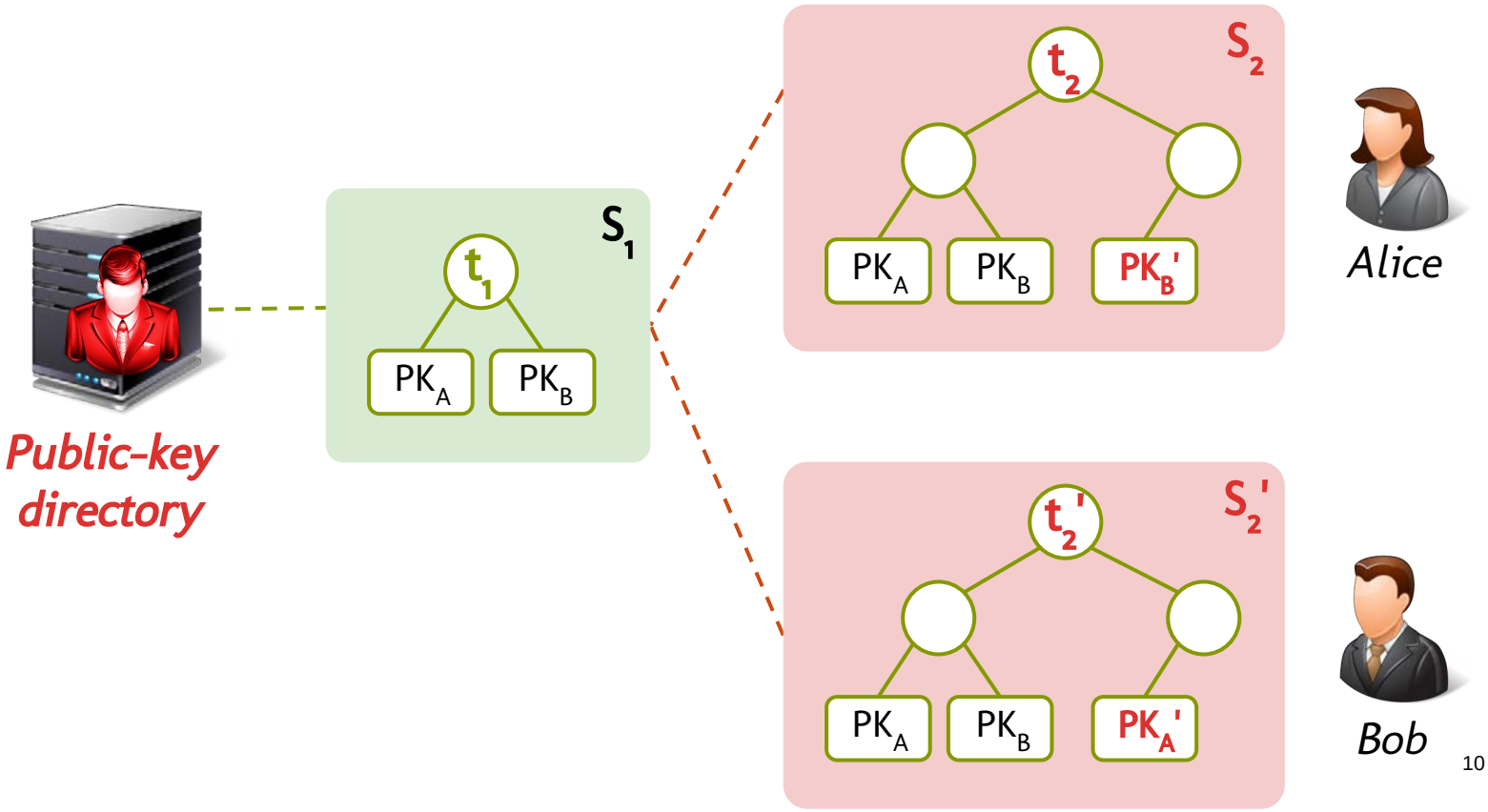


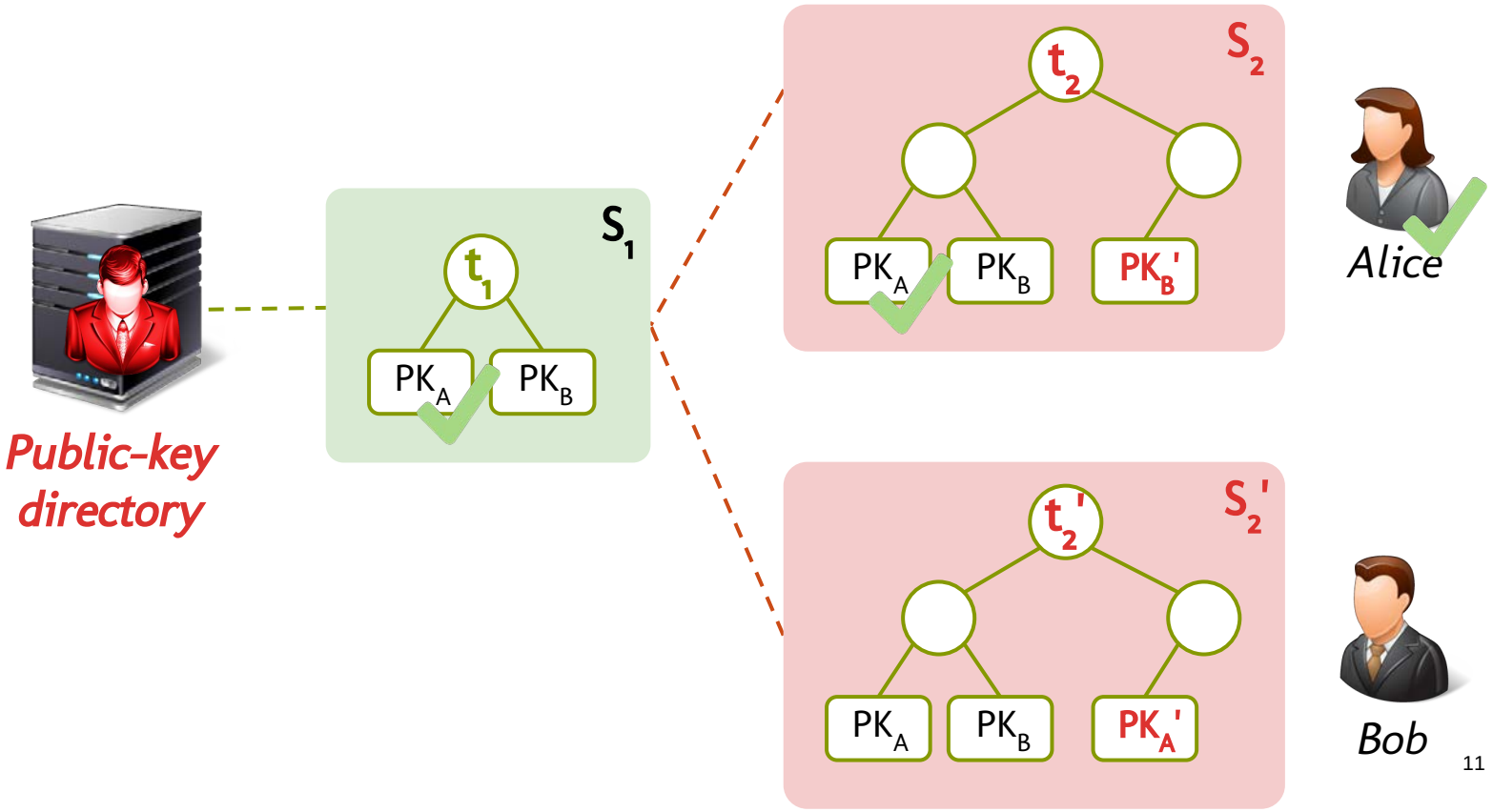
What is equivocation?

- s_2': Leave Bob's key intact, add fake PK_A' for Alice



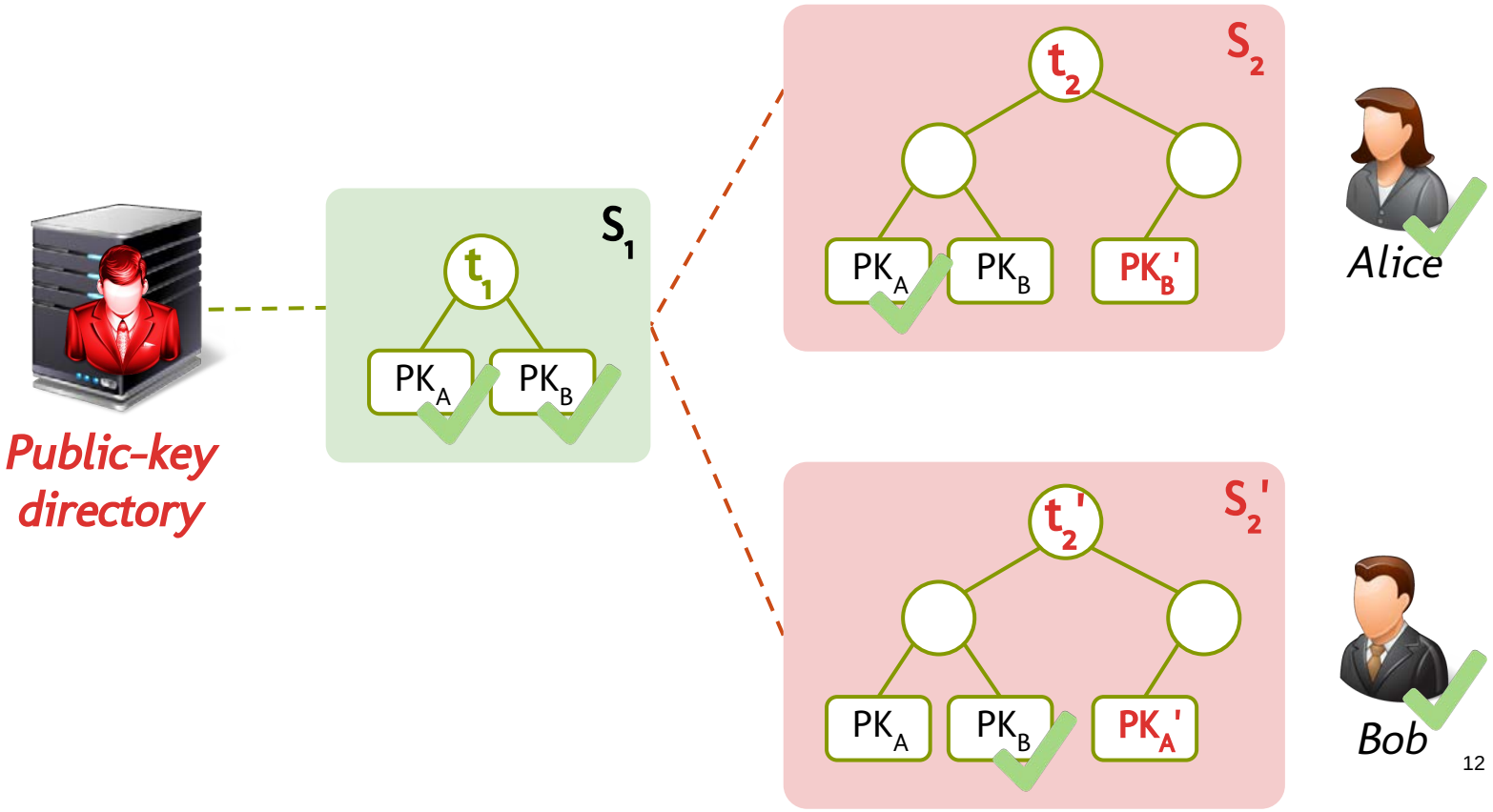
What is equivocation?

- Alice not impersonated in her view, but Bob is.



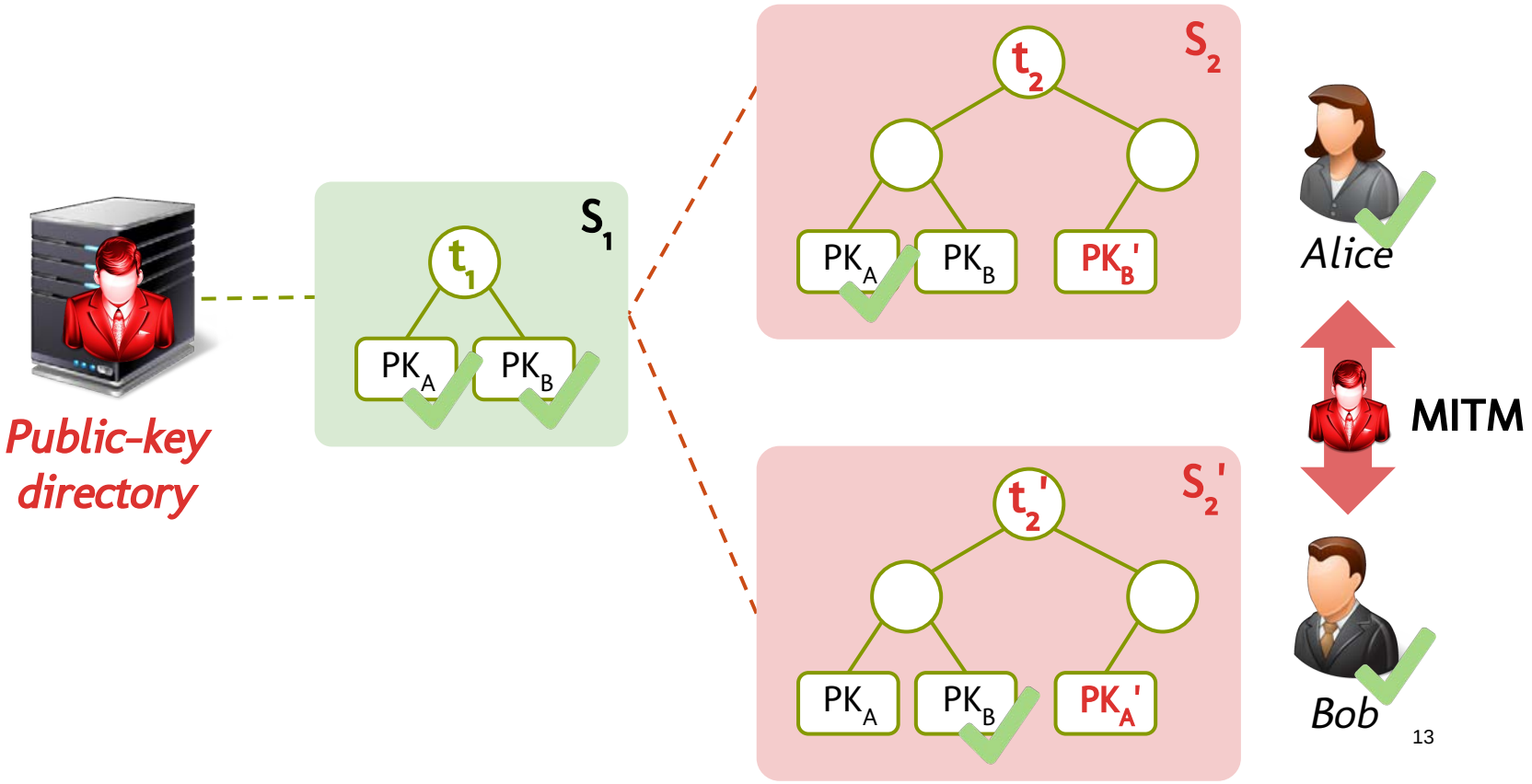
What is equivocation?

- Bob not impersonated in his view, but Alice is.



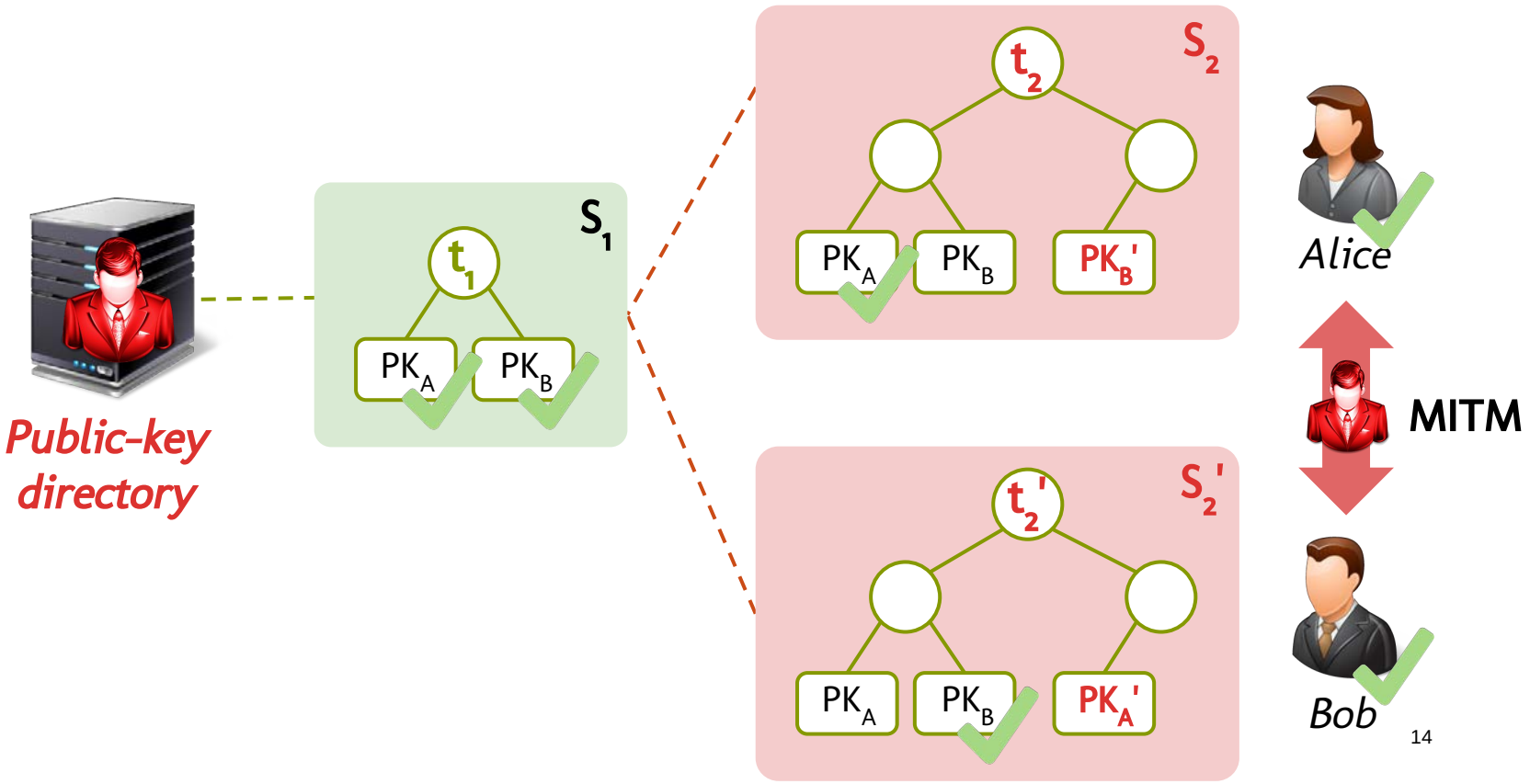
What is equivocation?

- Obtain fake keys for each other ⇒ **MITM**

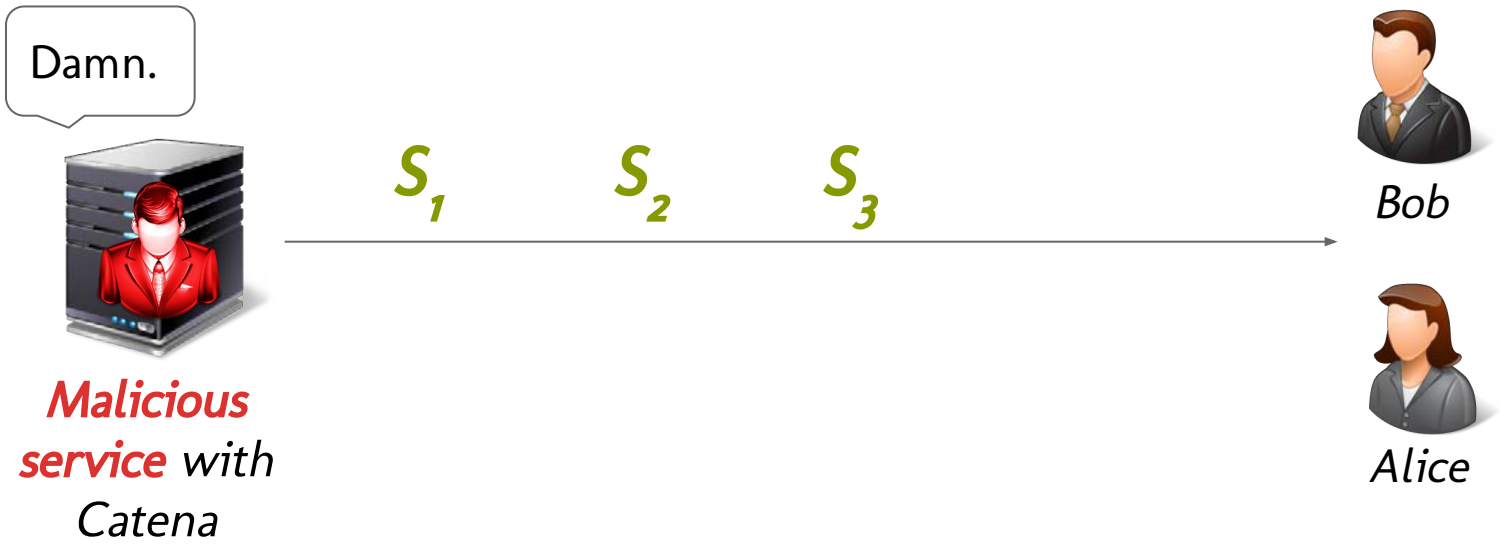


What is equivocation?

Bad: *"Stating different things to different people."*



Catena prevents equivocation!



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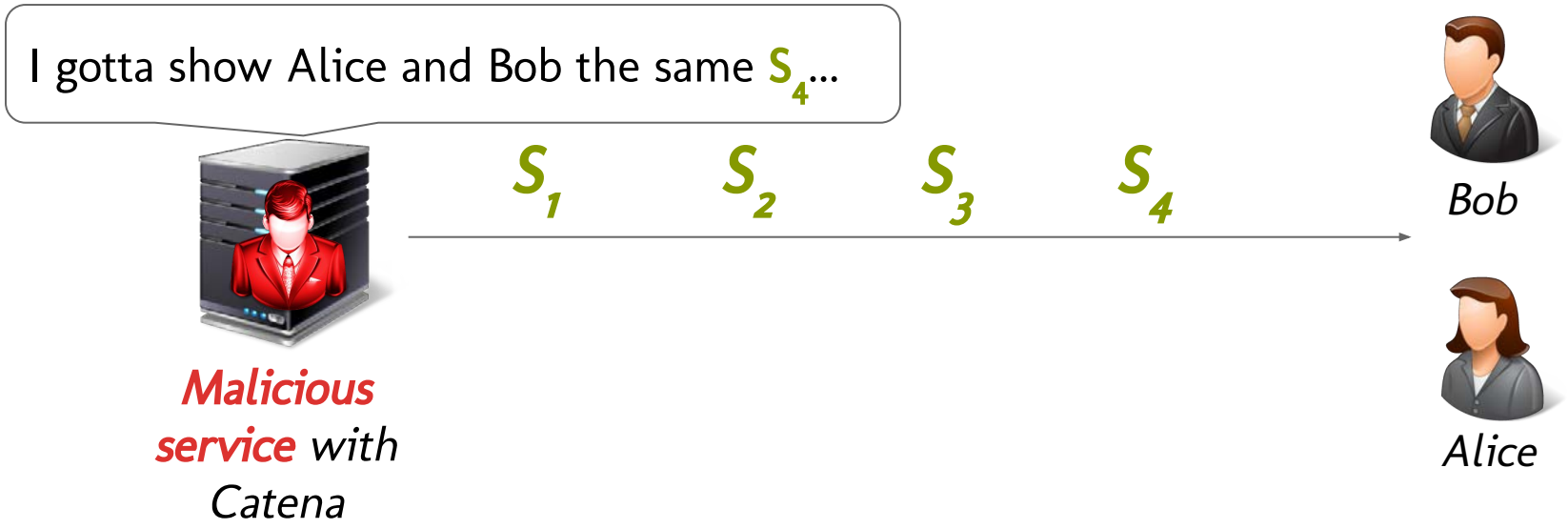

So what?

Secure software update

- Attacks on Bitcoin binaries

0.13.0 Binary Safety Warning

17 August 2016

Summary

Bitcoin.org has reason to suspect that the binaries for the upcoming Bitcoin Core release will likely be targeted by state sponsored attackers. As a website, Bitcoin.org does not have the technical resources to guarantee that we can defend ourselves from attackers of this calibre. We ask the Bitcoin community, and in particular the Chinese Bitcoin community to be extra vigilant when downloading binaries from our website.

Secure messaging

- HTTPS
- *"We assume a PKI."*

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"Blockchain" for X

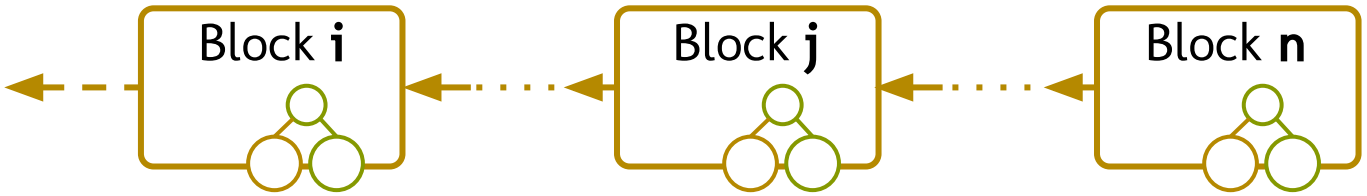
10,000 feet view

- Bitcoin-based append-only log,
  - Generalizes to other cryptocurrencies
- ...as hard-to-fork as the Bitcoin blockchain
  - Want to fork? Do some work!
- ...but efficiently auditable
  - 600 bytes / statement (but can batch!)
  - 80 bytes / Bitcoin block
- Java implementation (3500 SLOC)
  - https://github.com/alinush/catena-java

Overview

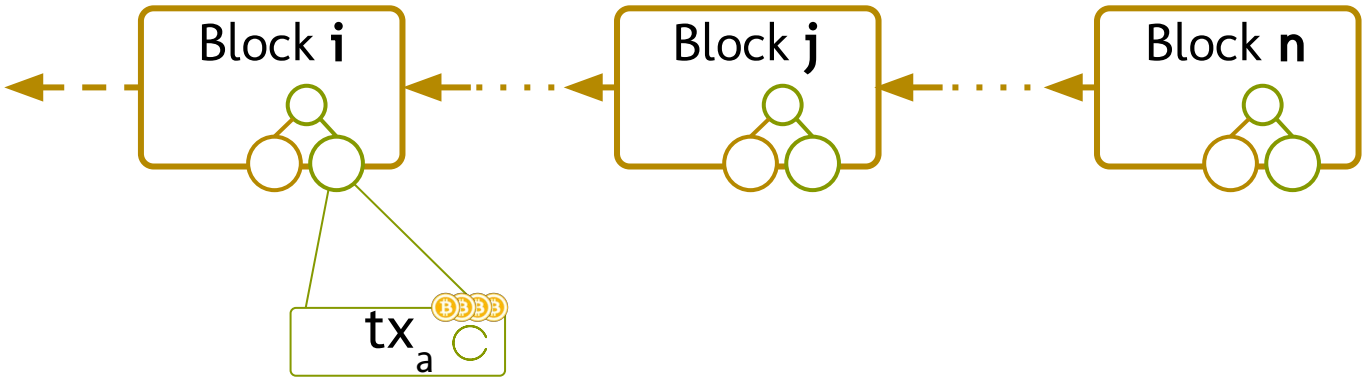
1. What?
2. How?
   a. **Bitcoin background**
3. Why?

Bitcoin blockchain



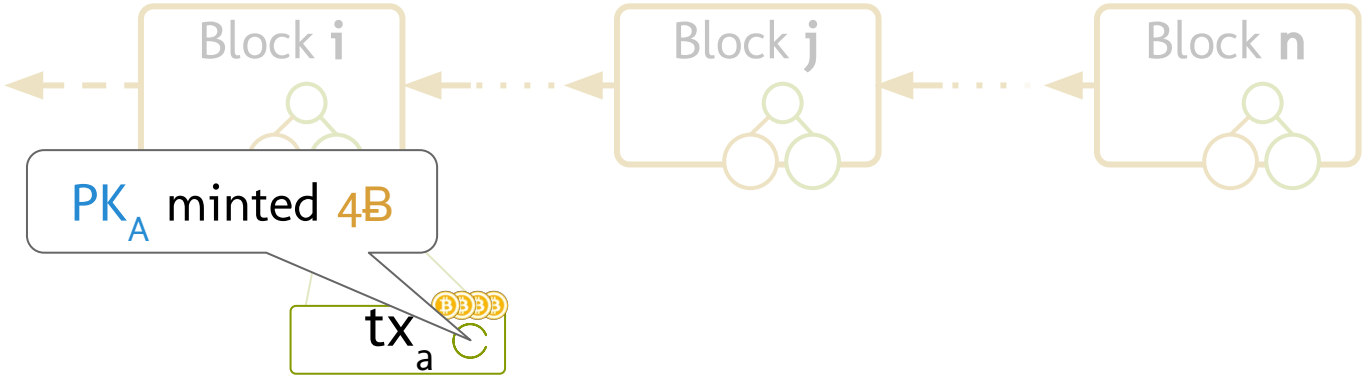
- Hash chain of blocks
  - Arrows are *hash pointers*
- Merkle tree of TXNs in each block
- Proof-of-work (PoW) consensus

Bitcoin blockchain



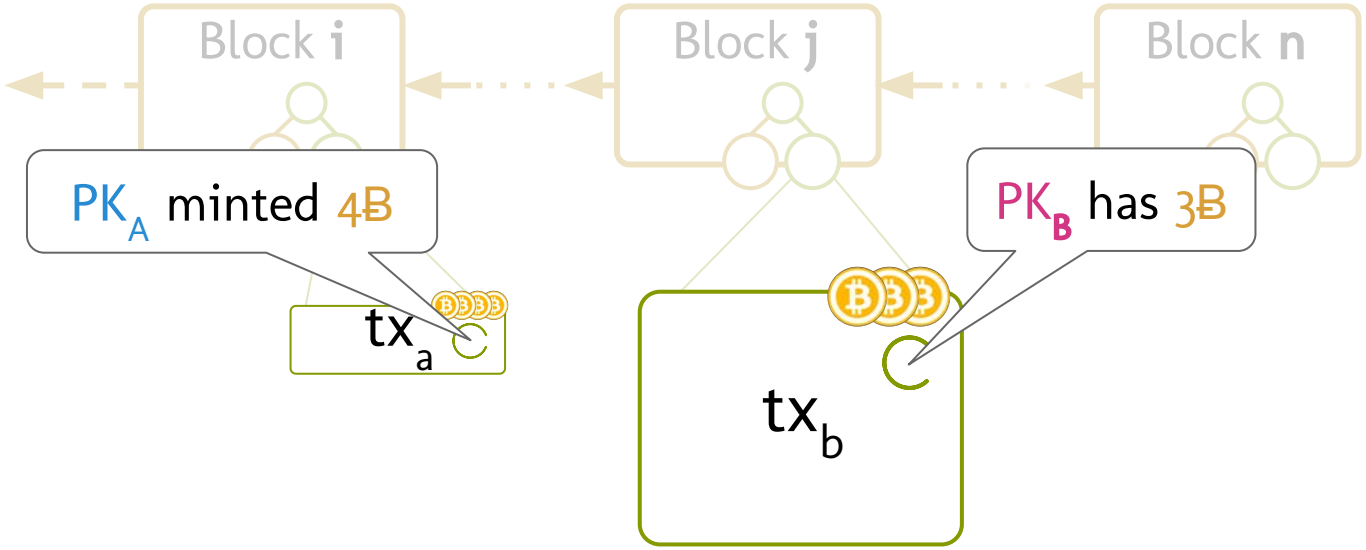
- Transactions mint coins

Bitcoin blockchain



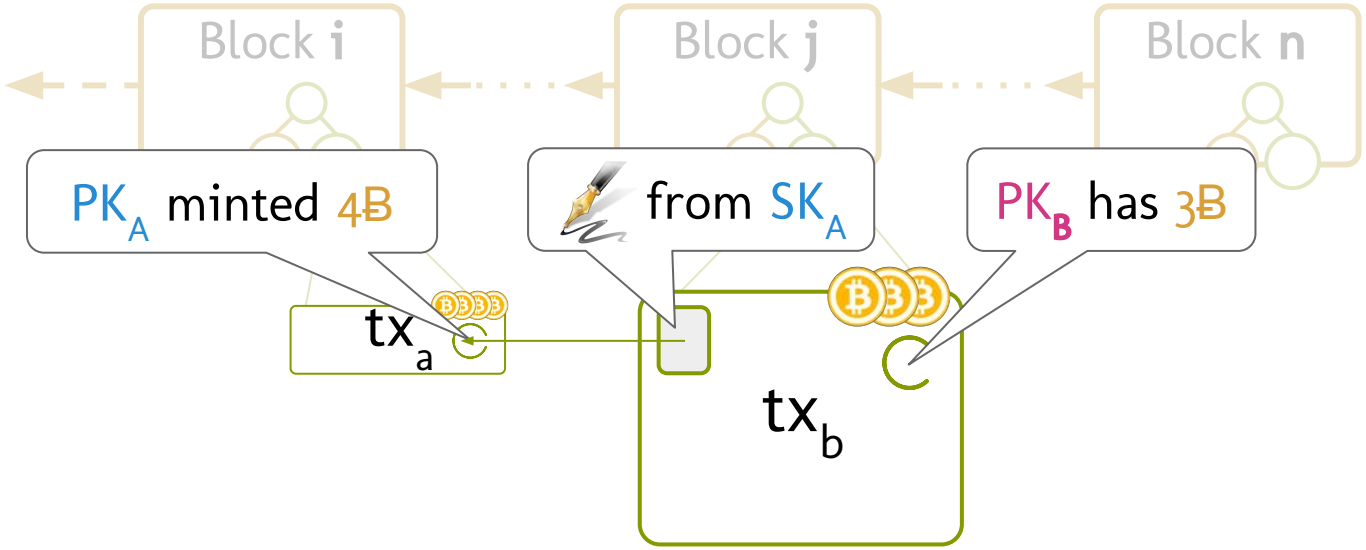
- Transactions mint coins
- Output = # of coins and owner's PK

Bitcoin blockchain



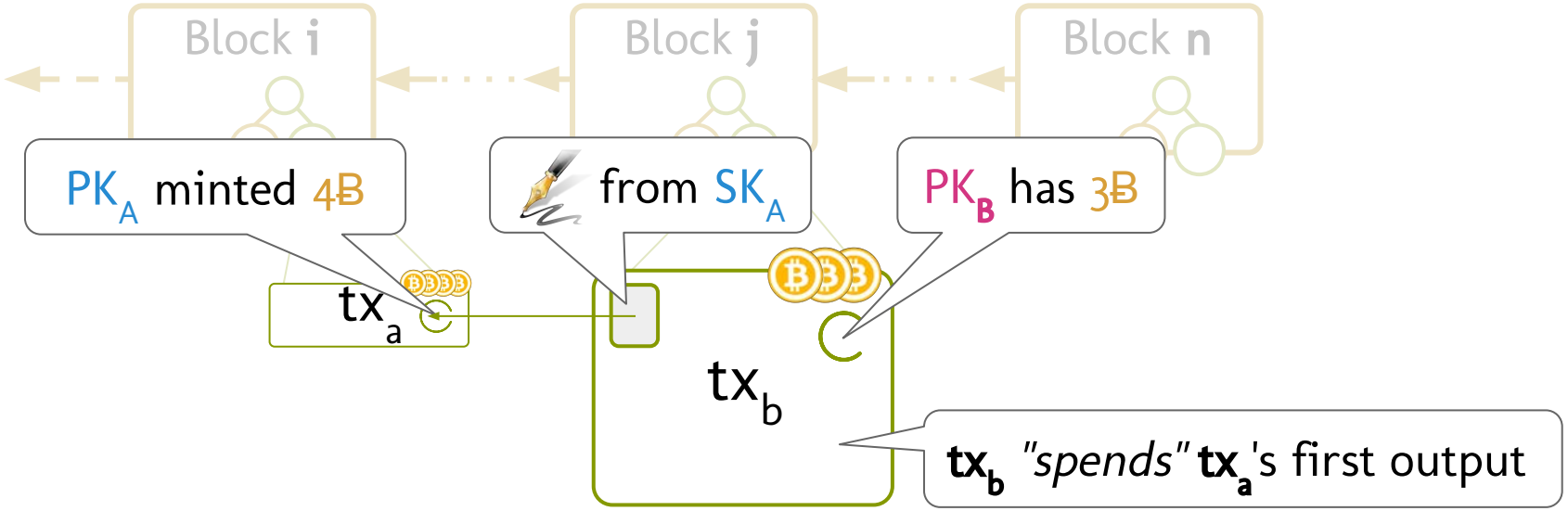
- Transactions mint coins
- Output = # of coins and owner's PK
- Transactions transfer coins (and pay fees)

Bitcoin blockchain



- Transactions mint coins
- Output = # of coins and owner's PK
- Transactions transfer coins (and pay fees)
- Input = hash pointer to output + digital signature

Bitcoin blockchain



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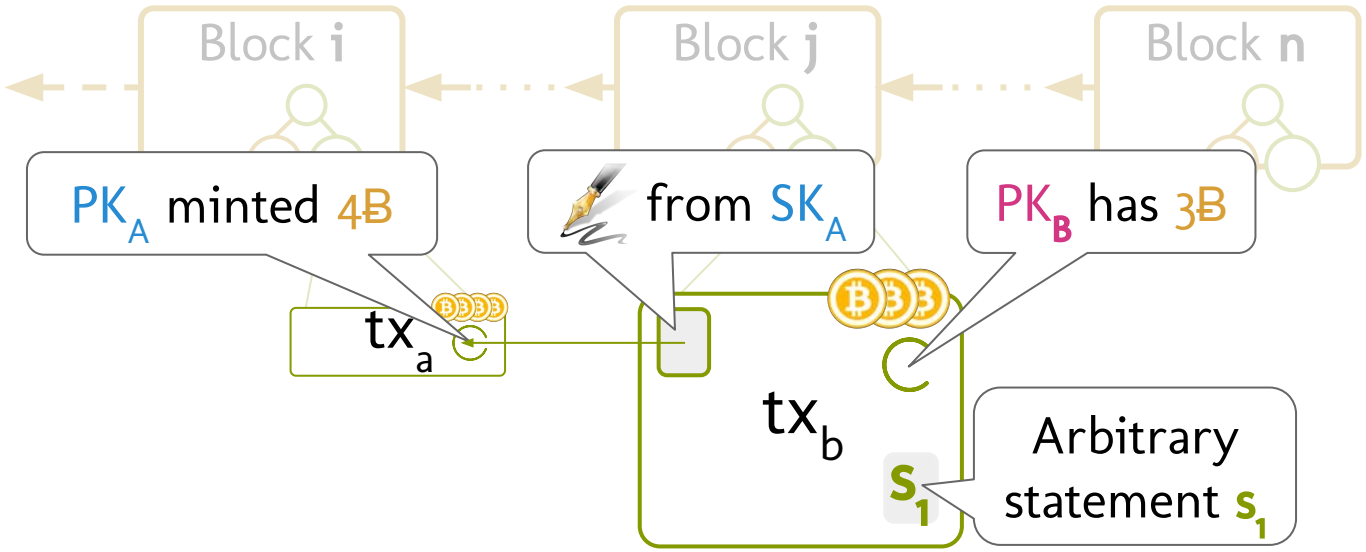
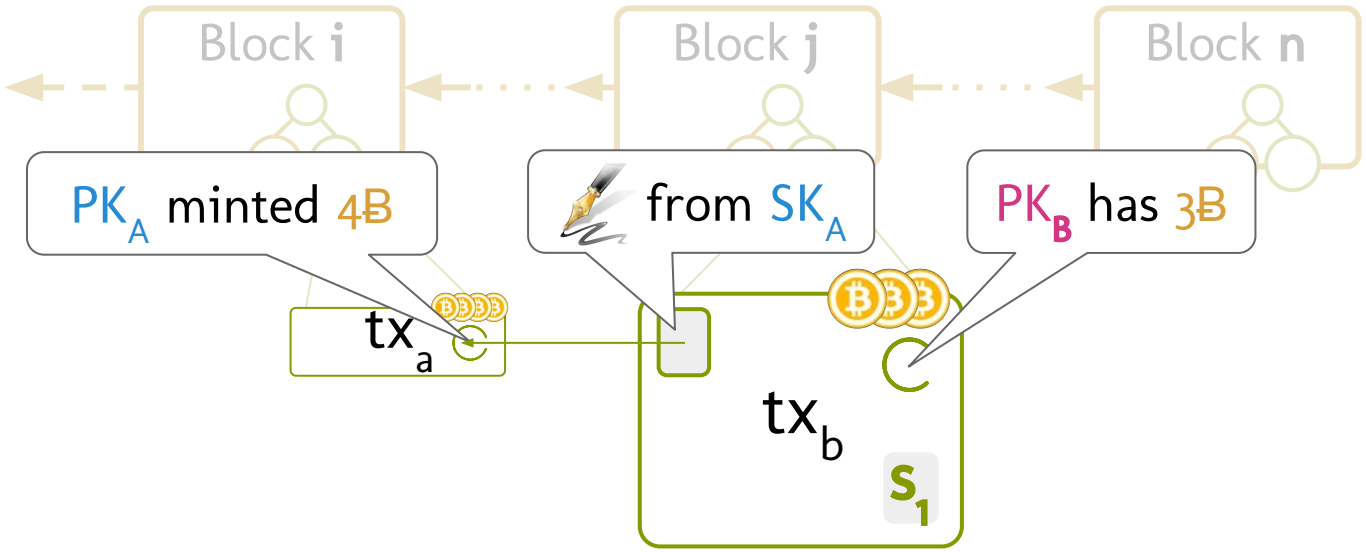


Data can be embedded in TXNs.

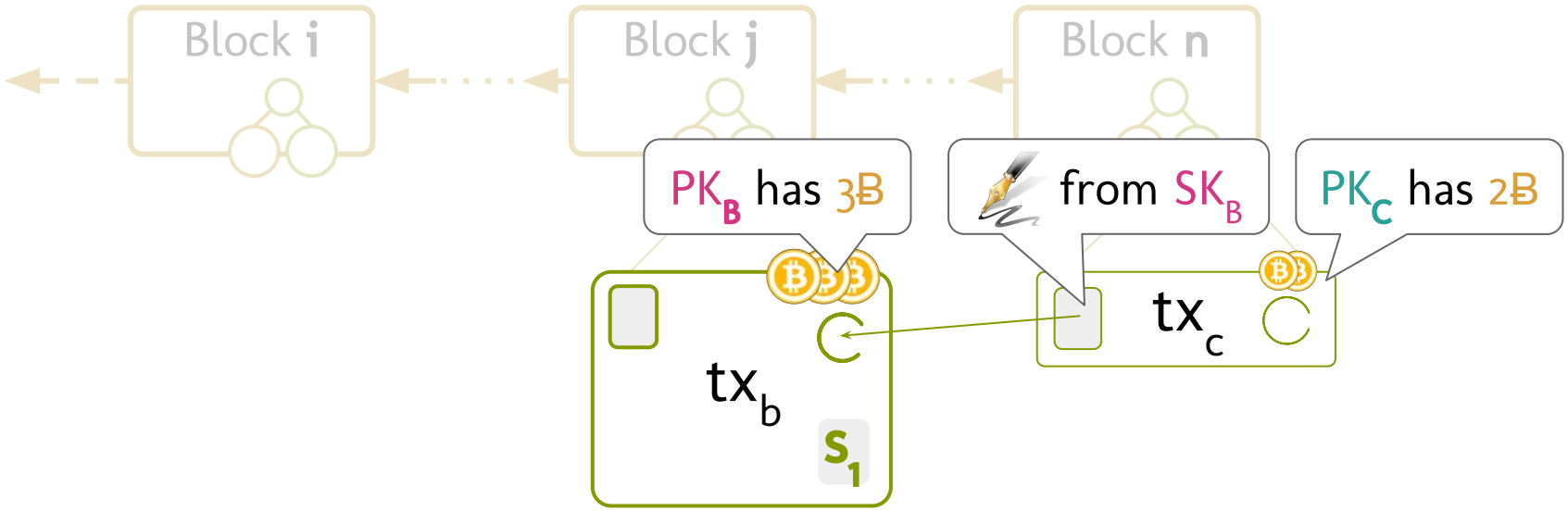
Bitcoin blockchain



Alice gives Bob 3Ƀ,

Bitcoin *miners* collected 1Ƀ as a *fee.*

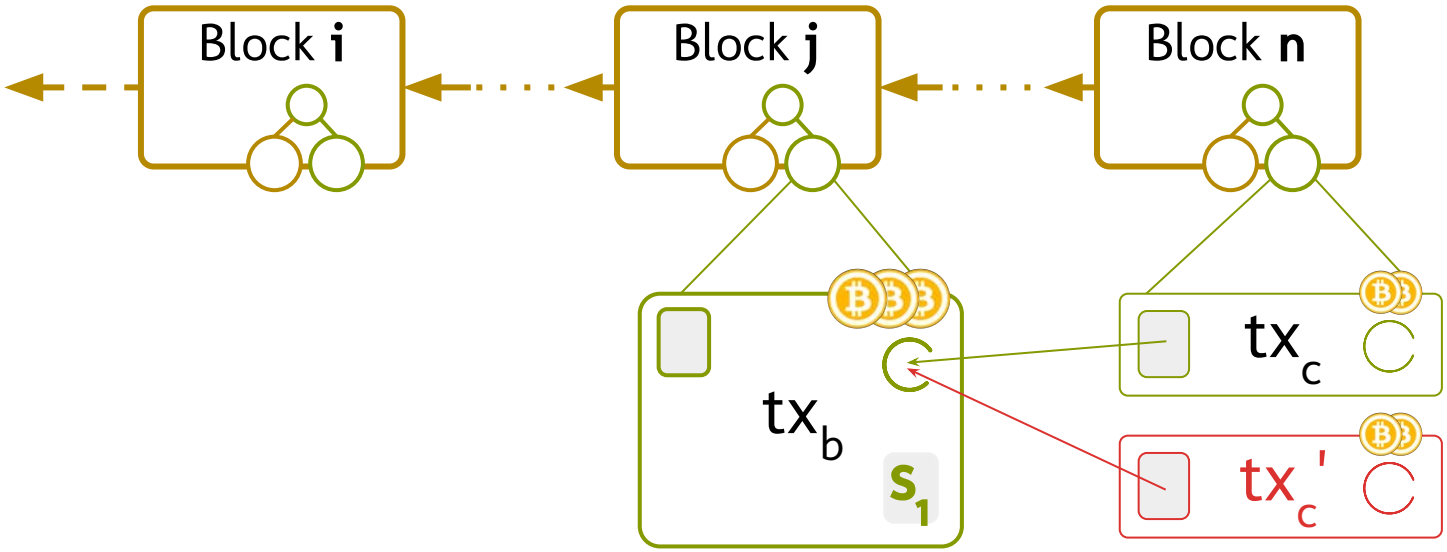
Bitcoin blockchain



Bob gives Carol 2Ƀ,

Bitcoin *miners* collected another Ƀ as a fee.

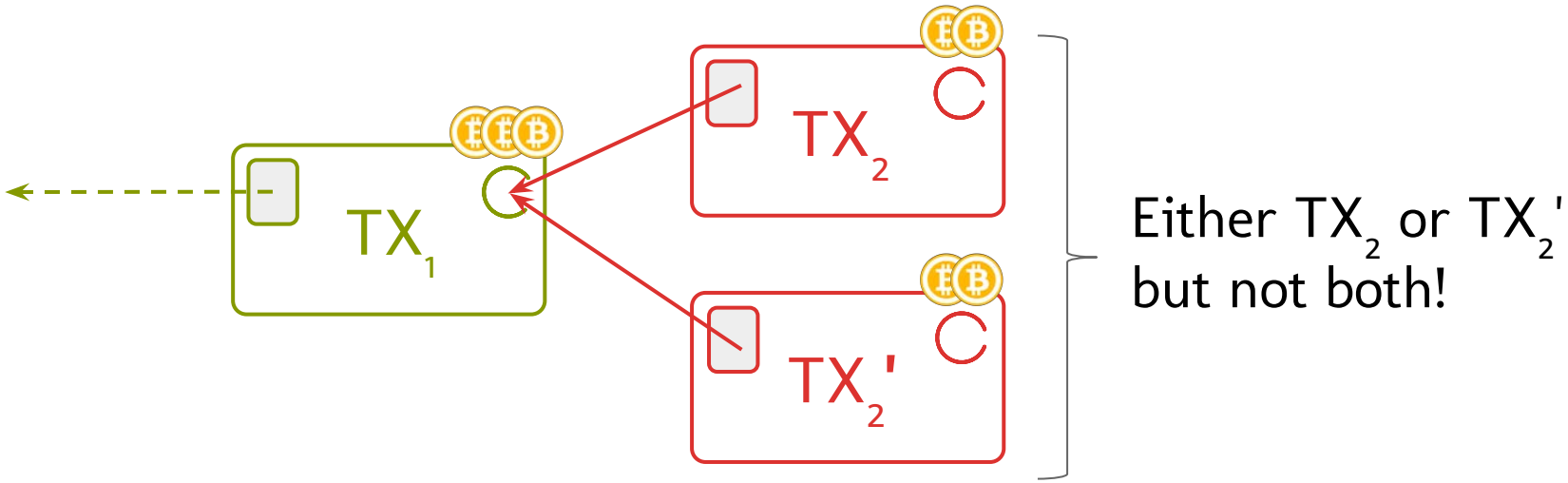
Bitcoin blockchain



No double-spent coins: A TXN output can only be referred to by a single TXN input.

Moral of the story

Proof-of-work (PoW) consensus ⇒ No double spends



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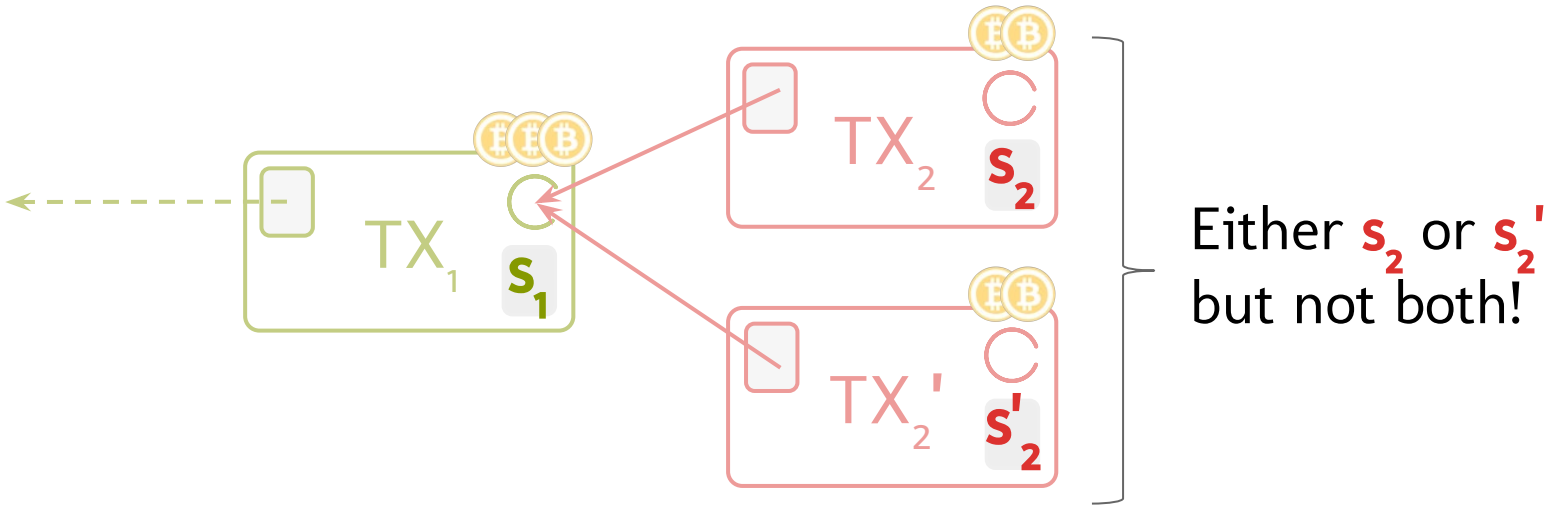
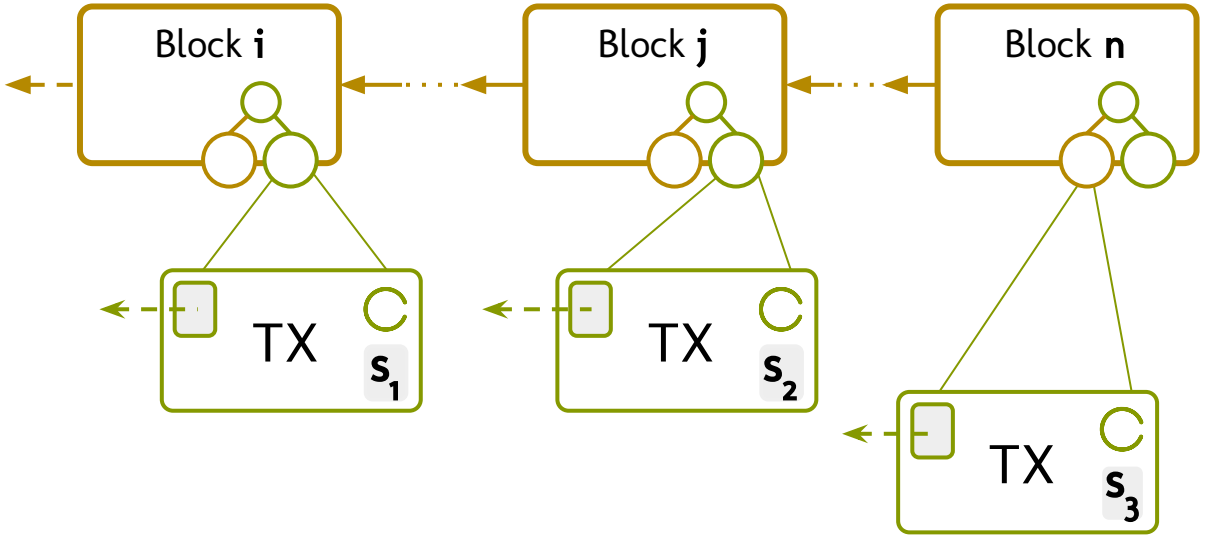


Overview

1. What?
2. How?
   a. Bitcoin background
   b. Previous work
3. Why?

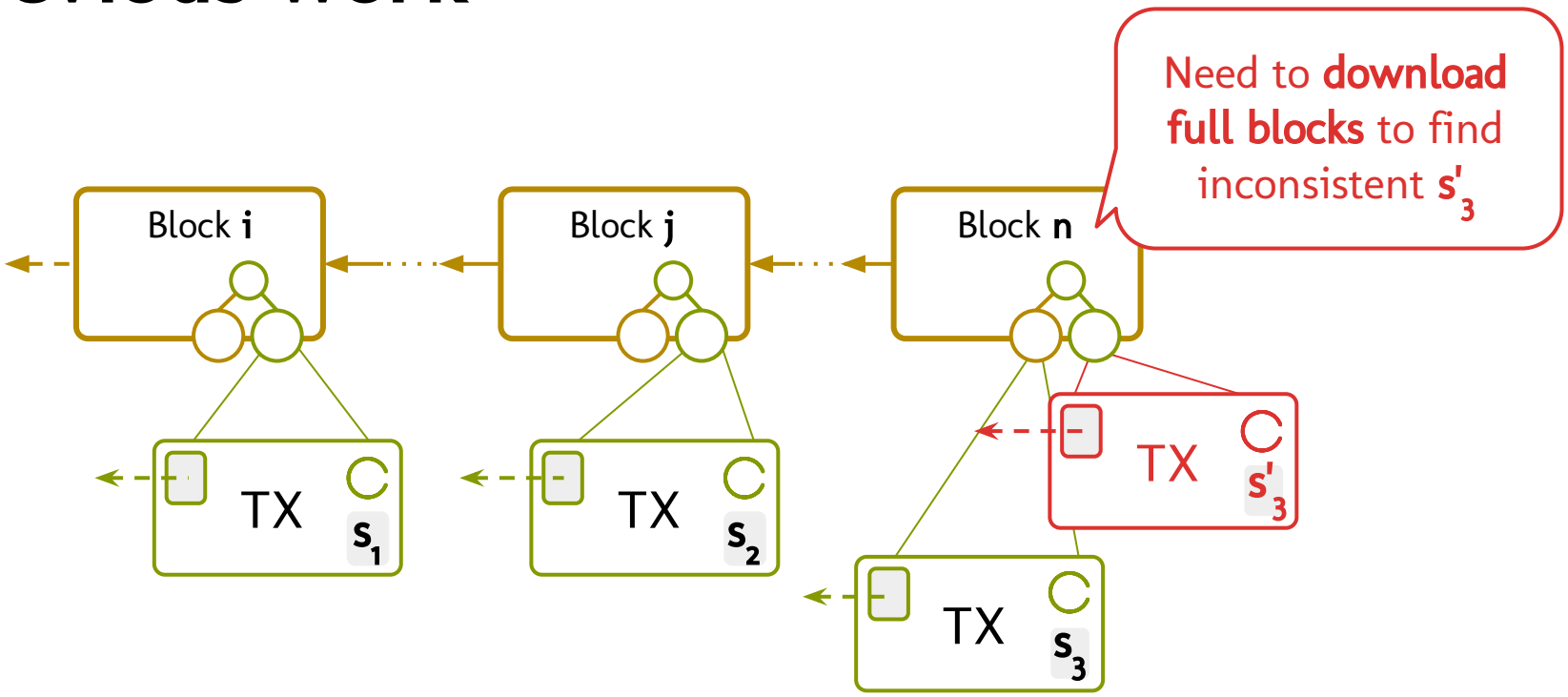
Previous work



blockstack

Keybase

Previous work



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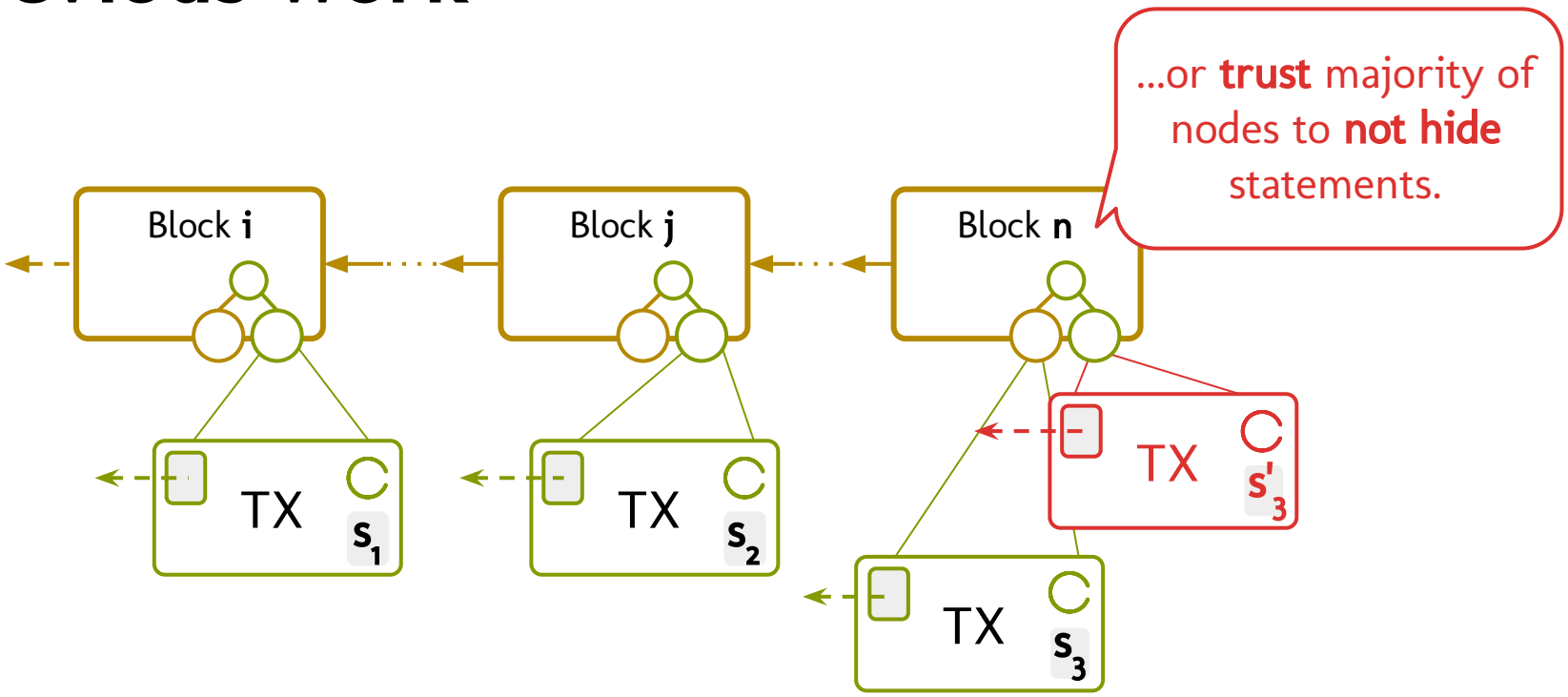
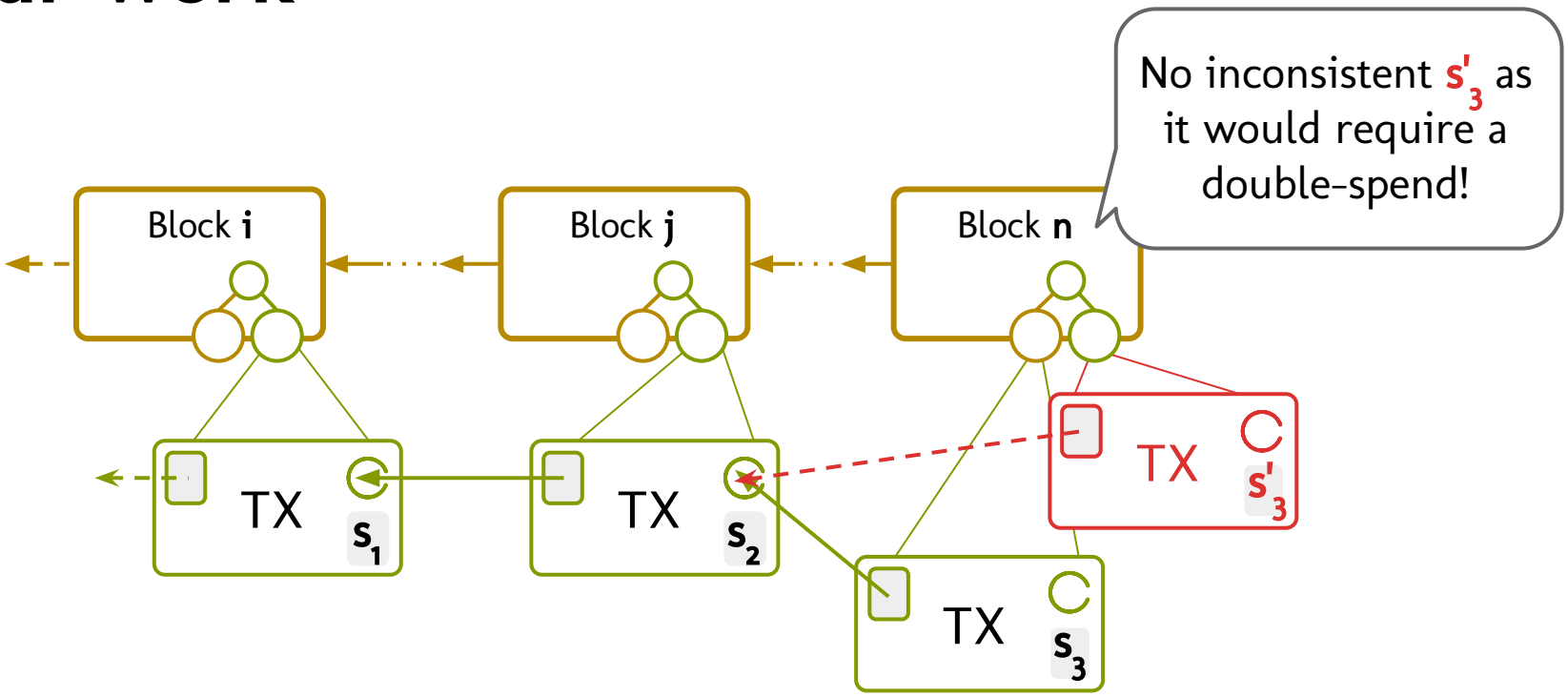


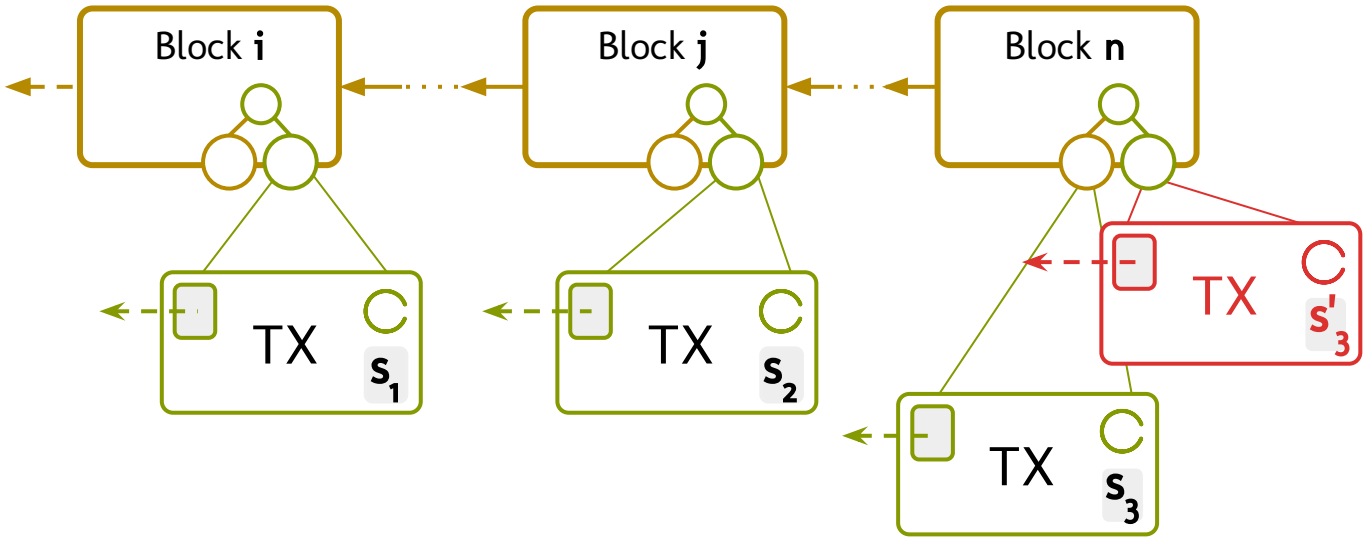
blockstack

Keybase

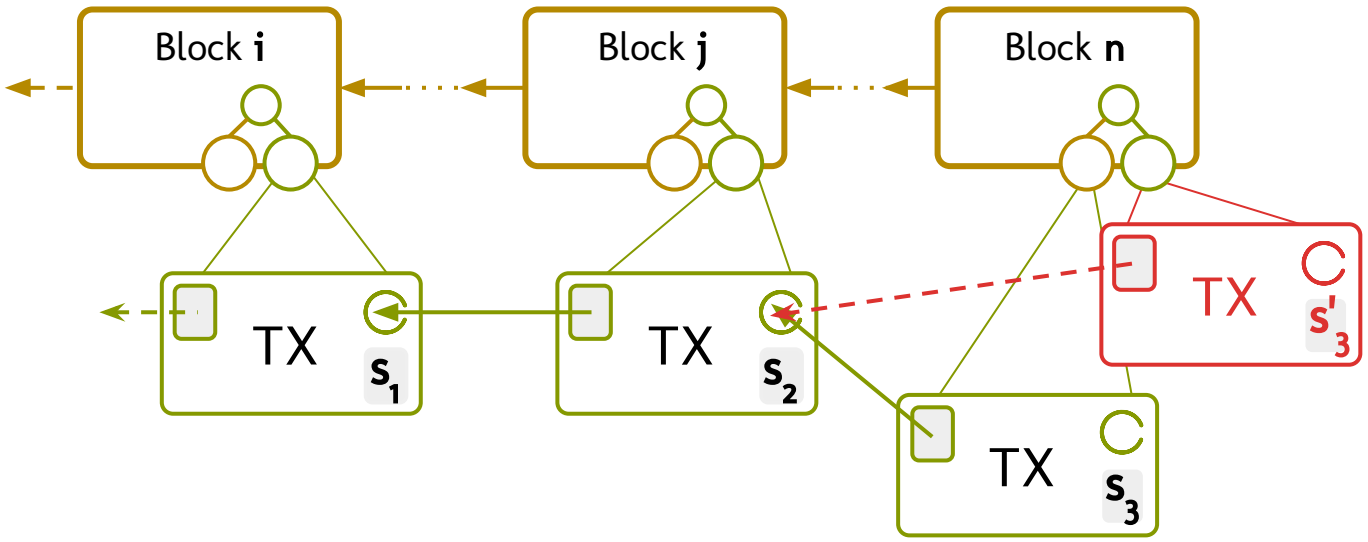
Our work


No inconsistent s'3 as it would require a double-spend!
Block i
Block j
Block n
TX
s1
TX
s2
TX
s3
TX
s'3

Previous work



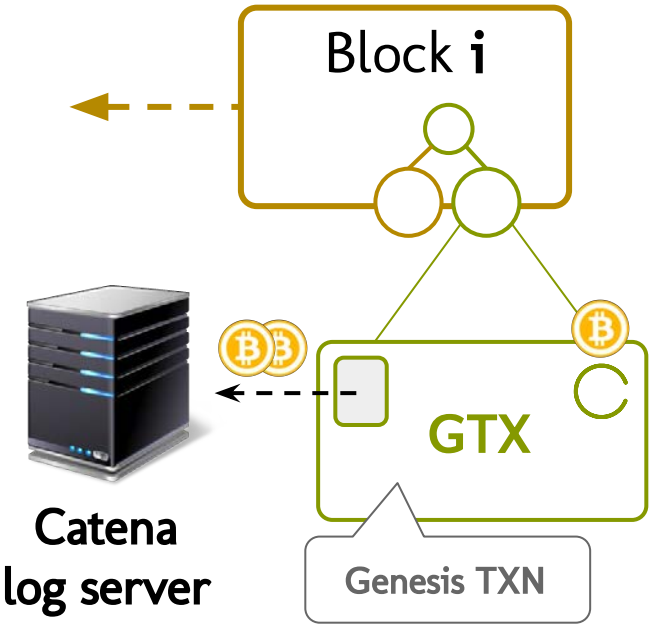
Our work



Overview

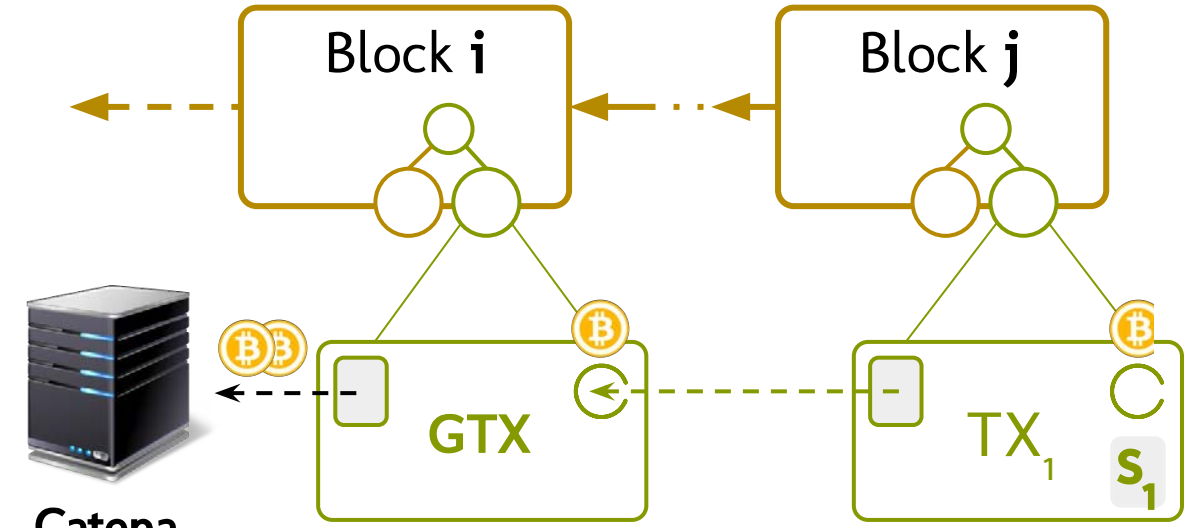
1. What?
2. How?
   a. Bitcoin background
   b. Previous work
   c. Design
3. Why?

Starting a Catena log



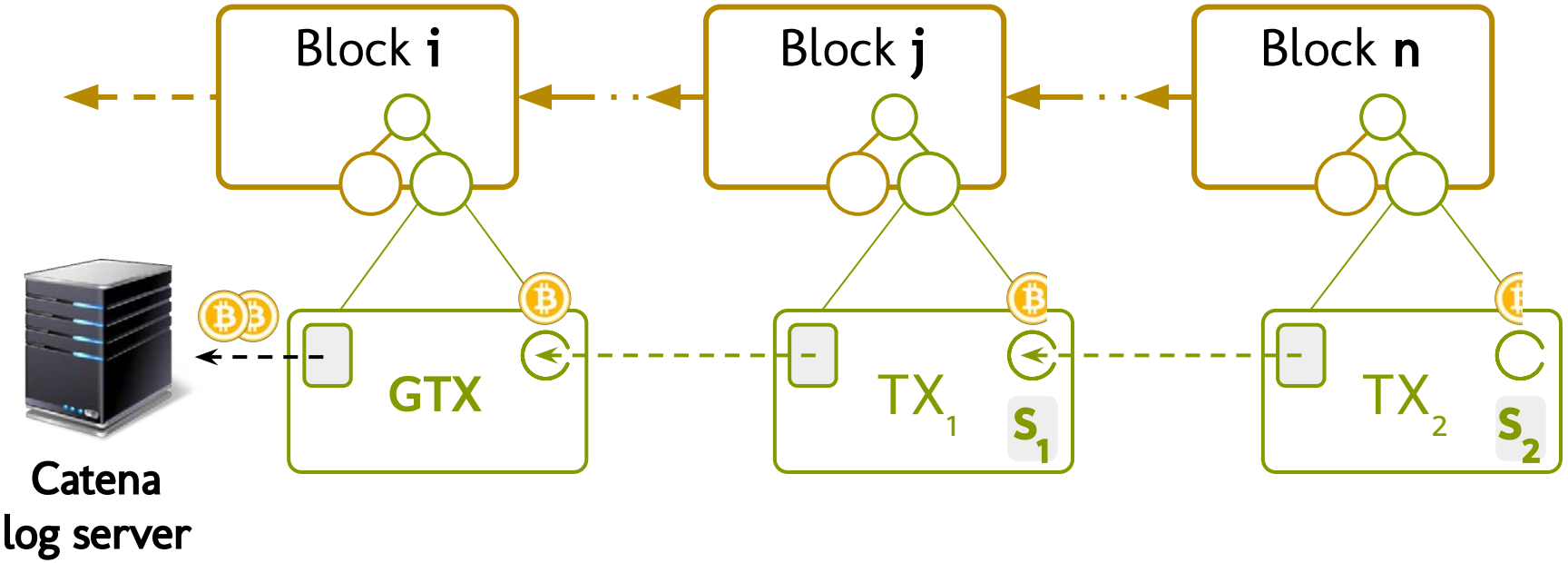
- *Genesis TXN* (GTX) = log's "public key"
- Coins from server back to server (minus fees)

Appending to a Catena log



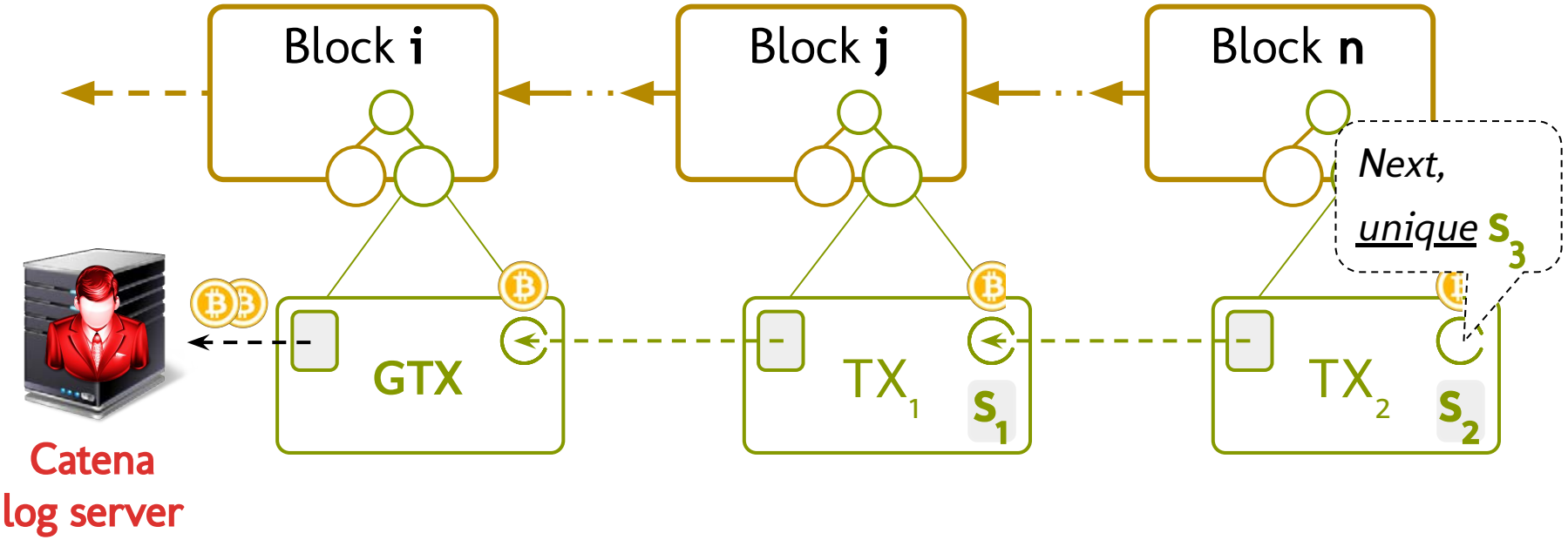
- TX_1 "spends" GTX's output, publishes s_1
- Coins from server back to server (minus fees)
- Inconsistent s_1' would require a double-spend

Appending to a Catena log



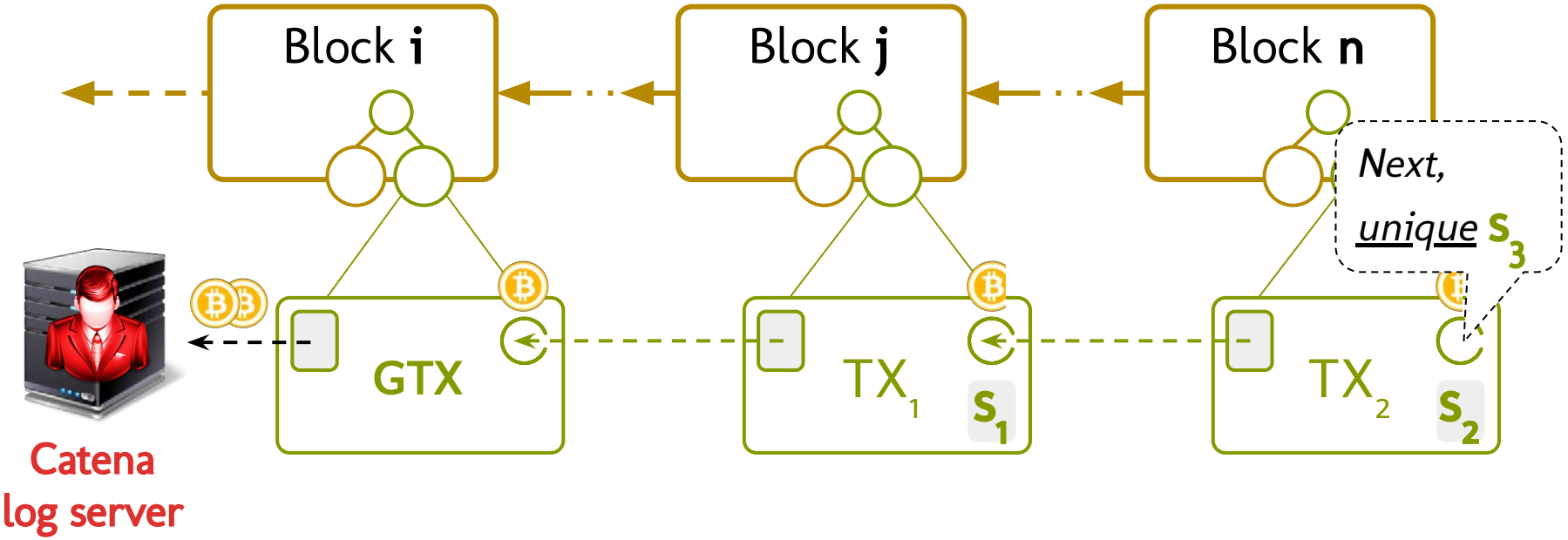
- TX_2 "spends" TX_1's output, publishes s_2
- Coins from server back to server (minus fees)
- Inconsistent s_2' would require a double-spend

Appending to a Catena log



- Server is compromised, still cannot equivocate.

Appending to a Catena log

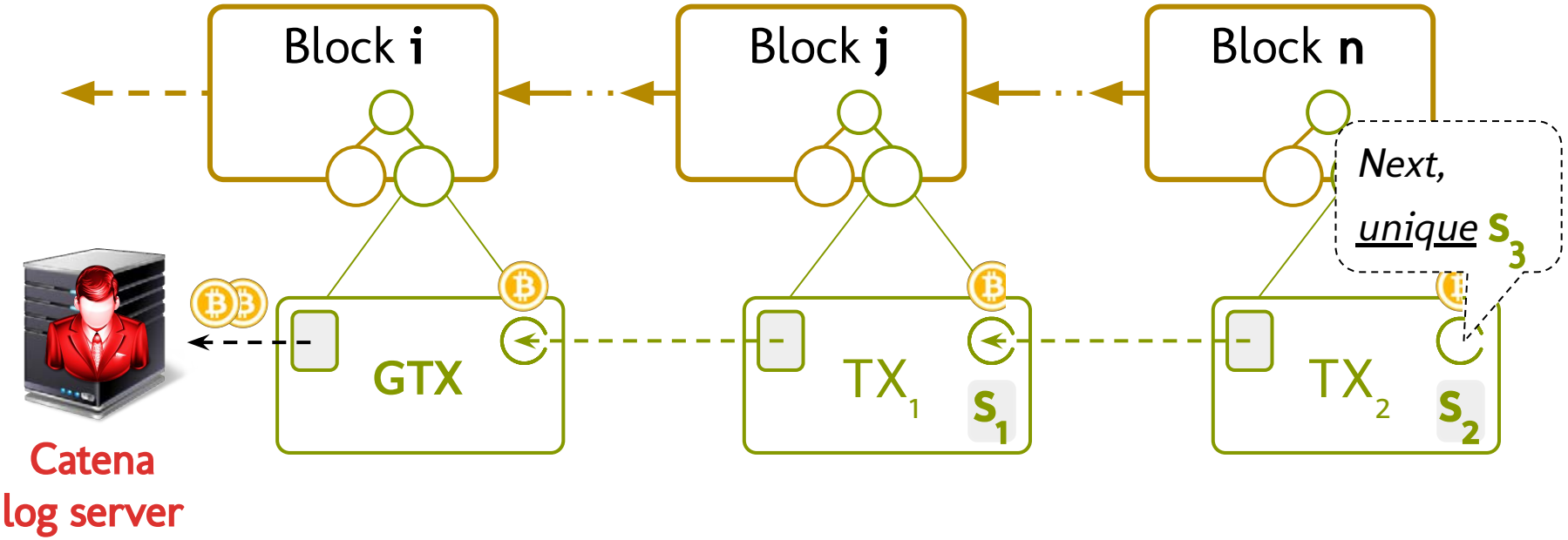


Advantages:

(1) Hard to fork

(2) Efficient to verify

Appending to a Catena log



Advantages:
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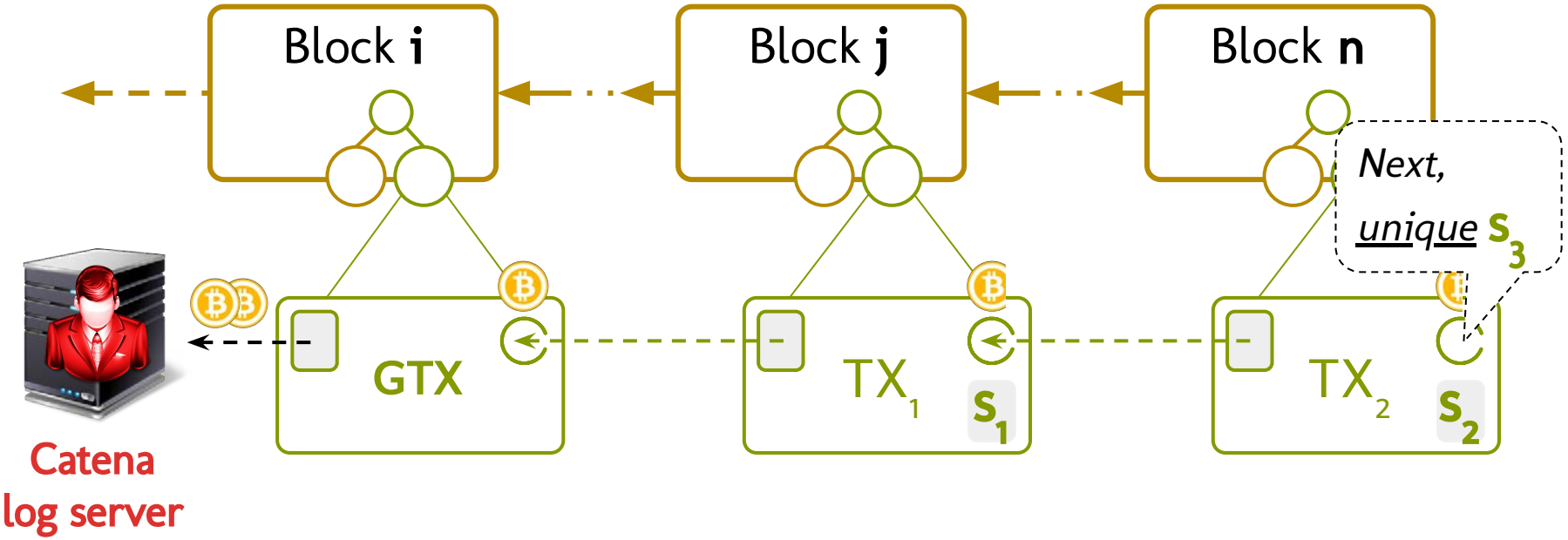
Disadvantages:
(1) 6-block confirmation delay

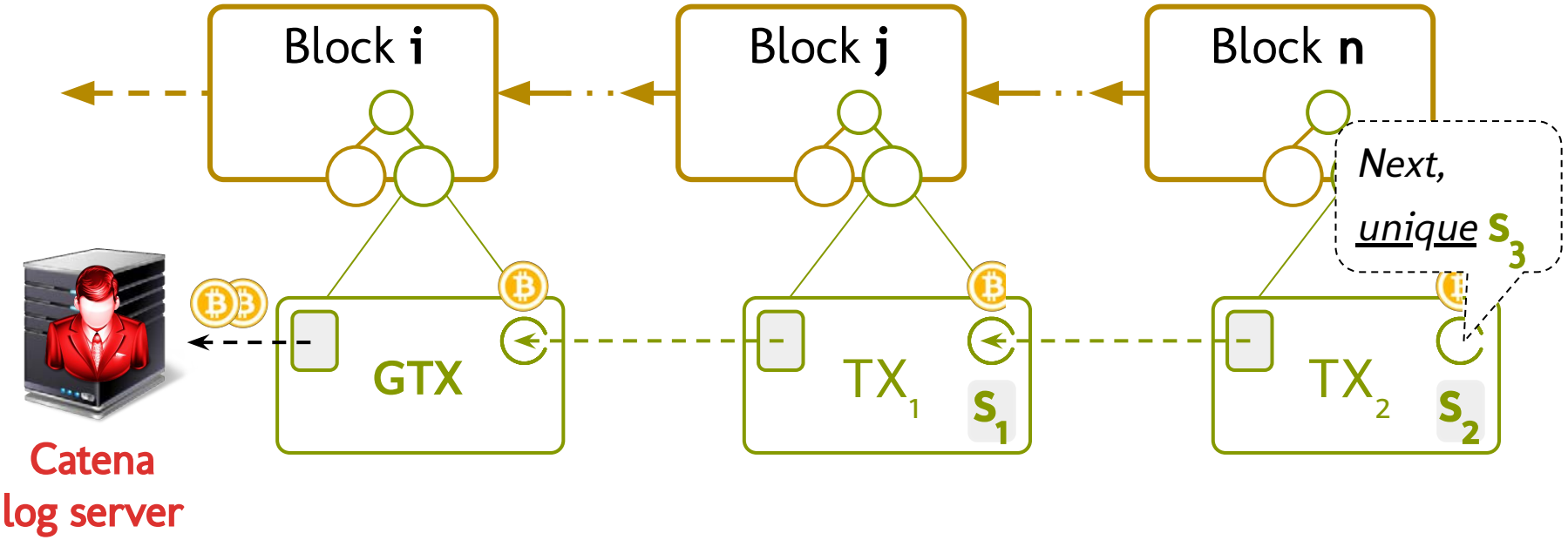
Appending to a Catena log



Advantages:
(1) Hard to fork
(2) Efficient to verify

Disadvantages:
(1) 6-block confirmation delay
(2) 1 statement every 10 minutes

Appending to a Catena log



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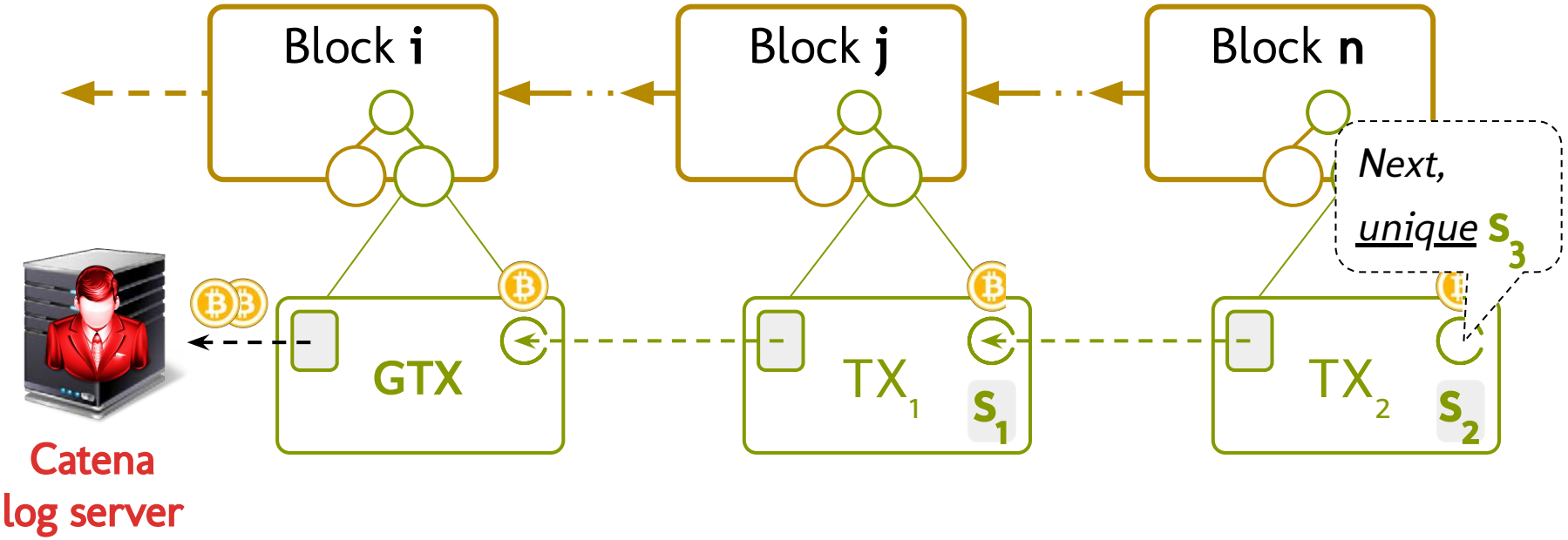
(3) Must pay Bitcoin TXN fees

Appending to a Catena log



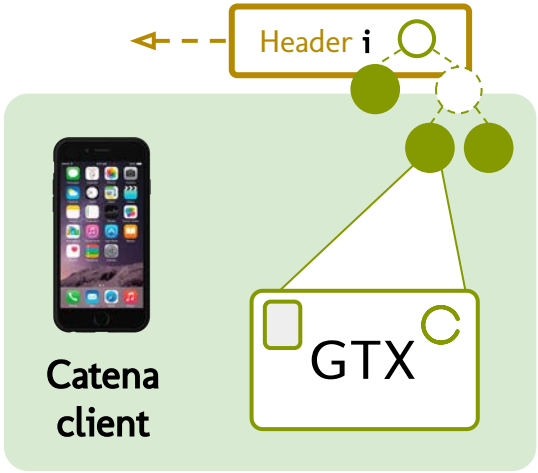
Advantages:
(1) Hard to fork
(2) Efficient to verify

Disadvantages:
(1) 6-block confirmation delay
(2) 1 statement every 10 minutes
(3) Must pay Bitcoin TXN fees
(4) No freshness guarantee

Overview

1. Catena: What?
2. Catena: How?
   a. Bitcoin background
   b. Previous work
   c. Design
   d. Efficient auditing
3. Potentially-interesting applications

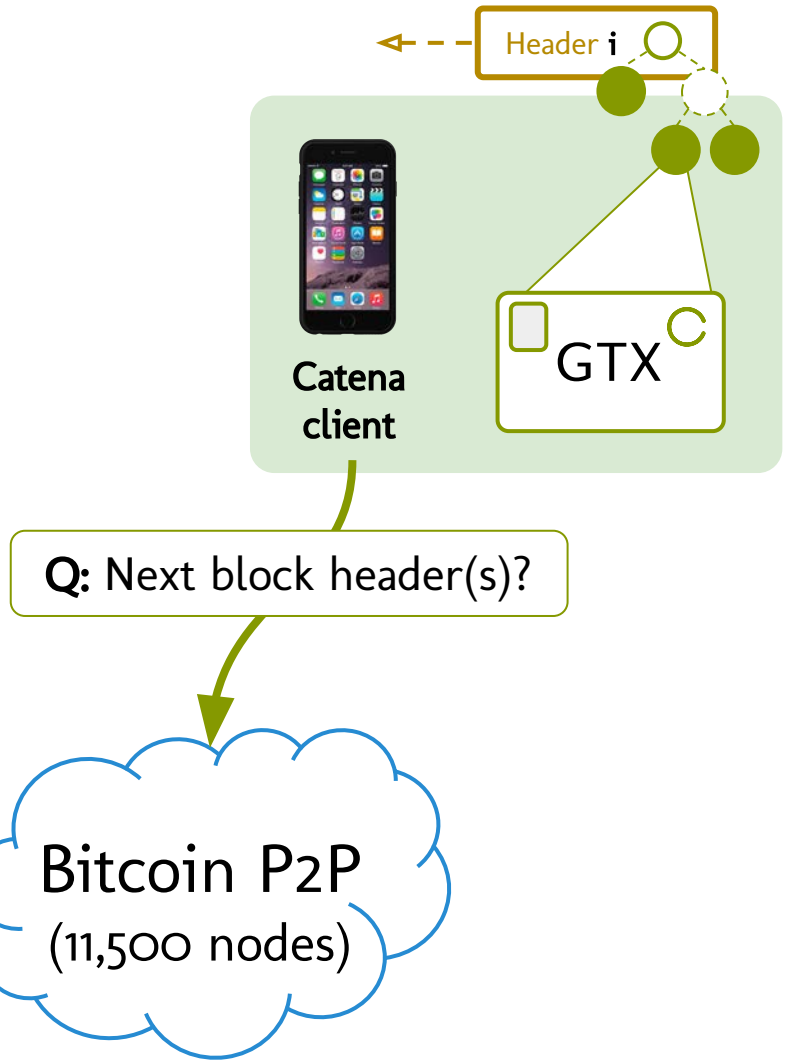
Efficient auditing



Bitcoin P2P
(11,500 nodes)

Catena log server

Efficient auditing



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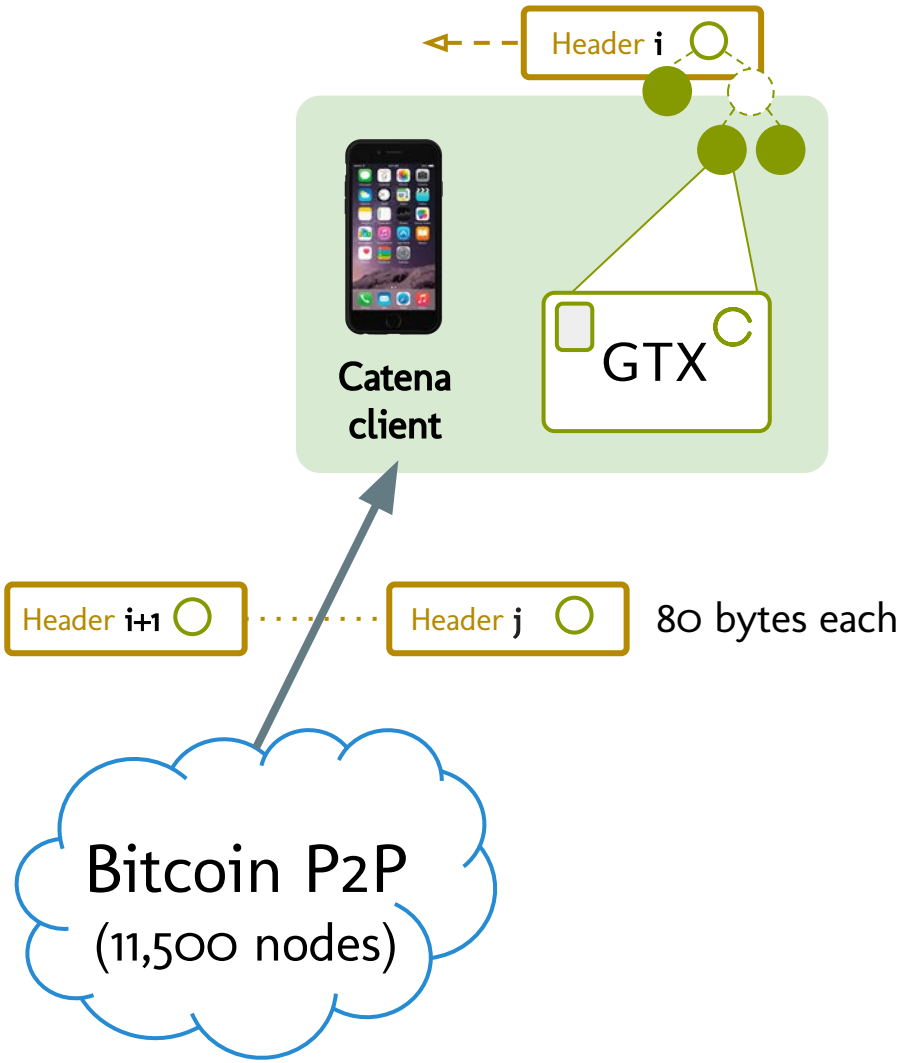

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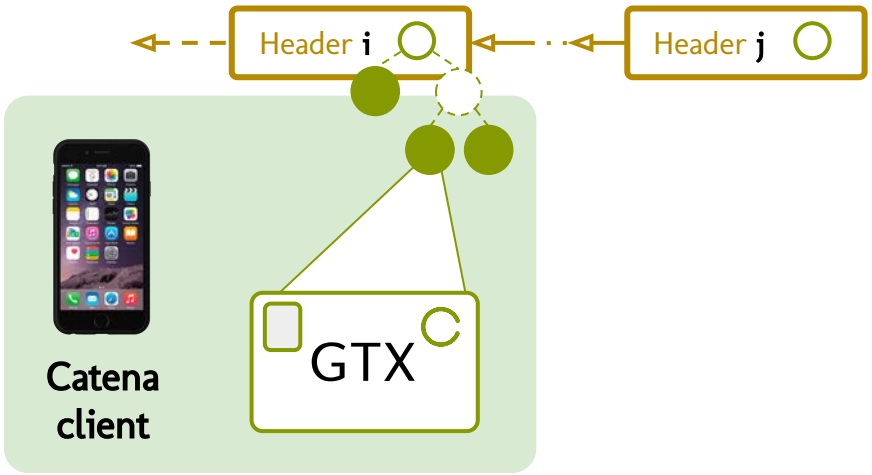

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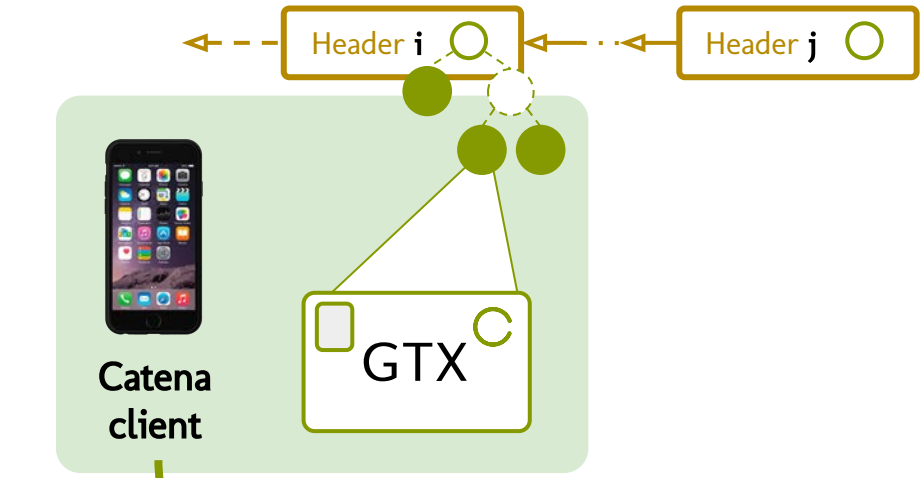

Q: What is s_1 in the log?

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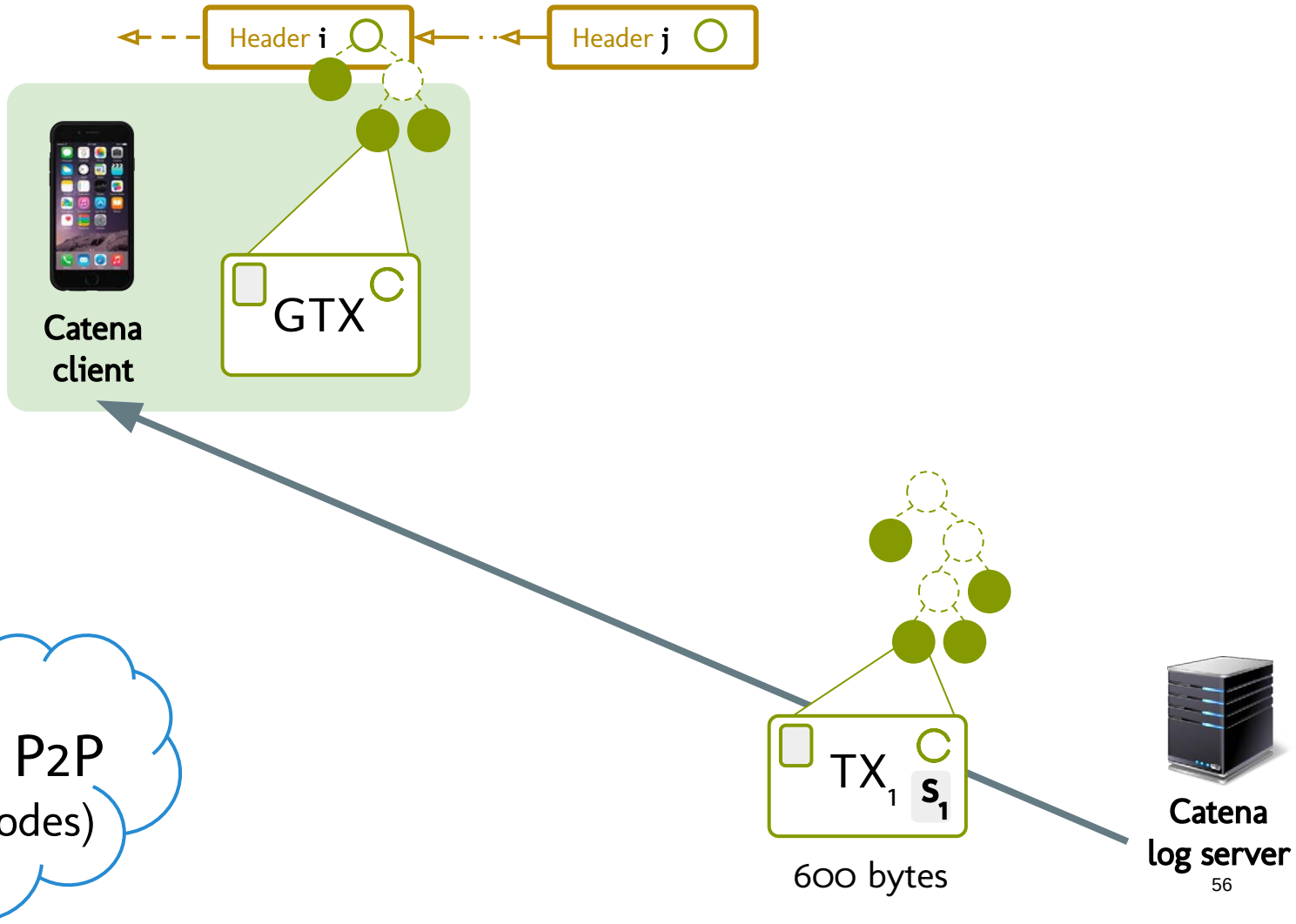

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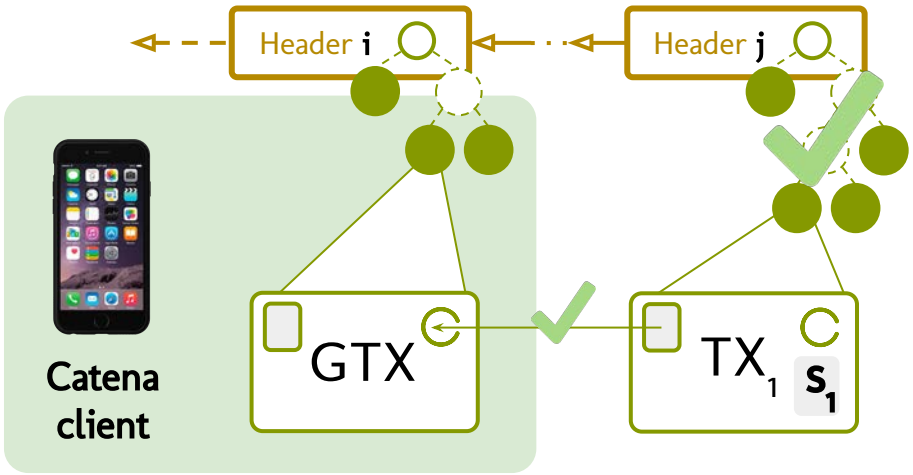
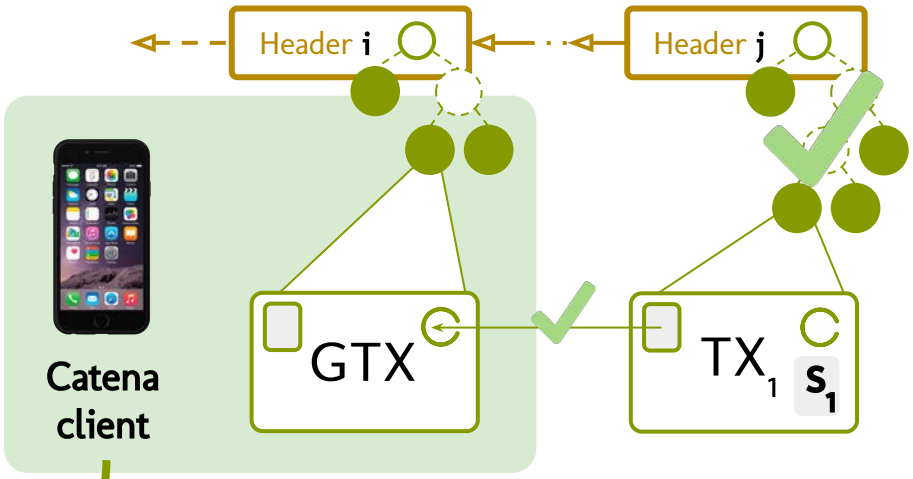


Bitcoin P2P
(11,500 nodes)

Catena log server

Efficient auditing

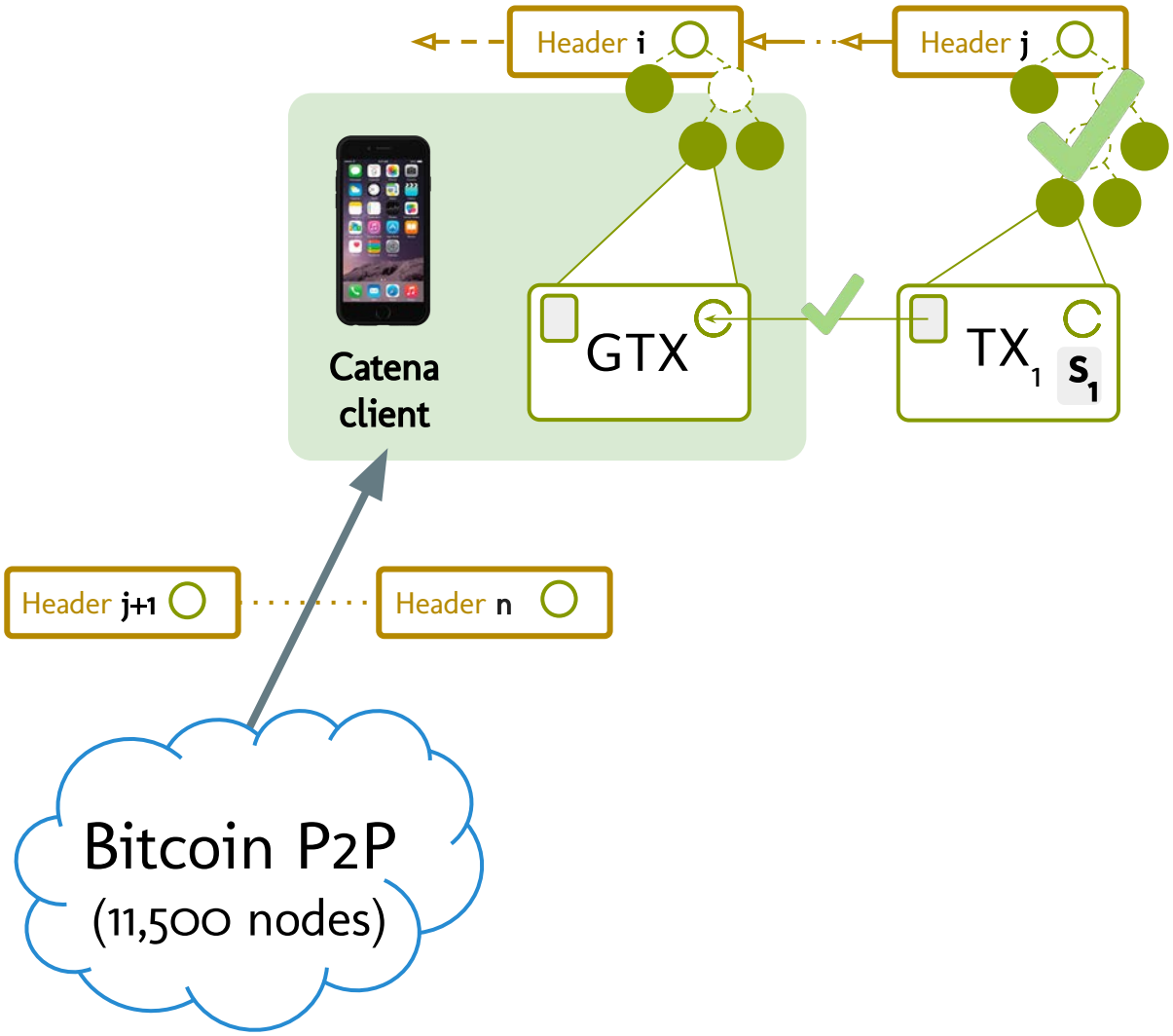


Q: Next block header(s)?

Bitcoin P2P
(11,500 nodes)

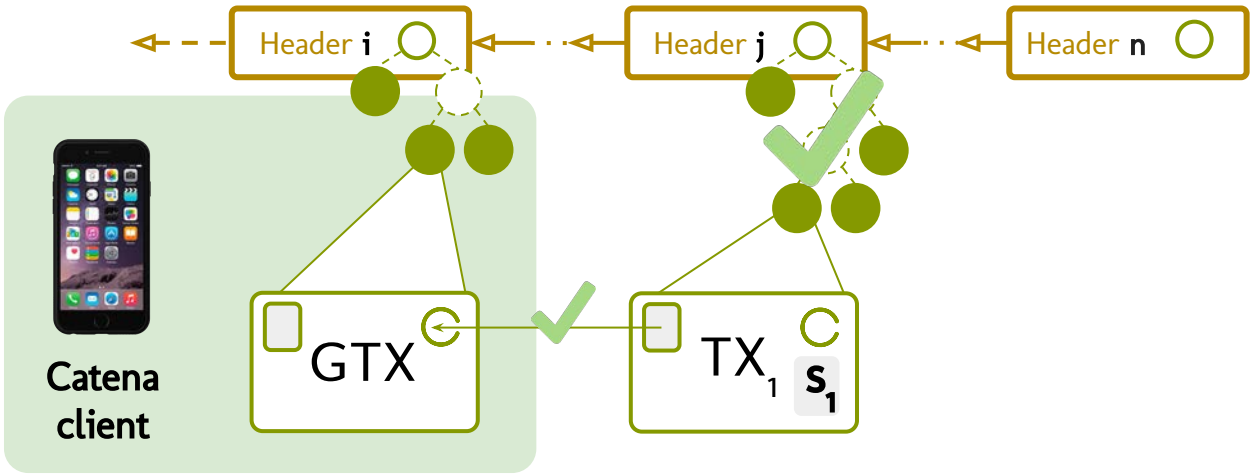
Catena log server

Efficient auditing



Catena log server

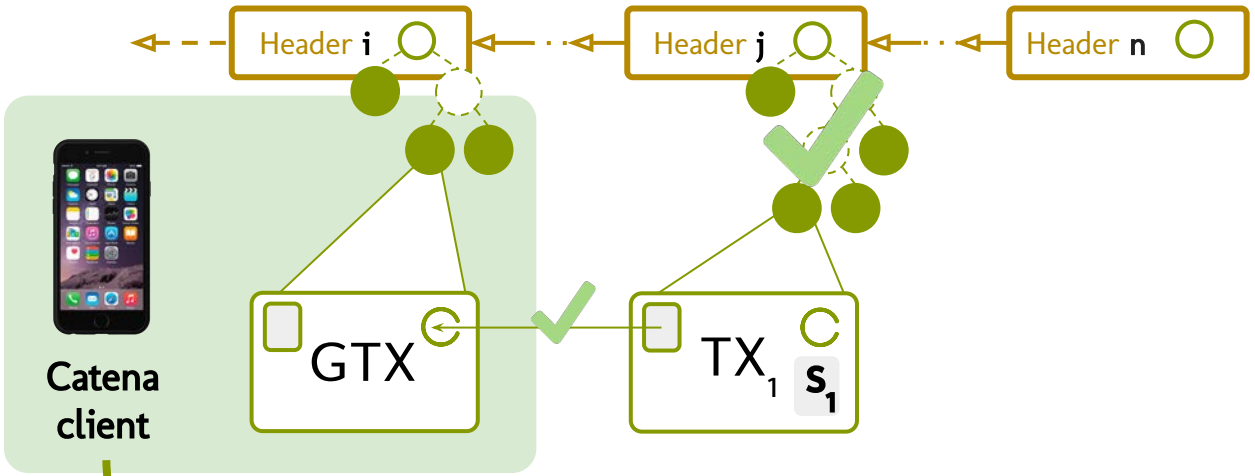
Efficient auditing



Bitcoin P2P
(11,500 nodes)

Catena log server

Efficient auditing

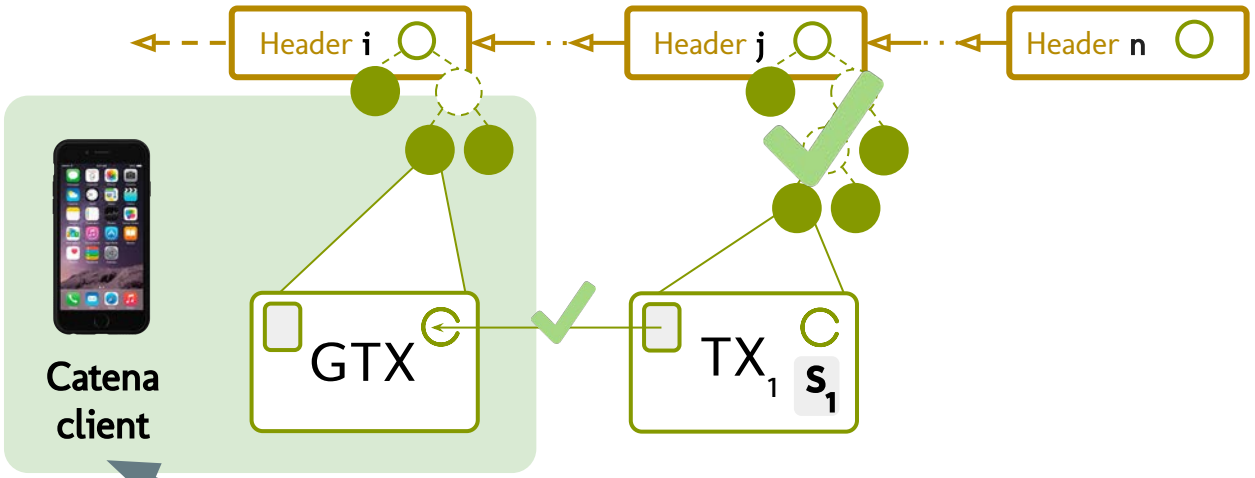


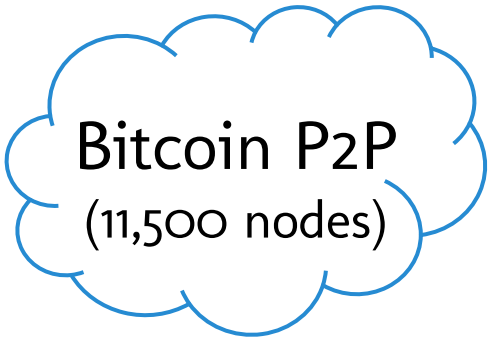
Q: What is s_2 in the log?

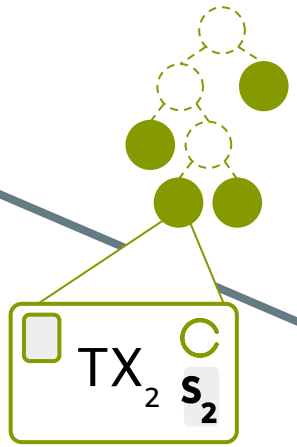
Bitcoin P2P
(11,500 nodes)

Catena log server

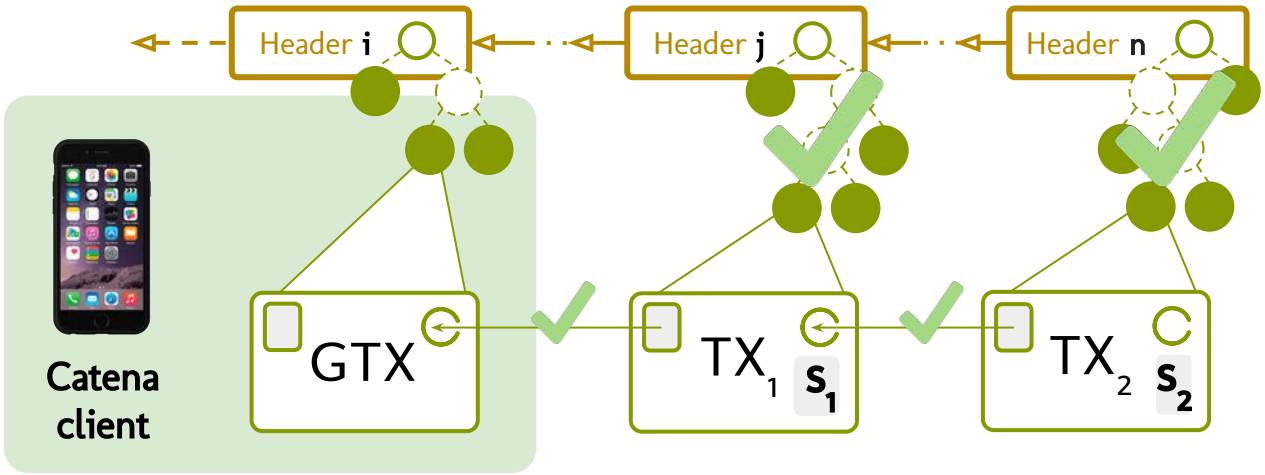
Efficient auditing







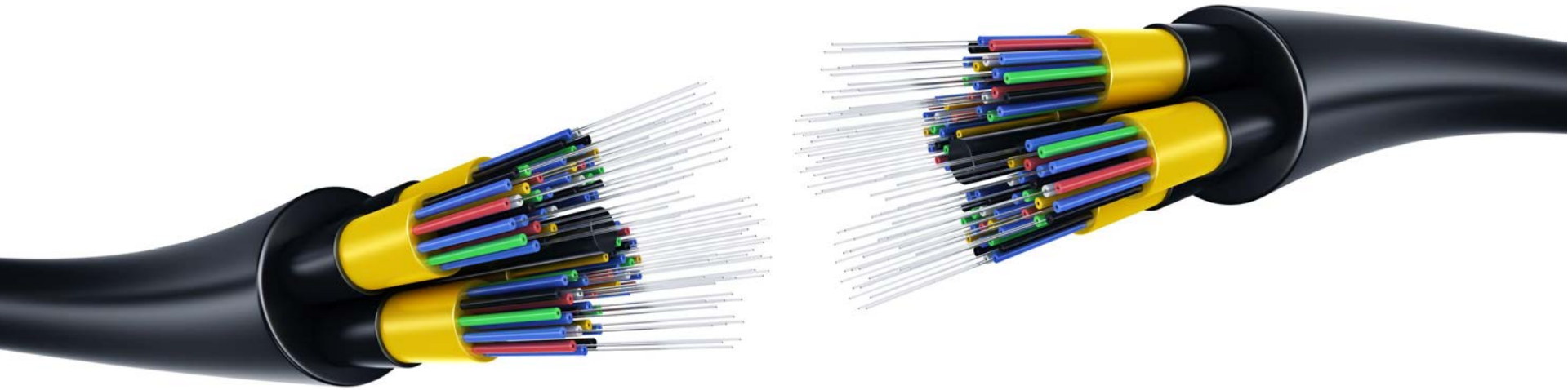
Efficient auditing



Bitcoin P2P
(11,500 nodes)

Catena log server

Auditing bandwidth



e.g., **500K** block headers + **10K** statements = **~46** MB

(80 bytes each) (around 600 bytes each)

Overview

1. What?
2. How?
   a. Bitcoin background
   b. Previous work
   c. Design
   d. Efficient auditing
   e. Scalability
3. Why?

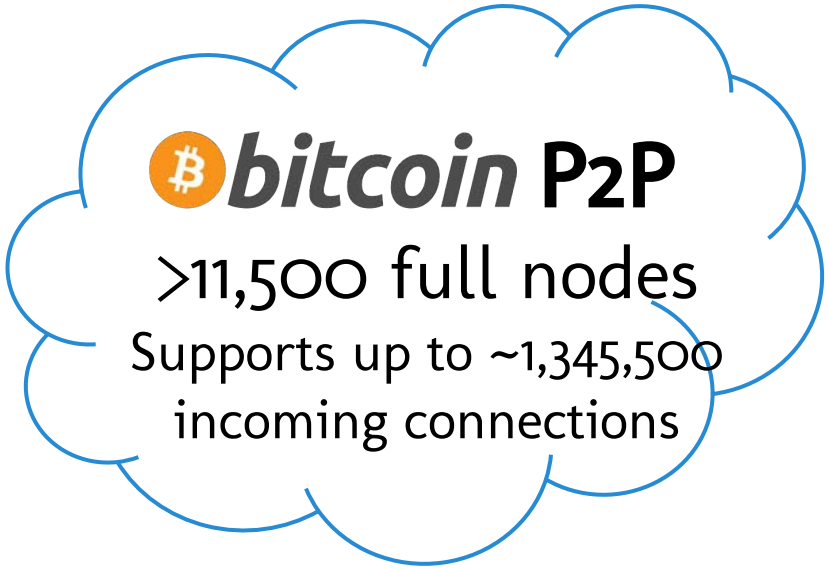
Catena scalability

Catena client 1

Catena client 2

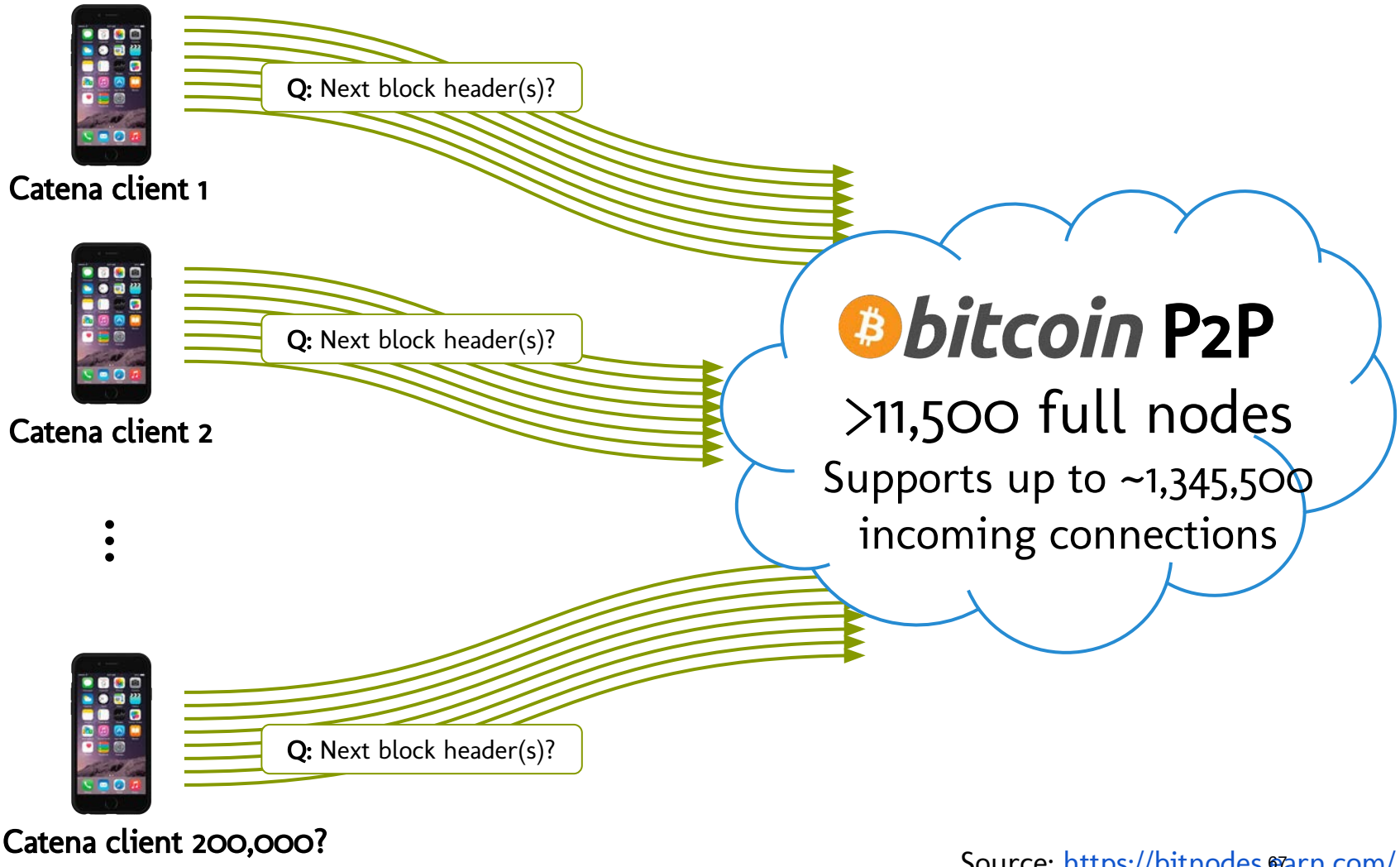
⋮

Catena client 200,000?



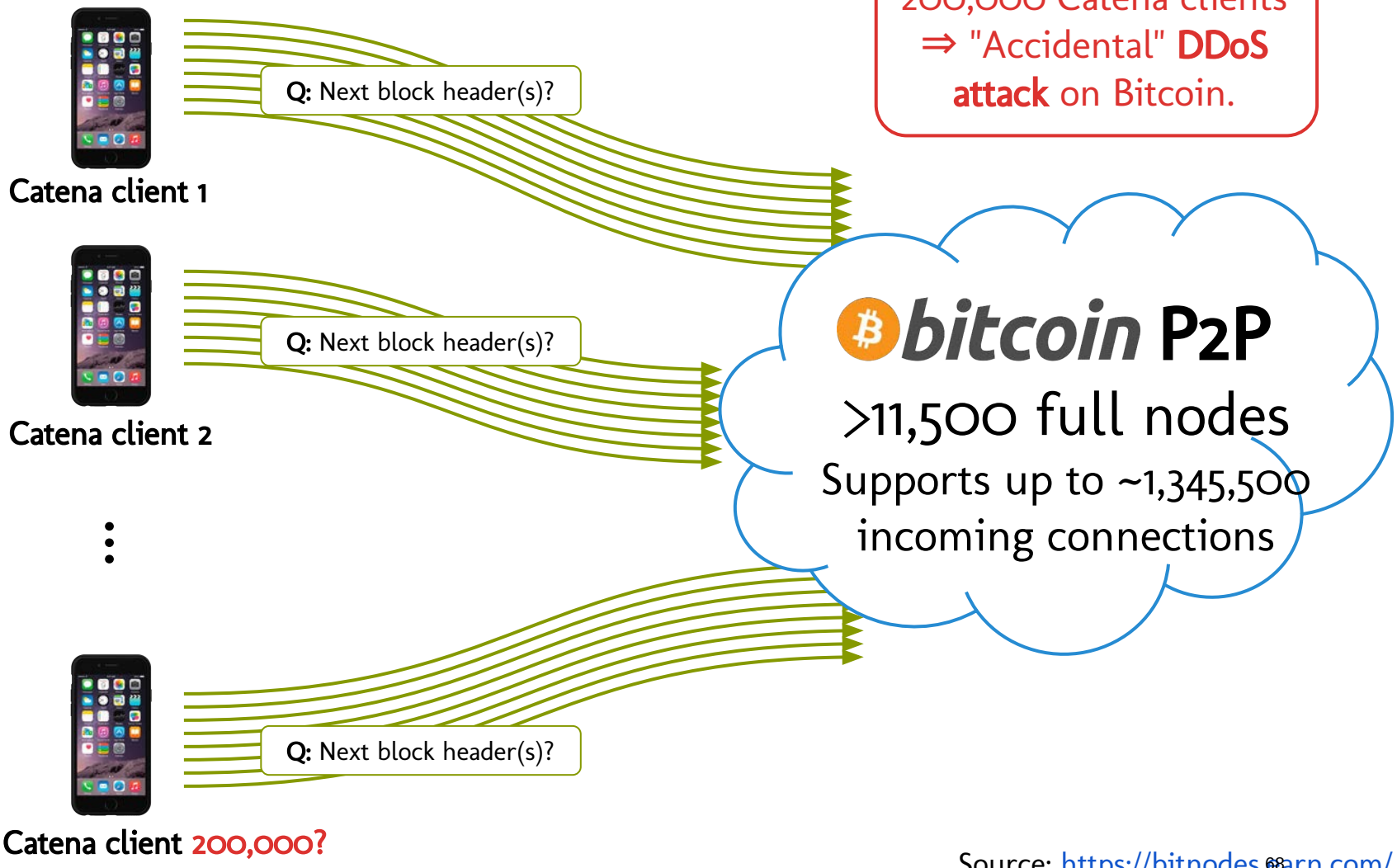
Source: https://bitnodes.earn.com/

Catena scalability



Source: https://bitnodes.earn.com/

Catena scalability



Source: https://bitnodes.earn.com/

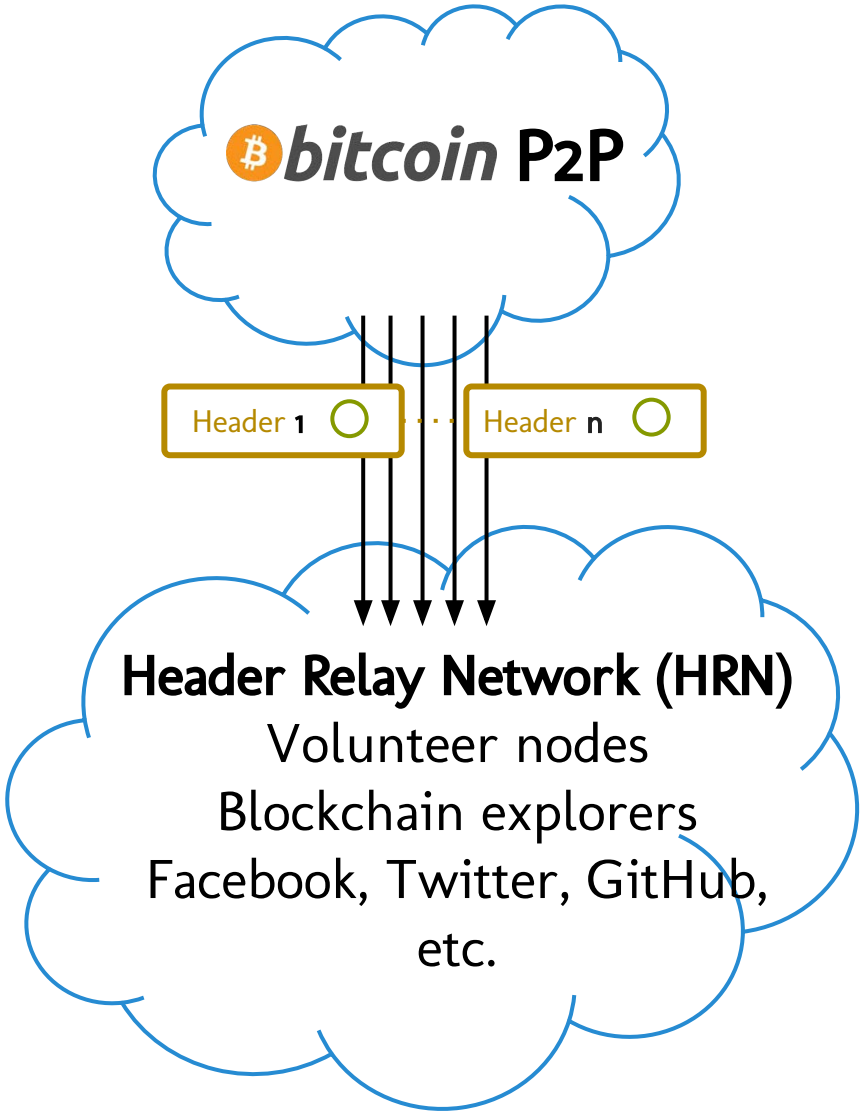
Catena scalability

Catena client 1

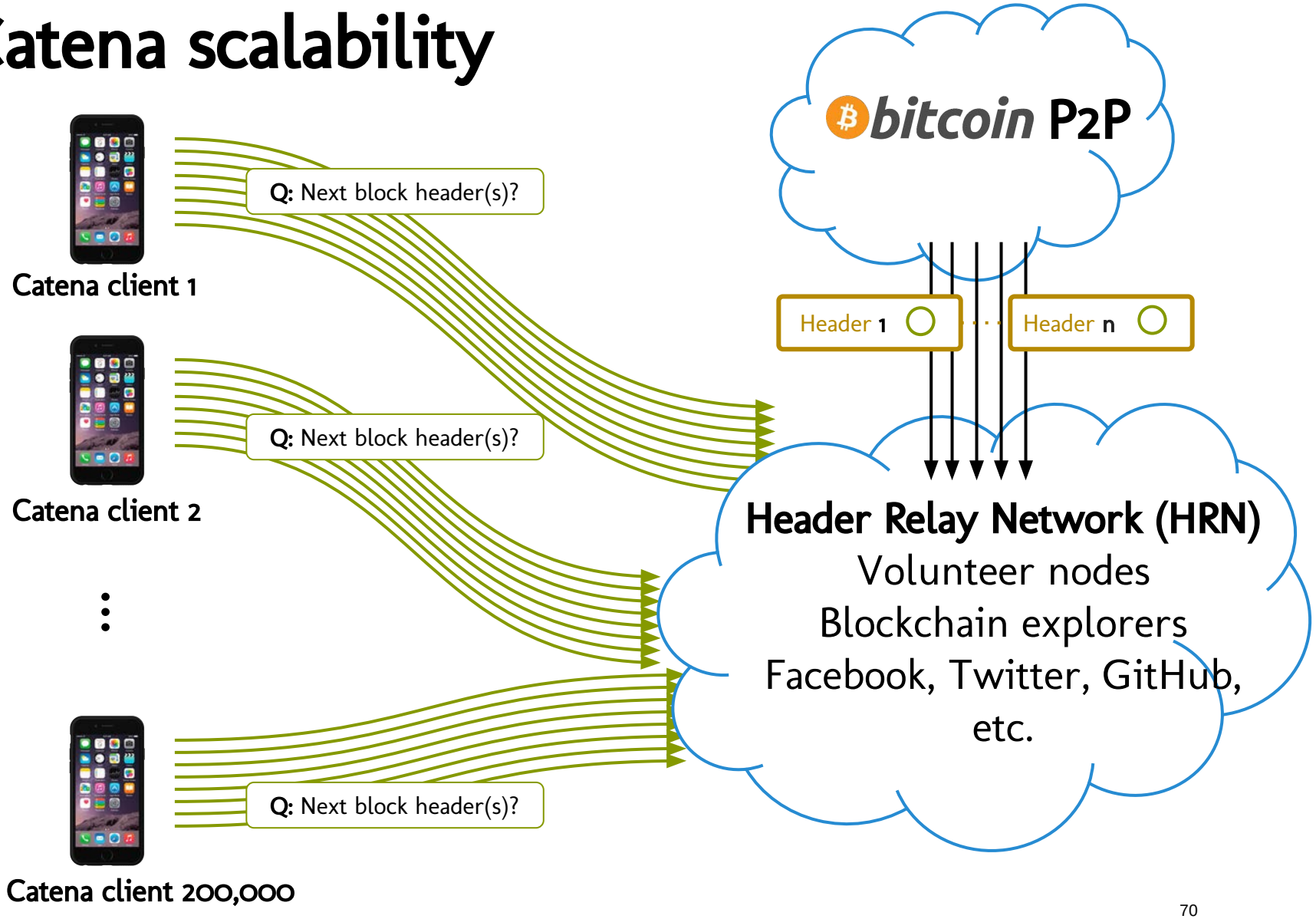
Catena client 2

⋮

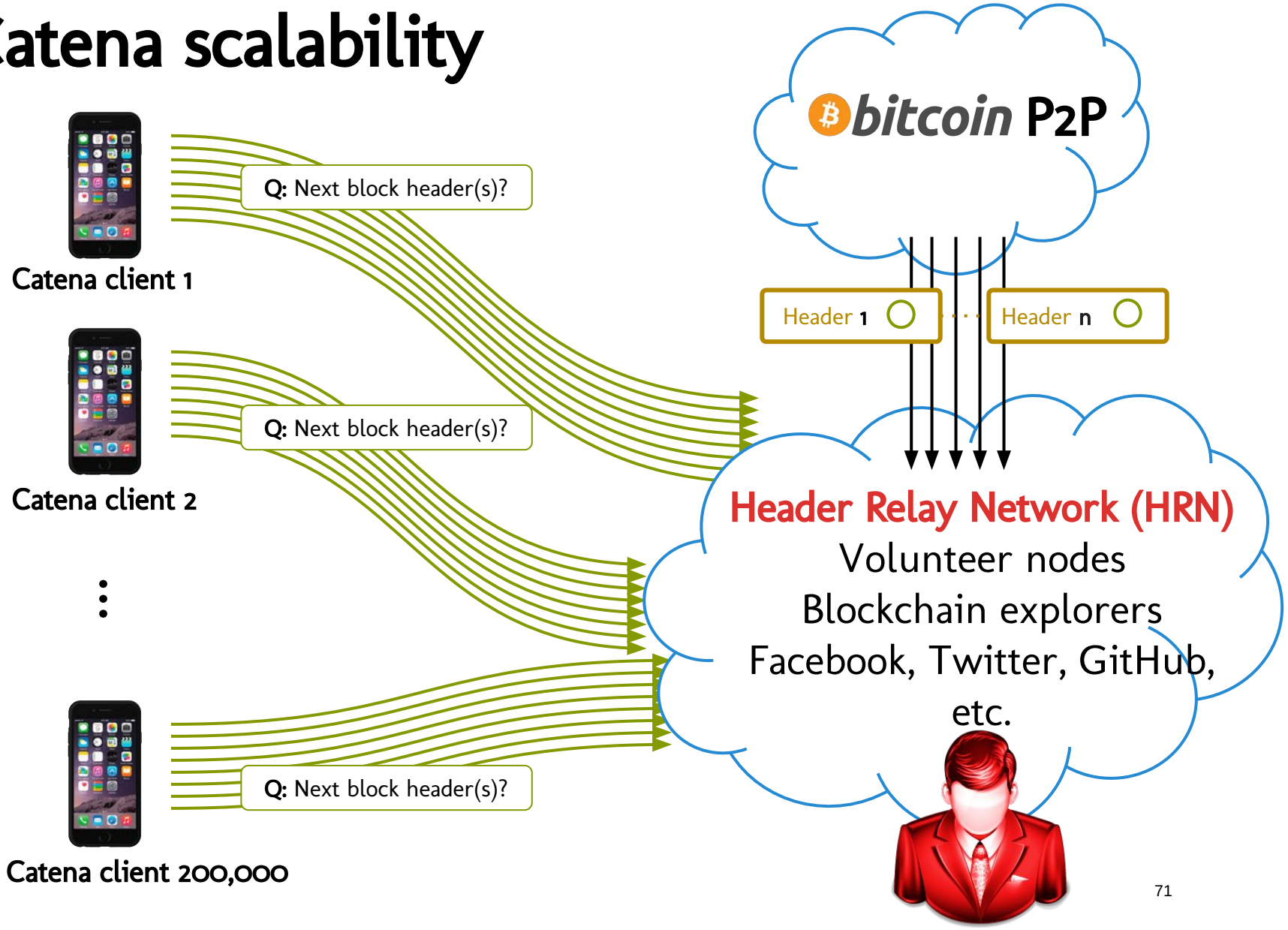
Catena client 200,000



Catena scalability



Catena scalability



The cost of a statement

To append a statement, must issue TXN and pay fee.

TXN size: 235-byte

Fee as of Dec 13th, 2017**:** $16.24 (10 mins)

Fee as of Feb 28th, 2017**:** $0.78 (10 mins)

PS: Statements can be "batched" using Merkle trees.

Latest fees: https://bitcoinfees.info/

Overview

1. What?
2. How?
3. Why?
    a. Secure software update

Secure software update

Example attack:

(1) Compromise bitcoin.org (or the network)

(2) Change the Bitcoin binary to your malicious binary

(3) Wait for people to install your malicious Bitcoin binary

(4) Steal their coins, steal their data, etc.

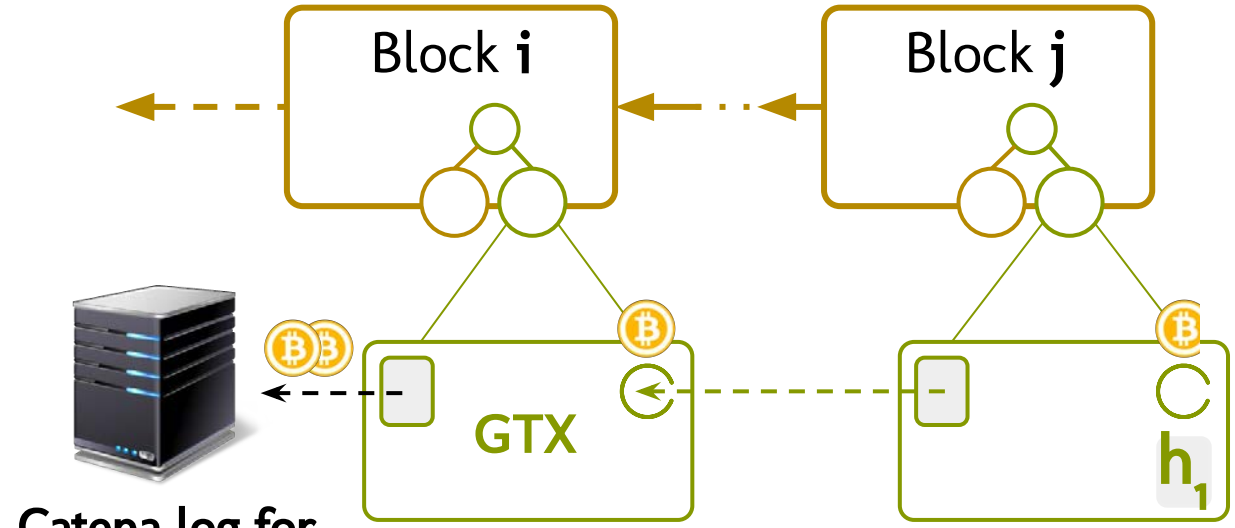
Example: bitcoin.org, "0.13.0 Binary Safety Warning," August 17th, 2016

Typical defense: Devs sign Bitcoin binaries with SK and protect SK.

Problem: (1) Not everyone checks sig. (2) Hard to detect stolen SK.

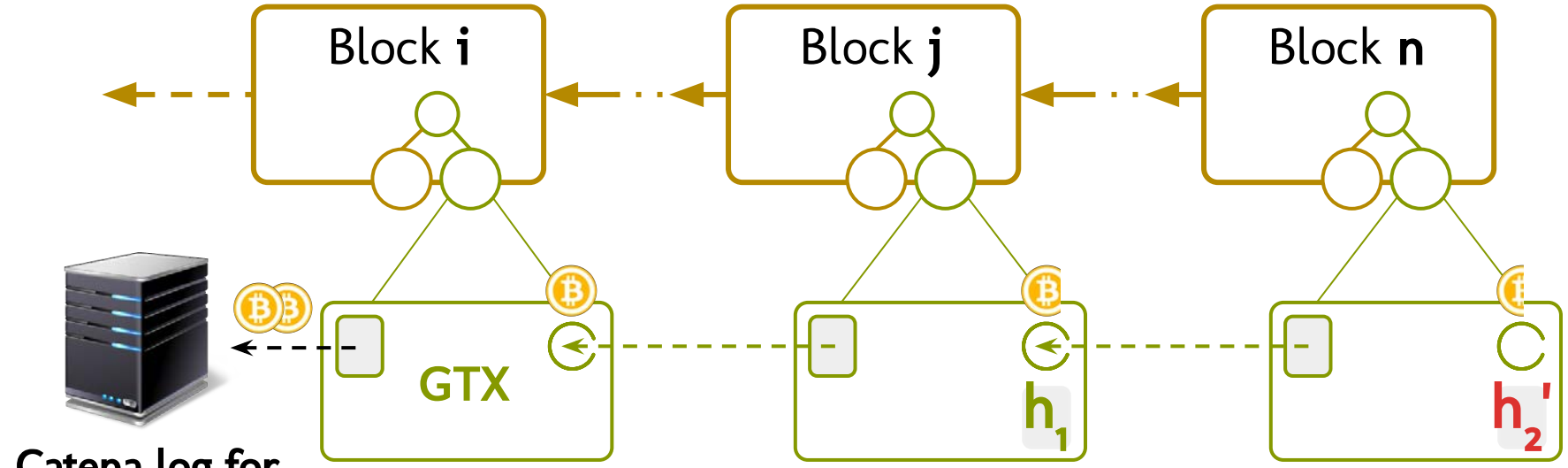
Solution: Publish signatures in a Catena log ⇒ **Can at least detect.**

Software transparency to the rescue



h_1 = SHA256(bitcoin-0.0.1.tar.gz)

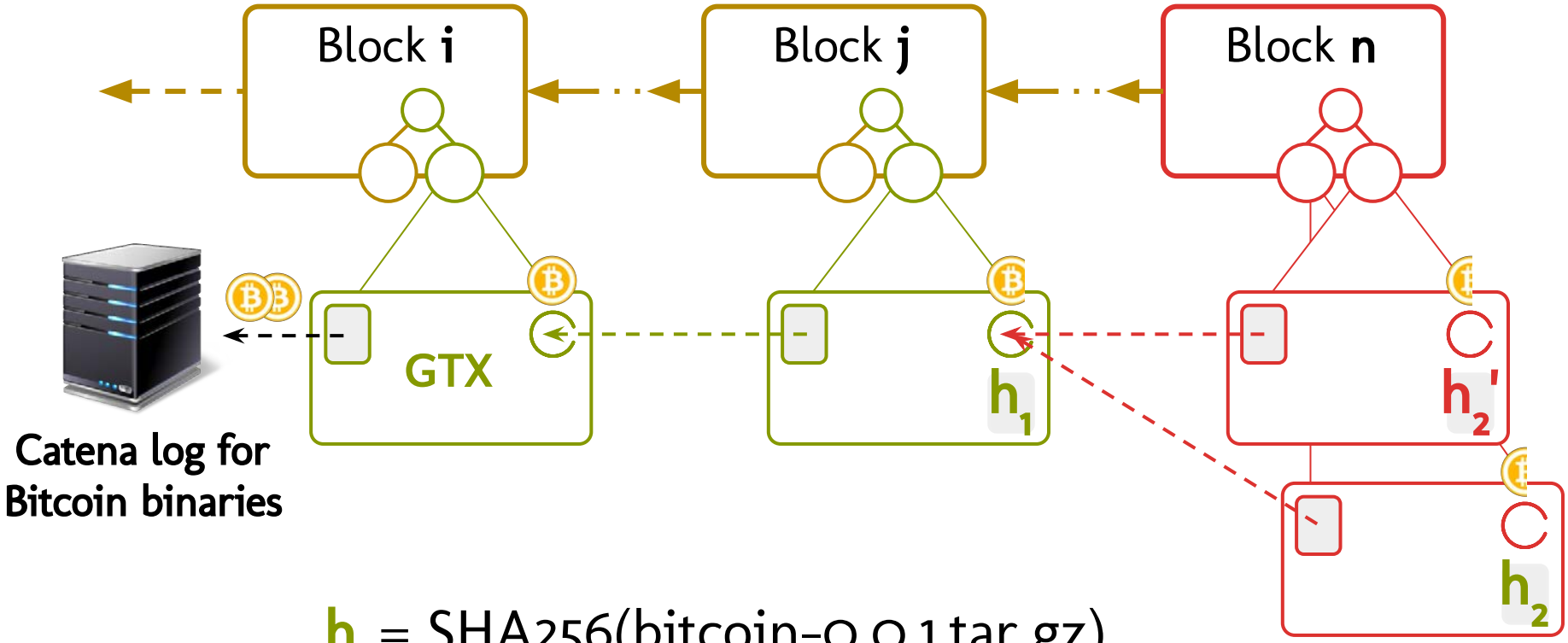
Software transparency to the rescue



h_1 = SHA256(bitcoin-0.0.1.tar.gz)

h_2' = SHA256(evilcoin-0.0.2.tar.gz)

Software transparency to the rescue

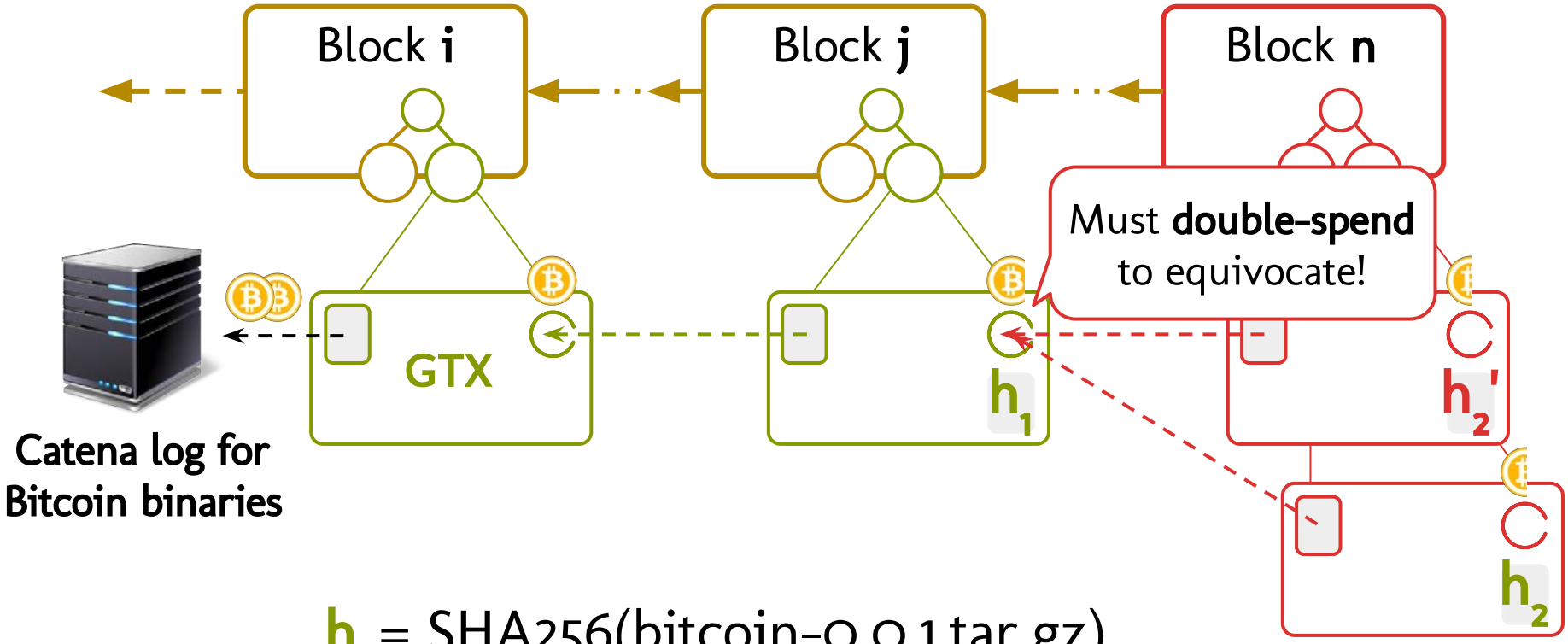


h_1 = SHA256(bitcoin-0.0.1.tar.gz)

h_2' = SHA256(evilcoin-0.0.2.tar.gz)

h_2 = SHA256(bitcoin-0.0.2.tar.gz)

Software transparency to the rescue



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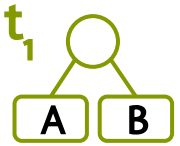
h_2' = SHA256(evilcoin-0.0.2.tar.gz)

h_2 = SHA256(bitcoin-0.0.2.tar.gz)

Overview

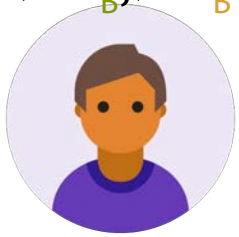
1. What?
2. How?
3. Why?
   a. Secure software update
   b. **Secure messaging**

Public-key distribution

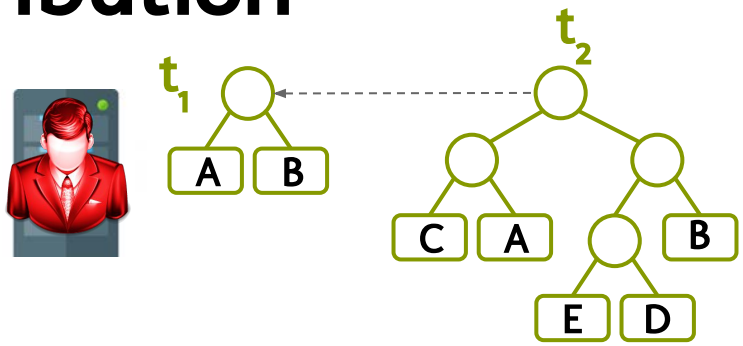


A = {*Alice*, PK_A}, SK_A

B = {*Bob*, PK_B}, SK_B



Public-key distribution



A = {*Alice*, PK_A}, SK_A

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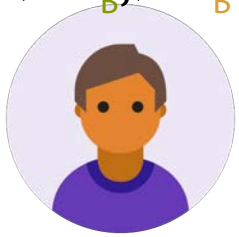
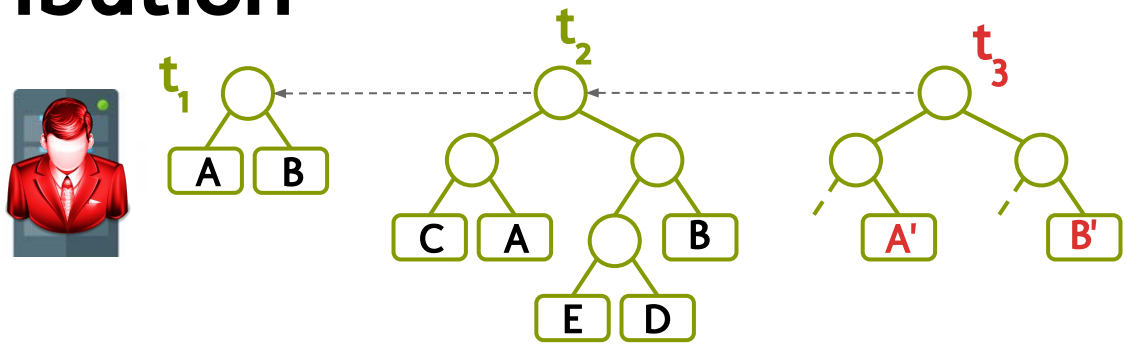


Public-key distribution

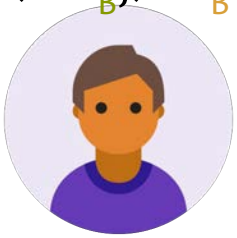


A = {*Alice*, PK_A}, SK_A

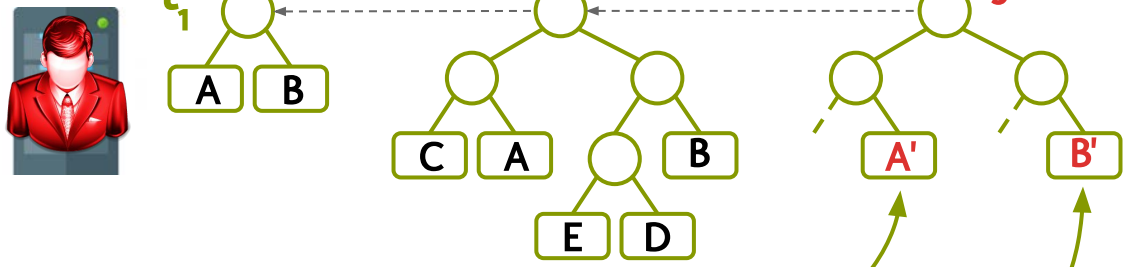
A' = {*Alice*, PK_M}, SK_M

B' = {*Bob*, PK_M}, SK_M

B = {*Bob*, PK_B}, SK_B



Public-key distribution



I've been impersonated!

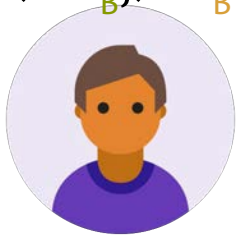
A = {*Alice*, PK_A}, SK_A

A' = {*Alice*, PK_M}, SK_M

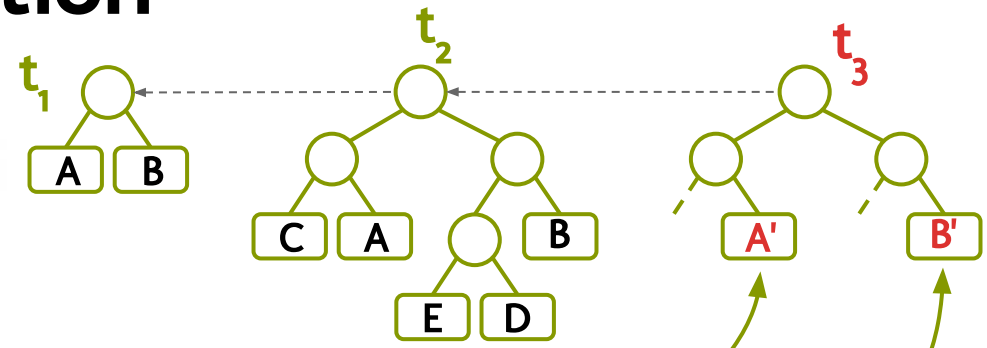
B' = {*Bob*, PK_M}, SK_M

I've been impersonated!

B = {*Bob*, PK_B}, SK_B



Public-key distribution



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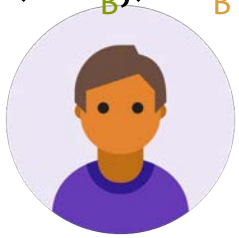
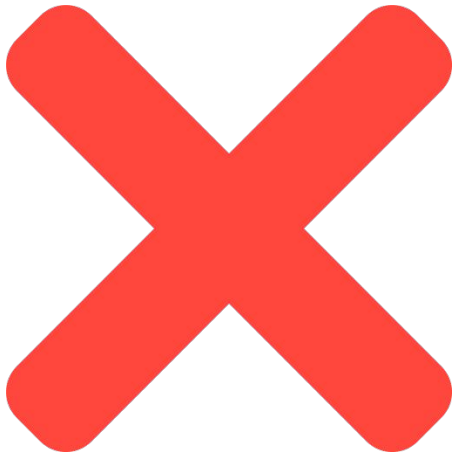
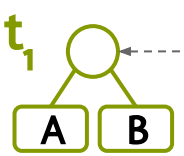
I've been impersonated!

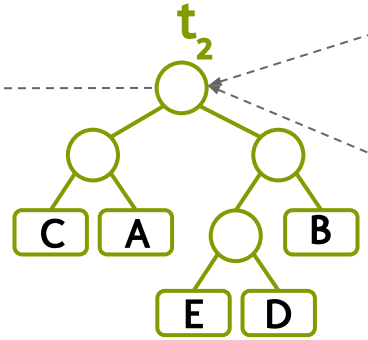
B = {*Bob*, PK_B}, SK_B

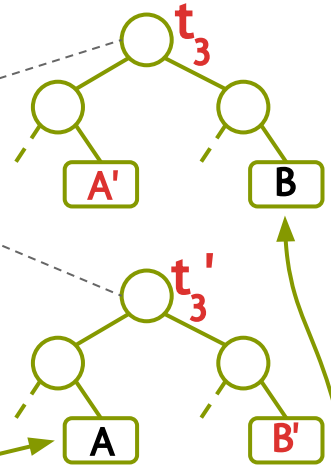


Public-key distribution









I'm **not** impersonated.

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I'm **not** impersonated.

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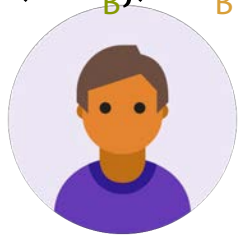
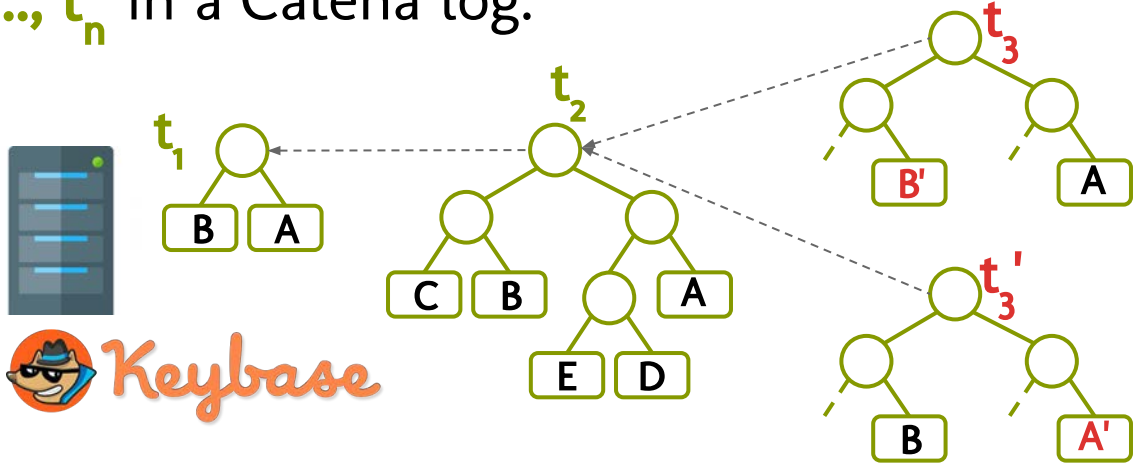
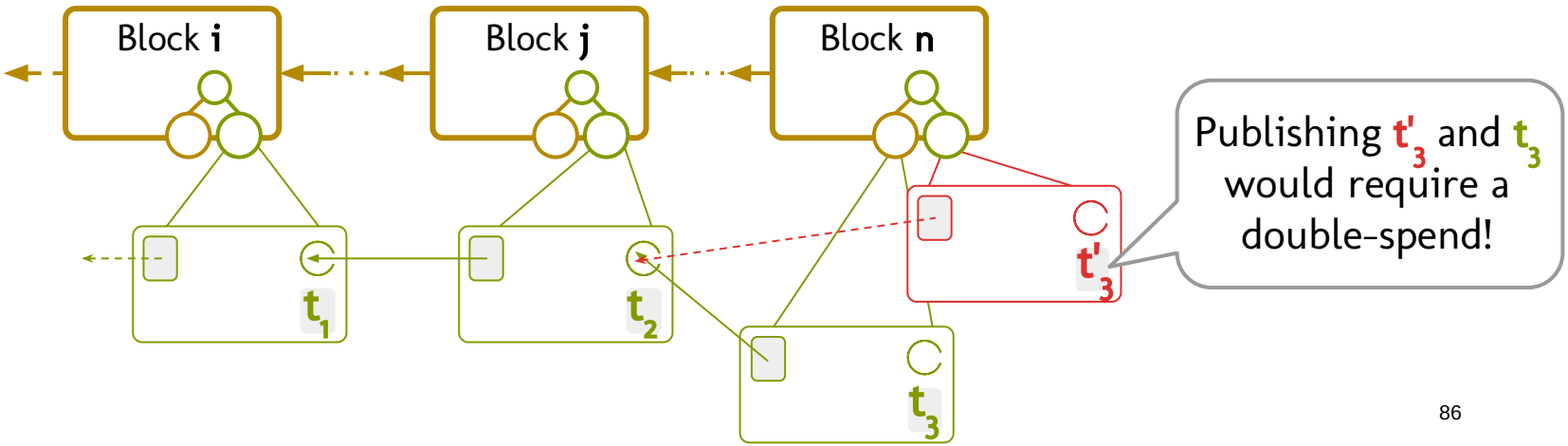


KeyChat

Idea: Store $t_1, t_2, \ldots, t_n$ in a Catena log.





Overview

1. What?
2. How?
3. Why?
    a. Secure software update
    b. Secure messaging
    c. "Blockchain" for X

I need a "blockchain" for ...

IoT? Self-driving cars? Digital identity? Issue diplomas? Health care? Voting?

"Blockchain" = Byzantine State Machine Replication (SMR) =

= Agree on log of ops + Execute ops = Agree on final state.

Permissioned "blockchain" via:

- Your favorite Byzantine SMR algorithm
- Ethereum Smart Contract (pay fees per Ethereum op)
- **Catena + 2f+1 replicas (pay fees per op batch)**

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- Your favorite Byzantine SMR algorithm
- Ethereum Smart Contract (pay fees per Ethereum op)
- **Catena + 2f+1 replicas (pay fees per op batch)**
- Don't need execution? Use Catena directly.

Permissionless "blockchain:" Roll your own. But proceed with caution?

Conclusions

What we did:

- Enabled applications to efficiently leverage Bitcoin's publicly-verifiable consensus
  - Download transactions selectively rather than full blockchain
  - ~46 MB instead of gigabytes of bandwidth

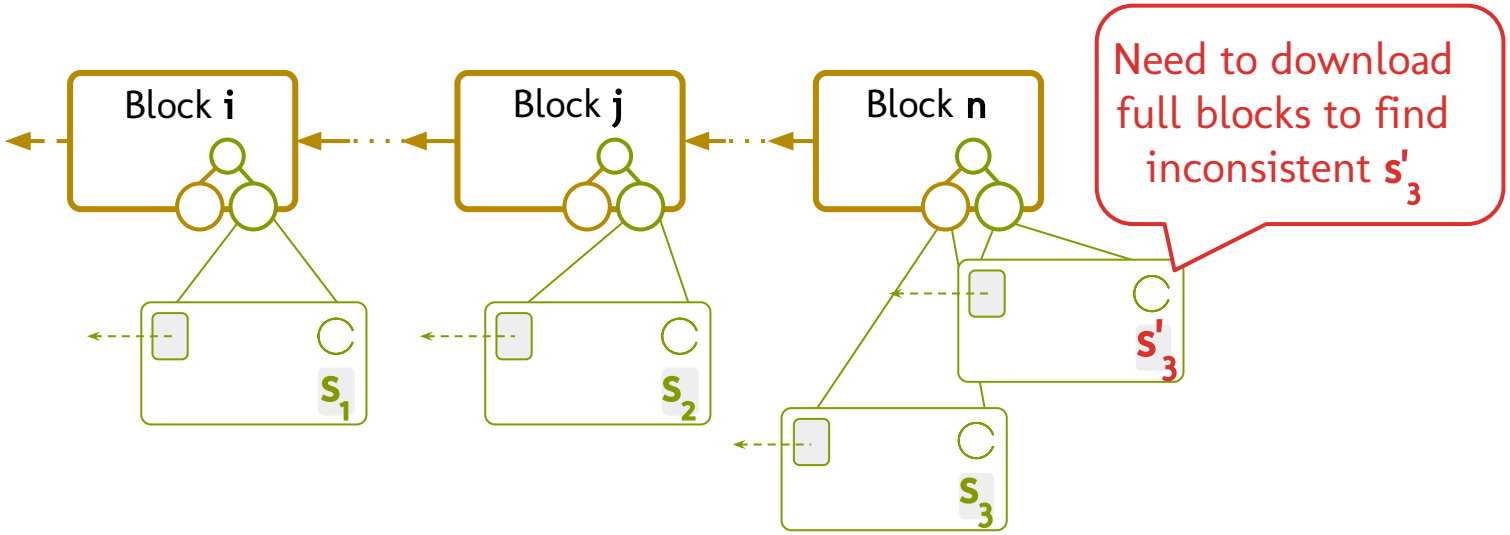
Why it matters:

- Secure software update schemes
- Public-key directories for HTTPS and secure messaging
- "Blockchain" for X

For more, read our paper!

Ask me questions! https://people.csail.mit.edu/alinush/

Previous work



Catena