Lecture 23: Blockchains

CS 181S

Spring 2024

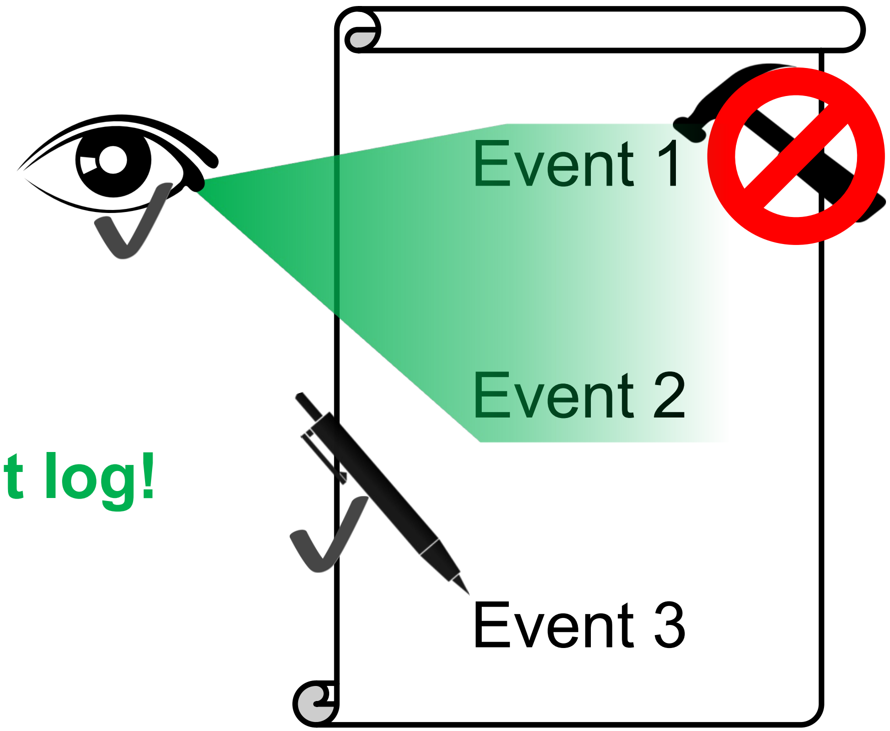
Blockchain: A public tamper-proof log

Publicly visible

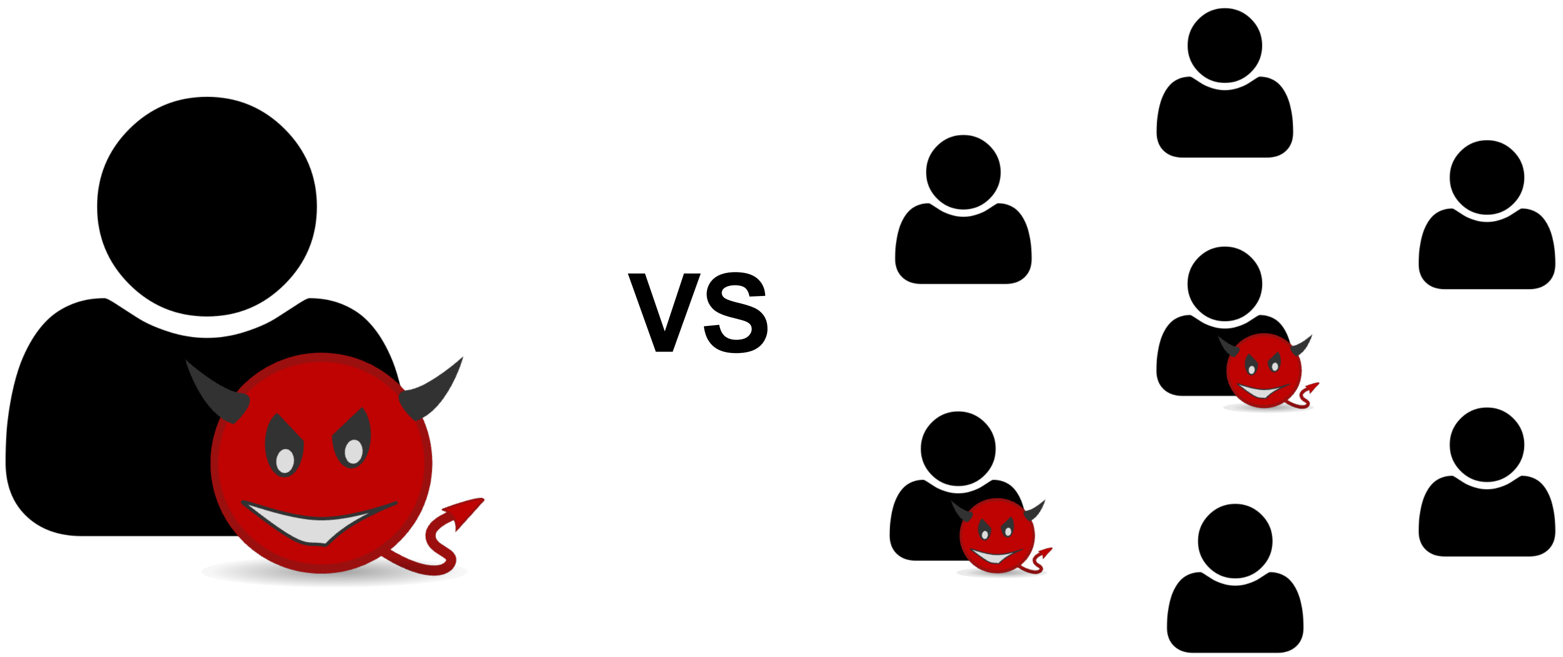
Publicly writable

Unmodifiable

Useful for an audit log!

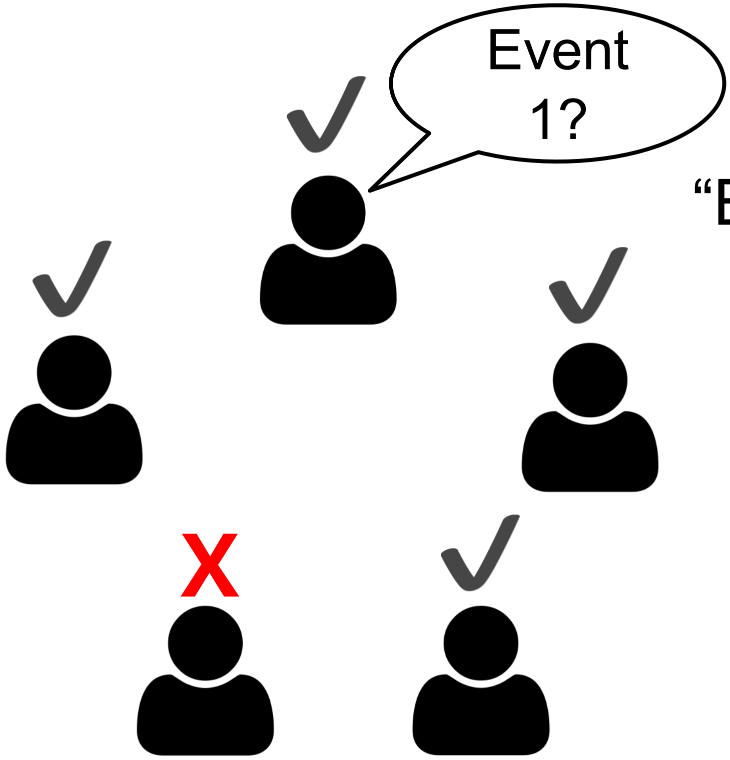


Preventing Tampering



Traditional Consensus

Members Vote



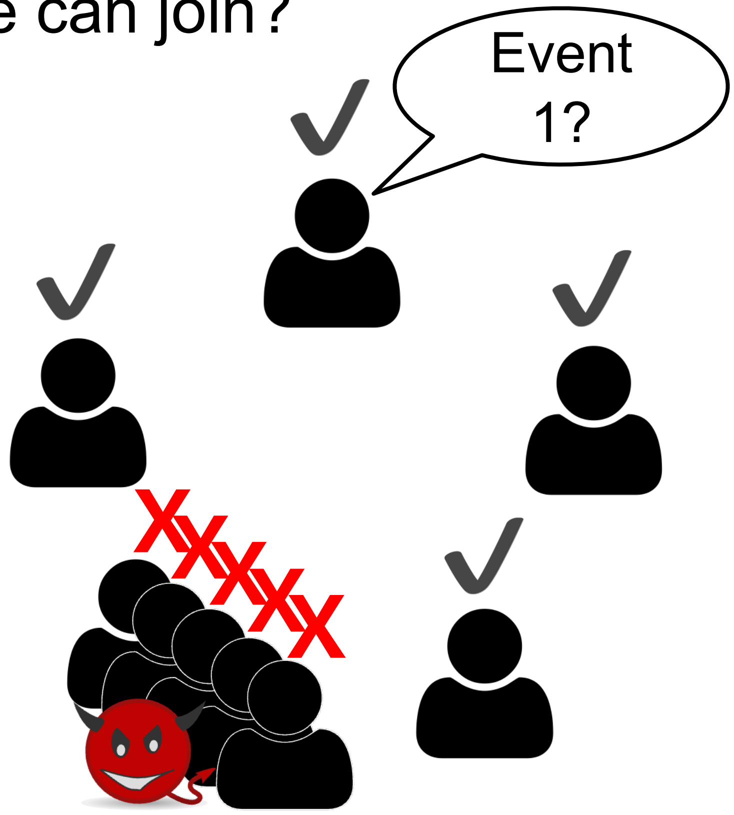
"Byzantine fault-tolerant (BFT) consensus"

Tolerates < 1/3 faulty

Must know who everyone is!

Sybil Attacks

What if anyone can join?



Defending against Sybil

Need a **scarce resource**

- BFT consensus uses identity – you only get one
- What else can we use?
  - Money (Proof of Stake)
  - Computational power (Proof of Work)

COMPUTATION AS A SCARCE RESOURCE: PROOF OF WORK

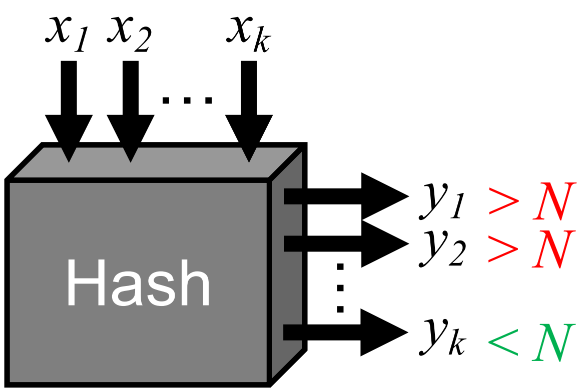
Proof of Work: The basics

Find x such that Hash$(x) < N$

- This could take a while…

What about replays?

- Add a nonce r
- Look for Hash$(r \| x) < N$



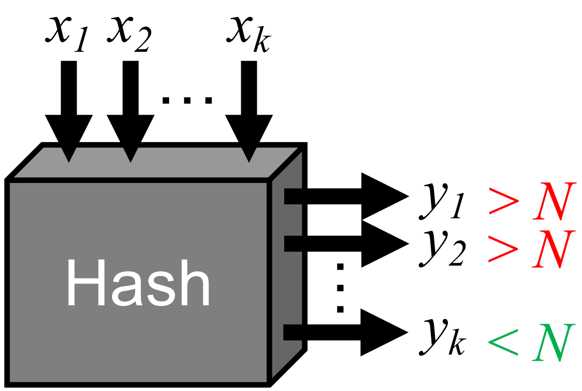
Proof of Work: Building a log

Make the nonce useful

Use a message digest!

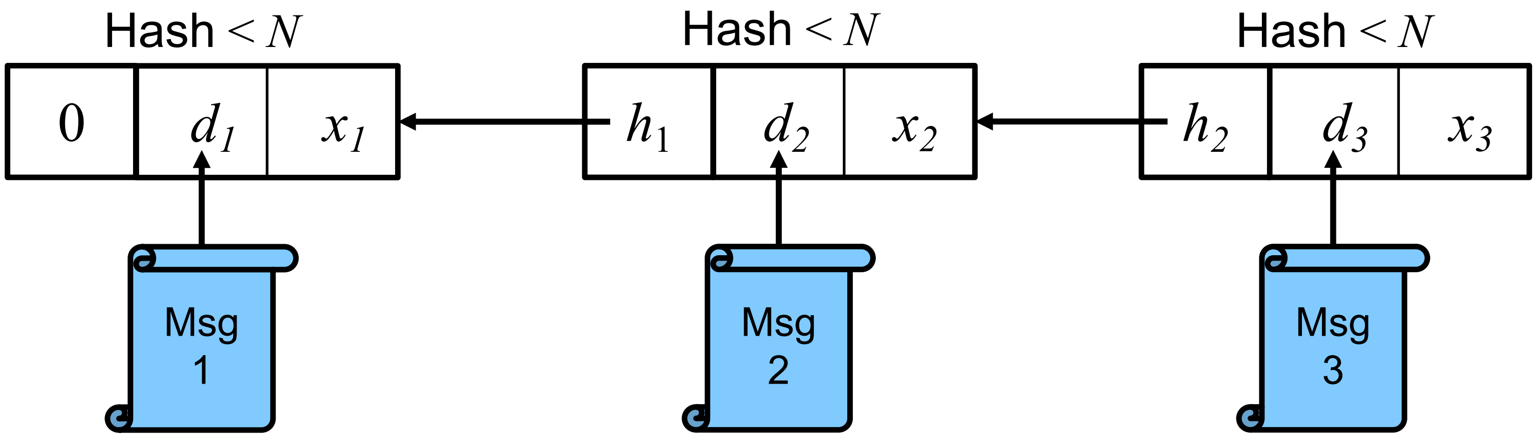
$d = \text{Digest}(m)$

Find x such that $\text{Hash}(d \,\|\, x) < N$



Proof of Work: Building a log

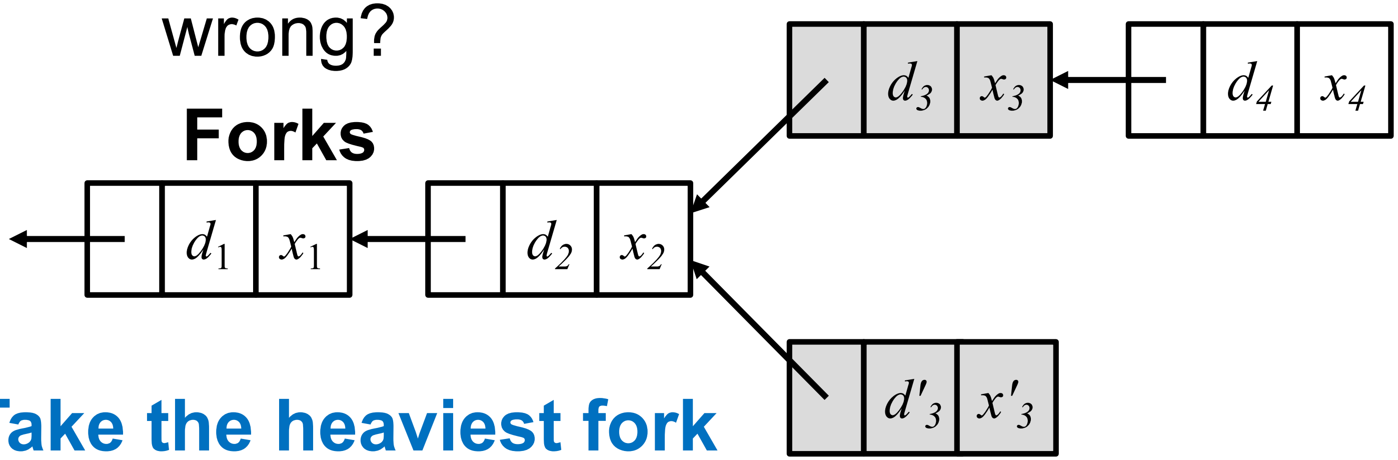
1. To add a message, generate a proof of work with that message
2. Connect each message to previous



Proof of Work: Coming to consensus

What can go wrong?

Forks



Take the heaviest fork (one with the most work)

Nakamoto Consensus

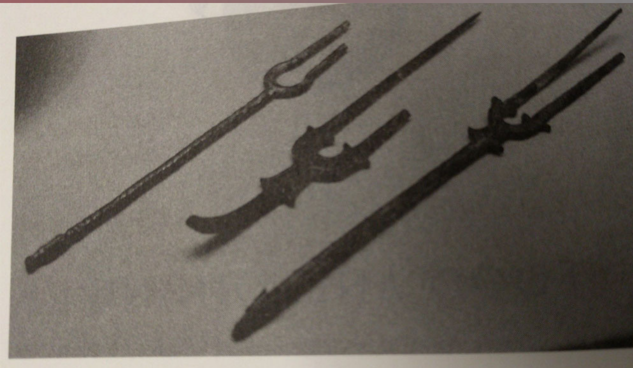


Fig. 4.1 Byzantine forks.

- If majority of computation is honest, honest parties will agree (eventually)
- Log is tamper-proof
  - It would require redoing all of the work to tamper

Blockchains for Audit

- **Individual accountability**
  - Everything is visible. Everyone is accountable.
- **Event reconstruction**
  - All of the events are there. Easy to reconstruct.
- **Real-time intelligence**
  - Miners can verify everything ~~as~~ it goes on the log.
    before!

Not just a log!

Authoritative record

- Instead of logging events elsewhere, the blockchain can record the definition of events (e.g. transactions)
- Online validation can prevent illegal events from ever happening!

What restrictions make sense?

Transaction Processing System

- Each block has a limited number of transactions (1 MB)
- Transactions cannot create money
  - Except coinbase transaction to reward miner
- Coins can only be spent once (spending creates new unspent coins)
- To spend a coin conditions must be met (e.g., owner authorizes)

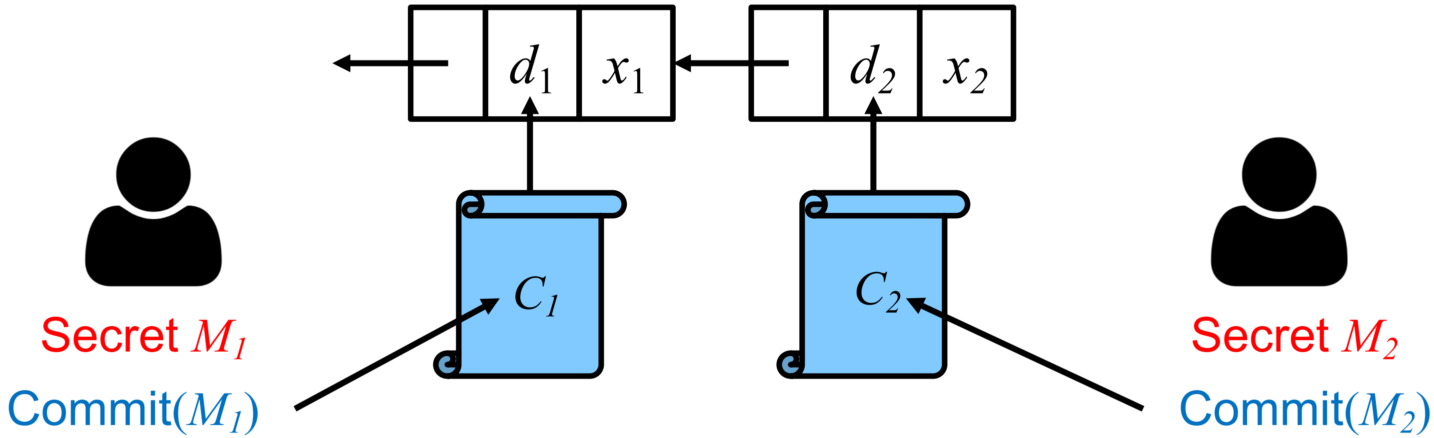
Bitcoin

BLOCKCHAINS AND CONFIDENTIALITY

What do we do with private data?

Cannot put it on the blockchain – everything is public

Only publish commitments



Commitment Schemes

- A commitment scheme Com is a two-phase, two-party protocol such that:
  - Secrecy: receiver does not learn anything about x from Com(x)
  - Binding: sender cannot produce alternative x' such that Com(x) = x'

- Example Protocol
  1. B->A: r
  2. A: choose random bit b. If b=0, Com(x) = Hash(x) else Com(x) = Hash(x) xor r
  3. A->B: Com(x)

     …

  1. A->B: x

What do we do with private data?

Cannot put it on the blockchain – everything is public

Only publish commitments

- Still tamper-proof ✓
- No longer able to see actions
  - Cannot reconstruct events X
  - Cannot perform online validation X ☹

Doing better with private data

Verify data validity without leaking secrets

Ongoing research with two main tools

1. Heavy-duty cryptographic constructs
   - Complex zero-knowledge proofs
2. Trusted hardware
   - Places trust in hardware instead of crypto or a large group

Zero-Knowledge Proof

- A zero-knowledge proof is a protocol that satisfies:
  1. **Completeness**: if the statement is true, a verifier will be convinced of this fact.
  2. **Soundness**: if the statement is false, no cheating prover can convince an honest verifier that it is true (except with some small probability).
  3. **Zero-knowledge**: if the statement is true, no verifier learns anything other than the fact that the statement is true.

Cryptographic Example

ZKP gives strong publicly verifiable integrity guarantees

- Sender authorized transaction
- Sender had money to send
- Transaction value was not negative
- Transaction was processed correctly

Can (provably) furnish transaction details to external auditor

Trusted Hardware

Special machine instructions

Isolate process from the surrounding system

Can remotely attest that they're running specific code

Uses (literally) hard-wired keys in the CPU

Trustworthy code can operate on secret data and attest to correctness

Examples:

- Intel Software Guard eXtensions (SGX)
- ARM TrustZone