Blockchains and large-scale distributed systems

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La grande aventure commence
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Chronology

1982 Byzantine Generals

1990 Paxos

1992 “ProofOfWork”

1999 PBFT

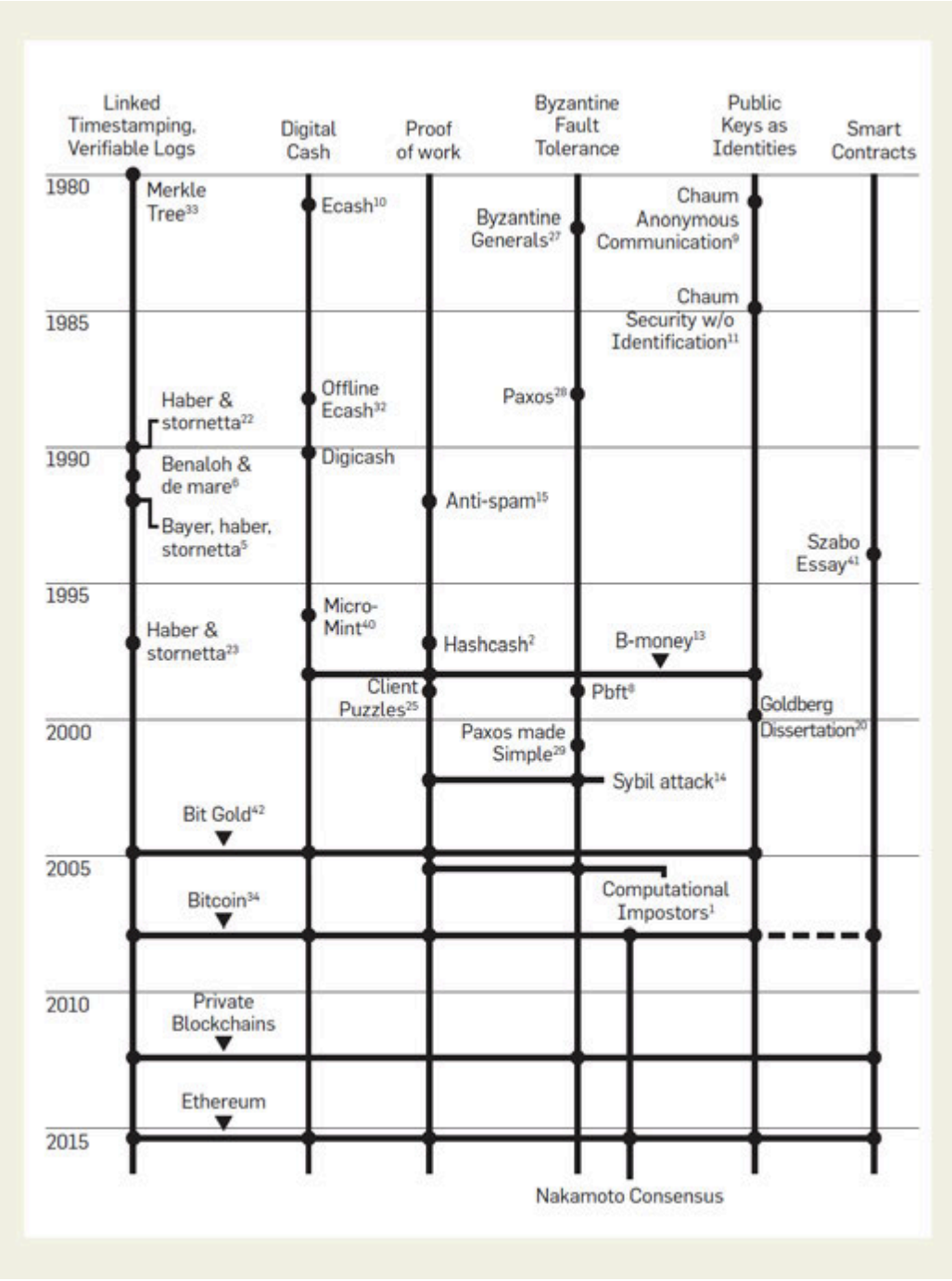
1995 Hashcash

2002 Sybil attack

2009 Bitcoin

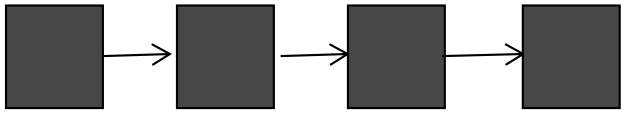
…

[Narayanan, CACM, Dec 2017]



Distributed ledger

Shared data structure: linear record of (blocks of) transactions



- Append-only
- Backtrack verifiable
- Consistent: total order

Open environment:

- No static membership
- No identities (public keys)

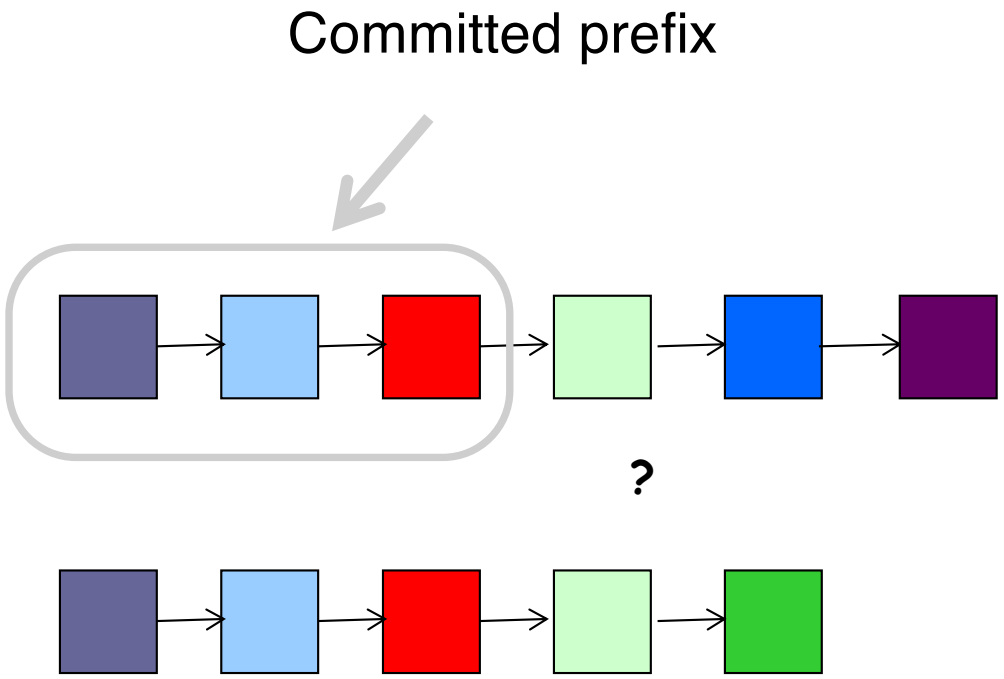
Sybil-resistant consistency?

- Sybil attack: the adversary can own an arbitrarily large fraction of participants
  - ✓ Why don't good guys do the same? ☺
- Classical (BFT) protocols don't work
  - ✓Bounds on faulty fraction (e.g., <1/3)

- Bitcoin:
  - ✓ Assume a synchronous system
  - ✓ Message delays are bounded by δ
  - ✓ Need to "slow down" updates (wrt δ)
  - ✓ Solve a puzzle before updating (PoW)

(Bitcoin) blockchain

- Clients broadcast an update
- Dedicated clients (miners) collect updates solve puzzles, update and broadcast their local ledgers
- Clients always choose the longest (verifiable) ledger
- Old enough blocks are considered consistent



When it works

- Expected time to solve the puzzle >> δ
- The adversary does not possess most of computing power

The probability of a fork drops exponentially with the staleness of blocks

When it does not work

- Asynchronous/eventually synchronous communication
- An adversary controls half of computing resources
- Even a small probability of error cannot be tolerated
- Energy consumption and throughput is an issue

When it is not needed

- No Sybil attacks
  - ✓ Participation under control

- No need for total order
  - ✓ Some form of causality is enough?

Bitcoin: A Peer-to-Peer Electronic Cash System

Satoshi Nakamoto
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www.bitcoin.org

Abstract. A purely peer-to-peer version of electronic cash would allow online payments to be sent directly from one party to another without going through a financial institution. Digital signatures provide part of the solution, but the main benefits are lost if a trusted third party is still required to prevent double-spending. We propose a solution to the double-spending problem using a peer-to-peer network.

...

The only way to confirm the absence of a transaction is to be aware of all transactions. In the mint based model, the mint was aware of all transactions and decided which arrived first. To accomplish this without a trusted party, transactions must be publicly announced [1], and we need a system for participants to agree on a single history of the order in which they were received.


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Cryptocurrency without consensus

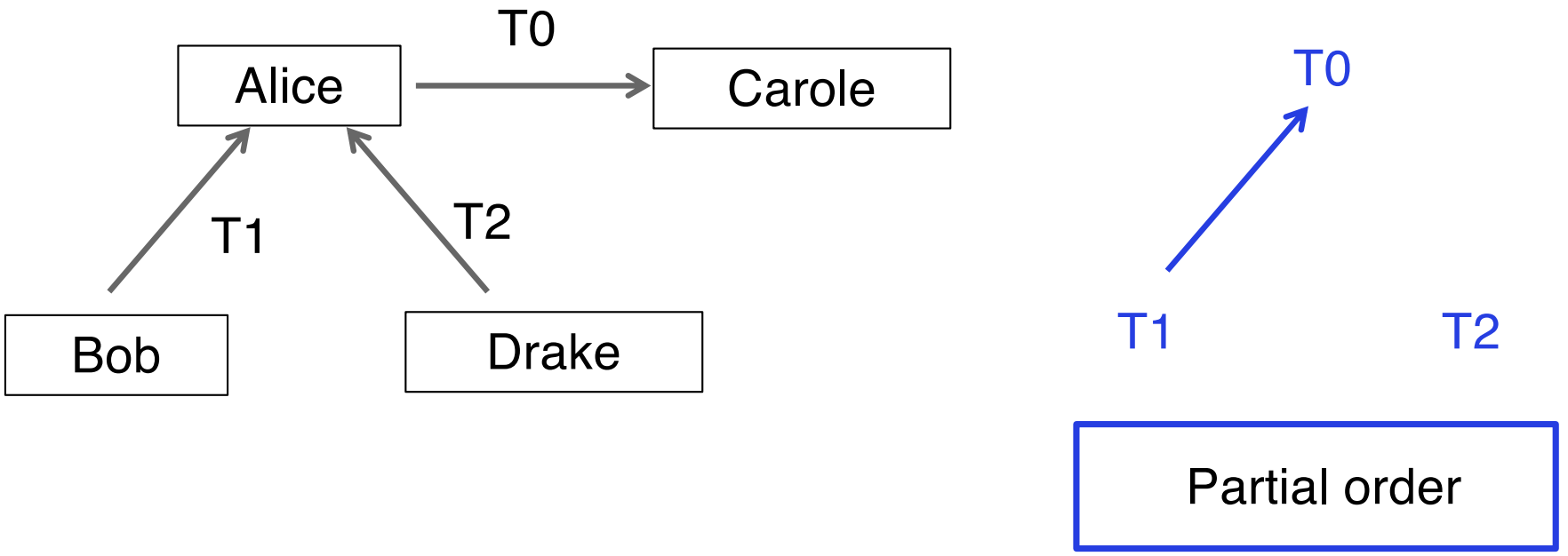
[Guerraoui et al., PODC'19]

- Consensus number of the asset transfer data type:
  - ✓k-owned (smart contracts with k parties) – k
- Asynchronous asset transfer algorithm
  - ✓1-owned: secure broadcast
  - ✓k-owned: k-consensus + secure broadcast
- No need of total order on transactions

Commutativity and causality

- T0: $100 from Alice to Carole
- T1: $100 from Bob to Alice
- T2: $100 from Drake to Alice

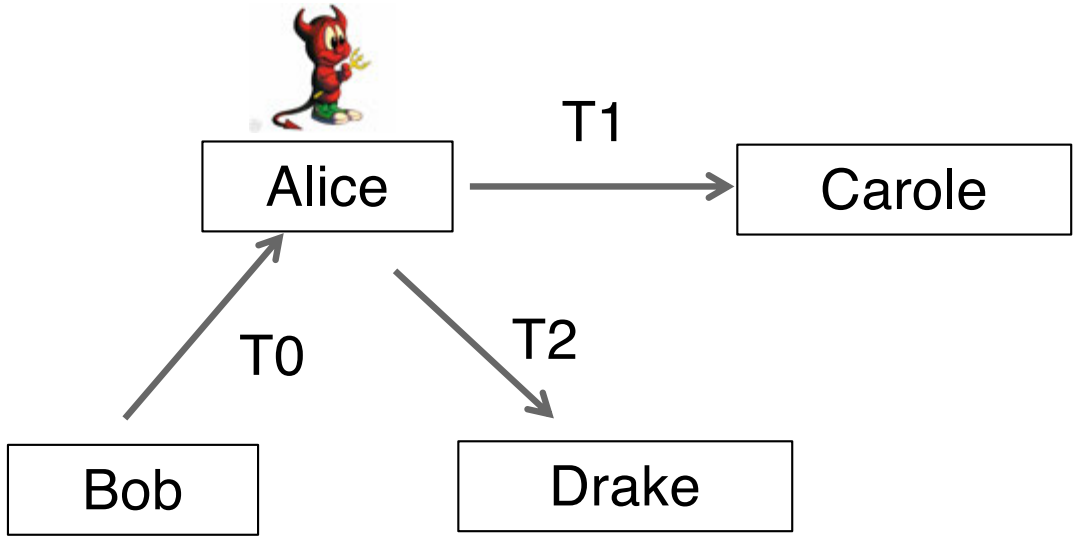
T0 causally depends on T1 (not enough funds otherwise)
T1 and T2 commute (T0 succeeds regardless of the order)

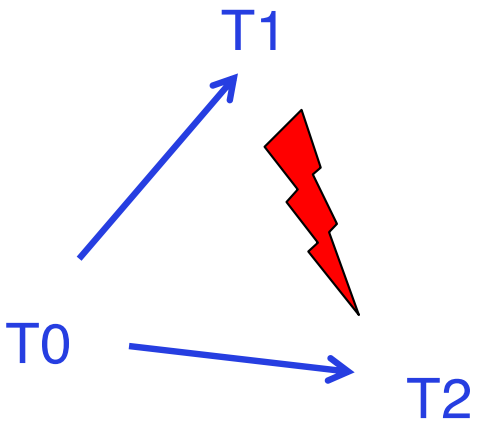


What about double-pending?

- T0: $100 from Bob to Alice
- T1: $100 from Alice to Carole
- T2: $100 from Alice to Drake

Alice's initial balance is 0, but it claims to both beneficiaries to have received money from Bob



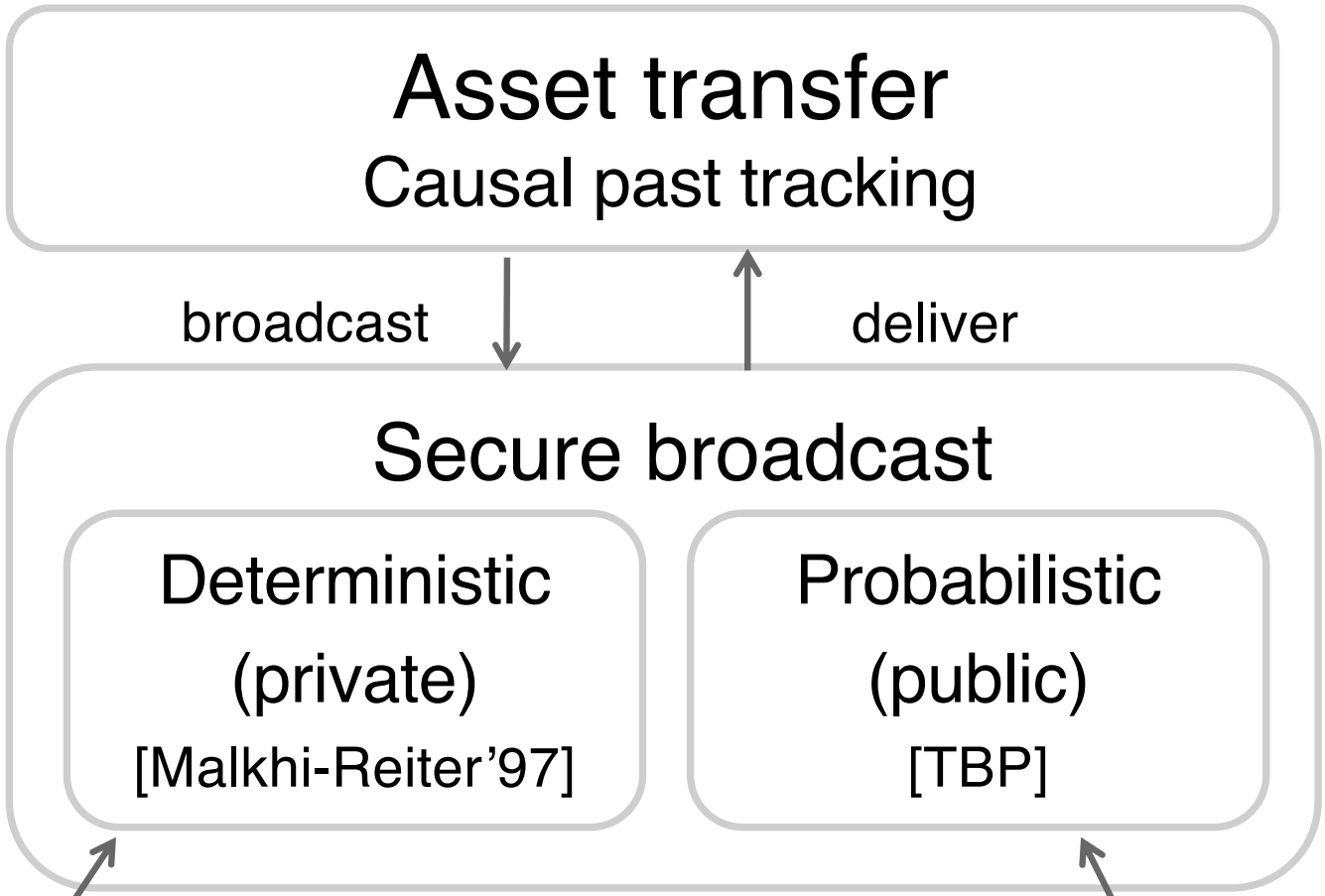


Asset transfer implementation

Message-passing, Byzantine failures

- Each transfer is equipped with its causal past (a set of incoming transactions)
- Make sure that a faulty account holder cannot lie about its causal past
- Secure broadcast [Bracha, 1987, Malkhi-Reiter, 1997]
  - ✓Source-order: messages by the same source are delivered in the same order

Modular approach: private and public



Intuition: deliver only if accepted by a Byzantine quorum (of 2f+1)

Intuition: deliver only if enough sample members are "ready"

Cryptocurrency without consensus

- Asset transfers do not always require total order
  - ✓Source order is sufficient for consistency
  - ✓(Asynchronous) secure broadcast
- Can be generalized to (limited-scope) ”smart contracts”
  - ✓only account owners need consensus, but still no global total order
- Coming: probabilistic and Sybil-tolerant secure broadcast can be implemented (coming)
  - ✓Permissionless asset transfer

Other algorithmic challenges

- Maintaining the system evolution
  - ✓Decentralized updates [Tezos]
  - ✓Local views, federated quorums [Stellar]
  - ✓Asynchronous reconfigurations [Dynastore]
- Concurrency in smart contracts
  - ✓Sequential programs run in a concurrent environment
- Blockchain ecosystems
  - ✓Cross-chain transactions
  - ✓Fair exchange/atomic commitment

Take-aways

- Blockchains do solve a new problem
  - ✓Maintaining a total order in an open system
  - ✓With a brute-force approach
  - ✓Scalability is a challenge
- The primary application of blockchains do not need blockchains
  - ✓A weaker abstraction may suffice
- Do not go for a technology
  - ✓Go for a problem

Thank you!