Lecture #20: Permissionless Consensus and Proof-of-Work

COMS 4995-001: The Science of Blockchains

URL: https://timroughgarden.org/s25/

Tim Roughgarden

Goals for Lecture #20

1. Introduction to permissionless consensus protocols.
   - will relax the assumption of a fixed and known validator set
2. Sybil attacks.
   - permissionless ➔ one participant can masquerade as many
3. Proof-of-work (PoW).
   - sybil-resistant method of selecting a random validator as leader
   - winner = first validator to partially invert a cryptographic hash function
4. Combining PoW with longest-chain (👍) or Tendermint (👎).

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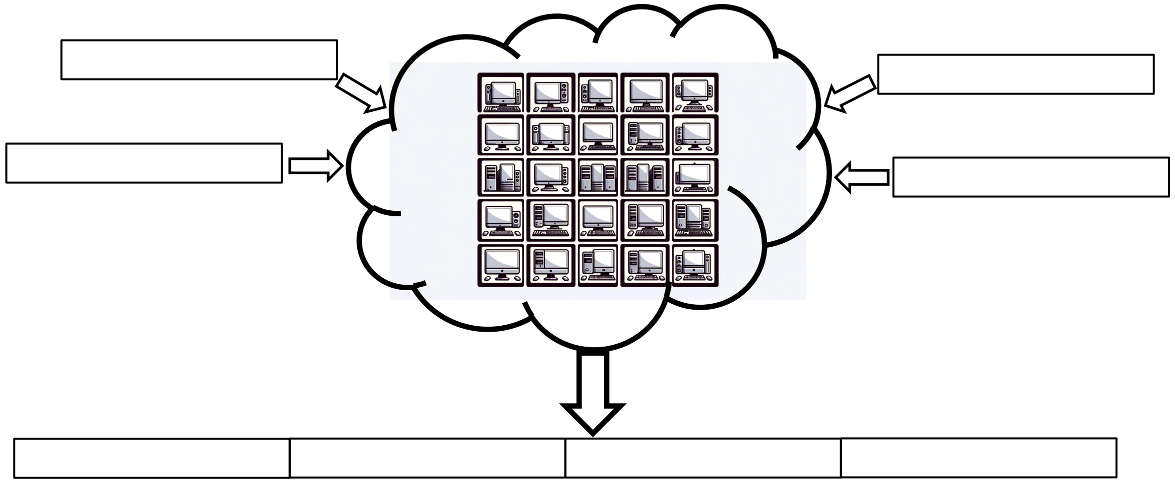
- want protocol that guarantees consistency and liveness
  - no disagreements across validators or time, all txs eventually included



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Standing assumption in Parts I + II: fixed and known set of n validators, each with known name, public key, and IP address.

- a.k.a. “permissioned” or “proof-of-authority” protocols

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- issue for Tendermint: how many votes constitute a quorum? (n unknown)
- issue for Tendermint and longest-chain: how to choose the leader of a view? (unknown validator set ➔ what does “round-robin order” mean?)

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- need sybil-proof random sampling method
  - probability of selection independent of number of pks used in protocol

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- NB: PoW/PoS are sybil-resistance mechanisms, not consensus protocols

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– probability of selection proportional to hashrate (sybil-resistant!)

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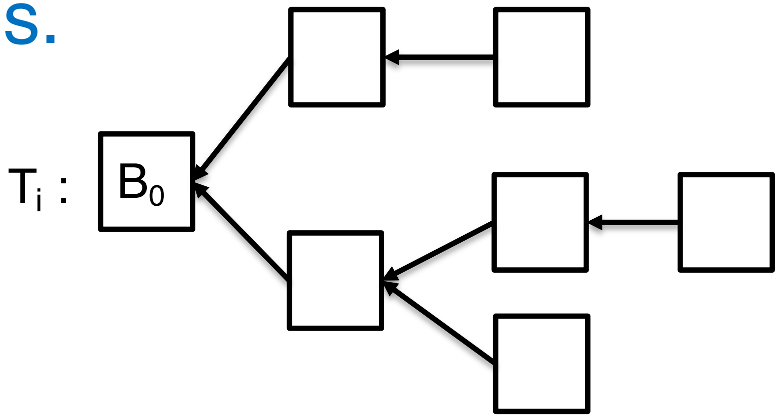

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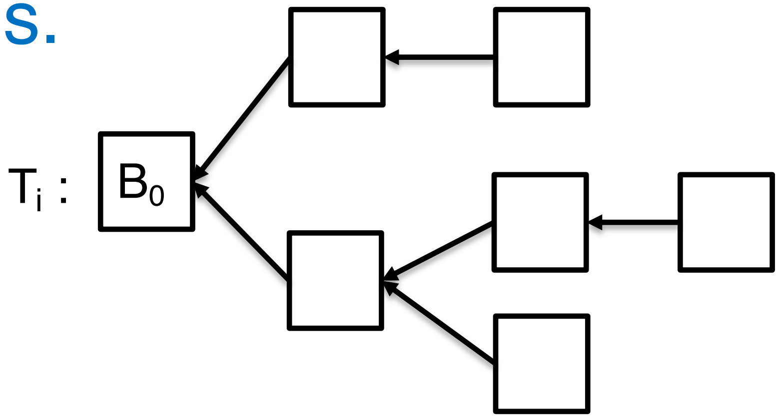
- B_0 = "genesis block"
- define view = Δ timesteps
- validators take turns as leader
- validator i maintains in-tree T_i of valid blocks, rooted at B_0
  - block B is valid in view v if:
    - annotated with a view v' $\leq$ v
    - signed by leader of view v'
    - annotated with (hash of header of) predecessor block B'' from a view v'' < v'
    - contains only valid txs



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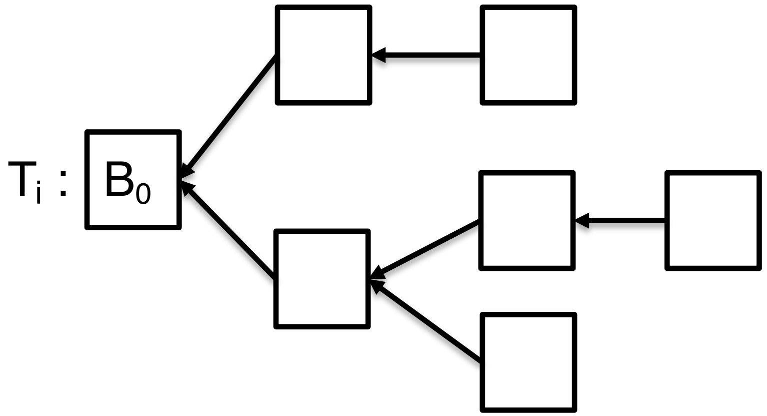

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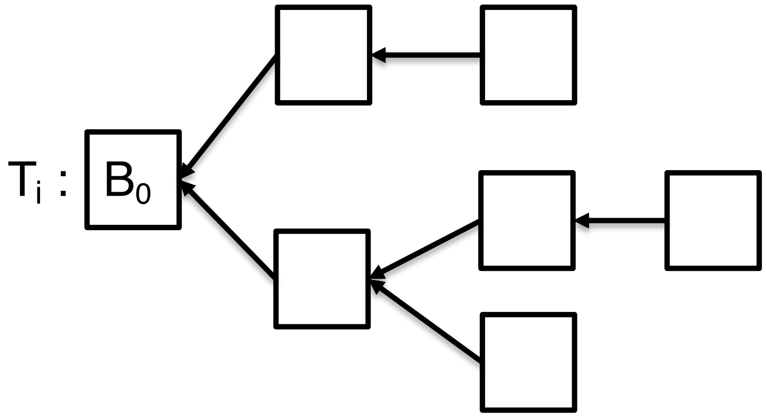

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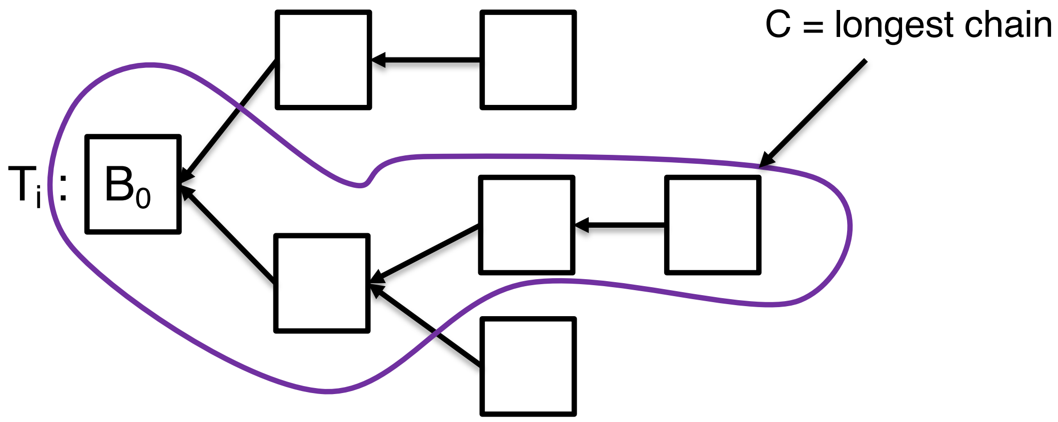

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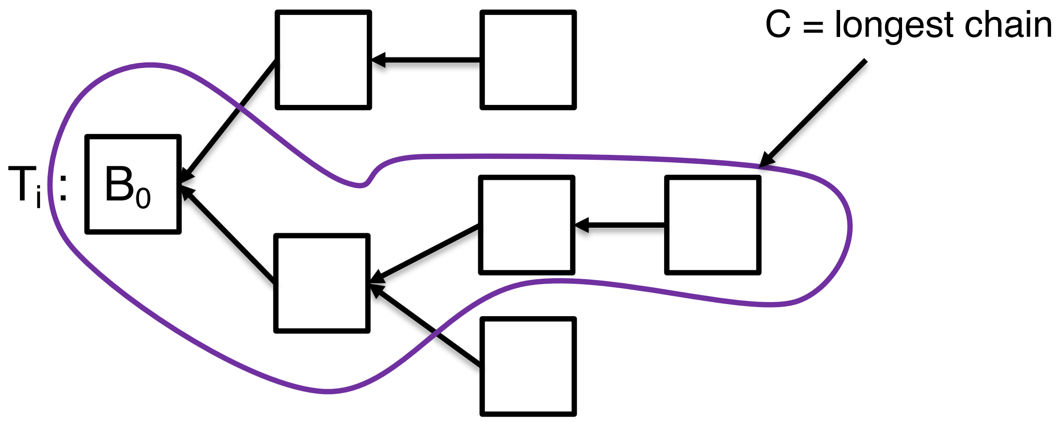

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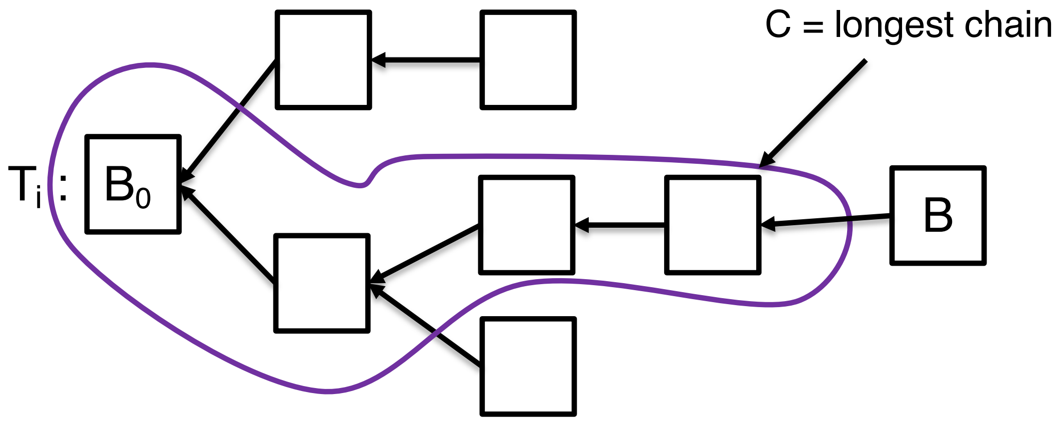
  - ℓ adds B to its in-tree (extending C)
  - ℓ sends B to all other validators



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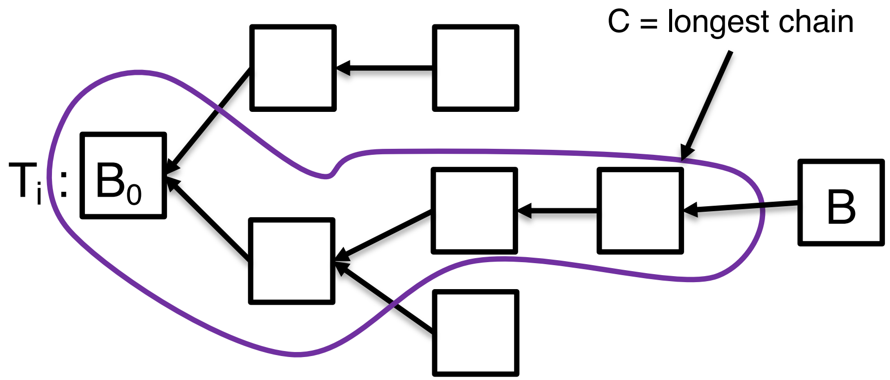

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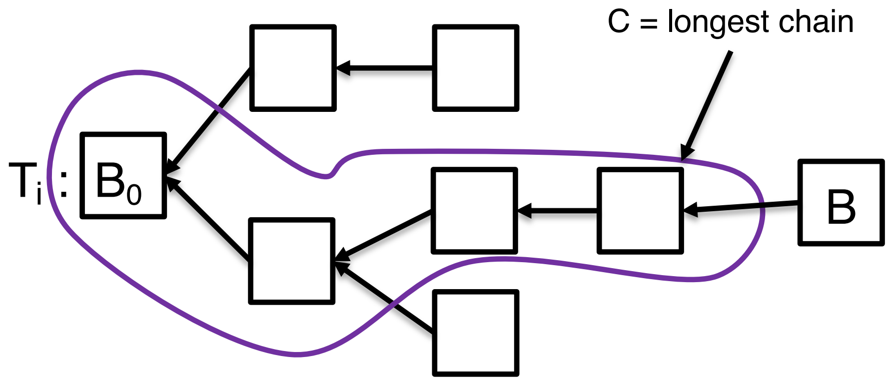

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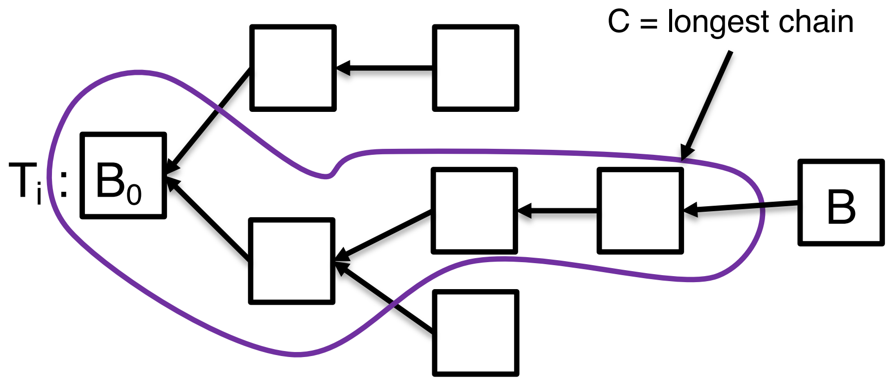

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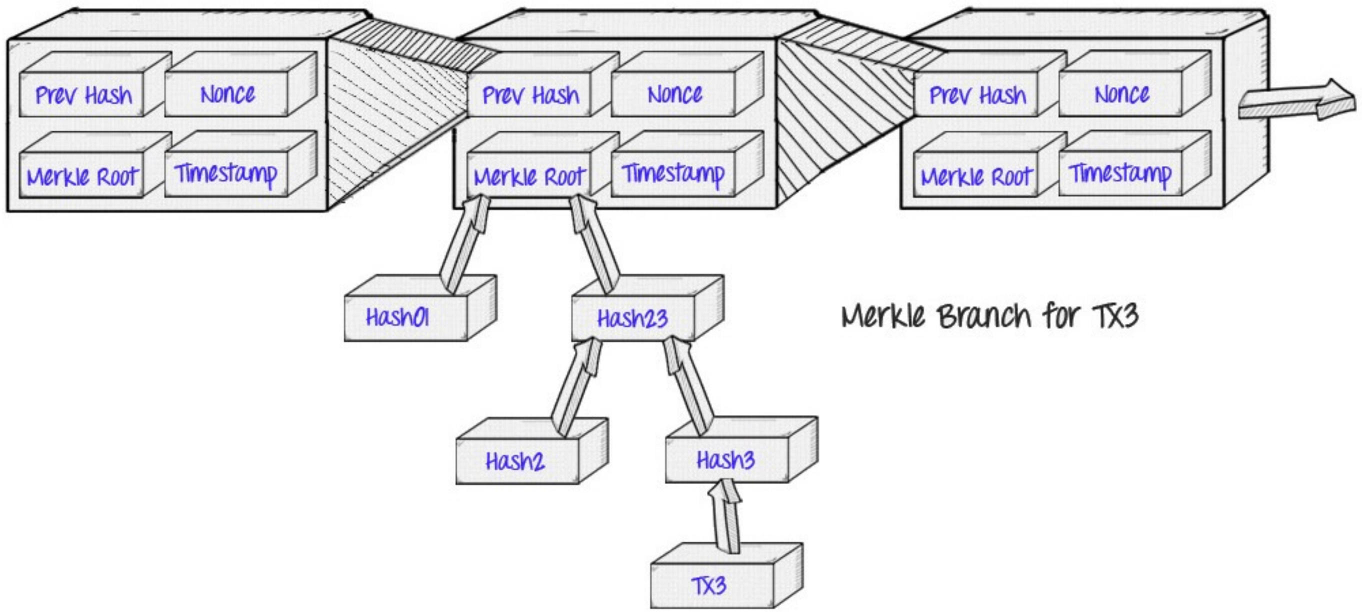
- x = block header of the form…

Recall: Bitcoin Block Headers

In Bitcoin: each block includes Merkle root of its txs (as metadata).

- block name = hash of its metadata ("block header"), not of entire block
- block name depends on each of its txs via Merkle root in block header



From "Merkling in Ethereum" by Vitalik Buterin https://blog.ethereum.org/2015/11/15/merkling-in-ethereum/

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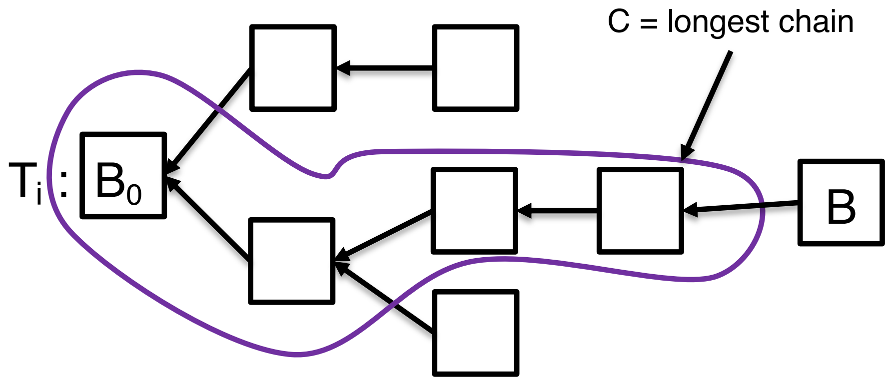

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- x = block header of the form < tx Merkle root || pred || pk || nonce >
  - point of the nonce: “grind” through possibilities until find a solution

Some Recent Bitcoin Blocks

Block 891328

00000000000000000001f5831d1c2c6d9ed1536b6d66ef1164c462250b75d36a

Block 891329

000000000000000000024eec6c0038843111d81decbf074e916401aee9eaef52

Block 891330

000000000000000000003c52639327ede237bf41b17ff73dcde093fde88ce579

Block 891331

0000000000000000000013029bd213f663a5b4472242efe0e74e2c3636153af78

Block 891332

0000000000000000000017296d2ac7ffde35a988c17c6d8728a3ed0036853d796

Some Recent Bitcoin Blocks

Block 891332

0000000000000000000017296d2ac7ffde35a988c17c6d8728a3ed0036853d796

Block was mined on 2025-04-07 07:01:06 GMT -4. It has 1 confirmation on the Bitcoin blockchain. There are 2800 transactions in block 891332.

PREVIOUS

DETAILS

HEIGHT	891332
STATUS	In best chain (1 confirmation)
TIMESTAMP	2025-04-07 07:01:06 GMT -4
SIZE	1617.481 KB
VIRTUAL SIZE	999 vKB
WEIGHT UNITS	3993.379 KWU
VERSION	0x23bdc000
MERKLE ROOT	1601e7d398911c9a6fa501e372fe84231acfbc5db9bf89aab5d43f8ad0b061ea
BITS	0x17025105
DIFFICULTY	121507793131898.06
NONCE	0x7951a124

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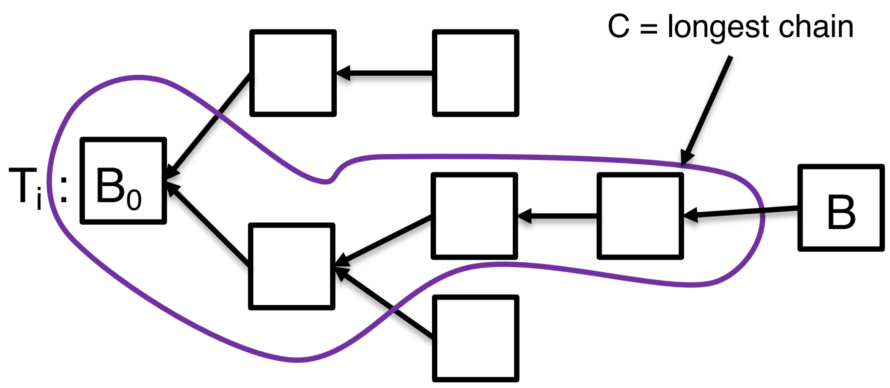

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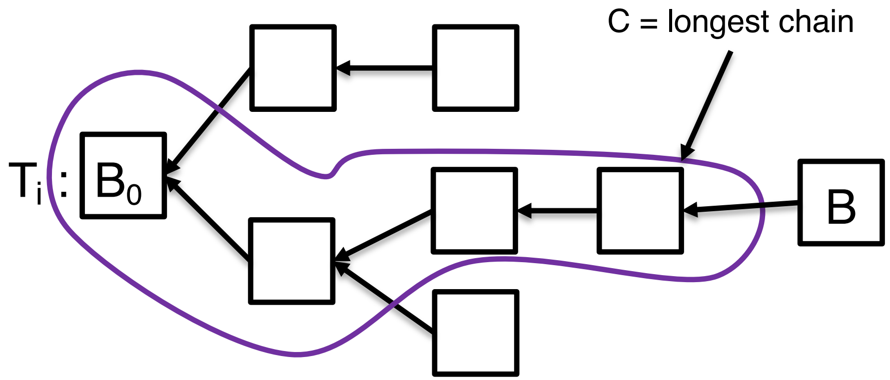

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Note: unlike permissioned version, impossible for validator to:

– specify multiple predecessors for a block (i.e., equivocate)

– specify a predecessor from a later view

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Recall guarantee: under these assumptions, (permissioned) longest-chain consensus is consistent and live.

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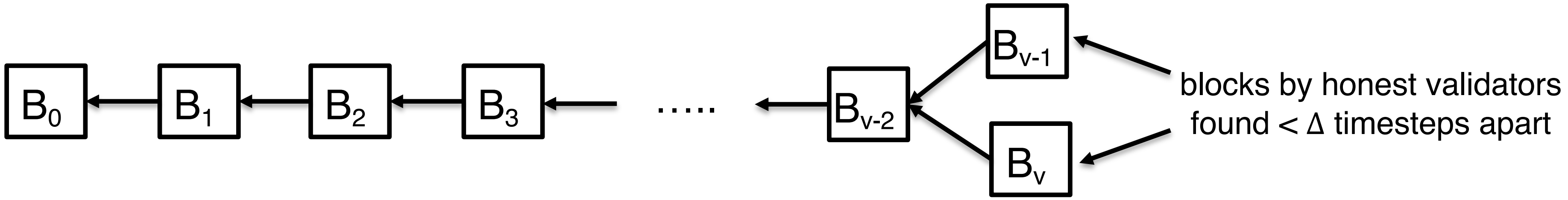

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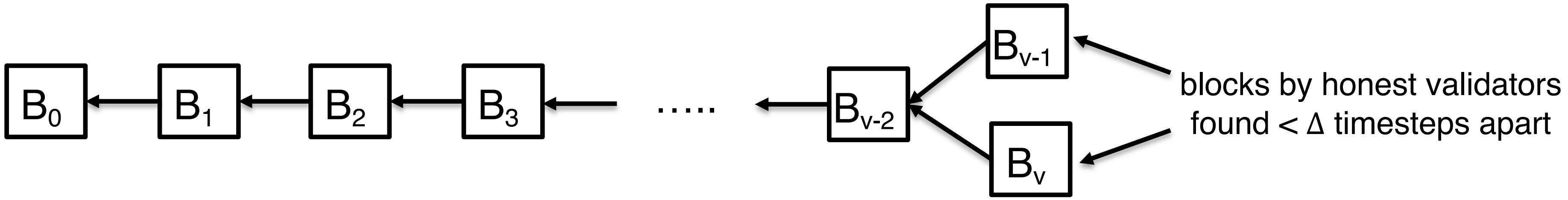

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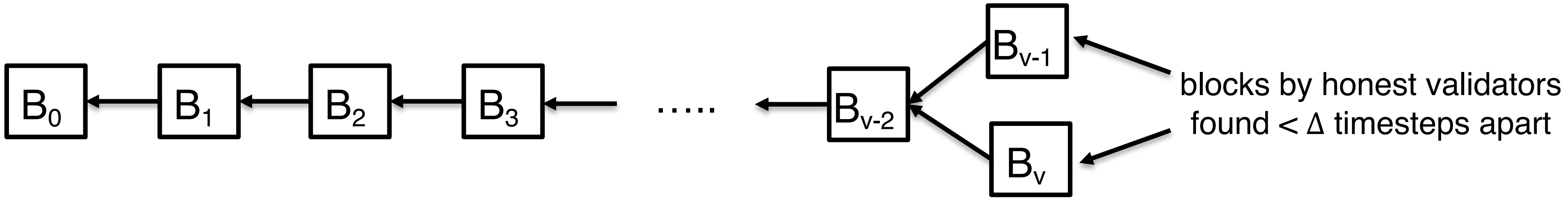

Consequence: some honestly produced blocks are "wasted."

- ➔ threshold for probabilistic consistency + liveness therefore < 50%
- but if honest forking is rare, threshold remains close to 50%
- primary reason for slow block rate in Bitcoin (one block/10 minutes)

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Questions:

- tweak Nakamoto consensus so that one/both problems fixed?
- combine PoW with Tendermint rather than longest-chain?

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1. no PoW protocol is consistent in partial synchrony
   - assuming protocol is live in synchrony with no Byzantine validators
   - rules out combining PoW with Tendermint in any straightforward way

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Facts: [Lewis-Pye/Roughgarden, 2020-3]

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   – assuming protocol is live in synchrony with no Byzantine validators
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Upshot: drawbacks of Nakamoto consensus fundamental to all PoW protocols.

– can be overcome (under extra assumptions) with proof-of-stake protocols

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Proof of (2): similar to proof of FLP Impossibility Theorem.

– churning validators can substitute for unbounded message delays