Blockchain:
Your Questions. Our Answers.

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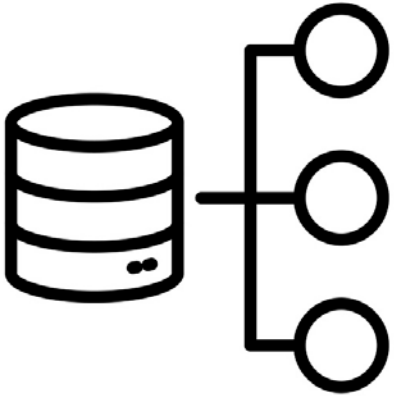
Previous models of computing



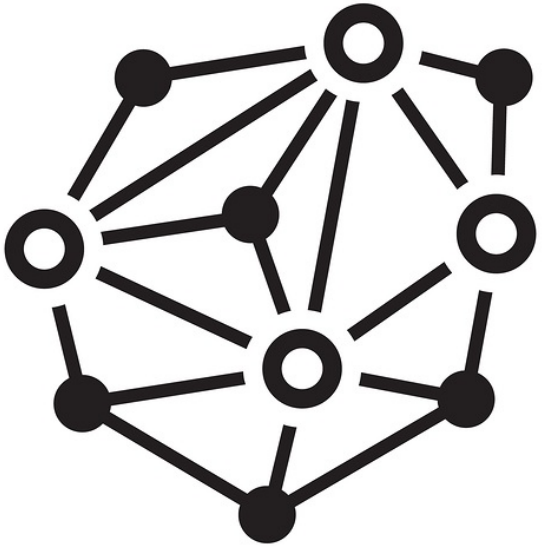
Data Storage:

Database

Program Execution:

Local

Blockchain



Data Storage:

Blockchain

Program Execution:

Blockchain

Blockchain Properties

Data on the chain cannot be removed

Identity fundamentally linked to activity

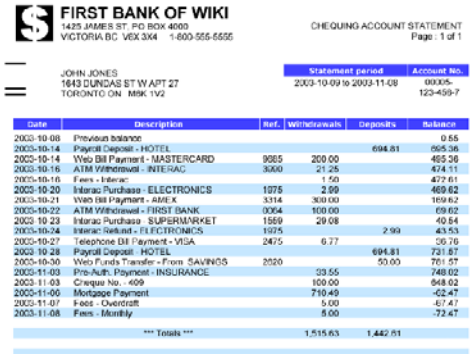
Easily auditable

Mediates untrusted party interactions

Classic Currency: Store of Value

- A $100 bill "*stores*" a $100 value
- My checking account "*stores*" a $148.23 balance
- If I pay Adam $48.23, there's an atomic transaction:

```
begin atomic
    Gabriel.Checking −= $48.23;
    Adam.Checking   += $48.23;
end atomic
```



FIRST BANK OF WIKI
1425 JAMES ST. PO BOX 4000
VICTORIA BC V6X 3X4 1-800-555-5555

CHEQUING ACCOUNT STATEMENT
Page : 1 of 1

JOHN JONES
1643 DUNDAS ST W APT 27
TORONTO ON M6K 1V2

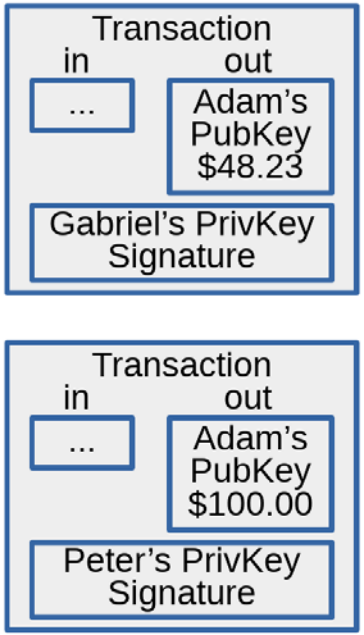
Statement period	Account No.
2003-10-09 to 2003-11-08	00005-123-459-7

Date	Description	Ref.	Withdrawals	Deposits	Balance
2003-10-08	Previous balance				0.55
2003-10-14	Payroll Deposit - HOTEL			694.81	695.36
2003-10-14	Web Bill Payment - MASTERCARD	9085	200.00		495.36
2003-10-16	ATM Withdrawal - INTERAC	3000	21.25		474.11
2003-10-16	Fees - Interac		1.50		472.61
2003-10-20	Interac Purchase - ELECTRONICS	1075	2.99		469.62
2003-10-21	Web Bill Payment - AMEX	3314	300.00		169.62
2003-10-22	ATM Withdrawal - FIRST BANK	0064	100.00		69.62
2003-10-23	Interac Purchase - SUPERMARKET	1569	29.08		40.54
2003-10-24	Interac Refund - ELECTRONICS	1075		2.99	43.53
2003-10-27	Telephone Bill Payment - VISA	2475	6.77		36.76
2003-10-28	Payroll Deposit - HOTEL			694.81	731.57
2003-10-30	Web Funds Transfer - From SAVINGS	2020		50.00	781.57
2003-11-03	Pre-Auth. Payment - INSURANCE		33.55		748.02
2003-11-03	Cheque No. - 409		100.00		648.02
2003-11-06	Mortgage Payment		710.49		-62.47
2003-11-07	Fees - Overdraft		5.00		-67.47
2003-11-08	Fees - Monthly		5.00		-72.47
	*** Totals ***		1,515.63	1,442.61	

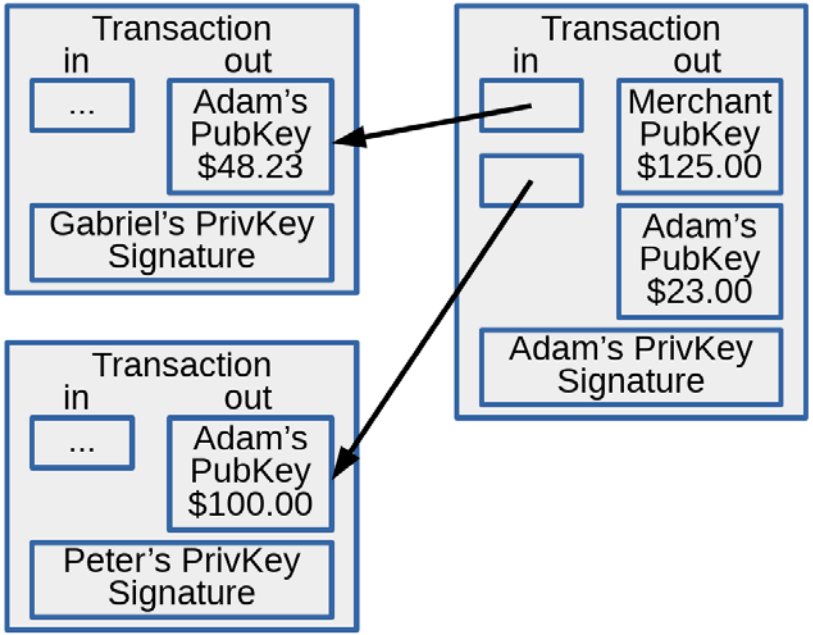
Cryptocoins: IOUs

- Gabriel owes Adam $48.23
- Peter owes Adam $100.00
  - Therefore, Adam "*has*" $148.23
    - Assuming IOUs collected instantly, on demand!
- To pay for something, Adam must:
  - Collect (some of) his IOUs
  - Issue a fresh IOU to the payee/merchant
- IOUs (a.k.a. *Transactions*) passed around by nodes of a distributed, P2P network

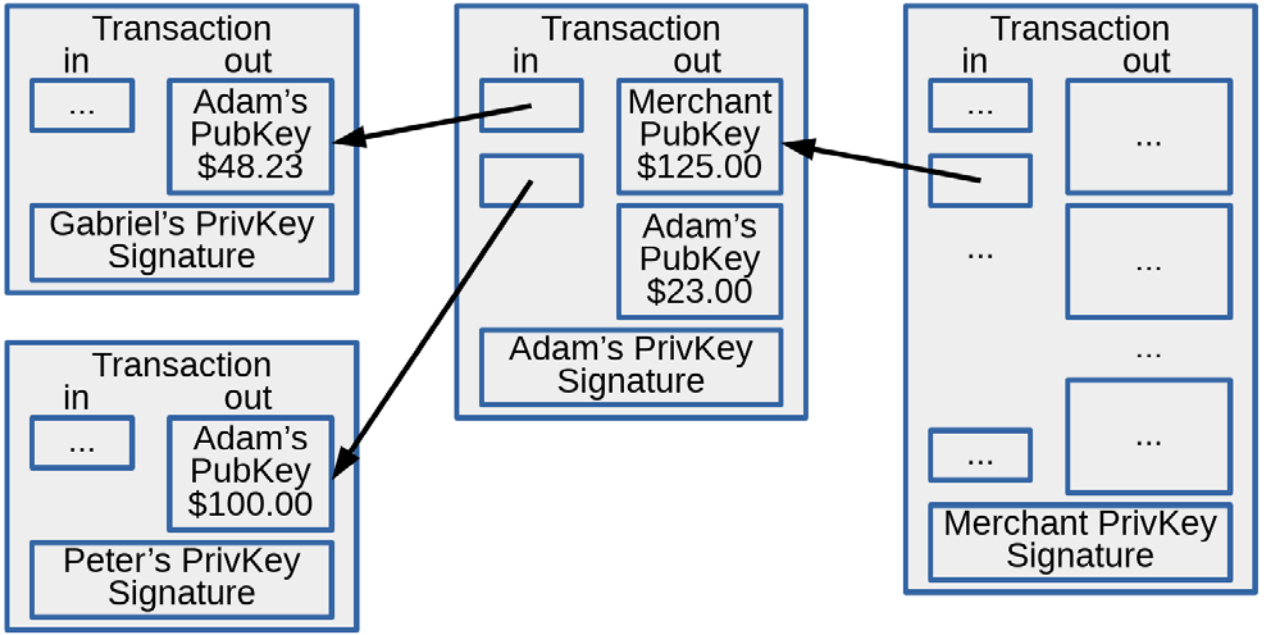
Transactions



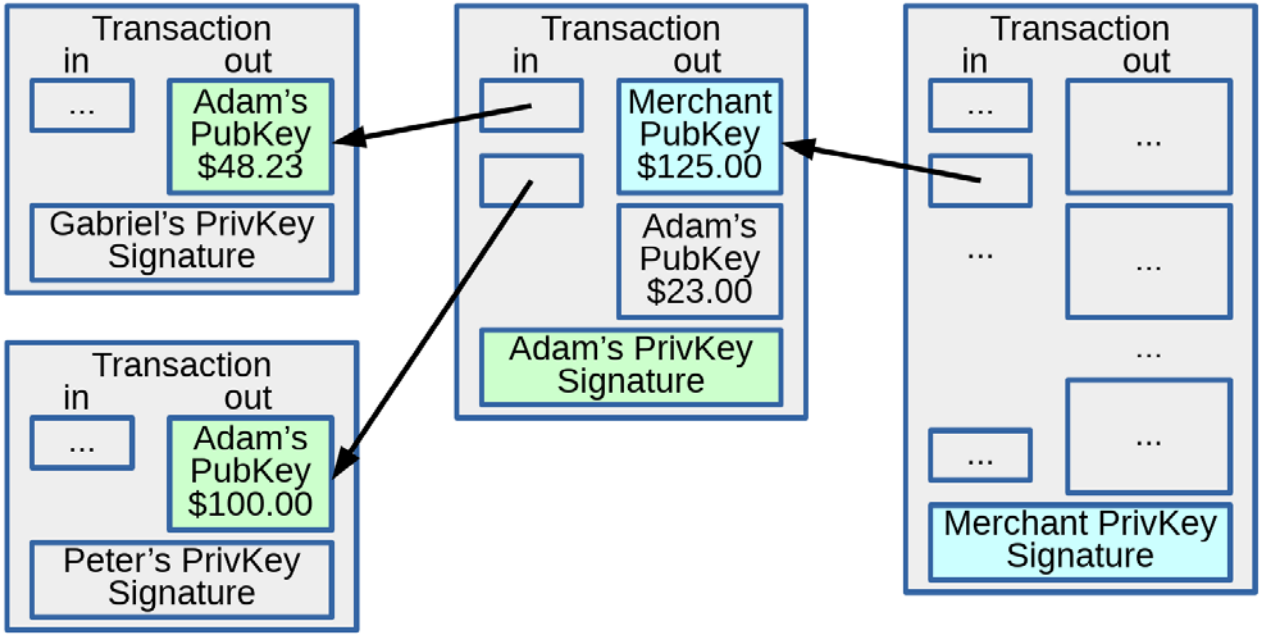
Transactions



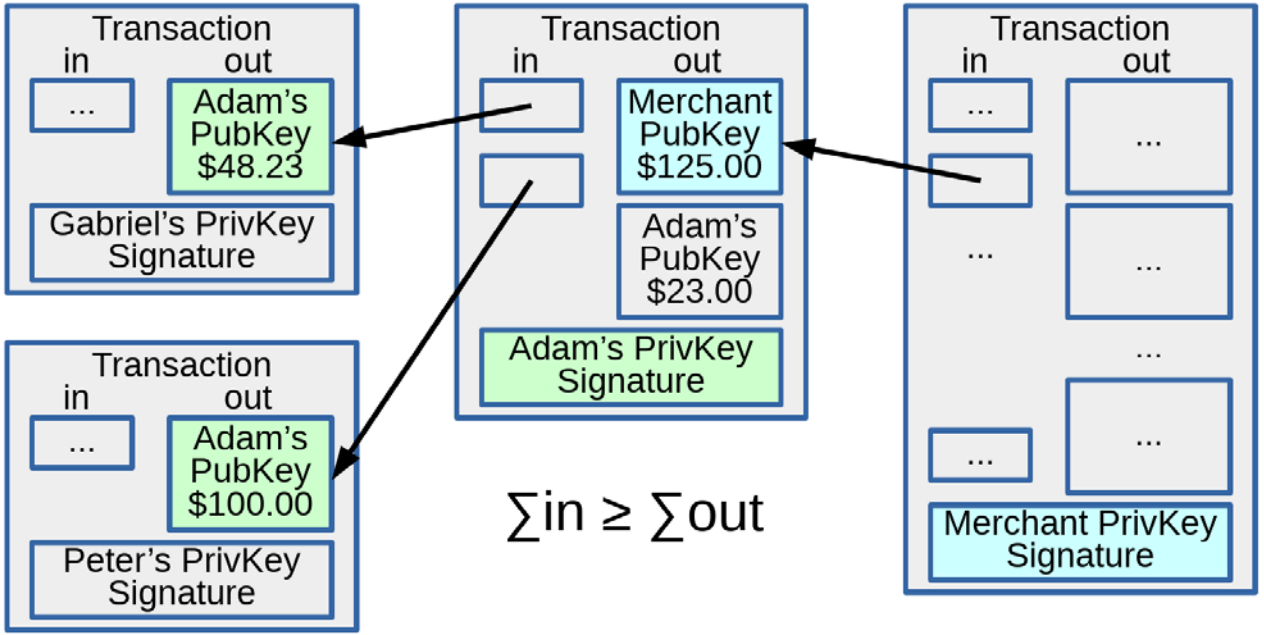
Transactions



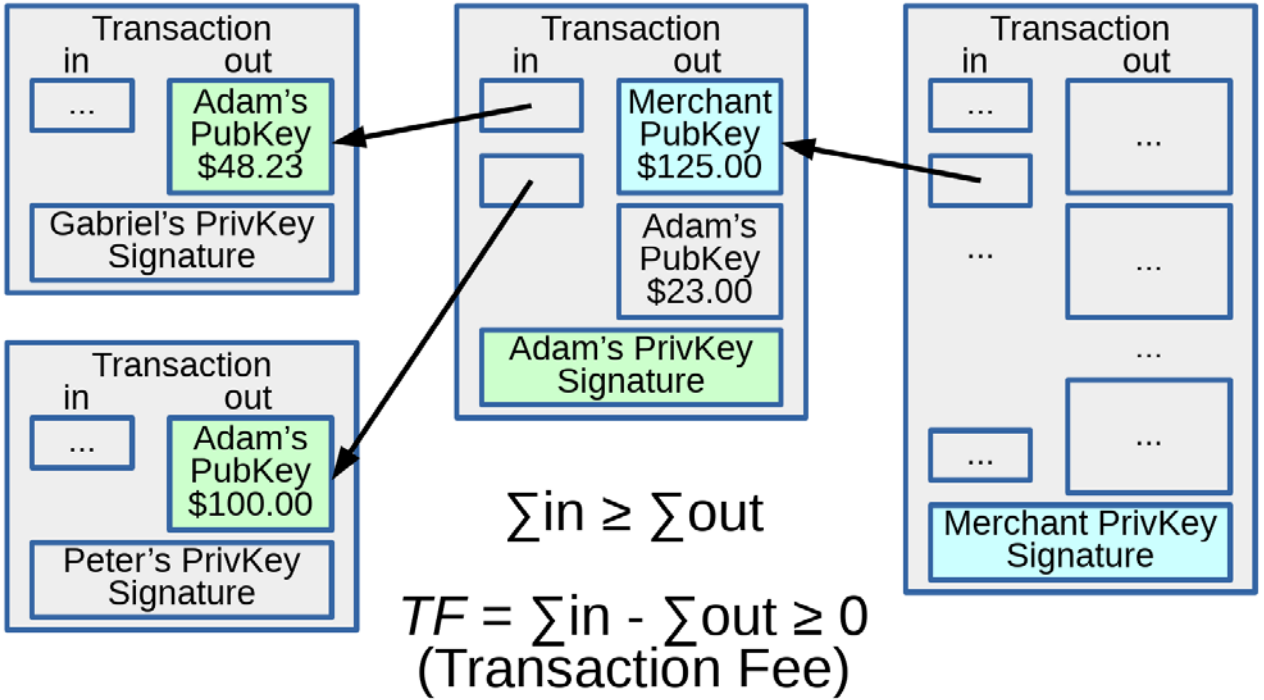
Transactions: Identity of Parties



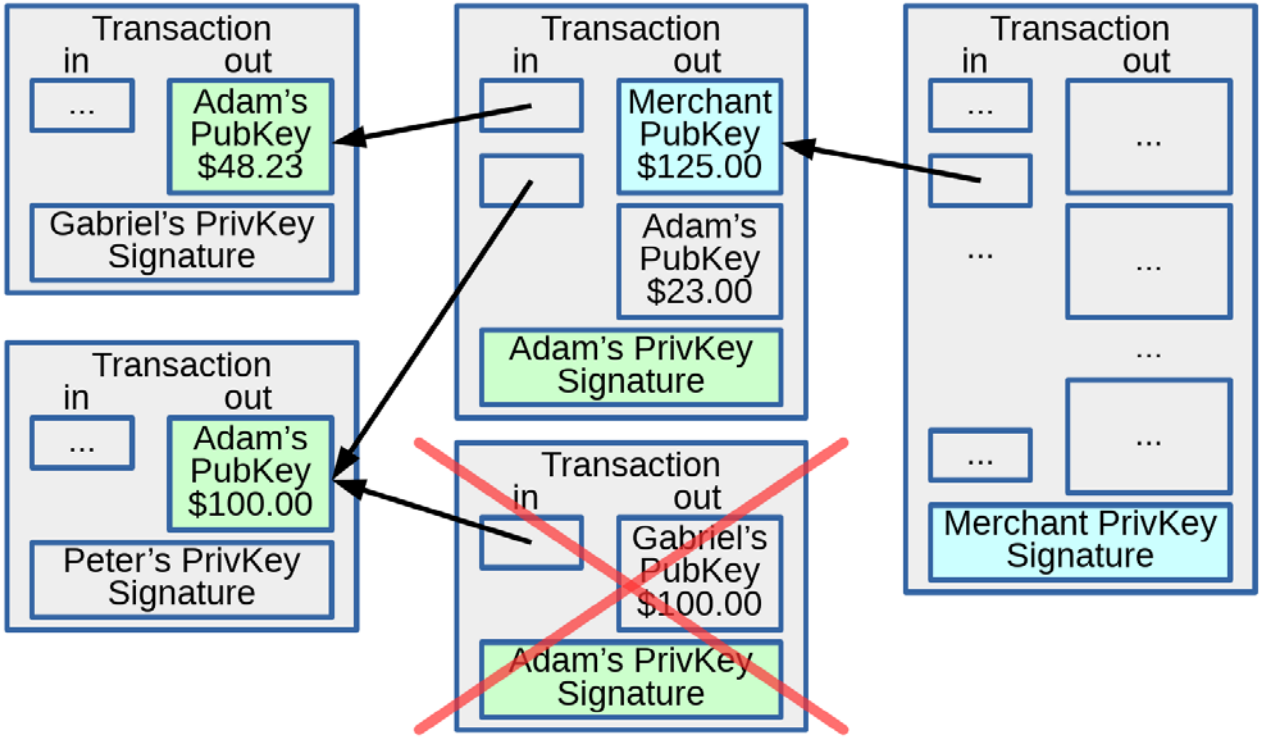
Transactions: No Overspending!



Transactions: No Overspending!

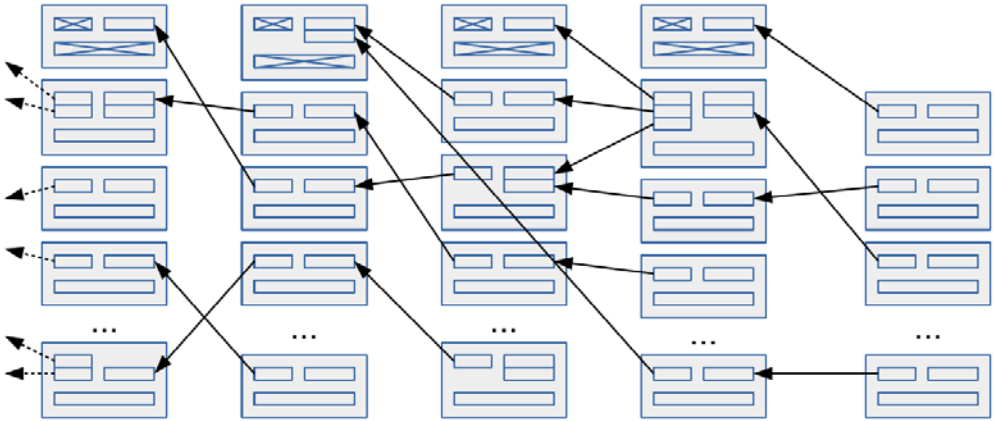


Transactions: No Double-Spending!



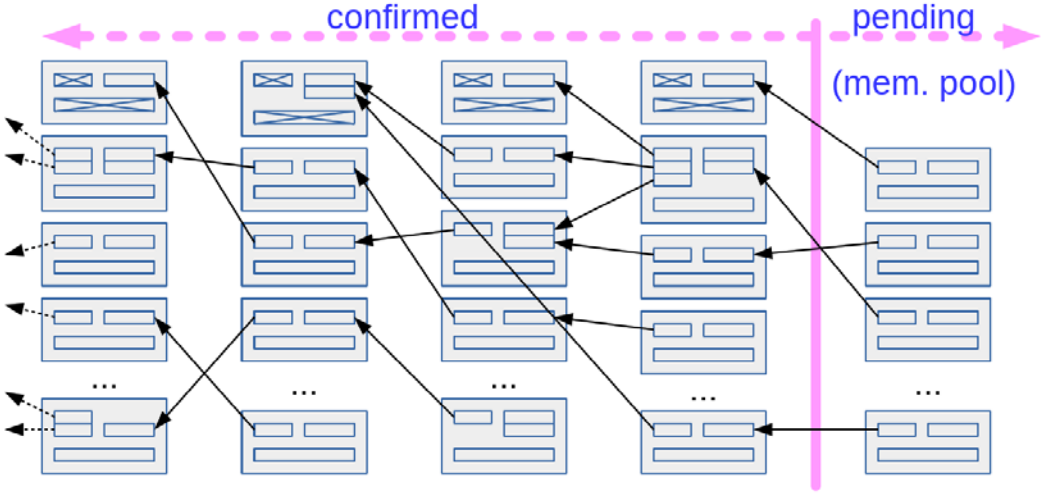
Ledger

- DAG of *all* transactions *ever* issued
  - Append-only data structure
- Every peer node maintains a copy



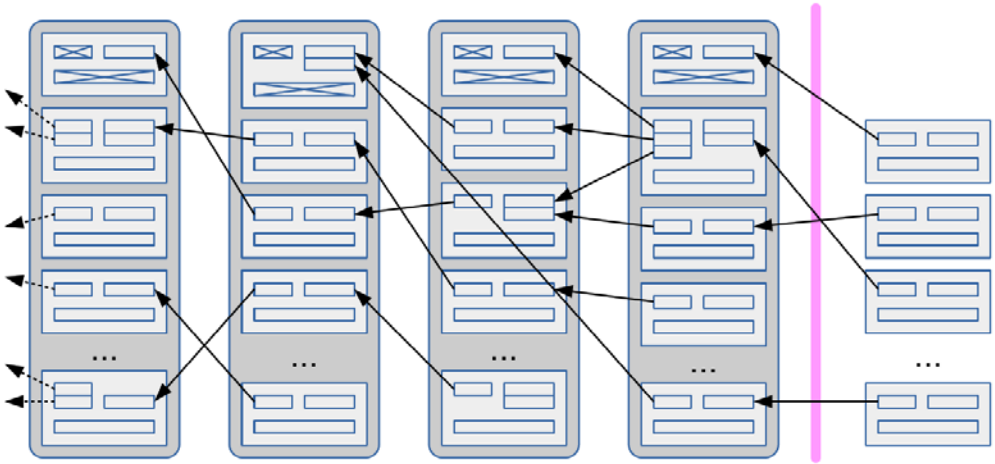
Ledger

- Existing (*confirmed*) transactions on HDD
- New (*pending*) transactions in Memory Pool
  - Must be valid w.r.t. existing state to be confirmed



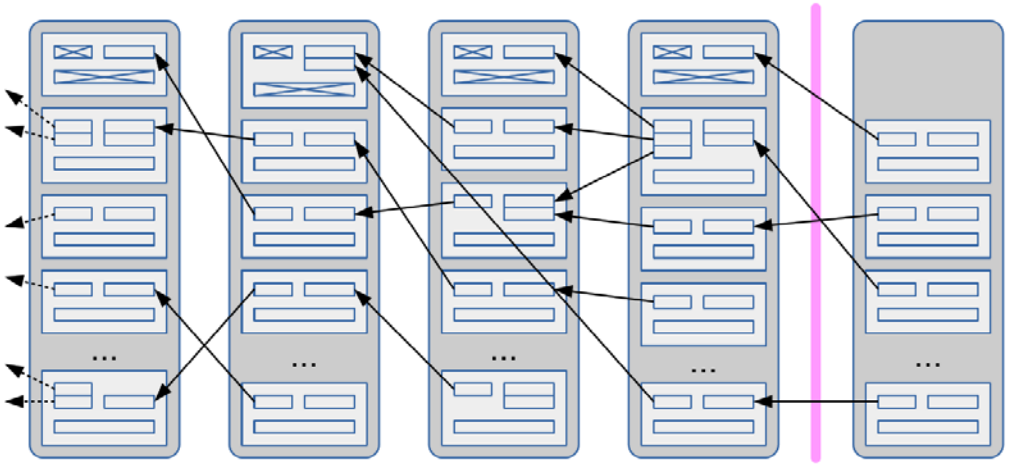
Transaction Blocks

- Confirmed transactions grouped in *blocks*



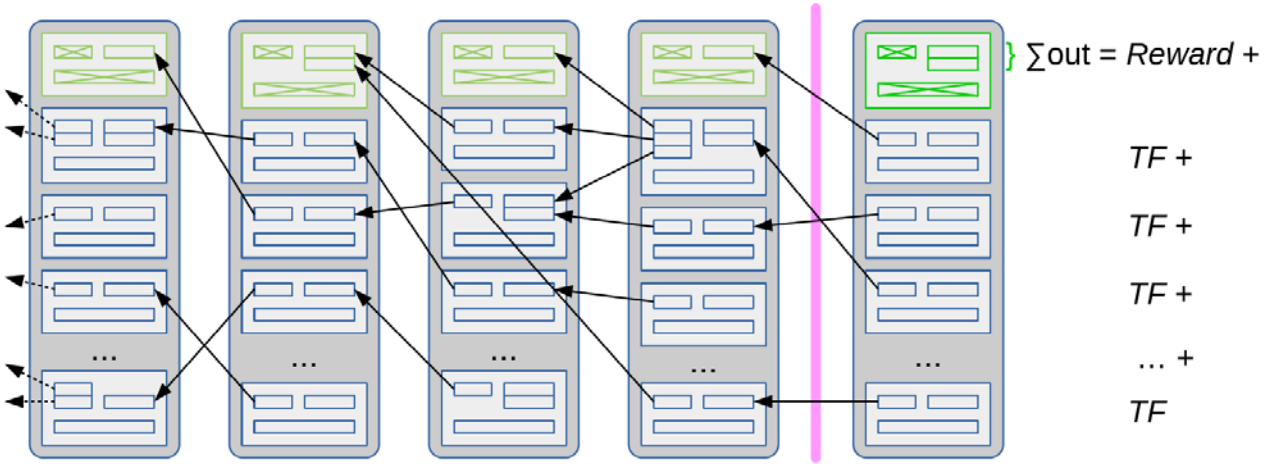
Transaction Blocks

- Confirmed transactions grouped in *blocks*
- Peers (*miners*) ***compete*** to create newest block
  - Containing newly validated (confirmed) transactions

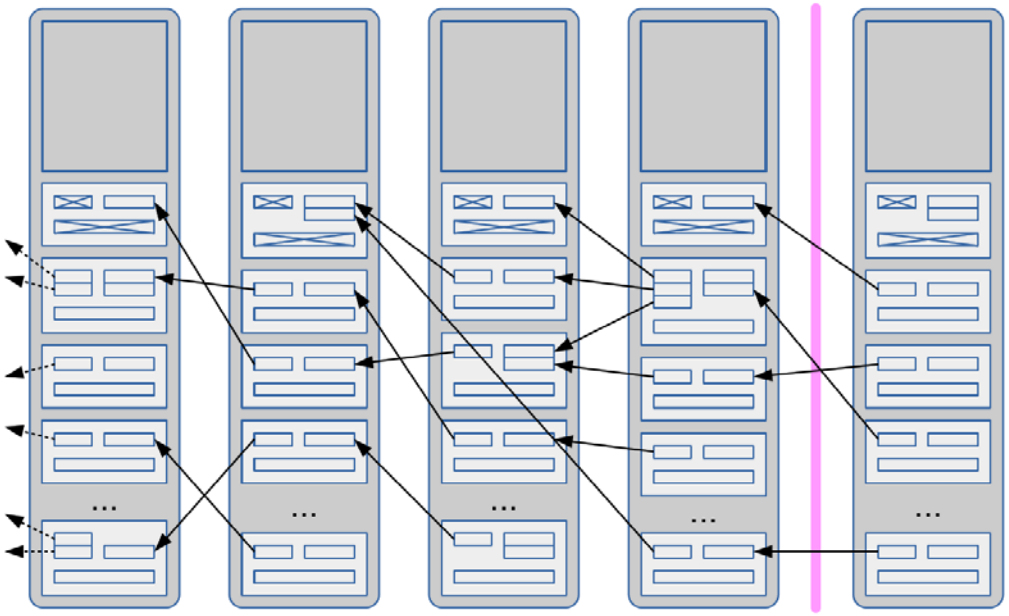


Coinbase Transactions

- Compensate miners for “community service” work
  - i.e., confirming users’ pending transactions
- *Reward* (freshly “minted” money)
  - Also *transaction fees* from each confirmed transaction

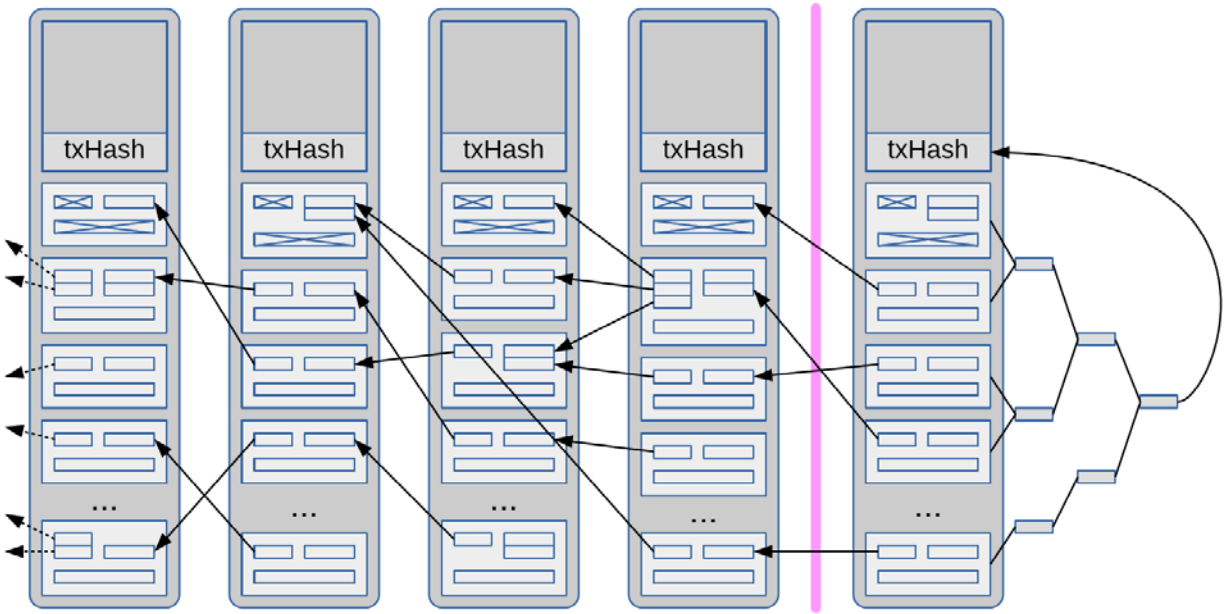


Block Header



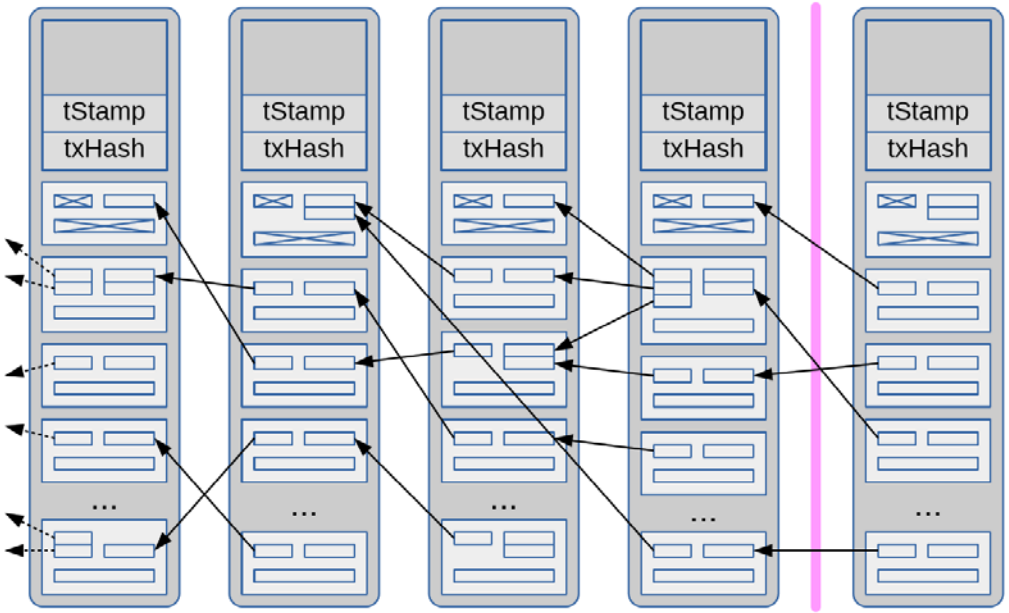
Block Header

- Merkle Tree root of transaction hashes
  - Uniquely identify transactions included in block



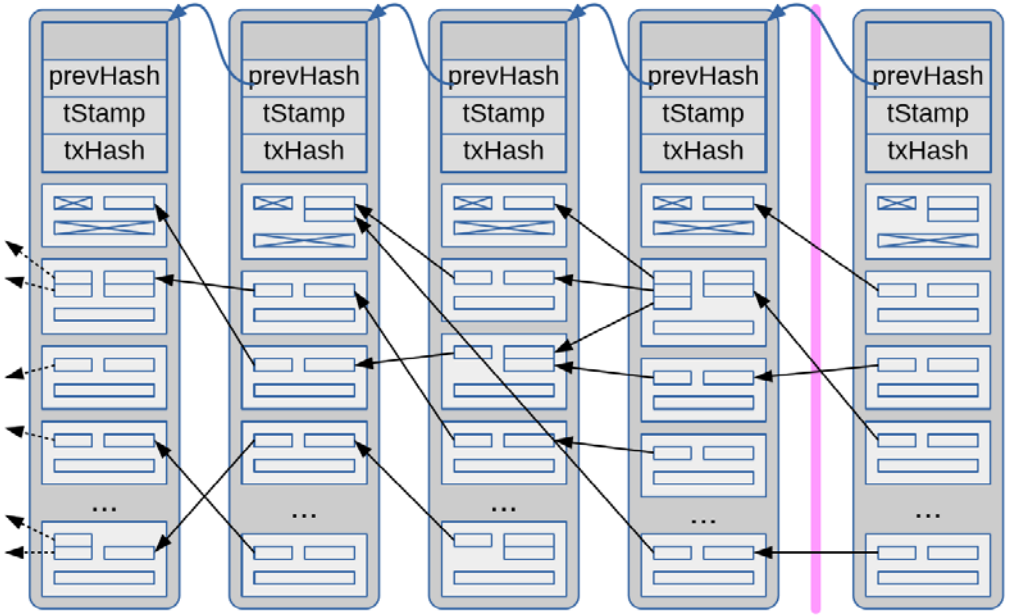
Block Header

- Timestamp of block creation
  - Monotonically increasing



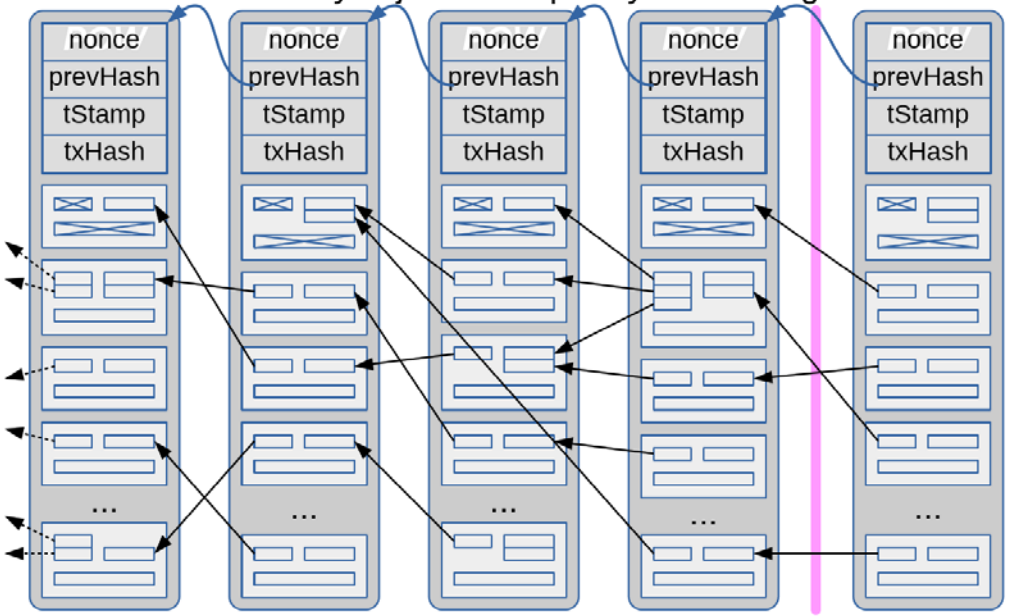
Block Header

- Hash of previous block header
  - Linked list → block *chain*



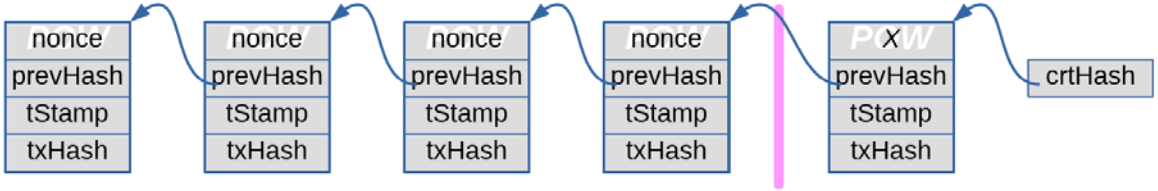
Block Header

- PoW nonce: limit block creation rate to 1 / 10min.
  - Give peers time to double-check block & transaction validity
  - Difficulty adjusted adaptively toward target block creation rate



PoW, a.k.a. “Difficult Math Puzzle”

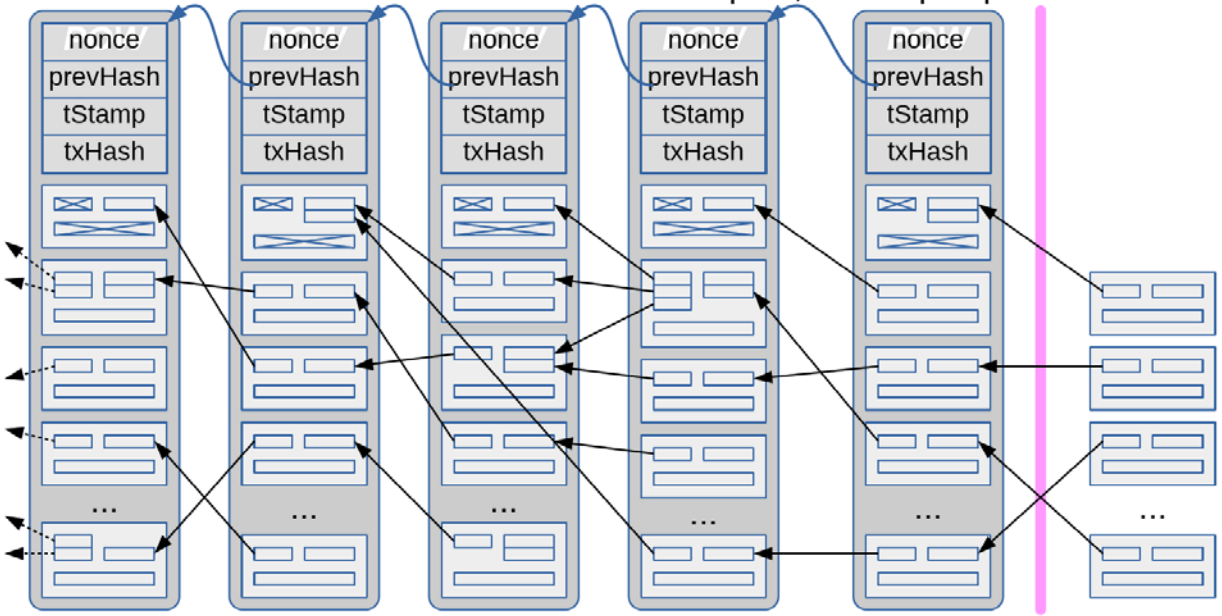
$H(x, \text{prevHash}, \text{tStamp}, \text{txHash}) \leq 0\text{x}\underbrace{00\ldots0}_{n\ 0\text{-bits}}\text{FF...F}$



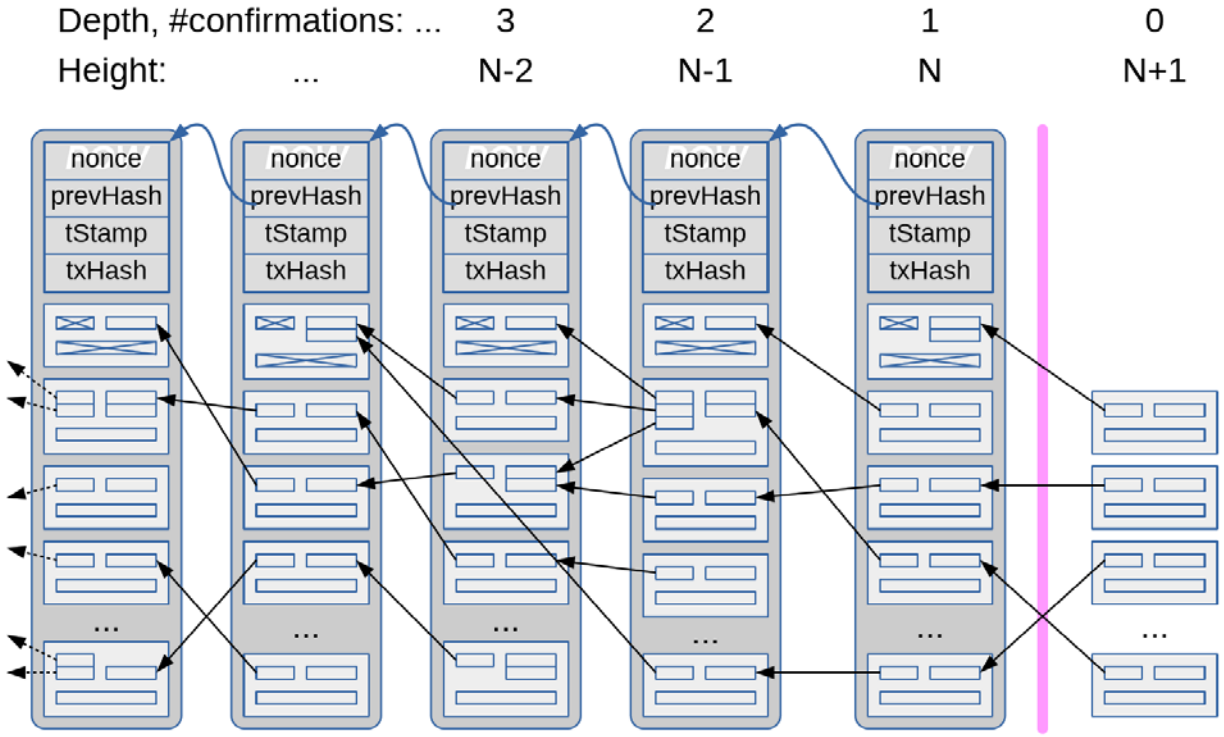
- Hash function *H* output unpredictable (by design)
  - No formula to solve for *x*: Try all *x* until solution found!
  - Statistically, difficulty (expected # of attempts) is $2^{(n-1)}$, where *n* is the # of leading 0-bits at output of *H* func.
- Goals:
  - Control block creation rate (every 10 minutes for BTC)
  - Prohibit changes in previously settled (confirmed) blocks

Blockchain

- Non-repudiable ledger of confirmed-transactions
  - Peers *always* prefer longest known blockchain (per protocol)
  - PoW makes it unfeasible to recompute, catch up to peers



Depth, Height, Confirmations



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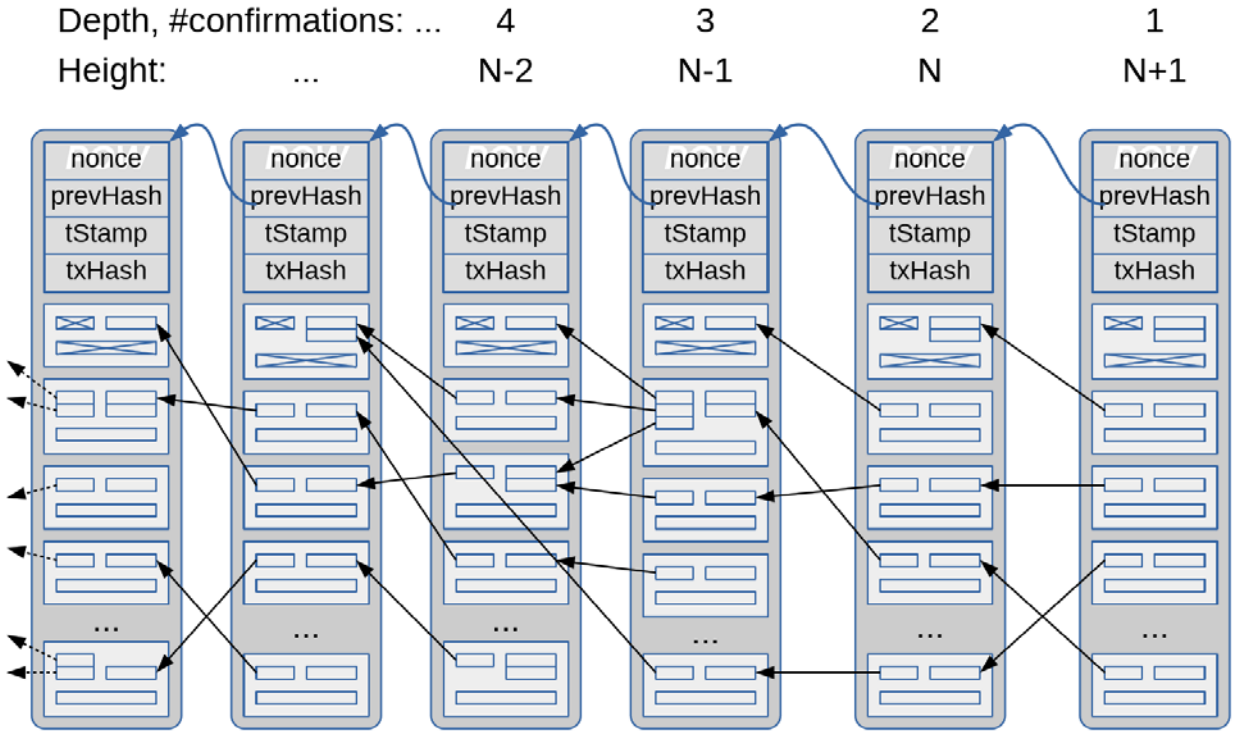
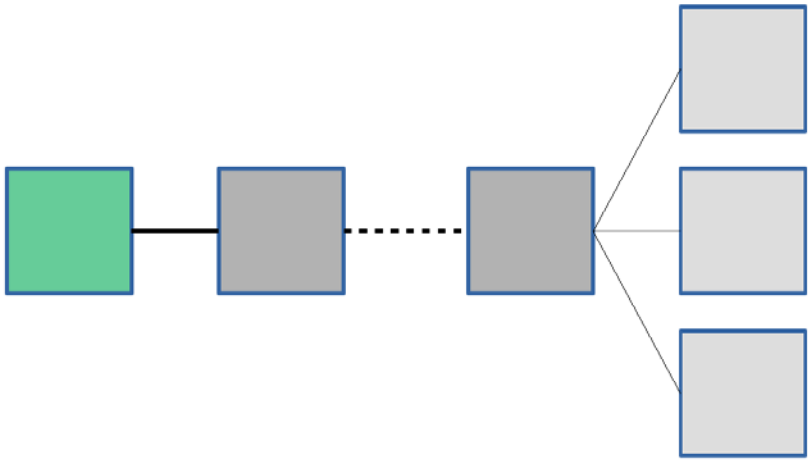


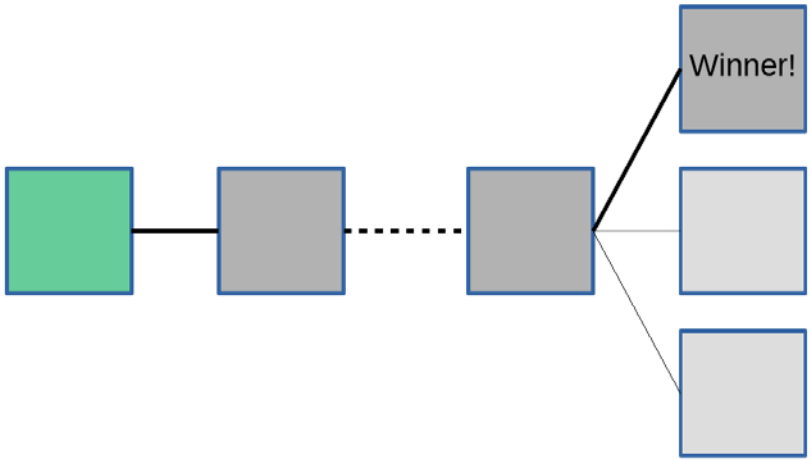
Stale Blocks

- Multiple miners race to create next block



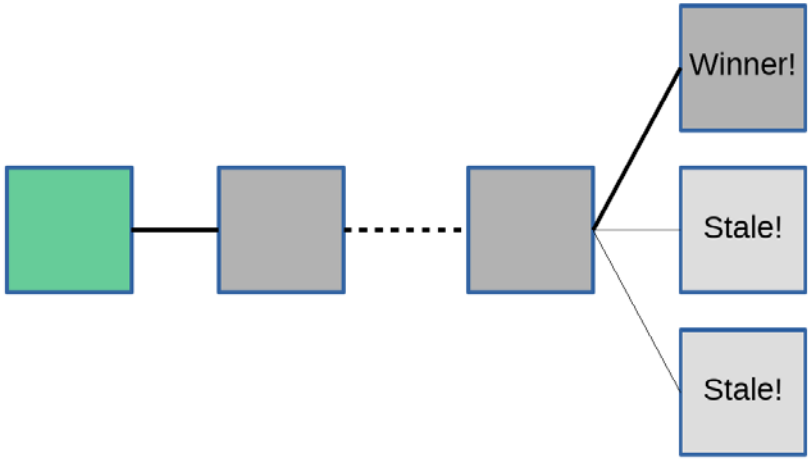
Stale Blocks

- Multiple miners race to create next block
- Winner broadcasts their block to all peers



Stale Blocks

- Multiple miners race to create next block
- Winner broadcasts their block to all peers
- Losers' work-in-progress becomes *stale*



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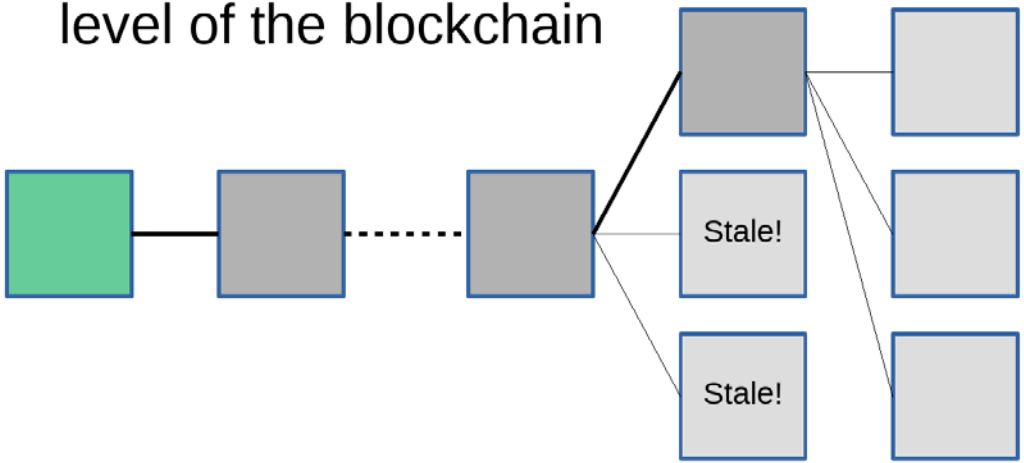
- Race restarts at next level of the blockchain



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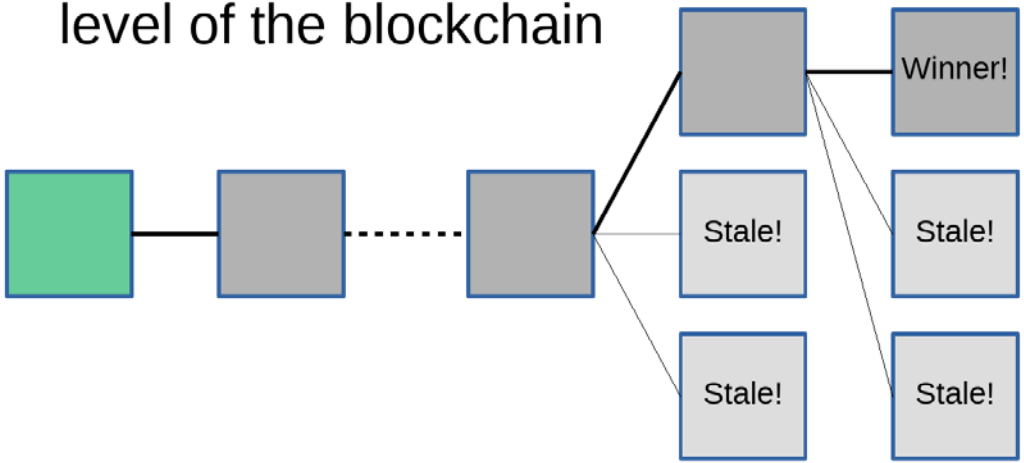
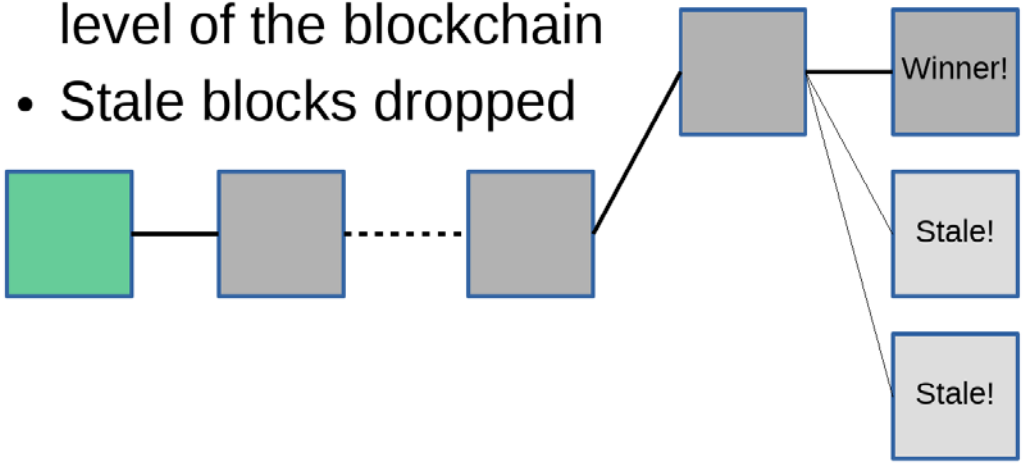


Stale Blocks

- Multiple miners race to create next block
- Winner broadcasts their block to all peers
- Losers' work-in-progress becomes *stale*
- Race restarts at next level of the blockchain
- Stale blocks dropped



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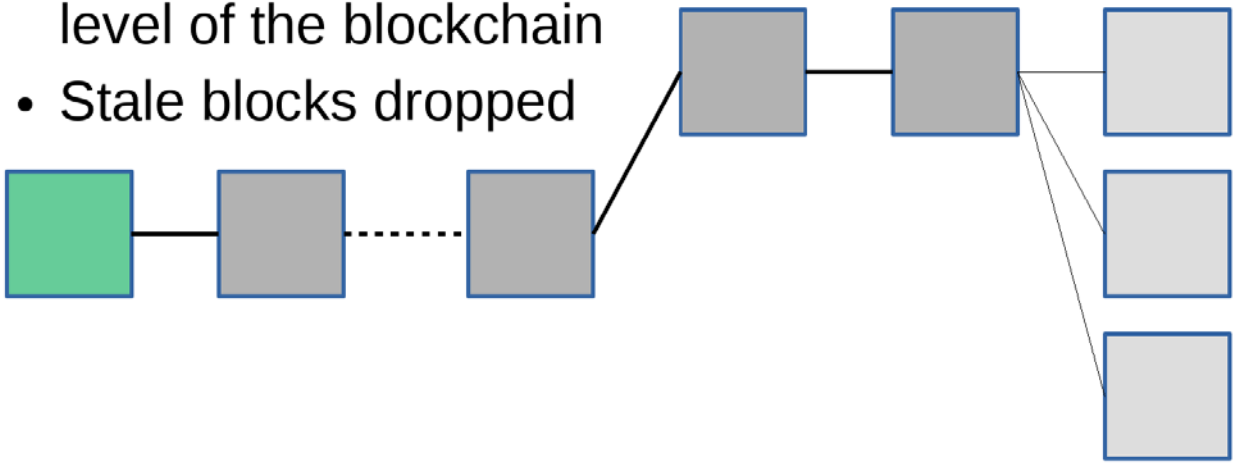
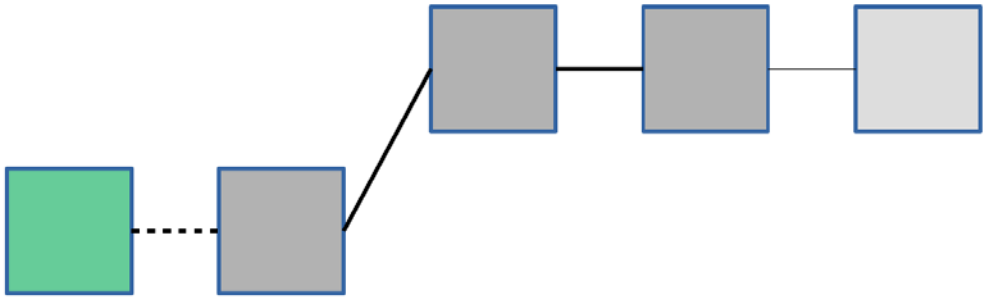
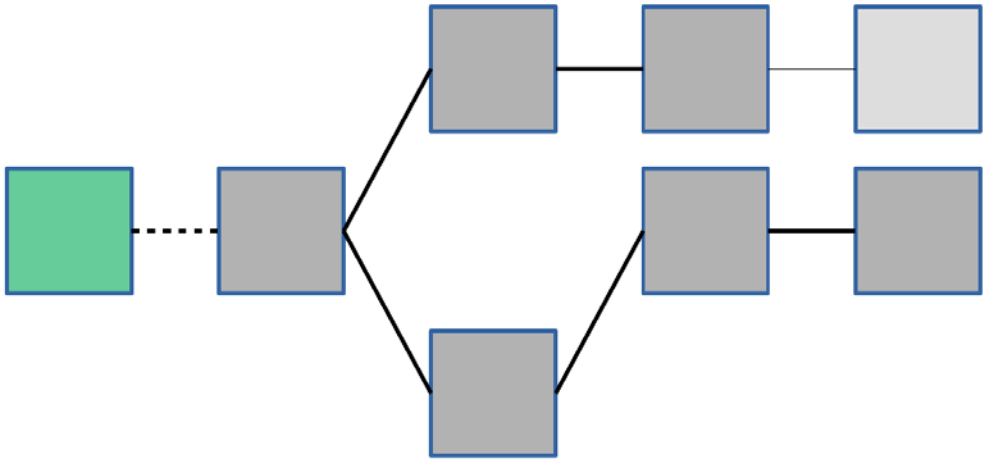


Orphan Blocks



Orphan Blocks

- Suddenly a valid, *longer* chain is announced
  - Presumably, after network delay or temp. partition



Orphan Blocks

- Suddenly, a valid longer chain is announced
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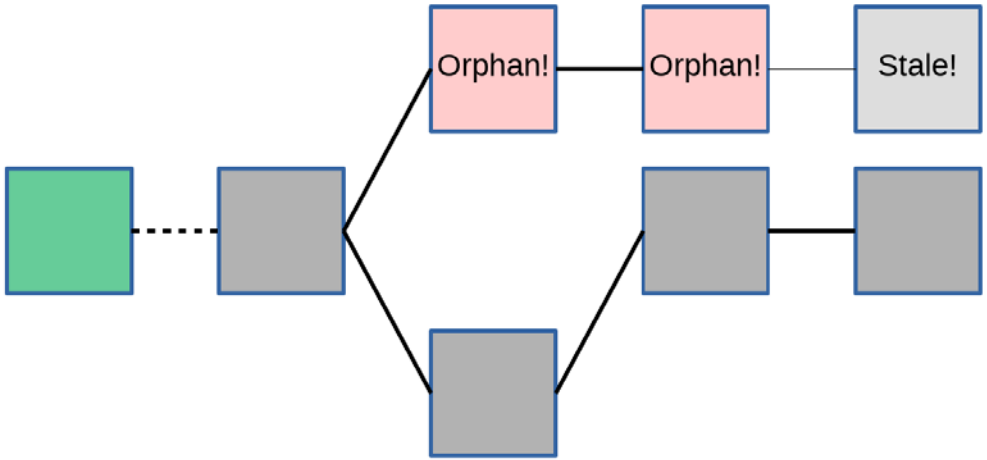

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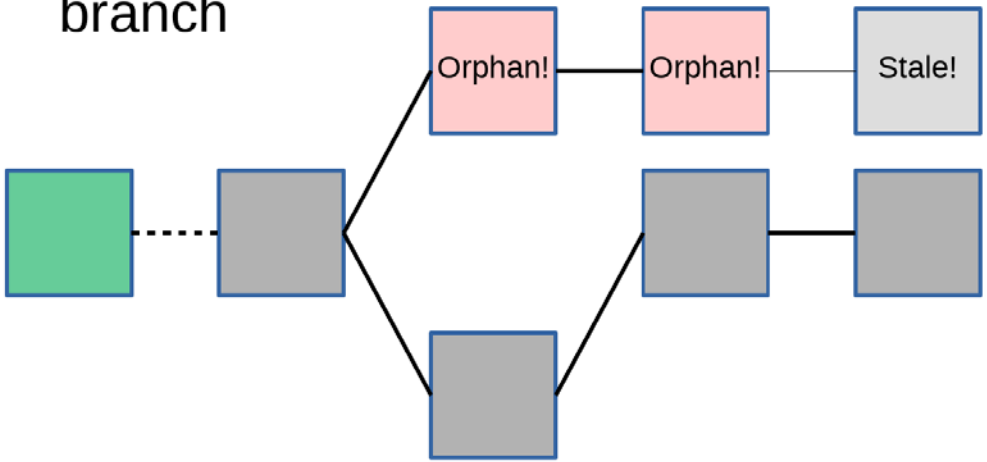
- Miners begin working on longer, preferred branch



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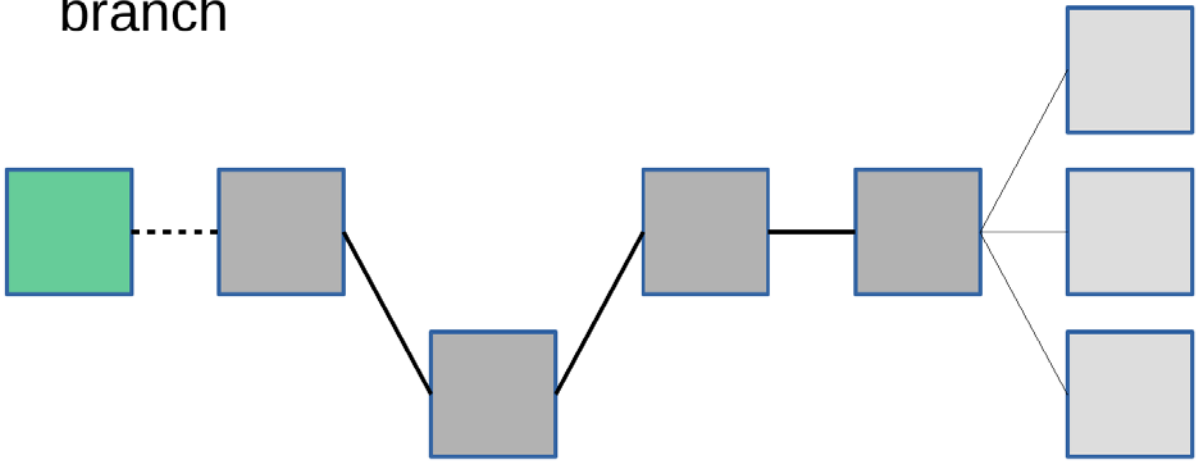
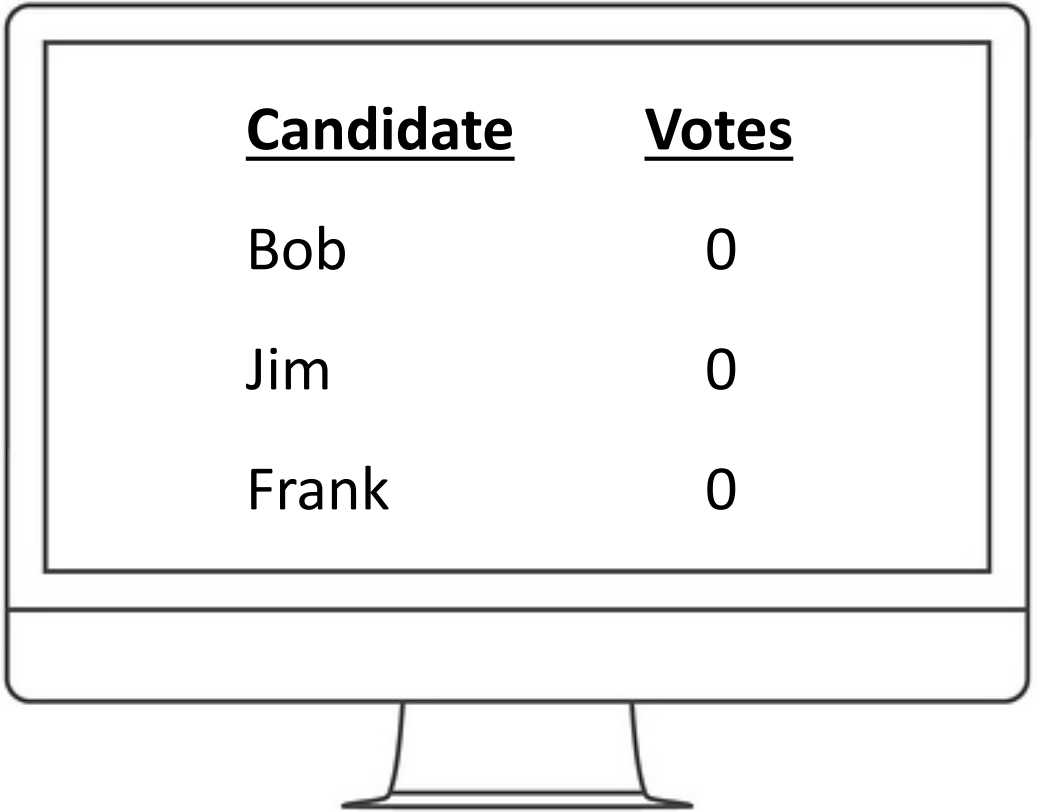
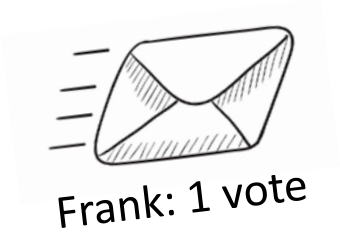


State: 1

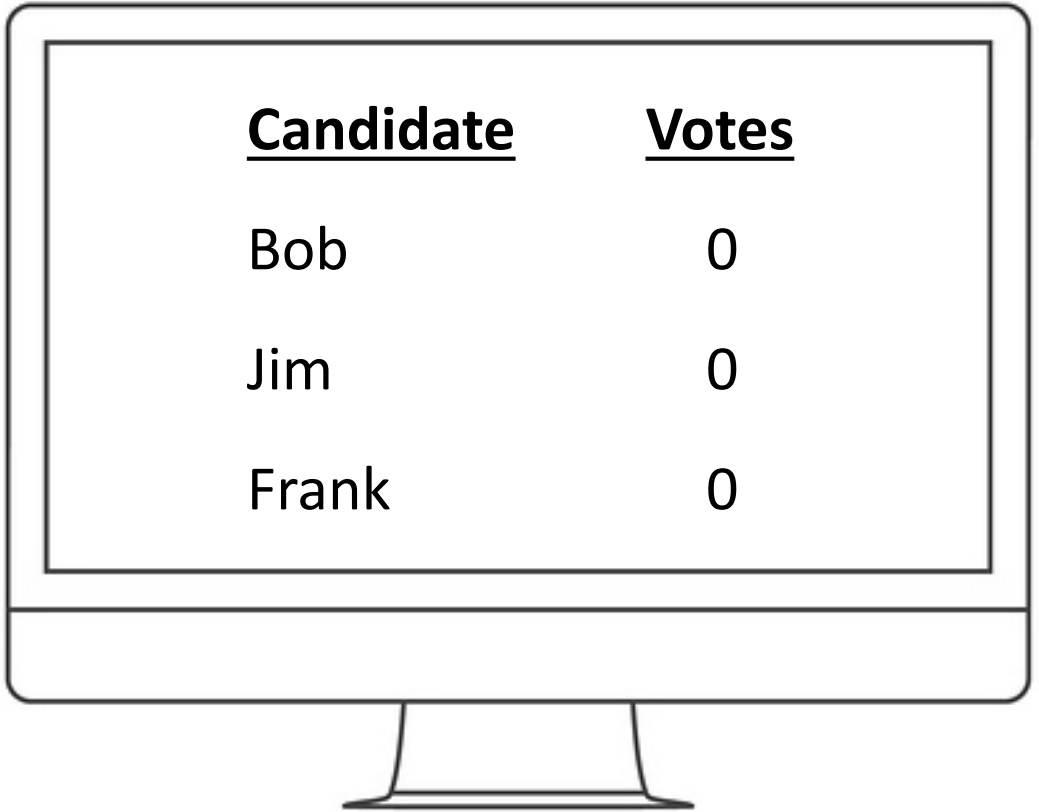


State: 1

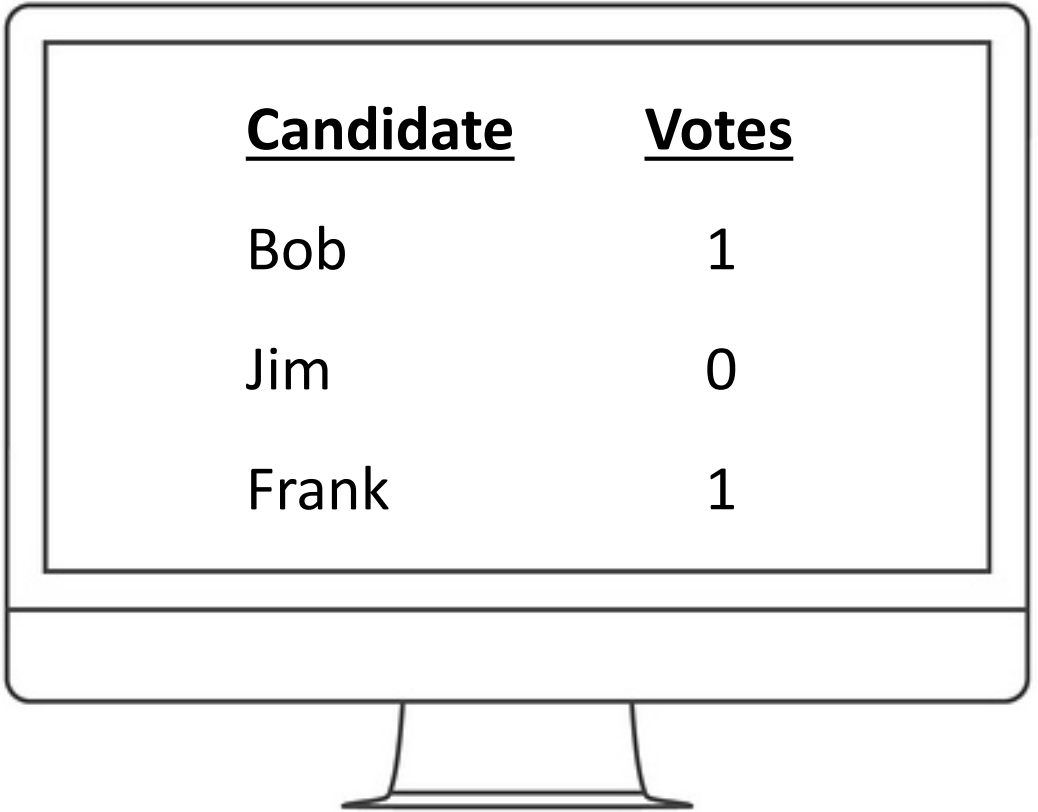
Bob: 1 vote



Frank: 1 vote

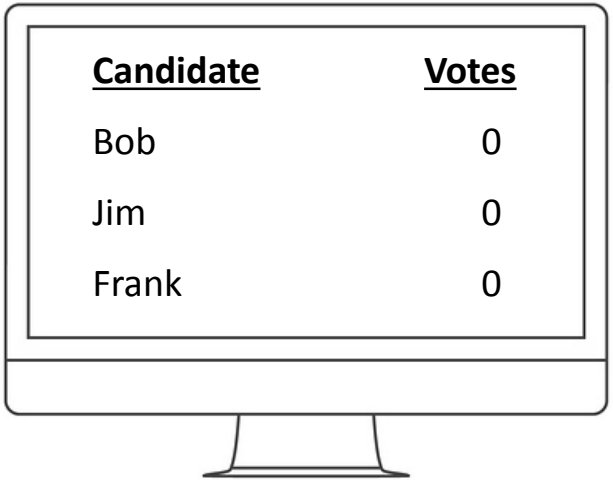


State: 2



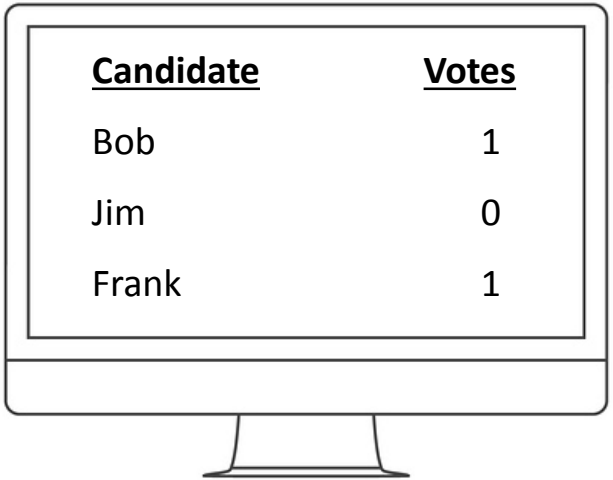
Candidate	Votes
Bob	1
Jim	0
Frank	1

State: 1



Candidate	Votes
Bob	0
Jim	0
Frank	0

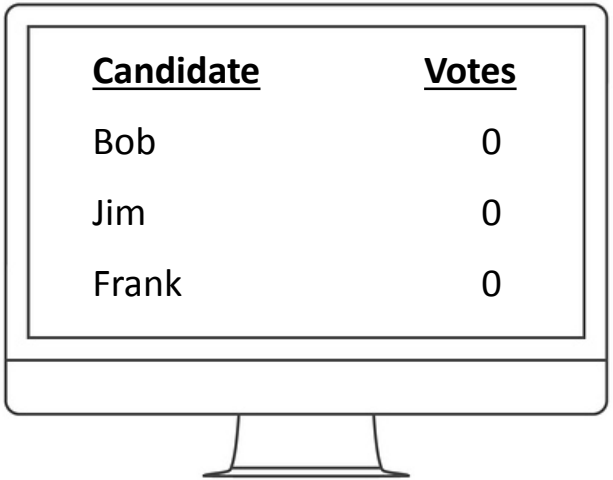
State: 2



Candidate	Votes
Bob	1
Jim	0
Frank	1

Equivalent to:

State: 1



State: 2

State 1 plus…

Bob: 1 vote

Frank: 1 vote

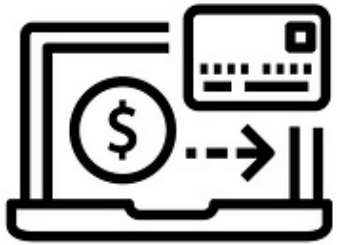
General purpose blockchains

Messages are… anything!

Each block is the system state at that time

$$\textit{Current State} = \textit{Original state} + \textit{All Changes}$$

Use cases abound



Payment System

Health Care Records

Real Estate Records

Addendum

High Energy Use

- As of Apr. 2018, the overall Bitcoin P2P network used cca. 930 kWh per *transaction* (not block)!
  - https://digiconomist.net/bitcoin-energy-consumption
  - Only slightly more than the *monthly* use of the average US home (900 kWh as of 2016)
- Increase in perceived BTC value → more competing miners → harder PoW difficulty (to maintain 10-minute block creation interval)
  - Non-linear increase in per-transaction electricity use
- Turns out, decentralization is highly expensive!

Blockchain: Executive Summary

Pros:

Authentication built-in

Easy to audit history

Easy to detect data manipulation

Very difficult to disrupt

Cons:

Proof-of-work very inefficient

- Alternatives exist!

State updates are slow

Best for simple computations

Bitcoin

Block #509169

Summary	
Number Of Transactions	1915
Output Total	10,289.28130284 BTC
Estimated Transaction Volume	1,818.68925455 BTC
Transaction Fees	0.4893378 BTC
Height	509169 (Main Chain)
Timestamp	2018-02-14 15:16:59
Received Time	2018-02-14 15:16:59
Relayed By	58COIN
Difficulty	2,874,674,234,415.94
Bits	392292856
Size	1132.416 kB
Weight	3992.574 kWU
Version	0x20000000
Nonce	1858980081
Block Reward	12.5 BTC

Hashes	
Hash	00000000000000000002c4b94355945eea353bc720c58a73c2b8593f489550cb3
Previous Block	00000000000000000001d620a2e3ad126ec5038bf42343c419eb6fcdf7240a471
Next Block(s)	
Merkle Root	3ad680735c45cc62b1ea6b7efeb34f82a2660c5e8280354c45f7ffa03c9137e2

Transactions

ab0da64ea834fd2acb81eb081d8103c9e31fd14a7d055f2ce2718c59dd4fa5df — 2018-02-14 15:16:59

No Inputs (Newly Generated Coins)	14DjTuAUh87cwRsbU1z6W8hZY6FnEkpfLS Unable to decode output address	12.9893378 BTC 0 BTC

12.9893378 BTC

4feb8981da942b10a2a384003fba1c1d78c8f192cd2747e43ae552ed237f267d — 2018-02-14 15:16:59

1H6ZZpRmMnrw8ytepV3BYwMjYYnEkWDqVP	12PaHiRJBmvJYmTpZ32Pswf8eYbKcAE131 1GpqR4vsdvEfgtNyiUrDrfDLTBJvnsentX 1H6ZZpRmMnrw8ytepV3BYwMjYYnEkWDqVP	0.4983 BTC 0.1495 BTC 5.01651602 BTC

5.66431602 BTC

Ethereum

Block 5089469

Previous | Next

Hash:	0x4b7ced1ac95fa07a06fbb0352468797bd038e8c1fb0f6d4de2838f5712469c27
Difficulty:	2,863,007,803,096,150
Miner:	✔ miningpoolhub1 (0xb293...) (Mined in 19s)
Reward:	3.13573 ETH | $2,777.29 (Block Reward: 3 ETH + Fee Reward: 0.13573 ETH + Uncle Inclusion Reward: 0 ETH)
Tx Fees:	0.13573 ETH | $120.22 (4.33% of the total block reward)
Tx / Uncles:	202 Transactions and 0 Uncles
Gas Limit:	8,000,029
Gas Usage:	83.8 % (6,701,815 of 8,000,029)
Lowest Gas Price:	1 GWei
Time:	02/14/2018 10:31:12 AM (a minute ago)
Size:	28,742 bytes
Extra	t3 (Raw: 0x7433)

202 Transactions | 0 Uncles | Details

Hash	Type	From	To	Value	Fee	Gas Price
0x00622dc883...	Tx	0x5BaEac0a0417a...	0x342DB8C17dF30...	0.03175 ETH	0.0021 ETH	100 GWei
0x2f21a28b88...	Tx	0x96b7DA642FAA7...	0xee4d84B1E8C78...	0.01 ETH	0.00208 ETH	99 GWei
0x4a6a150361...	Tx	✔ Bittrex (0xfbb1...)	0x419D0d8BdD9aF...	0 ETH	0.00531 ETH	90 GWei
↳	Call	0x419D0d8BdD9aF...	0x267808e5246D1...	0 ETH	0.0028 ETH	90 GWei
↳	Call	0x267808e5246D1...	0xe6a51Bd48f93A...	0 ETH	0.00247 ETH	90 GWei
0x7359bb70de...	Tx	0x45a0ba49c5244...	0xAA1A6e3e6EF20...	4.97698 ETH	0.00233 ETH	70 GWei

Existing blockchain programs are vulnerable

- Over **$40M** were stolen from TheDAO due to a bug in the implementation (June 2016)
- **$32M** were stolen due to a bug
  in a commonly used contract (June 2017)
- Bugs in smart contracts cannot be fixed after deployment

We want to build correct software, but current approaches have been shown to have security vulnerabilities

Obsidian: a new programming language

Goals

- Make certain vulnerabilities impossible
- Make it easier to write correct programs
- Show effectiveness and correctness

Components

1. Typestate-oriented programming
   - Shown to be helpful in documentation, but no studies of writing code
2. Resource types
   - Integration into an OO-style language is novel

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