Block Consensus: How a Distributed Network Agrees on One Truth

Mini-Lecture — 30 Minutes

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Blockchain, Crypto Economy & NFTs

Learning Objectives:

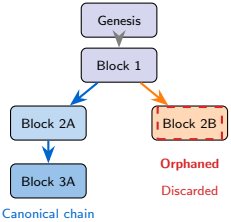
1. Explain how Bitcoin resolves temporary forks when two blocks are found simultaneously
2. Distinguish between "longest chain" and "most cumulative work"
3. Describe why 6 confirmations is the standard finality threshold

The Fork Problem

A Thought Experiment

Two miners in different countries solve the proof-of-work puzzle within milliseconds of each other. Both blocks are valid. The network's 50,000 nodes temporarily disagree about which block is canonical.

This happens roughly **once every 1–2 weeks** in Bitcoin — not an error, but an expected consequence of decentralised mining.



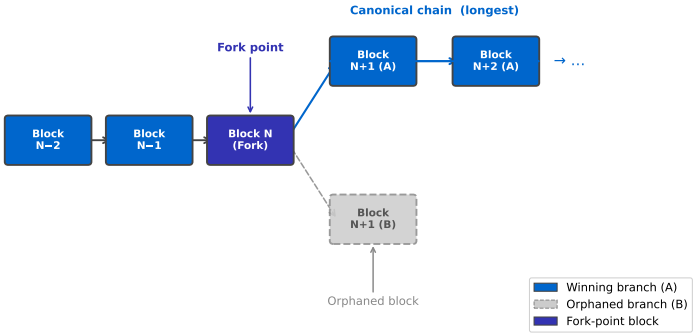
Analogy: Choosing a restaurant without talking. Everyone follows the same rule — *go where the most people are* — and the group converges without coordination.

Bitcoin's fork resolution works the same way: every node applies an identical chain-selection rule, and the network converges automatically.

Fork resolution: blockchain's answer to simultaneous writes in a distributed system

When the Chain Splits

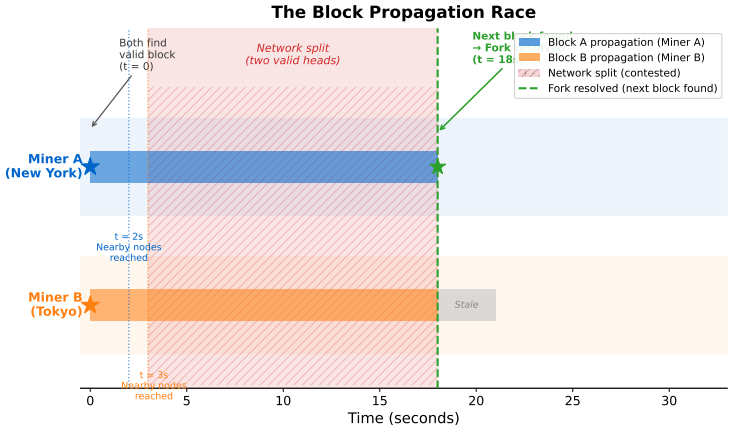
Fork Resolution: Longest Chain Wins



- Each node (circle) represents a valid block proposed by a miner
- Competing branches exist briefly — only one survives as canonical
- Orphaned blocks are discarded; their transactions return to the mempool

Bitcoin experiences natural forks roughly once every 1–2 weeks

The Block Propagation Race



- Block A and Block B race across the network after near-simultaneous discovery
- Nodes adopt whichever block they hear first — network splits temporarily
- The fork resolves when the next block extends one branch, making it longer

Block propagation takes 8–15 seconds — during this window, forks can form

Chain Selection: Length vs. Work

Common misconception: Bitcoin follows the *longest chain*.

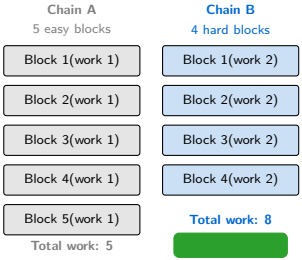
Reality: Bitcoin's code implements *most cumulative proof-of-work*.

Chain	Blocks	Cumulative Work
Chain A	5 blocks @ diff 1	Work = 5
Chain B	4 blocks @ diff 2	Work = 8
Winner		**Chain B**

Why it matters: An attacker cannot cheaply produce many low-difficulty blocks to rewrite history. Each block must represent real, expensive computation.

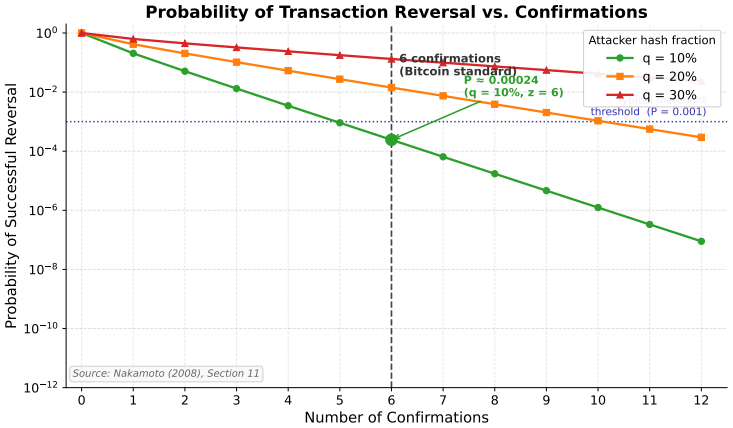
Formula:

$$\text{Cumulative Work} = \sum_i \frac{2^{256}}{\text{target}_i + 1}$$



Satoshi wrote "longest chain" but the code implements "most cumulative work"

Confirmation Probability



- Each confirmation multiplies the computational cost of a reversal attack
- Probability of successful reversal decays exponentially with confirmations
- Assumes attacker controls 10% of hash rate (Nakamoto 2008, Section 11)

Source: Nakamoto (2008), Section 11

The Math: Why 6 Confirmations?

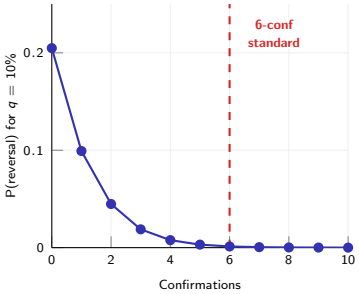
Nakamoto (2008) computed reversal probabilities for an attacker controlling fraction q of total hash rate:

q (attacker)	Confirmations	P(reversal)
10%	1	0.205%
10%	3	0.017%
10%	6	$<$0.002%
30%	6	17.7%

Analogy: Like cement drying — after 10 minutes it is *probably* solid, after 60 minutes it is *practically* solid. The risk never reaches exactly zero.

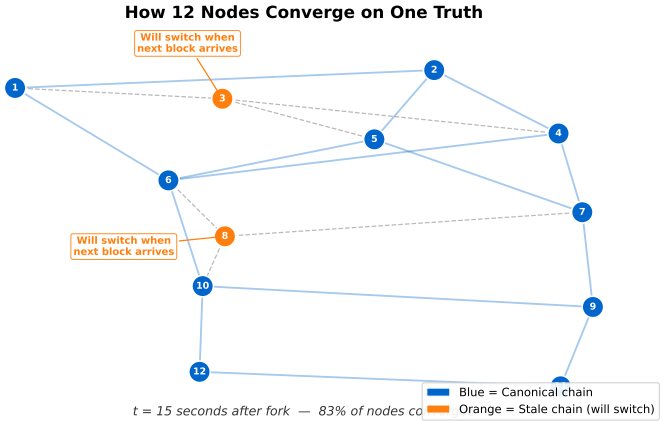
Practical thresholds:

- Coffee shop ($5): 0 confirmations acceptable
- Exchange deposit: 6 confirmations standard
- Large settlement ($1M+): 12+ confirmations



Each confirmation exponentially reduces the probability of reversal

How Nodes Converge



- Across 12 nodes, most converge on the canonical chain within seconds of fork resolution
- Nodes following divergent branches switch automatically once a longer chain is broadcast
- No voting, no leader — agreement emerges from identical rule application

Consensus is emergent — nodes following the same rule produces collective agreement

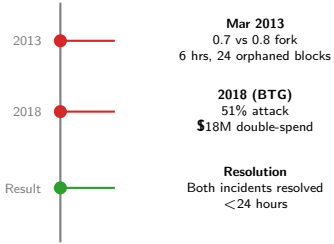
Historical Forks

March 2013 Accidental Fork

Bitcoin 0.7 and 0.8 nodes applied different database lock limits, causing a chain split lasting **6 hours** and orphaning **24 blocks**. Developers coordinated via IRC to downgrade mining pools to 0.7 — the wider-accepted version — allowing the network to converge on a single chain without a hard fork.

Bitcoin Gold 51% Attack (2018)

An attacker rented sufficient hash rate to double-spend **$18M** of Bitcoin Gold across multiple exchanges. The attack succeeded because BTG's hash rate was too low to make renting it expensive. Exchanges were forced to raise their confirmation thresholds to 50+ blocks.

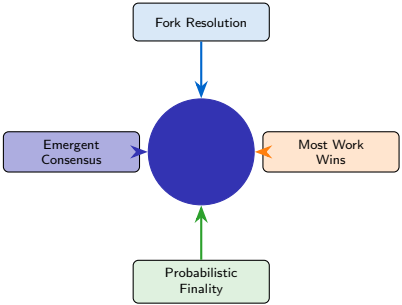


Both incidents resolved within hours — demonstrating Bitcoin's resilience

Key Takeaways

What You Should Now Know

1. **Forks are normal:** Two miners finding valid blocks simultaneously creates a temporary split; the chain-selection rule resolves it automatically within one block.
2. **Most cumulative work wins, not most blocks:** An attacker cannot rewrite history with cheap, low-difficulty blocks — real computation is required.
3. **Finality is probabilistic:** 6 confirmations reduces reversal probability below 0.002% for an attacker with 10% of hash rate — the practical industry standard.
4. **Consensus is emergent:** No voting, no leader, no central coordinator — agreement arises from every node applying the same rule independently.



Fork resolution + chain selection + probabilistic finality = Nakamoto Consensus

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A) Moderately risky — limited protection against a determined double-spend attempt B) Zero risk C) Extremely risky, equivalent to no confirmation D) Safe because miners already validated it

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C – Orphaned transactions re-enter the mempool and are typically re-confirmed within the next few blocks.

Answers reveal on click. Review any incorrect answers before proceeding.

Quiz — Questions 6–10

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A) To limit energy use B) To maximise miner revenue C) To slow transaction throughput D) It makes propagation delay negligible compared to block interval, minimising forks

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D – For tiny amounts, the economics of mounting an attack do not justify the reward; 0-conf is a rational business decision.

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A – As block subsidies decay, transaction fees are the intended long-run security budget — an open research question in Bitcoin economics.

Score: 9–10 Excellent | 7–8 Good | 5–6 Review slides | <5 Re-watch lecture.