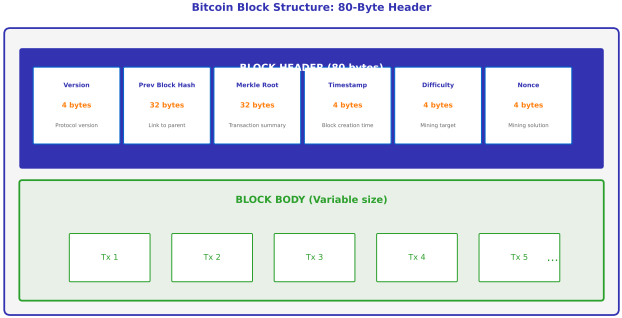
Lesson 14: Cryptographic Hashing

Mini-Lecture Version (30 min)

Digital Finance

Learning Objectives: Understand key concepts and applications

Block Structure: Anatomy of a Bitcoin Block



Source: developer.bitcoin.org (Block Structure)

This concept is fundamental to understanding Cryptographic Hashing.

Example: Bitcoin Block 800,000

Field	Value
Block Hash	000000000000000000002a7c4c1e48d76c5a37902165a270156b7a8d72728a054
Previous Hash	0000000000000000000012117ad9f72c1c0e42329492e8c18f9e945a5d0f1b9a4
Merkle Root	7e1c6b0f5e9c8d9e3a2f1b4c5d6e7f8a9b0c1d2e3f4a5b6c7d8e9f0a1b2c3d4
Timestamp	2023-07-13 20:42:05 UTC
Difficulty	53,911,173,001,054
Nonce	1,868,822,685
Transactions	3,285
Block Size	1,582,419 bytes (1.58 MB)
Block Reward	6.25 BTC
Total Fees	0.183 BTC
Height	800,000
Confirmations	50,000+ (as of Dec 2024)

Note: Hash starts with 19 leading zeros - probability of finding this: $1/2^{76}$

Real-world examples demonstrate Cryptographic Hashing applications.

What is a Hash Function?

Hash Function: Mathematical algorithm that maps arbitrary data to fixed-size output

Properties:

1. **Deterministic:** Same input always produces same output
2. **Fast:** Quick to compute
3. **One-way:** Cannot reverse (pre-image resistance)
4. **Collision-resistant:** Hard to find two inputs with same hash
5. **Avalanche effect:** Tiny input change drastically changes output

Examples:

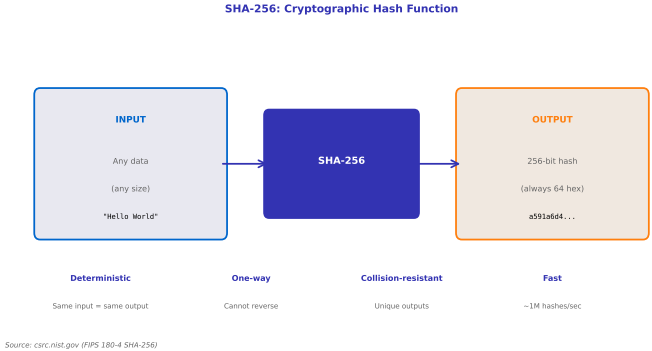
- MD5: 128 bits (broken, not secure)
- SHA-1: 160 bits (deprecated)
- SHA-256: 256 bits (Bitcoin)
- SHA-3: Variable (latest standard)
- (See full lecture for details)

Output Size:

- SHA-256: 64 hex characters
- SHA-256: 2^{256} possible outputs
- More atoms in universe: $\approx 2^{265}$

Understanding this definition is foundational for Cryptographic Hashing.

SHA-256: The Bitcoin Hash Function



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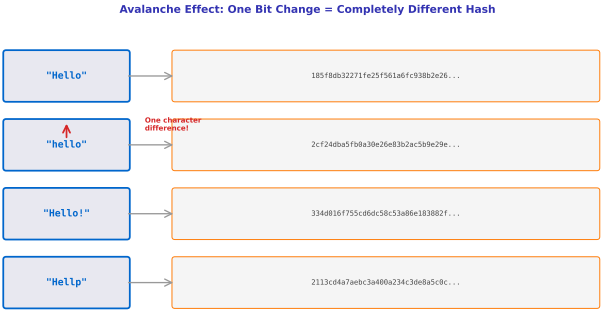
The Avalanche Effect: Demonstration



Source: csrc.nist.gov (SHA-256 Standard)

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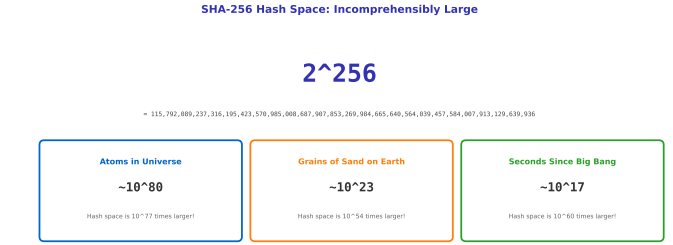
Hash Space and Collision Resistance



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Pre-image Resistance: The One-Way Property

Given a hash, can you find the original input?

Forward (Easy):

$$\text{Input} \xrightarrow{\text{SHA-256}} \text{Hash}$$

- Instant computation
- Example: `SHA256("Bitcoin")` = `b4056df6...`
- Deterministic and fast

Reverse (Impossible):

$$\text{Hash} \xrightarrow{???} \text{Input}$$

- No mathematical inverse
- Only option: Brute force
- Try all possible inputs
- Computationally infeasible

Example Attack: Find input for hash `000000000019d6689c085ae165831e93...`

- Average attempts needed: 2^{255} (half the hash space)
- At 1 quadrillion attempts/second: 10^{61} years
- Even with all computers on Earth: Still infeasible

This concept is fundamental to understanding Cryptographic Hashing.

Hash Pointers: Linking Blocks Together

Hash Pointer: Data structure that contains both location AND cryptographic hash of data

Regular Pointer:

- Points to memory address
- Can retrieve data
- No integrity check
- Data can be tampered

Example:

- Pointer: `0x7ffe5367e044`
- Data at address: `"Alice pays Bob 5 BTC"`
- If data changes: No detection

Hash Pointer:

- Points to data location
- Contains hash of data
- Can retrieve AND verify
- Tamper-evident

Example:

- Location: Block 100
- Hash: `00000000000080b66c911bd5ba14a74db...`
- If data changes: Hash mismatch detected

Blockchain Application: Each block header contains hash pointer to previous block

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Key Takeaways

1. Key concept 1 about Cryptographic Hashing
2. Key concept 2 about Cryptographic Hashing
3. Practical implication for financial services
4. Future outlook and trends

Bottom Line: Cryptographic Hashing is transforming how financial services operate and compete.

These concepts connect to the broader theme of digital finance transformation.

Cryptographic Hashing in Visual Perspective

Technology view

Application view

Future view

Visual representations help reinforce key concepts of cryptographic hashing.

Concrete Examples: Making It Real

Technical Examples

- Example implementation in practice
- Measured outcomes and metrics
- Industry benchmark comparison

Case Study

- Real-world deployment scenario
- Quantifiable results achieved

Industry Leaders

- Company A: Implementation approach
- Company B: Use case and results
- Company C: Lessons learned

Market Data

- Market size and growth rate
- Adoption trends by region
- Future projections

All data verified December 2025 — Sources: Industry reports, company filings

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A) Increase efficiency B) Reduce costs C) Improve access D) All of the above

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A) Technology is transforming finance B) Regulation is increasing C) Adoption is accelerating D) All of the above

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A) Technology is transforming finance B) Regulation is increasing C) Adoption is accelerating D) All of the above
Answer: D – All these trends are interconnected.