

# Distributed System : BitCoin & BlockChain

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# Bitcoin Mania

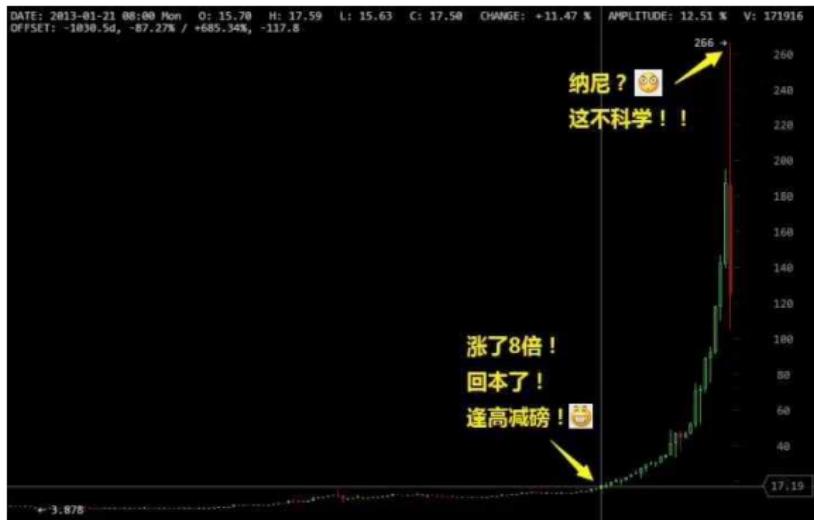
## Bitcoin Charts



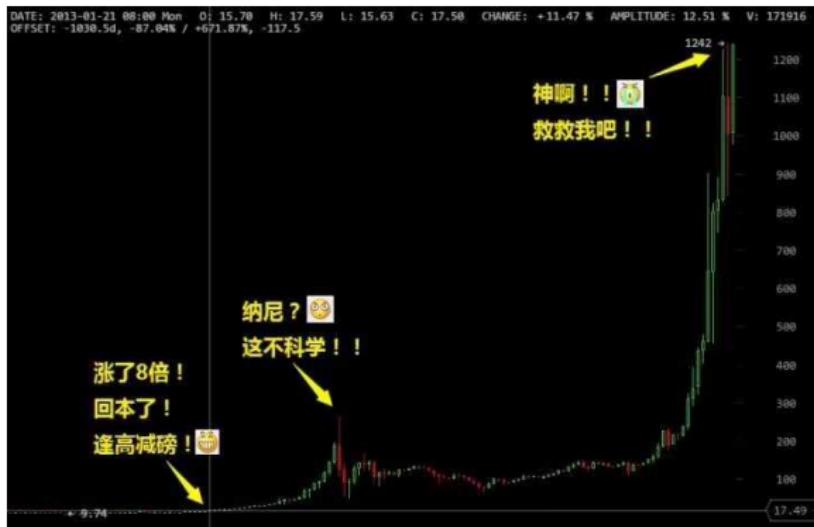
# Bitcoin Mania



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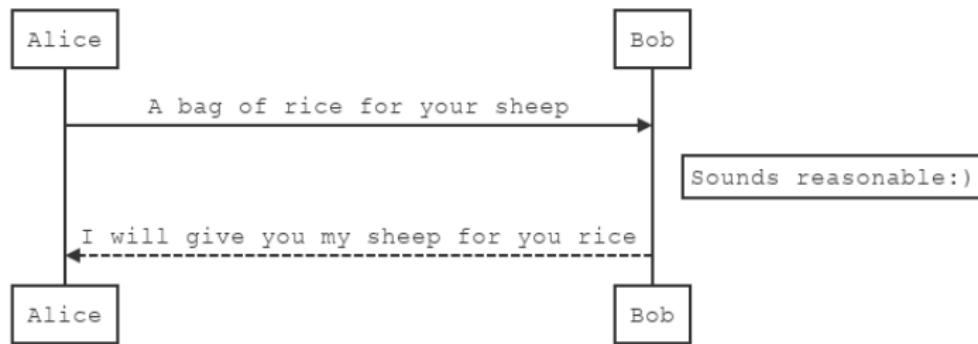


# BlockChain

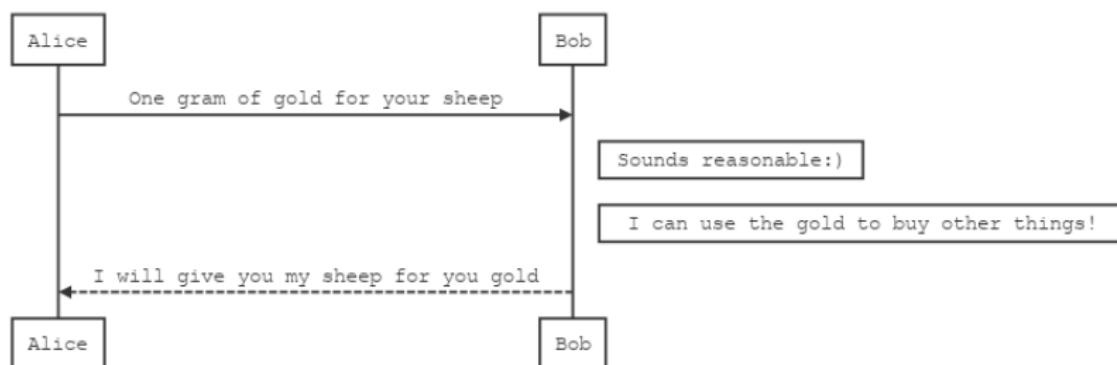
## 国务院 2016 年十三五报告

“十三五”时期，全球信息化发展面临的环境、条件和内涵正发生深刻变化...信息技术创新代际周期大幅缩短，创新活力、集聚效应和应用潜能裂变式释放，更快速度、更广范围、更深程度地引发新一轮科技革命和产业变革。物联网、云计算、大数据、人工智能、机器深度学习、**区块链**、生物基因工程等新技术驱动网络空间从人人互联向万物互联演进，数字化、网络化、智能化服务将无处不在。现实世界和数字世界日益交汇融合，全球治理体系面临深刻变革。全球经济普遍把加快信息技术创新、最大程度释放数字红利，作为应对“后金融危机”时代增长不稳定性和不确定性、深化结构性改革和推动可持续发展的关键引擎。

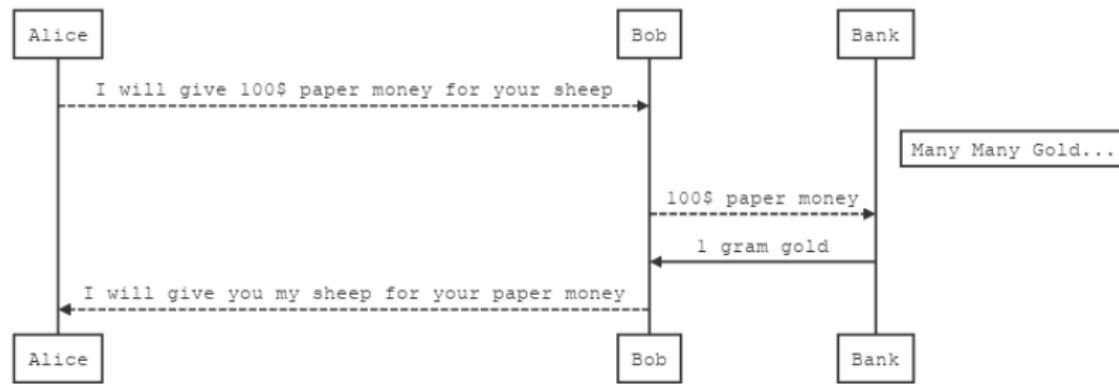
# Barter System



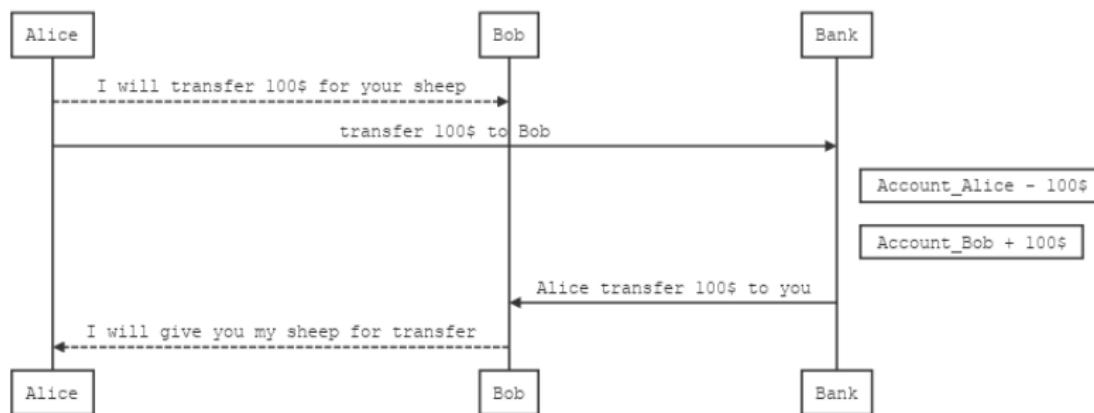
# Gold Money



# Paper Money



# Central Banking



# Nature of Money

## What is Money?

- **Medium of exchange**

- Standard object used in exchanging goods and services

- **Unit of account**

- Standard unit used for quoting prices

- **Store of value**

- Store wealth from one point in time to another

# What is Bitcoin?

## Wikipedia

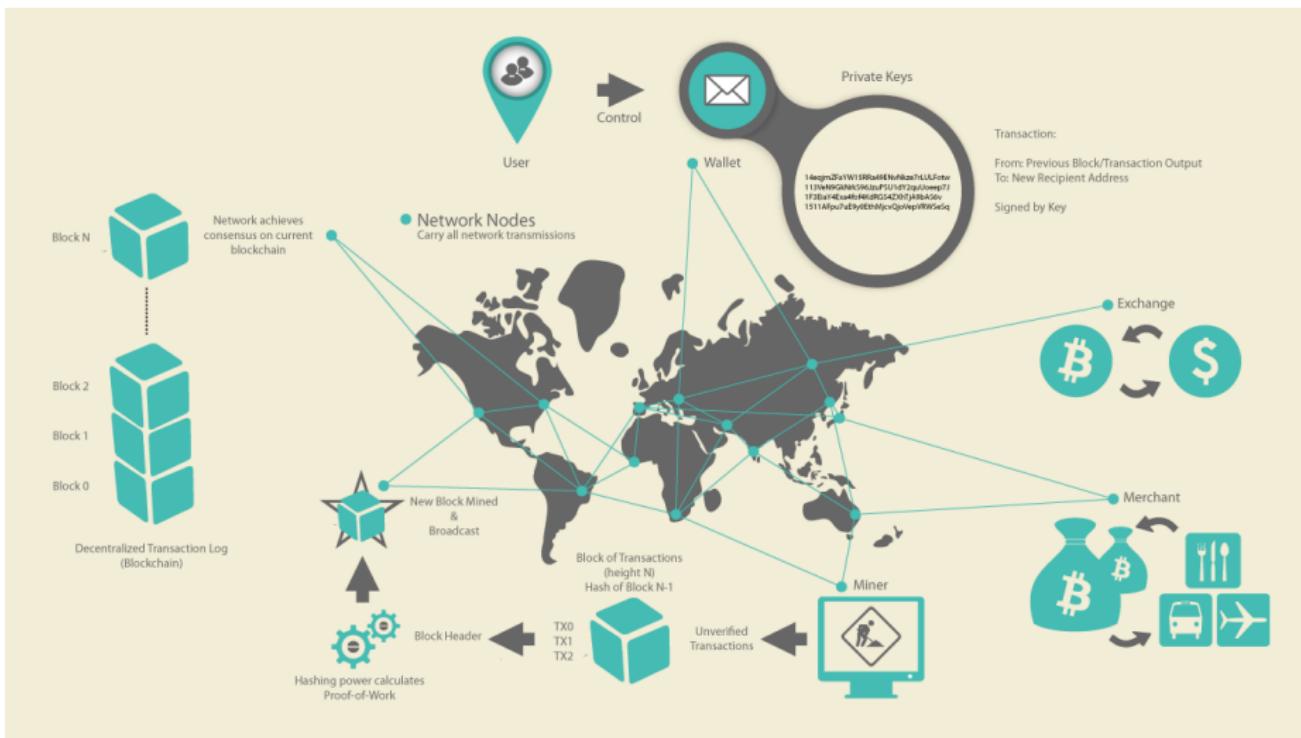
Bitcoin is the first **decentralized digital cryptocurrency**, as the **worldwide payment system** works without a central bank or single administrator. The network is **peer-to-peer** and transactions take place between users directly through the use of cryptography, without an intermediary. These **transactions** are verified by network nodes, which called **mining** and recorded in a **public distributed ledger** called a **blockchain**. Bitcoin was invented by an unknown person or group of people under the name **Satoshi Nakamoto** and released as **open-source software** in 2009.

# Video



Bitcoin, What is it?

# Bitcoin Overview



# Buying a cup of coffee

Alice buys a cup of coffee at Bob's coffee shop, paying with BTC.

```
1 bitcoin:1GdK9UzpHBzqzX2A9JFP3Di4weBwqgmoQA?\n2 amount=0.015&\n3 label=Bob's%20Cafe&\n4 message=Purchase%20at%20Bob's%20Cafe\n5\n6 Components of the URL\n7 A bitcoin address: "1GdK9UzpHBzqzX2A9JFP3Di4weBwqgmoQA"\n8 The payment amount: "0.015"\n9 A label for the recipient address: "Bob's_Cafe"\n10 A description for the payment: "Purchase_at_Bob's_Cafe"\n11
```



# Q & A

# Bitcoin: Challenges

## ■ Creation of a virtual coin

- How is it created in the first place?
- How do you prevent inflation?

## ■ Validation

- Is the coin legit? (**Proof-Of-Work**)
- How do you prevent a coin from **double-spending**?

## ■ Buyer and seller protection in online transactions

- Buyer pays, but the seller doesn't deliver
- Seller delivers, buyer pays, but the buyer makes a claim

## ■ Trust on third party

- Rely on proof instead of trust
- Verifiable by everyone
- No central bank

# CryptoCurrency



Bitcoin  
**BTC**



Myriad  
**MYR**



Dogecoin  
**DOGE**



Dash  
**DASH**



Expance  
**EXP**



Stellar  
**STR**



Ethereum  
**ETH**



Bitshares  
**BTS**



Supernet  
**UNITY**



Monero  
**XMR**



Factom  
**FCT**



Dashcoin  
**DSH**



Litecoin  
**LTC**



Reddcoin  
**RDD**



Bitcoindark  
**BTCD**



Ripple  
**XRP**



Syscoin  
**SYS**



Clams  
**CLAM**



MaidSafeCoin  
**MAID**



Peercoin  
**PPC**



Qora  
**QORA**



Namecoin  
**NMC**



Emercoin  
**EMC**



Archcoin  
**ARCH**



BlackCoin  
**BLK**



Monacoin  
**MONA**



Primecoin  
**XPM**



Nxt  
**NXT**



Sibcoin  
**SIB**



Novacoin  
**NVC**

# Bitcoin Overview

```
1 function mine()
2 {
3     while (true)
4     {
5         longestChain = getLongestValidChain();
6
7         A number that changes every time, so that you don't waste time
8         trying to calculate a valid blockHash with the same input.
9         nonce = getNewNonce();
10
11        currentTXs = getUnconfirmedTransactionsFromNetwork();
12        newBlock = getNewBlock(longestChain, currentTX, nonce);
13
14        Hash function, and this is what all the *mining* machines are doing
15        blockHash = sha256(newBlock)
16
17        if (meetRequirements(blockHash))
18        {
19            broadcast(newBlock)
20            now the height of the block chain is incremented by 1
21            if the new block is accepted by other peers
22            and all the TXs in the new block are "confirmed"
23        }
24    }
25 }
26
```

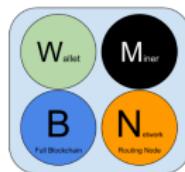
# Bitcoin Overview

```
1 function sendBTC(amount)
2 {
3     sourceTXs = pickConfirmedTransactionsToBeSpent(amount);
4     tx = generateTX(sourceTx, targetAddrs, amount, fee);
5     signedTx = sign(tx, privateKeysOfAllInputAddress);
6     broadcast(signedTx);
7 }
8
```

# P2P Network

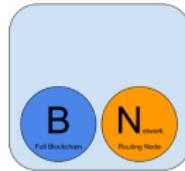
The steps to run the network are as follows:

- New transactions are broadcast to all nodes.
- Each node collects new transactions into a block.
- When node finds a proof-of-work, it broadcast the block to all nodes.
- Nodes accept the block only if all transactions in it are valid and not already spent.
- Nodes express their acceptance of the block by working on creating the next block in the chain, using the hash of the accepted block as previous hash.



## Reference Client (Bitcoin Core)

Contains a Wallet, Miner, full Blockchain database, and Network routing node on the bitcoin P2P network.



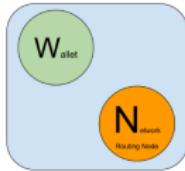
## Full Block Chain Node

Contains a full Blockchain database, and Network routing node on the bitcoin P2P network.



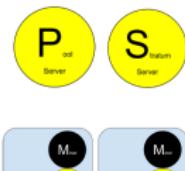
## Solo Miner

Contains a mining function with a full copy of the blockchain and a bitcoin P2P network routing node.



## Lightweight (SPV) wallet

Contains a Wallet and a Network node on the bitcoin P2P protocol, without a blockchain.



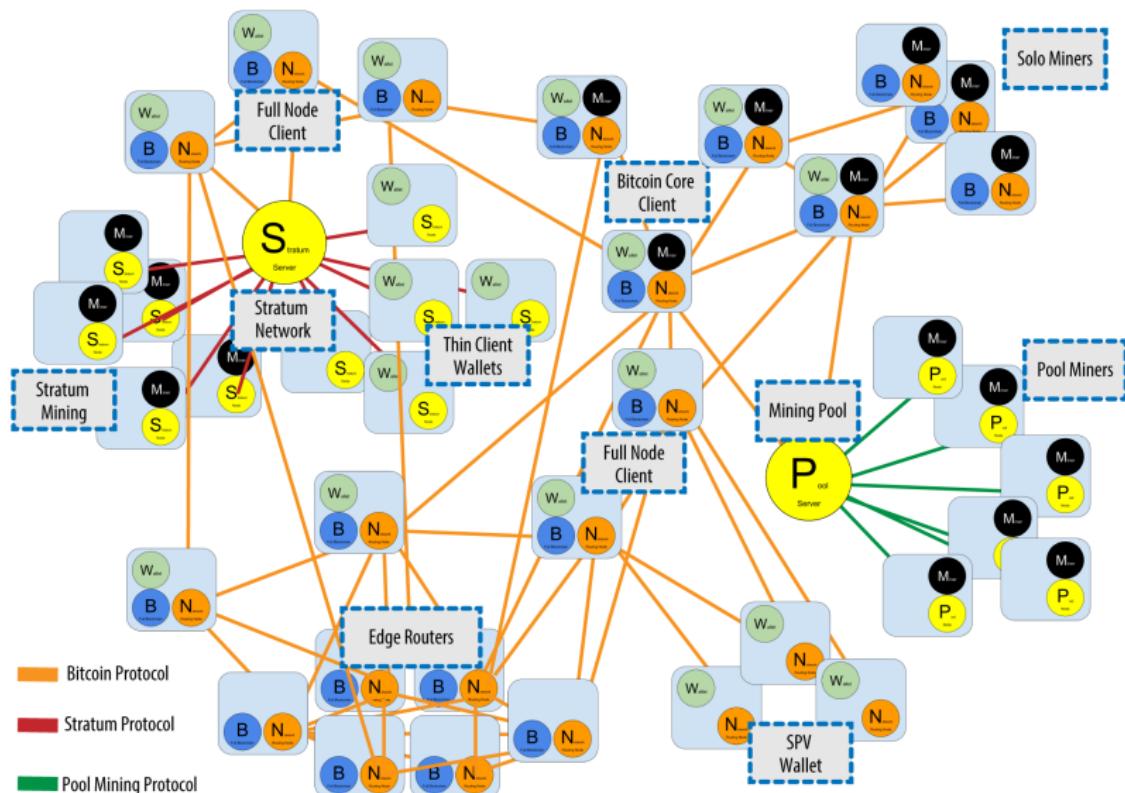
## Pool Protocol Servers

Gateway routers connecting the bitcoin P2P network to nodes running other protocols such as pool mining nodes or Stratum nodes.



## Mining Nodes

Contain a mining function, without a blockchain, with the Stratum protocol node (S) or other pool (P) mining protocol node.



# Security in Bitcoin

## ■ Authentication

- Am I paying the right person?

## ■ Integrity

- Is the coin double-spent?
- Can an attacker reverse or change transactions?

## ■ Availability

- Can I make a transaction anytime I want?

## ■ Confidentiality

- Are my transactions private? Anonymous?

# Security in Bitcoin

- **Authentication -> Public Key Crypto: Digital Signatures**
  - Am I paying the right person?
- **Integrity -> Digital Signatures and Cryptographic Hash**
  - Is the coin double-spent?
  - Can an attacker reverse or change transactions?
- **Availability -> Broadcast messages to the P2P network**
  - Can I make a transaction anytime I want?
- **Confidentiality -> Pesudonymity**
  - Are my transactions private? Anonymous?

# Cryptographic Hash Function

- **Computationally efficient**

- **Consistent**

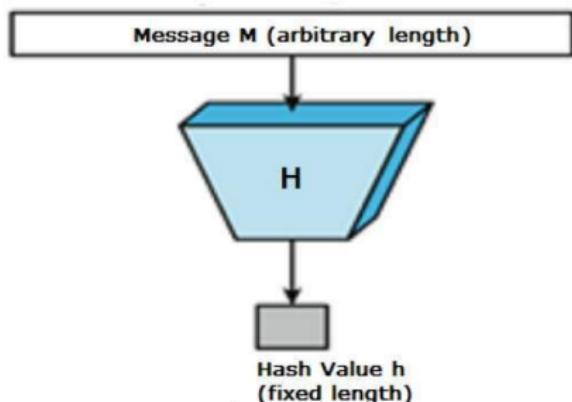
$\text{hash}(x)$  always yields same result.

- **Collision Resistant**

Given  $\text{hash}(W) = Z$ , hard to find  $X$  such that  $\text{hash}(X) = Z$

- **One-way**

Given  $Y$ , hard to find  $X$  s.t.  $\text{hash}(X) = Y$



Common Hash Functions:

- MD5
- SHA-1
- SHA-2
- SHA-256
- SHA-384
- SHA-512

# Hash Function Example

```

1  SHA224("")           0x d14a028c2a3a2bc9476102bb288234c415a2b01f828ea62ac5b3e42f
2  SHA256("")           0x e3b0c44298fc1c149afbf4c8996fb92427ae41e4649b934ca495991b7852b855
3
4
5

```

Even a small change in the message will result in a mostly different hash.

```

1  SHA224("The\u00e9quick\u00e9brown\u00e9fox\u00e9jumps\u00e9over\u00e9the\u00e9lazy\u00e9dog")
2  0x 730e109bd7a8a32b1cb9d9a09aa2325d2430587ddbc0c38bad911525
3  SHA224("The\u00e9quick\u00e9brown\u00e9fox\u00e9jumps\u00e9over\u00e9the\u00e9lazy\u00e9dog .")
4  0x 619cba8e8e05826e9b8c519c0a5c68f4fb653e8a3d8aa04bb2c8cd4c
5

```

Proof of work first sight:

Given a basic string **hello world!** + random number **nonce**

We need the digest have 4 leading 0.

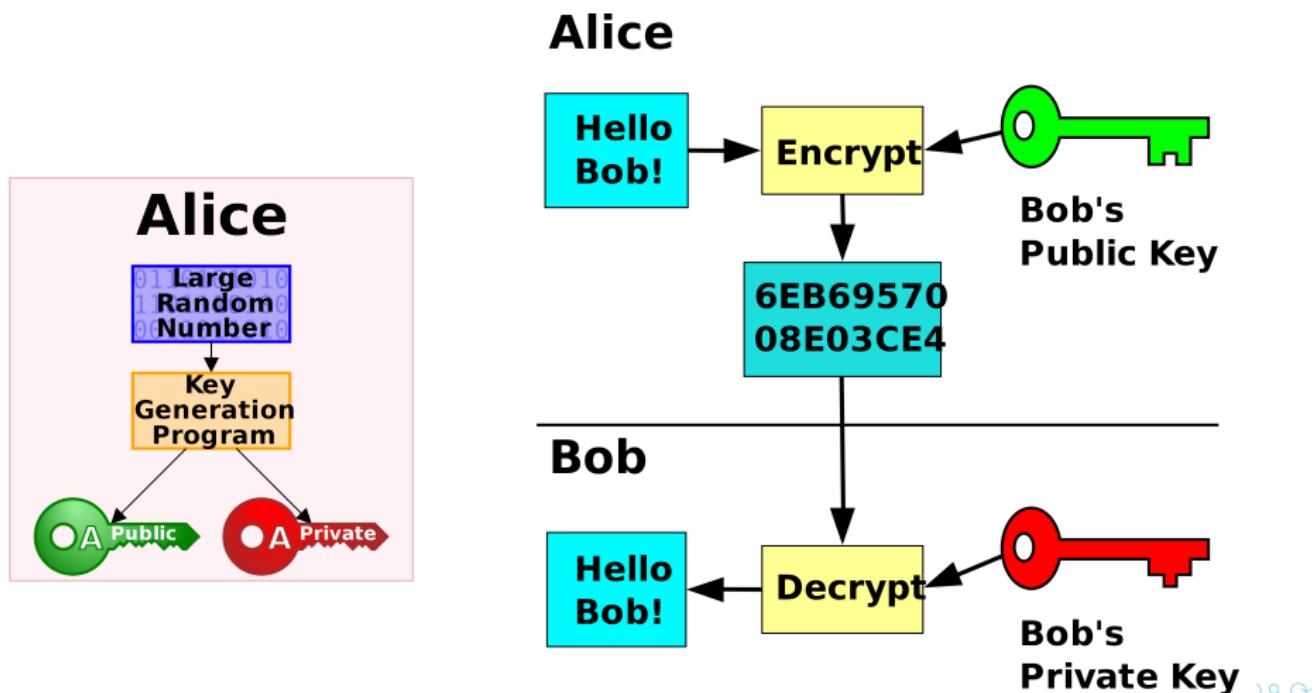
```

1  "Hello,\u00e9world!0" => 1312af178c253f84028d480a6adc1e25e81caa44c749ec81976192e2ec934c64
2  "Hello,\u00e9world!1" => e9afc424b79e4f6ab42d99c81156d3a17228d6e1eef4139be78e948a9332a7d8
3  "Hello,\u00e9world!2" => ae37343a357a8297591625e7134cbea22f5928be8ca2a32aa475cf05fd4266b7
4  ...
5  "Hello,\u00e9world!4248" => 6e110d98b388e77e9c6f042ac6b497cec46660def75a55ebc7cfdf65cc0b965
6  "Hello,\u00e9world!4249" => c004190b822f1669cac8dc37e761cb73652e7832fb814565702245cf26ebb9e6
7  "Hello,\u00e9world!4250" => 0000c3af42fc31103f1fdc0151fa747ff87349a4714df7cc52ea464e12dc4e9
8

```

# Public Key Crypto: Encryption

Key pair: Public Key and Private Key

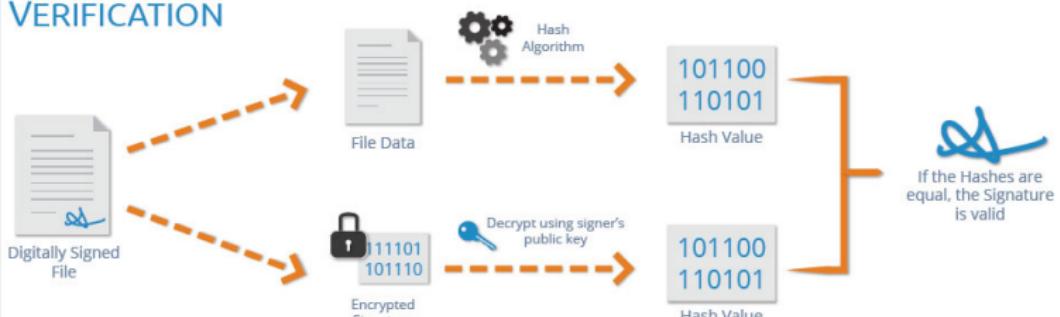


# Public Key Crypto: Digital Signature

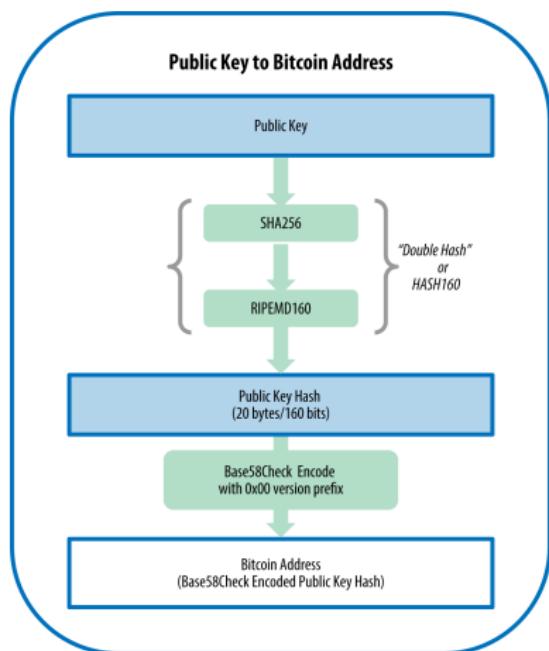
## SIGNING



## VERIFICATION



# Public Key to Bitcoin Address



# Transactions

## Transaction 7957a35fe64f80d234d76d83a2a8f1a0d8149a41d81de548f0a65a8a999f6f18

INPUTS From  
From (previous transactions Joe has received):  
Joe 0.1000 BTC

### OUTPUTS To

Output #0 Alice's Address

0.1000 BTC (spent)

Transaction Fees: 0.0005 BTC

## Transaction 0627052b6f28912f2703066a912ea577f2ce4da4caa5a5fbdb8a57286c345c2f2

INPUTS From  
From (previous transactions Alice has received):  
Alice 0.1000 BTC

### OUTPUTS To

Output #0 Bob's Address

0.0150 BTC (spent)

Output #1 Alice's Address (change) 0.0845 BTC (unspent)

0.0005 BTC

Transaction Fees: 0.0005 BTC

## Transaction 2bbac8bb3a57a2363407ac8c16a67015ed2e88a4388af58cf90299e0744d3de4

INPUTS From  
From (previous transactions Bob has received):  
Bob 0.0150 BTC

### OUTPUTS To

Output #0 Gopesh's Address

0.0100 BTC (unspent)

Output #1 Bob's Address (change) 0.0845 BTC (unspent)

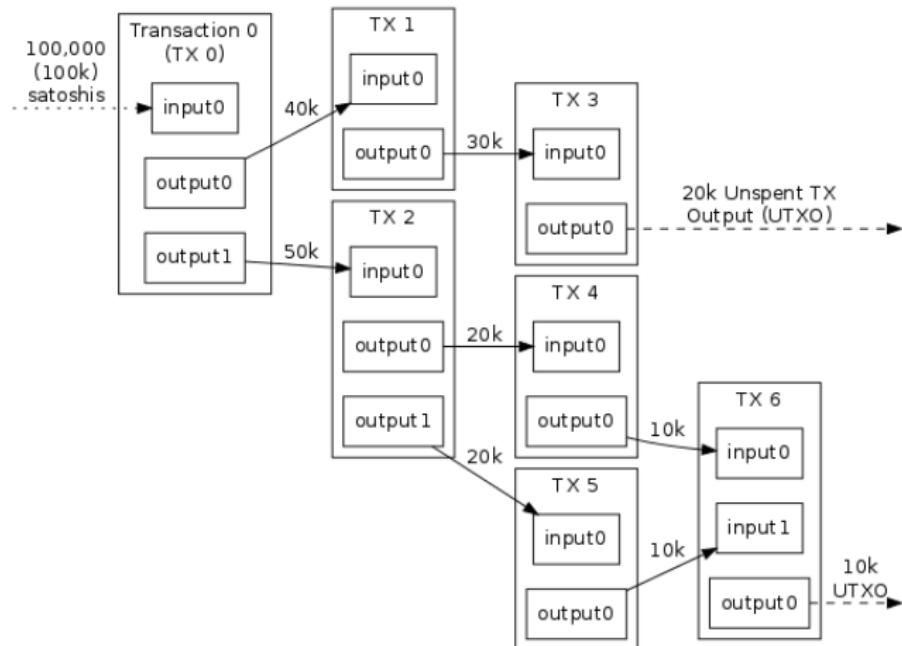
0.0005 BTC

Transaction Fees:

- **transaction input:** Where the coin is coming from, usually a previous transaction's output.
- **transaction output:** Assigns a new owner to the value by associating it with a key.
- **transaction fees:** Small payment collected by the miner.

## UTXO(Unspent Transaction Output)

- UXTO is the fundamental building block of a bitcoin transaction.
  - There are **NO Accounts** in bitcoin, there are **ONLY UTXO**.



# Transactions

Transaction as Double-Entry Bookkeeping			
Inputs	Value	Outputs	Value
Input 1	0.10 BTC	Output 1	0.10 BTC
Input 2	0.20 BTC	Output 2	0.20 BTC
Input 3	0.10 BTC	Output 3	0.20 BTC
Input 4	0.15 BTC		
Total Inputs:	0.55 BTC	Total Outputs:	0.50 BTC
<u>Inputs</u>	<u>0.55 BTC</u>		
<u>Outputs</u>	<u>0.50 BTC</u>		
Difference	<u>0.05 BTC (implied transaction fee)</u>		

Table 5-1. The structure of a transaction

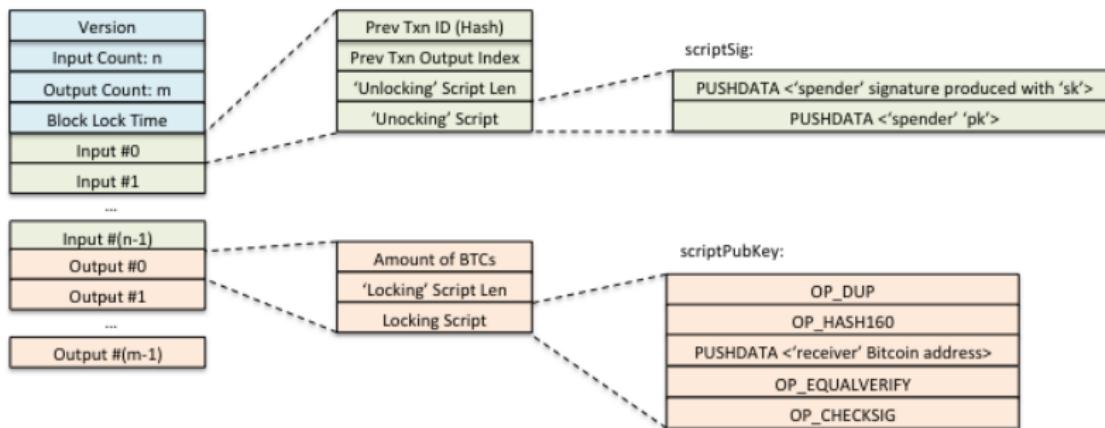
Size	Field	Description
4 bytes	Version	Specifies which rules this transaction follows
1-9 bytes (VarInt)	Input Counter	How many inputs are included
Variable	Inputs	One or more Transaction Inputs
1-9 bytes (VarInt)	Output Counter	How many outputs are included
Variable	Outputs	One or more Transaction Outputs
4 bytes	Locktime	A unix timestamp or block number

- A transaction is a transfer of bitcoin value that is broadcast to the network and collected into blocks.
- A transaction typically references previous transaction outputs as new transaction inputs and dedicates all input Bitcoin values to new outputs.
- Once transactions are buried under enough **confirmations** they can be considered **irreversible**.

# Regular Bitcoin Transaction

## Transaction Data Structure:

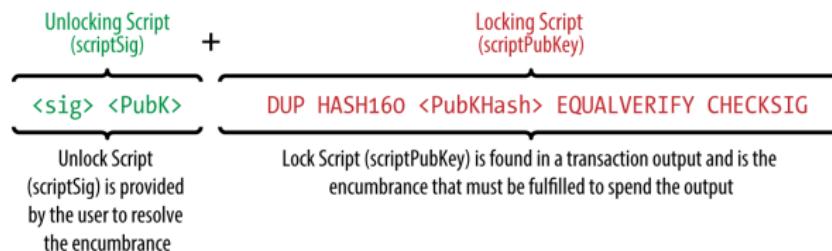
Bitcoin Transaction Message



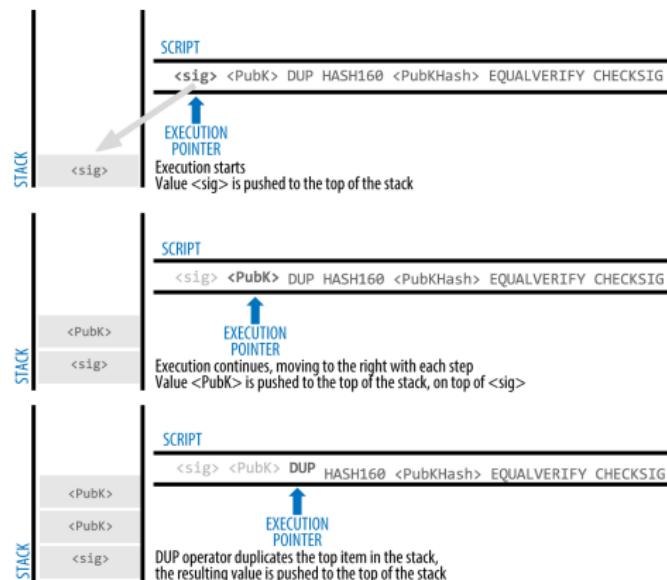
## Transaction Example: The Famous Pizza Transaction

# Transaction Script: Lock + Unlock

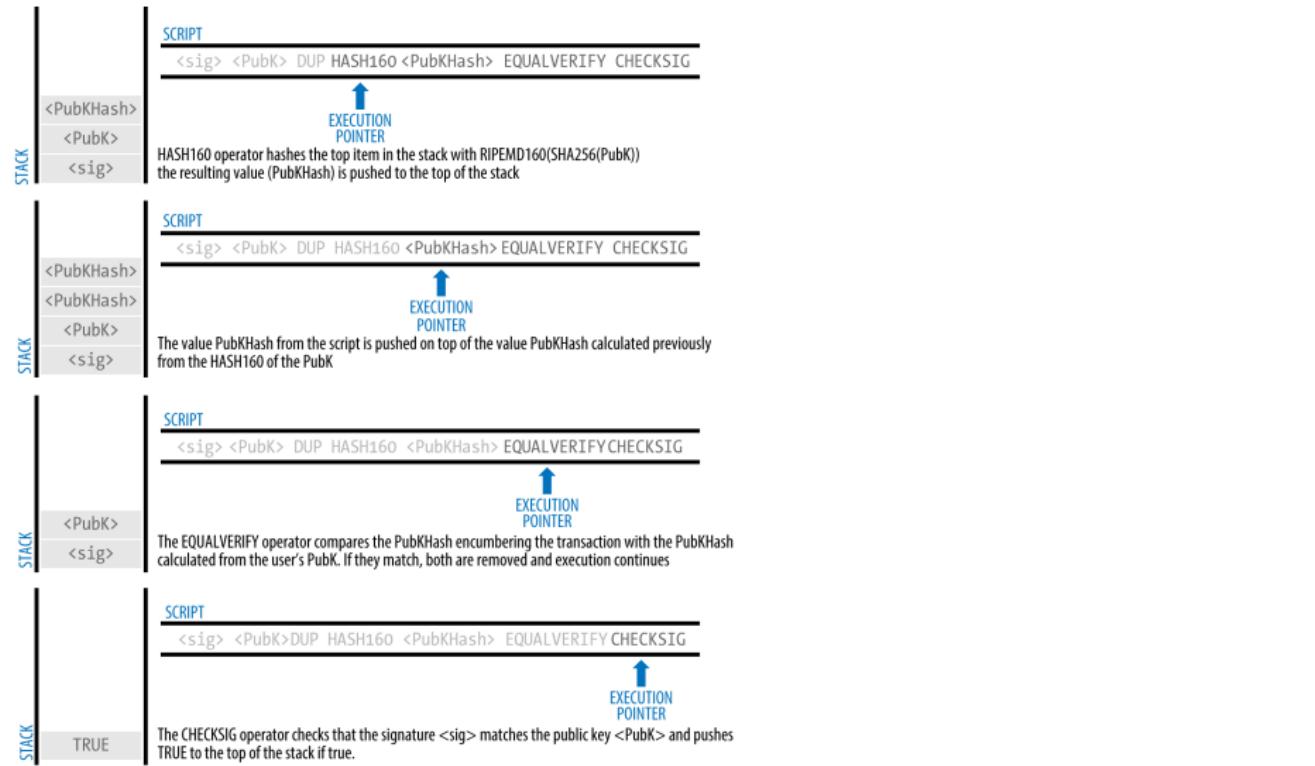
- Transaction Verification relies on **Locking Script** and **Unlocking Script**
- A Locking Script(**scriptPubkey**) specifies the conditions that must be met to spend the output in the future.
- An Unlocking Script(**scriptSig**) solves the conditions placed on an output by a Locking Script and allows the output to be spent.
- Every bitcoin client will validate transactions by executing the locking and unlocking scripts together.



# Transaction Script

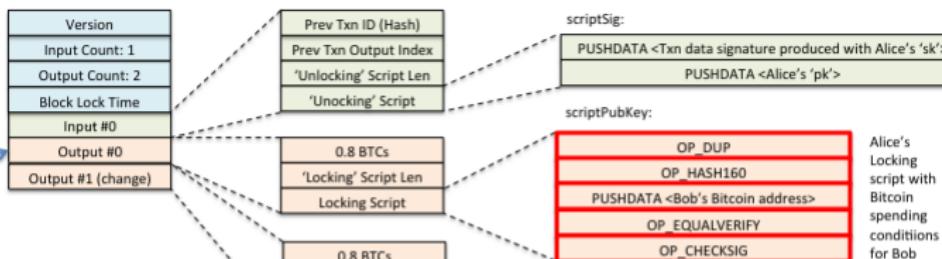


# Transaction Script

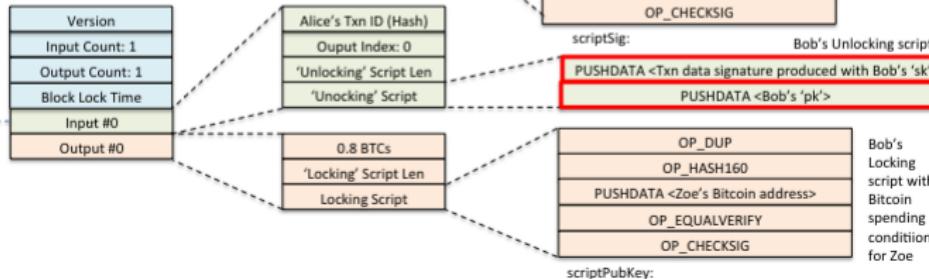


# Bitcoin Transaction Verification

Alice's Transaction Message (previous)

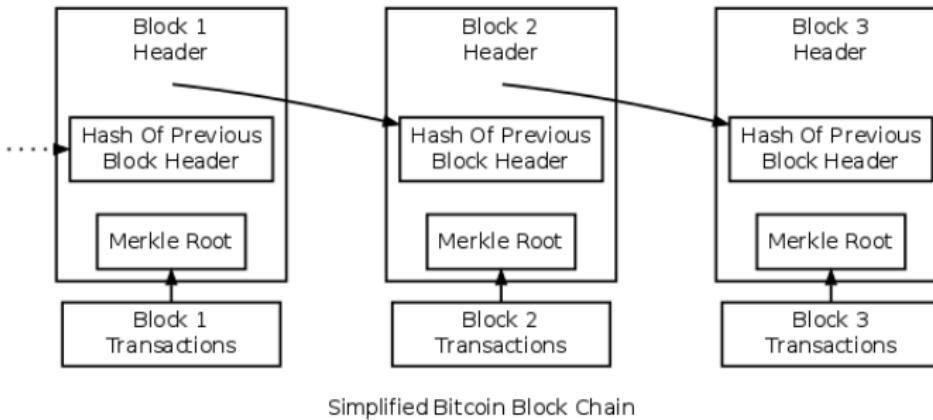


Bob's Transaction Message (current)



# BlockChain Overview

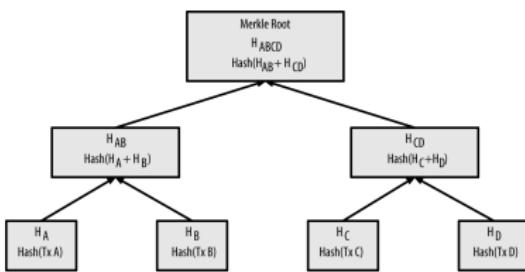
- The block chain provides Bitcoin's public ledger, an ordered and timestamped record of transactions.
- This system is used to protect against double spending and modification of previous transactions records.
- Each full node in the Bitcoin network independently stores a block chain containing only blocks validated by that node.



# BlockChain Data Structure

version	02000000
previous block hash (reversed)	17975b97c18ed1f7e255adf297599b55 330edab87803c817010000000000000000
Merkle root (reversed)	8a97295a2747b4f1a0b3948df3990344 c0e19fa6b2b92b3a19c8e6badc141787
timestamp	358b0553
bits	535f0119
nonce	48750833
transaction count	63
coinbase transaction	
transaction	
...	

Block hash  
 0000000000000000  
 e067a478024addfe  
 cdc93628978aa52d  
 91fabd4292982a50



- **Block Header:** 80 bytes, whereas transactions is at least 250 bytes.
- **Nonce:** A counter used for proof-of-work algorithm.
- **Difficulty:** How difficult it is to find a hash below a given target.
- **Coinbase:** The content of the **input** of a generation transaction.

1 The Times 03/Jan/2009 Chancellor on brink of second bailout for banks.

## The Genesis Block

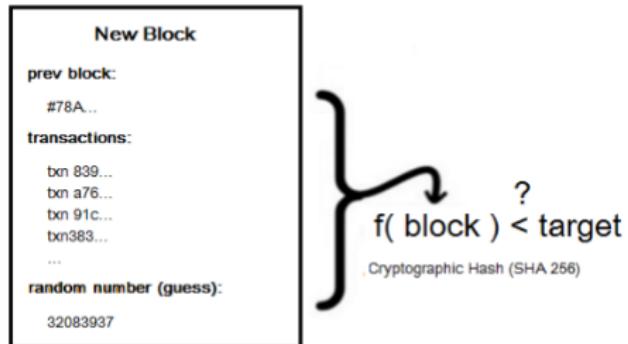
```
1 bitcoin getblock 000000000019d6689c085ae165831e934ff763ae46a2a6c172b3f1b60a8ce26f
2 {
3     "hash" : "000000000019d6689c085ae165831e934ff763ae46a2a6c172b3f1b60a8ce26f",
4     "confirmations" : 308321,
5     "size" : 285,
6     "height" : 0,
7     "version" : 1,
8     "merkleroot" : "4a5e1e4baab89f3a32518a88c31bc87f618f76673e2cc77ab2127b7afdeda33b",
9     "tx" : [
10         "4a5e1e4baab89f3a32518a88c31bc87f618f76673e2cc77ab2127b7afdeda33b"
11     ],
12     "time" : 1231006505,
13     "nonce" : 2083236893,
14     "bits" : "1d00ffff",
15     "difficulty" : 1.00000000,
16     "nextblockhash" : "00000000839a8e6886ab5951d76f411475428afc90947ee320161bbf18eb6048"
17 }
18 }
```

The difficulty value updates every 2 weeks to ensure that it takes 10 minutes(on average) to add a new block to the BlockChain.

# Proof Of Work

- Block contains transactions to be validated and previous hash value.
- Pick a nonce such that  $H(\text{prev hash}, \text{nonce}, \text{Tx}) < E$ .
- Verification is easy, But proof-of-work is hard.

## Block Puzzle



## Difficulty Target and Re-Target

Every 2016 blocks, all nodes re-target the Proof-of-Work difficulty.

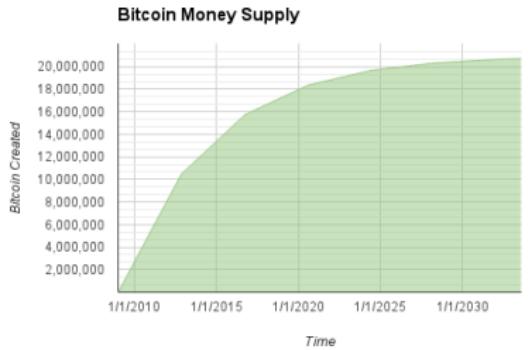
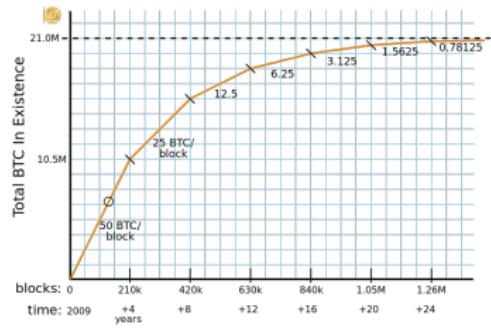
## Re-Target Code in bitcoind

```
1 // Limit adjustment step
2 int64_t nActualTimespan = pindexLast->GetBlockTime() - nFirstBlockTime;
3 LogPrintf("nActualTimespan=%d before bounds\n", nActualTimespan);
4 if (nActualTimespan < params.nPowTargetTimespan/4)
5     nActualTimespan = params.nPowTargetTimespan/4;
6 if (nActualTimespan > params.nPowTargetTimespan*4)
7     nActualTimespan = params.nPowTargetTimespan*4;
8
9 // Retarget
10 const arith_uint256 bnPowLimit = UintToArith256(params.powLimit);
11 arith_uint256 bnNew;
12 arith_uint256 bnOld;
13 bnNew.SetCompact(pindexLast->nBits);
14 bnOld = bnNew;
15 bnNew *= nActualTimespan;
16 bnNew /= params.nPowTargetTimespan;
17
18 if (bnNew > bnPowLimit)
19     bnNew = bnPowLimit;
```

# Mining and Consensus

## Definition

Mining **secures** the bitcoin system and enables the emergence of network-wide **consensus** without a **central authority**. The reward of newly mined coins and transaction fees is an **incentive scheme** that aligns the actions of miners with the **security of the network**, while simultaneously implementing the **monetary supply**.



# Decentralize Consensus

When there is no central authority, how can everyone in the network realize consensus?

## ■ tradition consensus algorithm

- Paxos, Raft, ...
- Failure model: Not Byzantine(Node may fail, But not malicious)
- Leader election.
- Focusing on log(database), more universe

## ■ blockchain consensus algorithm

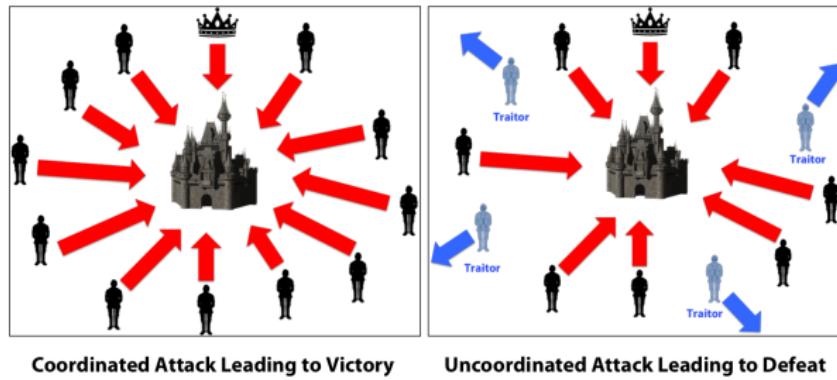
- PoW, PoS(Proof of Stake), ...
- Failure model: Byzantine(Node may be malicious)
- No election.
- Focusing on transaction.

Anyway, all the consensus algorithm comply with the **majority rule**.

# Byzantine Generals' Problem

Story background:

- Generals of army surround enemy city
- Actions in union required to win
- Some generals may be traitors
- Messengers are reliable



# Proof of Work

## ■ Fork

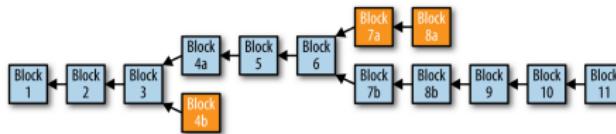
- when 2 miners mine a block at the same time.

## ■ Orphan

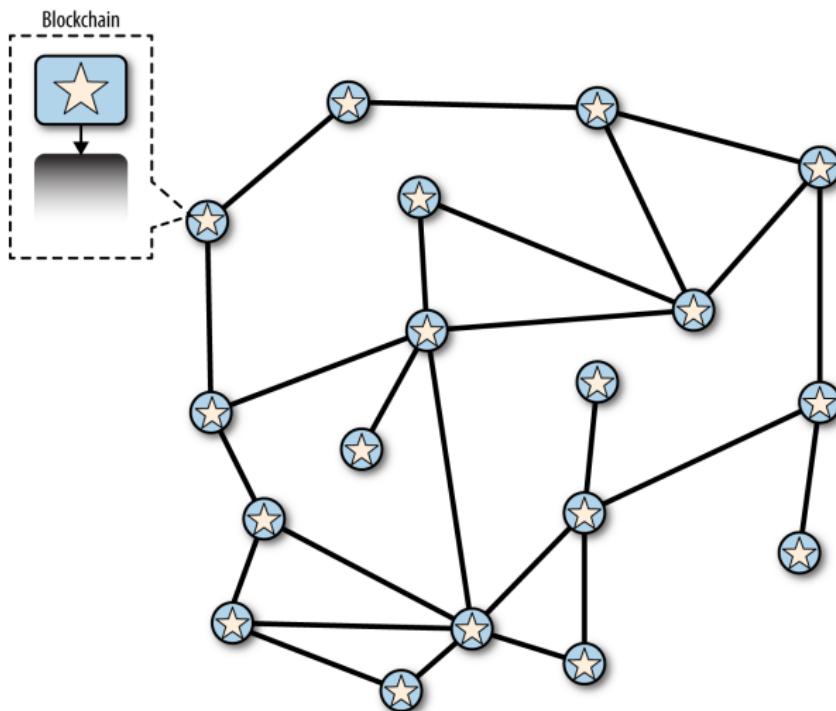
- Only one can be in the chain, the other is called **Orphan**

## ■ Fork/Dispute Resolution

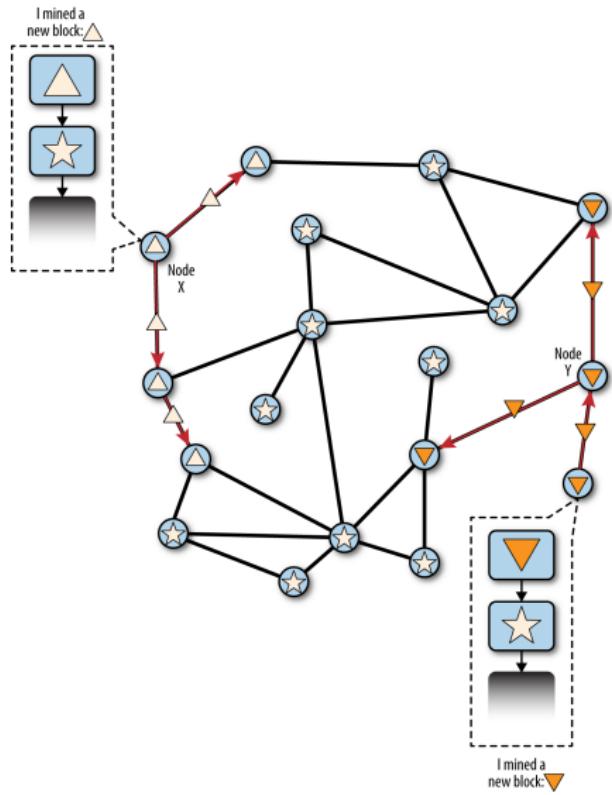
- The longest block chain is valid.



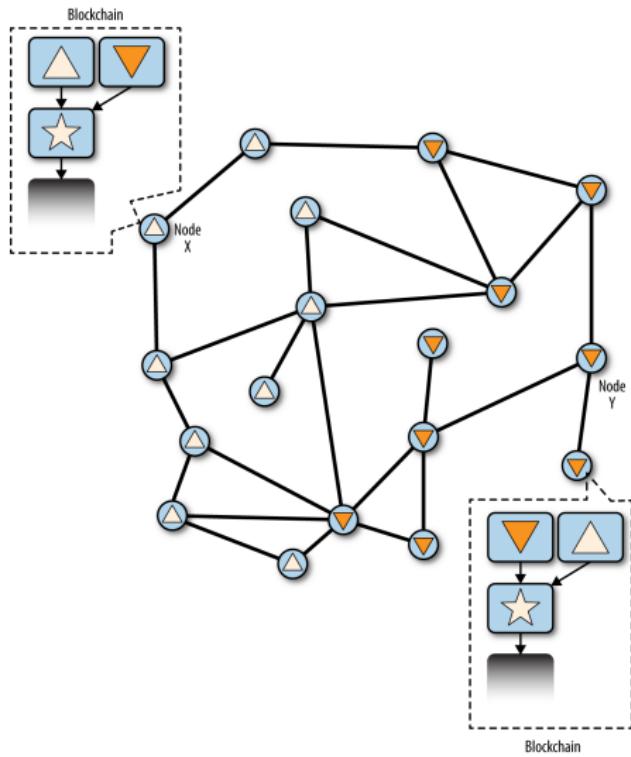
# Block Chain Fork



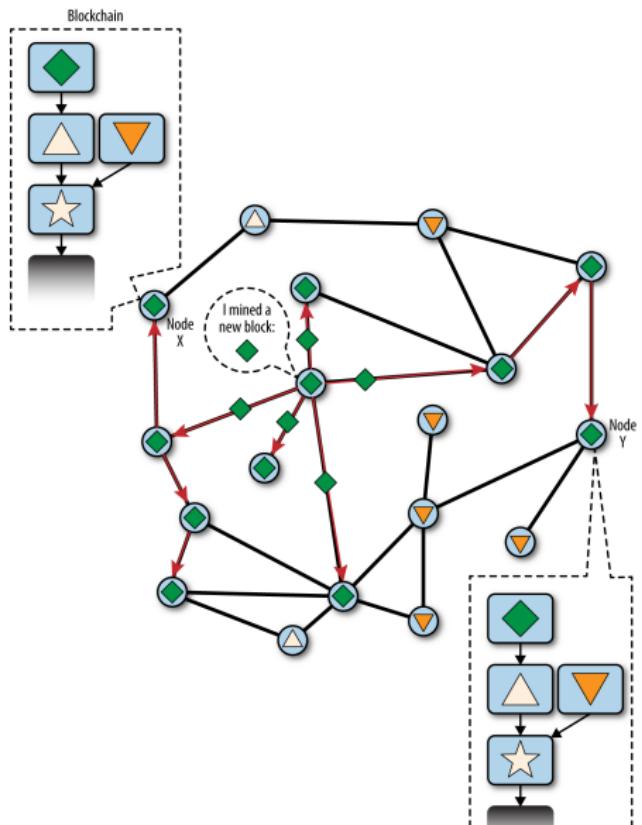
# Block Chain Fork



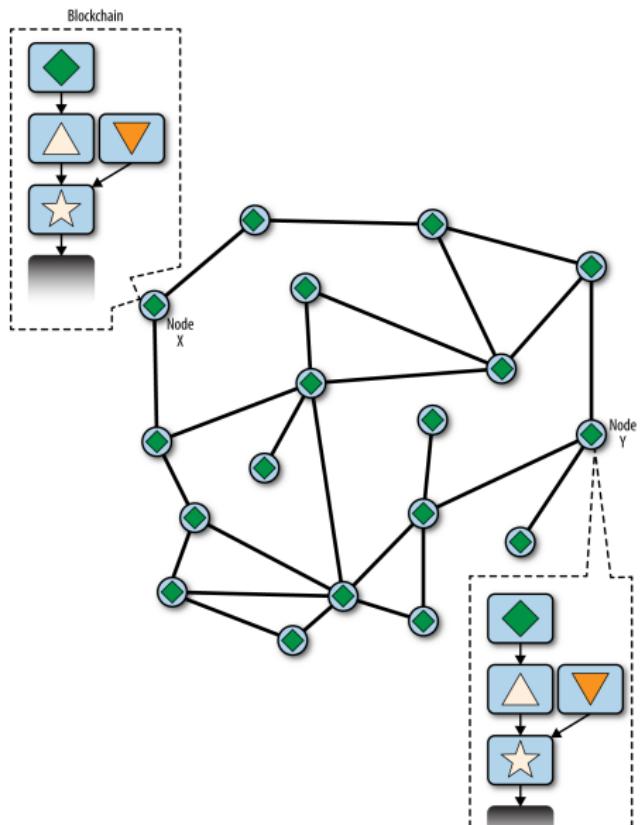
# Block Chain Fork



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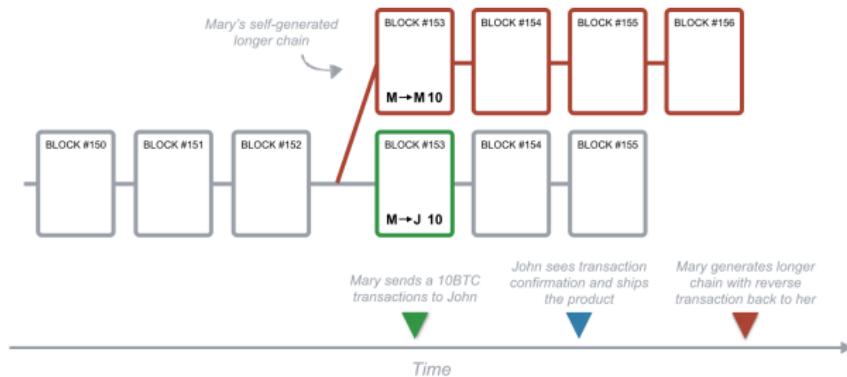


# Block Chain Fork



# Double Spending Attack

Any attacker is competing against the whole network.



- Each block contains a reference to the previous block.
- 51% computing power of the whole network have a 50% chance to solve a block before some other node does.
- Create 2, 3 or more blocks in a row is even harder.

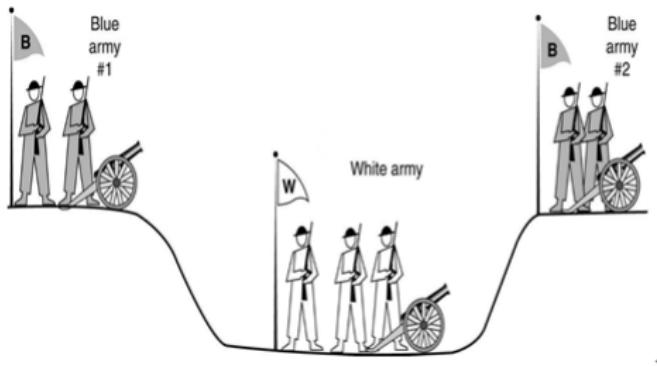
# Blockchain Transactions Security

Transactions get more and more secure with time.

- A block is added to the chain every 10 minutes on average.
- Waiting for 6 blocks (1 hour) gives a quite high probability that the transaction has been processed and is **non reversible**.

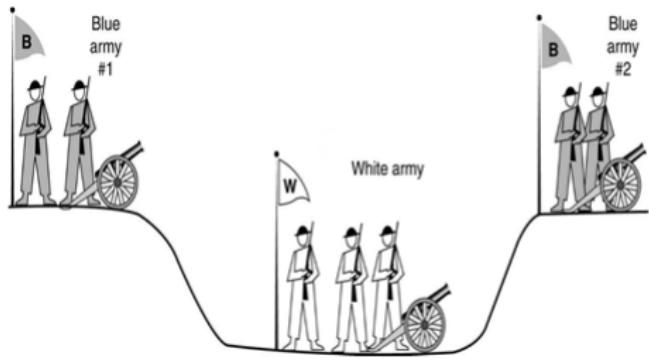


# Two Generals' Problem



- Two **generals** need to coordinate an attack.
  - Must **agree** on time to attack.
  - They will win only if they attack **simultaneously**.
  - Communicate through **messengers**.
  - Messengers may be **killed** on their way.

# Two Generals' Problem

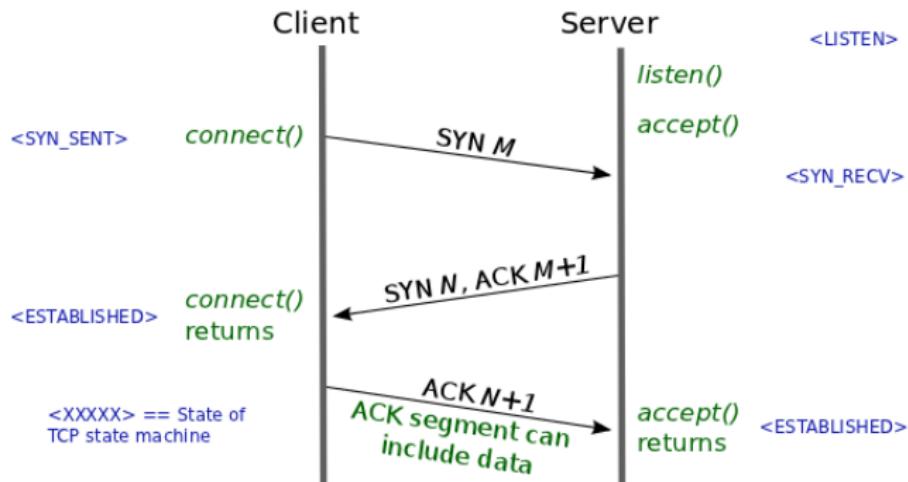


- Let's try to solve it for general g1 and g2.
- g1 sends **time of attack** to g2.
  - Problem: how to ensure g2 received message?
  - Solution: let g2 ack receipt of message.
  - Problem: how to ensure g1 received ack?
  - Solution: let g1 ack the receipt of the ack.
  - ...
- This problem is **impossible** to solve!

# Engineering approaches: TCP handshake

A pragmatic approach to dealing with the Two Generals's Problem

- Accept the **uncertainty** of the Communication channel.
- Not attempt to eliminate it, but mitigate it to an acceptable degree.
- Classic Example is TCP handshake protocol.



# Q & A