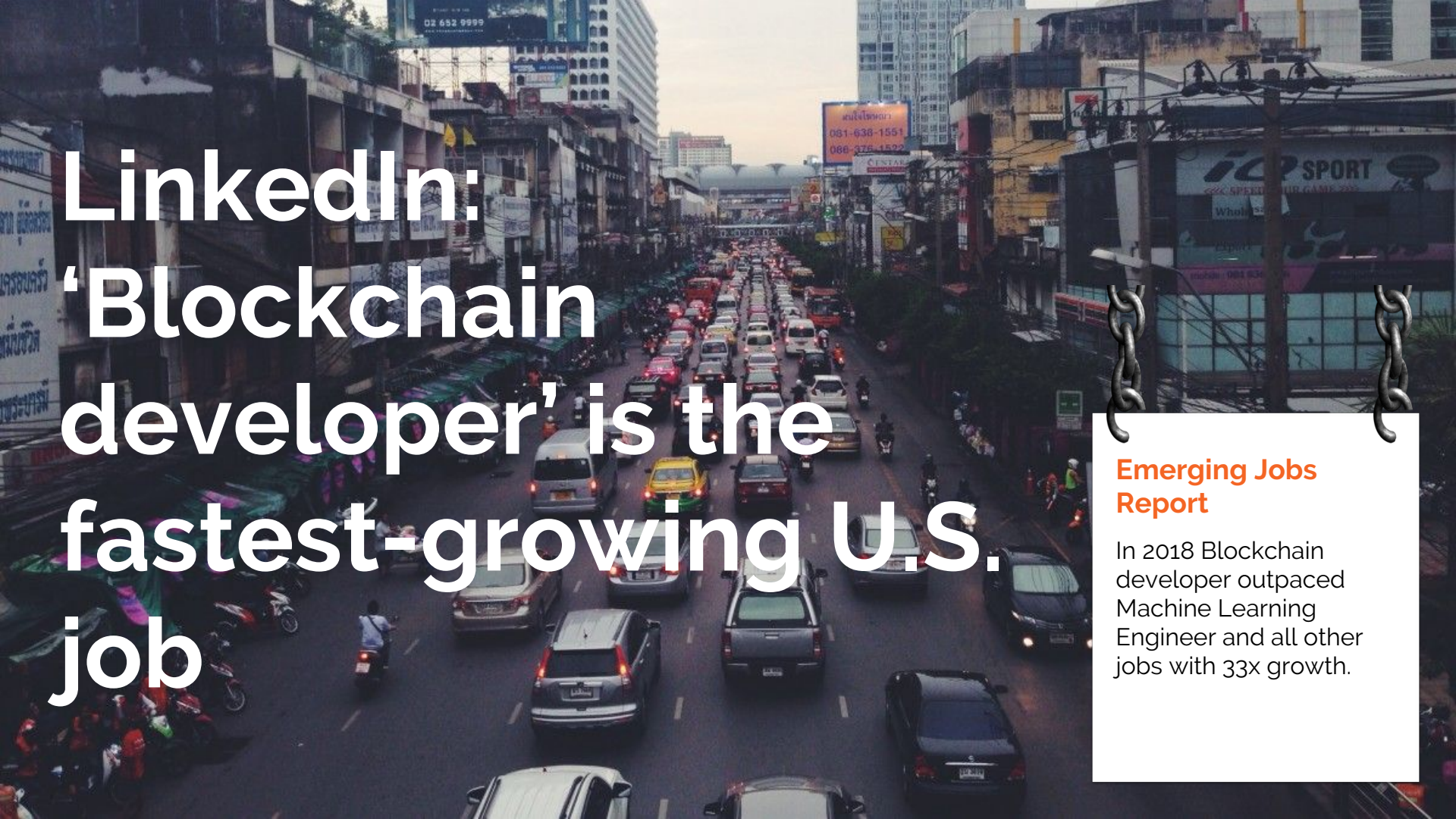
Blockchain Fundamentals:

Creating your own Blockchain

Jordan Baczuk



LinkedIn: ‘Blockchain developer’ is the fastest-growing U.S. job

Emerging Jobs Report

In 2018 Blockchain developer outpaced Machine Learning Engineer and all other jobs with 33x growth.

Who should take this course?

1.2 What is Blockchain?

1. Blockchain

A data structure of time ordered events on which nodes in a distributed network can agree based on a consensus algorithm.

➔ **Data Structure**
A chain of blocks linked by references to the previous block's hash

➔ **Time Order**
Order of events is established

➔ **Consensus**
Network participants agree on what is a valid block. E.g. based on a proof-of-work (hash value threshold).

Block 0

Header

Version 01000000 (1)

Previous Block Hash

0x0000000000000000000000000000000000000000000000000000000000000000 (no previous block)

Transaction Merkle Hash

0x3ba3edfd7a7b12b27ac72c3e67768f617fc81bc3888a51323a9fb8aa4b1e5e4a

Time 1296688602 (2/2/11 11:16)

Bits 0x207fffff (PoW target)

Nonce 0x02000000

Hash

★ 0x0f9188f13cb7b2c71f2a335e3a4fc328bf5beb436012afca590b1a11466e2206

Block 1

Header

Version 01000000 (1)

★ **Previous Block Hash**

0x0f9188f13cb7b2c71f2a335e3a4fc328bf5beb436012afca590b1a11466e2206

Transaction Merkle Hash

0x44aa82c19492f2b2bdbd379618e3aca0af5b120df4864daaf28623bb34ec4bed

Time 1538228638 (9/29/18 1:43)

Bits 0x207fffff (PoW target)

Nonce 0x01000000

Hash

0x172ec34bd4e15ce07b48cc82b3bf4b03b24f66f37e7c68e61a51fbbd63fc2c92

Bitcoin for Individuals

Bitcoin is the easiest way to transact at a very low cost.

Mobile payments made easy

Security and control over your money

Works everywhere, anytime

Bitcoin P2P e-cash paper

Satoshi Nakamoto satoshi at vistomail.com
Fri Oct 31 14:10:00 EDT 2008

- Previous message: Fw: SHA-3 lounge
- **Messages sorted by:** [date] [thread] [subject] [author]

I've been working on a new electronic cash system that's fully
peer-to-peer, with no trusted third party.

The paper is available at:
http://www.bitcoin.org/bitcoin.pdf

The main properties:
 Double-spending is prevented with a peer-to-peer network.
 No mint or other trusted parties.
 Participants can be anonymous.
 New coins are made from Hashcash style proof-of-work.
 The proof-of-work for new coin generation also powers the
    network to prevent double-spending.

Bitcoin: A Peer-to-Peer Electronic Cash System

Abstract. A purely peer-to-peer version of electronic cash would
allow online payments to be sent directly from one party to another
without the burdens of going through a financial institution.
Digital signatures provide part of the solution, but the main
benefits are lost if a trusted party is still required to prevent
double-spending. We propose a solution to the double-spending
problem using a peer-to-peer network. The network timestamps
transactions by hashing them into an ongoing chain of hash-based
proof-of-work, forming a record that cannot be changed without
redoing the proof-of-work. The longest chain not only serves as
proof of the sequence of events witnessed, but proof that it came
from the largest pool of CPU power. As long as honest nodes control
the most CPU power on the network, they can generate the longest
chain and outpace any attackers. The network itself requires
minimal structure. Messages are broadcasted on a best effort basis,
and nodes can leave and rejoin the network at will, accepting the
longest proof-of-work chain as proof of what happened while they
were gone.

Full paper at:
http://www.bitcoin.org/bitcoin.pdf

Satoshi Nakamoto

bitcoin / bitcoin

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Bitcoin Core integration/staging tree https://bitcoincore.org/en/download

bitcoin c-plus-plus p2p cryptocurrency cryptography

19,196 commits | 5 branches | 213 releases | 603 contributors | MIT

Branch: master | New pull request | Create new file | Upload files | Find file | Clone or download

MarcoFalke Merge #15127: docs: Clarifying testing instructions ... Latest commit 5da08e0 3 hours ago

.github	Get more info about GUI-related issue on Linux	14 days ago
.travis	If tests are ran with (ASan + LSan), Docker needs access to ptrace	12 days ago
.tx	tx: Update transifex slug 016x→017x	5 months ago
build-aux/m4	Bump the minimum Qt version to 5.2	2 months ago
build_msvc	Fix the build problem in libbitcoin_server	5 days ago
contrib	Merge #15054: Update copyright headers to 2018	10 days ago
depends	Merge #13884: depends: Enable bdb unicode support for Windows	6 days ago
doc	Fix download link	2 days ago
share	Merge #14701: build: Add CLIENT_VERSION_BUILD to CFBundleGetInfoString	28 days ago
src	Merge #14517: qt: Fix start with the `-min` option	6 hours ago
test	Merge #15127: docs: Clarifying testing instructions	3 hours ago
.appveyor.yml	appveyor: Script improvement part II	2 months ago
.gitattributes	Separate protocol versioning from clientversion	4 years ago
.gitignore	gitignore contents of db4 folder	3 months ago
.python-version	[test] Travis: enforce Python 3.4 support in functional tests	29 days ago
.travis.yml	Merge #15020: Build: add names to Travis jobs	6 days ago
CONTRIBUTING.md	Botbot.me (IRC logs) not available anymore	8 days ago
COPYING	[Trivial] Update license year range to 2019	10 days ago

Section 2: Fundamentals

2: Fundamentals

2.1 Blocks

2.2 Transactions

2.3 Script

2.4 Addresses

2.5 Mining

2.1 Blocks

```
$ bitcoin-cli -regtest getblockhash 0
0f9188f13cb7b2c71f2a335e3a4fc328bf5beb436012afca590b1a11466e2206

$ bitcoin-cli -regtest getblock
0f9188f13cb7b2c71f2a335e3a4fc328bf5beb436012afca590b1a11466e2206 0
010000000000000000000000000000000000000000000000000000000000000000000000
2b27ac72c3e67768f617fc81bc3888a51323a9fb8aa4b1e5e4adae5494dffff7f20020000
0100000000000000000000000000000000000000000000000000000000ffffffff4d04ffff001
d0104455468652054696d65732030332f4a616e2f32303039204368616e63656c6c6f72206f6e20627269
6e6b206f66207365636f6e64206261696c6f757420666f722062616e6b73ffffffff0100f2052a0100000
0434104678afdb0fe5548271967f1a67130b7105cd6a828e03909a67962e0ea1f61deb649f6bc3f4cef38
c4f35504e51ec112de5c384df7ba0b8d578a4c702b6bf11d5fac00000000
```

Block Structure

1. **Block Header**
   The metadata that is hashed to produce the block hash
2. **Transaction Counter**
   The number of transactions in the block
3. **Transactions**
   The raw transaction data for all transactions in the block

1. Block Header

- **Version (4B)**
  Block format version
- **Previous Block Hash (32B)**
  Hash of the preceding block
- **Merkle Root Hash (32B)**
  Hash of all transactions
- **Time (4B)**
  Epoch timestamp
- **Bits (4B)**
  Compact format of the hash target
- **Nonce (4B)**
  Number incremented during mining

```
$ bitcoin-cli -regtest getblockhash 0
0f9188f13cb7b2c71f2a335e3a4fc328bf5beb436012afca590b1a11466e2206

$ bitcoin-cli -regtest getblock
0f9188f13cb7b2c71f2a335e3a4fc328bf5beb436012afca590b1a11466e2206 0
010000000000000000000000000000000000000000000000000000000000000000000000
0003ba3edfd7a7b12b27ac72c3e67768f617fc81bc3888a51323a9fb8aa4b1e5e4ada
e5494dffff7f2002000000010100000001000000000000000000000000000000000000
000000000000000000000000000000ffffffff4d04ffff001d0104455468652054696d
65732030332f4a616e2f323030392043686616e63656c6c6f72206f6e206272696e6b2
06f66207365636f6e64206261696c6f757420666f722062616e6b73ffffffff0100f2
052a01000000434104678afdb0fe5548271967f1a67130b7105cd6a828e03909a6796
2e0ea1f61deb649f6bc3f4cef38c4f35504e51ec112de5c384df7ba0b8d578a4c702b
6bf11d5fac00000000
```

SHA256

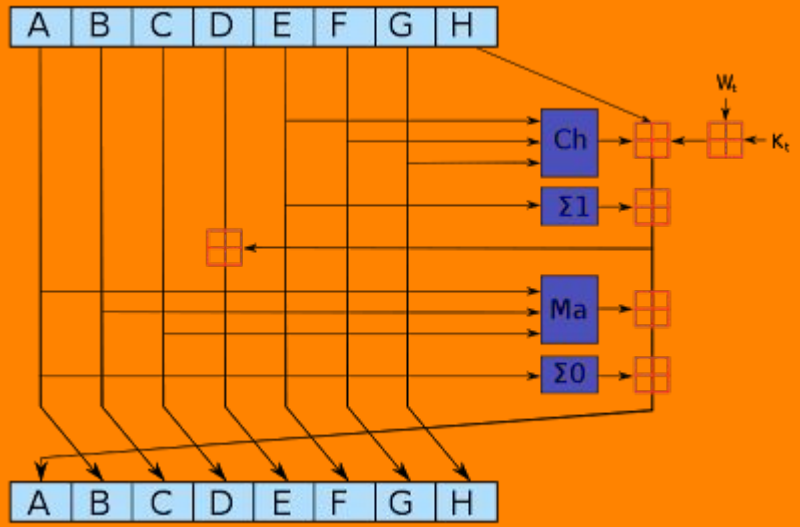


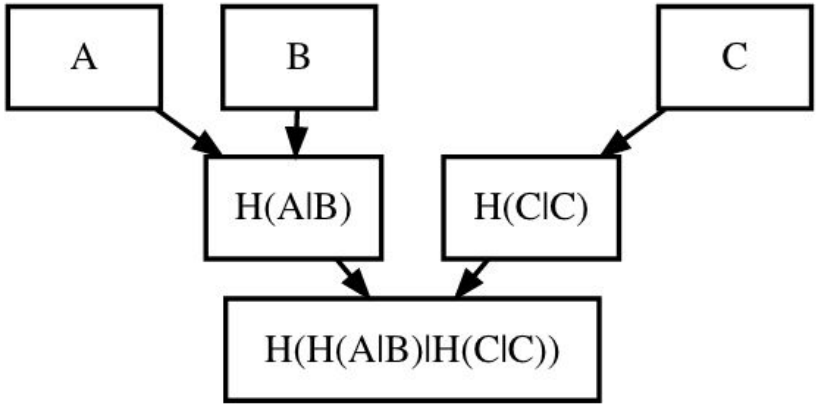
Diagram created by kockmeyer, CC BY-SA 3.0.

Merkle Trees

Row 1: Transaction hashes (TXIDs)
(A is coinbase; C can spend output from B)

Row 2: Hashes of paired TXIDs

Merkle root



Example Merkle Tree Construction [Hash function H() = SHA256(SHA256())]

https://bitcoin.org/en/developer-reference#merkle-trees

nBits - compact format

0x181bc330 →	0x1bc330	*	256	^	(0x18	-	3)
nBits In Big-Endian Order	Significand (Mantissa)		Base		Exponent		Bytes In Significand

Result: 0x1bc330000000000000000000000000000000000000000000

Converting nBits Into A Target Threshold

https://bitcoin.org/en/developer-reference#target-nbits

1. Block Header

- **Version** 01000000 (1)
- **Previous Block Hash**
  00000000000000000000000000000000000000000000000000000000
- **Merkle Root Hash**
  3ba3edfd7a7b12b27ac72c3e67768f617fc81bc3888a51323a9fb8aa4b1e5e4a
- **Time** dae5494d (1296688602 Wednesday, February 2, 2011 11:16:42 PM GMT)
- **Bits** ffff7f20
  (7fffff0000000000000000000000000000000000000000000000000000)
- **Nonce** 02000000 (2)

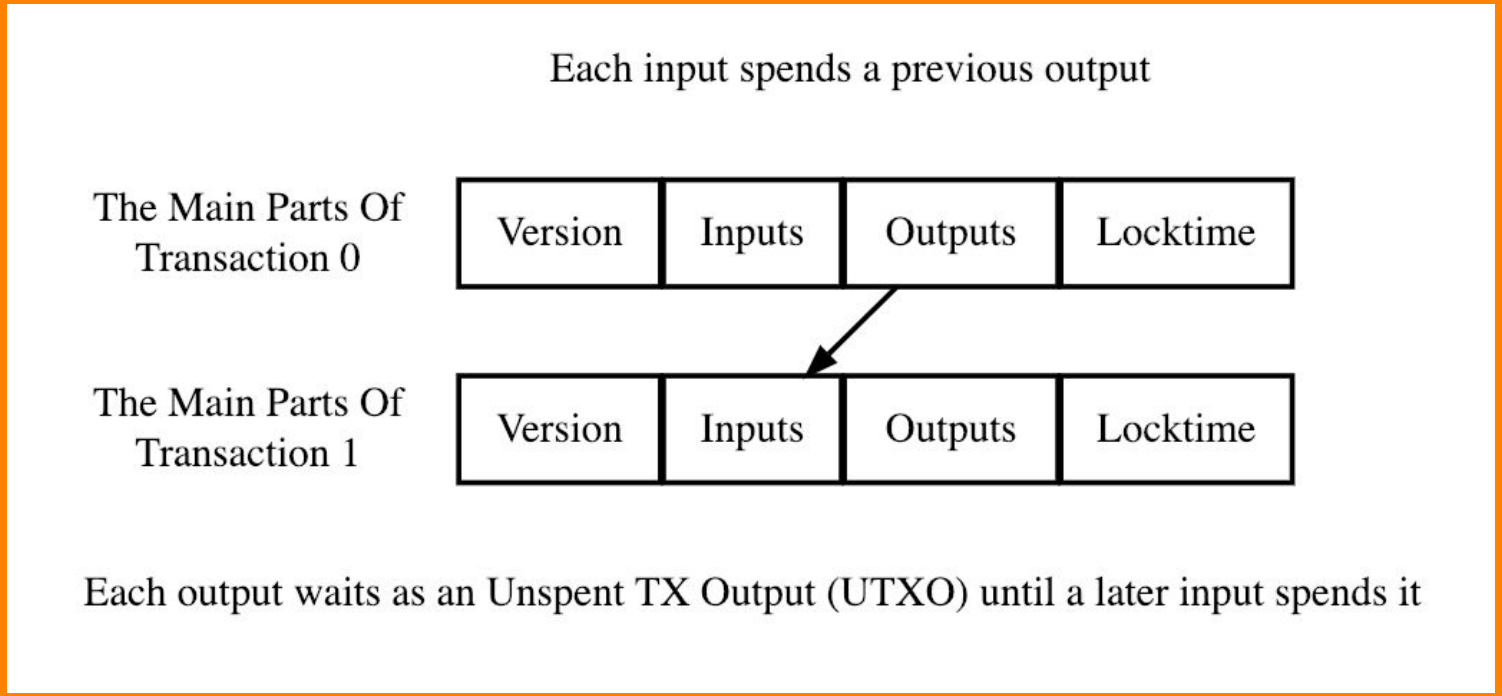
```
$ bitcoin-cli -regtest getblockhash 0
0f9188f13cb7b2c71f2a335e3a4fc328bf5beb436012afca590b1a11466e2206

$ bitcoin-cli -regtest getblock
0f9188f13cb7b2c71f2a335e3a4fc328bf5beb436012afca590b1a11466e2206 0
01000000
0000000000000000000000000000000000000000000000000000000000000000
3ba3edfd7a7b12b27ac72c3e67768f617fc81bc3888a51323a9fb8aa4b1e5e4a
dae5494d ffff7f20 02000000
0101000000010000000000000000000000000000000000000000000000000000
0000000ffffffff4d04ffff001d0104455468652054696d65732030332f4a616e2f32
303039204368616e63656c6c6f72206f6e206272696e6b206f66207365636f6e64206
261696c6f757420666f722062616e6b73ffffffff0100f2052a01000000434104678a
fdb0fe5548271967f1a67130b7105cd6a828e03909a67962e0ea1f61deb649f6bc3f4
cef38c4f35504e51ec112de5c384df7ba0b8d578a4c702b6bf11d5fac00000000
```

Transactions

331875e7fdc924999784467a13a96d980e04fadc7dc61859f38b279c72242de7			
Inputs		**Outputs**	
3aYtFTY3H6Vp1NQLTJuBQ8tvswuKgQ82Ro	14.55036232 **BTC**	3PzbAbCdefgWBu6kciJp3tPw7Hmf8QBZE7	22.4577213 **BTC**
3aYtFTY3H6Vp1NQLTJuBQ8tvswuKgQ82Ro	14.55022179 **BTC**	3HrSWAtu1ri3tXsd5PWjP6esCd8ebZcv8y	6.642641 **BTC**

Inputs and Outputs



https://bitcoin.org/en/developer-guide#transactions

2.2 Transactions

```
$ bitcoin-cli -regtest getblockhash 0
0f9188f13cb7b2c71f2a335e3a4fc328bf5beb436012afca590b1a11466e2206

$ bitcoin-cli -regtest getblock
0f9188f13cb7b2c71f2a335e3a4fc328bf5beb436012afca590b1a11466e2206 0
010000000000000000000000000000000000000000000000000000000000000000000000
2b27ac72c3e67768f617fc81bc3888a51323a9fb8aa4b1e5e4adae5494dffff7f20020000000101000000
0100000000000000000000000000000000000000000000000000000000000000ffffffff4d04ffff001
d0104455468652054696d65732030332f4a616e2f32303039204368616e63656c6c6f72206f6e20627269
6e6b206f66207365636f6e64206261696c6f757420666f722062616e6b73ffffffff0100f2052a0100000
0434104678afdb0fe5548271967f1a67130b7105cd6a828e03909a67962e0ea1f61deb649f6bc3f4cef38
c4f35504e51ec112de5c384df7ba0b8d578a4c702b6bf11d5fac00000000
```

Tx Structure

- **Version (4B)**
  Transaction format version
- **Flag (2B Array)**
  Optional, used for witness data
- **Input Counter (var int)**
  Number of inputs
- **Inputs**
  List of transaction inputs to be spent
- **Output Counter (var int)**
  Number of outputs
- **Outputs**
  List of transaction outputs to send to

Tx Structure cont.

- **Witnesses**
  Optional list of witness data (if flag is set)
- **Lock time (4B)**
  Block height or timestamp that indicates when the tx will be final.

Tx Structure

- **Version (4B)**
  01000000 (1)
- **Flag (2B Array)**
  N/A
- **Input Counter (var int)**
  01 (1)
- **Inputs**
  0000000000000000000000000000000000000000000000000000000000000000ffffffff4d...73ffffffff
- **Output Counter (var int)**
  01 (1)

```
$ bitcoin-cli -regtest getblockhash 0
0f9188f13cb7b2c71f2a335e3a4fc328bf5beb436012afca590b1a11466e2206

$ bitcoin-cli -regtest getblock
0f9188f13cb7b2c71f2a335e3a4fc328bf5beb436012afca590b1a11466e2206
0
010000000000000000000000000000000000000000000000000000000000000000000000
00000003ba3edfd7a7b12b27ac72c3e67768f617fc81bc3888a51323a9fb8aa4b
1e5e4adae5494dffff7f200200000001 01000000 01
0000000000000000000000000000000000000000000000000000000000000000ffffffff
ffffffff4d04ffff001d0104455468652054696d65732030332f4a616e2f323030
39204368616e63656c6c6f72206f6e206272696e6b206f66207365636f6e64206
261696c6f757420666f722062616e6b73ffffffff 01
00f2052a01000000434104678afdb0fe5548271967f1a67130b7105cd6a828e03
909a67962e0ea1f61deb649f6bc3f4cef38c4f35504e51ec112de5c384df7ba0b
8d578a4c702b6bf11d5fac 00000000
```

Tx Structure cont.

- **Outputs**
  00f2052a01000000434104678afdb0fe5548271967f1a67130b7105cd6a828e03909a67962e0ea1f61deb649f6bc3f4cef38c4f35504e51ec112de5c384df7ba0b8d578a4c702b6bf11d5fac
- **Witnesses**
  N/A
- **Lock time (4B)**
  00000000 (N/A)

```
$ bitcoin-cli -regtest getblockhash 0
0f9188f13cb7b2c71f2a335e3a4fc328bf5beb436012afca590b1a11466e2206

$ bitcoin-cli -regtest getblock
0f9188f13cb7b2c71f2a335e3a4fc328bf5beb436012afca590b1a11466e2206
0
010000000000000000000000000000000000000000000000000000000000000000000003ba3edfd7a7b12b27ac72c3e67768f617fc81bc3888a51323a9fb8aa4b1e5e4adae5494dffff7f200200000001 01000000 01
0000000000000000000000000000000000000000000000000000000000000000ffffffff4d04ffff001d0104455468652054696d65732030332f4a616e2f32303039204368616e63656c6c6f72206f6e206272696e6b206f66207365636f6e6420261696c6f757420666f722062616e6b73ffffffff 01
00f2052a01000000434104678afdb0fe5548271967f1a67130b7105cd6a828e03909a67962e0ea1f61deb649f6bc3f4cef38c4f35504e51ec112de5c384df7ba0b8d578a4c702b6bf11d5fac 00000000
```

Input Structure

- **Previous tx hash (32B)**
  Tx Hash of output to be spent
- **Previous utxo index (4B)**
  Index of the specific output (txs can have multiple outputs)
- **scriptSig Length (var int)**
  Length of scriptSig in bytes
- **scriptSig**
  Executed before the scriptPubKey, which must return true in order to spend
- **Sequence Number**
  Used as relative locktime

Input Structure

- **Previous tx hash (32B)**
  (all zeroes, N/A for coinbase transaction)
- **Previous utxo index (4B)**
  ffffffff (N/A for coinbase transaction)
- **scriptSig Length (var int)**
  4d (77 Bytes)
- **scriptSig**
  04ffff001d0104455468652054696d6573
  2030332f4a616e2f32303...73
- **Sequence Number**
  ffffffff

```
$ bitcoin-cli -regtest getblockhash 0
0f9188f13cb7b2c71f2a335e3a4fc328bf5beb436012afca590b1a11466e2206

$ bitcoin-cli -regtest getblock
0f9188f13cb7b2c71f2a335e3a4fc328bf5beb436012afca590b1a11466e2206
0
010000000000000000000000000000000000000000000000000000000000000000000003ba3edfd7a7b12b27ac72c3e67768f617fc81bc3888a51323a9fb8aa4b1e5e4adae5494dffff7f20020000000101000000010000000000000000000000000000000000000000000000000000000000ffffffff 4d04ffff001d0104455468652054696d65732030332f4a616e2f323030392043686616e63656c6c6f72206f6e206272696e6b206f66207365636f6e64206261696c6f757420666f722062616e6b73 ffffffff0100f2052a01000000434104678afdb0fe5548271967f1a67130b7105cd6a828e03909a67962e0ea1f61deb649f6bc3f4cef38c4f35504e51ec112de5c384df7ba0b8d578a4c702b6bf11d5fac00000000
```

Coinbase Message

Satoshi Nakamoto

```
$ printf
"04ffff001d0104455468652054696d65732030332f4a616e
2f32303039204368616e63656c6c6f72206f6e206272696e6
b206f66207365636f6e64206261696c6f757420666f722062
616e6b73" | xxd -r -p && echo


��EThe Times 03/Jan/2009 Chancellor on brink of
second bailout for banks
```

Output Structure

- **Coin value (8B)**
  Amount of coin being sent in satoshis (1e8 satoshis per Bitcoin)
- **scriptPubKey Length (var int)**
  Length of scriptPubKey in bytes
- **scriptPubKey**
  Executed after the scriptSig (provided when this output is spent in the future)

Output Structure

- **Coin value (8B)**
  00f2052a01000000 (50 BTC or 5000000000 satoshis)
- **scriptPubKey Length (var int)**
  43 (67 Bytes)
- **scriptPubKey**
  4104678afdb0fe5548271967f1a67130b7105cd6a828e03909a67962e0ea1f61deb649f6bc3f4cef38c4f35504e51ec112de5c384df7ba0b8d578a4c702b6bf11d5fac

```
$ bitcoin-cli -regtest getblockhash 0
0f9188f13cb7b2c71f2a335e3a4fc328bf5beb436012afca590b1a11466e2206

$ bitcoin-cli -regtest getblock
0f9188f13cb7b2c71f2a335e3a4fc328bf5beb436012afca590b1a11466e2206
0
010000000000000000000000000000000000000000000000000000000000000000000000
00000003ba3edfd7a7b12b27ac72c3e67768f617fc81bc3888a51323a9fb8aa4b
1e5e4adae5494dffff7f2002000000010100000001000000000000000000000000
0000000000000000000000000000000000000000ffffffff4d04ffff001d0104
455468652054696d65732030332f4a616e2f32303039204368616e63656c6c6f7
2206f6e206272696e6b206f66207365636f6e64206261696c6f757420666f7220
62616e6b73ffffffff 0100f2052a01000000 43
4104678afdb0fe5548271967f1a67130b7105cd6a828e03909a67962e0ea1f61d
eb649f6bc3f4cef38c4f35504e51ec112de5c384df7ba0b8d578a4c702b6bf11d
5fac 00000000
```

Script

OP_DUP OP_HASH160 306e2ea1eed91bf66dfe5d94f3957d4ba63bde84
OP_EQUALVERIFY OP_CHECKSIG

2.3 Script

```
script                                                                  |  stack
------------------------------------------------------------------------+--------
0                                                                       |
030cfcefa07af9dd6dbe770b87d7dbdd2c31ba7f4fcf8f3a1196d502f13561b046      |
OP_DUP                                                                  |
OP_HASH160                                                              |
306e2ea1eed91bf66dfe5d94f3957d4ba63bde84                                |
OP_EQUALVERIFY                                                          |
OP_CHECKSIG                                                             |
#0000 0
btcdeb> step
```

Script Example P2PKH

P2PKH is a pay-to-public key-hash script where the coins are sent to the hash of a public key. In order to spend them, the scriptSig must provide the public key and a valid signature using the private key.

```
scriptPubKey (raw): 76a914306e2ea1eed91bf66dfe5d94f3957d4ba63bde8488ac

scriptPubKey (assembly): OP_DUP OP_HASH160
PUSHDATA(20)[306e2ea1eed91bf66dfe5d94f3957d4ba63bde84] OP_EQUALVERIFY OP_CHECKSIG
```

Addresses

3J98t1WpEZ73CNmQviecrnyiWrnqRhWNLy

Address Types

- **Pay to Pubkey Hash (P2PKH)**
  Hash of a public key
- **Pay to Script Hash (P2SH)**
  Hash of a script, must provide redeem script that hashes to the right value
- **Bech32 (Segregated Witness)**
  Custom encoding, represents witness scripts

Bitcoin Cryptography

- Uses Elliptic Curve secp256k1
- Private keys can be any 256 bit number from 0x1 to 0xFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFEBAAEDCE6AF48A03BBFD25E8CD0364140
- Currently uses ECDSA for transaction signing
- supports compressed public keys (33 bytes instead of 65 bytes)

Mining

0x000000000019d6689c085ae165831e934ff763ae46a2a6c172b3f1b60a8ce26f

50 BTC

Block Validation

- **Block Hash**
  Must be <= network target
- **Timestamp**
  - Greater than median time of last 11 blocks
  - < 2 hours in the future
- **Transactions**
  - No double spends
  - Spends are authorized
  - Valid coinbase tx exists

Proof of Work Consensus

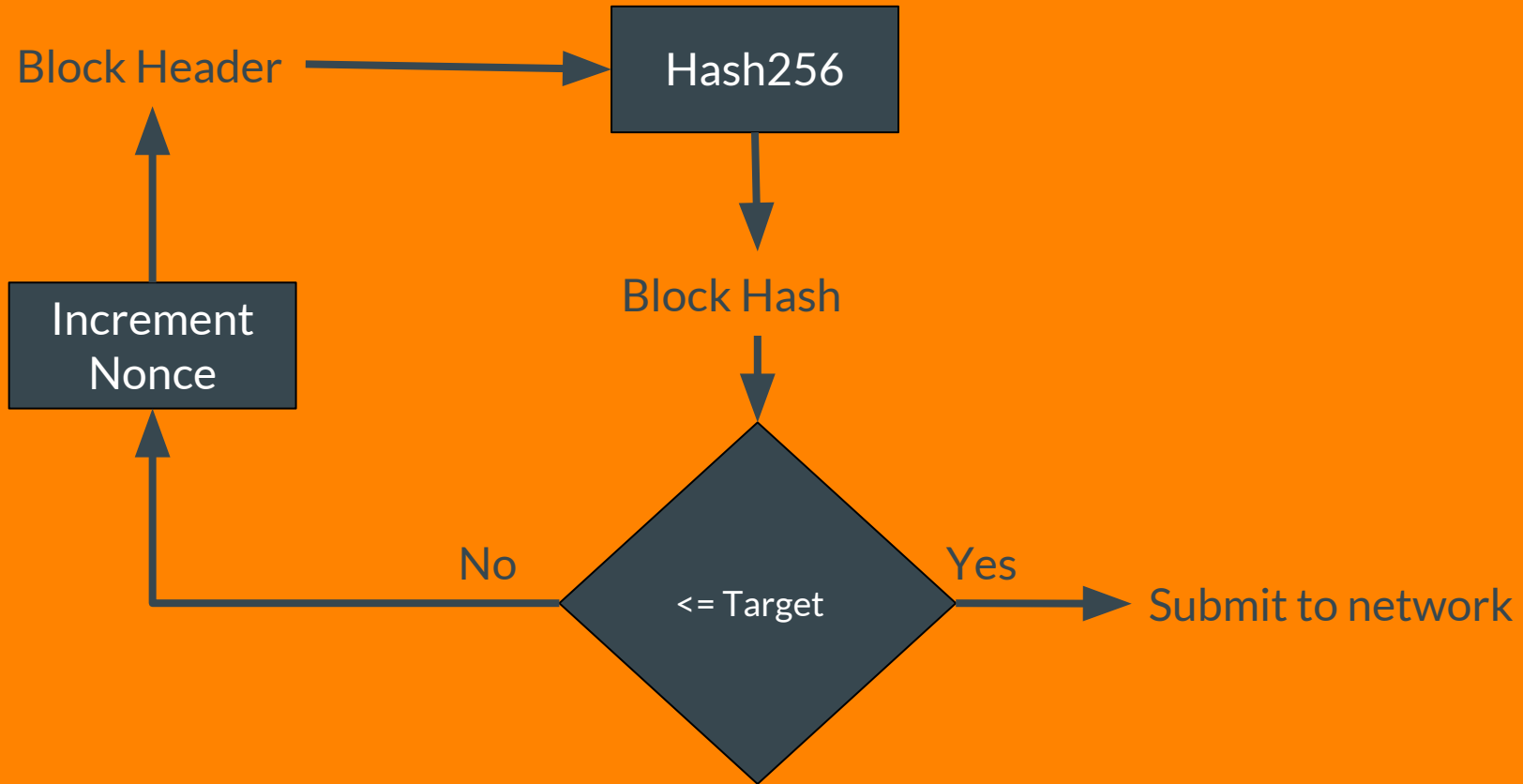
Target:

```
00000000000fffffffffffffffffffffffffffffffffffffffffffffffffffff
```

Example Solution:

```
000000000019d6689c085ae165831e934ff763ae46a2a6c172b3f1b60a8ce26f
```

Mining Process



Resources

- Bitcoin Wiki: https://en.bitcoin.it/wiki/
- Bitcoin Stackexchange: https://bitcoin.stackexchange.com
- Bitcoin.org: https://bitcoin.org/en/developer-documentation
- Course Discord Server: https://discord.gg/DaREKEP

Section 3: Design

Customizations

- **Branding**
  - Rename project
  - Change address prefixes
- **Networking**
  - Ports, message prefixes, seeds
- **Consensus Rules**
  - Max coin supply, block rewards, halving interval
  - Max block size, block time
  - Activate BIPs, clear checkpoint data

Customizations

- **Consensus (cont.)**
  - New genesis block
  - Difficulty retargeting interval
- **Standards**
  - OP_RETURN data limit
- **Advanced**
  - Premine