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<https://drive.google.com/file/d/16zVbDqjxpEgUEAweWTCrijpivTsONW8h/view?usp=sharing>

PV204 Security technologies

Bitcoin basics I.

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WHY BITCOIN?

Especially if you are not interested in Bitcoin.

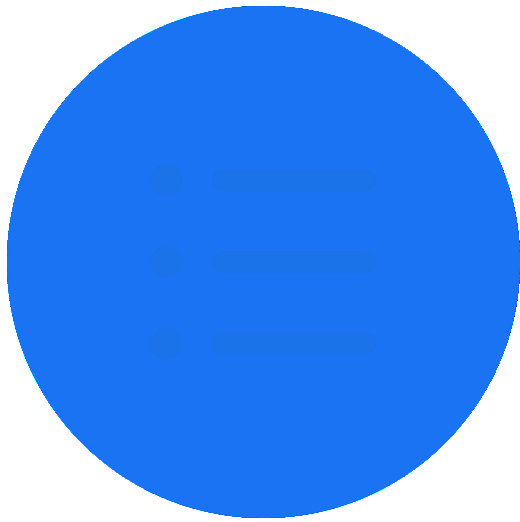
“Bitcoin fixes everything!”



fixes this

Goals for the lecture

- Bitcoin does not fix everything, but is on a frontline
 - No safety net, no chargeback, attacker anonymous => security technique must really work, great for battle-testing security ideas, natural “bug bounty program”
- 6 main tech pieces we will cover (also usable outside Bitcoin world)
 1. How to backup key(s) (single seed, BIP39, Shamir)
 2. How to make always fresh keys (derivation via BIP32, also address privacy)
 3. How to protect signing key against malware
 - (multisig, hardware wallet, airgap pc + tx broadcast, mpc sig)
 4. How to introduce restricted signing policy (time, limit... lockscript/multisig)
 5. How to protect your financial privacy (CoinJoin, Tor)
 6. How to use hardware wallet with secure element

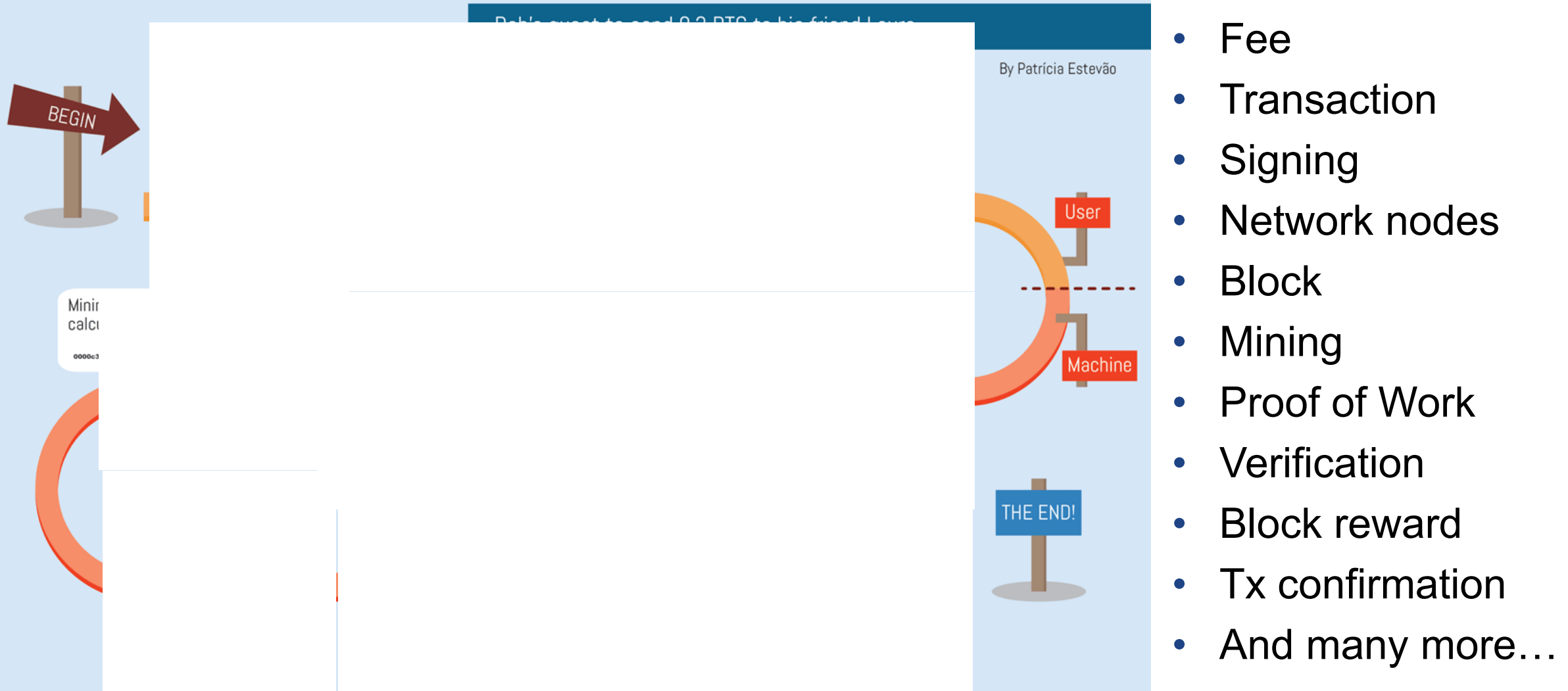


**What is your previous exposure to the cryptocurrencies?
Please check all items which applies to you.**

① Start presenting to display the poll results on this slide.

BASICS

THE BITCOIN TRANSACTION LIFE CYCLE



Main design goals of the Bitcoin

1. Decentralization

- No central authority or intermediary (=> no single point of failure), possibility of self-custody
- No limitation on network participants (no permission to join is required)
- Applies to executing a transaction, but also development, infrastructure, mining...

2. Transparency

- All transactions recorded on public ledger; validity of every “bitcoin” easy to verify
- Total number of bitcoins in circulation easy to assess (monetary policy, fixed supply)

3. Security based on cryptography (mainly signature, hash functions)

- Ownership of bitcoins proved only cryptographically (no “chargeback” based on human decision)
- Protection of bitcoins reduced to protection of private key(s)

4. Pseudonymity of participants

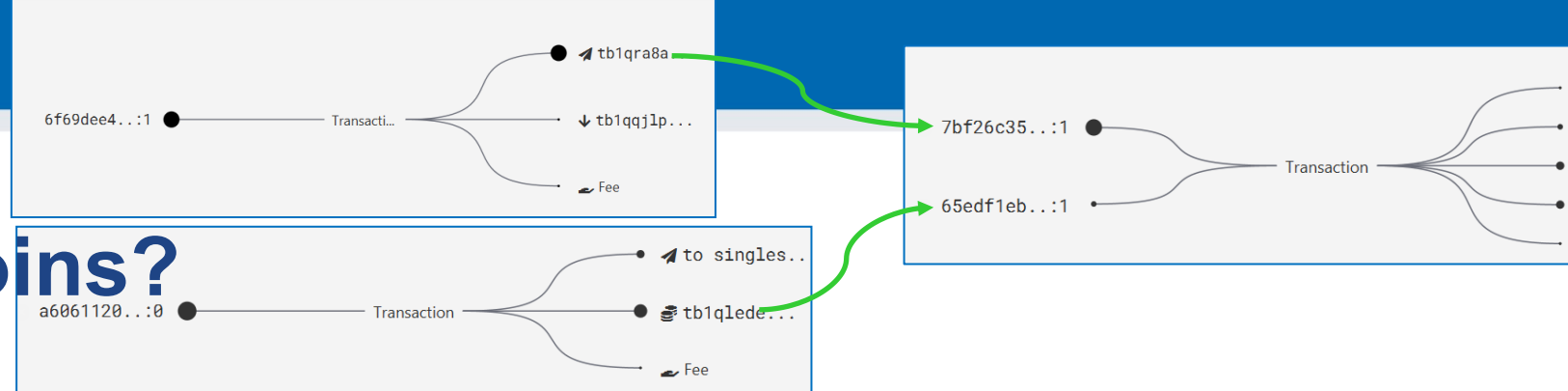
- bitcoins connected to public keys, not usernames (does not automatically mean anonymity!)

Problems to tackle

- How to prevent double spending?
- How to allow for permissionless participation?
- Who will store authoritative copy of public ledger?
- How to prevent modification of ledger history?
- Who will include next block in blockchain?
- How to maintain decentralization in distant future?
- ...

Double-spending problem and Bitcoin's solution

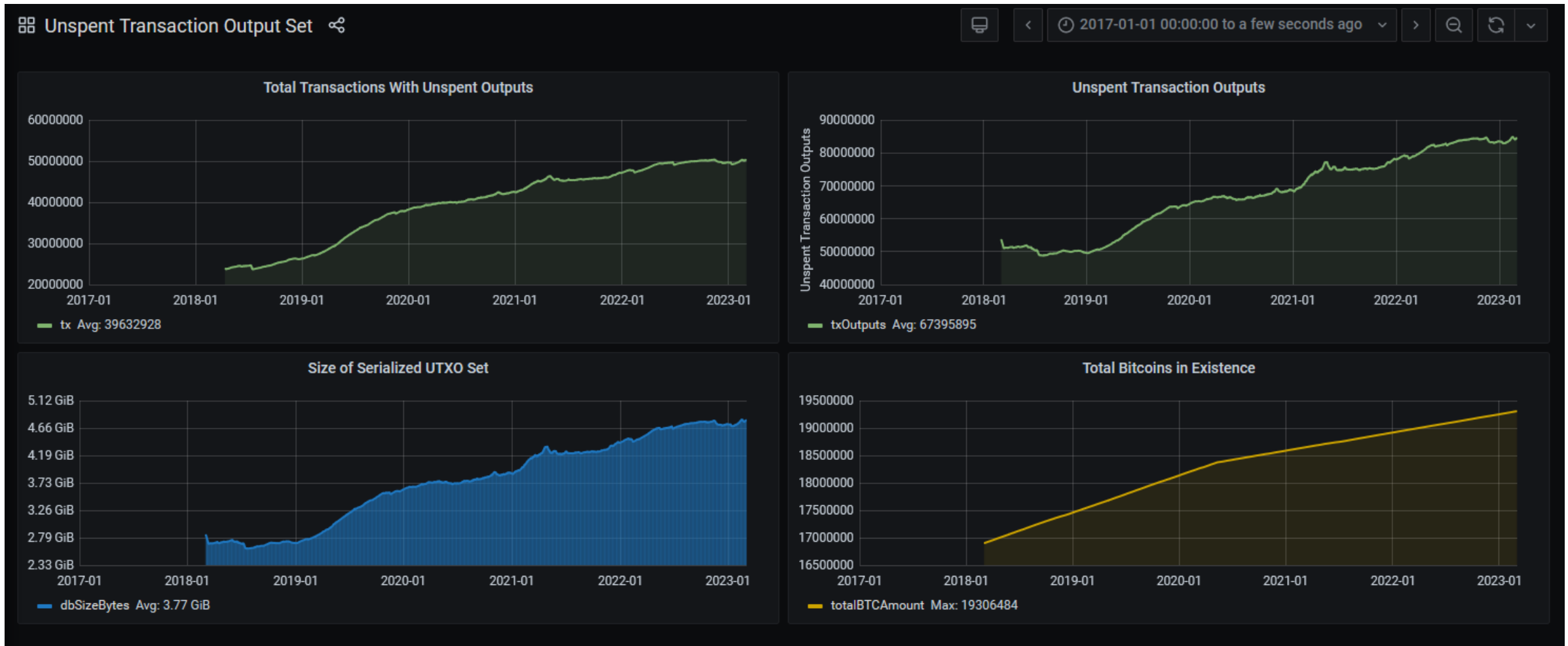
- Digital data are inherently easy to copy perfectly
 - If used as monetary coins, how to prevent double/triple... spending the same coin?
 - Previous proposals (eCash, B-money, Bit Gold..) required central party for prevention
- Digital coin X is “spent” by a transaction between users A and B
 - Double spend is another transaction from A to C using same coin X
- If all transactions are ordered strictly in time, double spend is not possible
 - Later transaction with same coin X is invalid
 - Decentralized ordering is costly as all participants need to agree on global state
- If ordered after every transaction => costly and slow
- Bitcoin orders in **batches** of transaction **every 10 minutes** on average
 - User needs to wait one (or more blocks) for ordering (longer => higher certainty)



Where are my bitcoins?

- Public ledger of all transactions (blockchain)
 - Replicated between all Bitcoin fullnodes (P2P network)
- “Bitcoin holdings” - sum of values of not-yet-spent transactions control
 - Unspent Transaction Output (UTXO)
- “Bitcoin receive” operation – generate variable part of lockscript (public) and share with sender + monitor blockchain for my transaction
- “Bitcoin send” operation – take “your” UTXO and use it as input to new one
 - Specify recipient by script specifying what must be done in future send (lockscript)
 - Typical lockscript is “prove that you can sign with private key corresponding to THIS public key”
- Protection and handling of private keys is paramount
 - “Not your keys, not your bitcoin!”

UTXO set = all currently valid “bitcoins”

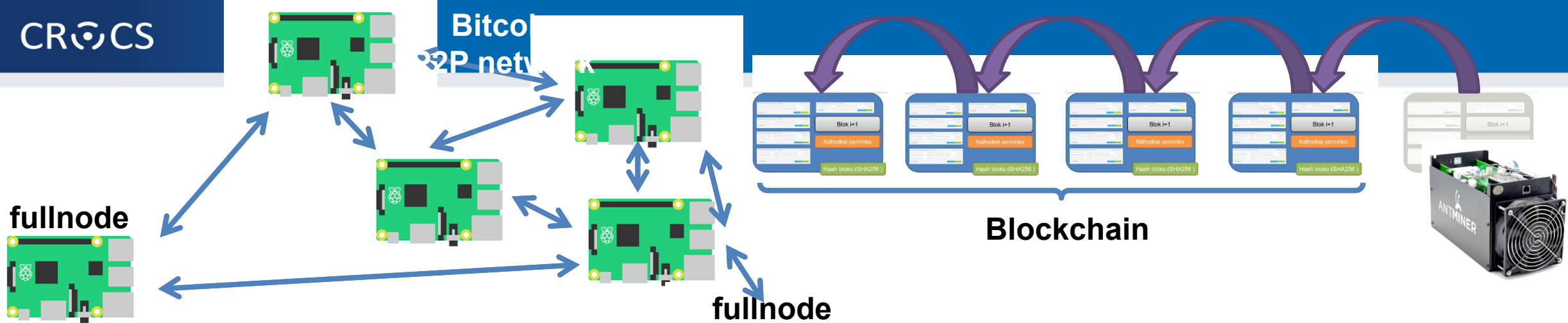


<https://statoshi.info/d/000000009/unspent-transaction-output-set?orgId=1&refresh=10m&from=1483225200000&to=now>

Problem: How to allow for permissionless participation?

BITCOIN NETWORK

Bitcoin P2P net



fullnode

Blockchain

fullnode

SW-only wallet



With hardware wallet



P2P Bitcoin network map <https://bitnodes.io/>

REACHABLE BITCOIN NODES

Updated: Sat Mar 18 10:21:17 2023 CET

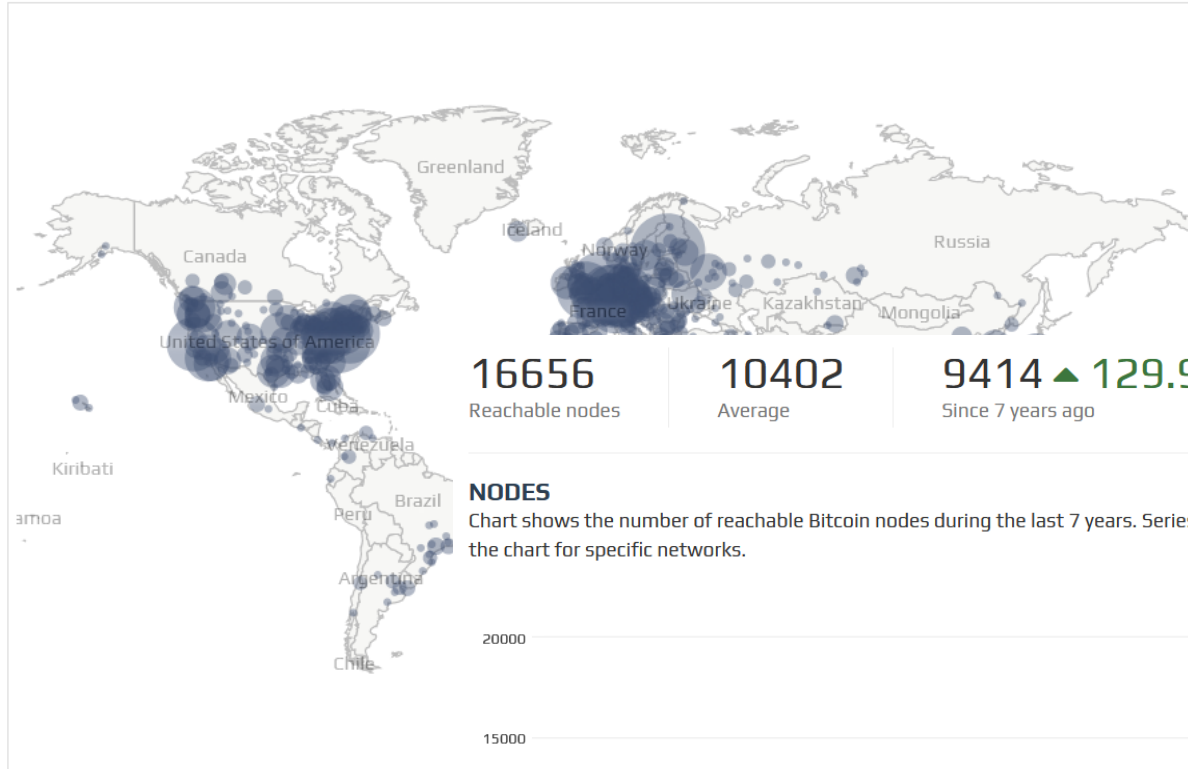
16537 NODES

CHARTS

IPv4: +0.1% / IPv6: +0.6% / .onion: +21.8%

Top 10 countries with their respective number of reachable nodes are as follows.

RANK	COUNTRY	NODES
1	n/a	9992 (60.42%)
2	United States	1752 (10.59%)
3	Germany	1403 (8.48%)
4	France	448 (2.71%)
5	Netherlands	398 (2.41%)
6	Canada	273 (1.65%)
7	Finland	240 (1.45%)
8	United Kingdom	211 (1.28%)
9	Russian Federation	169 (1.02%)



Map shows concentration of reachable

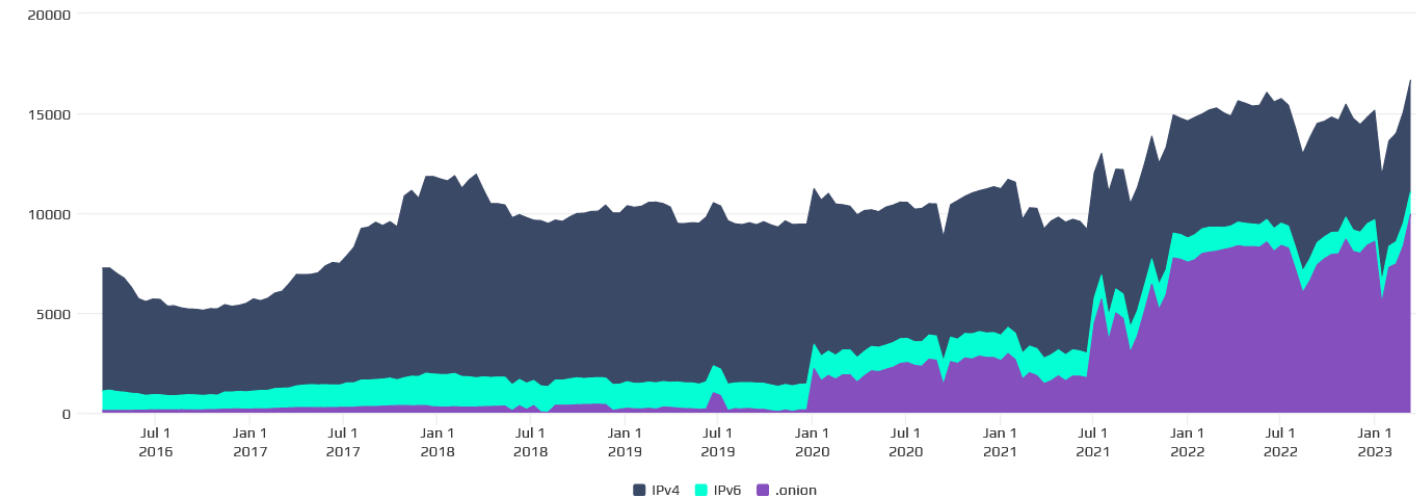
16656 Reachable nodes
 10402 Average
 9414 ▲ 129.99% Since 7 years ago

NODES

Chart shows the number of reachable Bitcoin nodes during the last 7 years. Series can be enabled or disabled from the legend to view the chart for specific networks.

24h 90d 1y 7y

Lo 5135 Hi 16656 Avg 10402 Last 16656 nodes



What is Bitcoin “fullnode”

- Software capable to connect and interact with P2P network
- Downloads whole blockchain, fully verifies all blocks (PoW) and transactions starting from the Genesis block (or trusted checkpoint)
 - Dynamically builds own UTXO set (unspent txs) and Mempool (unconfirmed txs)
- Propagates new incoming blocks and transactions
- No formal specification of Bitcoin consensus exists
 - Bitcoin Core software is defacto specification (<https://github.com/bitcoin/bitcoin>)
 - Other implementations also exists (but large majority of nodes are Bitcoin Core)
- Currently several days to fully synchronize (CPU/bandwidth), ~465GB
- Can be run over Tor to protect user privacy
- Bitcoin wallet needs to connect to some fullnode (your = better privacy)

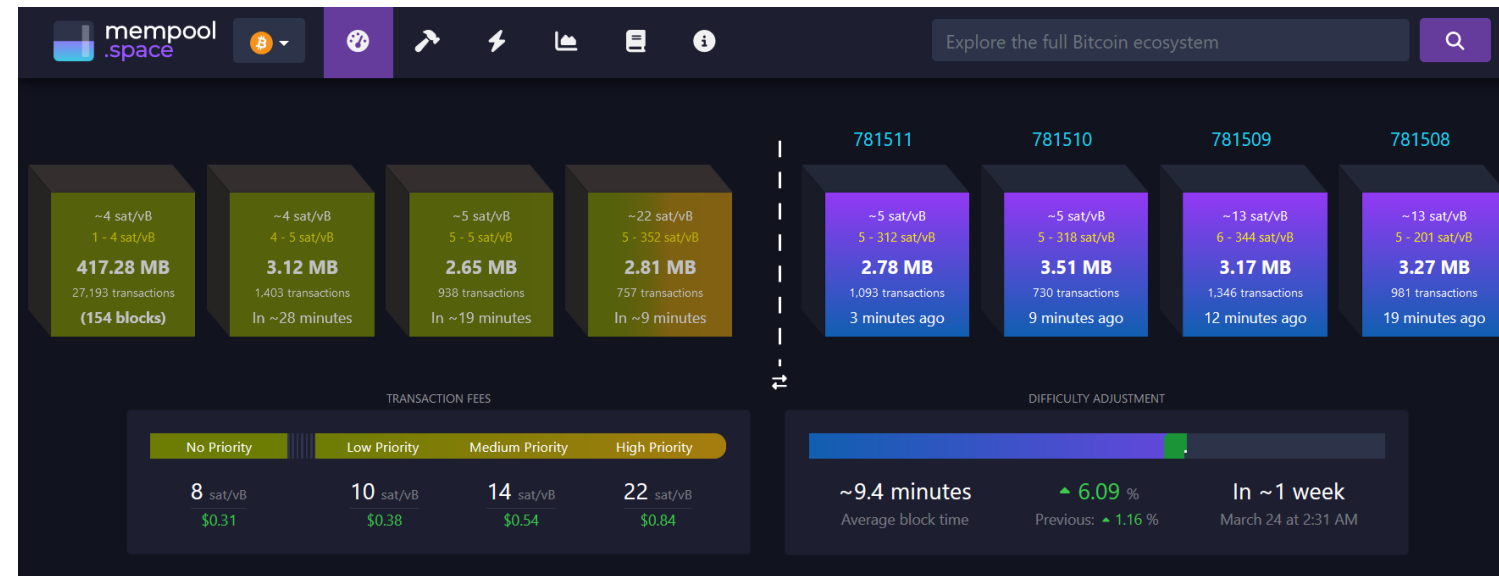
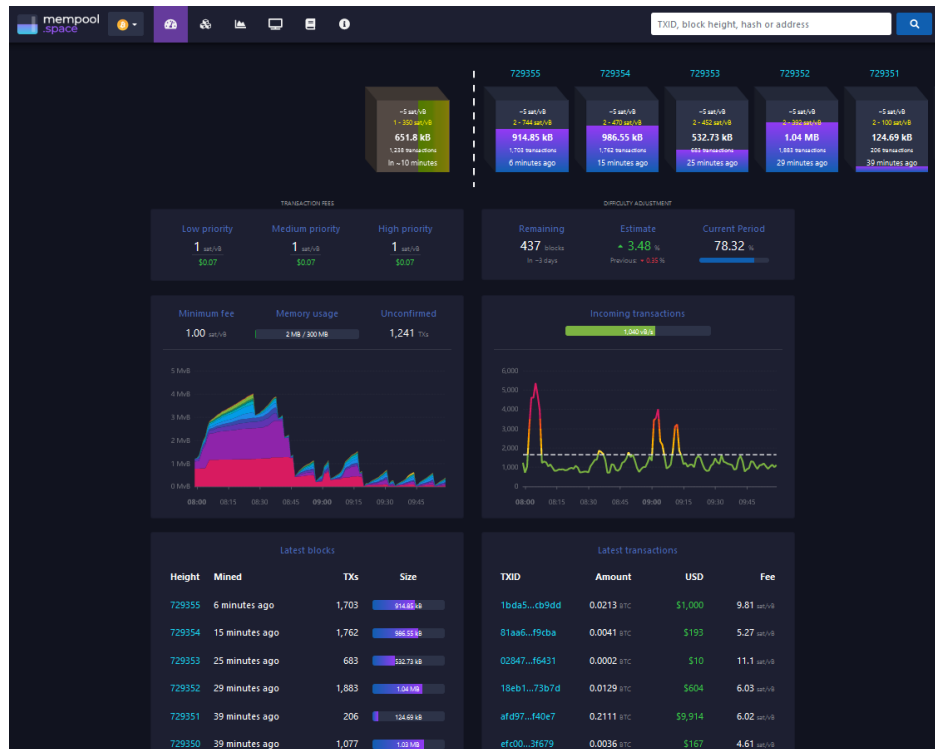
Networks in Bitcoin (Mainnet, Testnet, Regtest, Signet)

- Mainnet – main, global production network (“real” bitcoins)
- Testnet – testing network (global, some mining happens...)
 - Restarted from time to time, contains many different types and versions of TXs
- Regtest – local instance of Bitcoin network
 - Used for local testing (integration, regression, debugging)
 - Blockchain started from block 0, you are the only miner
 - (mined bitcoins unusable on Mainnet)
 - You can insert own transactions, decide on mining new blocks, debug...
- Signet – testing network like Testnet, but with features not yet active on Mainnet
 - Initially for testing Taproot, now for future possible softforks
- (Lightning – second layer network of payment channels atop of mainnet)
 - Practically instant and very low fees independently from mainnet

Mempool – unconfirmed transactions

- Every fullnode maintains own list of unconfirmed transactions (mempool)
 - No single global mempool! But local mempools tend to synchronize quickly
- Miners construct next block from transactions maximizing profit (mostly)
- What if tx is in a mempool, but with too low fee (not getting confirmed)?
 1. Child pays for parent –additional transaction spending output of previous (high fee)
 2. Replace By Fee (RBF) flag – new tx, but with higher fee, replaced by nodes
 3. (Wait for purge, pay miner out of band...)
- If too many unconfirmed txs present, some existing are purged (removed)
 - Default size of mempool (for Bitcoin Core) is ~300MB
 - Selection depends on configuration (low-fee tx, large tx, old tx)
 - If discarded, it can be re-inserted later from other nodes or resubmitted (by owner)

Popular mempool explorer – <https://mempool.space>



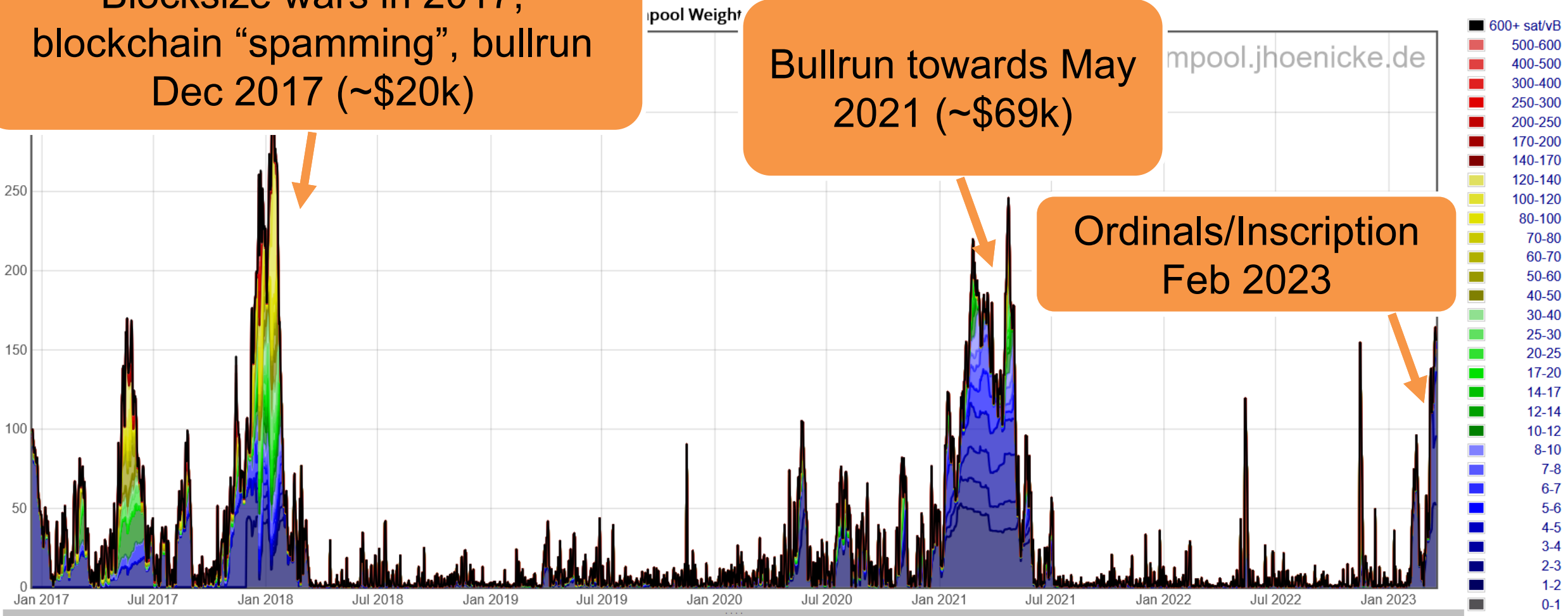
- Can be run on your own fullnode (privacy improvement)
- Testnet version <https://mempool.space/testnet>

Mempool size in time

Blocksize wars in 2017, blockchain “spamming”, bullrun Dec 2017 (~\$20k)

Bullrun towards May 2021 (~\$69k)

Ordinals/Inscription Feb 2023

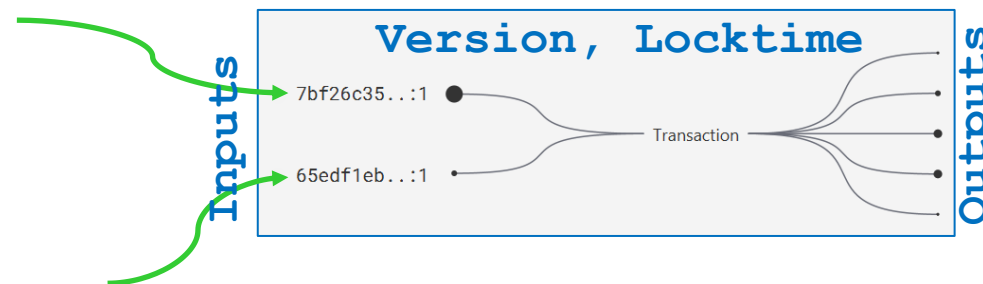


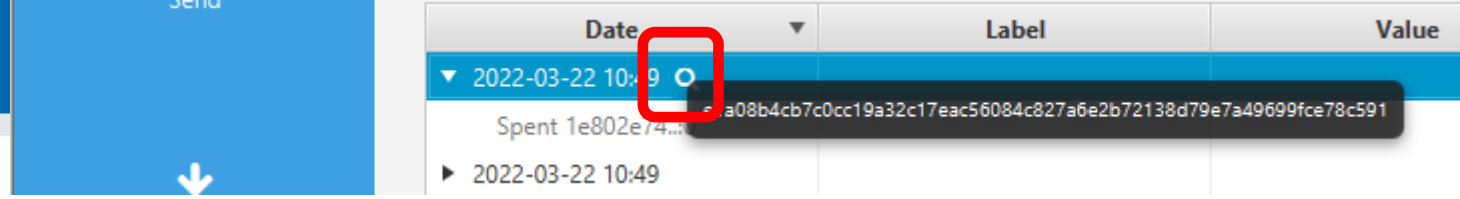
DEMO: LOOK AND COMMENT THE CURRENT MEMPOOL STATE

TRANSACTION

Transaction components

- Binary structure optimized for small size (further decreased over time)
 - Version
 - Inputs (bitcoins spent, points to some previous tx output + unlock script)
 - Outputs (bitcoins received, description of lock script)
 - Locktime (when starts to be valid, absolute or relative, time or block height)
- Can be created offline, broadcasted immediately or later (Lightning)

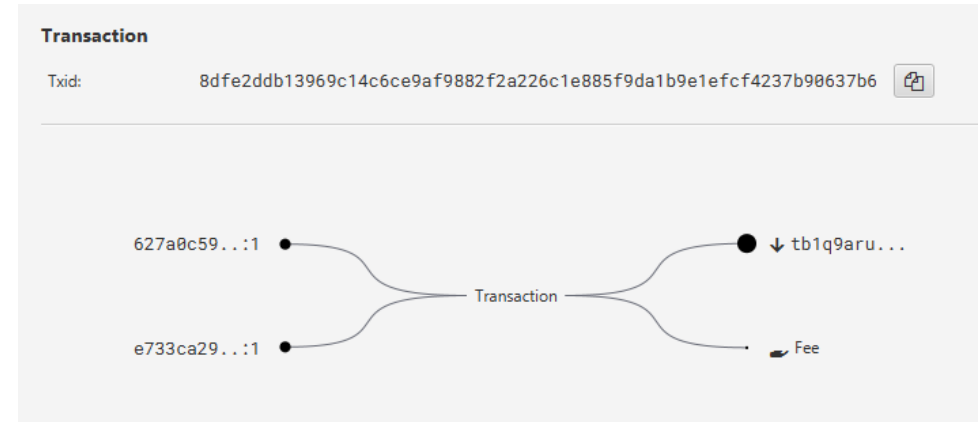
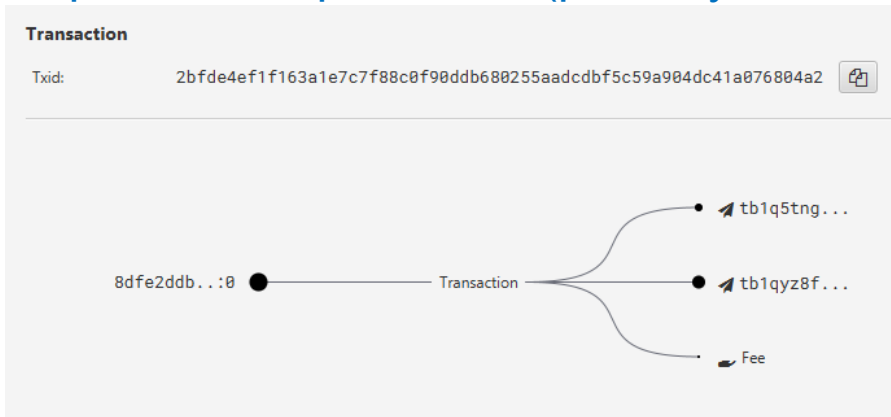




Various transactions can be created

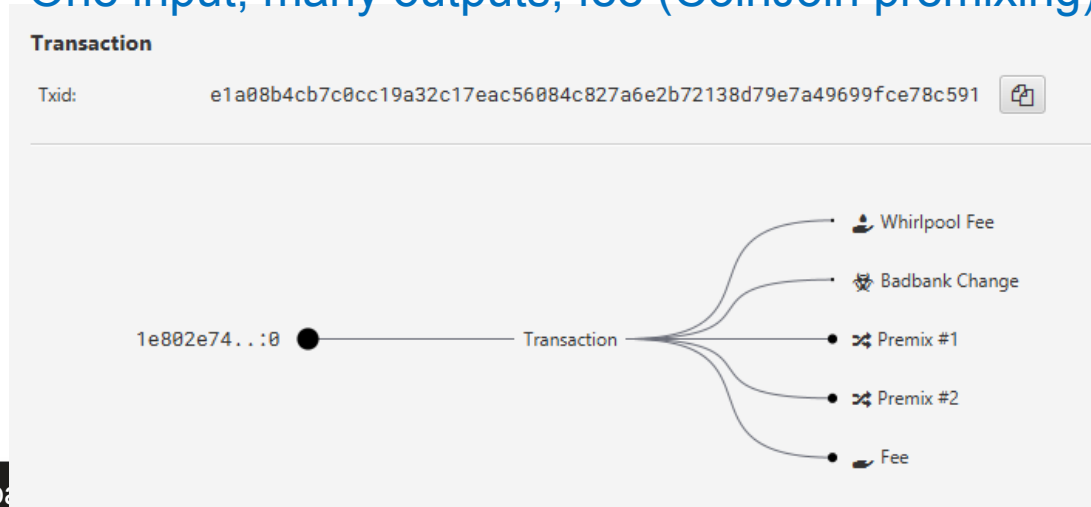
One input, two outputs + fee (possibly classic pay)

Two inputs, one output + fee (possibly consolidation)



One input, many outputs, fee (CoinJoin premixing)

Many inputs, many outputs, fee...



Standard pay (change likely bc1)

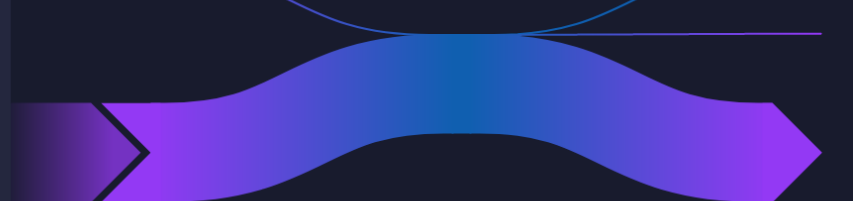


Inputs & Outputs

Details

bc1qcfmq98y3f2yxfpwm4...cd317jrh	0.01824993 BTC	16g2ZjLHG86GmTxJJtVXQc...qBfWYAfK	0.01430567 BTC
		bc1qcfmq98y3f2yxfpwm4...cd317jrh	0.00391114 BTC
			0.01821681 BTC

Standard pay (0.04) with consolidation



Inputs & Outputs

Details

bc1q7e7j5u8rk6we50j2y4v...xssws7q	0.00433811 BTC	bc1q9c1hq4mp36h4v4cfmd...7731ru3d	0.04000000 BTC
bc1q7e7j5u8rk6we50j2y4v...xssws7q	72.63982966 BTC	bc1q7e7j5u8rk6we50j2y4v...xssws7q	72.60409777 BTC
			72.64409777 BTC

Consolidation (even annotated OP_RETURN)

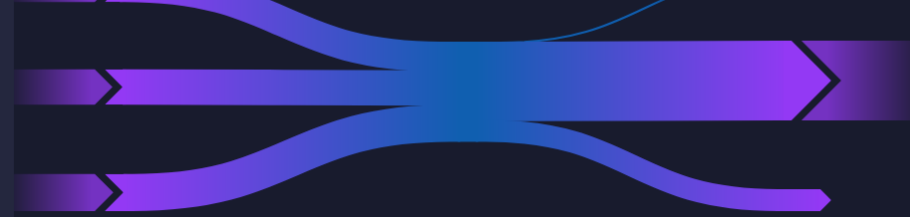


Inputs & Outputs

Details

bc1qpram147gzdrznusqt6x...549jwzja	117.11561344 BTC	bc1qpram147gzdrznusqt6x...549jwzja	117.14108466 BTC
bc1qpram147gzdrznusqt6x...549jwzja	0.00241705 BTC	OP_RETURN consolidate	0.00000000 BTC
bc1qpram147gzdrznusqt6x...549jwzja	0.00619855 BTC		
bc1qpram147gzdrznusqt6x...549jwzja	0.00010001 BTC		
bc1qpram147gzdrznusqt6x...549jwzja	0.00158000 BTC		
bc1qpram147gzdrznusqt6x...549jwzja	0.00591711 BTC		
bc1qpram147gzdrznusqt6x...549jwzja	0.00355191 BTC		
bc1qpram147gzdrznusqt6x...549jwzja	0.00158659 BTC		
bc1qpram147gzdrznusqt6x...549jwzja	0.00225320 BTC		
bc1qpram147gzdrznusqt6x...549jwzja	0.00200000 BTC		

Multisig pay (3.87) from multiple inputs

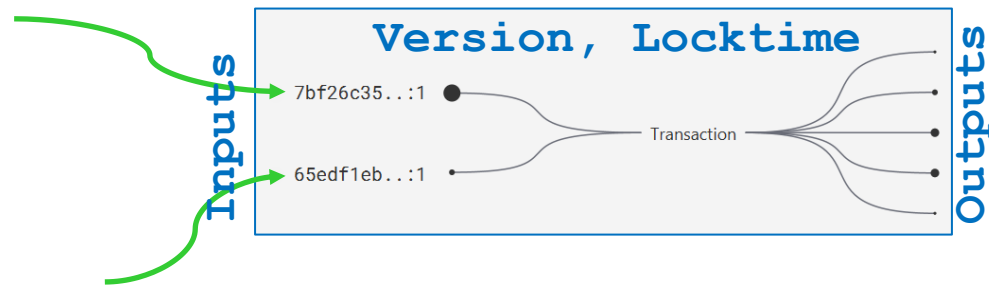


Inputs & Outputs

Details

bc1qc8dyets2cdckkf29kd...aswdf19e	1.43051325 BTC	365n1rywJ6V6xGU3BMZMsfg...jy4AXp3J	3.87400001 BTC
bc1qguwfqf0np430ygmrv...wsxghtjq	1.69673127 BTC	bc1qn8x5suzaucq7cu0hn4mk...nq9sc45p	1.03549133 BTC
bc1qn8x5suzaucq7cu0hn4mk...nq9sc45p	1.78239593 BTC		
			4.90949134 BTC

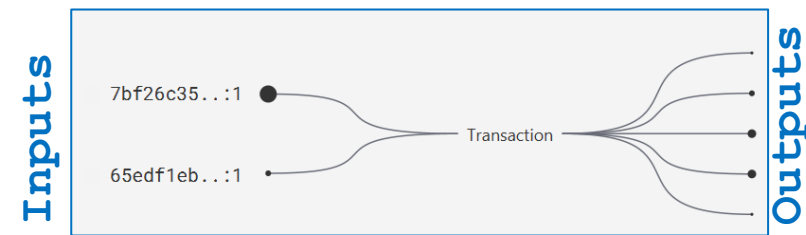
**DEMO: LOOK AT CURRENT MEMPOOL
TRANSACTIONS (CONFIRMED,
UNCORFIRMED)**



LOCK AND UNLOCK SCRIPTS

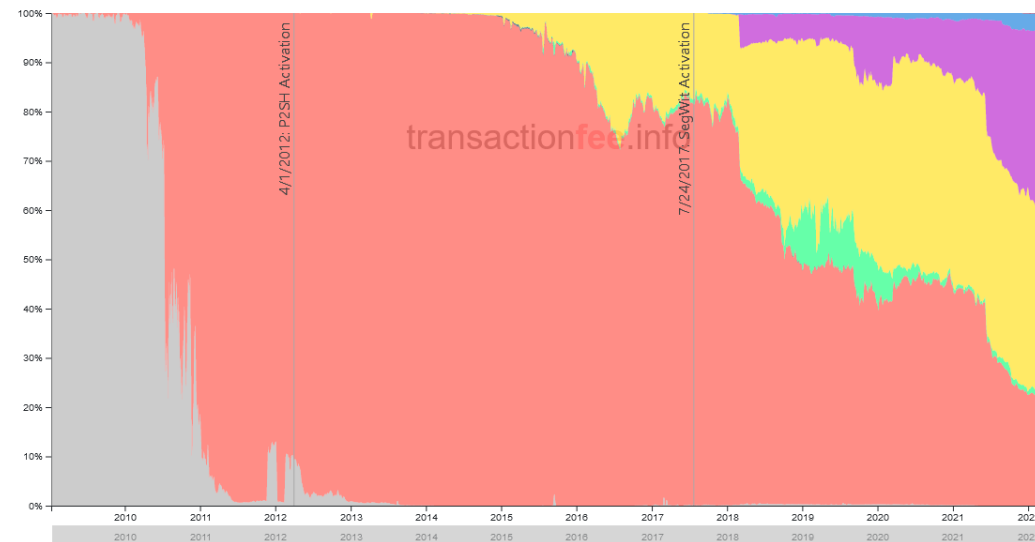
Types of receiving “addresses”

- There is no “address” defined in Bitcoin network
- Standard patterns how to construct lock script emerged over the time
 - e.g., unlock if signature is verifiable with the public key stored in lock script (P2PK)
 - “Address” is the variable part of the lock script differing between (different receivers / transactions)
- *Notation warning: scriptSig (script + signature), scriptPubKey (initial meaning script + public key == P2PK)*
- Well-known standard types of lock scripts
 - Pay-to-public-key (P2PK)
 - Pay-to-public-key-hash (P2PKH, starts with 1)
 - Pay-to-script-hash (P2SH, BIP16)
 - OP_RETURN (any data 40B)
 - Native Pay-to-witness-script-hash (P2WSH, starts with 3)
 - P2WSH-nested-in-P2SH
 - P2SH-P2WPKH, P2SH-P2WSH
 - Native P2WPK, P2WSH (Bech32, starts with bc1)
 - Pay-to-Taproot (P2TR, Schnorr signature, starts bc1p)



Output Types by Count

Shows the distribution of output types by output count per day.



1/9/2009 - 3/28/2022

step plot

annotations

moving average days

[show permalink](#)

P2PK
 P2PKH
 P2MS
 OP_RETURN
 P2SH
 P2WPKH
 P2WSH
 P2TR

Pay-to-public-key (P2PK), Pay-to-public-key-hash (P2PKH)

- Pay-to-public-key (P2PK)
 - Lock script contains direct value of public key and instructions to push signature and verify with the public key
 - Used initially by Satoshi and others, now infrequent
 - Disadvantage: if practical dlog attack against secp256k1 is found, private key can be computed
- Pay-to-public-key-hash (P2PKH), starts with '1'
 - Lock script contains hash of public key later used for signature verification
 - Advantage: smaller lockscript, attacker does not know public key until spent

P2PKH - script execution (https://nioctib.tech/)

To

1B9DXkcnXbVXEEpRpcXzfhWe8uK16XvbMr

0.05149519 BTC - Transaction

ScriptPubKey - P2PKH

OP_DUP OP_HASH160

0x6f3f0b93b060ea9c0d76989c9747c9b6cfad617d OP_EQUALVERIFY

OP_CHECKSIG

Paying from

1B9DXkcnXbVXEEpRpcXzfhWe8uK16XvbMr

0.05149519 BTC - Transaction

ScriptSig - P2PKH

0x304402205c5876144bf491eb6aece2625cbc3049819f35094e8feaf808399de0c29b593d022048267261596dcd8a49659f0a9c74f2a423d6c7bef02058b56a8b90fb39e8ff901

0x02b621afa86afdb74d874e876413cf199833f4a5f68e10335134876eebe29bbe6d

Interpret or debug

To

14Z9hhyEbccWepjruEnoSvQvuSjd7QVN9Y

0.00064007 BTC - Transaction

ScriptPubKey - P2PKH

OP_DUP OP_HASH160

0x26fcf3b9cc3e0d2fc51fc69e58b63b41e2094f44 OP_EQUALVERIFY

OP_CHECKSIG

18hgAeKFH4L93DR8nGL9LHx9yWntnCjbW8

0.05 BTC - Transaction

ScriptPubKey - P2PKH

OP_DUP OP_HASH160

0x547a369b70f0241ebd1e8288397dd34f2c11ac6b OP_EQUALVERIFY

OP_CHECKSIG

Stack

Script

```
0x304402205c5876144bf491eb6aece2625cbc3049819f35094e8feaf808
399de0c29b593d022048267261596dccb8a49659f0a9c74f2a423d6c7bef
02058b56a8b90fb39e8ff901
```

```
0x02b621afa86afdb74d874e876413cf199833f4a5f68e10335134876eebe
29bbe6d
```

OP_DUP OP_HASH160

```
0x6f3f0b93b060ea9c0d76989c9747c9b6cfad617d OP_EQUALVERIFY
```

OP_CHECKSIG

Executing Script PubKey [3]

Stack

```
0x02b621afa86afdb74d874e876413cf199833f4a5f68e10335134876eebe
29bbe6d
```

```
0x304402205c5876144bf491eb6aece2625cbc3049819f35094e8feaf808
399de0c29b593d022048267261596dccb8a49659f0a9c74f2a423d6c7bef
02058b56a8b90fb39e8ff901
```

OP_DUP OP_HASH160

```
0x6f3f0b93b060ea9c0d76989c9747c9b6cfad617d OP_EQUALVERIFY
```

OP_CHECKSIG

Executing Script PubKey [7]

Stack

1

```
0x02b621afa86afdb74d874e876413cf199833f4a5f68e10335134876eebe
29bbe6d
```

```
0x304402205c5876144bf491eb6aece2625cbc3049819f35094e8feaf808
399de0c29b593d022048267261596dccb8a49659f0a9c74f2a423d6c7bef
02058b56a8b90fb39e8ff901
```

OP_VERIFY OP_CHECKSIG

Stack

```
0x304402205c5876144bf491eb6aece2625cbc3049819f35094e8feaf808
399de0c29b593d022048267261596dccb8a49659f0a9c74f2a423d6c7bef
02058b56a8b90fb39e8ff901
```

Script

```
0x02b621afa86afdb74d874e876413cf199833f4a5f68e10335134876eebe
29bbe6d
```

OP_DUP OP_HASH160

```
0x6f3f0b93b060ea9c0d76989c9747c9b6cfad617d OP_EQUALVERIFY
```

OP_CHECKSIG

Executing Script PubKey [4]

Stack

```
0x02b621afa86afdb74d874e876413cf199833f4a5f68e10335134876eebe
29bbe6d
```

```
0x02b621afa86afdb74d874e876413cf199833f4a5f68e10335134876eebe
29bbe6d
```

```
0x304402205c5876144bf491eb6aece2625cbc3049819f35094e8feaf808
399de0c29b593d022048267261596dccb8a49659f0a9c74f2a423d6c7bef
02058b56a8b90fb39e8ff901
```

Script

OP_HASH160 0x6f3f0b93b060ea9c0d76989c9747c9b6cfad617d

OP_EQUALVERIFY OP_CHECKSIG

Executing Script PubKey [8]

Stack

```
0x02b621afa86afdb74d874e876413cf199833f4a5f68e10335134876eebe
29bbe6d
```

```
0x304402205c5876144bf491eb6aece2625cbc3049819f35094e8feaf808
399de0c29b593d022048267261596dccb8a49659f0a9c74f2a423d6c7bef
02058b56a8b90fb39e8ff901
```

Script

OP_CHECKSIG

Stack

```
0x02b621afa86afdb74d874e876413cf199833f4a5f68e10335134876eebe
29bbe6d
```

```
0x304402205c5876144bf491eb6aece2625cbc3049819f35094e8feaf808
399de0c29b593d022048267261596dccb8a49659f0a9c74f2a423d6c7bef
02058b56a8b90fb39e8ff901
```

Script

OP_DUP OP_HASH160

```
0x6f3f0b93b060ea9c0d76989c9747c9b6cfad617d OP_EQUALVERIFY
```

OP_CHECKSIG

Executing Script PubKey [5]

Stack

```
0x6f3f0b93b060ea9c0d76989c9747c9b6cfad617d
```

```
0x02b621afa86afdb74d874e876413cf199833f4a5f68e10335134876eebe
29bbe6d
```

```
0x304402205c5876144bf491eb6aece2625cbc3049819f35094e8feaf808
399de0c29b593d022048267261596dccb8a49659f0a9c74f2a423d6c7bef
02058b56a8b90fb39e8ff901
```

Script

```
0x6f3f0b93b060ea9c0d76989c9747c9b6cfad617d OP_EQUALVERIFY
```

OP_CHECKSIG

Executing Script PubKey [9]

Stack

1

Script

Stack

```
0x6f3f0b93b060ea9c0d76989c9747c9b6cfad617d
```

```
0x6f3f0b93b060ea9c0d76989c9747c9b6cfad617d
```

```
0x02b621afa86afdb74d874e876413cf199833f4a5f68e10335134876eebe
29bbe6d
```

```
0x304402205c5876144bf491eb6aece2625cbc3049819f35094e8feaf808
399de0c29b593d022048267261596dccb8a49659f0a9c74f2a423d6c7bef
02058b56a8b90fb39e8ff901
```

Script

OP_EQUALVERIFY OP_CHECKSIG

Executing Script PubKey [6]

Stack

```
0x6f3f0b93b060ea9c0d76989c9747c9b6cfad617d
```

```
0x6f3f0b93b060ea9c0d76989c9747c9b6cfad617d
```

```
0x02b621afa86afdb74d874e876413cf199833f4a5f68e10335134876eebe
29bbe6d
```

```
0x304402205c5876144bf491eb6aece2625cbc3049819f35094e8feaf808
399de0c29b593d022048267261596dccb8a49659f0a9c74f2a423d6c7bef
02058b56a8b90fb39e8ff901
```

Script

OP_EQUALVERIFY OP_CHECKSIG

Execution Succeeded

Pay to script hash (P2SH), BIP16, starts with '3'

- Lock script separated into two parts
 - 1) commitment to the script (hash value, checked later)
 - 2) actual lock script (hash value must match the commitment)
- Sending tx sets output's ScriptPub to the commitment
 - Shorter as only hash is posted, not whole lock script
 - Lock script is provided only later when spending (privacy, fee to be paid)
 - Lock script can have multiple spending paths (Merkle tree) and only the one used is posted (better for privacy)
- Redeeming tx provides actual lock script + unlock script

Executing **Script Sig** [0]

Stack
Commitment to script Script

Script
0x0020a7e8b9a8e9a191fbe1ab72bc888f2f33f0f31d79e7d53ffab95caf305244895c
OP_HASH160 0x535c40bcfe82e218a8d744f6262c8299b23466d6
OP_EQUAL

Executing **Script Sig** [1]

Stack
0x0020a7e8b9a8e9a191fbe1ab72bc888f2f33f0f31d79e7d53ffab95caf305244895c

Script
OP_HASH160 0x535c40bcfe82e218a8d744f6262c8299b23466d6
OP_EQUAL

Executing **Script PubKey** [2]

Stack
0x0020a7e8b9a8e9a191fbe1ab72bc888f2f33f0f31d79e7d53ffab95caf305244895c

Script
OP_HASH160 0x535c40bcfe82e218a8d744f6262c8299b23466d6

If initial script structure was commitment and value on stack is true, special code branch of code is executed, using original witness script

Executing **Script PubKey** [3]

Stack
0x535c40bcfe82e218a8d744f6262c8299b23466d6

Script
0x535c40bcfe82e218a8d744f6262c8299b23466d6 OP_EQUAL

Executing **Script PubKey** [4]

Stack
0x535c40bcfe82e218a8d744f6262c8299b23466d6
0x535c40bcfe82e218a8d744f6262c8299b23466d6

Script
OP_EQUAL

Check script hash

Execu

Stack
1

Script

Stack
0x3044022006eface088364596f612ddd158a4101c71ff770bc5a6bbe35930d9790376b87a022047e165e0fce43a446a7524b5530023e805a7460c1b564f96182f2c1efa5003c901
0x3044022053d0678e8994a4b10fa883047f584d372026cf6576a84bebdae0c131c04bb622022066a6b7f64dee7606a6db9d30b0b7dfd42e2c0250a98adb61d13

Witness script is executed (here 2-of-3 multisig) OP_FALSE is used to push 0 on stack (multisig bug)

Executing **Script P2SH** [6]

Stack
OP_FALSE
0xa7e8b9a8e9a191fbe1ab72bc888f2f33f0f31d79e7d53ffab95caf305244895c

Executing **Script P2SH** [7]

Stack
0
Script
0xa7e8b9a8e9a191fbe1ab72bc888f2f33f0f31d79e7d53ffab95caf305244895c

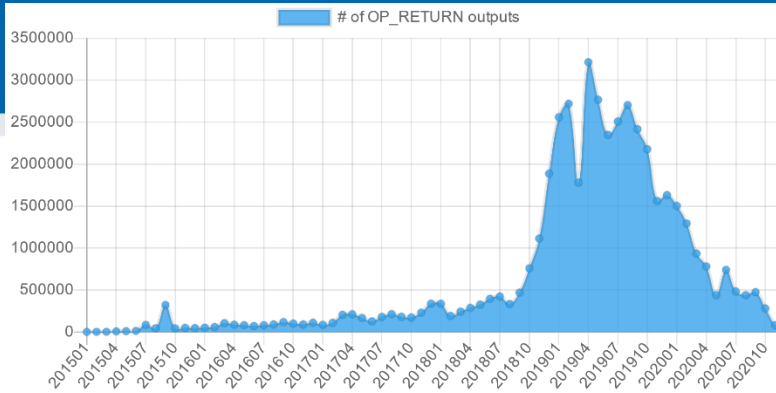
Executing **Script P2SH** [8]

Stack
0xa7e8b9a8e9a191fbe1ab72bc888f2f33f0f31d79e7d53ffab95caf305244895c
0
Script

Interesting, non-standard scripts

- SHA1 collision bounty
 - Bitcoins locked to script requiring two different inputs hashed to same SHA1 hash
 - Redeemed shortly after Google published SHA1 collision blocks
 - <https://blockstream.info/tx/8d31992805518fd62daa3bdd2a5c4fd2cd3054c9b3dca1d78055e9528cff6adc>
 - <https://nioctib.tech/#/transaction/f2f398dace996dab12e0cfb02fb0b59de0ef0398be393d90ebc8ab397550370b>
 - More details: https://bitcoinjs-guide.bitcoin-studio.com/bitcoinjs-guide/v5/part-three-pay-to-script-hash/puzzles/computational_puzzle_sha1_collision_p2sh.html
 - Similar bounties for

OP_RETURN



- If OP_RETURN is encountered during execution of unlock+lock script, it is FALSE
 - Such output is provably unspendable
- Somewhat controversial instruction
 - Some feels, that blockchain shall not be used for non-financial data (USDT was initially on Bitcoin via OP_RETURN)
 - But there were already ways how to store arbitrary data into blockchain anyway (e.g., bytes of value, invalid address)
- Analysis of OP_RETURN data
 - <https://www.blockchainresearchlab.org/2020/03/13/how-do-op-return-transactions-impact-bitcoin/>
 - <https://opreturn.org/>

Paying from

1HnhWpkMHMjgt167kvgcPyrMmsCQ2WPgg

0.0022 BTC - Transaction output 1

ScriptSig - P2PKH

```

0x30450220446df4e6b875af246800c8c976de7cd6d7d95016c4a8f7bcd
ba81679cbda242022100c1ccfacfeb5e83087894aa8d9e37b11f5c054a75
d030d5bfd94d17c5bc953d4a01
    
```

```

0x045901f6367ea950a5665335065342b952c5d5d60607b3cdc6c69a03d
f1a6b915aa02eb5e07095a2548a98dcd84d875c6a3e130bafadfd45e694
a3474e71405a4
    
```

Interpret or debug

To

No address

0 BTC - not spent yet

ScriptPubKey - NULL DATA

charley loves heidi

```

OP_RETURN 0x636861726c65792066766573206865696469
    
```

1HnhWpkMHMjgt167kvgcPyrMmsCQ2WPgg

0.002 BTC - Transaction

ScriptPubKey - P2PKH

```

OP_DUP OP_HASH160
0xb8268ce4d481413c4e848ff353cd16104291c45b OP_EQUALVERIFY
OP_CHECKSIG
    
```

<https://nioctib.tech/#/transaction/f2f398dace996dab12e0cfb02fb0b59de0ef0398be393d90ebc8ab397550370b>

Miniscript (A. Poelstra, P. Wuille, S. Kanjalkar, 2019)

- Language for easier and error-prone creation of Bitcoin scripts
 - Subset of Bitcoin script language
 - Human-readable, easy to express complex locking conditions
 - <https://bitcoin.sipa.be/miniscript/>
- Simple building blocks (policies)
 - Single-key, Multi-key,
 - Time-locks, Check-sequence,
 - Hash-lock...
- Compiler creates optimal script
 - And cost analysis

Supported policies:

- `pk(NAME)`: Require public key named *NAME* to sign. *NAME* can be any string up to 16 characters.
- `after(NUM), older(NUM)`: Require that the `nLockTime/nSequence` value is at least *NUM*. *NUM* cannot be 0.
- `sha256(HEX), hash256(HEX)`: Require that the preimage of 64-character *HEX* is revealed. The special value *H* can be used as *HEX*.
- `ripemd160(HEX), hash160(HEX)`: Require that the preimage of 40-character *HEX* is revealed. The special value *H* can be used as *HEX*.
- `and(POL, POL)`: Require that both subpolicies are satisfied.
- `or([N@]POL, [N@]POL)`: Require that one of the subpolicies is satisfied. The numbers *N* indicate the relative probability of each of the subexpressions (so `9@` is 9 times more likely than the default).
- `thresh(NUM, POL, POL, ...)`: Require that *NUM* out of the following subpolicies are met (all combinations are assumed to be equally likely).

Miniscript examples

A single key

Policy

```
pk(key_1)
```

Miniscript output:

```
pk(key_1)
```

Spending cost analysis

- Script: 35 WU
- Input: 73.000000 WU
- Total: 108.000000 WU

Resulting script structure

```
<key_1> OP_CHECKSIG
```

A 3-of-3 that turns into a 2-of-3 after 90 days

Policy

```
thresh(3,pk(key_1),pk(key_2),pk(key_3),older(12960))
```

Miniscript output:

```
thresh(3,pk(key_1),s:pk(key_2),s:pk(key_3),sln:older(12960))
```

Spending cost analysis

- Script: 122 WU
- Input: 166.250000 WU
- Total: 288.250000 WU

Resulting script structure

```
<key_1> OP_CHECKSIG OP_SWAP <key_2> OP_CHECKSIG OP_ADD OP_SWAP <key_3>
OP_CHECKSIG OP_ADD OP_SWAP OP_IF
  0
OP_ELSE
  <a032> OP_CHECKSEQUENCEVERIFY OP_0NOTEQUAL
OP_ENDIF
OP_ADD 3 OP_EQUAL
```

Warning: Why not put “blockchain” everywhere?

- ~~“Blockchain not Bitcoin”, “Blockchainize everything”~~... claims
- Permissionless distributed consensus on global state is very expensive
 - Confirmation time, storage space, energy expenditure (PoW)...
 - Most applications does not need it!
 - Especially when other components of application are centralized (development, governance decisions, data storage...)

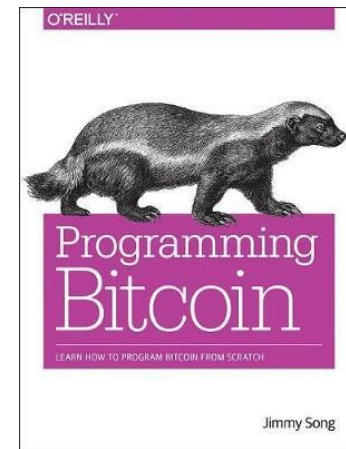
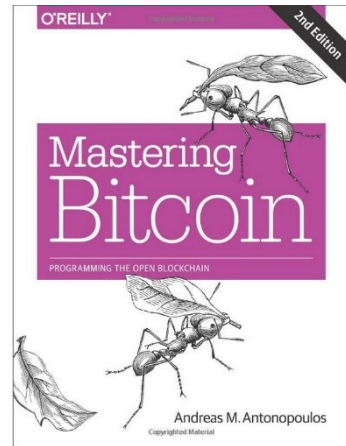


Study materials

- **Mandatory reading**
 - Bitcoin's academic pedigree (Arvind Narayanan, Jeremy Clark)
 - <https://dl.acm.org/doi/10.1145/3132259> (copy in IS)
 - Explanation of roots of Bitcoin key components
- If you were not familiar with basics of Bitcoin before
 - Watch 'But how does bitcoin actually work?' by 3Blue1Brown (26min)
 - <https://www.youtube.com/watch?v=bBC-nXj3Ng4>
 - Read slides Hello Bitcoin (including notes under every slide)
 - From <https://www.hellobitco.in/>, copy of slides in IS

Further reading

- Mastering Bitcoin (Andreas M. Antonopoulos and others)
 - <https://github.com/bitcoinbook/bitcoinbook>
- Programming Bitcoin (Jimmy Song)
 - <https://github.com/jimmy-song/programming-bitcoin>
- List of interesting resources
 - <https://blockonomi.com/bitcoin-educational-resources/>
 - <https://learnmeabitcoin.com/>, <https://learnmeabitcoin.com/technical/>



**THANK YOU FOR COMING, SEE YOU
NEXT WEEK**