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How Bitcoin Works

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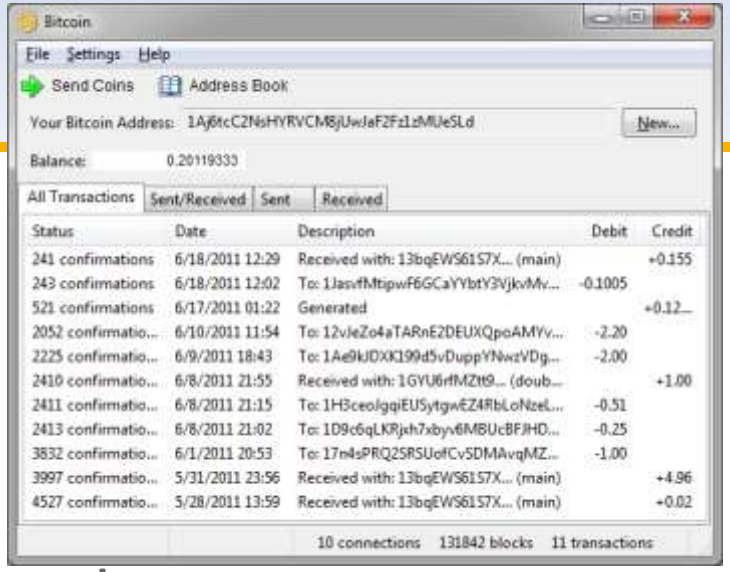
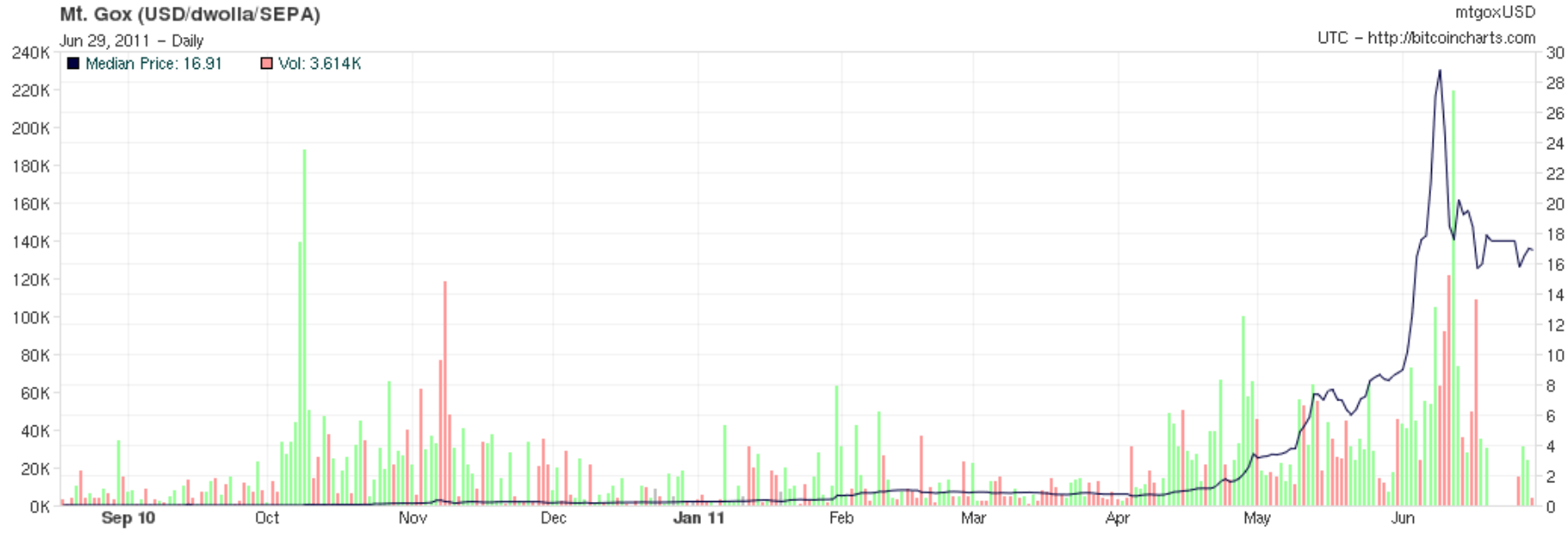
Overview



- **Electronic currency system**
- **Decentralized**
  - No trusted third party involved
  - Unstructured peer-to-peer network
- **Non-reversible**
  - Cryptographic proof instead of trust
- **Open source beta software (C++, wxWidgets)**
- **Currency unit: BTC**

Timeline

- 1993: ecash (DigiCash/David Chaum)
- 1998: Crypto-currency ideas (W. Dai, N. Szabo)
- Nov 2008: Whitepaper by Satoshi Nakamoto
- Feb 2009: Initial Bitcoin release

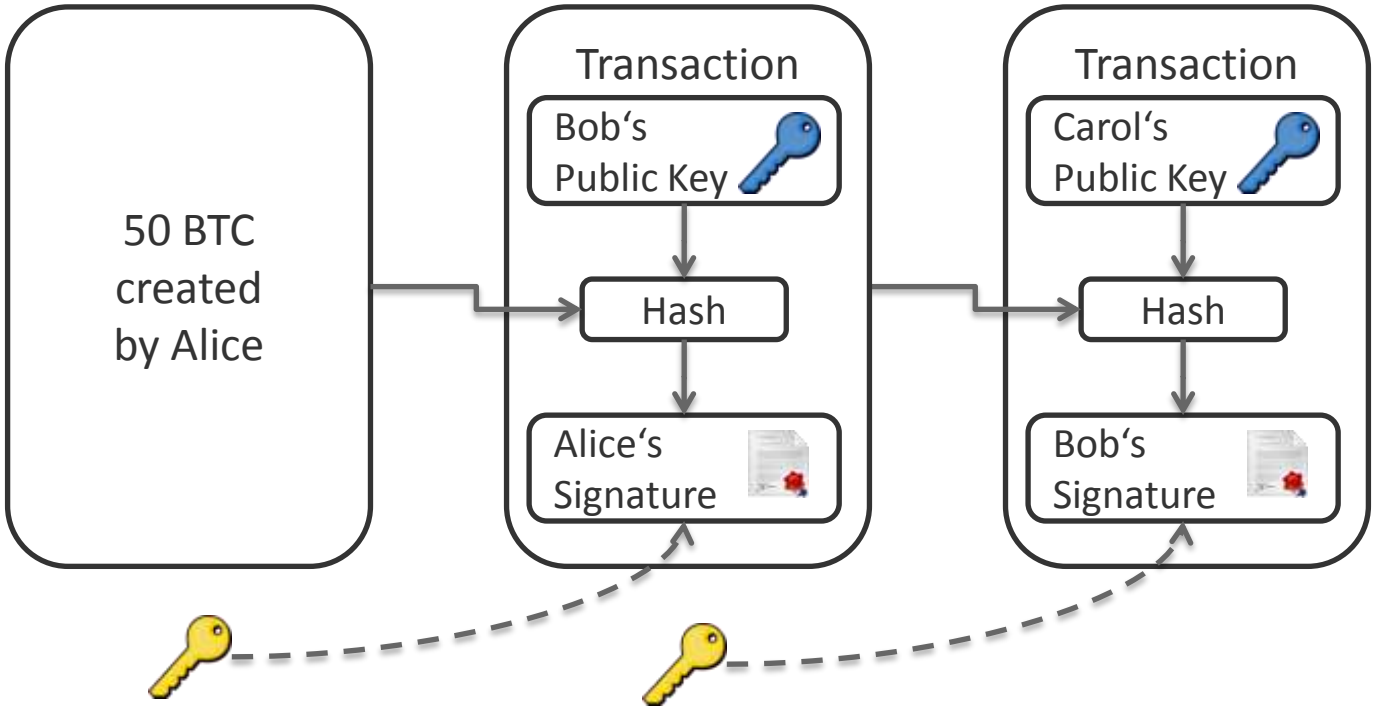


Concept

- **Clients invest computing power to create coins**
  - By solving cryptographic puzzles
  - Difficulty of puzzles adapts
  - Number of coins limited
- **Public transactions for coin transfers**
  - Senders and receivers have addresses
  - Authorized by private key signatures
- **Honest majority prevents double-spending**
  - Public transaction database

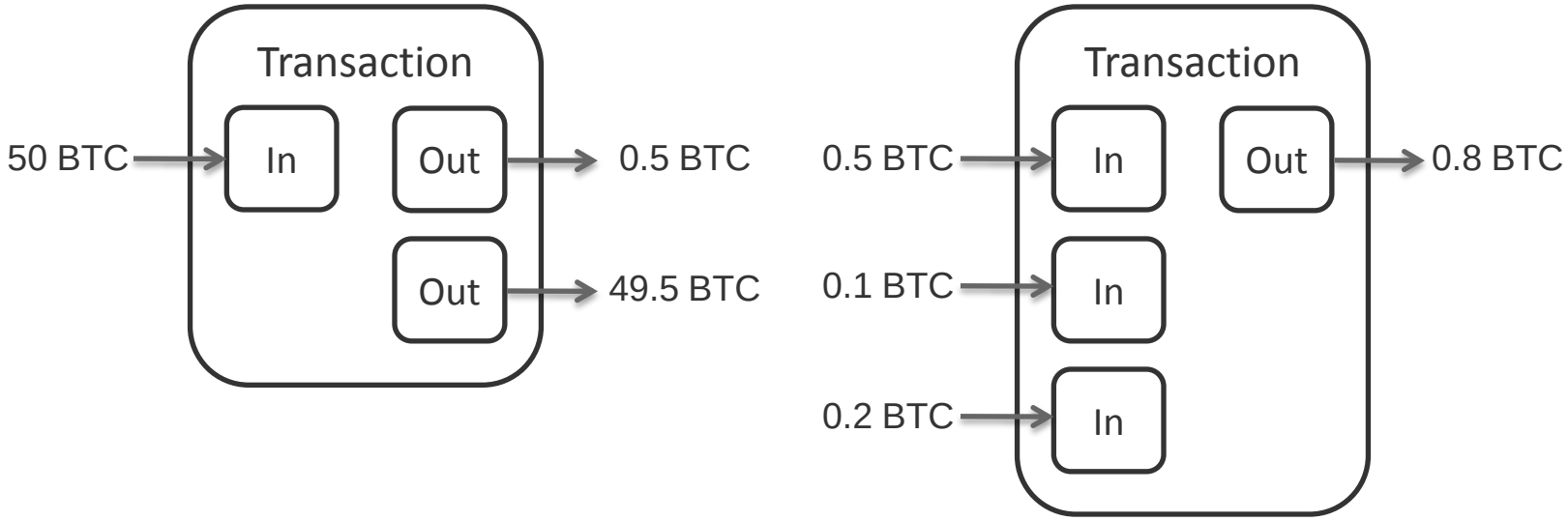
Transactions

- **Public transfers between Bitcoin addresses**
- **Signed by previous coin owner**



Splitting and Combining Coins

- **Coins can be split up to 10^{-8} BTC**

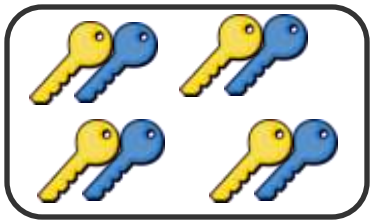


Bitcoin Address

- **Fingerprint of public key**
- **25 bytes identifier**
  - Format version: 0x01
  - Fingerprint: RIPEMD160(SHA256(pub))
  - Checksum: 4 bytes of SHA256(fingerprint)
- **Base58 encoded**
  - Alphanumeric alphabet (without I, O, l, 0, +, /)
  - *E.g. 1BpCB9Qzm2LePrQKu6RzASzEKvjc6utsQQ*

Key Handling

- **Client generates public/private key pairs**
  - ECDSA 256 bit
  - Stores them in wallet file



- **Wallet contains key pairs, not coins**
- **Private key authorizes transactions**
- **If keys are stolen, thief may use your coins**
- **If keys are lost, coins are lost**
- **No wallet encryption nor backup in v0.3.23 GUI**

Networking (1/2)

- **Unstructured peer-to-peer network**
- **IRC bootstrapping**
  - Nickname contains IP endpoint, e.g. u4euc453wZ599zQ
  - ‚u', base58(IP address, port, checksum)
- **Freenode used at the beginning**
  - Users got k-lined for botnet-like behavior
- **Moved to dedicated network in mid 2010**
  - #bitcoin overcrowded, now using #bitcoin[00-99]

Networking (2/2)

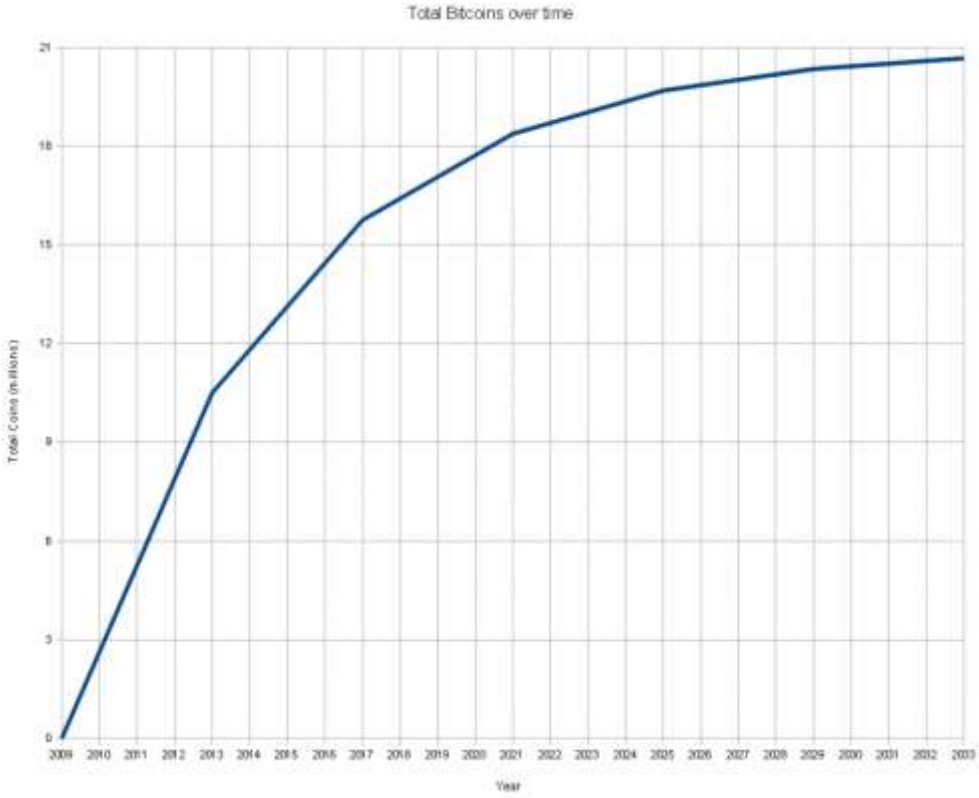
- **DNS bootstrapping**
  - Without update channel
- **Built-in fallback peer list**
- **Peer exchange**
- **Port 8333/TCP**
- **UPnP**
- **Purpose of networking:**
  - Flood transactions
  - Share distributed database (block chain)

Mining Coins (1/3)

- **Solve cryptographic challenge to create coins**
  - Find a *block* whose hash value is below target value
  - SHA256(SHA256(block)) < target
- **Random client finds solution first**
- **Chance proportional to computing power**
- **On average one solution every 10 minutes**
- **Difficulty adapts to keep solving rate constant**
- **If found: announce block which is proof-of-work**

Mining Coins (2/3)

- **Payout per block: 50 BTC**
- **Halves every 4 years**
- **In 2033:**
  - Payout < 1 BTC
  - 20.7 million BTC in circulation

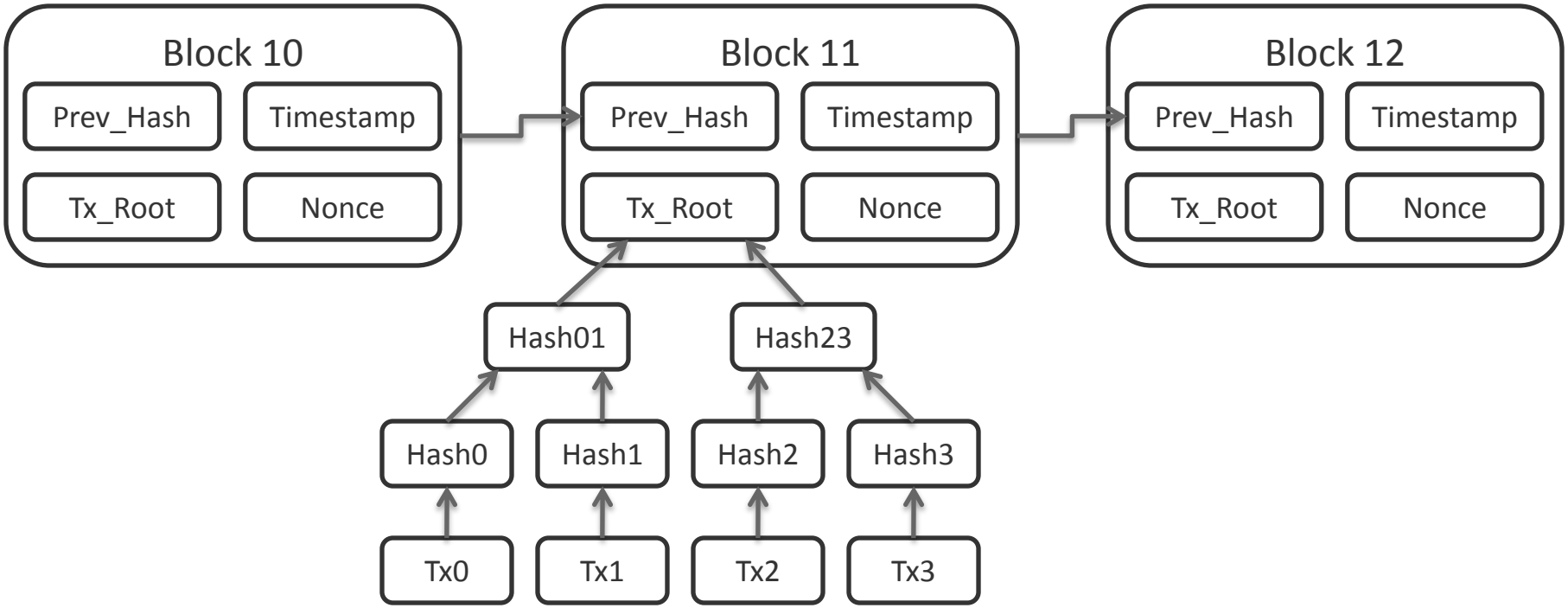


- **Total number of Bitcoins is a geometric series and approaches maximum of 21 million BTC**

Mining Coins (3/3)

- **Bitcoin requires processing power for operation**
  - The more honest clients work, the harder cheating is
- **Hash rate vs. power consumption**
- **GPU mining is common, CPU mining pointless**
- **ATI cards better suited than NVIDIA**
- **Mining pools share payout**
- **In future: FPGA, ASIC?**

Block Chain (1/3)



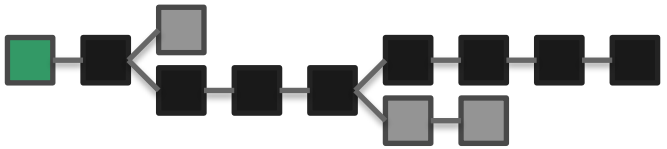
- **Blocks commit transactions**
- **First transaction is generation of coins**

Block Chain (2/3)

- **Clients have built-in *Genesis* block**
  - Newer versions also have checkpoint blocks
- **Download, validate and store block chain from untrusted network**
  - Check whether block hashes < target value
  - Verify known checkpoints
  - Verify balance and check for double-spending
- **Forging chain is computationally infeasible**

Block Chain (3/3)

- **Block chain may fork**



  - Due to propagation delay in p2p network
  - Due to attacker injecting forged blocks
- **Use first block received, save the other one**
- **Switch to other chain, if it becomes longer**
- **Transactions confirmed after 6 blocks**
  - Double-spending becomes unlikely
- **Ignore orphaned block chains**
  - Generated coins mature after 100 blocks

Adapting Difficulty

- **Allowed block timestamp**
  - time < now + 2h
  - time > median of past 11 blocks

- **uint32 nBits value** greater ≙ less difficult

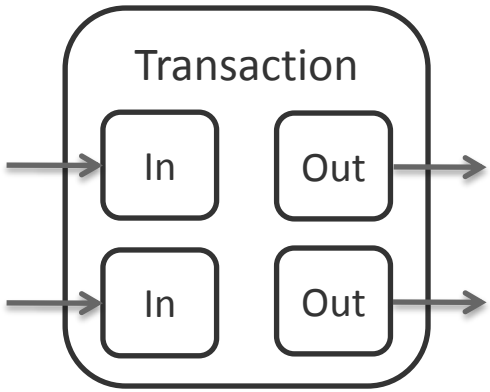
- **nBits adapts every 2016 blocks (≈2 weeks)**
  - $nBits \cdot ((time_{cur} - time_{cur-2016}) / 2\ weeks)$
- **256 bit target hash value**
  - $uint24 \cdot 2^{(8 \cdot (uint8 - 3))} = 0x00000000001D932F0...$

Scalability

- **Transactions flooded in network**
  - Pending until someone commits them in new block
- **Does not scale with number of transactions**
- **Block chain mirrored on all clients**
  - 300 MB after 2,5 years of operation
- **Storage usage can be further optimized**
  - Compress block chain to 240 MB
  - Prune redeemed transactions from hash tree
  - Estimated ≈70% of transactions can be pruned

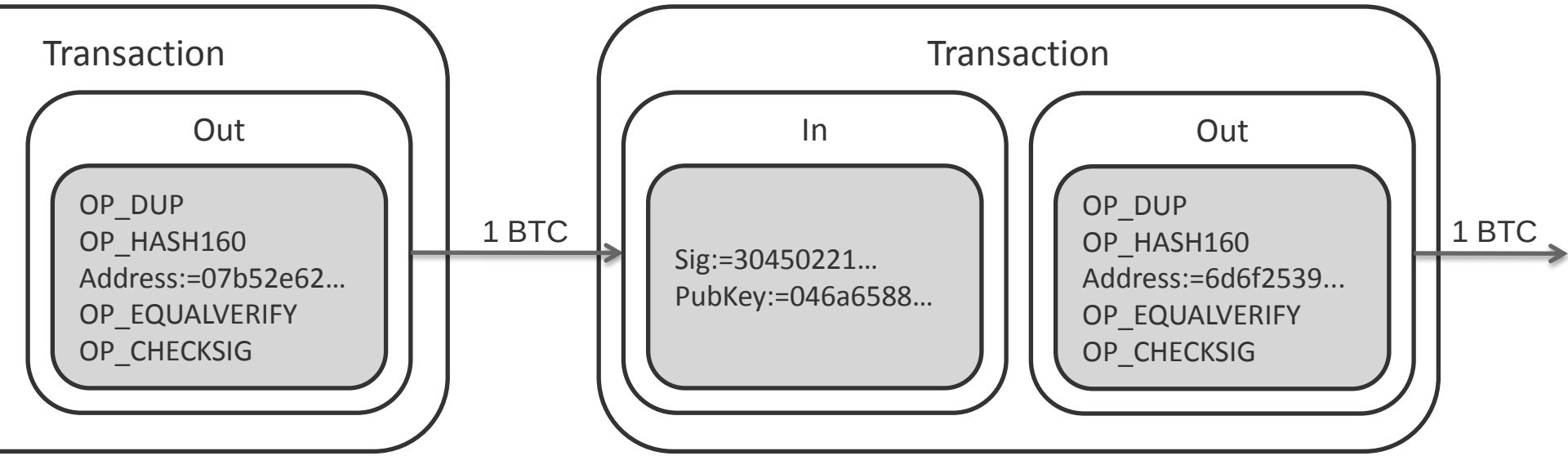
Transaction Fee and Priority

- **Fee to keep transaction count low**
  - Sender may pay fee to mining client who finds block
  - Fee is voluntary, but so is commitment in block
- **Transaction priority** greater ≙ higher priority
  - $\text{sum}(\text{value}_{\text{in}} \cdot \text{age}_{\text{in}}) \,/\, \text{size}$
- **Transaction ignored if fee too low**
  - May be done by both, relays and miners
  - Minimum fee depends on space left in new block
- **Fee serves as incentive for mining clients**



Transaction Script

- **Scripting language for verification**
- **Simple stack machine without loops**



Privacy

- **Transactions traceable in public block chain**

Transaction[?]	Fee[?]	Size (kB)[?]	From (amount)[?]	To (amount)[?]
ea1fc5bf38...	0	0.135	Generation: 50 + 0.178 total fees	12oxGihmrUEZRf4p8ApokzQzDkf6M4Z26c: 50.178
0b6572ba5a...	0.01	0.439	16tMYLgDawEya3VPzAuFcPGEdAxp8ASRxs: 0.21 1KX7s7hbo3PgwdfyTet2YJ53STVfB6Fy6D: 6.49	1Lsd745FNdQumjFK3wYxevLmpALD5ojAzM: 0.19 1FffCkjmGJigrWpUAM9HYQCAR7fqhrHi9Q: 6.5

- **Weak anonymity (pseudonymity)**
- **Anonymity vanishes if identity linked to address**
- **To keep payments private, …**
  - … keep addresses private
  - … use different addresses
  - … use trusted mixing service

Conclusion

- **Peer-to-peer accounting system**
- **Relying on honest majority**
- **Growing public log file (block chain)**
  - Limited scalability
  - Limited privacy
- **Public key cryptography for authorization**
- **Proof-of-work to prevent double-spending**
  - Requires vast amount of computing power
- **Technically sophisticated experiment**