Bitcoin and Cryptocurrency Technologies
Lecture 3: Bitcoin Data Model

Yuri Zhykin

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Bitcoin Data Model

- **Bitcoin Block Chain** (or **Bitcoin Time Chain** is a distributed, highly-redundant database of transaction records that strongly guarantees the *existence, validity and order* of transactions.
- **Bitcoin Protocol** is a distributed protocol of maintaining the Bitcoin transaction database that imposes strict rules about transaction validity and enforces the database guarantees through the **Proof-of-Work** system.
- If a transaction record is added to the database, one can be sure that it
  - definitely happened,
  - is provably valid,
  - it happened strictly before or after the other transactions.

Transaction

- **Tx**
  - **version**
  - **inputs**
  - **outputs**
  - **witnesses**
  - **locktime**
- **Inputs** - a list of transaction inputs - references to the outputs of other transactions, that are consumed by this transaction.
- **Outputs** - a list of newly created outputs that specify, where all the bitcoin from the outputs referenced by inputs is being transferred.
- **Locktime** restricts the moment in time, when the transaction can be included in the transaction records database.

Transaction ID

- **Transaction ID** is not included in the transaction data structure, since it can be computed from the binary representation of the transaction:

$$TXID = SHA256(SHA256(TX_{binary}))$$

- *TXID* is a 32-byte sequence and is usually represented as a 64-character hex-encoding of the 32-byte sequence:

```
169e1e83e930853391bc6f35f605c6754cfead57cf8387639d3b4096c54f18f4
```

Transaction Output

- **TxOutput**
  - **amount**
  - **lock-script**
- **Amount** - an amount of bitcoin currency units, called “satoshis” represented as an integer (1 BTC = 10^8 satoshis).
- **Lock-script** - a computational (usually “supply a valid signature”) problem that must be solved in order to spend this output, expressed as Bitcoin Script program.

Transaction Input

- **TxInput**
  - **previous-tx-id**
  - **previous-tx-index**
  - **unlock-script**
- Transaction input is a reference to the transaction output being spent along with the solution to the lock-script of that output.
- **Previous transaction ID** - a TXID of the transaction that created the output.
- **Previous transaction index (VOUT)** - an index of the output in the output list of the transaction referenced by previous transaction ID.
- **Unlock-script** - a solution to the *lock-script* of the output being spent represented as Bitcoin Script program.

Transaction Witness

- **Witness** is an additional structure in the transaction that was introduced as a protocol upgrade (called **SegWit** - **Seg**regated **Wit**ness) in 2017 as a first step in a long-term plan to improve Bitcoin security, scalability and flexibility.
- **Witness** allows to store complex *unlock-scripts* (solutions) to the *lock-scripts*, which accounts for a large part of the transaction size.

UTXO (Unspent Transaction Output) Set

- All bitcoin in existence is represented via a set of **unspent transaction outputs** (**UTXOs**) - a set of records of the form $(amount, owner)$ that can be provably verified as not used in any known transaction.
- Every regular Bitcoin transaction consumes some existing UTXOs and generates new UTXOs.
- An entity "owns" bitcoin if the UTXO set contains outputs that have that entity as the *owner* part.

Transaction Fee

- **Transaction fee** is a difference between the amounts in the spent outputs and the amounts in the newly generated outputs:

$$TxFee = \sum_{i=1}^{n} InputAmount(txin_i) - \sum_{j=1}^{m} Amount(txout_j),$$

Block

- Block
  - **header**
  - **transactions**
- **Header** is a structure that contains metadata about the block and all components necessary for the Proof-of-Work system.
- **Transactions** is an ordered list of transactions that were included in the given block.

Block Header 1/4

- BlockHeader
  - **version**
  - **previous-block-hash**
  - **transaction-merkle-tree-root**
  - **timestamp**
  - **proof-of-work-bits**
  - **proof-of-work-nonce**
- **Block hash** (or **block ID** is calculated as

$$BlockID = SHA256(SHA256(BlockHeader_{binary}))$$

- **Previous block hash** is the “chain” part of the “block chain” term: every next block references the previous one, and modifying any information in any block modifies the hashes of all the blocks that follow (avalanche effect of the cryptographic hash functions).

Block Header 2/4

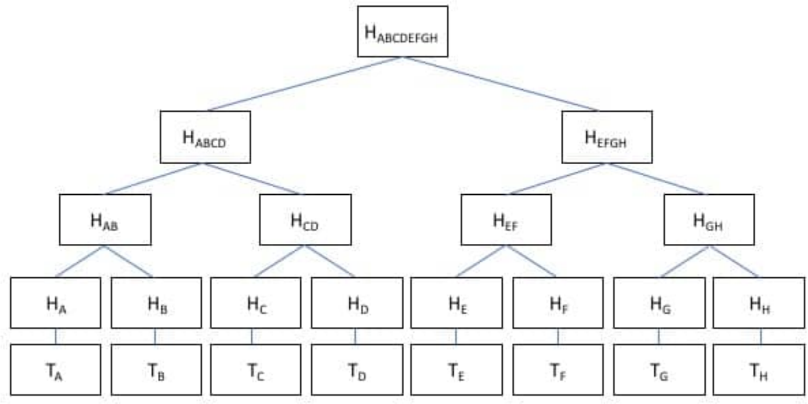
- **Proof-of-Work bits** is an encoded target value for the Proof-of-Work algorithm: the resulting PoW solution must be less than the number represented by this field:

$$BlockID = SHA256(SHA256(BlockHeader)) < Target$$

- **Bits** value is recalculated every 2016 blocks (roughly 2 weeks) to ensure that the average time to solve the PoW problem is kept around 600 seconds (10 minutes).
- This recalculation is called **difficulty adjustment**: if the average time for the last 2016 blocks was less than 10 minutes, increase PoW difficulty by selecting a smaller target value, otherwise decrease it.
- **Proof-of-Work nonce** (**nonce** = **N**umber used **ONCE**) - a value that is incremented when running brute force search for the PoW solution.

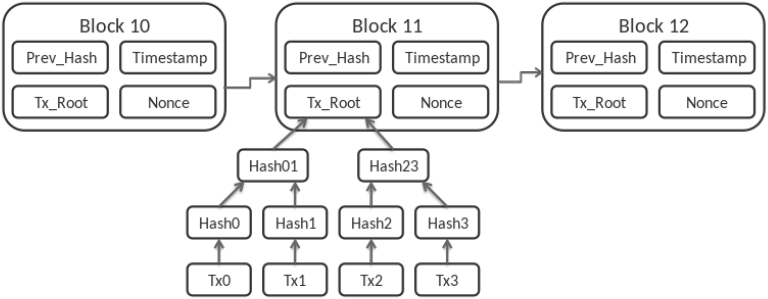
Block Header 3/4

- **Transaction Merkle Tree Root** - a root of a Merkle Tree - a 32-byte sequence that cryptographically includes all transactions in the block and ensures their sequence:



Block Header 4/4

- Previous block hashes link blocks and transactions they contain into a linear sequence chain via a cryptographic commitments.
- Changing a single bit in a transaction completely changes the merkle root, which changes block hash, which, in turn changes hash of the next block and so on.



Mining

- **Mining** is a process of computing Proof-of-Work solutions for new blocks.
- Miner
  - selects a number of pending transactions,
  - builds a Merkle tree and uses its root to construct the new block header with the last known block's hash as the previous block hash.
  - performs a brute force search of the Proof-of-Work solution

$$SHA256(SHA256(BlockHeader)) < Target$$

  - if the PoW solution is found **before** an alternative solution is received over the peer-to-peer network, it can be published for the network to accept it as the new highest known block.

Coinbase Transaction and Halving Events

- In order to incentivize miners to do their job, Bitcoin Protocol allows to add a special transaction at the beginning of the transaction list of each new block.
- This transaction is called **coinbase transaction** and has no inputs, only outputs, thus "generating" new bitcoins.
- Additionally, miners can add all transaction input-output amount differences (*transaction fees*) to the coinbase transaction amount.
- **Halving events** - in order to keep bitcoin supply limited, the amount of new bitcoins started with 50 BTC and is reduced by the factor of 2 every 210000 blocks, eventually reaching 0, at which point the bitcoin supply will stop growing.

Useful Resources

- Learn me a Bitcoin by Greg Walker - a great resource that explains multiple technical details about Bitcoin
  - https://learnmeabitcoin.com/

The End

Thank you!