CSE446: Blockchain & Cryptocurrencies

Lecture – 9: Bitcoin-3

BRAC UNIVERSITY

Inspiring Excellence

Agenda

- Bitcoin components
  - Users
  - Node & Network
  - Blockchain

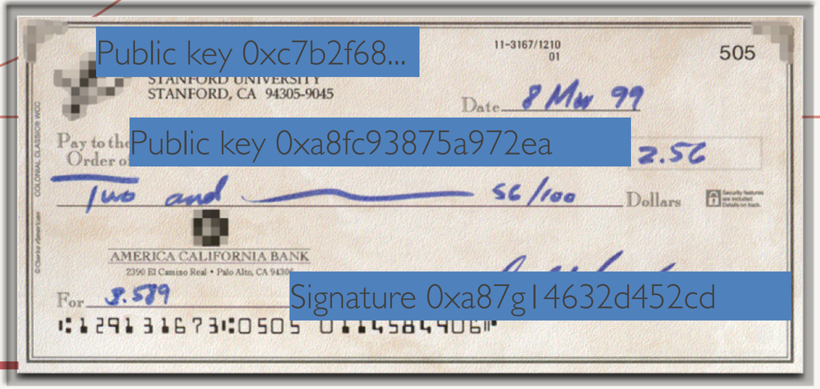
Bitcoin blockchain

- There are three different things to understand
  - Transaction
  - Block
  - Blockchain

Transaction

- Transactions are the most important part of the bitcoin system
- Everything else in bitcoin is designed to ensure that transactions can be created, propagated on the network, validated, and finally added to the global ledger of transactions (the blockchain)
- Transactions are data structures that encode the transfer of value between participants in the bitcoin system
  - A transaction transfers money from somebody to somebody else
- Each transaction is a public entry in bitcoin's blockchain, the global double-entry bookkeeping ledger
  - an entry that affects at least two different accounts
- All transactions are public
- Everybody can see all transactions in a blockchain explorer

Transaction



Public key 0xc7b2f68...

STANFORD UNIVERSITY
STANFORD, CA 94305-9045

11-3167/1210
01

505

Date 8 Mw 99

Pay to the Order of Public key 0xa8fc93875a972ea 2.56

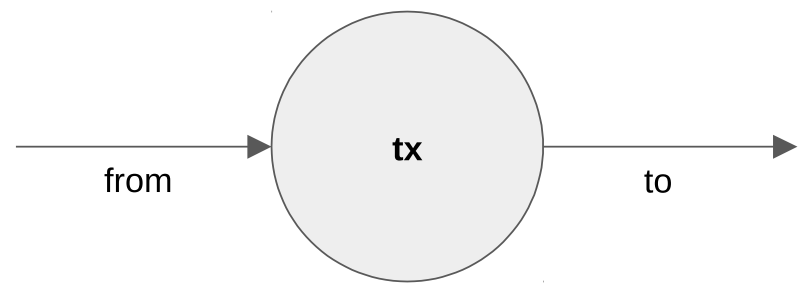
Two and 56/100 Dollars

AMERICA CALIFORNIA BANK
2350 El Camino Real • Palo Alto, CA 94306

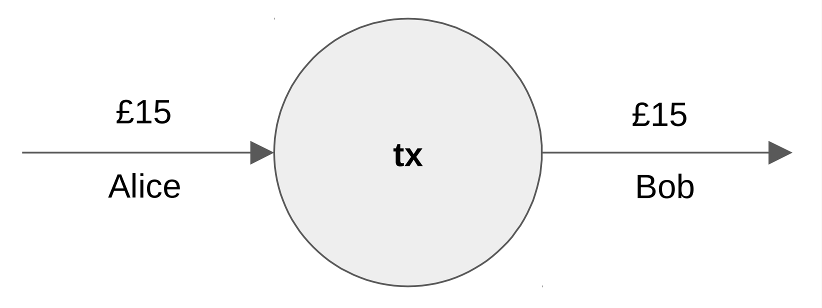
For 8.589

Signature 0xa87g14632d452cd

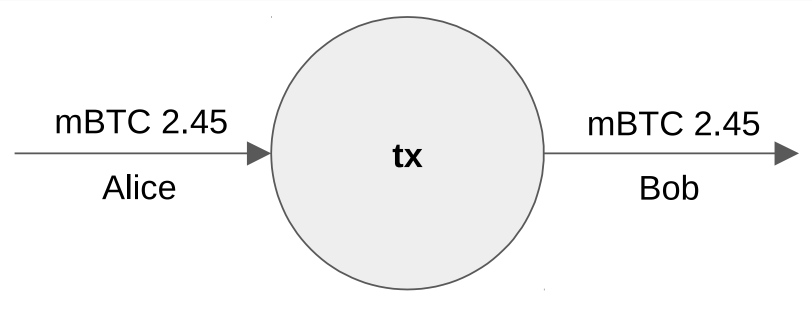
⑆1291 31673⑆0505 0114584906⑈



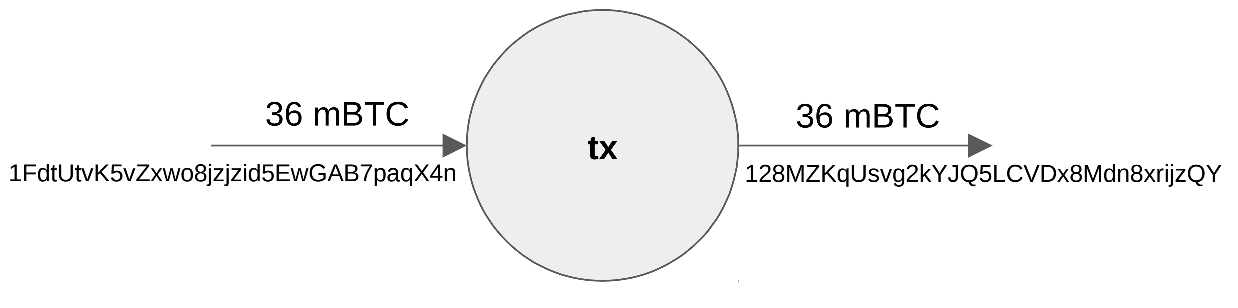
Abstract format of any transaction



A traditional transaction

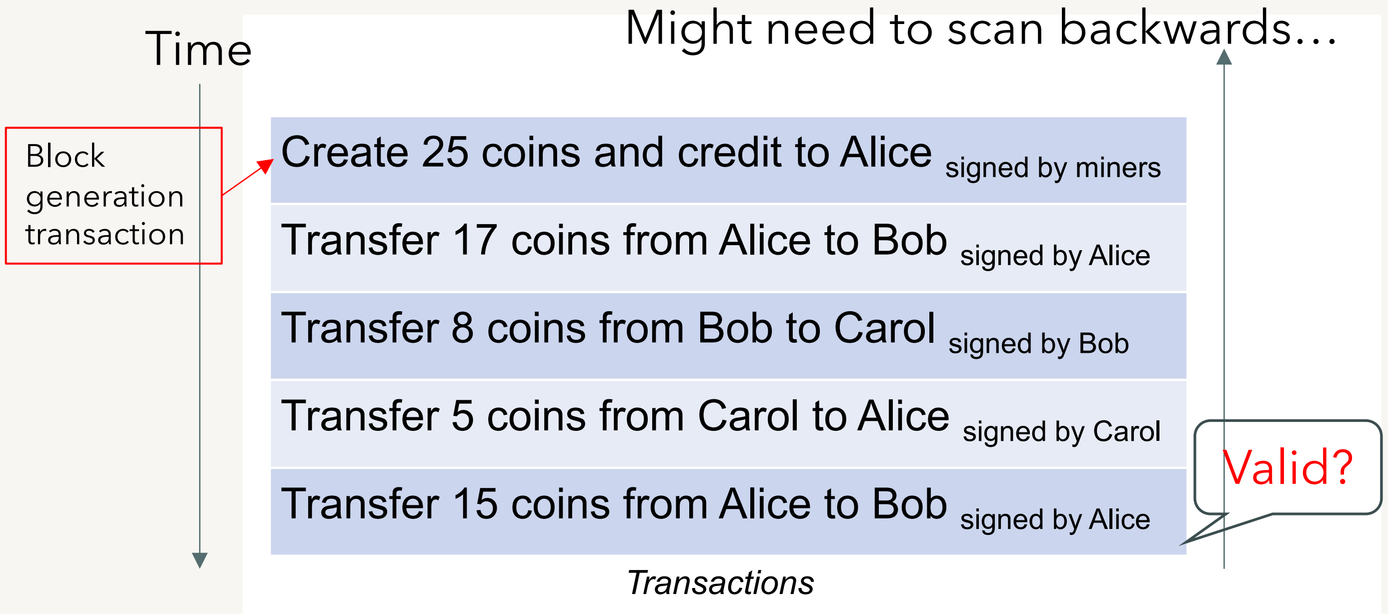


Abstract format of a bitcoin transaction


36 mBTC
1FdtUtvK5vZxwo8jzjzid5EwGAB7paqX4n
tx
36 mBTC
128MZKqUsvg2kYJQ5LCVDx8Mdn8xrijzQY

A bitcoin transaction

Account/transaction based Ledger?



Time

Might need to scan backwards…

Block generation transaction

Create 25 coins and credit to Alice signed by miners

Transfer 17 coins from Alice to Bob signed by Alice

Transfer 8 coins from Bob to Carol signed by Bob

Transfer 5 coins from Carol to Alice signed by Carol

Transfer 15 coins from Alice to Bob signed by Alice

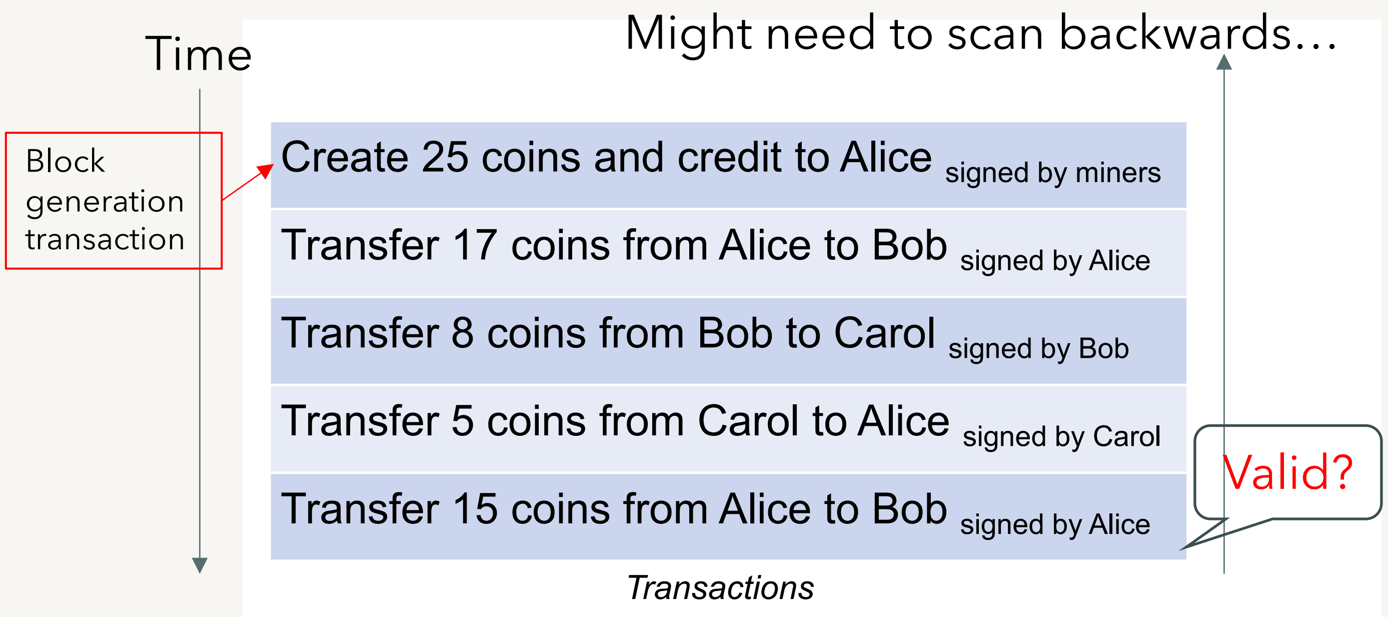
Valid?

Transactions

- *Intuitively*: At first, we consider Bitcoin to use an account-based ledger. However, an account-based approach takes a lot of effort to track the balances of every account
- In an account-based ledger, transactions can transfer arbitrary amounts of coins between accounts
- Transactions lead to a “world-state” of accounts and account balances

Bitcoin Basics- Gallersdörfer, U., Holl, P., & Matthes, F. (2020). "Blockchain-based Systems Engineering". Lecture Slides. TU Munich.

Account/transaction based Ledger?



Might need to scan backwards…

Time

Block generation transaction

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Transfer 17 coins from Alice to Bob signed by Alice

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Transfer 5 coins from Carol to Alice signed by Carol

Transfer 15 coins from Alice to Bob signed by Alice

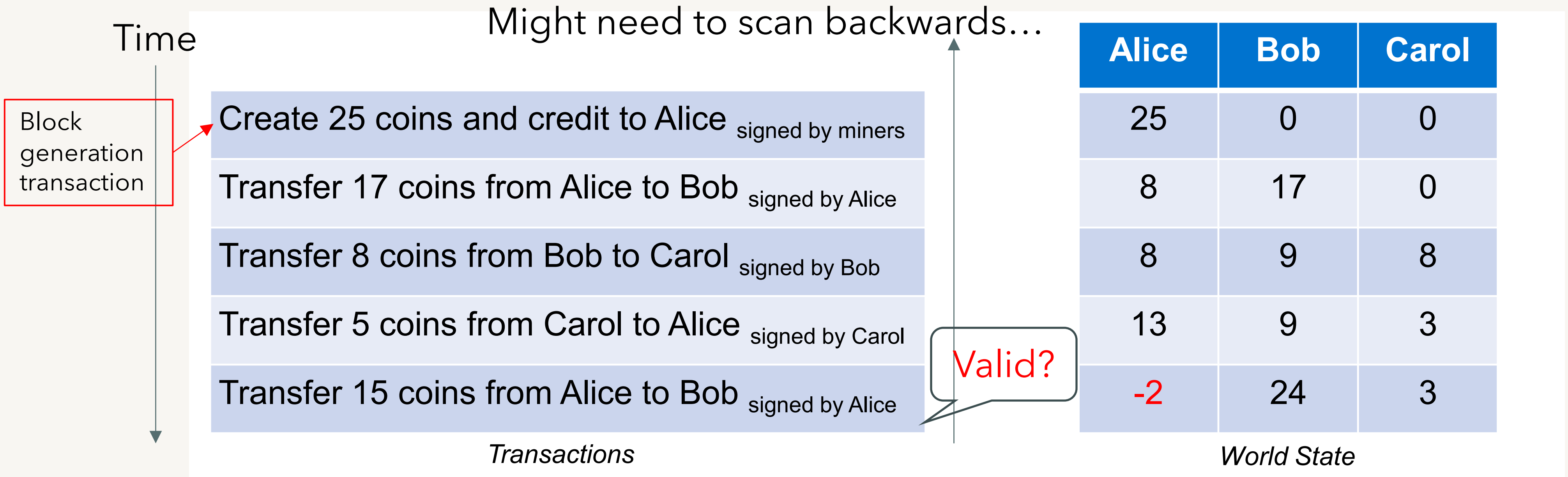
Valid?

Transactions

- To validate a certain transaction, you might need to track very old transactions
- Since you do not know which old transaction, you need track each of the previous transactions one by one until you find the desired ones

Bitcoin Basics- Gallersdörfer, U., Holl, P., & Matthes, F. (2020). "Blockchain-based Systems Engineering". Lecture Slides. TU Munich.

Account/transaction based Ledger?



Might need to scan backwards…

Create 25 coins and credit to Alice signed by miners
Transfer 17 coins from Alice to Bob signed by Alice
Transfer 8 coins from Bob to Carol signed by Bob
Transfer 5 coins from Carol to Alice signed by Carol
Transfer 15 coins from Alice to Bob signed by Alice

Transactions

Alice	Bob	Carol
25	0	0
8	17	0
8	9	8
13	9	3
-2	24	3

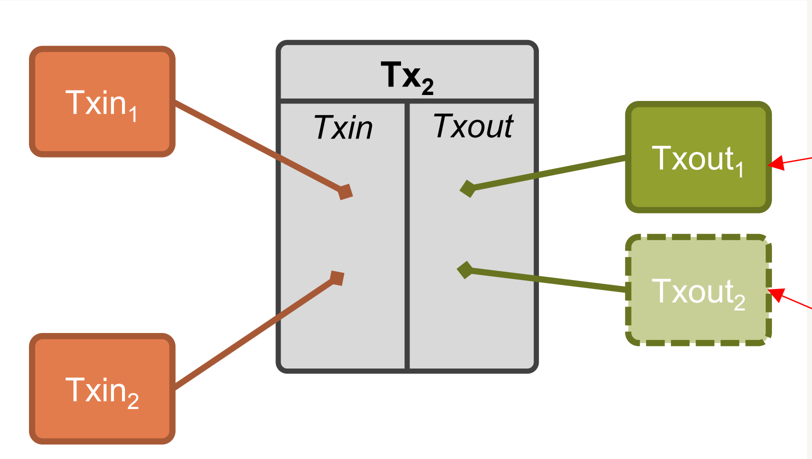
World State

- One option is to maintain the world state in a separate database
  - Remember, in the world state you store the account balance
- That would require to maintain two separate databases: world state and transactions

Account/transaction based Ledger?

- Bitcoin’s solution: a transaction-based ledger
- By using a transaction-based ledger, Bitcoin enables wallet owners to define conditional transactions using Bitcoin Script

Transaction Based Ledger



Output not consumed, not used as inputs in other transactions These are known as **UTXO (Unspent Transaction Output)**

Output consumed, used as inputs in other transactions. These are known as **STXO (Spent Transaction Output**)

- Transactions (Tx) have a number of inputs and a number of outputs
  - Inputs (Txin): Former outputs, that are being consumed
  - Outputs (Txout): New outputs transferring the value
- In transactions (coinbase transaction) where new coins are created, no Txin is used (no coins are consumed)
- Each transaction has a unique identifier (TxID). Each output has a unique identifier within a transaction
- We refer to them (in this example) as *#TX[#txout]*, e.g., 1[1], which is the second Txout of the second transaction

Bitcoin Basics- Gallersdörfer, U., Holl, P., & Matthes, F. (2020). "Blockchain-based Systems Engineering". Lecture Slides. TU Munich.

Transaction Based Ledger

This is known as a coinbase transaction

Create 25 coins and credit to Alice signed by miners

Transfer 17 coins from Alice to Bob signed by Alice

Transfer 8 coins from Bob to Carol signed by Bob

Transfer 5 coins from Carol to Alice signed by Carol

Transfer 15 coins from Alice to Bob signed by Alice

Transactions

0	Txin: Ø Txout: 25.0 -> Alice signed by the miner
1	Txin: 0[0] Txout: 17.0 → Bob, 8.0 → Alice signed by Alice
2	Txin: 1[0] Txout: Txout: 8.0 → Carol, 9.0 → Bob signed by Bob
3	Txin: 2[0] Txout: 5.0 → Alice, 3.0 → Carol signed by Carol
4	Txin: 1[1], 3[0] Txout: 15.0 → Bob, ? → Alice signed by Alice

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Transaction Based Ledger

Create 25 coins and credit to Alice signed by miners

Transfer 17 coins from Alice to Bob signed by Alice

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Transfer 15 coins from Alice to Bob signed by Alice

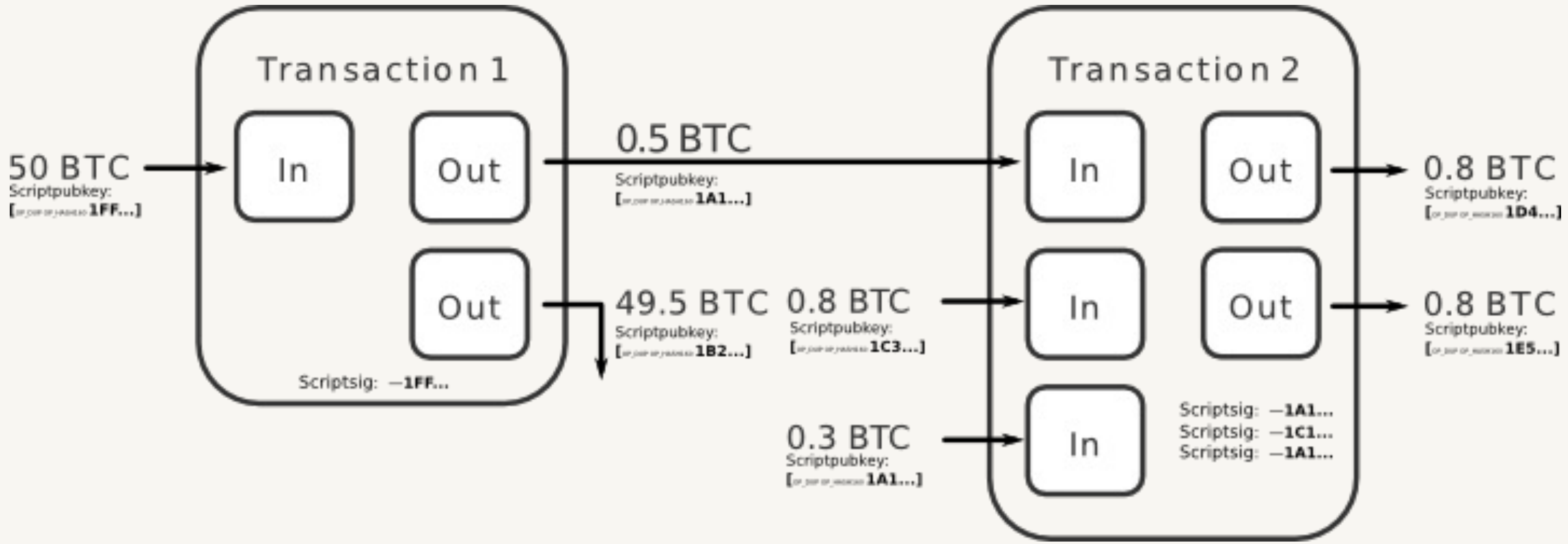
Transactions

0	Txin: Ø Txout: 25.0 -> Alice signed by the miner
1	Txin: 0[0] Txout: 17.0 → Bob, 8.0 → Alice signed by Alice
2	Txin: 1[0] Txout: Txout: 8.0 → Carol, 9.0 → Bob signed by Bob
3	Txin: 2[0] Txout: 5.0 → Alice, 3.0 → Carol signed by Carol
4	Txin: 1[1], 2[0] Txout: 15.0 → Bob, ? → Alice signed by Alice

Joined payment

Bitcoin Basics- Gallersdörfer, U., Holl, P., & Matthes, F. (2020). "Blockchain-based Systems Engineering". Lecture Slides. TU Munich.

Connecting different transactions

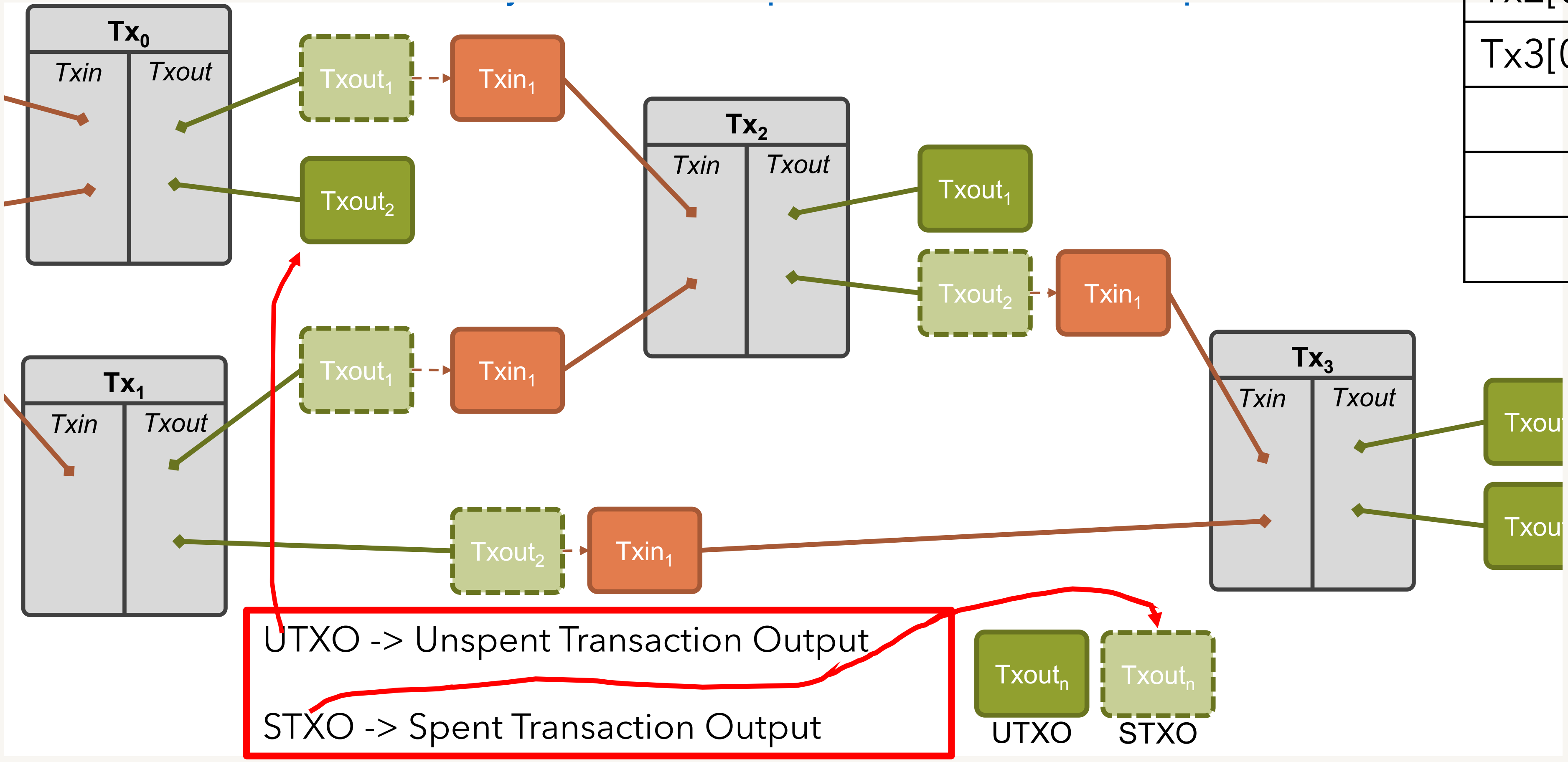


Source: http://s3.amazonaws.com/main-newsbtc-images/2015/11/27120846/Coinjoin.png

All UTXOs are maintained
in an UTXO Table

Tx0[1]
Tx2[0]
Tx3[0]
...
...
...

Connecting different transactions



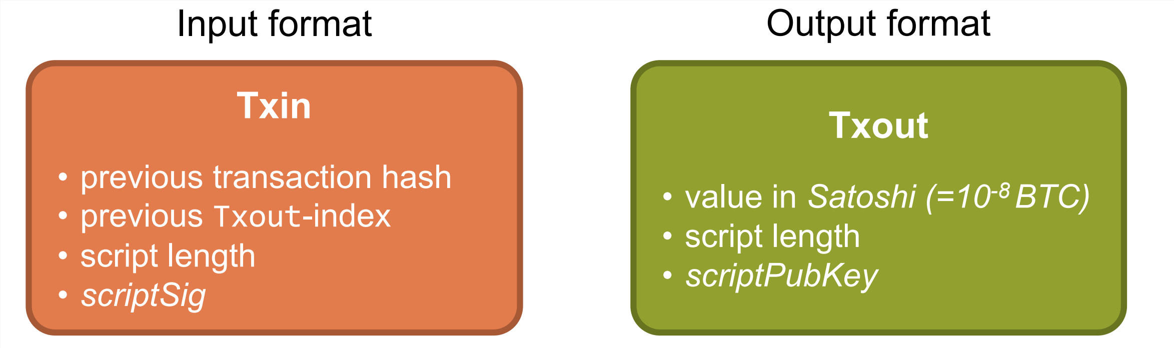
UTXO -> Unspent Transaction Output

STXO -> Spent Transaction Output

Bitcoin Basics- Gallersdörfer, U., Holl, P., & Matthes, F. (2020). "Blockchain-based Systems Engineering". Lecture Slides. TU Munich.

Transaction

- Each transaction has a list of inputs and outputs
- All inputs reference an existing unspent output or a coinbase transaction
- Inputs and outputs contain scripts (scriptSig, scriptPubKey) for verification and other metadata
- lock_time: is the time at which a particular transaction can be added to the blockchain, 0 means now



Input format

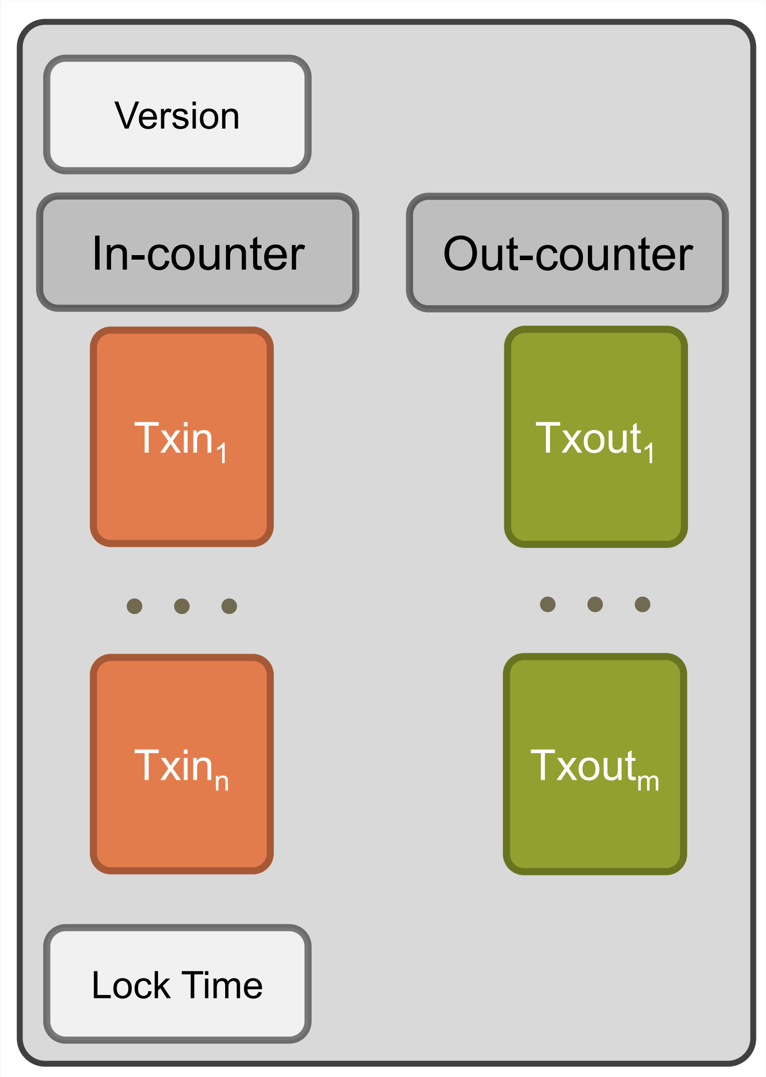
Txin

- previous transaction hash
- previous Txout-index
- script length
- *scriptSig*

Output format

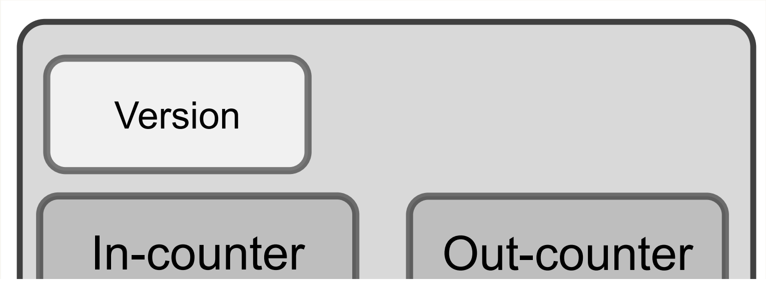
Txout

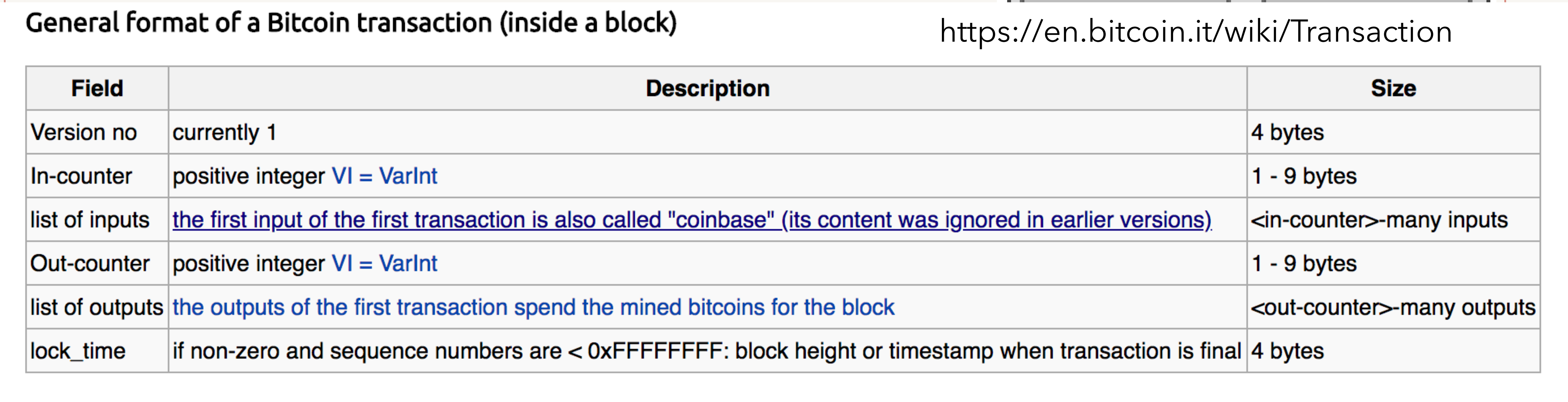
- value in *Satoshi (=10^{-8} BTC)*
- script length
- *scriptPubKey*



Transaction

- All inputs reference an existing unspent output or a

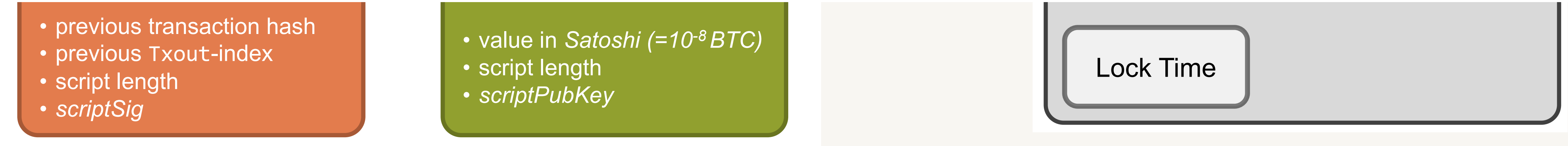




General format of a Bitcoin transaction (inside a block)

https://en.bitcoin.it/wiki/Transaction

Field	Description	Size
Version no	currently 1	4 bytes
In-counter	positive integer VI = VarInt	1 - 9 bytes
list of inputs	the first input of the first transaction is also called "coinbase" (its content was ignored in earlier versions)	<in-counter>-many inputs
Out-counter	positive integer VI = VarInt	1 - 9 bytes
list of outputs	the outputs of the first transaction spend the mined bitcoins for the block	<out-counter>-many outputs
lock_time	if non-zero and sequence numbers are < 0xFFFFFFFF: block height or timestamp when transaction is final	4 bytes

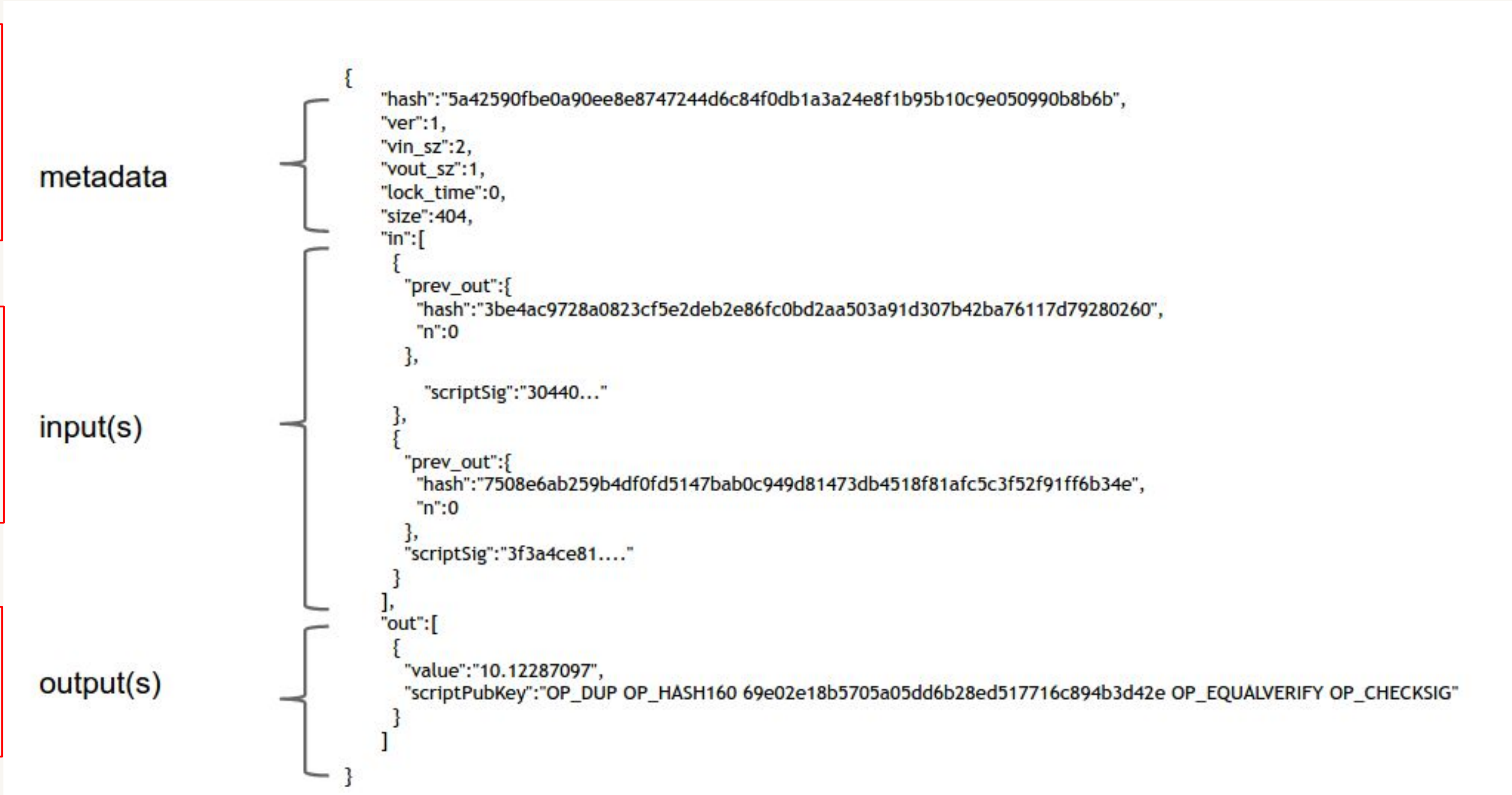


Transaction

It contains the size of the transaction, the number of inputs and outputs, the version and a lock-time. The hash is the transaction ID (TxID) discussed later

An array of all inputs. Each input contains the previous transaction hash (TxID) and the index of Txout. Also a signature *script (scriptSig)* is provided.

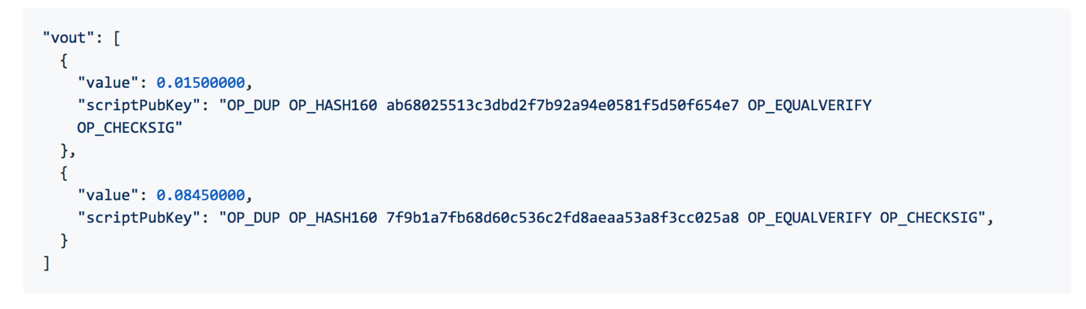
An array of all outputs. One output has two fields: the amount of the transferred coins and the scriptPubKey.



```
{
    "hash":"5a42590fbe0a90ee8e8747244d6c84f0db1a3a24e8f1b95b10c9e050990b8b6b",
    "ver":1,
    "vin_sz":2,
    "vout_sz":1,
    "lock_time":0,
    "size":404,
    "in":[
     {
      "prev_out":{
       "hash":"3be4ac9728a0823cf5e2deb2e86fc0bd2aa503a91d307b42ba76117d79280260",
       "n":0
      },
        "scriptSig":"30440..."
     },
     {
      "prev_out":{
       "hash":"7508e6ab259b4df0fd5147bab0c949d81473db4518f81afc5c3f52f91ff6b34e",
       "n":0
      },
      "scriptSig":"3f3a4ce81...."
     }
    ],
    "out":[
     {
      "value":"10.12287097",
      "scriptPubKey":"OP_DUP OP_HASH160 69e02e18b5705a05dd6b28ed517716c894b3d42e OP_EQUALVERIFY OP_CHECKSIG"
     }
    ]
}
```

Transaction output

- An output contains instructions for sending bitcoins
  - Value is the number of Satoshi (1 BTC = 100,000,000 Satoshi) that this output will be worth when claimed
- There can be more than one output, and they share the combined value of the inputs
- If the input is worth 50 BTC but you only want to send 25 BTC,
  - Bitcoin will create two outputs worth 25 BTC: one to the receiver, and one back to you (known as "*change*", though you send it to yourself)
- Any input bitcoins not redeemed in an output is considered a *transaction fee*; whoever generates the block will get it



```
"vout": [
  {
    "value": 0.01500000,
    "scriptPubKey": "OP_DUP OP_HASH160 ab68025513c3dbd2f7b92a94e0581f5d50f654e7 OP_EQUALVERIFY
    OP_CHECKSIG"
  },
  {
    "value": 0.08450000,
    "scriptPubKey": "OP_DUP OP_HASH160 7f9b1a7fb68d60c536c2fd8aeaa53a8f3cc025a8 OP_EQUALVERIFY OP_CHECKSIG",
  }
]
```

https://github.com/bitcoinbook/bitcoinbook/blob/develop/ch06.asciidoc

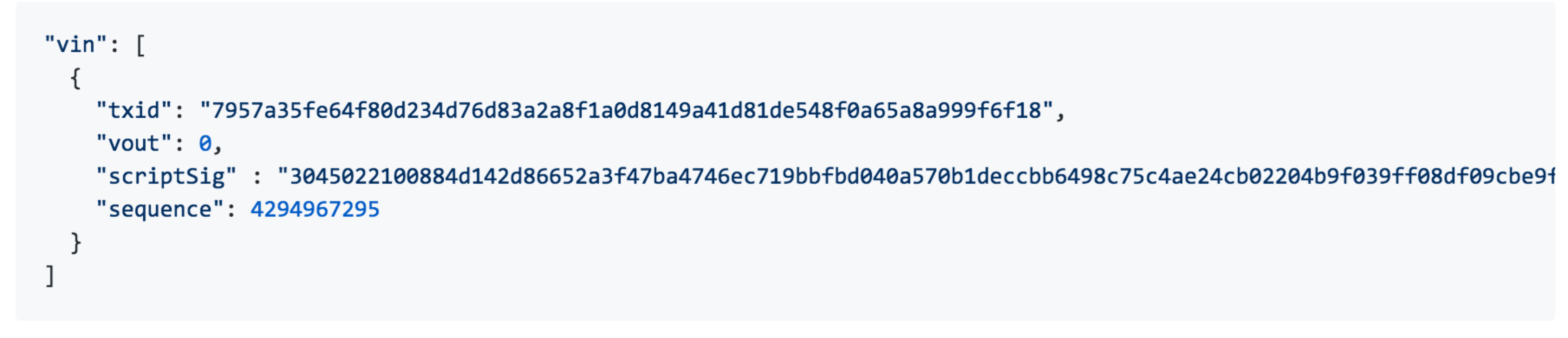
Transaction output

- Almost all outputs are spendable chunks, known as UTXO (unspent transaction outputs)
  - The collection of all UTXO is known as the UTXO set or the UTXO table
- The UTXO set grows as new UTXO is created and shrinks when UTXO is consumed
- Every transaction represents a change in the UTXO set
- When we say that a user's wallet has "received" bitcoin
  - what we mean is that the wallet has detected an UTXO that can be spent with one of the keys controlled by that wallet

Transaction output

- The concept of a balance is created by the wallet application
  - The wallet calculates the user's balance by scanning the blockchain and aggregating the value of any UTXO the wallet can spend with the keys it controls
- Most wallets maintain a database or use a database service to store a quick reference set of all the UTXO they can spend with the keys they control
- Transaction outputs has another component:
  - A cryptographic puzzle that determines the conditions required to spend the output
  - The cryptographic puzzle is also known as a *locking script*, a *witness script*, or a scriptPubKey

Transaction input

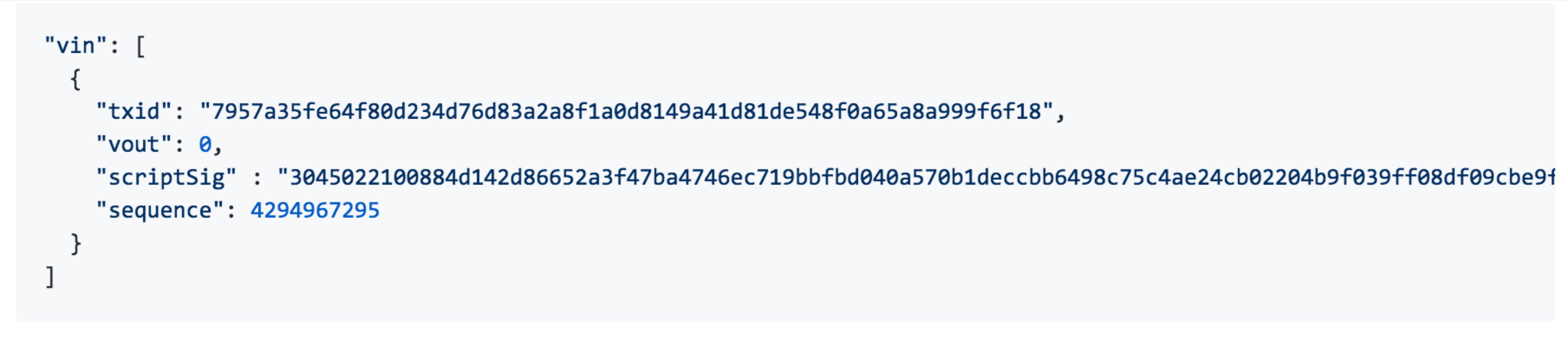


```
"vin": [
  {
    "txid": "7957a35fe64f80d234d76d83a2a8f1a0d8149a41d81de548f0a65a8a999f6f18",
    "vout": 0,
    "scriptSig" : "3045022100884d142d86652a3f47ba4746ec719bbfbd040a570b1deccbb6498c75c4ae24cb02204b9f039ff08df09cbe9f
    "sequence": 4294967295
  }
]
```

https://github.com/bitcoinbook/bitcoinbook/blob/develop/ch06.asciidoc

- Transaction inputs identify (by reference) which UTXO will be consumed and provide proof of ownership through an unlocking script (scriptSig)
- To build a transaction
  - a wallet selects from the UTXO it controls, UTXO with enough value to make the requested payment
  - Sometimes one UTXO is enough, other times more than one is needed
  - For each UTXO that will be consumed to make this payment, the wallet creates one input pointing to the UTXO and unlocks it with an unlocking script (scriptSig)

Transaction input



```
"vin": [
  {
    "txid": "7957a35fe64f80d234d76d83a2a8f1a0d8149a41d81de548f0a65a8a999f6f18",
    "vout": 0,
    "scriptSig" : "3045022100884d142d86652a3f47ba4746ec719bbfbd040a570b1deccbb6498c75c4ae24cb02204b9f039ff08df09cbe9f
    "sequence": 4294967295
  }
]
```

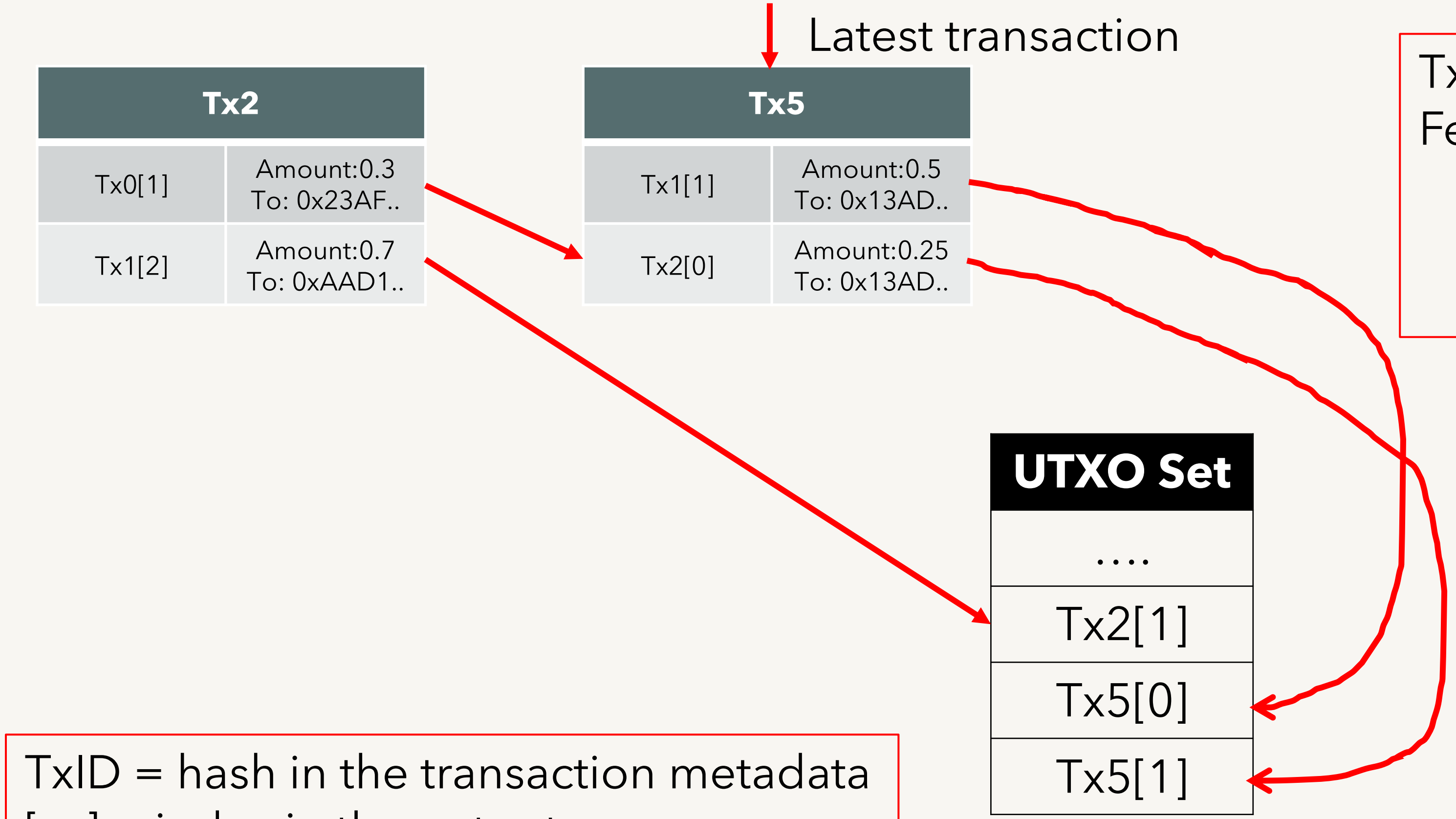
https://github.com/bitcoinbook/bitcoinbook/blob/develop/ch06.asciidoc

- The input contains three main elements:
  - A transaction ID, referencing the transaction that contains the UTXO being spent
  - An output index (vout), identifying which UTXO from that transaction is referenced (first one is zero)
  - A *scriptSig*, which satisfies the conditions placed on the UTXO, unlocking it for spending

Transaction id & fee

- The data structure of transactions does not have a field for fees
- Instead, fees are implied as the difference between the sum of inputs and the sum of outputs
- Any excess amount that remains after all outputs have been deducted from all inputs is the fee that is collected by the miners:
  - Fees = Sum(Inputs) – Sum(Outputs)
- Each transaction is identified by an identifier, called *transaction id* (TxID)
- TxID is created by double hashing the serialized all inputs and outputs and other data within the transaction
  - id = SHA256(SHA256(serialized input + output + other data))

Transaction



Latest transaction

Tx2	
Tx0[1]	Amount:0.3 To: 0x23AF..
Tx1[2]	Amount:0.7 To: 0xAAD1..

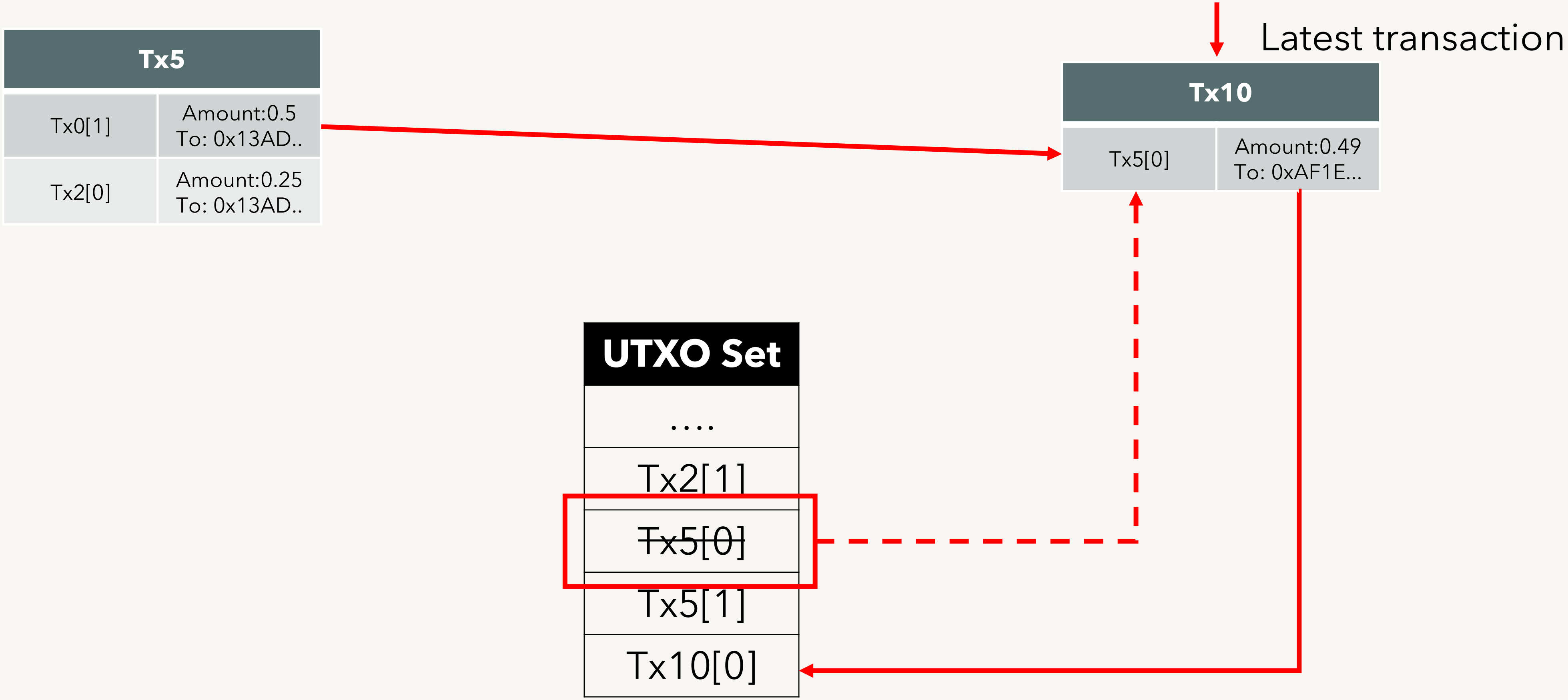
Tx5	
Tx1[1]	Amount:0.5 To: 0x13AD..
Tx2[0]	Amount:0.25 To: 0x13AD..

UTXO Set
….
Tx2[1]
Tx5[0]
Tx5[1]

Tx1[1] = 0.5, Tx2[0] = 0.3
Fee = sum(input) – sum(output)
= (0.5 + 0.3) – (0.5 + 0.25)
= 0.8 – 0.75
= 0.05

TxID = hash in the transaction metadata
[…] = index in the output

Transaction



Latest transaction

Tx5	
Tx0[1]	Amount:0.5 To: 0x13AD..
Tx2[0]	Amount:0.25 To: 0x13AD..

Tx10	
Tx5[0]	Amount:0.49 To: 0xAF1E...

UTXO Set
....
Tx2[1]
~~Tx5[0]~~
Tx5[1]
Tx10[0]

Question?