Bitcoin

Orfeas Stefanos Thyfronitis Litos

Special thanks to Dionysis Zindros

University of Edinburgh – Informatics School 28/11/2017

Lecture aims

- What is bitcoin
- Addresses, keys
- Transactions, change
- Bitcoin graph, edges, nodes, balances, owners, utxo, coinbase
- Wallets
- Mining, consensus, blockchain, genesis
- Proof-of-work, difficulty, confirmations, miner payment, fees
- Bitcoin value

Bitcoin

- Digital currency
- Allows sending money online

Bitcoin advantages

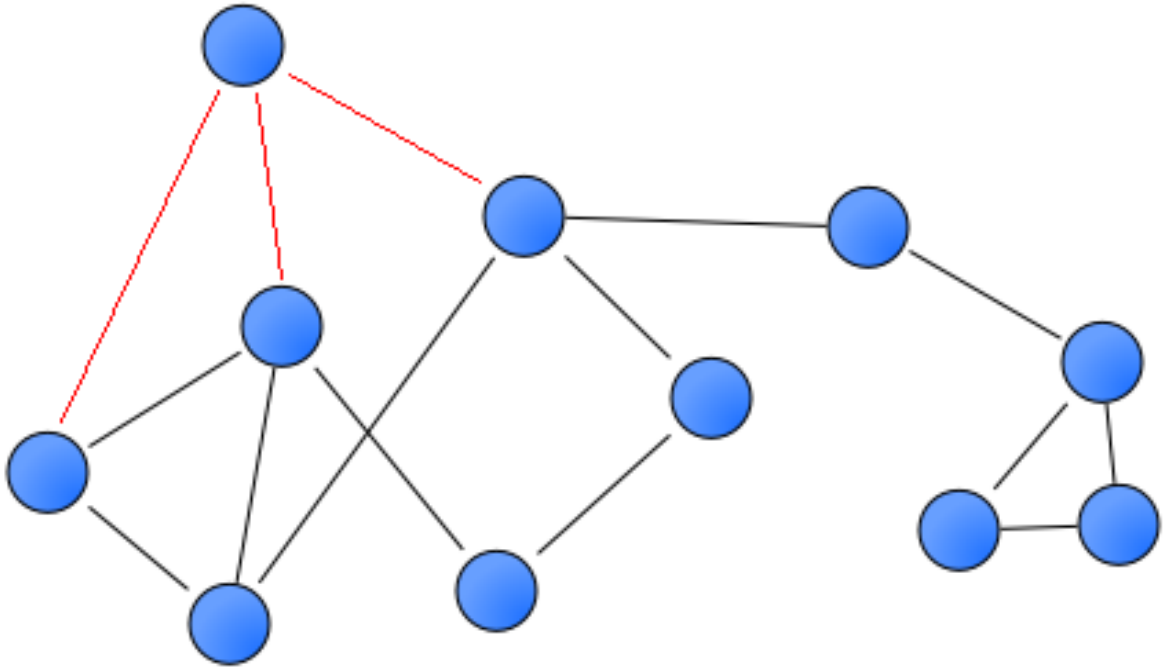
- Instantaneous money transfer (< 1 sec)
  - Instead of 1 - 2 days for local bank transactions
  - or 20 days for international bank transactions
- Fast transaction confirmation (10 min)
- Security through cryptographic and mathematical properties
  - Instead of security against forgery through chemical/physical properties

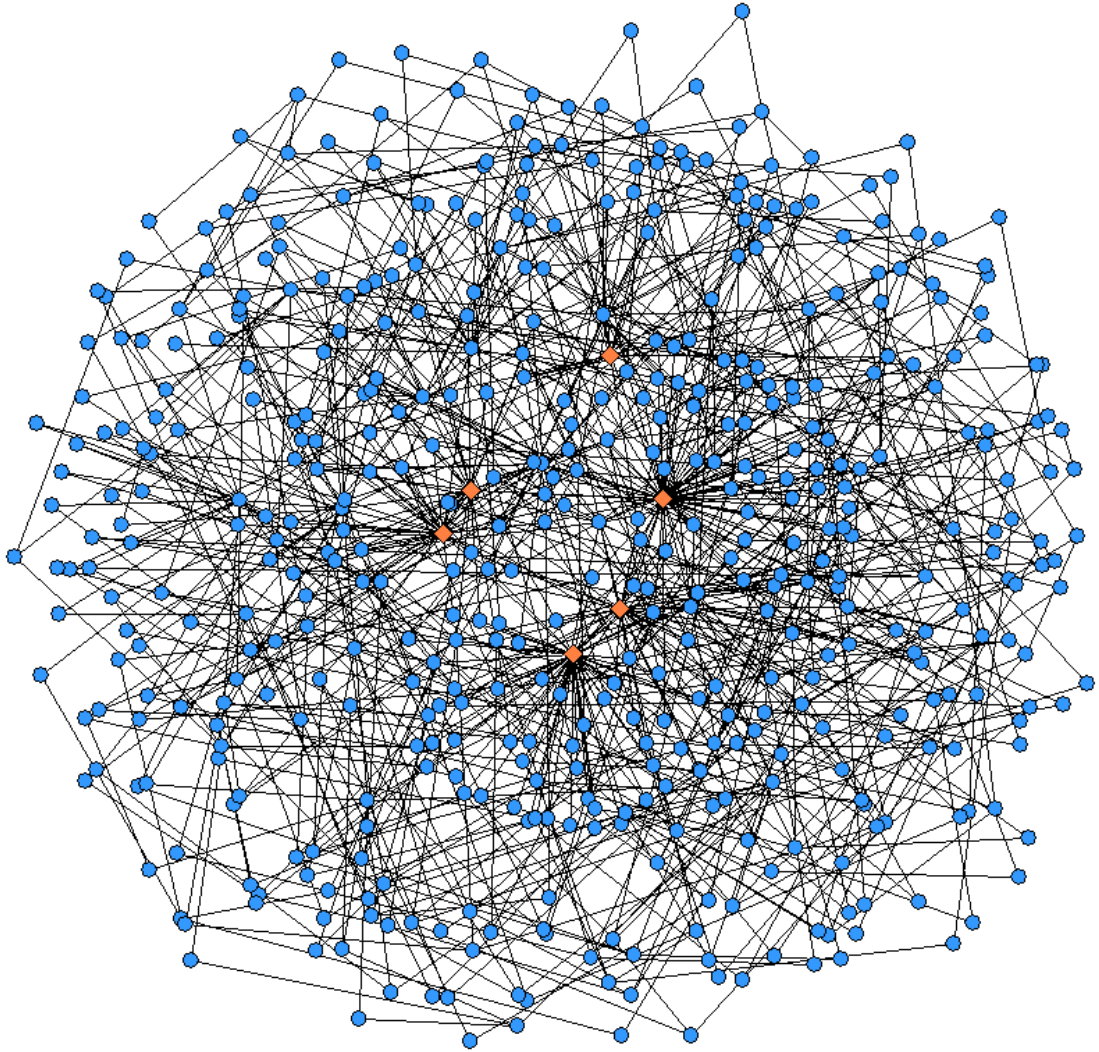
How can I get bitcoin?

- In the same way you get pounds!
- You can **work** and get paid in bitcoin
- You can **sell** products and services for bitcoin
- You can **exchange** pounds for bitcoin
  - With exchange services
    - https://cex.io
  - With somebody else in person
    - https://localbitcoins.com
    - A friend with bitcoin that is willing to exchange

Bitcoin network

- All nodes connected to common p2p network
- Every node runs a bitcoin implementation (bitcoind, bcoin, etc.)
- Most implementations are open source
- Anyone can **freely** join the network
- Nodes do not have to trust the network! Everybody assumes that neighbours may lie





Keys

- Bitcoin uses an elliptic curve (secp256k1) for its public key cryptography
- A user can create a keypair (P, x)
  - P: public key
  - x: private key
- An **address** can be generated from the public key
- We **receive** coins with the address
- We **spend** coins with the private key

Keys example

Private key:

5JXesisRRU2Z7HMmwMpNtoiYk1QDMVjV3HLoYMd1PTKEkJhJT1z

Public key:

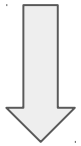
**045a5f526dfe5d5995bf95f1229e70e21818190883c40ab3590458476ad34aaae5
9bc772b98a587035b452638b59238e2a39e954b43ab7a4f32408664d36ec1575**

Address: **133GT5661q8RuSKrrv8q2Pb4RwSpUTQU1Z**

Keys example

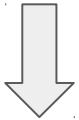
Private key:

5JXesisRRU2Z7HMmwMpNtoiYk1QDMVjV3HLoYMd1PTKEkJhJT1z



Public key:

045a5f526dfe5d5995bf95f1229e70e21818190883c40ab3590458476ad34aaae5
9bc772b98a587035b452638b59238e2a39e954b43ab7a4f32408664d36ec1575



Address: **133GT5661q8RuSKrrv8q2Pb4RwSpUTQU1Z**

Keys example

Private key:

5JXesisRRU2Z7HMmwMpNtoiYk1QDMVjV3HLoYMd1PTKEkJhJT1z

Public key:

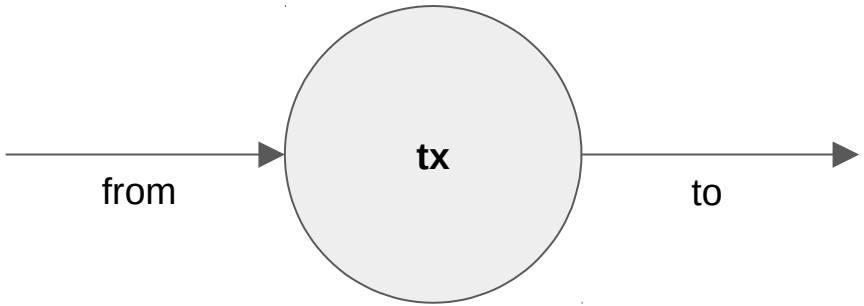
045a5f526dfe5d5995bf95f1229e70e21818190883c40ab3590458476ad34aaae5
9bc772b98a587035b452638b59238e2a39e954b43ab7a4f32408664d36ec1575

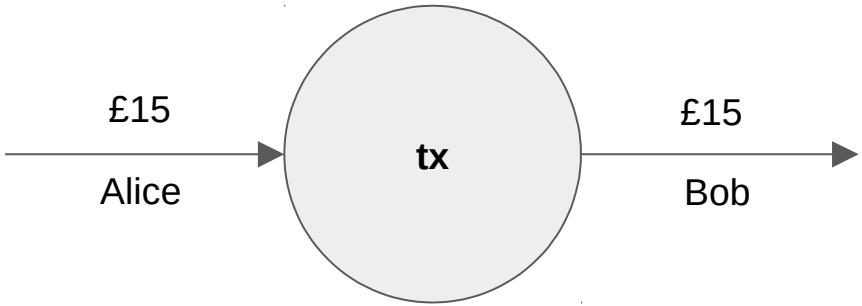
Address: **133GT5661q8RuSKrrv8q2Pb4RwSpUTQU1Z**

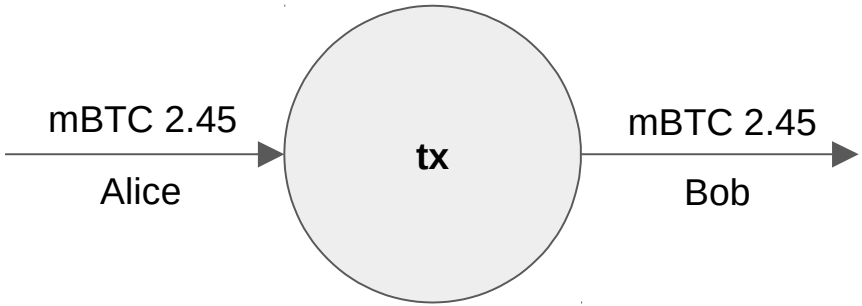
Always one

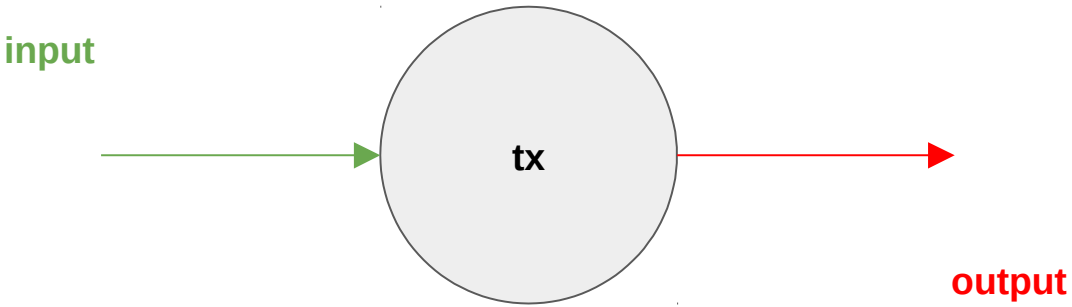
Transactions

- The basic structure in bitcoin is a **transaction** (tx)
- A transaction transfers money from somebody to somebody else



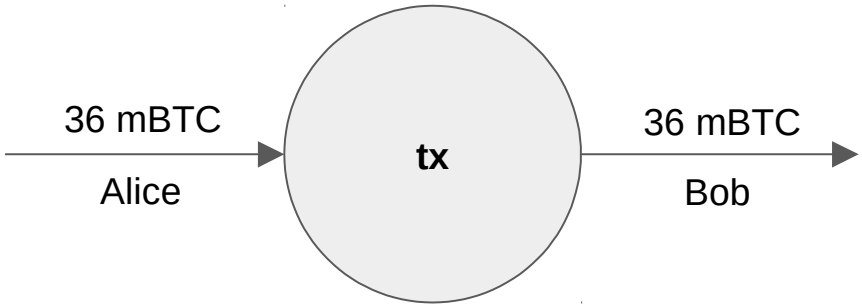

£15
Alice
tx
£15
Bob

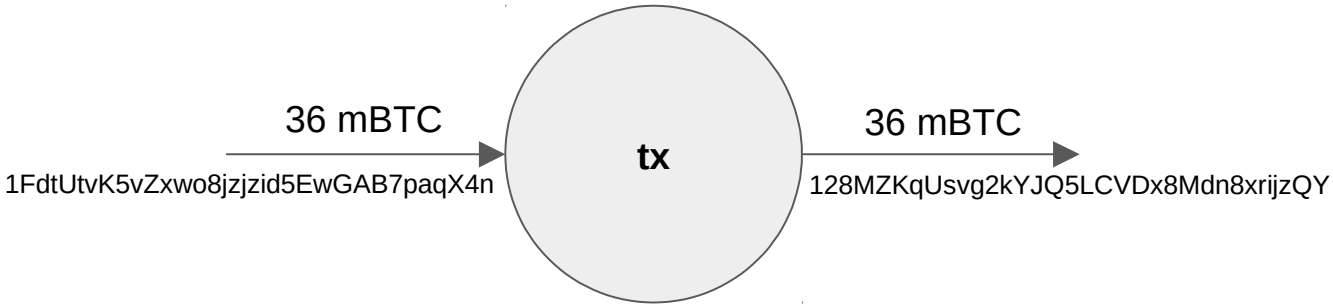

mBTC 2.45
Alice
tx
mBTC 2.45
Bob

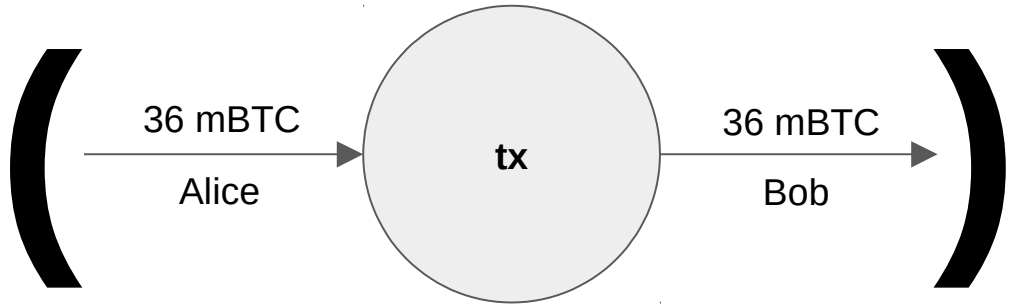

input
tx
output

Public Transactions

- **All transactions are published!**
- **Everybody** can see **all** transactions
- Users create a **new** address whenever they receive bitcoin
- **Reusing** addresses would be **bad** for **privacy**

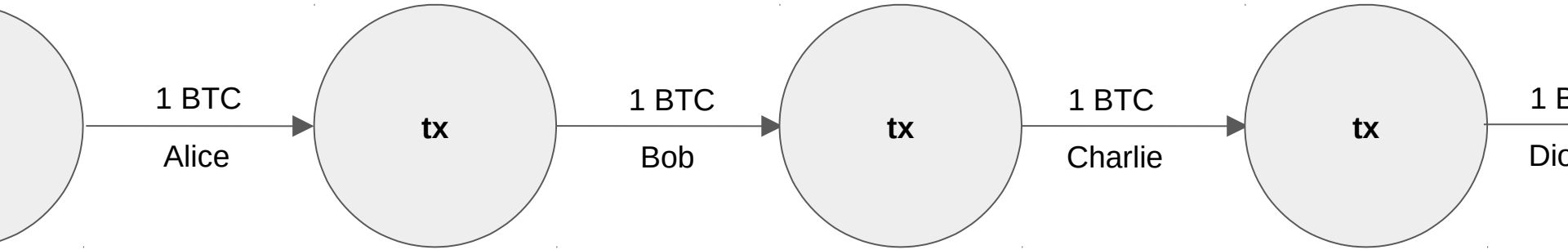

36 mBTC
Alice
tx
36 mBTC
Bob


36 mBTC
1FdtUtvK5vZxwo8jzjzid5EwGAB7paqX4n
tx
36 mBTC
128MZKqUsvg2kYJQ5LCVDx8Mdn8xrijzQY

txid = $SHA256^2$ 

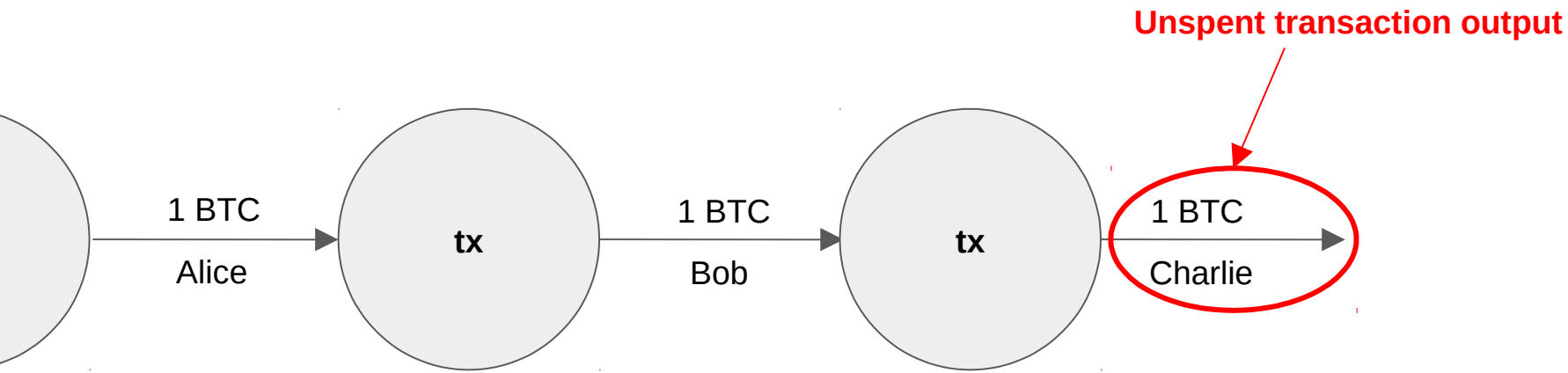
The transaction graph

- Payments are done through **linking** transaction nodes
- Money is a **chain of transactions**



Unspent money

- Spendable money are **outgoing unlinked edges**
  - unspent transaction outputs - utxo



How do I ask for money?

- I generate a private key and its corresponding public key and address
- I **send** the **address** to the **payer**, e.g. through chat
- I **watch the network** for a transaction that pays me

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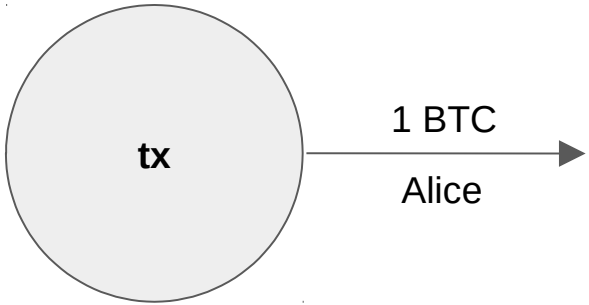
- I **watch the network** for a transaction that pays me

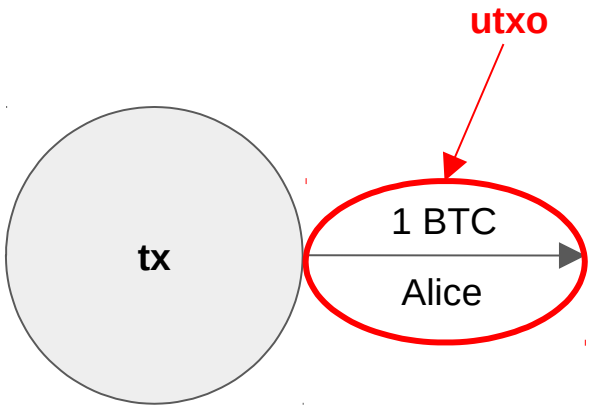
What money do I own?

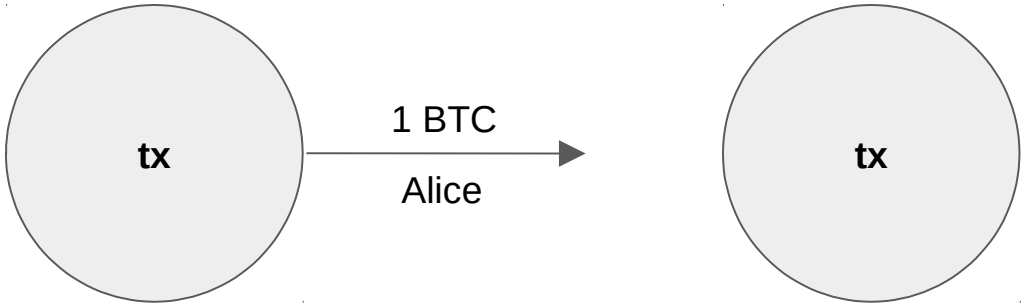
- The ones that are still in the UTXO, thus are still unspent
  - Otherwise I have transferred ownership to someone else
- On the outgoing edge there is a **public** key for which I hold the **private** key
- To calculate my balance, I sum the outgoing values

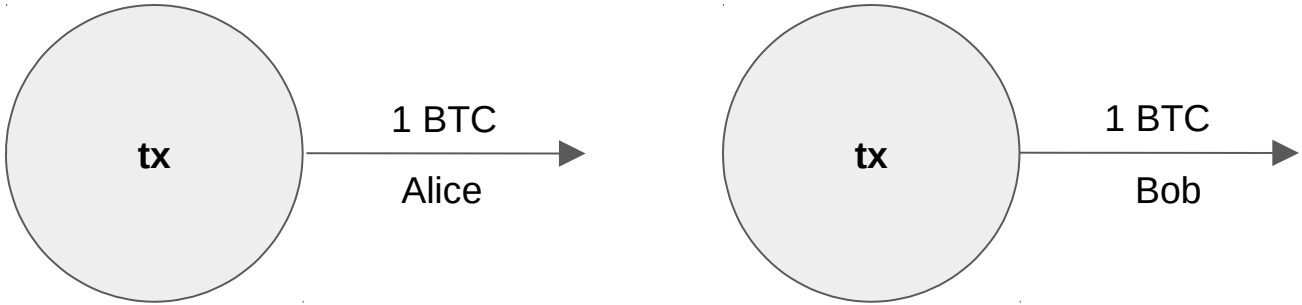
How do I spend money?

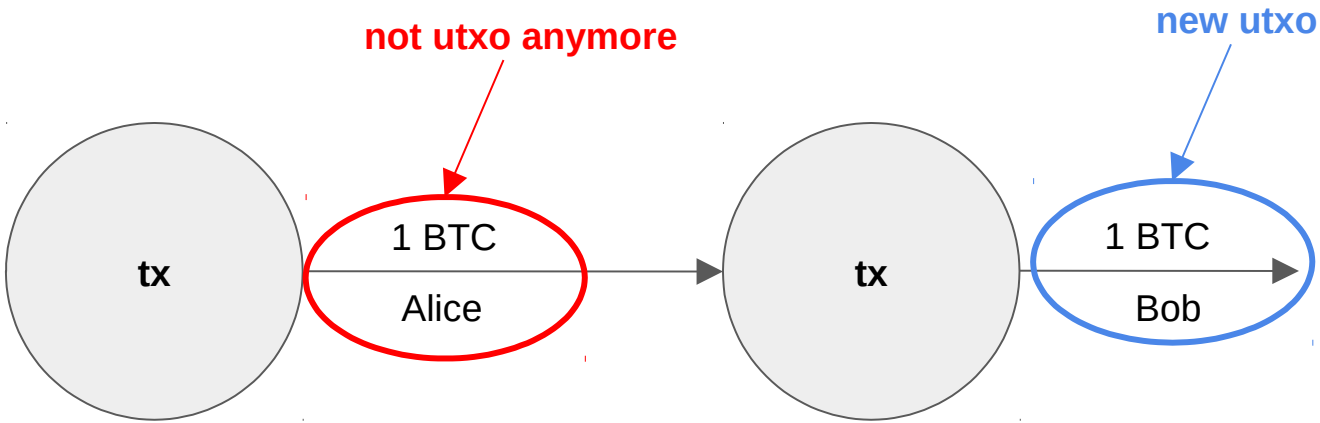
- I find a transaction that has a **UTXO** of which I am the **owner**
- I create a **new transaction**
- **With one incoming and one outgoing edge**
- I connect the **incoming edge** of the **new** transaction with the **old UTXO**
- Now the old UTXO is not a UTXO anymore – it was just spent
- The **outgoing edge** of the **new tx** is unconnected – it is the **new UTXO**
- I specify the **value** and the **owner** (address) of the new outgoing edge

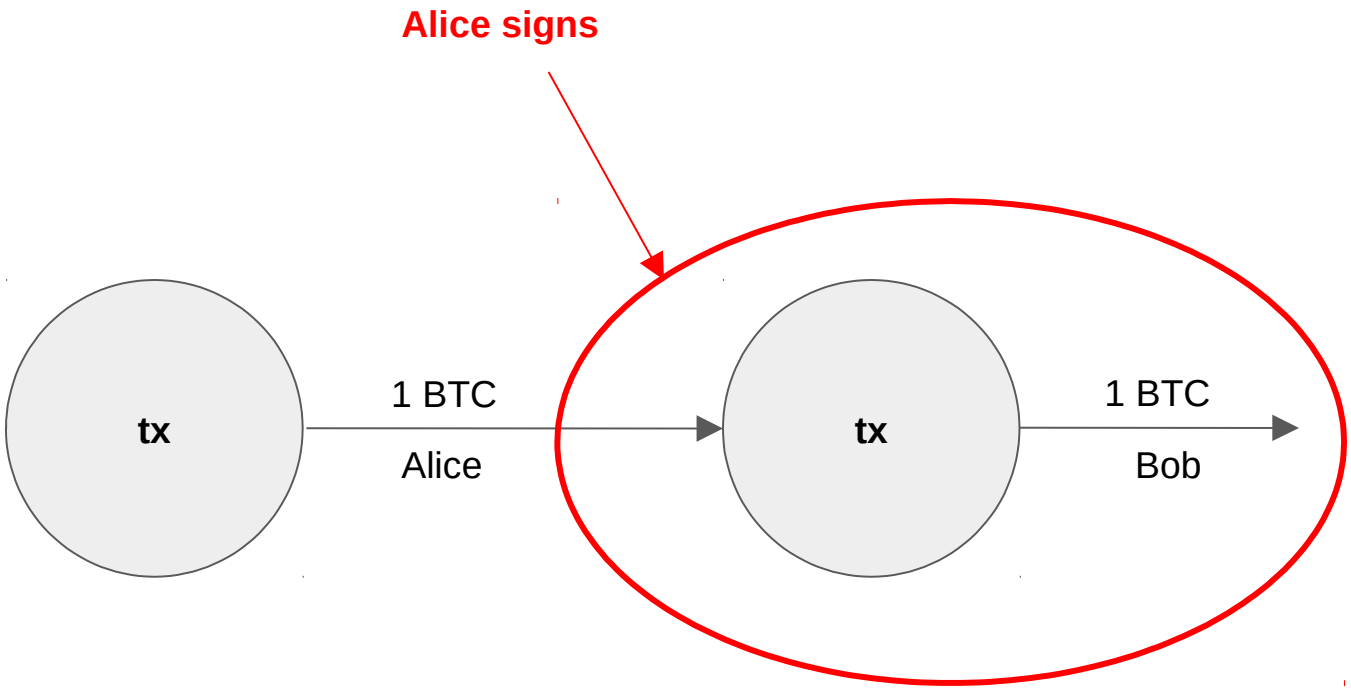

tx
1 BTC
Alice


utxo
tx
1 BTC
Alice


tx
1 BTC
Alice
tx


tx
1 BTC
Alice
tx
1 BTC
Bob


not utxo anymore
new utxo
tx
1 BTC
Alice
tx
1 BTC
Bob



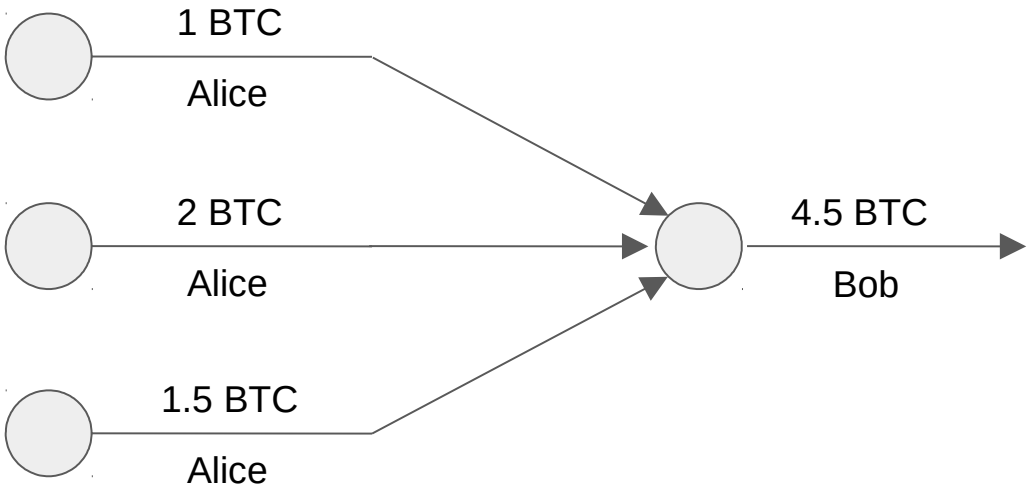
No one else can forge this signature

Transaction broadcasting

- **Broadcast**: When I create a transaction, I send it to all my neighbours
- **Relay**: When I receive a transaction from a neighbour, I check if it is valid an then send it to the rest of my neighbours
- In a few moments, the whole network learns about a new transaction

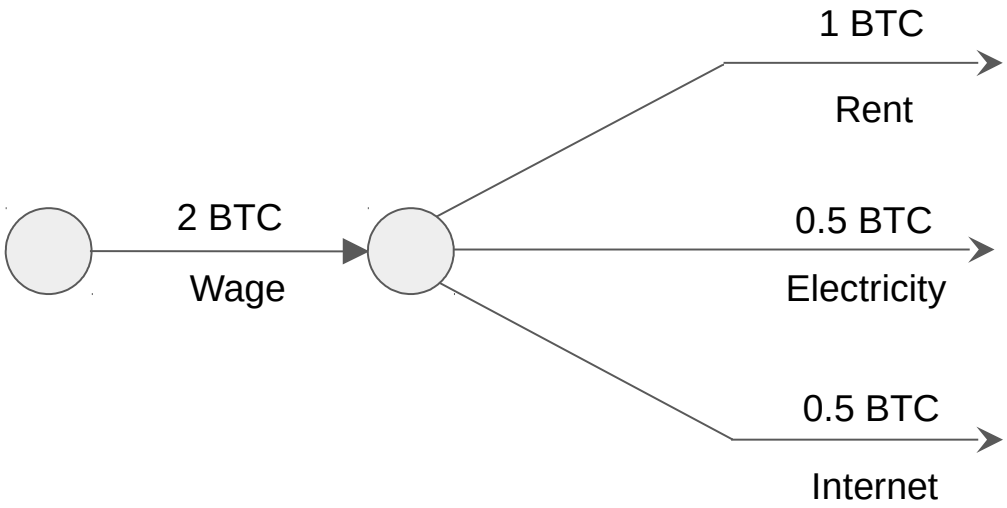
One transaction – many inputs

- I can spend money from many UTXOs in one transaction



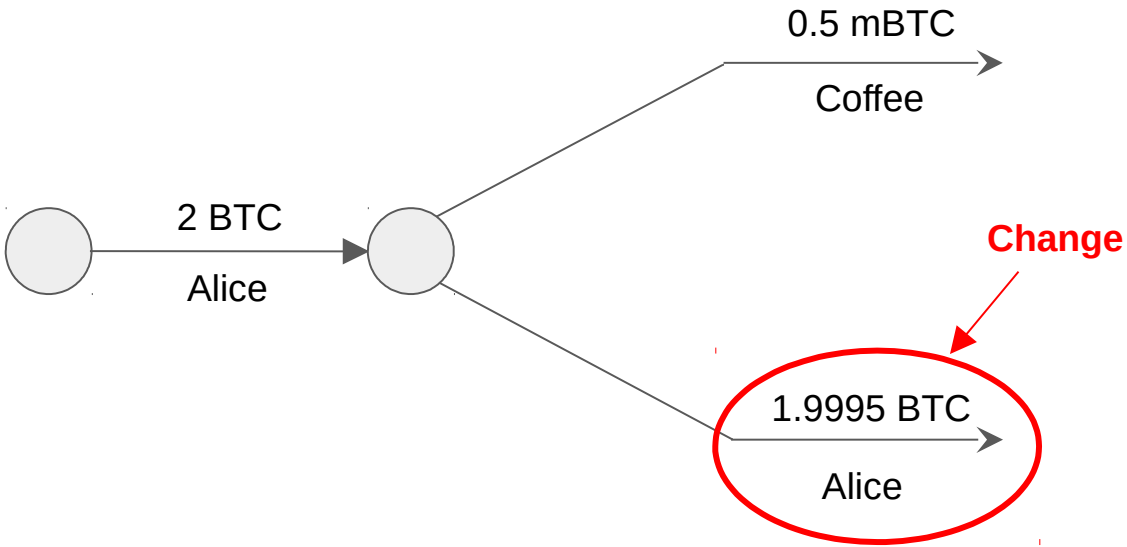
One transaction – many outputs

- I can pay multiple recipients with one transaction



One transaction – many outputs

- ...or keep **change** in case of a small transaction
- I give change to myself, not the seller

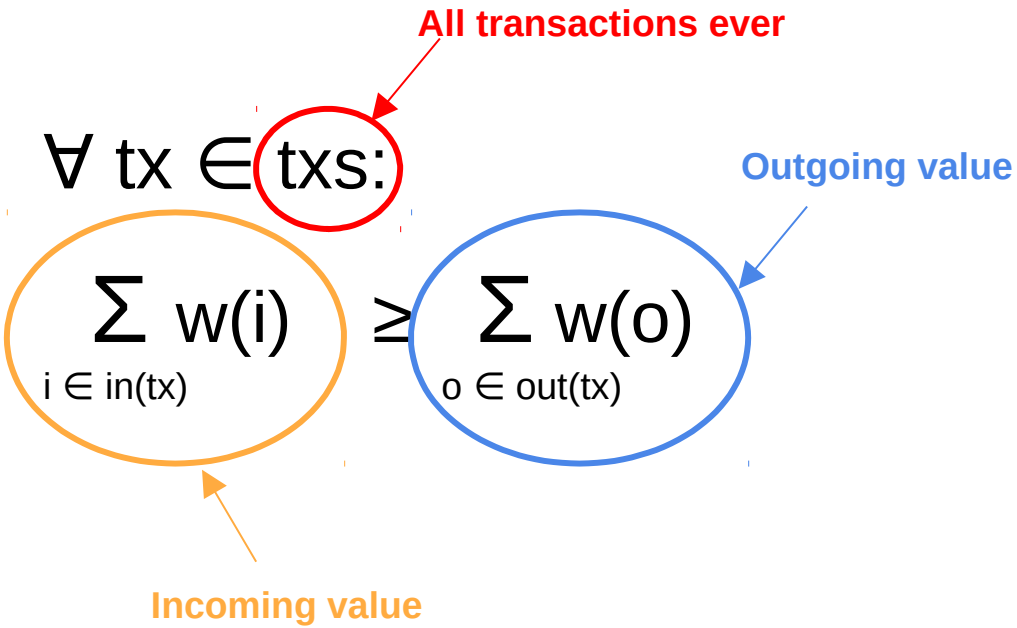


Kirchhoff’s Law

$$\forall\ tx \in txs:$$

$$\sum_{i \in in(tx)} w(i) \quad \geq \quad \sum_{o \in out(tx)} w(o)$$

Kirchhoff’s Law



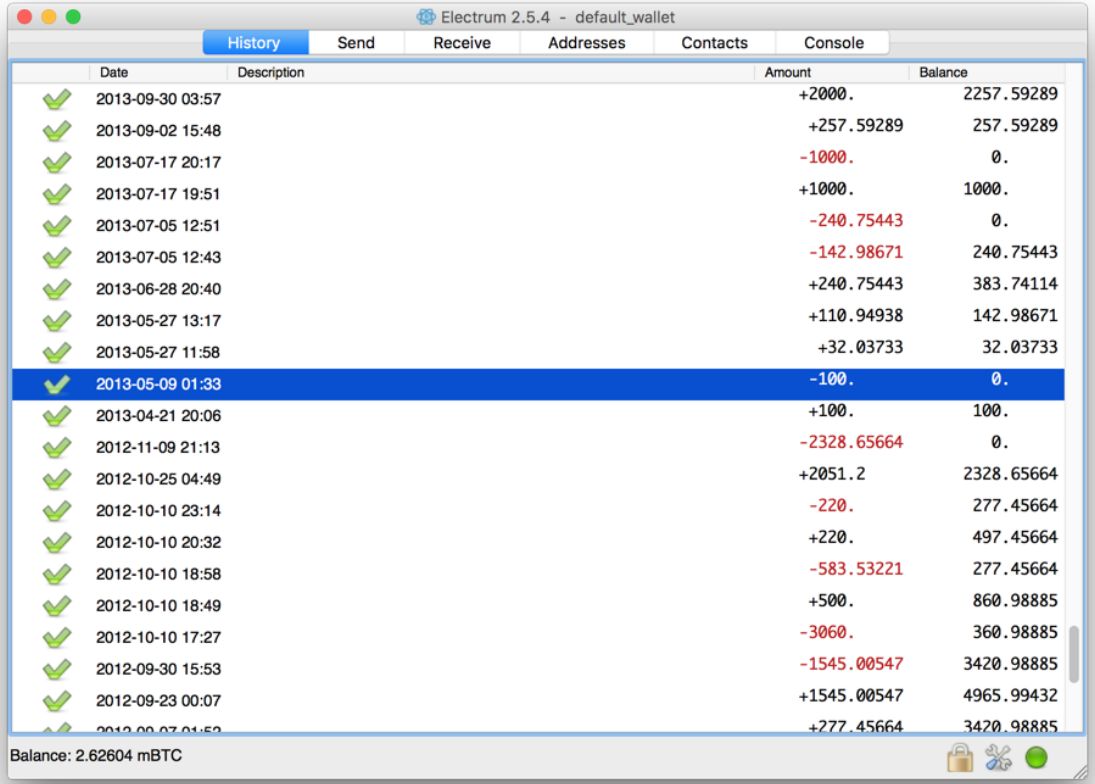
Transaction validity

- To ensure the validity of a newly received transaction
- I already know some **valid** transactions with UTXOs
- I verify Kirchhoff’s law
- I verify the digital signature
- I verify that the inputs connect to already known **valid UTXOs**
  - This verifies that money is spent **exactly one time**

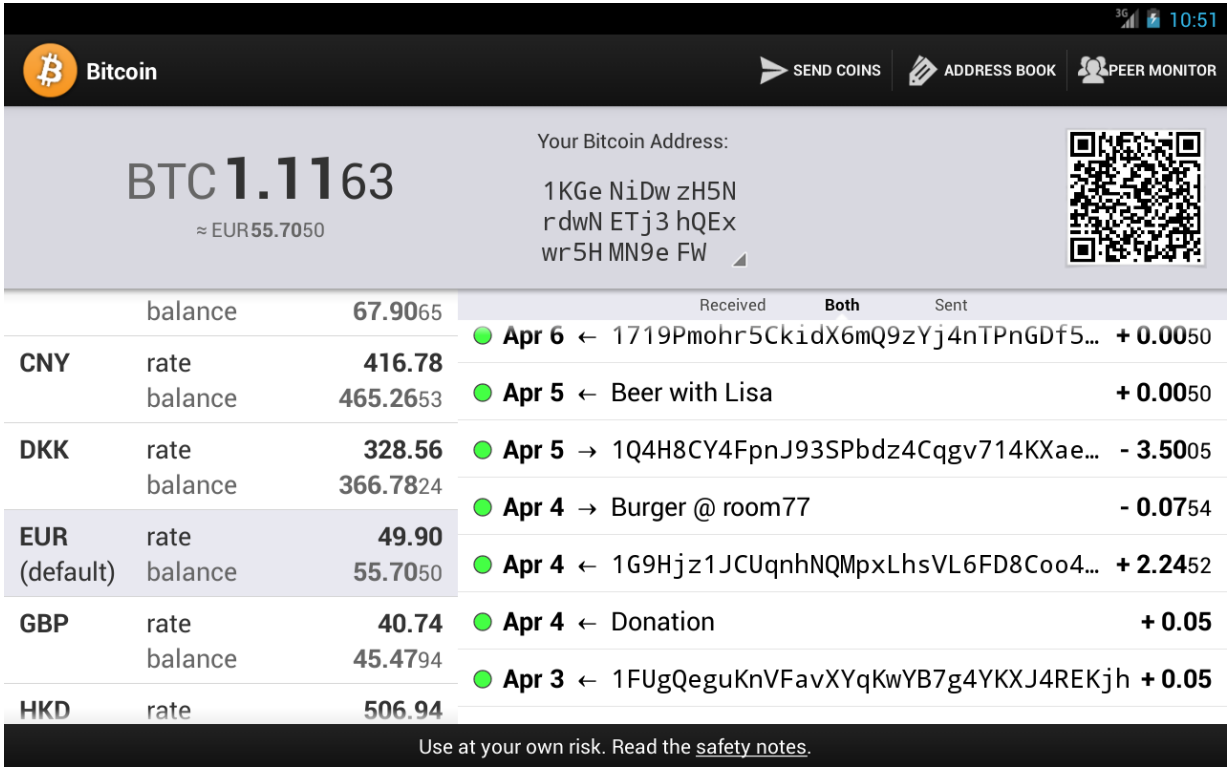
Wallet

- A bitcoin **private key set**
- Usually an application
- Mobile or Desktop

Desktop wallet - Electrum

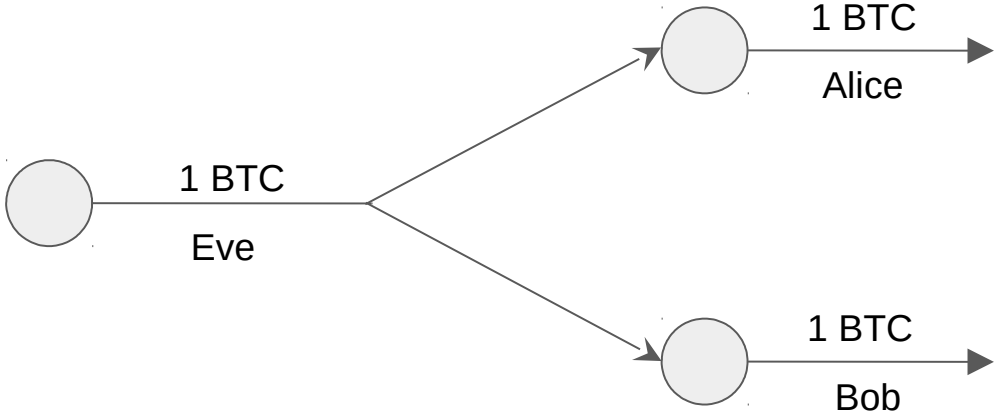


Mobile wallet - Android



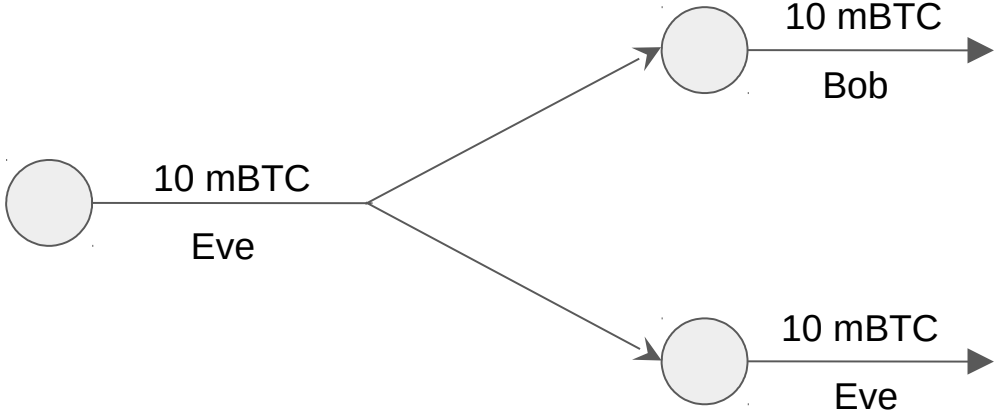
Double spending

- Two transactions that spend the same output are named **double spend**
- Kirchhoff’s law holds for both transactions
- All signatures are valid



Double spending attack

- Eve buys shoes from Bob
- She simultaneously double spends to herself
- She takes the shoes and leaves
- Bob learns about the double spend later

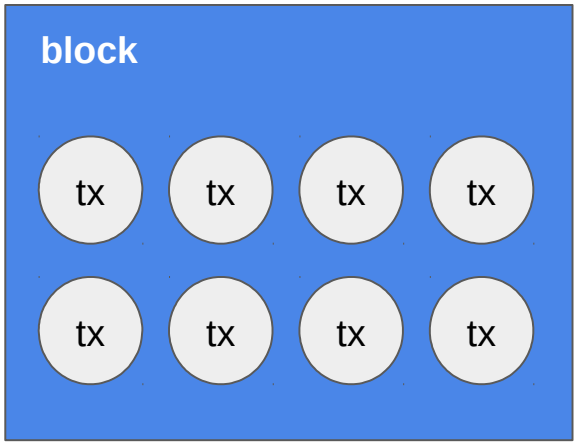


The arrow of time

- We need to put transactions in some order
- We must be able to answer: Did tx A happen before tx B?
- The answer should be **common for everyone in the network**
- Global agreement on a common truth is named **consensus**
  - This is where the bitcoin novelty is

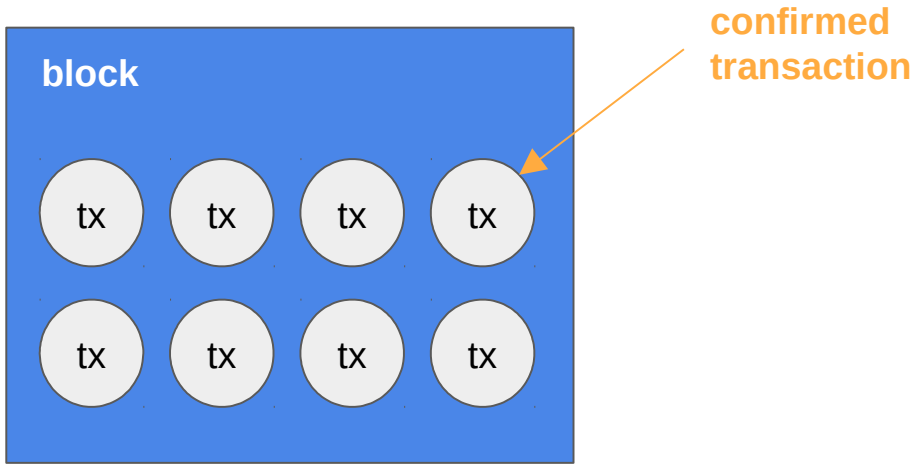
Block

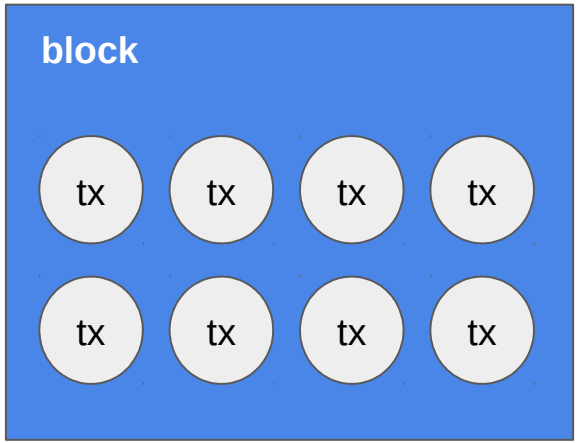
- Contains many transactions
- It cannot contain double spends, that is txs that spend the same output
- Each transaction can appear **only once** in a block



Block

- The network is set to create **one block every 10 minutes**
- A newly created block contains the **most recent transactions** that did not exist in previous blocks
- Blocks are **broadcast** and **relayed** in the network, just like transactions
- The $SHA256^2$ of the block is the **block id**
- A transaction in a valid block is called **confirmed**

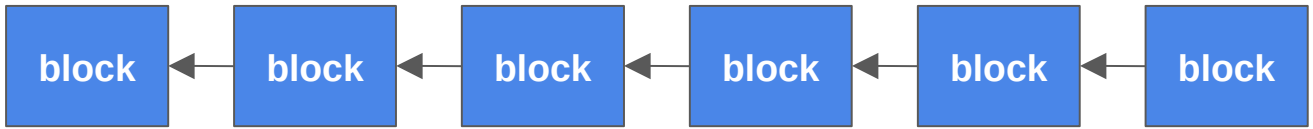

block
tx
tx
tx
tx
tx
tx
tx
tx
confirmed
transaction

$$\text{blockid} = \text{SHA256}^2\Big($$ 

$$\Big)$$

Blockchain

- Each block refers to its **previous** block
- It contains a pointer to the blockid of its **parent**
- A later block cannot contain a double spend of a previous one
- ...or a transaction that appeared in a previous block
- This connected list is called **blockchain**



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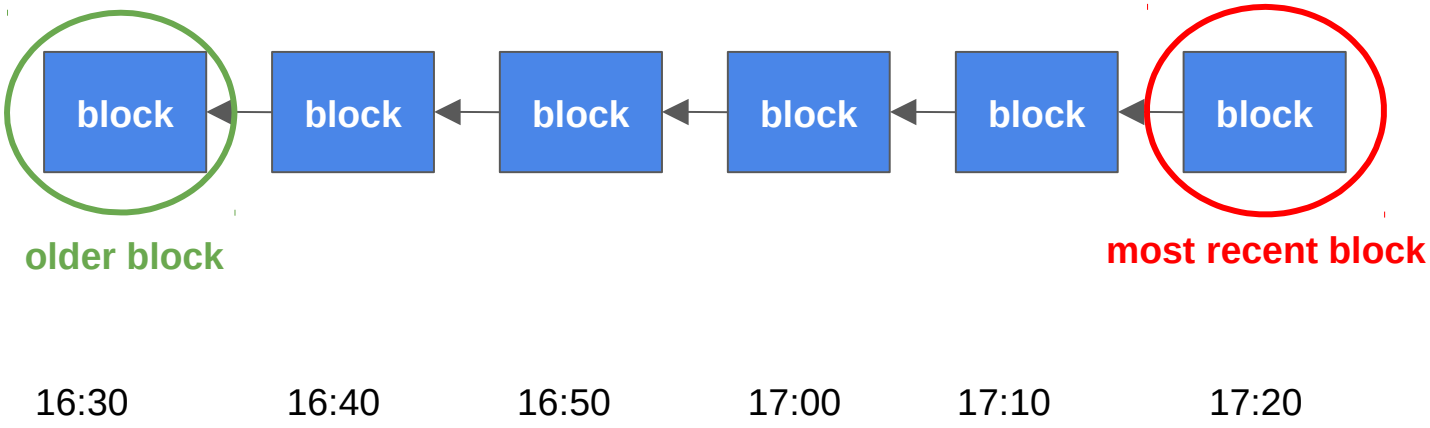


Blockchain

- Achieves **consensus**
- Tx A **precedes** tx B if A **is contained in a previous block** from B
- If we want to ensure that a transaction will not be double spent, we have to wait for it to be confirmed

Who creates blocks?

- **Anybody** can create a block
- The system is free for everybody
- Each block must contain a **proof of work SHA256²**
- The proof of work has such a **difficulty** that the **entire network** create **1 block every 10 minutes on expectation**

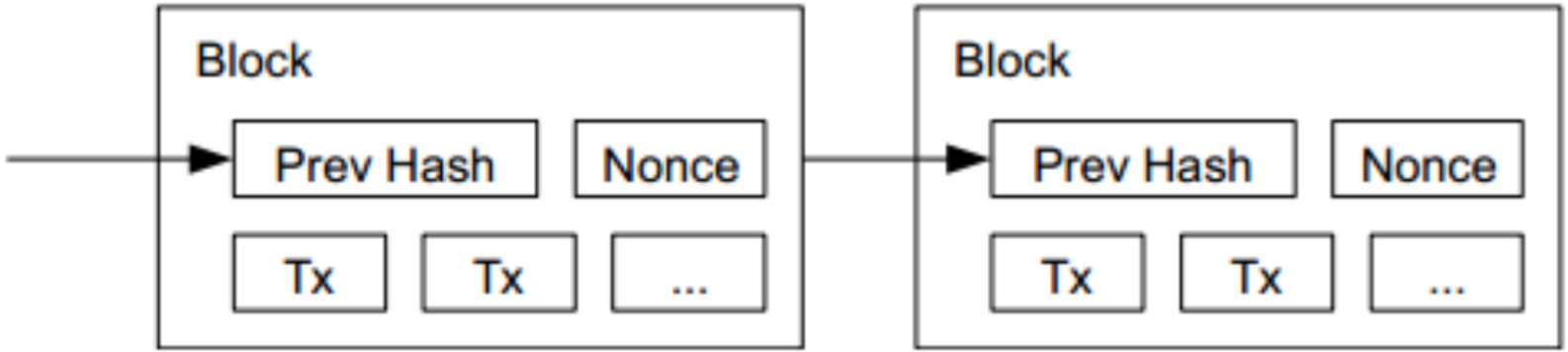
E(block generation time) = 10 min

Mining

- The process of block creation is called **mining**
- There are **many miners** who try to mine blocks
- Each miner has a **small probability** to extract a particular block
- When a miner successfully mines a block, she **broadcasts** it
- The rest of the nodes **relay** it

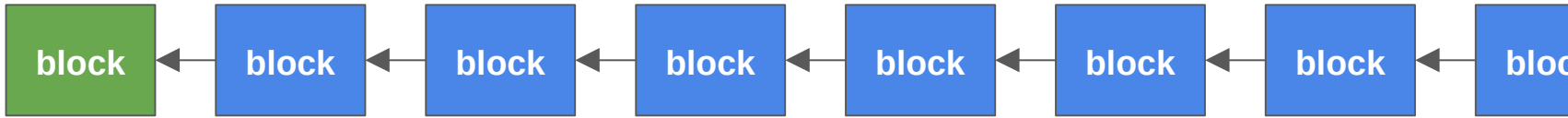
Bitcoin proof of work

$$\mathbf{SHA256^2(txs \,||\, nonce \,||\, parent\text{-}blockid) < \varepsilon}$$


Block
Prev Hash
Nonce
Tx
Tx
...
Block
Prev Hash
Nonce
Tx
Tx
...

Genesis block

- The **first** block in the blockchain is the genesis block
- It is **hard-coded** in the bitcoin software
- Every valid blockchain begins from the genesis
  - It is the **base** of the **induction** for block validity confirmation



genesis block

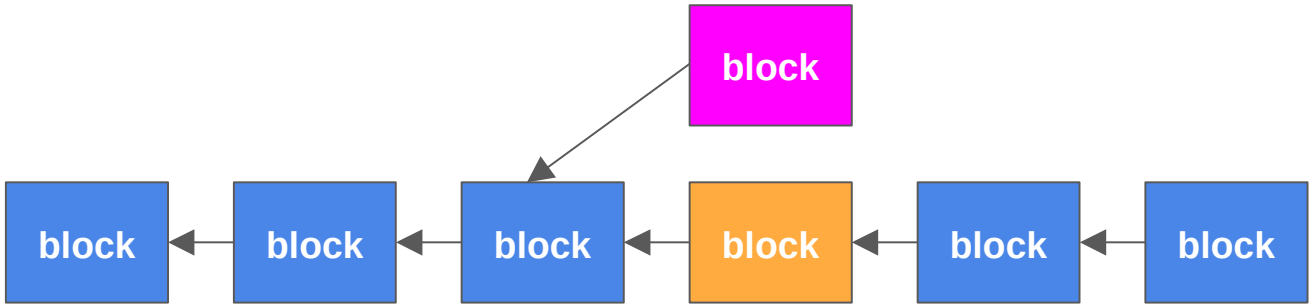
Genesis block

- Contains the text “The Times 03/Jan/2009 Chancellor on brink of second bailout for banks”
- This proves that the block was created **on or after** 3 January 2009
- We also know that it was made **on or before** 3 January 2009 because we observed it on the network
- Thus it was made **on** 3 January 2009


THE TIMES
£1.50
Eat Out from £5
More than 900 great restaurants, including four Gordon Ramsay favourites from £15
Israel prepares to send tanks and troops into Gaza
Chancellor on brink of second bailout for banks
99p
Michael Sheen
Frost, Nixon and me
Working mums
So that's how she does it
Detox in style
The best spas on the planet
Salman Rushdie
I won't marry again
Giant killing?
Guide to the FA Cup third round

Blockchain forks

- Often two valid blocks may be mined simultaneously
- This creates a **blockchain fork**



Blockchain fork

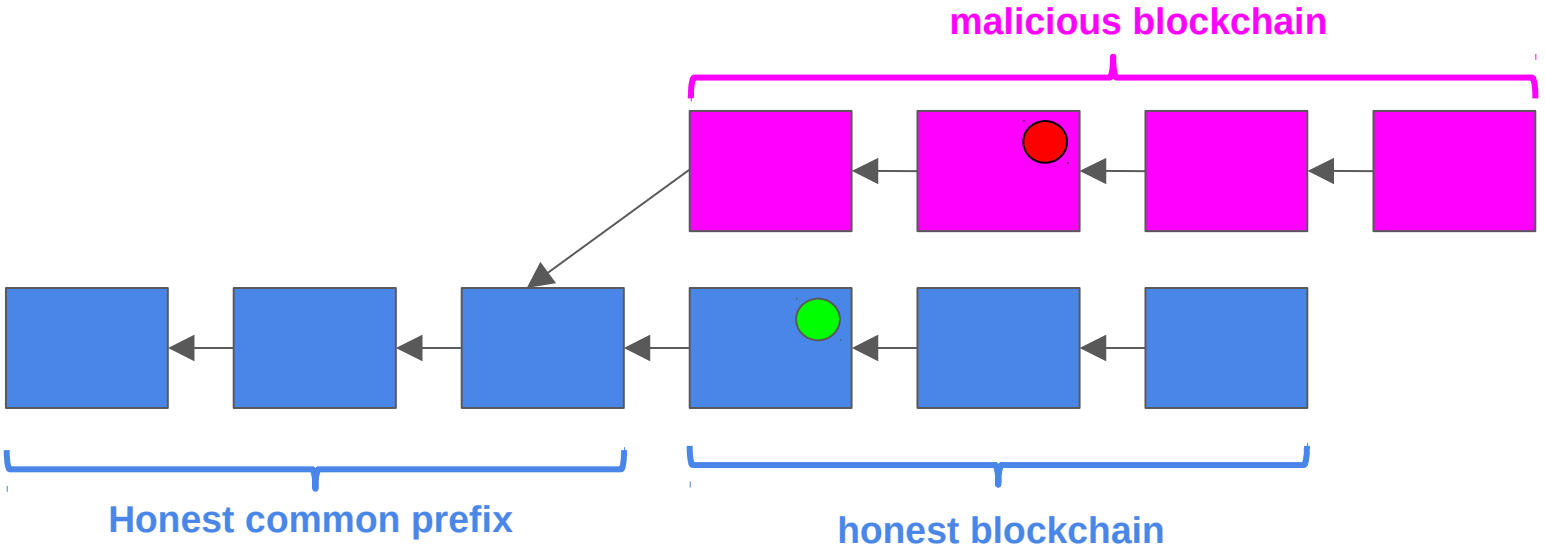
- A blockchain fork is a problem because it prevents us from maintaining the arrow of time
- We have the same problem as ordering transactions
- Which of the two blocks is **the most recent valid block**?
- What happens if two rival blocks contain **double spends**?

Algorithm for resolving rival blockchains

- We observe two rival blockchains on the network
- The valid blockchain is the one with the **maximum height**
- If the two blockchains have the **same height**, we choose one at **random**.
- The chosen block is the one on top of which we mine and/or trust for transaction confirmation

Double spending

- To successfully double spend, I have to create a malicious **parallel blockchain** equal or longer than the honest one



Double spending difficulty

- Double spending requires **great computational power**
- The malicious actor must control more computational power than the rest of the network
- Otherwise the probability of catching up with the honest blockchain falls **exponentially** with the length of the honest blockchain
- He can achieve it if he controls more than 50% of all the computational power in the world
- This is called a **51%-attack**

What can a malicious miner achieve?

- Can he double spend?
  - ?
- Can he prevent money from being spent?
  - ?
- Can he spend our money?
  - ?

What can a malicious miner achieve?

- Can he double spend?
  - Yes – he makes a parallel blockchain containing the malicious transaction
- Can he prevent money from being spent?
  - Yes – he makes a parallel blockchain that does not contain the undesired transaction
- Can he spend our money?
  - No – he doesn’t have our private keys!

Mining incentives

- A miner is rewarded in 2 ways:

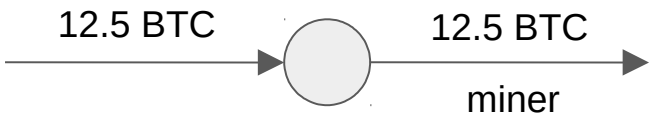
1. With all the remaining money from the transactions she confirms:

$$\text{fees} = \sum_{tx \in block} \left[\sum_{i \in in(tx)} w(i) - \sum_{o \in out(tx)} w(o) \right]$$

Mining incentives

- A miner is rewarded in 2 ways:

2. With **one** coinbase transaction she is allowed to put in the block with a value of 12.5 BTC



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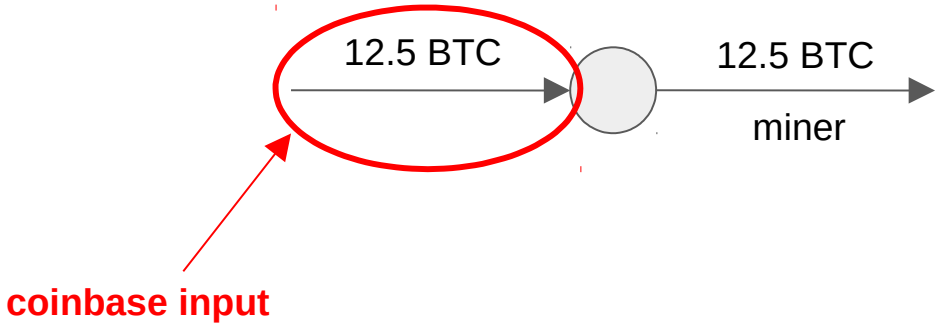


Coinbase transaction

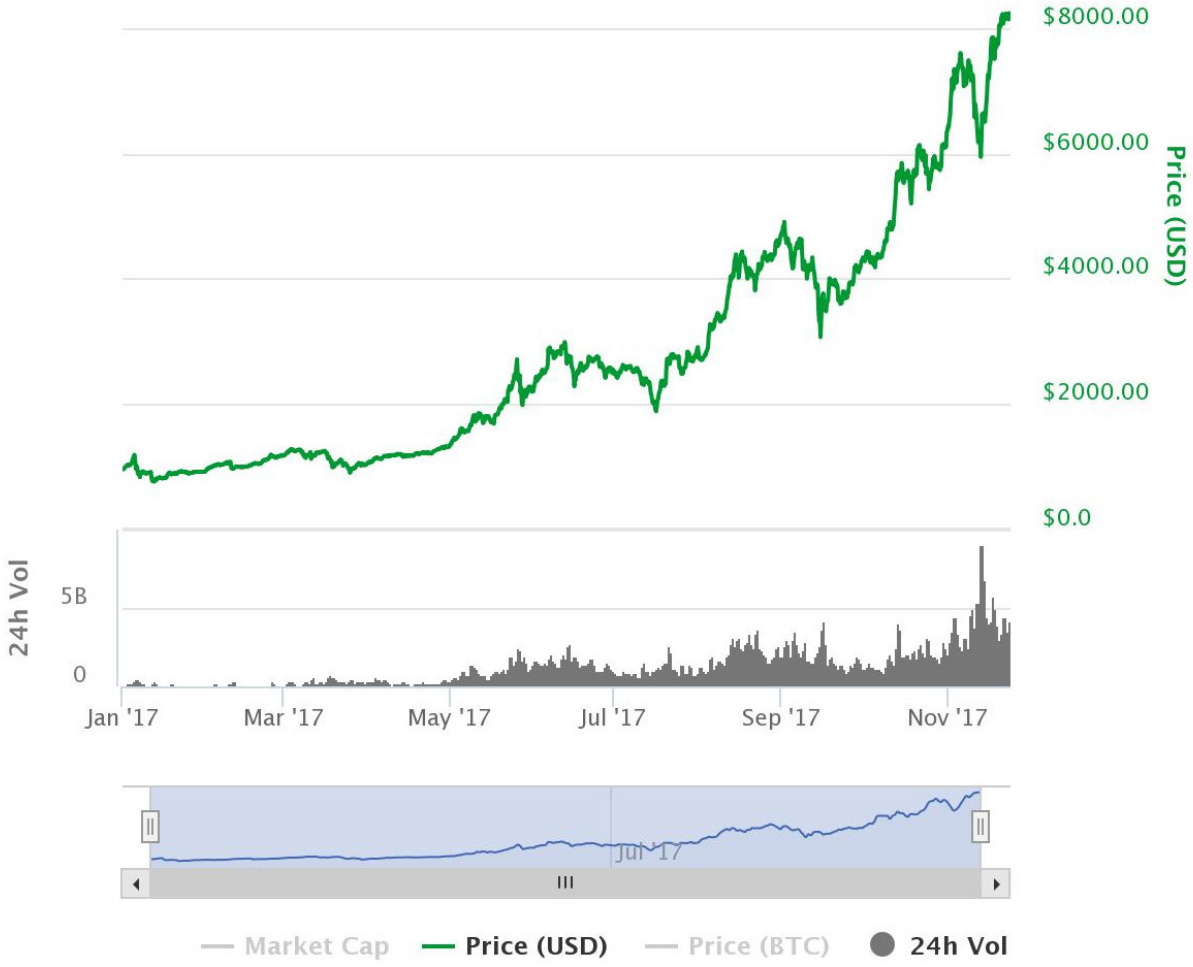
- A coinbase transaction is the only one that can have **an incoming edge with no beginning**
- It is the **induction base** for transactions validity confirmation
- **Exactly one** coinbase transaction is allowed in each block
- The coinbase value must be 12.5 BTC
- This is the **only** way to create bitcoin

Bitcoin value

- Extreme variance
- 23/11/2017: **1 BTC = £6,130**
- 2016: 1 BTC = £590
- Max 2013: 1 BTC = £750
- Min 2013: 1 BTC = £45
- 2012: 1 BTC = £6
- 2010: 1 BTC = £0.05
- 22/5/2010: First purchase with bitcoin


22 May 2010: One pizza for 10,000 BTC

Bitcoin Charts



coinmarketcap.com

What we learned

- What is bitcoin
- Addresses, keys
- Transactions, change
- Bitcoin graph, edges, nodes, values, owners, utxo, coinbase
- Wallets
- Mining, consensus, blockchain, genesis
- Proof-of-work, difficulty, confirmations, rewards, fees
- Bitcoin value