

Blockchains & Distributed Ledgers

Lecture 01

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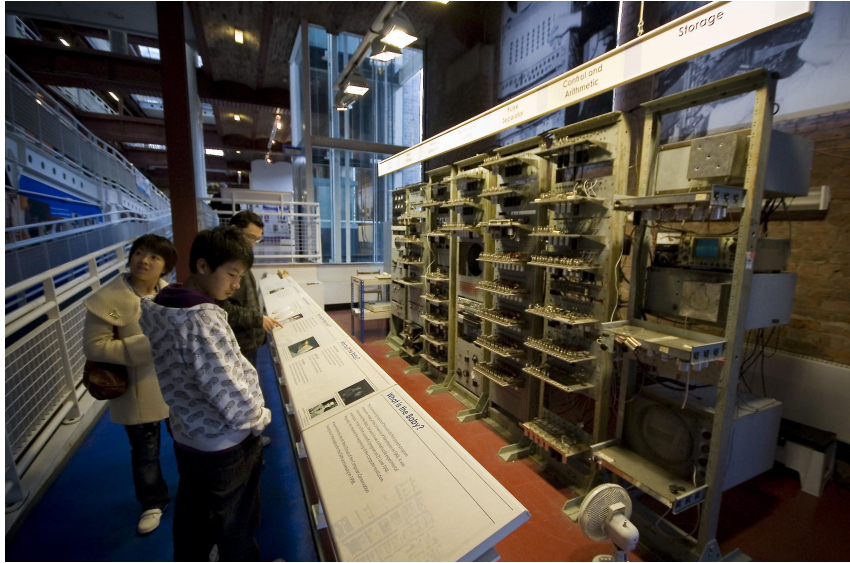


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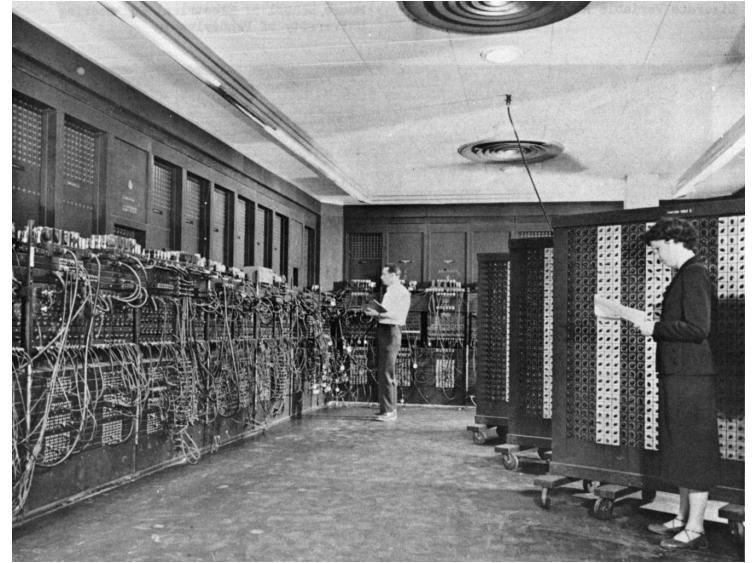
Introduction

- Historical background
- Introduction to decentralized ledgers
- The never-ending book parable
- The first blockchain application
- Hash functions
- Digital signatures
- Why blockchains?

Once upon a time...



Manchester baby



ENIAC

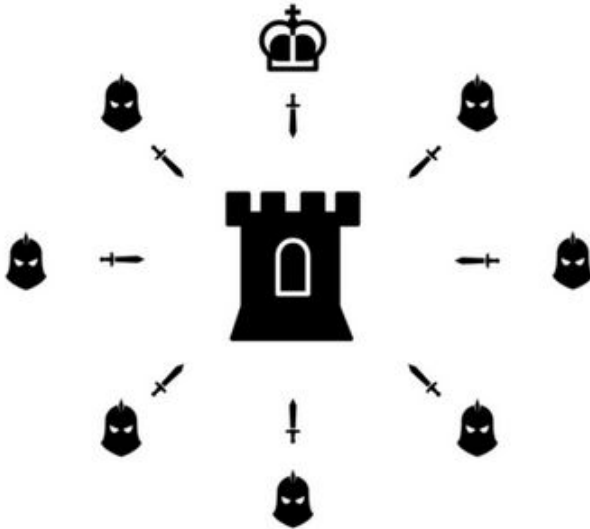
Centrally-controlled systems

- A **single person** (party/node) controls who can read/write/delete data
- If the person/party/node dies/is dishonest/crashes, **the system crashes**



Controlled-access distributed systems

- Nodes **collectively** control the system
- If only few nodes faulty, system **remains operational**
- Controlled participation - only authorized parties



Open-access distributed systems?

- Nodes **collectively** control the system
- If only few nodes faulty, system **remains operational**
- **Anyone** can participate, join or leave as they please

**EVERYONE
IS WELCOME**

(Except for Fascists)

What is a blockchain ?

- A blockchain is a distributed database that satisfies a unique set of safety and liveness properties
- Distributed ledgers use a blockchain protocol as one means of implementation
- To understand it, we can focus on its first application

Why study blockchains?

Why study blockchains?

- Good foundations for exploring security of information systems in general
- Explore decentralisation, a property of increasing importance in the design of modern information systems
- Solid understanding of many security critical components, including:
 - Key management
 - Software security
 - Privacy preserving technologies
 - Public Key Infrastructure
- Novel opportunities for applications on various aspects of societal organisation
- It's fun!

The never-ending book parable



A book of data

- Anyone can be a scribe and produce a page
- New pages are produced indefinitely, as long as scribes are interested in doing so
- Each new page requires some effort to produce



Importance of consensus

- If multiple conflicting books exist, which is the “right one” ?

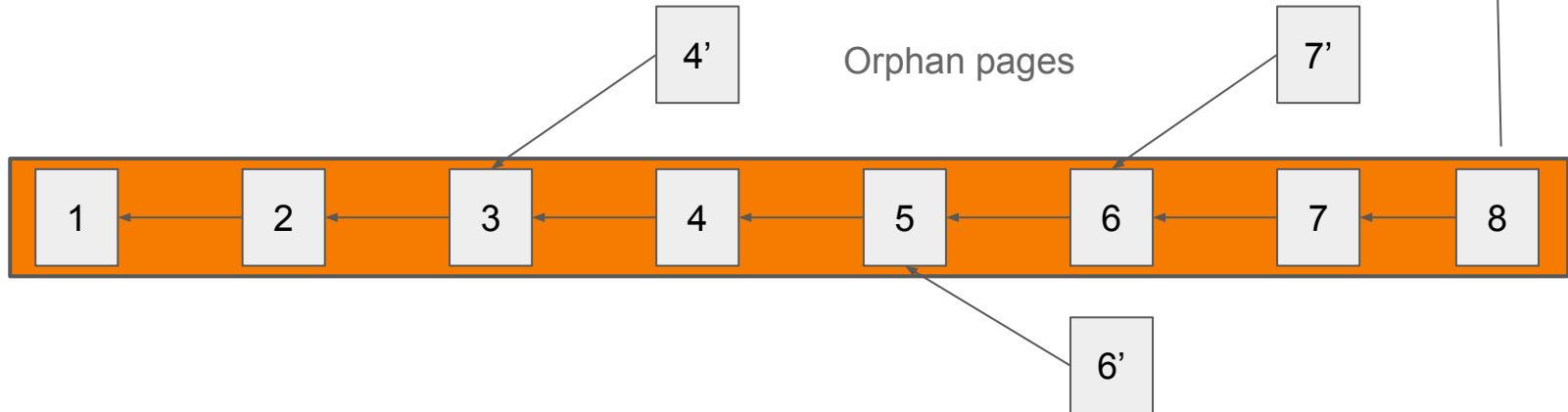
Choosing the correct book ?



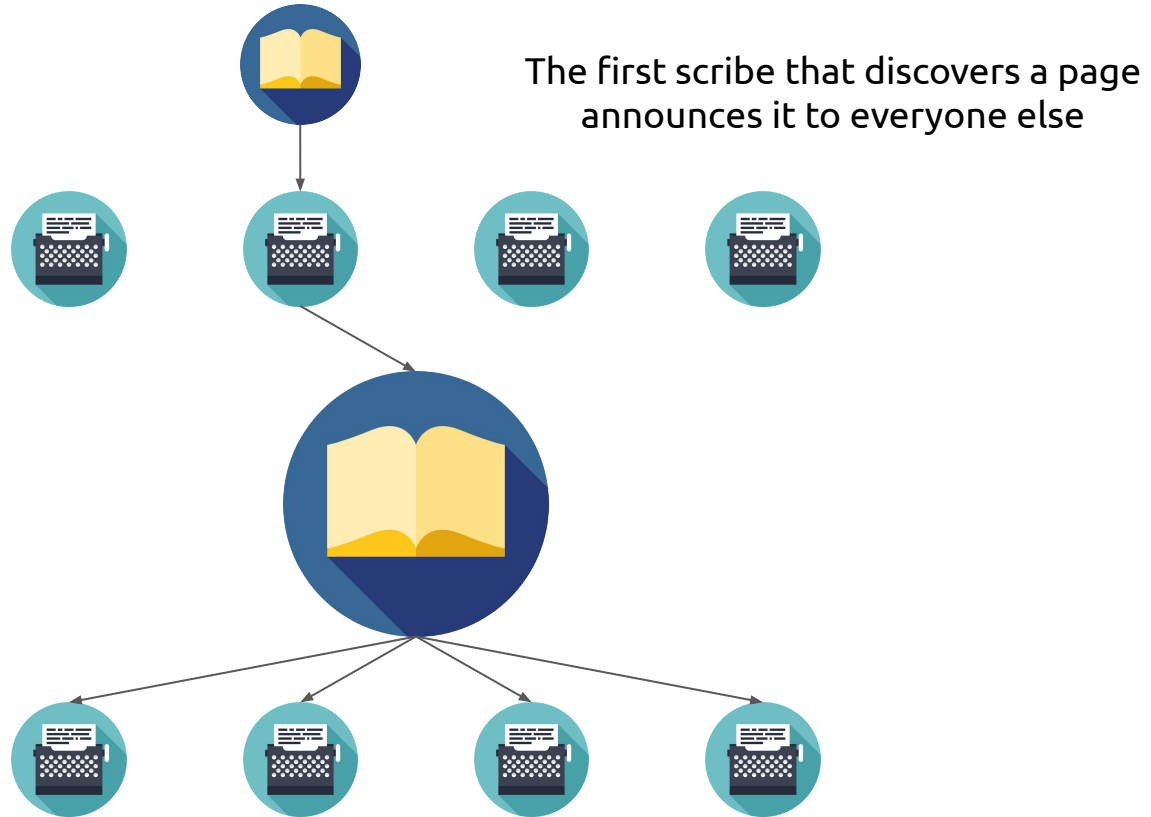
The **correct book** to work on & refer to is the book with the most pages. If multiple exist, just pick one at random.

Assembling the current book

- Each page refers only to the previous one
- Current assembled by stringing together the longest sequence of pages

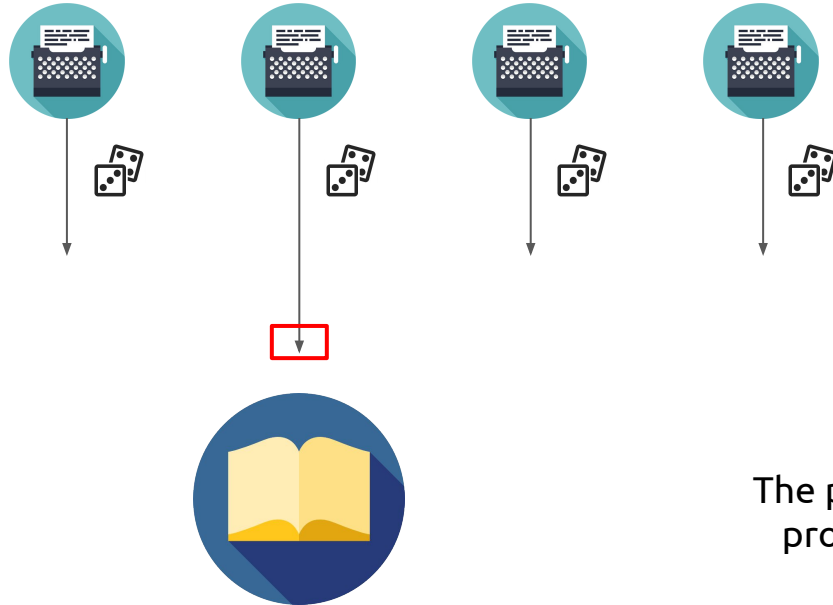


Rules of extending the book



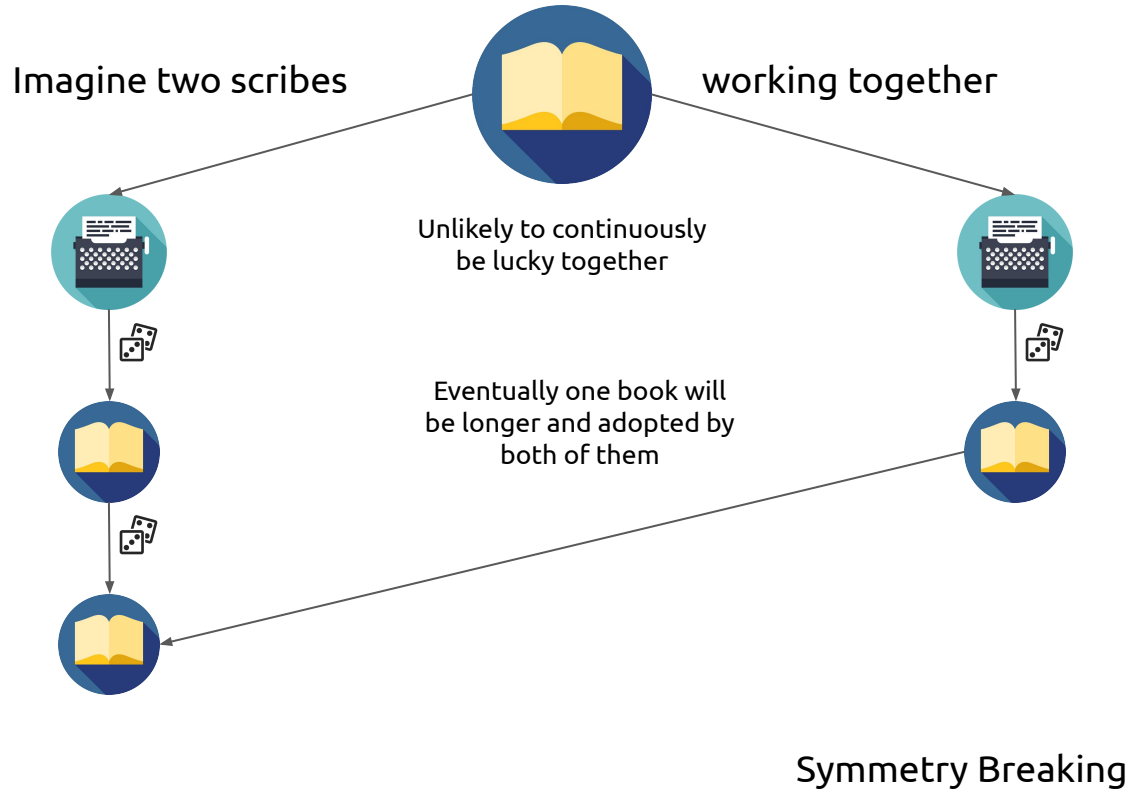
Effort is needed to produce a page

Equivalent to: each page needs a special combination from a set of dice to be rolled.



The probabilistic nature of the process is paramount to its security





The benefits of randomness



Being a scribe

- Anyone can be a scribe for the book
- As long as one has a set of dice
- The more dice one has, the higher the likelihood to produce the winning combination to make a page

Parable & Reality

	The “blockchain”
	“Miners” / Computer systems that organize transactions in blocks
	Solving a cryptographic puzzle that is moderate hard to solve
	Using a computer to test for a solution from a large space of candidate solutions

The first blockchain application

Blockchain applications

- Effort is needed to produce a page
 - Why would anyone care to constantly roll dices?
- Decentralization is complex
 - What kind of application could benefit from a completely decentralized database?

Bitcoin

What is bitcoin ?



Why would people participate?

- Utility: “that property in any object, whereby it tends to produce benefit, advantage, pleasure, good, or happiness” (Jeremy Bentham, 1870)
- Homo Economicus:
 - Constantly acts rationally and optimally
 - Aims to maximize its financial gain

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- Utility: “that property in any object, whereby it tends to produce benefit, advantage, pleasure, good, or happiness” (Jeremy Bentham, 1870)
- Homo Economicus:
 - Constantly acts rationally and optimally
 - Aims to maximize its financial gain
- People would participate in Bitcoin, if they are financially rewarded
- Users would pay others to run the system
- Free market (everywhere)

What is Bitcoin (trying to be)?

- Money
 - Competing with GBP £, USD \$, EUR €, etc
 - *Medium of exchange*: give money to get goods and vice versa
 - *Unit of account*: price goods, for accounting/debt purposes
 - *Short/Medium-term store of value*: can be exchanged for the same amount of goods in the (not so distant) future

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- Payment system

- Competing with cash, bank deposit operation network, Visa, Mastercard, etc
- High throughput (large volume of transactions/sec)
- Low latency (fast transaction settlement)
- Uninterrupted service

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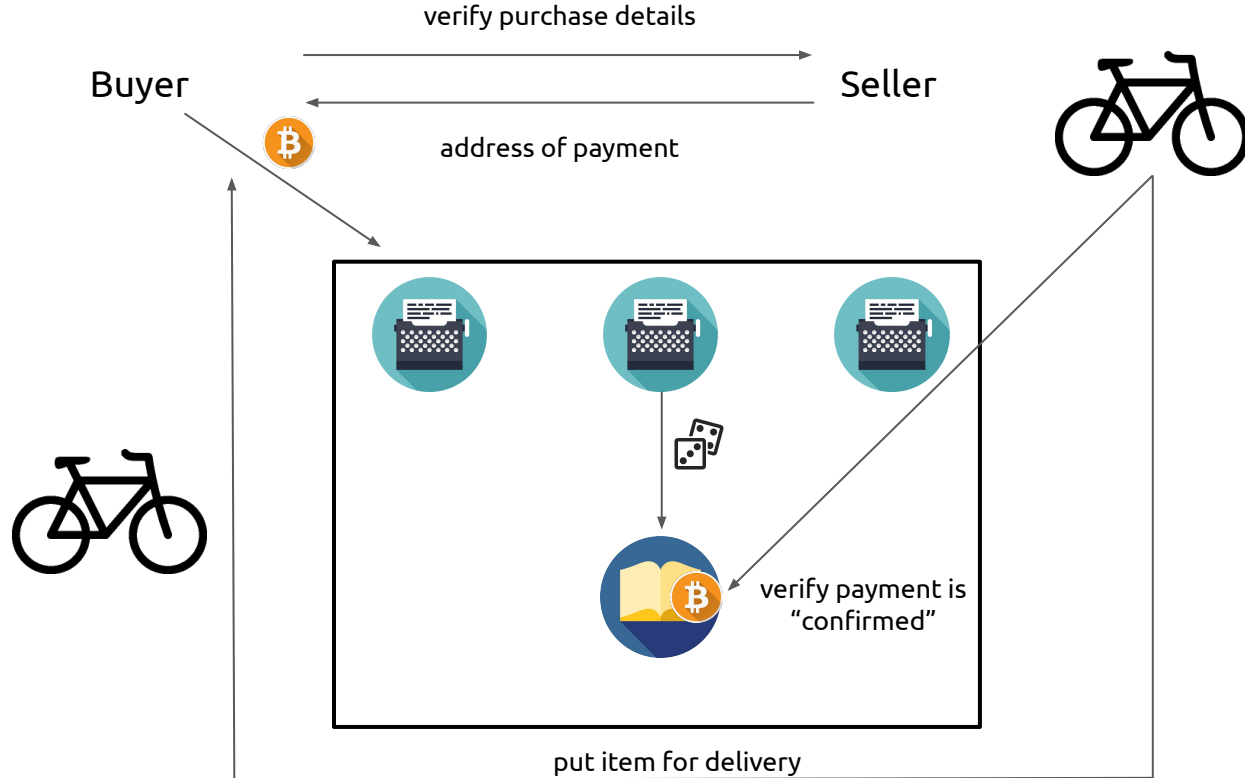
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- Commodity

- Competing with gold, silver, oil, etc
- A (useful) material that can be bought/sold

Using the Bitcoin book



Person to person



Advantages

- Resilience
 - The book is shared across the network
 - Even if some nodes crash or are corrupted, system is operational
- Censorship resistance
 - Anyone can participate
 - Geographical disparity of nodes
 - Good alternative for borderline (or beyond) legal financial transactions
- Digital and Open
 - New applications can be easily built on top of it
 - Programs can be hosted on the ledger itself (smart contracts)

Disadvantages

- Bad as money
 - Price fluctuations and circulation does not follow economic growth (bad store of value)
 - Nothing is priced in Bitcoin (bad unit of account)
 - Slow and expensive (bad medium of exchange)
 - Low throughput (~5 tx/sec)
 - High latency (60 mins)
 - High fees^{***} (~3\$)
- Irreversibility
 - If a transaction is processed, it cannot be deleted/reversed
 - If user's bitcoins are stolen or loses key, no recovery mechanism exists
- Environmental inefficiency
 - Bitcoin CO₂ footprint*: 76.44 Mt (~Colombia)
 - *Single* Bitcoin tx CO₂ footprint*: 820.84 kg (~1.8M VISA transactions)
 - Single Bitcoin tx e-waste^{**}: 242g (~1.5 iPhones)

*<https://digiconomist.net/bitcoin-energy-consumption>

**<https://www.sciencedirect.com/science/article/pii/S0921344921005103>

***<https://bitinfocharts.com/comparison/bitcoin-transactionfees.html>

Smart contract



From Money to Smart Contracts

- Since we have created **the book**, why stop at recording monetary transactions?
- We can encode in the book's pages **arbitrary relations** between accounts
- Scribes can **perform tasks and take action**, like verifying that stakeholders comply to contractual obligations

Questions to Consider

- How are pages created? Since the book is empty at the beginning, where do the money come from?
- How is it possible to sign something digitally?
- How does a page properly refer to the previous page?

Questions to Consider

- How are pages created? Since the book is empty at the beginning, where do the money come from? - **Proof-of-Work**
- How is it possible to sign something digitally? - **Digital signatures**
- How does a page properly refer to the previous page? - **Hash functions**

Hash Functions

- An algorithm that produces a fingerprint of a file.
- what are the required properties (traditionally):
 - a. Efficiency
 - b. A good spread for various input distributions.
- What are Security/Cryptographic considerations

$$\mathcal{H} : \{0, 1\}^* \rightarrow \{0, 1\}^\lambda$$

Collision resistance

Collision attack

Find $x, y : \mathcal{H}(x) = \mathcal{H}(y)$

Second pre-image attack

Find $y : \mathcal{H}(x) = \mathcal{H}(y)$

For given x

Birthday paradox

- How many people should be in a room so that the probability that two of them share a birthday becomes larger than 50%?

Birthday paradox

- How many people should be in a room so that the probability that two of them share a birthday becomes larger than 50%?

n possible dates, k people

$$\begin{aligned}\Pr[\neg Col] &= \frac{n}{n} \cdot \frac{n-1}{n} \cdot \frac{n-2}{n} \cdots \frac{n-k+1}{n} = \\ &= \prod_{l=1}^{k-1} \left(1 - \frac{l}{n}\right) \leq \exp\left(-\frac{1}{n} \sum_{l=1}^{k-1} l\right) = \exp(-k(k-1)/2n)\end{aligned}$$

$$\Pr[\neg Col] = \frac{1}{2} \Rightarrow k \approx 1.177\sqrt{n}$$

What do we learn about collision finding?

Describe an algorithm that finds collisions taking advantage of the Birthday paradox.

Pre-image attack

Given $\mathcal{H}(m)$ $m \in \{0, 1\}^t$

Find an element of $\mathcal{H}^{-1}(\mathcal{H}(m))$

Generic algorithm tries all possible candidates

Complexity: ?

One-way functions

$$f : X \rightarrow Y$$

easy : given x find $f(x)$

hard : given $f(x)$ sample $f^{-1}(f(x))$

Do one-way functions exist?

Relates to most important open question in computer science right now:

$$P \neq NP$$

Hash function instantiations

- **Retired.** MD5, SHA1.
- **Current.** SHA2, SHA3, available for 224,256,384,512 bits fingerprints.
- **Bitcoin.** Uses SHA2 with 256 bits output, SHA-256.

Digital Signatures

- Can be produced by one specified entity.
- Can be verified by anyone (that is suitably “equipped” and “initialised”).
- Cannot be forged on a new message even if multiple signatures have been transmitted.

Digital Signatures

Three algorithms (**KeyGen**, **Sign**, **Verify**)

KeyGen : takes as input the *security parameter*.
returns the signing-key and verification-key.

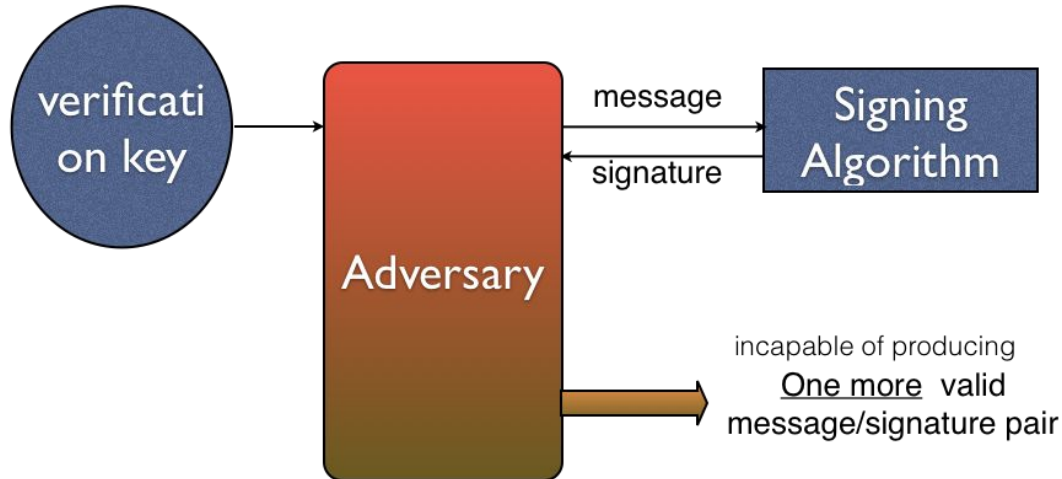
Sign : takes as input the *signing-key* and
the *message* to be signed and
returns a signature.

Verify : takes as input the *verification-key*,
a *message* and a *signature* on the message and
returns either True or False.

Digital Signature Security

Digital Signature Security

Existential Unforgeability under a Chosen Message Attack (EU-CMA)



Constructing Digital Signatures

- Major challenge:
 - what prevents the adversary from learning how to *sign* messages by analyzing the *verification-key*?
- Exercise: construct a digital signature based on a hash-function that is one-time secure (i.e., it is secure for signing only a single message)

Digital Signature Implementations

- Based on the RSA (Rivest Shamir Adleman), one way trapdoor function (with hardness that relates to the factoring problem)
 - The RSA algorithm
- Based on the discrete-logarithm problem
 - the DSA algorithm
- Bitcoin. Uses ECDSA, a DSA variant over elliptic curve groups

Proof-of-Work

- Objective: given some *data*, ensure that some amount of work has been invested for computing them

```
int counter;  
counter = 0  
while Hash(data, counter) > Target  
    increment counter  
return counter
```

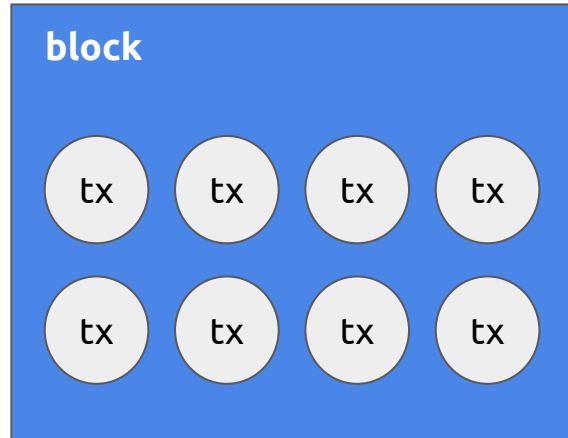
- In this case: Proof-of-Work of *data* equals to a value *w* with the property $\text{Hash}(\textit{data}, w) \leq \text{Target}$
- (Informal) Properties:
 - efficient verification
 - no computational shortcuts (i.e., independent of algorithm that computes it complexity is proportional to Target)
 - independence for symmetry-breaking

Proof-of-Work Algorithms

- Hashcash (as in previous slide)
- Memory hardness
 - ASIC resistance (ASIC = Application Specific Integrated Circuit)
 - A number of algorithms proposed: scrypt, argon, progpow

Bitcoin in practice

Blocks



BLOCKS**TRANSACTIONS**

Height

Age

Transactions

Miner

Size (bytes)

[564593](#)

4 minutes

2734

[Unknown](#)

1,185,499

[564592](#)

9 minutes

2725

[AntPool](#)

1,297,232

[564591](#)

16 minutes

2537

[BTC.com](#)

1,183,625

[564590](#)

54 minutes

1757

[F2Pool](#)

1,158,256

[564589](#)

1 hour

2230

[BitClub Network](#)

1,300,144

[View More](#)

Blocks

Summary	
Number Of Transactions	2973
Output Total	7,994.71534627 BTC
Estimated Transaction Volume	1,428.50299957 BTC
Transaction Fees	0.12706551 BTC
Height	543028 (Main Chain)
Timestamp	2018-09-25 15:56:10
Received Time	2018-09-25 15:56:10
Relayed By	SlushPool
Difficulty	7,152,633,351,906.41
Bits	388454943
Size	1152.48 kB
Weight	3993.111 kWU
Version	0x20000000
Nonce	3705848148
Block Reward	12.5 BTC

Total transactions

Hashes	
Hash	0000000000000000000a318feb2fc7c2c9dc43c2d1de1606bb5f0cc6dc1d115
Previous Block	00000000000000000003006dab6f32132e7eeda37d2cca4a961339bad35b1e80
Next Block(s)	0000000000000000000868c5eac591d4df331b4c8b4b12c33d40dfddac3feaff
Merkle Root	4dfd79c993bc63e5db09cbda62e9d9df7da1a7d8f1605e97a5ceb1f939509d31

Block ID

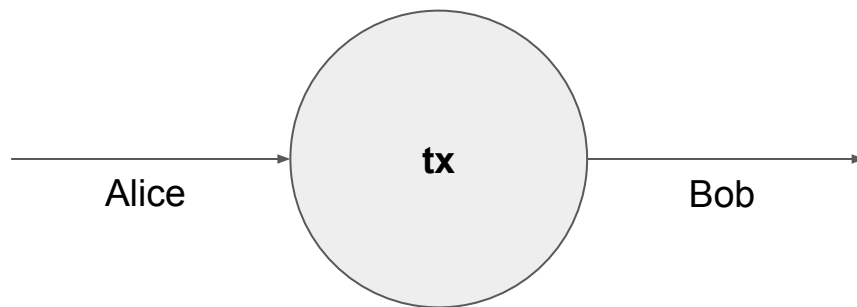
Parent ID

Total fees

Block difficulty

Reward

Transactions



BLOCKS

TRANSACTIONS

Transaction Hash	Age	Amount (BTC)	Amount (USD)
7dd6b6e07ea48577ce11fd43cbf20e259d187defc0888eaa698d7...	5 seconds	1.91072766 BTC	\$7,304.54
94613360083b2e9bdff659d026021c3df9abad4820cf2bb6add...	3 seconds	0.02130671 BTC	\$81.45
bbda790399d9f44f25d247ea2785b9a687b714665b1fb021cd537...	3 seconds	1.23166111 BTC	\$4,708.53
5d96b437de67fc604b025671f4fa199832b60fc21aedcf94b0455...	2 seconds	0.05533534 BTC	\$211.54
6e7e9284d3c45111a036dab93aae7f7b057e76935c6186051cf92d...	2 seconds	0.03158347 BTC	\$120.74

[View More](#)

Transactions

Transaction ID

Receiver

Sender

Total amount

0.00113384 BTC

0.00113384 BTC

13hieCEtALdjjZf5hfXEvaqaYitDe9sqQj (0.00013129 BTC - Output)
14L3kyHjMr74ShVweF5CYVvxbQE9gDWdPH (0.0001 BTC - Output)
1JaR2C4y17FW8N4VrwPWTzhrb5xahRFYzV (0.00049266 BTC - Output)
1LgadWMGeGKEKbLafBcRdMySVNrX9QTmnf (0.0004435 BTC - Output)
156MijasU1ohN22qgFusBiBFUrg4NQG2h3 (0.0000365 BTC - Output)

1BHUA4m4Zb5zz5gDrPmXbvHjETzXAUeEcp7 - (Spent)

Summary	
Size	781 (bytes)
Weight	3124
Received Time	2018-09-25 14:29:54
Included In Blocks	543028 (2018-09-25 15:56:10 + 86 minutes)
Confirmations	21456
Visualize	View Tree Chart

Block number
& timestamp

Confirmations

Inputs and Outputs	
Total Input	0.00120395 BTC
Total Output	0.00113384 BTC
Fees	0.00007011 BTC
Fee per byte	8.977 sat/B
Fee per weight unit	2.244 sat/WU
Estimated BTC Transacted	0.00113384 BTC
Scripts	Hide scripts & coinbase

Addresses

- Like an IBAN (or email)
- You send bitcoins to a person by sending bitcoins to one of their addresses
- You can have as many addresses as you want
- No need to be online to create an address
- Pseudonymous: a unique address used for each transaction
- Wallet: the application that controls a user's addresses

Digital wallet: Bitcoins in your computer or phone



Development

- Local blockchains:
 - Used for **local development**
 - Instant mining
 - Very small in size
- You can use a local Ethereum blockchain online with Remix
- Testnets:
 - Used for **testing and experimenting**
 - Very useful, specifically for smart contract development
 - Different blockchain and different genesis block
 - Coins with **no real value**, separated and distinct from actual coins
 - Different ports and DNS seeds
 - Ethereum: Rinkeby, Ropsten, Kovan
- In class we will use our own Ethereum testnet
- Main net (production):
 - Blockchains are **immutable and irreversible**
 - You cannot simply update your code once deployed!

Explorers

- An online blockchain browser
- Displays the contents of individual blocks and transactions
- Displays the transaction histories and balances of addresses
- Quick way to see if your transactions are confirmed
- Bitcoin:
 - <https://www.blockchain.com/explorer> (Mainnet)
 - <https://testnet.blockexplorer.com/> (Testnet)
- Ethereum:
 - <https://etherscan.io/> (Mainnet)
 - <https://ropsten.etherscan.io/> (Testnet)
 - <https://rinkeby.etherscan.io/> (Testnet)

Faucet

- A way to get test coins necessary for any testing
- Ethereum:
 - <https://faucet.rinkeby.io/>
 - <https://faucet.metamask.io/>
 - <https://faucet.ropsten.be/>
- Bitcoin:
 - <http://tbtc.bitaps.com/>
 - <https://bitcoinafaucet.uo1.net/>
 - <https://testnet-faucet.mempool.co/>
 - <https://block.io/> (Online testnet wallet)