Digital Gold Institute

OPEN timestamps

UNIVERSITÀ DEGLI STUDI DI MILANO BICOCCA

Blockchain Certification: Bitcoin & OpenTimestamps

Bicocca University, Milan, 25th January 2019

Ferdinando Maria Ametrano

Bitcoin: A Protocol and a Currency

- **B**itcoin: protocol, software, and community
- **b**itcoin**s**: units of the currency

bitcoins are sent using the Bitcoin protocol

- bitcoins are the native digital asset intrinsic to the Bitcoin protocol

Bitcoin: The Protocol

- Distributed public ledger of transactions
- Shared with peer-to-peer technology
- Massively duplicated across network nodes
- Allowing the ownership transfer of a native digital scriptural asset
- Whose native “digital token” can be exchanged, but not duplicated
- Keeps records of every transaction forever

Bitcoins: The Currency

- Only exist as public ledger documented transactions
- Are associated to public address(es) like

1FEz167JCVgBvhJBahpzmrsTNewhiwgWVG

It is mine; you are **REALLY** encouraged to tip

- the bitcoin distributed public ledger certifies for everybody how many bitcoins are associated to any address

https://blockstream.info/address/1FEz167JCVgBvhJBahpzmrsTNewhiwgWVG

Asymmetric Cryptography: Public/Private Key Pair

Two mathematically linked keys perform opposite digital signature functions:

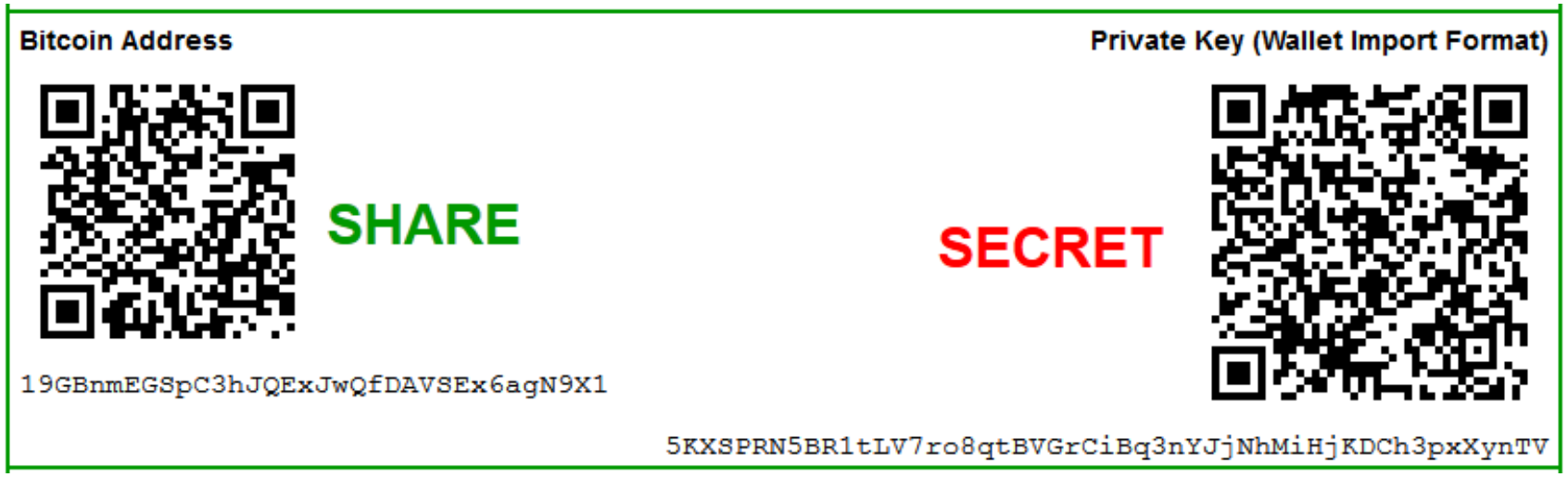
- The private (secret) key used to generate the signature
- The public key used by anyone to verify the signature

- The public key derives from the private key, but the private key cannot be derived from the public one
- A bitcoin address is derived from a public key, but the public key cannot be derived from the address
- Private key -> public key -> bitcoin address

Asymmetric Cryptography: Public/Private Key Pair

- Private key -> public key -> bitcoin address
- The corresponding private key allows spending from that address

https://www.bitaddress.org



A Bitcoin Transaction: From Alice's Address to Bob's Address

- Transaction: amount + Bob's address (+ Alice's public key)
- Alice's private key digitally signs the transaction
- The transaction is broadcasted to the network
- With Alice's public key any network node can verify that:
  - Amount is at Alice's address disposal
  - Digital signature is valid, the transaction has not been tampered or modified: the private key associated to Alice's address has signed the transaction
- The transaction is then published to the public ledger
- Everybody knows that the Bob's address has received the transacted amount

Double Spending Problem

- To securely transfer value using digital means has been possible for decades
- In digital cash schemes, a single digital token, being just a file that can be duplicated, can be spent twice
- A centralized trusted party has always been required to prevent *double spending*

Bitcoin Network: A Distributed Back-office

- All network nodes validate and clear all transactions
- Mining nodes provide the additional computational power required for transaction settlement

- Without a central trusted party, how do they reach *distributed consensus* on the transaction history?
- Consensus in a distributed asynchronous network with faulty (or malicious) nodes is a very hard problem: Computer Science even provides impossibility results

Bitcoin's Public Ledger: A Chain of Blocks

- Transactions are bundled in blocks (about one block every 10 minutes) and sequentially chained
- The cryptographic link between blocks requires computing power to be created
- A block is valid only if it includes valid transactions

Mining

- Miners compete to finalize (settle) a new block of transactions
- The winner providing *proof-of-work* for the finalization of a new block is rewarded with the issuance of new bitcoins in a special *coinbase* transaction included in that same block
- Miners solve the double spending problem:
  - A double spending transaction would invalidate the block
  - an invalid block would be rejected from the network
  - the bitcoin reward would be removed from transaction history
  - the winning miner would have wasted his work

Ledger Immutability

- Because of the *proof-of-work*, the chances of a block being altered decrease exponentially with the number of blocks chained after it

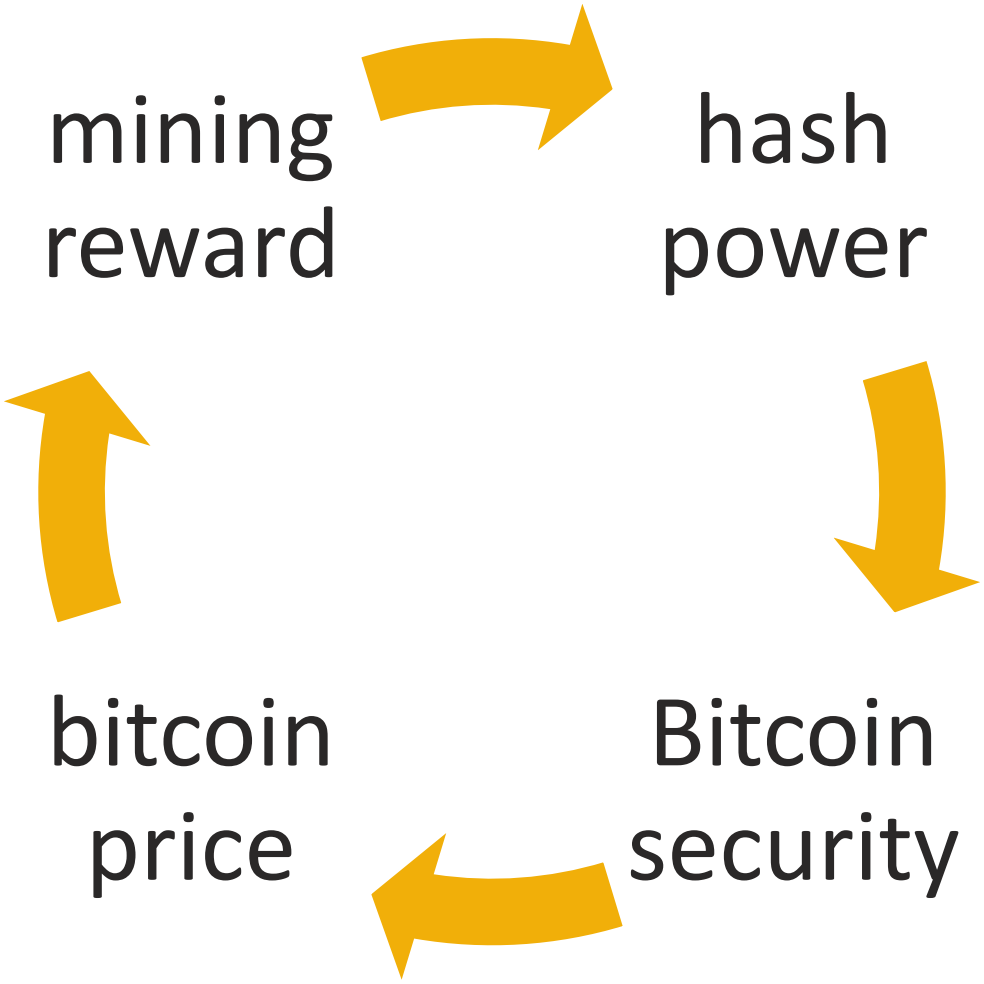
- The chain of blocks is a history of transactions resilient to network attackers because it cannot be altered without huge resources

- Computing power is measured in hash/s, hash being the basic operation needed for validation

Nakamoto Distributed Consensus

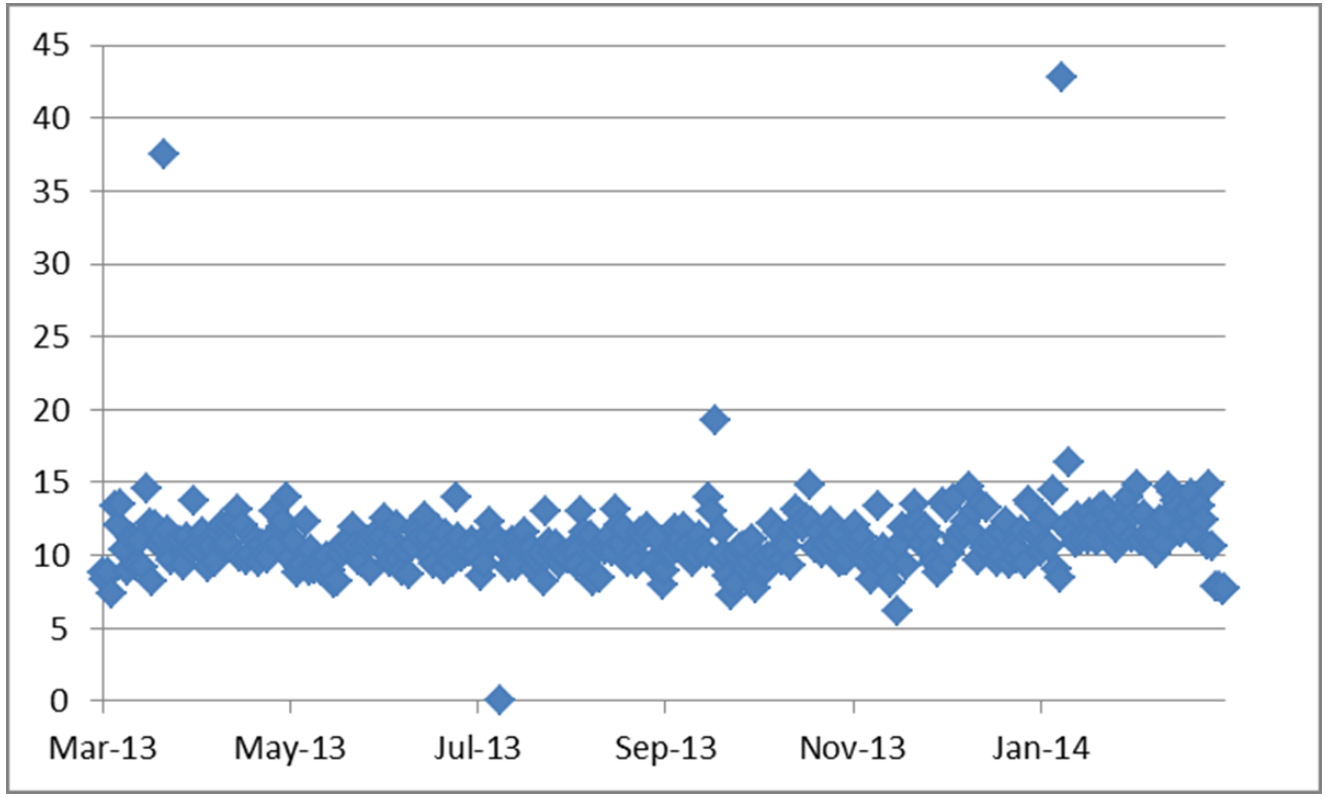
- Practical Byzantine Fault Tolerant (PBFT) *distributed consensus* is achieved using *(game theory) economic incentive* for the mining nodes to be honest
- Double spending is solved without a central trusted party
- Bitcoin can resist attacks of malicious agents, as long as they do not control network majority
- Miners are compensated for their proof-of-work using seigniorage revenues, i.e. issuance of new bitcoins
- Seigniorage revenues subsidize the network

Virtuous Cycle



Validation Process: Block Generation

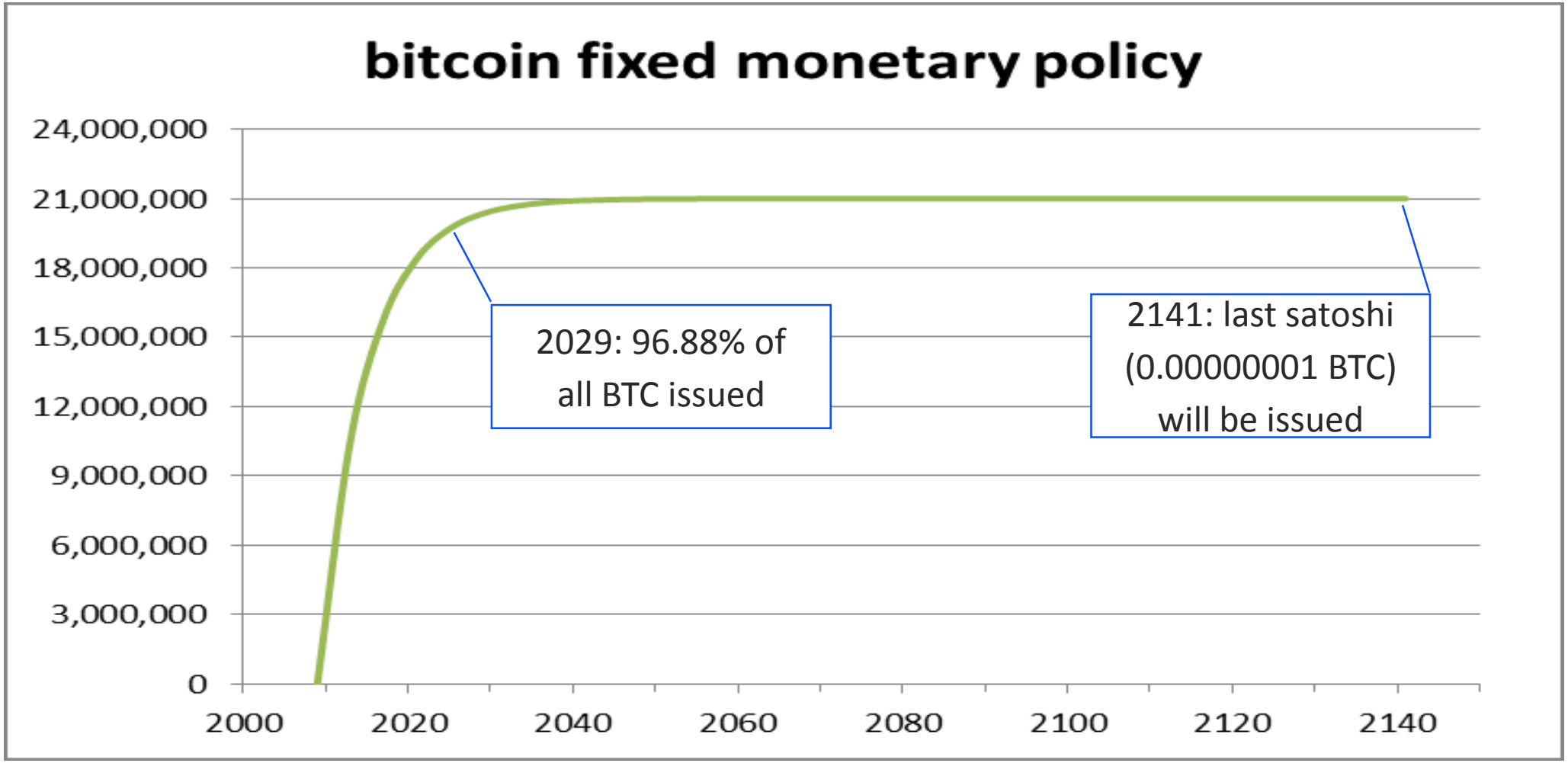
The *proof-of-work* difficulty is adapted about every 2 weeks (2016 blocks) to the overall available computing power ensuring about one block every 10 minutes



Bitcoin Monetary Rule

- 2009: 50BTC per block, every 10 minutes
  - halving every 4Y
- This is the only way new bitcoins are released
- It is called mining because of its similarity with the progressive scarcity of gold extraction
- Supply is free of discretionary intervention

Bitcoin *Inelastic* Supply: Deterministic Decreasing Rate



What Makes Bitcoin Special?

- Digital and scriptural: it only exists as validated transaction
- Asset, not liability
- Bearer instrument
- It can be transferred but not duplicated (i.e. it can be spent, but not double-spent)
- Scarce in digital realm, as nothing else before
- It mimics gold monetary policy

What Makes Bitcoin Special?

Bitcoin is digital gold

with a secure uncensorable embedded

settlement network

- More a crypto-commodity then a crypto-currency
- This is the groundbreaking achievement by Satoshi Nakamoto, not blockchain "technology"

Bitcoin as (Digital) Gold in the History of (Crypto)Money

gold	bitcoin
▪ Its adoption was not centrally planned	▪ Its adoption has not been centrally planned
▪ For centuries it has been the most successful form of money	▪ It is the most successful form of cryptocurrency
▪ It has bootstrapped all monetary systems we know of	▪ It is bootstrapping new monetary systems
▪ It has been surpassed by other kind of money without becoming obsolete	▪ It might be surpassed by more advanced type of cryptocurrencies without becoming obsolete

"Bitcoin in 2014 Is Like Internet in 1994: Weird and Scary" (Marc Andreessen)

American entrepreneur, investor, and software engineer; coauthor of Mosaic, cofounder of Netscape

https://twitter.com/pmarca/status/677658844504436737

The Wallet Garden Model

- Controlled access to web content and services
- Offered in the late ‘90s and early ‘00s by Compuserve, AOL (and to some extent MSN)

- Corporates wanted to go online, but not in the wild unregulated internet, populated by anonymous agents

- They eventually realized that perceived risks, which are real, are outweighed by benefits

What is The Blockchain?

[A hash pointer linked list of blocks]

- An append-only sequential data structure
- New blocks can only be appended at the end of the chain
- To change a block in the middle of the chain, all subsequent blocks need to be changed
- <u>Very inefficient compared to a relational database</u>

Blockchain Without Bitcoin

Blockchain without an *intrinsic native digital asset*

Does it make sense?

- No bitcoin
- No asset available to reward miners
- Appointed validator officials required

Central governance is required!

Why should validators use a blockchain,
i.e. a subpar data structure, instead of a database?

"Blockchain – not bitcoin – will prove revolutionary in banking"

"When a wise man points at the moon the fool examines the finger."

(Confucius)

*"When a wise man points **at the bitcoin** the fool examines **the blockchain**."*

(Ametrano)

http://www.economist.com/news/leaders/21677198-technology-behind-bitcoin-could-transform-how-economy-works-trust-machine

Blockchain Beyond Bitcoin

There is no blockchain without bitcoin

There is blockchain beyond bitcoin

Andreas Antonopoulos

Write Data On the Blockchain

There is a special Bitcoin Script operator *OP_RETURN* that can be used to store 80 bytes of arbitrary data in the blockchain

Timestamp

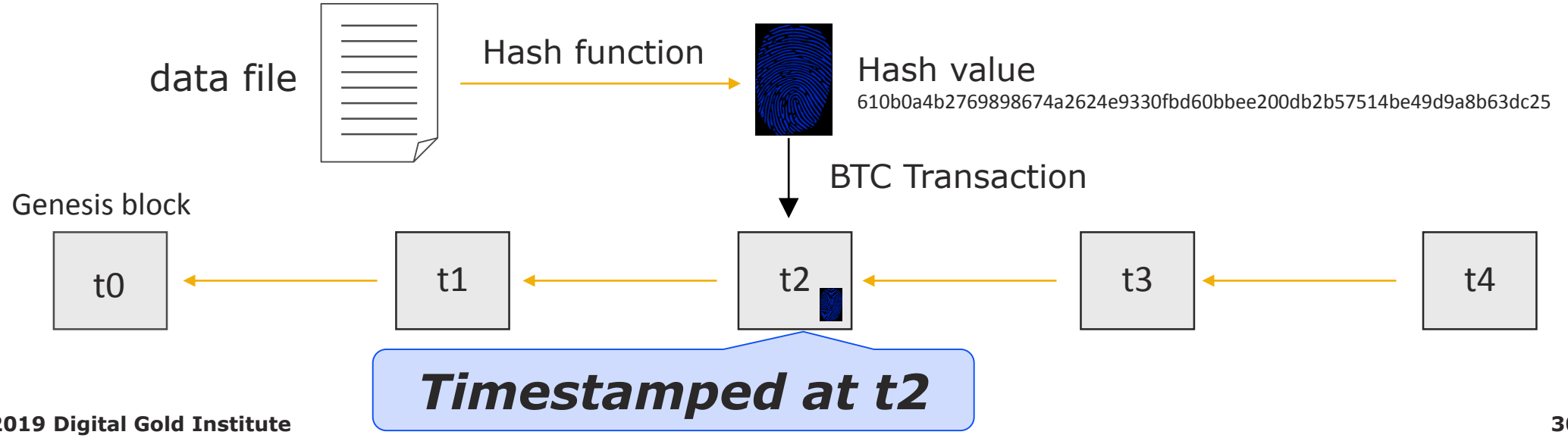
- A timestamp proves that some data existed prior to some point in time, providing a relevant document with a certain sure date, e.g. postmark
- Law requires dates to be certified by public officials and notary services
- For digital documents, timestamping is based on digital signature by certification authority

Hash Function

- A function that maps input data of arbitrary length to a hash value, i.e. an output data of a fixed length
  - *Non-invertible* (one-way: input data can not be regenerated from the output hash value)
  - *Collision-resistant*: computationally unfeasible to find 2 inputs that produce the same output
- The resulting **hash value is a** reliably **unique identifier** for any input data: it can be considered its unique digital fingerprint
- The hash value does not reveal the input data
- Bitcoin uses the (Secure Hash Algorithm) SHA256 that generates a fixed size 256-bit (32-byte) output

Blockchain as Timestamping Certification Authority

- A generic data file can be *hashed* to produce a short unique identifier, equivalent to its digital fingerprint
- Such a fingerprint can be associated to a bitcoin transaction (irrelevant amount) and hence *attested* on the blockchain
- Blockchain immutability provides time-stamping, proving the data file existence at that moment in time in that specific status



Blockchain Timestamping

Pro:

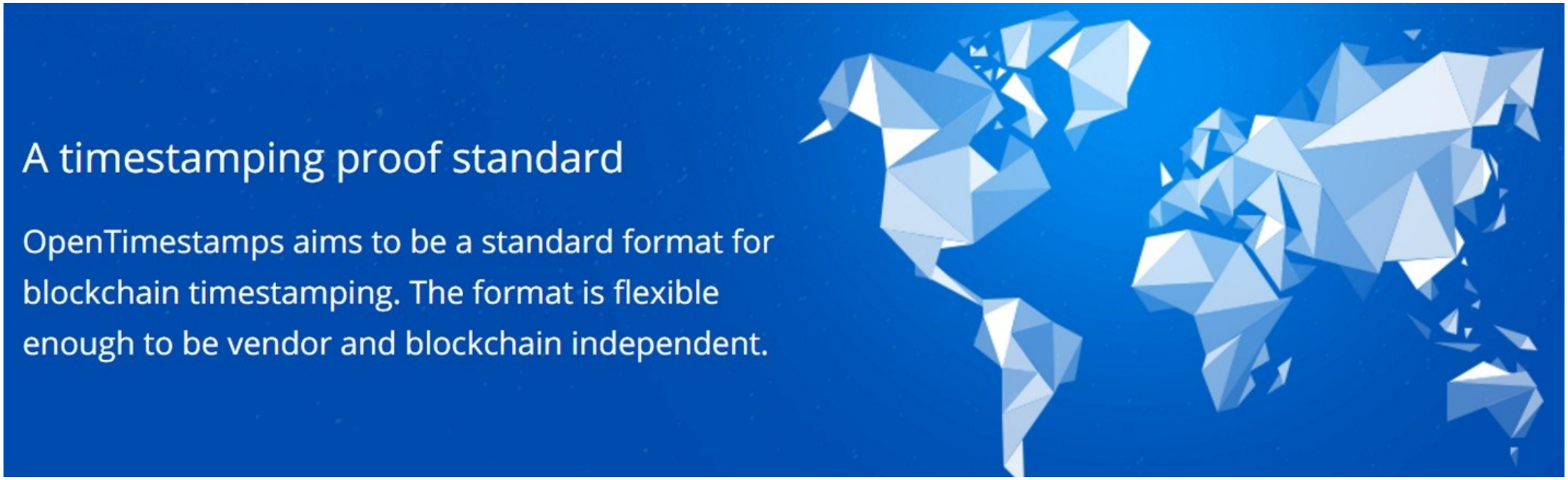
- Digital public proof, easily auditable by everyone
- The proof cannot be faked, manipulated, or removed
- Certification authority cannot be bribed
- Can be used along with regulatory timestamping prescription

Cons:

- Not efficient (one transaction per document)
- Lack of standardization

To solve the above limits, Peter Todd and Riccardo Casatta have proposed an open standard consisting in a set of operations for creating provable blockchain timestamps and later independently verifying them

An Open Timestamping Standard



- Third party auditability (suitable for regulatory prescriptions)
- Scalable: timestamp an unlimited number of documents with a single transaction
- Convenient: public server provides the service for free

OpenTimestamps: Distributed , Trust-minimizing, Scalable, Convenient

- **Trust**: OpenTimestamps uses decentralized, publicly auditable, blockchains, removing the need for trusted authorities; OpenTimestamps's architecture is designed to support multiple, cross-checked, notarization methods
- **Scalability**: OpenTimestamps scales indefinitely, allowing timestamps to be created for free by combining an unlimited number of timestamps into one blockchain transaction by leveraging Merkle-tree
- **Convenience**: OpenTimestamps can create a third-party-verifiable timestamp in about a second; you don't need to wait for a blockchain confirmation

https://petertodd.org/2016/opentimestamps-announcement

OpenTimestamps: Trust

- Decentralized, independent, uncensorable, cross-jurisdictional
- Third party auditable
- Blockchain agnostic

Please note that a timestamp is as reliable as the used blockchain:

- very reliable when using Bitcoin because that blockchain is secured by huge computational power (proof-of-work);
- much less reliable with other public permissionless blockchain;
- when used with private permissioned blockchain its reliability depends on the reliability of the chain governance: in that case traditional certification authorities are probably better.

OpenTimestamps: Scalability

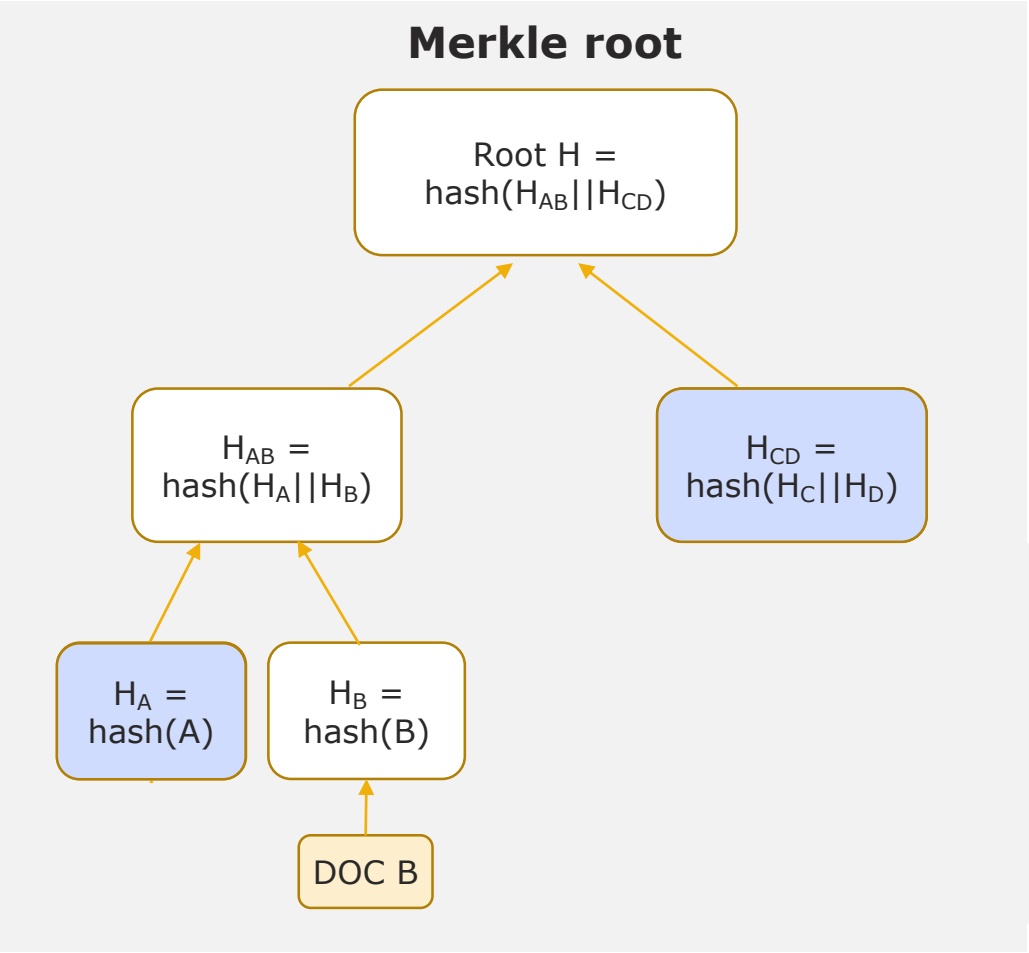
An OpenTimestamps *calendar server* provides *"aggregation before attestation"*:

1. aggregation of multiple documents in a Merkle tree data structure
2. attestation of all documents at the same time using just a single blockchain transaction

- Moreover, a calendar server can offer its services to multiple remote OpenTimestamps clients

Merkle Tree: Hash Pointer Binary Tree

- Merkle tree can efficiently summarize large sets of data into one single hash
  1. Hash all documents
  2. Calculate the hash of the $H_A||H_B$ concatenation to obtain H_{AB}, the next level of the tree
  3. Iterate the process
- The membership proof is O(log N): to prove that DOC_B is in the tree only 2 data are needed: H_A and H_{CD}
- Timestamp the tree root only



OpenTimestamps: Convenience

- While anyone can timestamp with permissionless blockchain(s) by paying the transaction fees, OpenTimestamps provides public servers free to use without any registration or API key
- Verifiable timestamp are created in about a second
- Public format: no vendor lock-in
- Independently verifiable: no need for calendar server after timestamping

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Scarcity in the Digital Domain

Home Vision Team OpenTimestamps Blog About

OPEN timestamps

Drop below a file to **stamp** it: its *.ots* OpenTimestamps receipt will be downloaded automatically. The hash of the file will be calculated inside your browser preserving your privacy.

Alternatively, drop below an *.ots* receipt/proof file to **verify** it.

Drop here a file to **stamp** OR an *.ots* receipt/proof file to **verify**

https://www.dgi.io/ots/

Drop below a file to **stamp** it: its *.ots* OpenTimestamps receipt will be downloaded automatically. The hash of the file will be calculated inside your browser preserving your privacy.

Alternatively, drop below an *.ots* receipt/proof file to **verify** it.

Bitcoin is digital gold.txt 24 B

SHA256:
610b0a4b2769898674a2624e9330fbd60bbee200db2b57514be49d9a8b63dc25

SUCCESS!

OpenTimestamps receipt created and download started

Drop below a file to **stamp** it: its *.ots* OpenTimestamps receipt will be downloaded automatically. The hash of the file will be calculated inside your browser preserving your privacy.

Alternatively, drop below an *.ots* receipt/proof file to **verify** it.

Bitcoin is digital gold.txt.ots 1.9 kB

Stamped SHA256 hash:
610b0a4b2769898674a2624e9330fbd60bbee200db2b57514be49d9a8b63dc25

VERIFIED!

Bitcoin block 471809 attests existence as of 2017-06-18 CEST

Drop here the original file to check that its hash matches the stamped one

Bitcoin is digital gold.txt.ots 1.9 kB

Stamped SHA256 hash:
610b0a4b2769898674a2624e9330fbd60bbee200db2b57514be49d9a8b63dc25

VERIFIED!

Bitcoin block 471809 attests existence as of 2017-06-18 CEST

Bitcoin is digital gold.txt 24 B

SHA256:
610b0a4b2769898674a2624e9330fbd60bbee200db2b57514be49d9a8b63dc25

SUCCESS!

The provided file is the stamped one: its hash value matches the stamped one

What Timestamping is Not

It should be obvious, but it is worth mentioning that timestamping:

- can be selectively revealed to show convenient evidence and hiding inconvenient evidence (e.g. timestamping a bet outcome and its opposite, later revealing only the right one)
- does not prove authorship (that should be proved using a digital signature);
- can be repudiated (*"it was not me…"*) if not digitally signed;
- does not ensure veracity, validity, correctness, or accuracy of the timestamped document.

The Foolish Blockchain Certification

- IBM Food Trust
- EY Wine Blockchain
- Carrefour chicken
- Etc.

- just dishonest marketing gimmick, i.e. misleading advertising.

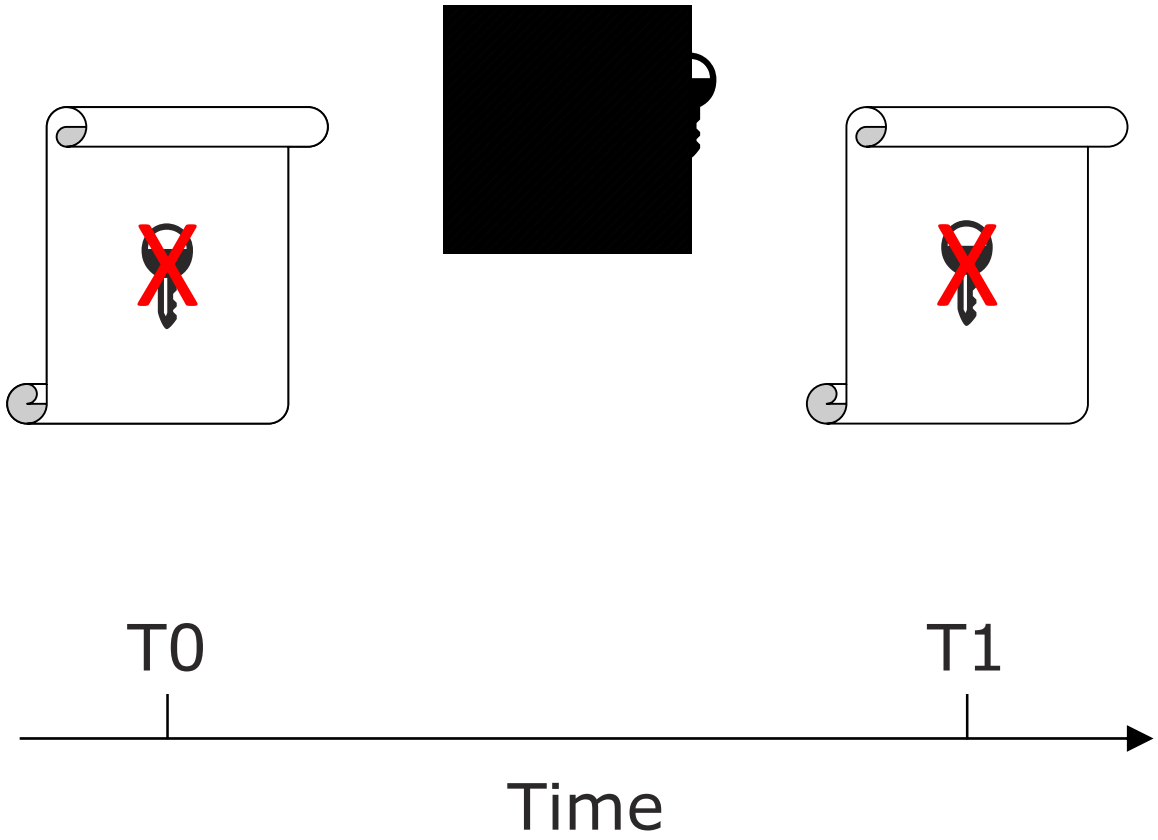
https://www.ametrano.net/2018/10/11/Not-a-blockchain/

Use Case 1: Digital Signature without Timestamping

- What if a signing private key is stolen?
- The key revocation certificate is issued to signal that signatures *after* the theft should be considered invalid

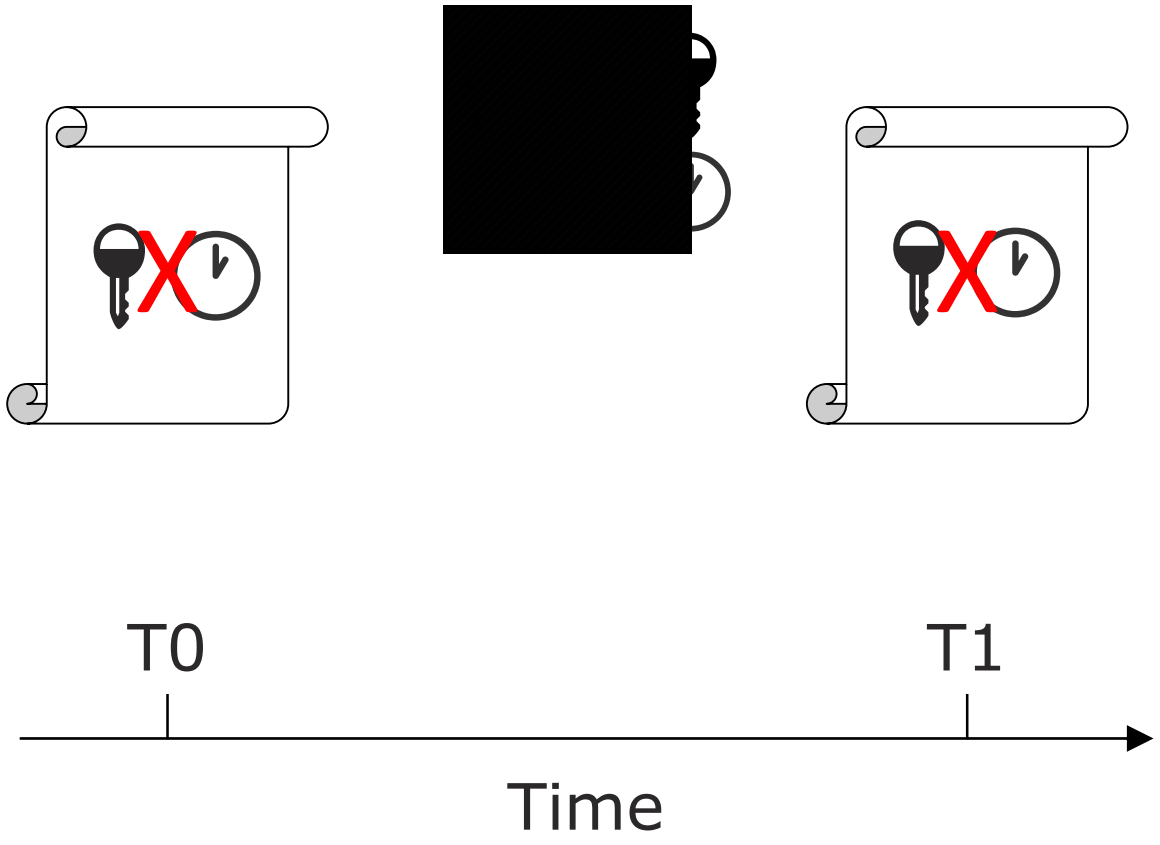
WRONG!!

- Every signature performed with that key should be considered invalid because the thief can backdate documents



Use Case 1: Digital Signature with Timestamping

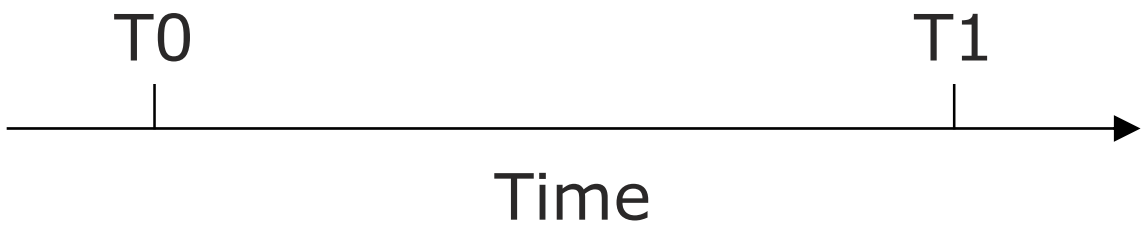
- Traditional timestamping relies on a third-party central authority signing with its private key
- What if the timestamper's private key is stolen?
- Every timestamp created by that key must be considered invalid because the thief can backdate timestamps



Use Case 1: Digital Signature with Blockchain Timestamping

- Blockchain notarization is an effective hardening approach
- What if the traditional timestamper's private key is stolen?

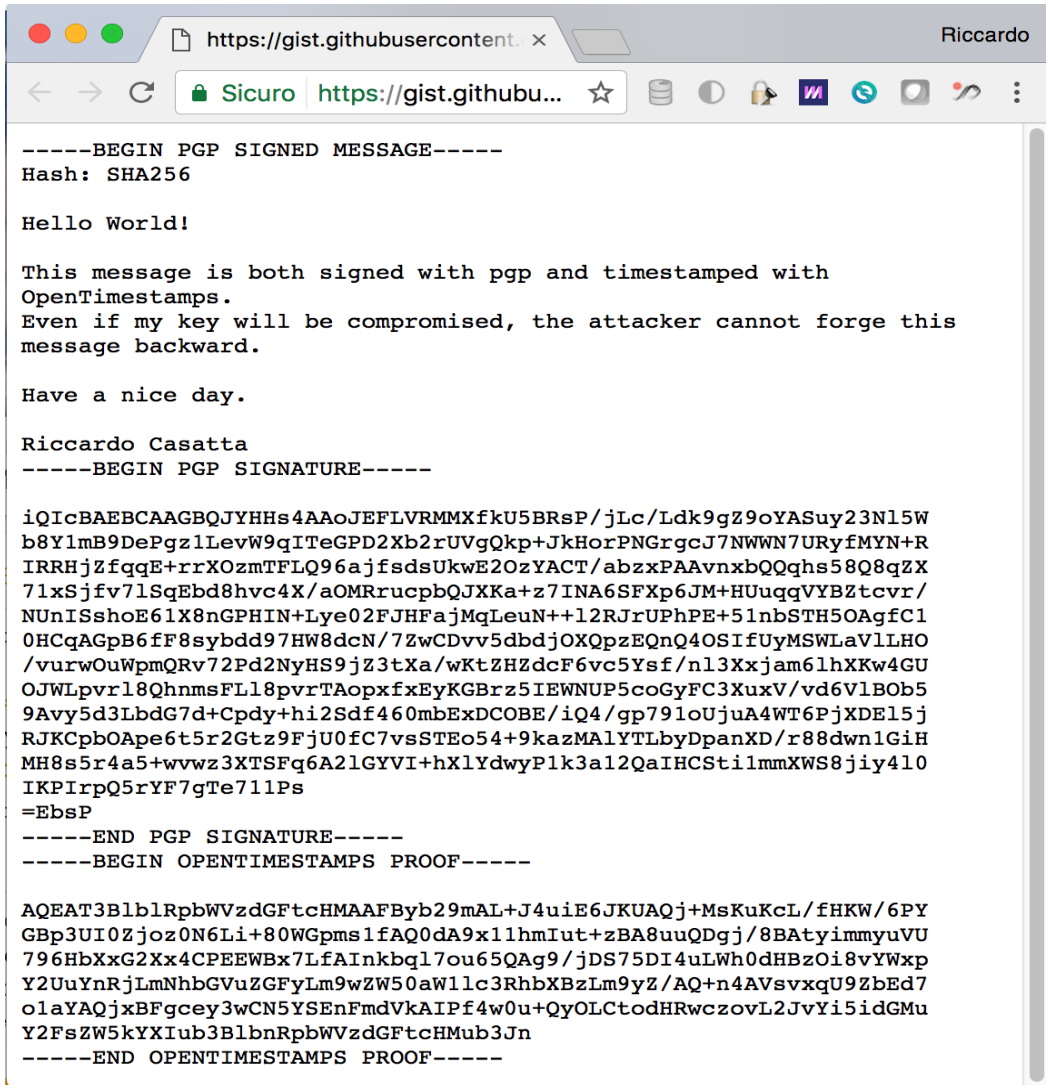
Blockchain timestamps cannot be backdated!



Use Case 1: Hardened Digital Signature

Hardened digital signature

Timestamping that cannot be backdated




```
-----BEGIN PGP SIGNED MESSAGE-----
Hash: SHA256

Hello World!

This message is both signed with pgp and timestamped with
OpenTimestamps.
Even if my key will be compromised, the attacker cannot forge this
message backward.

Have a nice day.

Riccardo Casatta
-----BEGIN PGP SIGNATURE-----

iQIcBAEBCAAGBQJYHHs4AAoJEFLVRMMXfkU5BRsP/jLc/Ldk9gZ9oYASuy23Nl5W
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=EbsP
-----END PGP SIGNATURE-----
-----BEGIN OPENTIMESTAMPS PROOF-----

AQEAT3BlblRpbWVzdGFtcHMAAFByb29mAL+J4uiE6JKUAQj+MsKuKcL/fHKW/6PY
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Y2FsZW5kYXIub3BlbnRpbWVzdGFtcHMub3Jn
-----END OPENTIMESTAMPS PROOF-----
```

https://gist.github.com/RCasatta/6824c80e3de137f0d8d230f622e4bbaa

Use Case 2: Timestamp Internet

- OpenTimestamps is used to timestamp the whole Internet Archive https://archive.org/
- This has been possible thanks to the high scalability of the OpenTimestamps protocol
- For the first time historical archived data cannot be altered without being noticed

http://nova.ilsole24ore.com/progetti/la-blockchain-da-il-tempo-al-web/

Use Case 3: Regulatory Compliance

- Broker-dealers have started using notarization to satisfy the regulatory prescriptions for storing required records exclusively in non-rewriteable and non-erasable electronic storage media.
- WORM (write once read many) optical media has been used so far, but it is quite impractical, especially for large data set
- Compliance can be achieved anchoring rewritable data sources to the blockchain, providing accurate and secure time-stamping resilient to manipulation

http://www.coindesk.com/intesa-sanpaolo-trade-data-bitcoin-blockchain/
https://www2.deloitte.com/it/it/pages/financial-services/articles/l_integrita-dei-dati-di-trading---deloitte-italy---financial-ser.html
https://drive.google.com/drive/folders/0B8tGDTaBY4-Nb3ZuRmgzRXJXOUk

Use Case 4: Publicly Verifiable Certificates

It is easy to verify documents:

- signed by the issuer
- timestamped on blockchain

It would be easy to provide public web-portals for drag-and-drop verification

Blockchain Certification: the Italian Law

ECONOMIA DIGITALE | DECRETO SEMPLIFICAZIONI

Valore legale della blockchain e smart contract: primo via libera al Senato

- di Alessandro Longo | 23 gennaio 2019

Primo via libera alla norma – come emendamento al decreto Semplificazioni, ora al Senato – che inserisce per la prima volta nel nostro ordinamento le "tecnologie basate su registri distribuiti come la Blockchain" e una definizione di smart contract. Il primo aspetto è "la possibilità di dare un valore giuridico a una transazione che sfrutti un registro elettronico distribuito e

- AGID will have to provide technical specification
- Let's hope for the best…
- Blockchain cannot be used to track provenance of Italian tomatoes as Di Maio wishes…

https://www.ilsole24ore.com/art/tecnologie/2019-01-23/valore-legale-blockchain-e-smart-contract-primo-via-libera-senato-173759.shtml?uuid=AEkVaiKH

Anchoring: A New Security Paradigm

- Bitcoin blockchain network security is preserved by a computation power unparalleled in human history
- Other networks can tap into this security via anchoring (i.e. periodic time-stamping of their network status)
- Any “stateful system with global memory” can outsource its security to the bitcoin network, piggybacking its resilience
- Bitcoin seigniorage revenues might provide security for all transactional networks
- Bitcoin mining as global outsourced decentralized security

Digital Gold Jewelry

What jewelry is for gold,
notarization could be for bitcoin:

not essential

but effective at leveraging its beauty

Bibliography

- Satoshi Nakamoto, Bitcoin: A Peer-to-Peer Electronic Cash System (2008) https://bitcoin.org/bitcoin.pdf
- OpenTimestamps protocol https://opentimestamps.org/
- Bitcoin & Blockchain Technology, Milano-Bicocca University, Spring 2019 https://www.ametrano.net/bbt/
- Ferdinando Ametrano, Bitcoin, Blockchain and Distributed Ledger Technology: Hype or Reality? (2017) https://ssrn.com/abstract=2832249
- Ferdinando Ametrano, "Bitcoin: oro digitale, finanza e tulipani" (2018), https://goo.gl/eyjDJ2
- Intervista ("Le Iene", Mediaset), http://bit.ly/2H2qwqf
- Bitcoin, YouTube videos, https://goo.gl/byVNqP
- Ferdinando Ametrano, Bitcoin as Digital Gold (2018), United Nations Department of Economic and Social Affairs; video: https://goo.gl/NkEC9w; slides: https://goo.gl/szzBXh
- Ferdinando Ametrano, Blockchain Needs A Native Digital Asset, https://www.finextra.com/videoarticle/1241/blockchain-needs-a-native-digital-asset

Takeaways

- Blockchain timestamping is the decentralized digital alternative to traditional certification authorities
- Its OpenTimestamps standardization is trust-minimizing, scalable, convenient and free
- Timestamping is not magic: it provides proof of existence at a given date, it does not convey authorship, non-repudiation, veracity, guaranteed origin, etc.
- Most of the time, timestamping only makes sense if coupled with digital signature or alternative authorship proofs
- Centralized timestamping on private permissioned blockchain is no different from traditional Certification Authority
- For a decentralized timestamp to be reliable, it must use bitcoin
- Timestamping, notarization, and anchoring are digital gold jewelry

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