Sustainable Blockchains

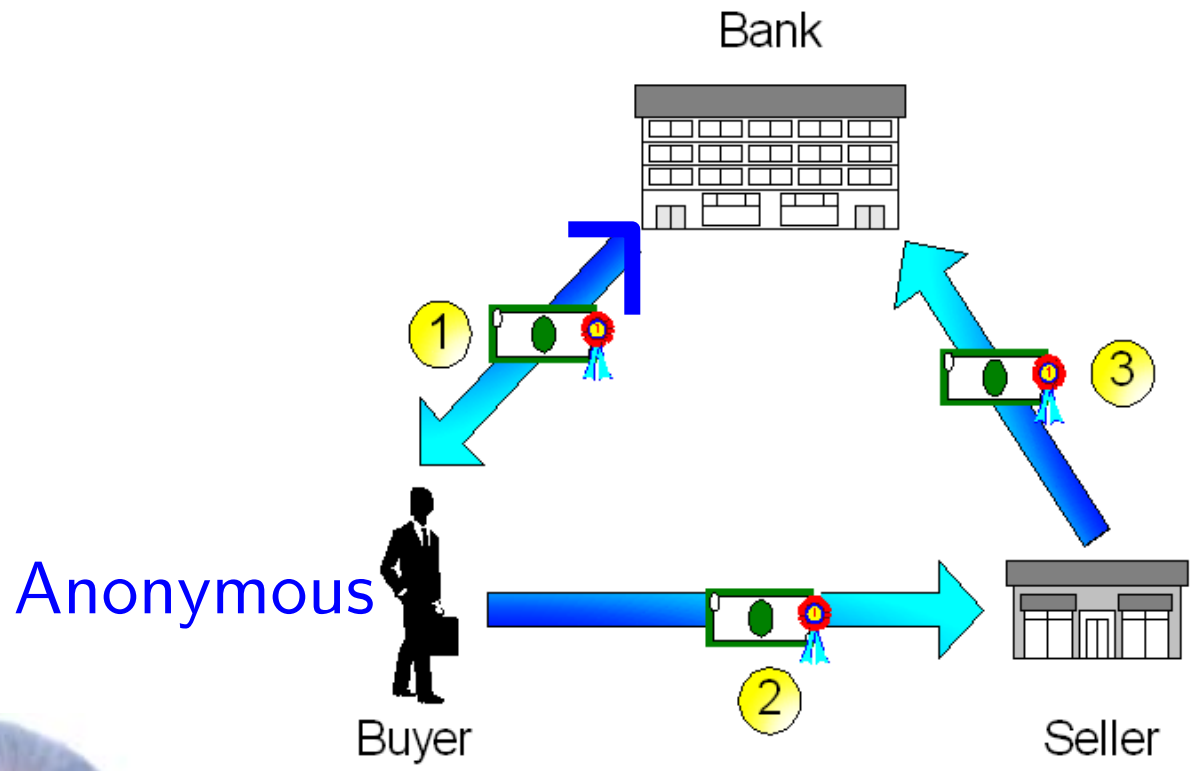
Krzysztof Pietrzak

Institute of Science and Technology Austria

Public Lecture Series "Sustainability in Computer Science"

Nov. 25 2024

(Centralized) Anonymous E-Cash, 80-90's



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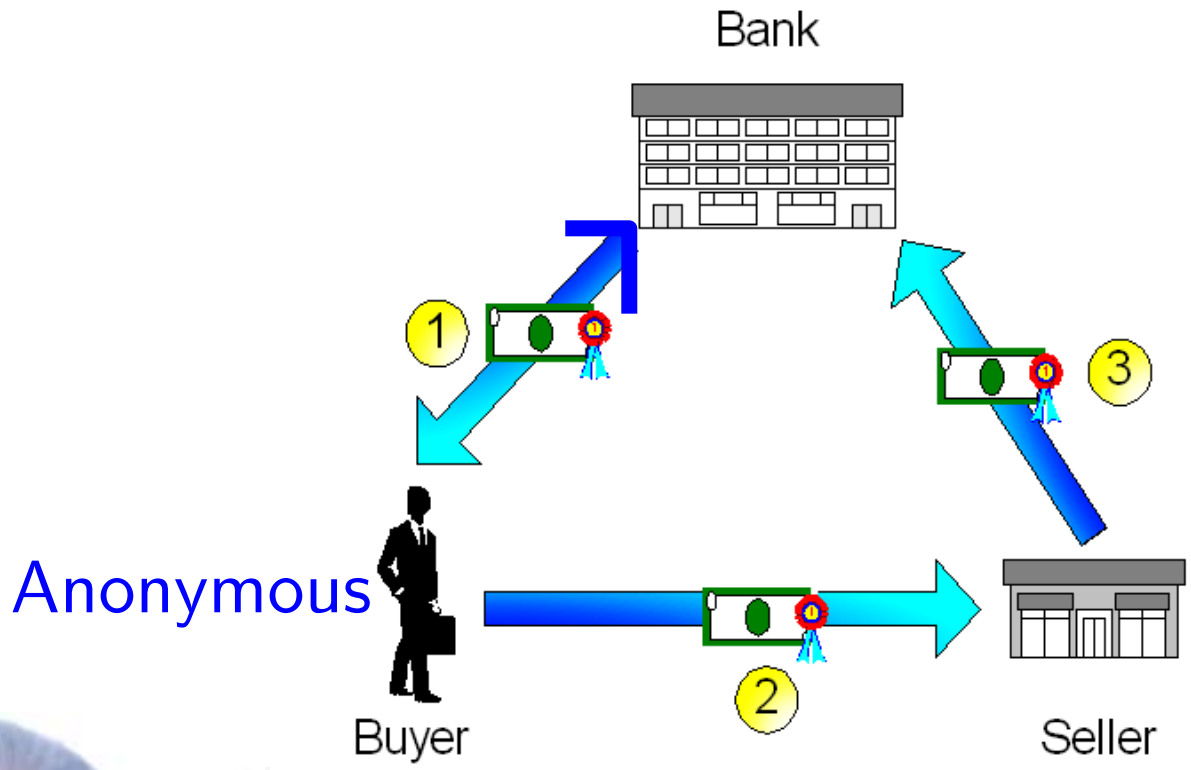

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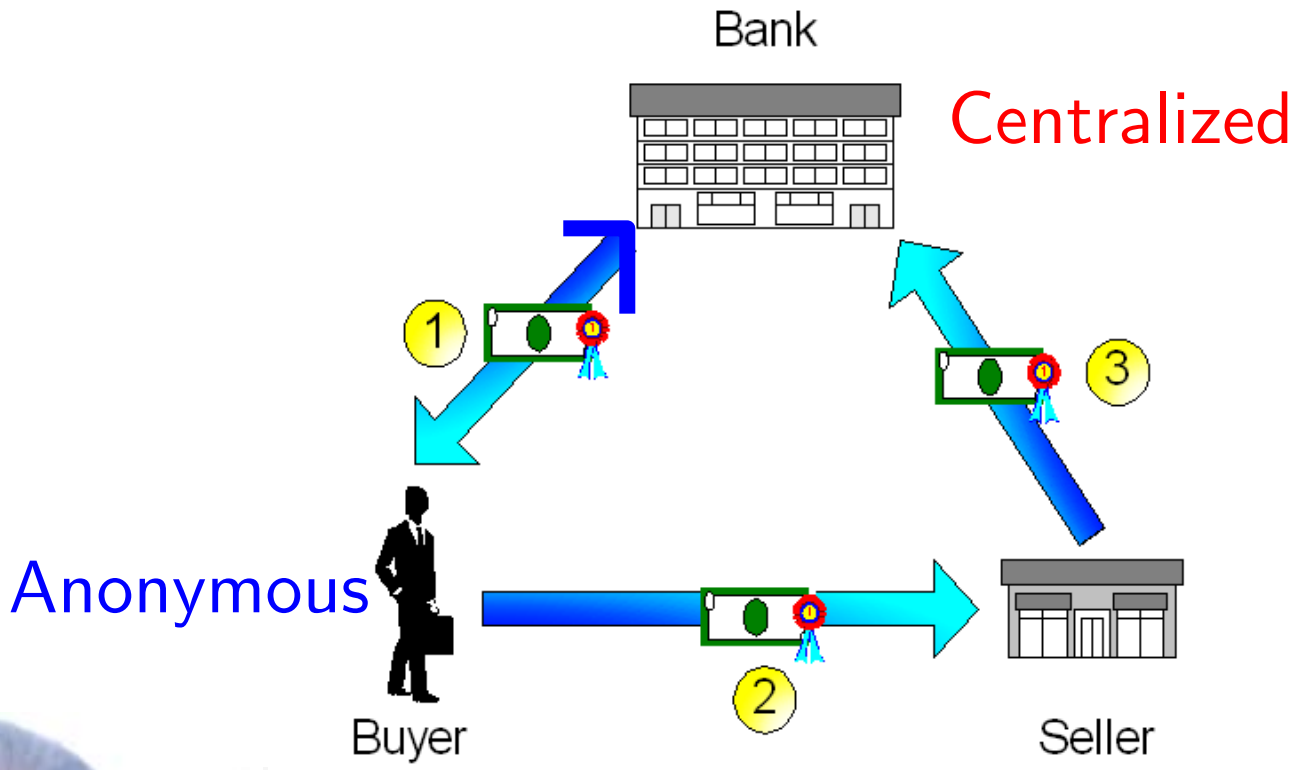
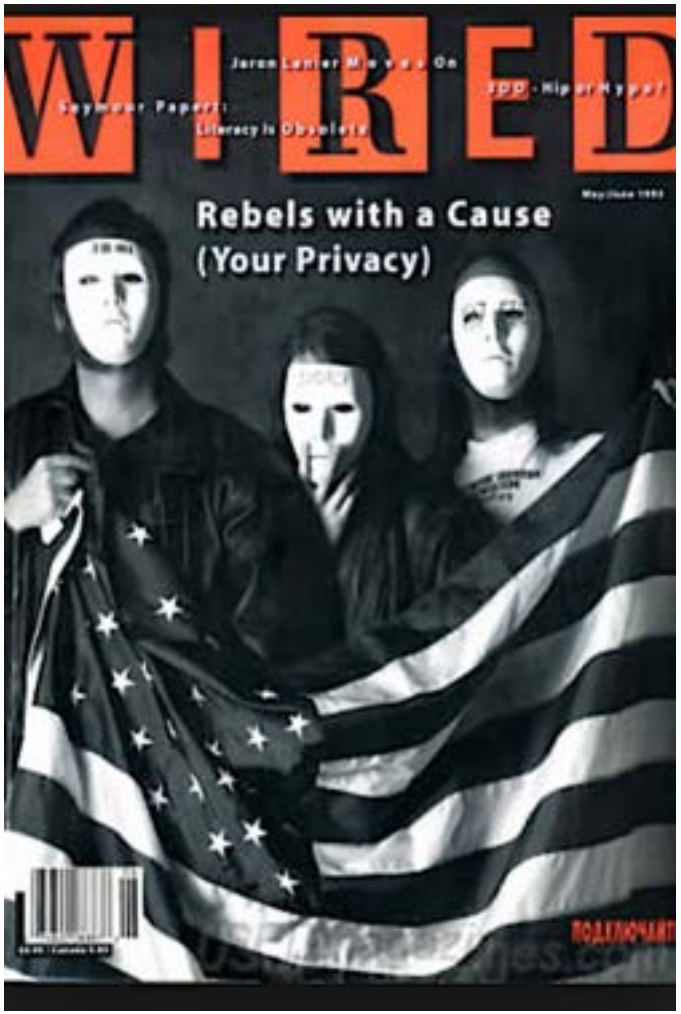
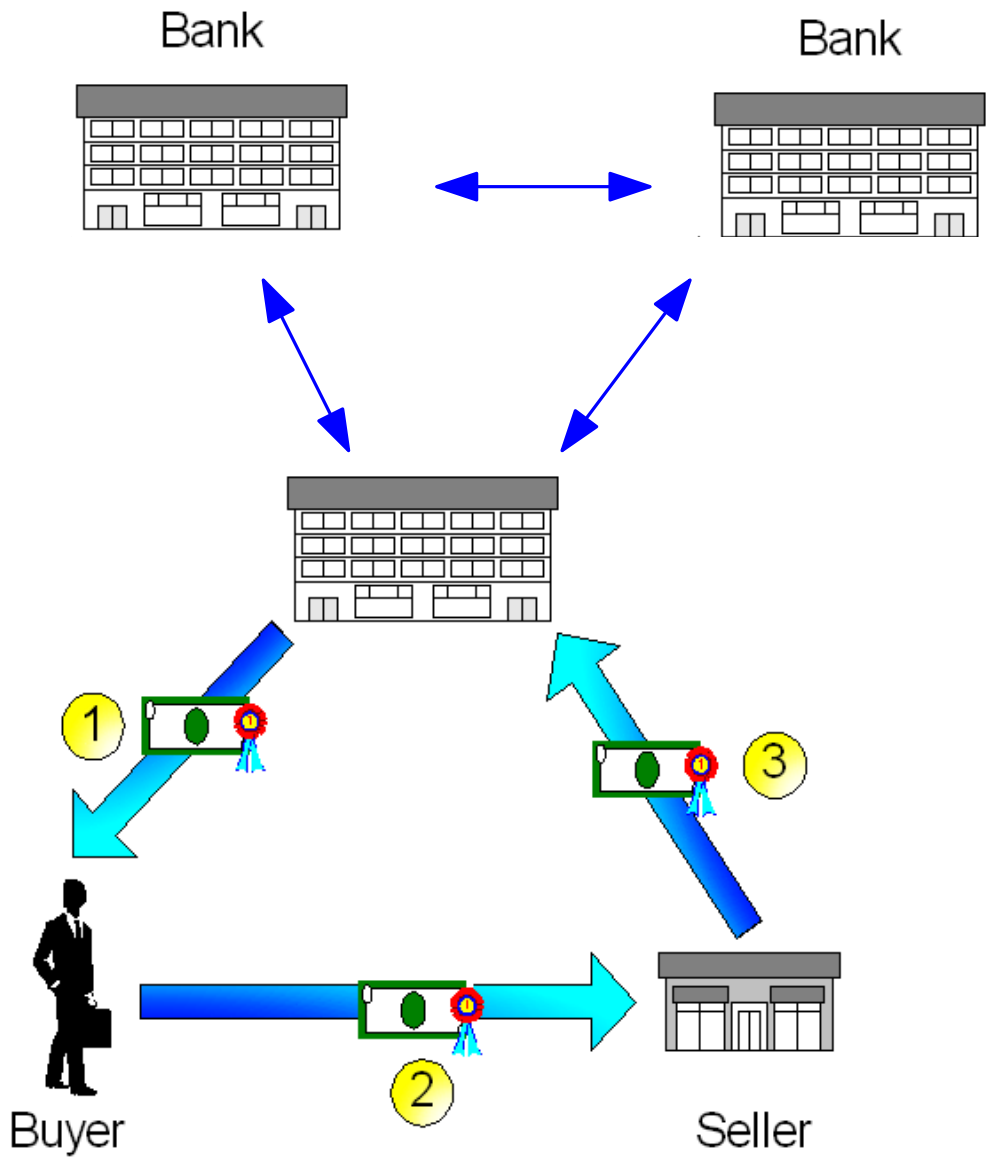


https://en.wikipedia.org/wiki/Cypherpunk

A **cypherpunk** is any activist advocating widespread use of strong cryptography and privacy-enhancing technologies as a route to social and political change.



Decentralization using 80s Crypto



Permissonless E-Cash / Nov. 2008

Bitcoin: A Peer-to-Peer Electronic Cash System

Satoshi Nakamoto
satoshin@gmx.com
www.bitcoin.org

Abstract. A purely peer-to-peer version of electronic cash would allow online payments to be sent directly from one party to another without going through a financial institution. Digital signatures provide part of the solution, but the main benefits are lost if a trusted third party is still required to prevent double-spending. We propose a solution to the double-spending problem using a peer-to-peer network. The network timestamps transactions by hashing them into an ongoing chain of hash-based proof-of-work, forming a record that cannot be changed without redoing the proof-of-work. The longest chain not only serves as proof of the sequence of events witnessed, but proof that it came from the largest pool of CPU power. As long as a majority of CPU power is controlled by nodes that are not cooperating to attack the network, they'll generate the longest chain and outpace attackers. The network itself requires minimal structure. Messages are broadcast on a best effort basis, and nodes can leave and rejoin the network at will, accepting the longest proof-of-work chain as proof of what happened while they were gone.

Bitcoin Consensus

Consensus in a permissionless setting is impossible

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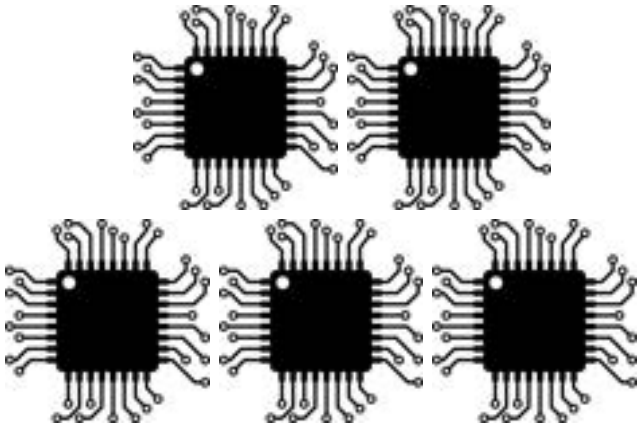
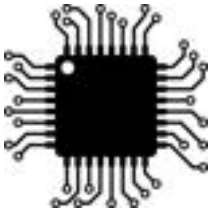
Consensus in a permissionless setting is impossible

Bitcoin Consensus

Nakamoto Consensus

Assumption: Majority of computing power controlled by honest parties





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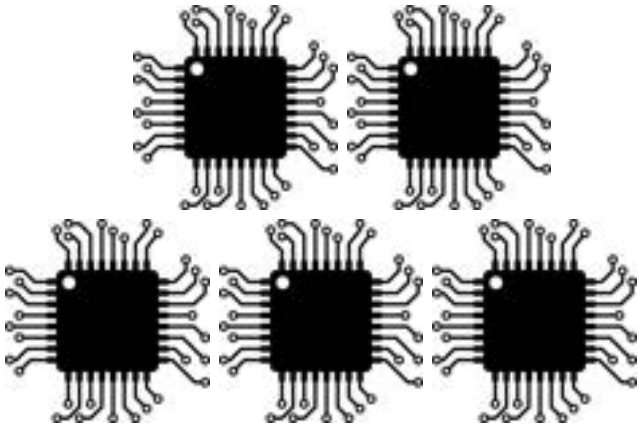
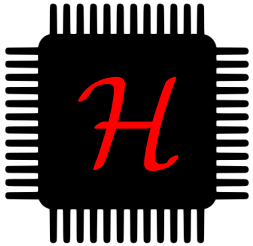


Proofs of Work [DworkNaor92]

How can  prove that it evaluated $\mathcal{H}$ 10^9 times?



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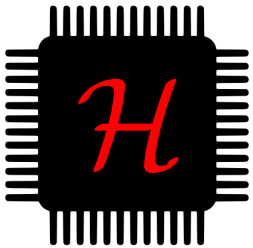
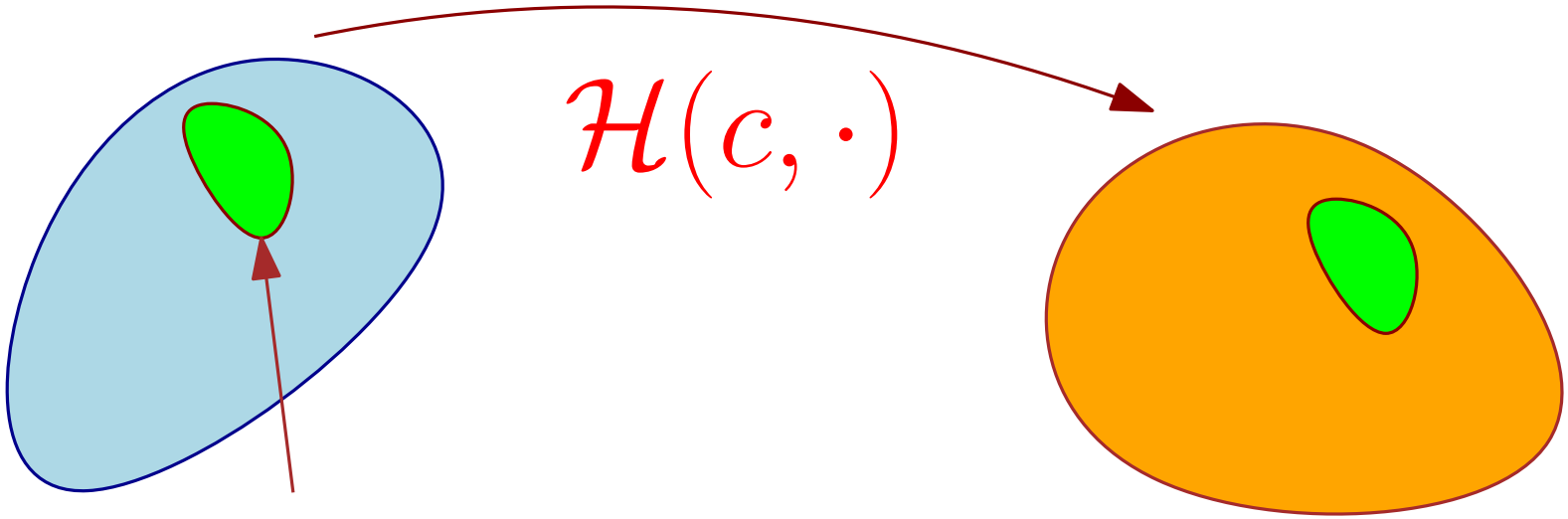


$$\mathcal{H}(1)$$
$$\mathcal{H}(2)$$
$$\mathcal{H}(3)$$
$$\vdots$$
$$\mathcal{H}(1000000000)$$

Proofs of Work [DworkNaor92]

How can  prove that it evaluated $\mathcal{H}$ 10^9 times?

c



$$\{X \ : \ \mathcal{H}(c, X) = 000000000\ldots\}$$

Proofs of Work [DworkNaor92]

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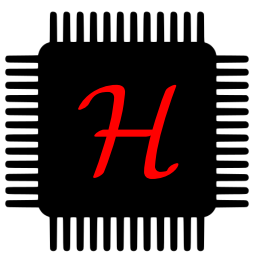

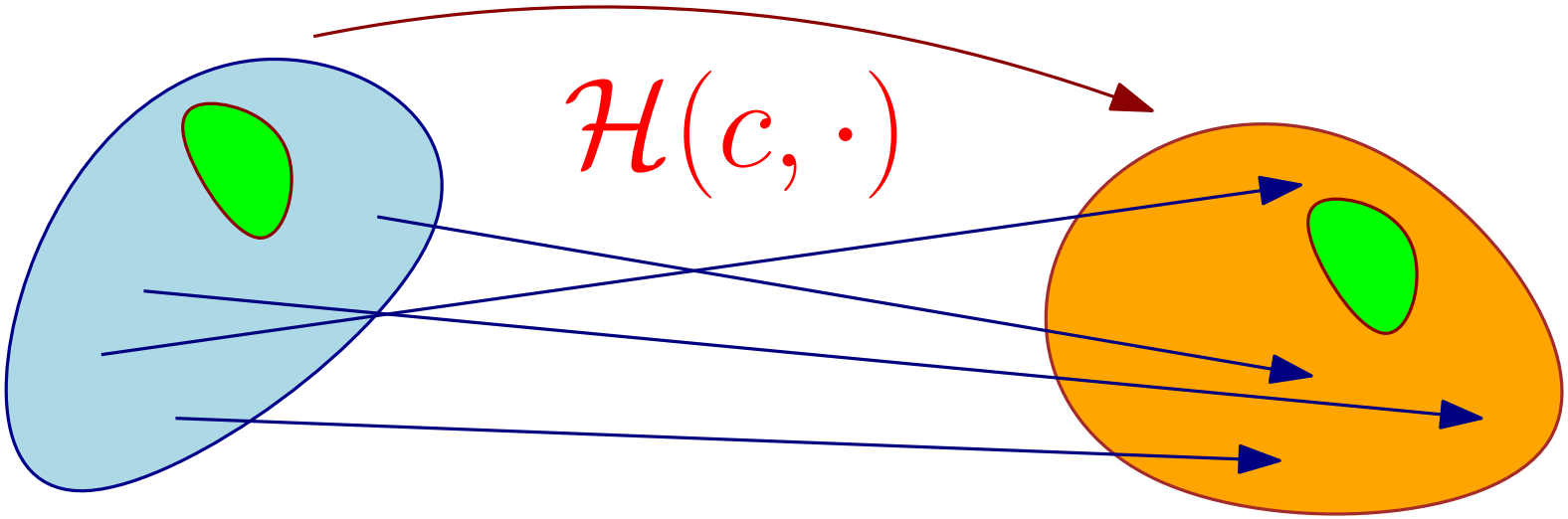

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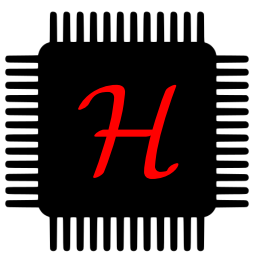
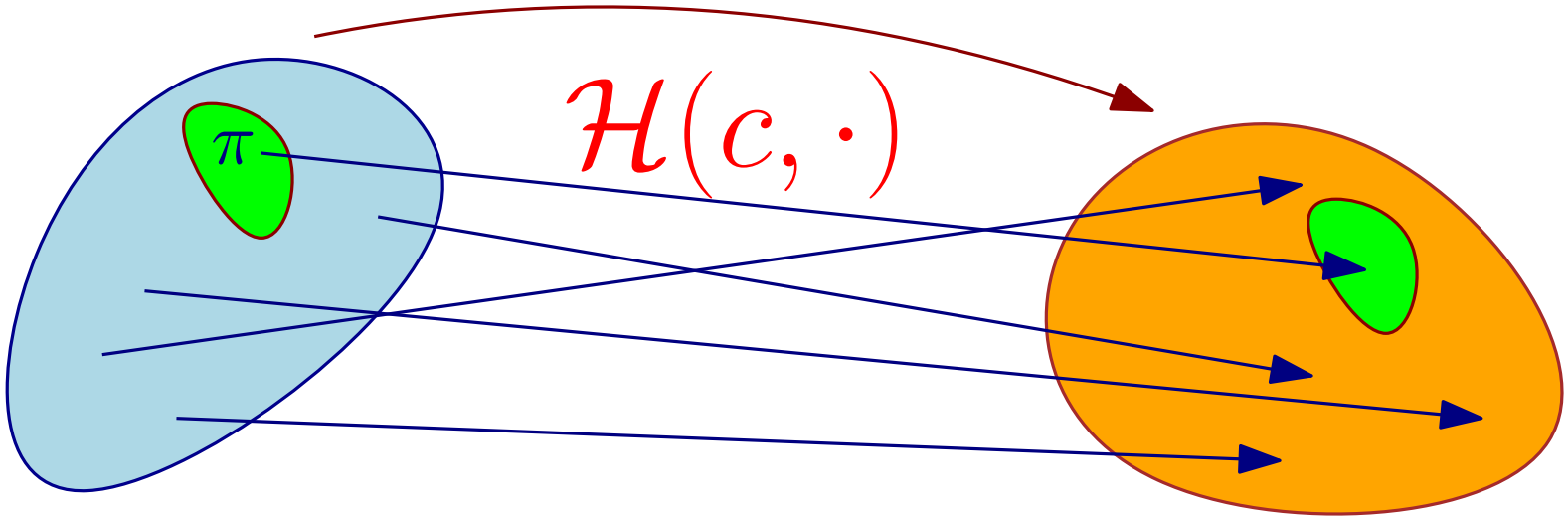


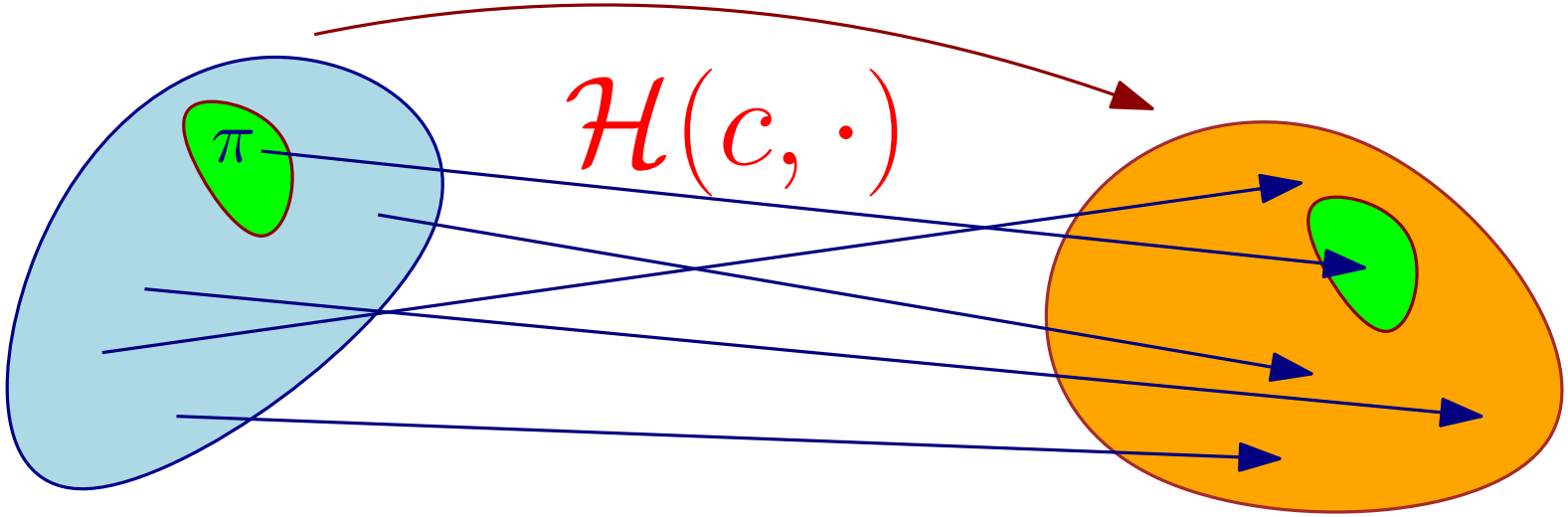


Proofs of Work [DworkNaor92]

How can  prove that it evaluated $\mathcal{H}$ 10^9 times?

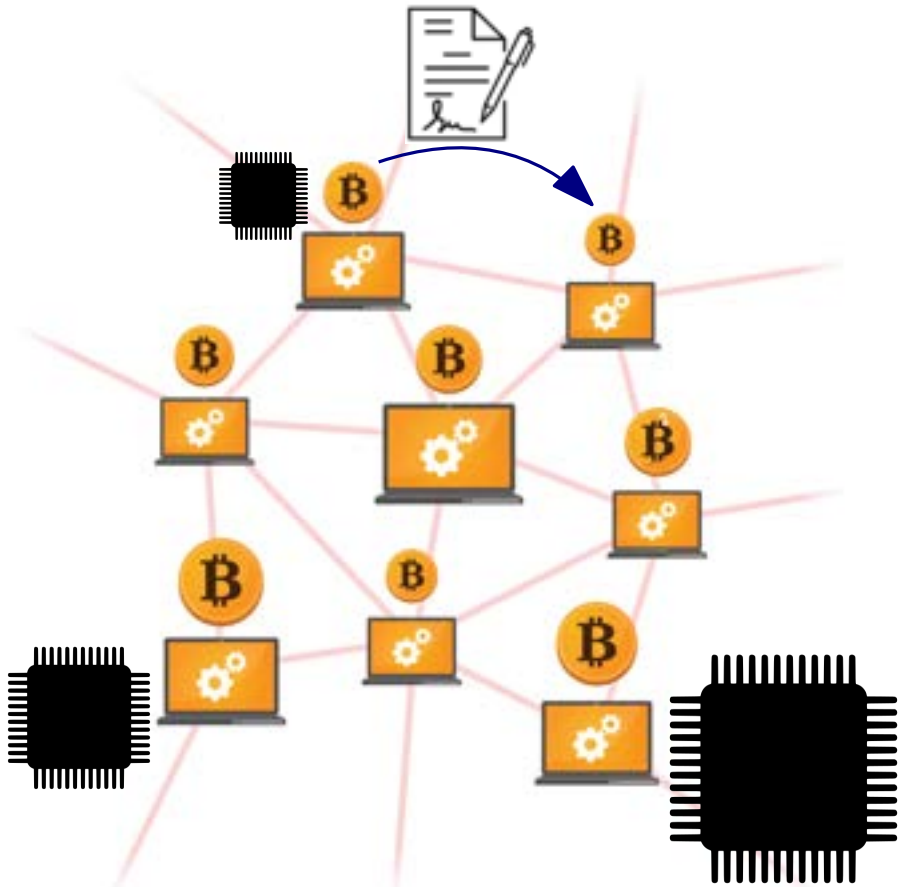
$\xrightarrow{\pi}$

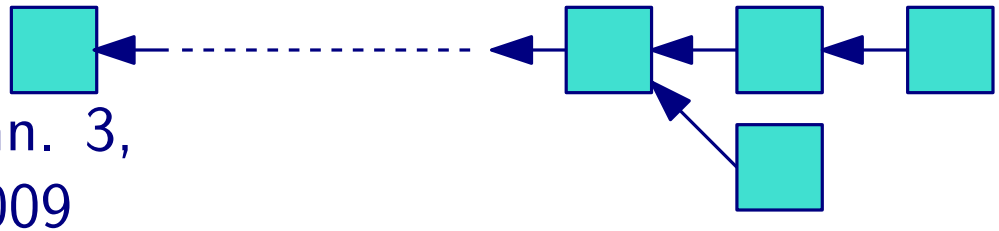
$$\mathcal{H}(c, \pi) \stackrel{?}{=} 000000000 \star\star\star\star$$



10^9 required in expectation to find a proof π

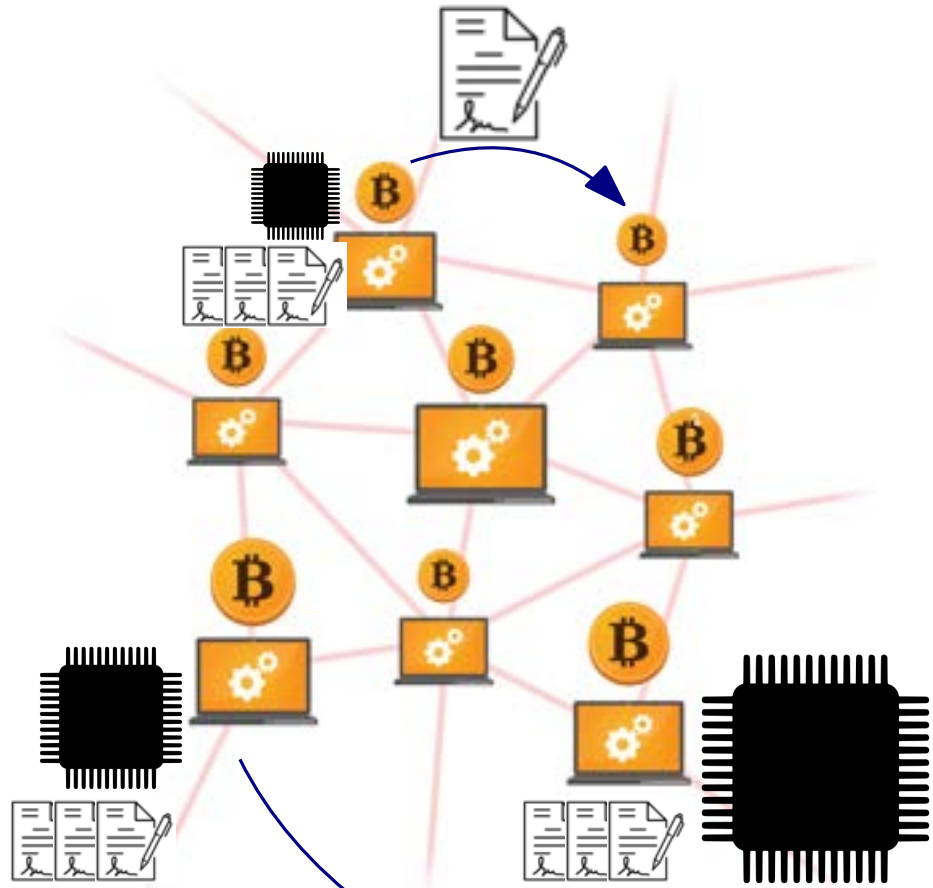
Proofs of Work in Bitcoin

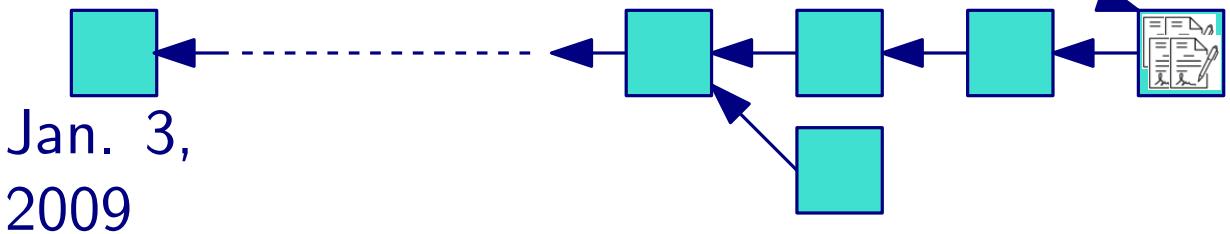




Jan. 3, 2009

Proofs of Work in Bitcoin





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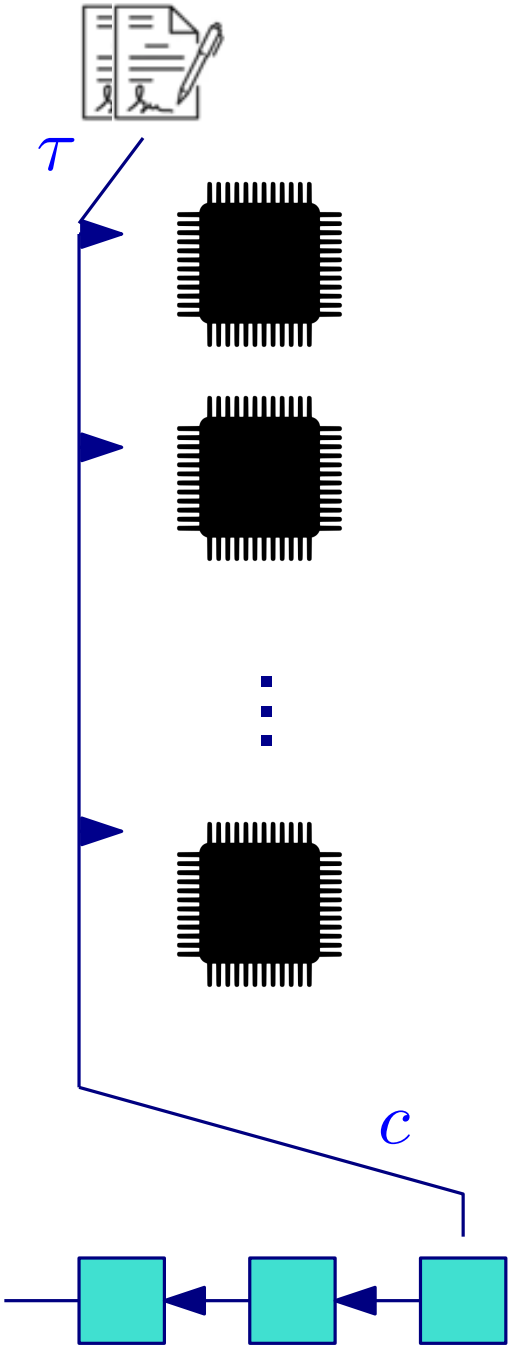

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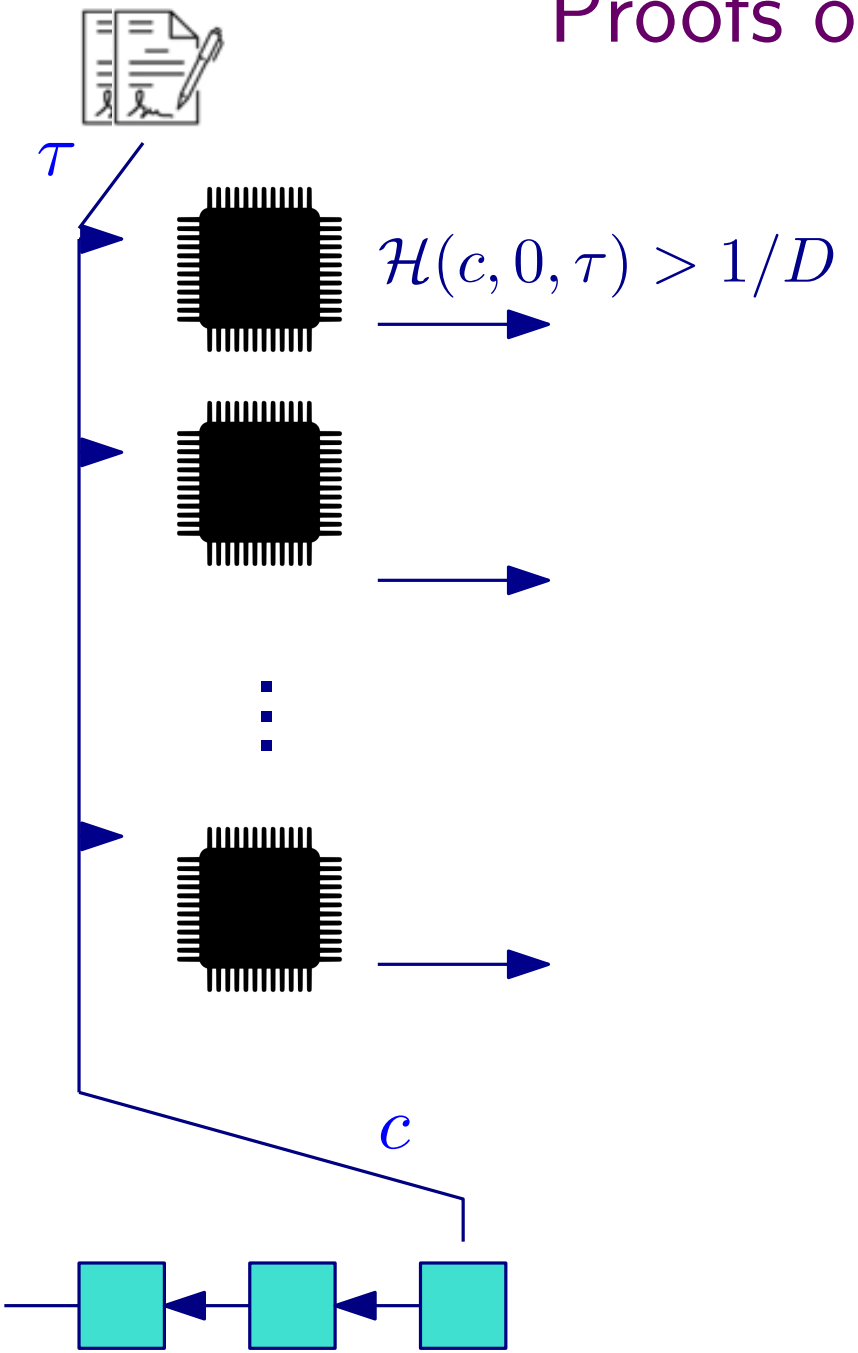

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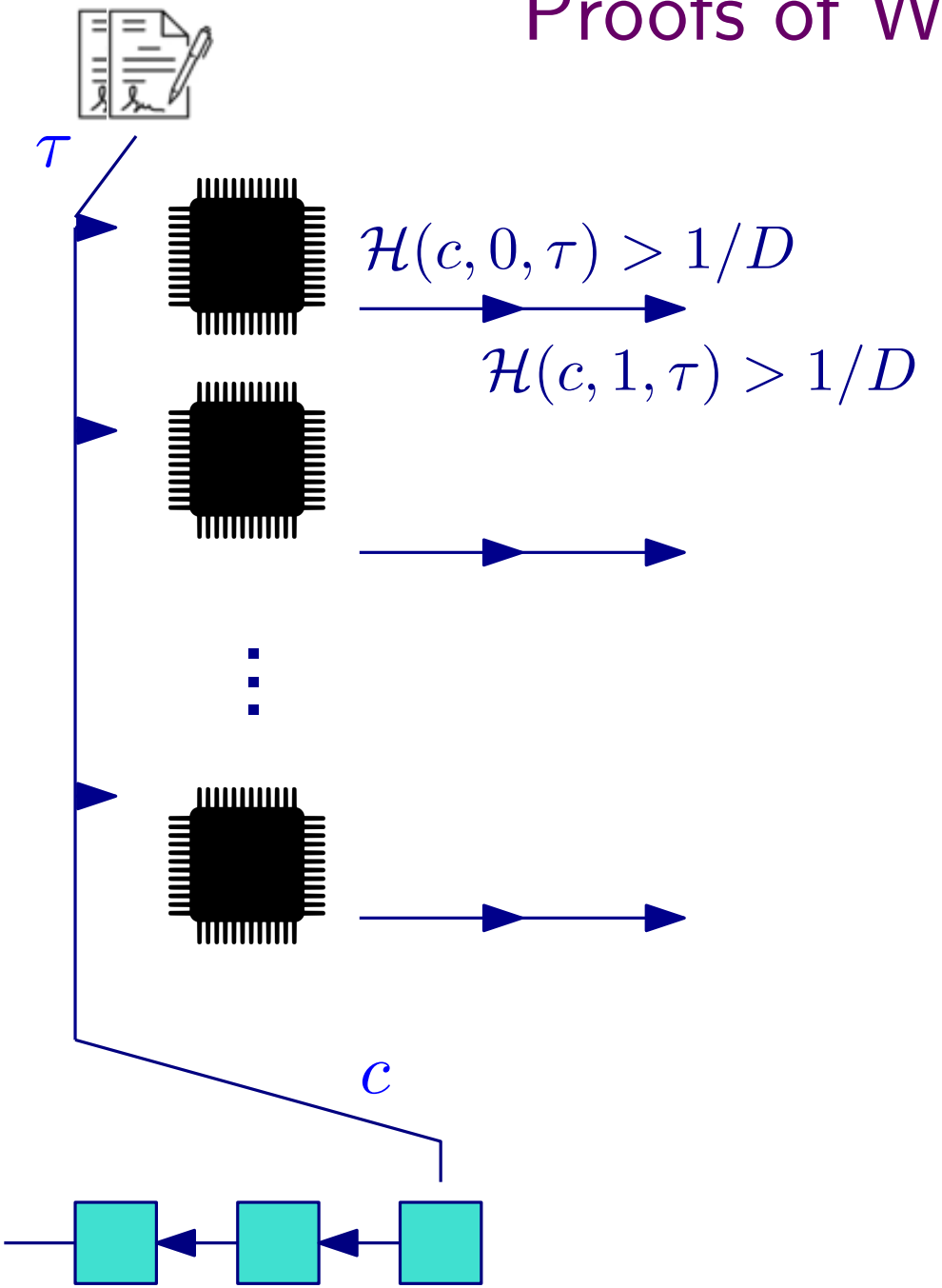

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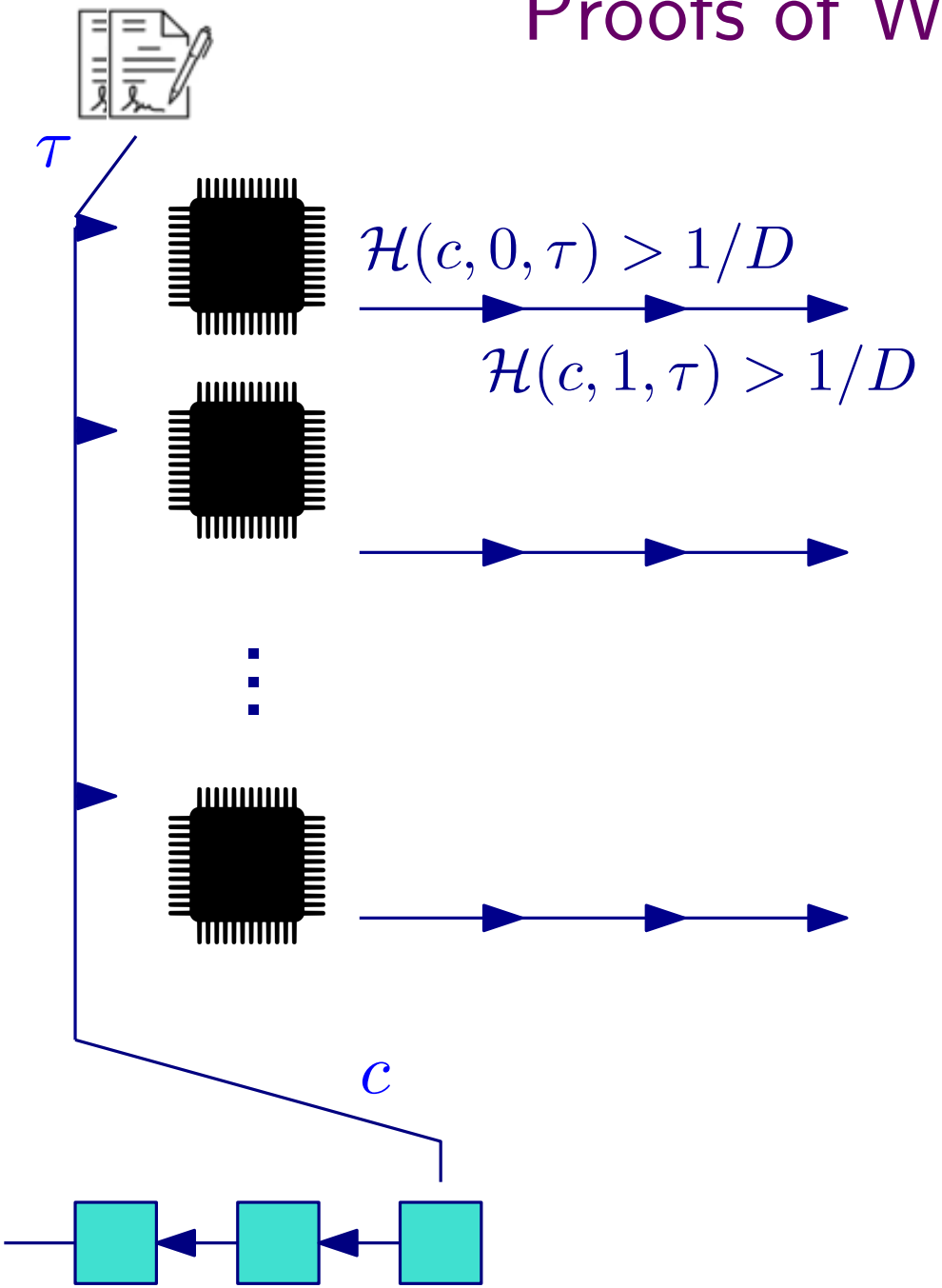

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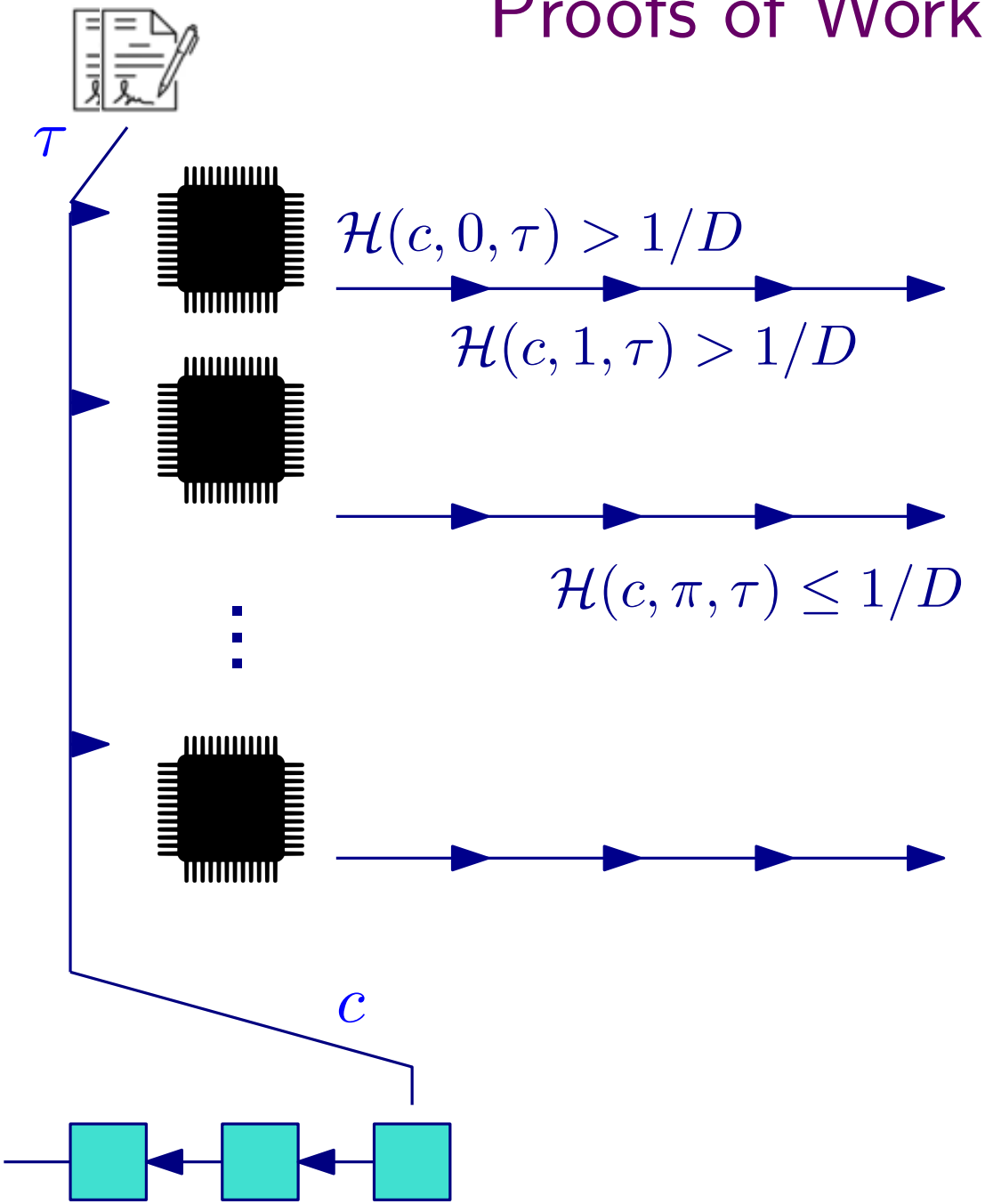

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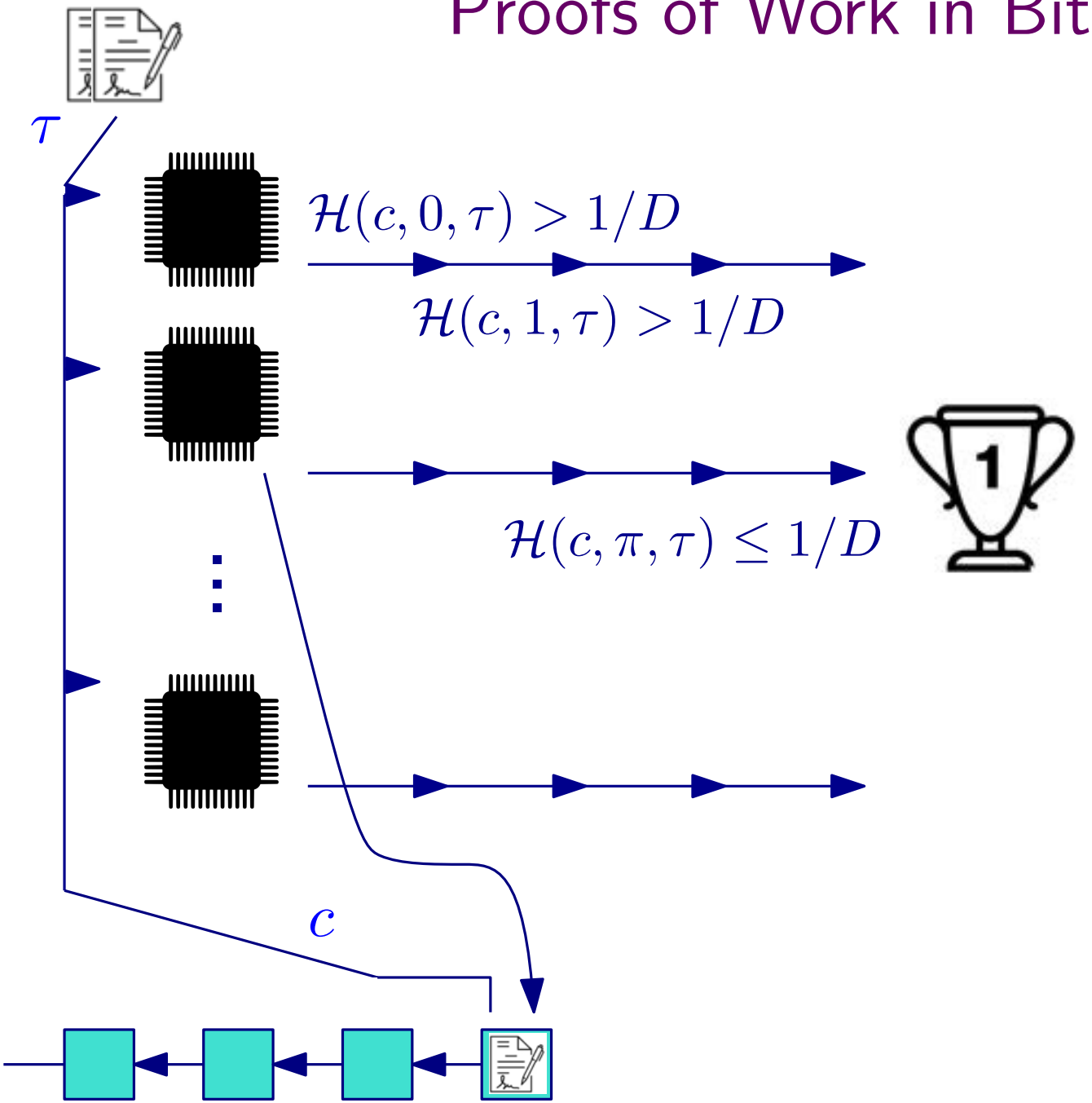
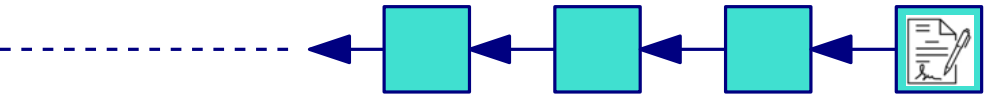


Security of Bitcoin



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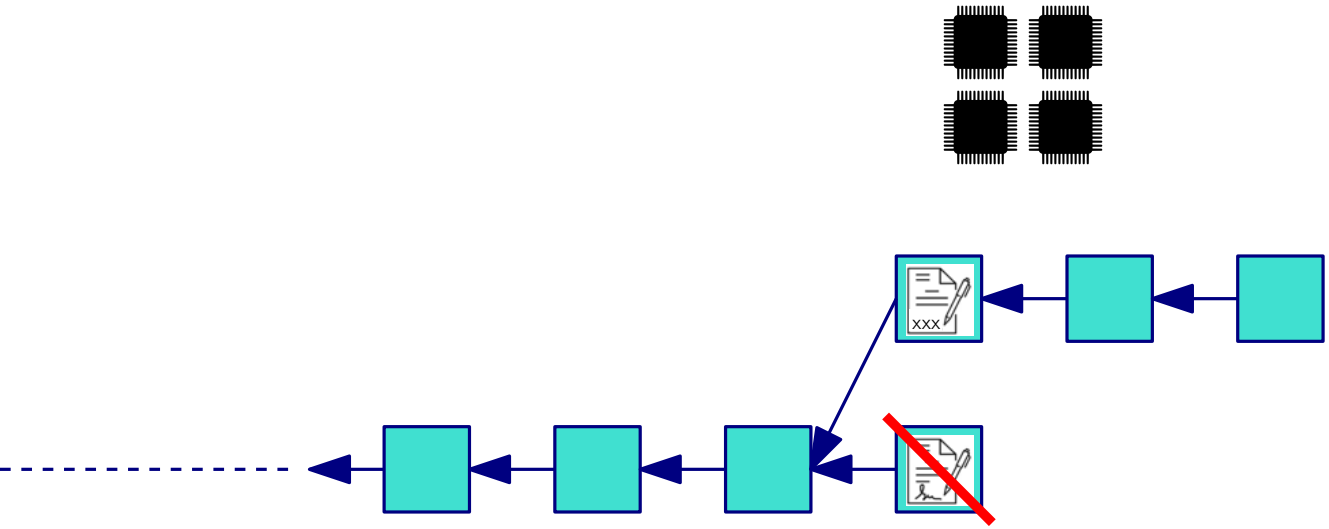

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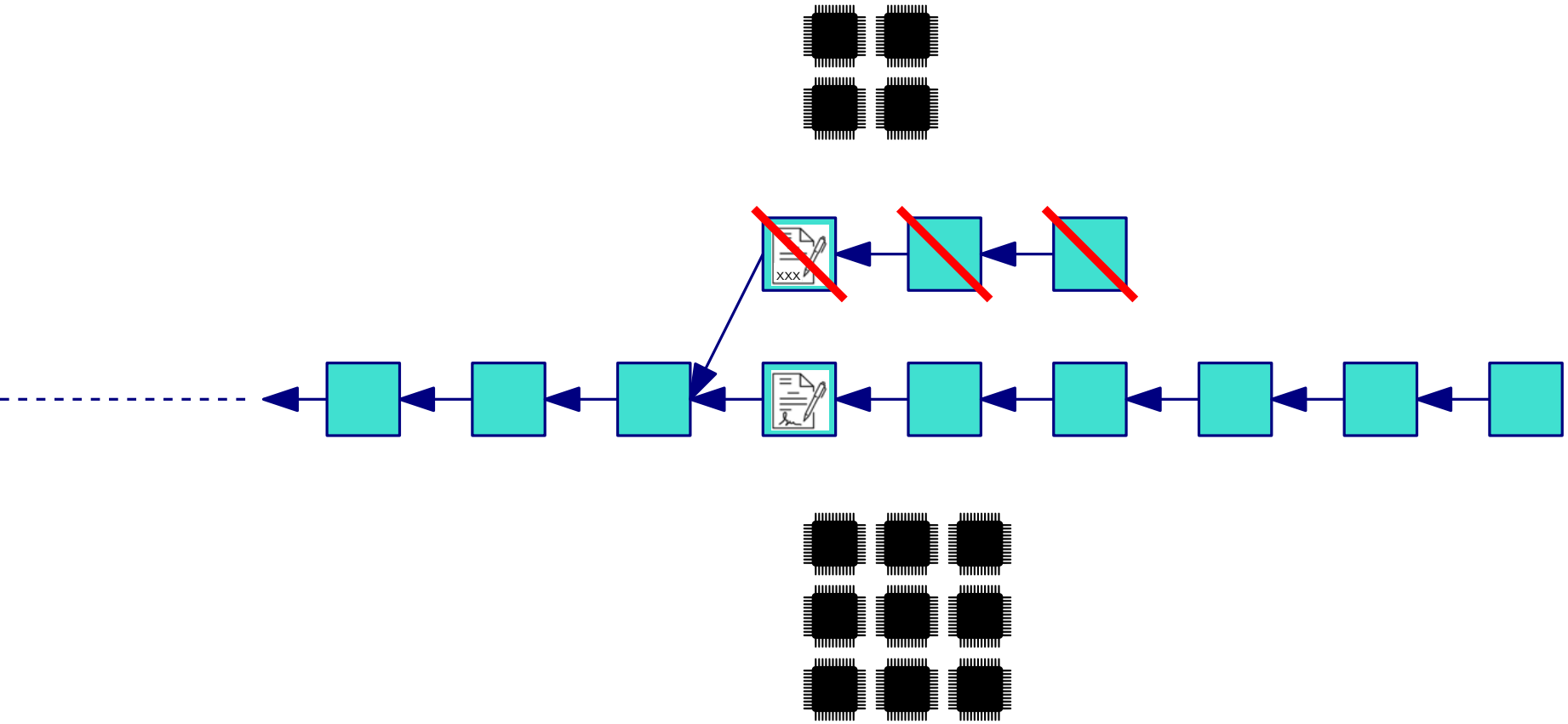
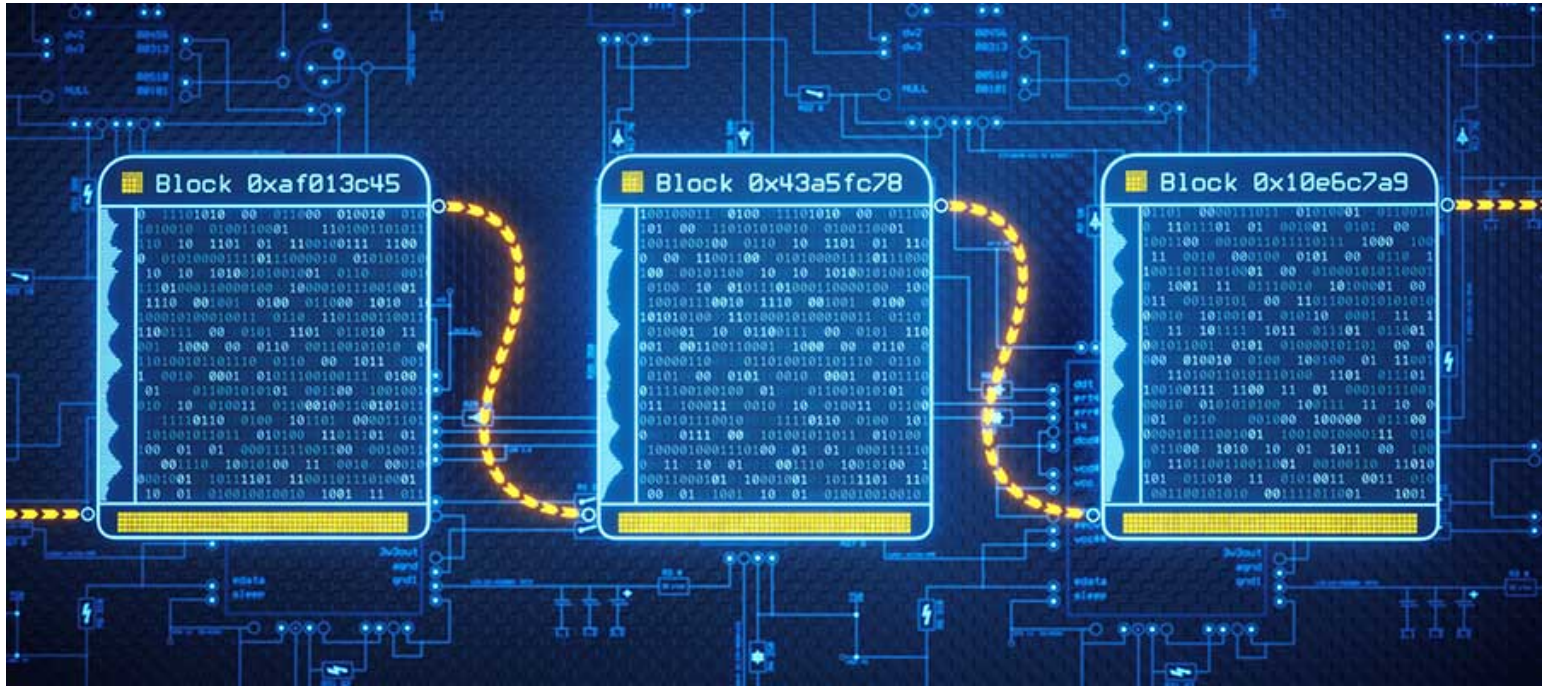


Consensus and Application Layer



Sustainability of Blockchains

Ecological footprint from PoW mining

Sustainability of Blockchains

Ecological footprint from PoW mining

Scalability

Sustainability of Blockchains

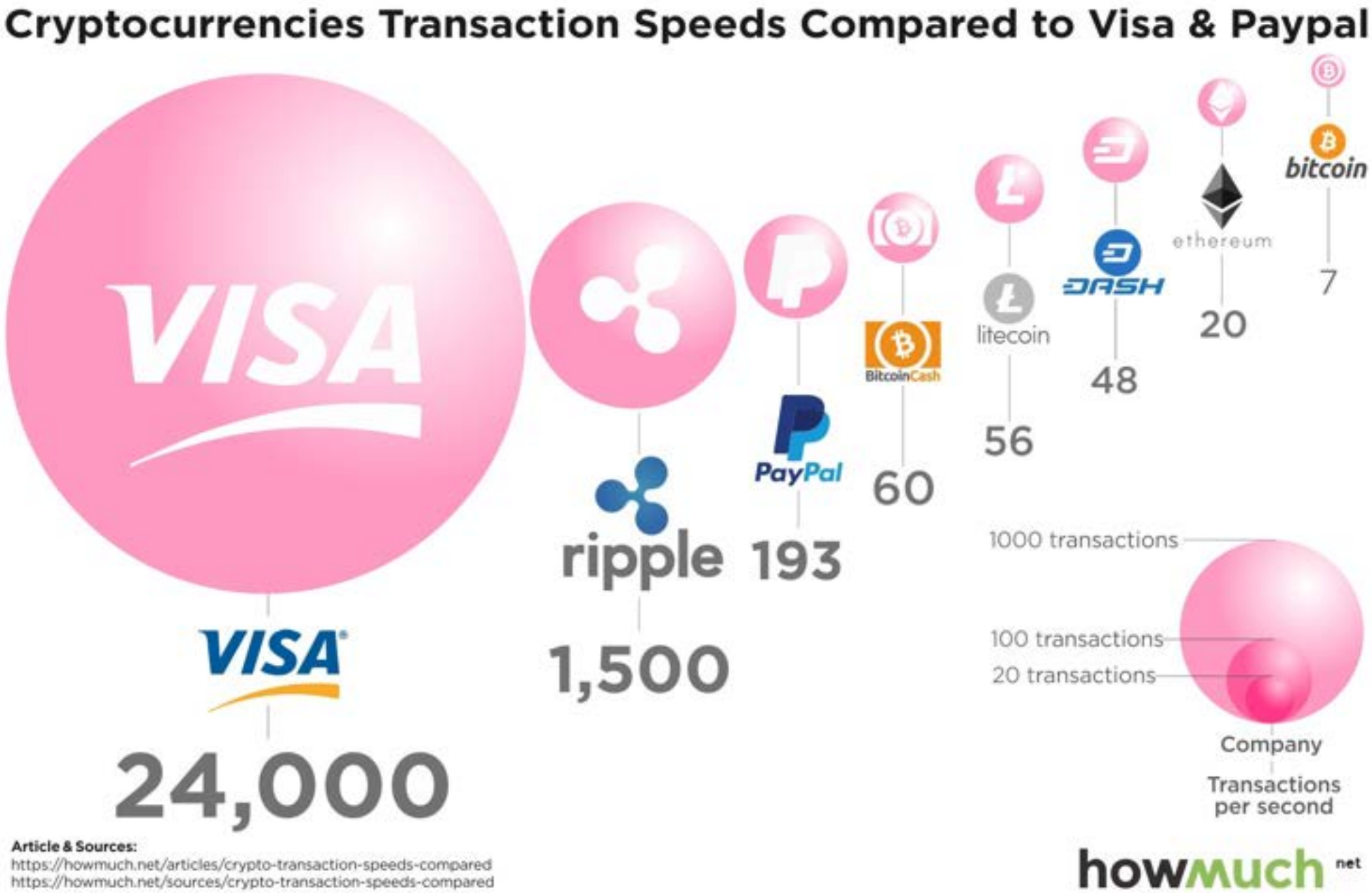
Ecological footprint from PoW mining

Scalability

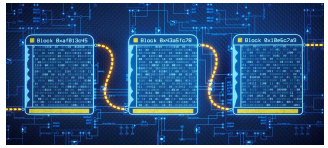
Blockchains **for** sustainability

Scalability

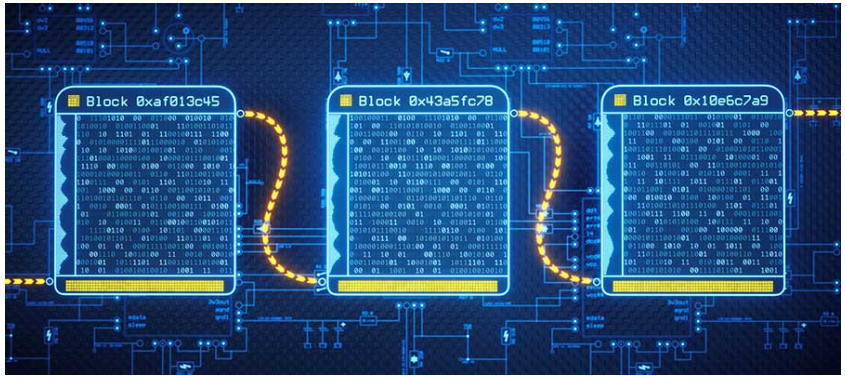
Transactions per second



Scaling Blockchains



Increase block size and/or rate



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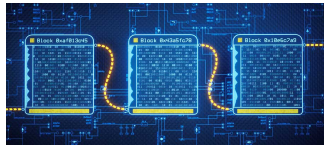

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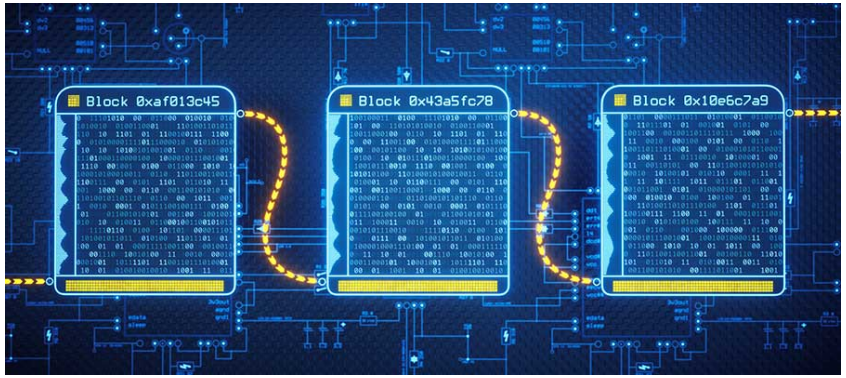
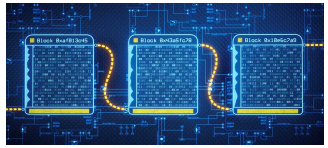


Space-efficient blockchains

Georg Fuchsbauer Jan 27, 2025

Scaling Blockchains



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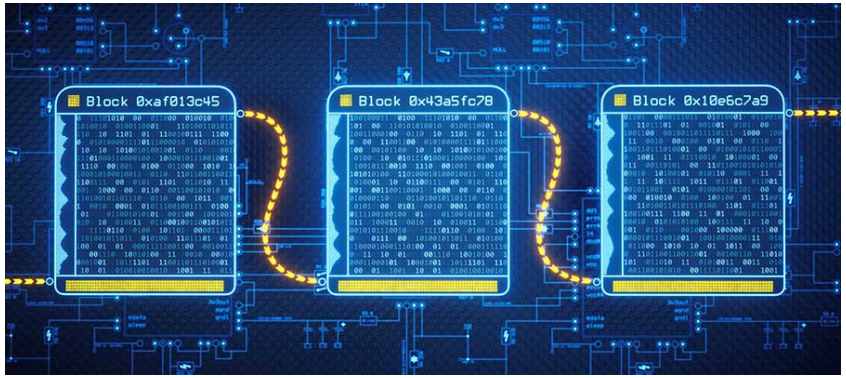
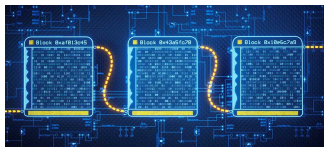
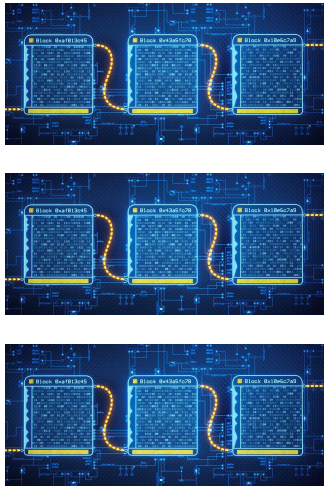


Space-efficient blockchains

Georg Fuchsbauer Jan 27, 2025

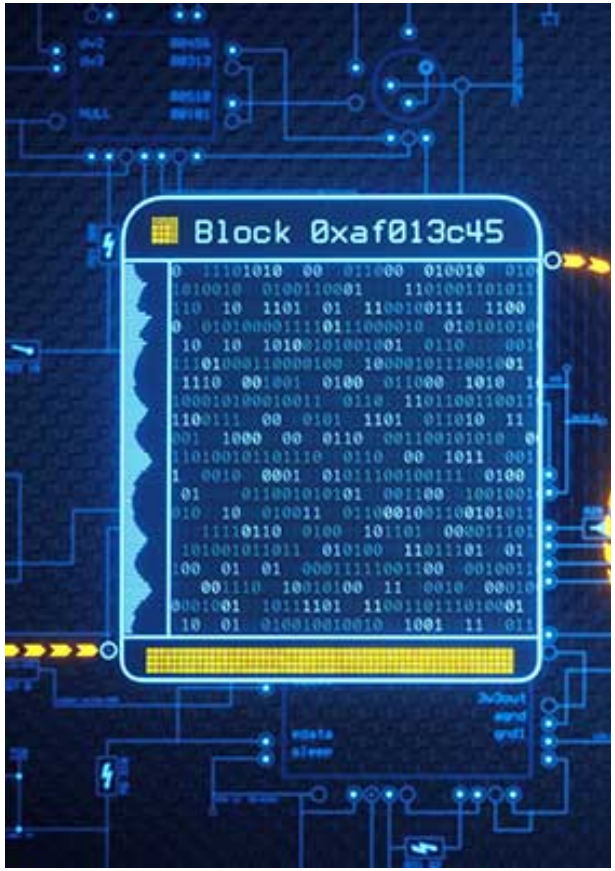


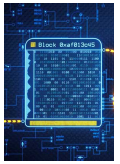
Sharding



Scaling Blockchains

Layer 2 Solution: Rollups





crypto magic
ZK-SNARKs[a]

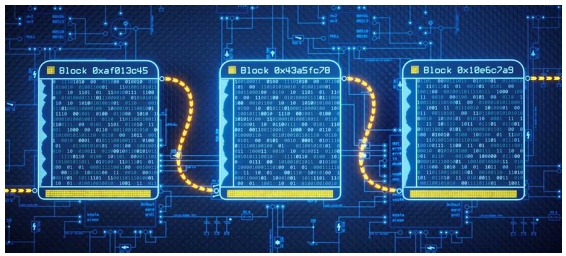
[a] Zero-Knowledge Succinct Non-Interactive Argument of Knowledge

Scaling Blockchains

Layer 2 solution: Payment Networks

Payment network, e.g. Lightning

bitcoin
LIGHTNING ACCEPTED HERE

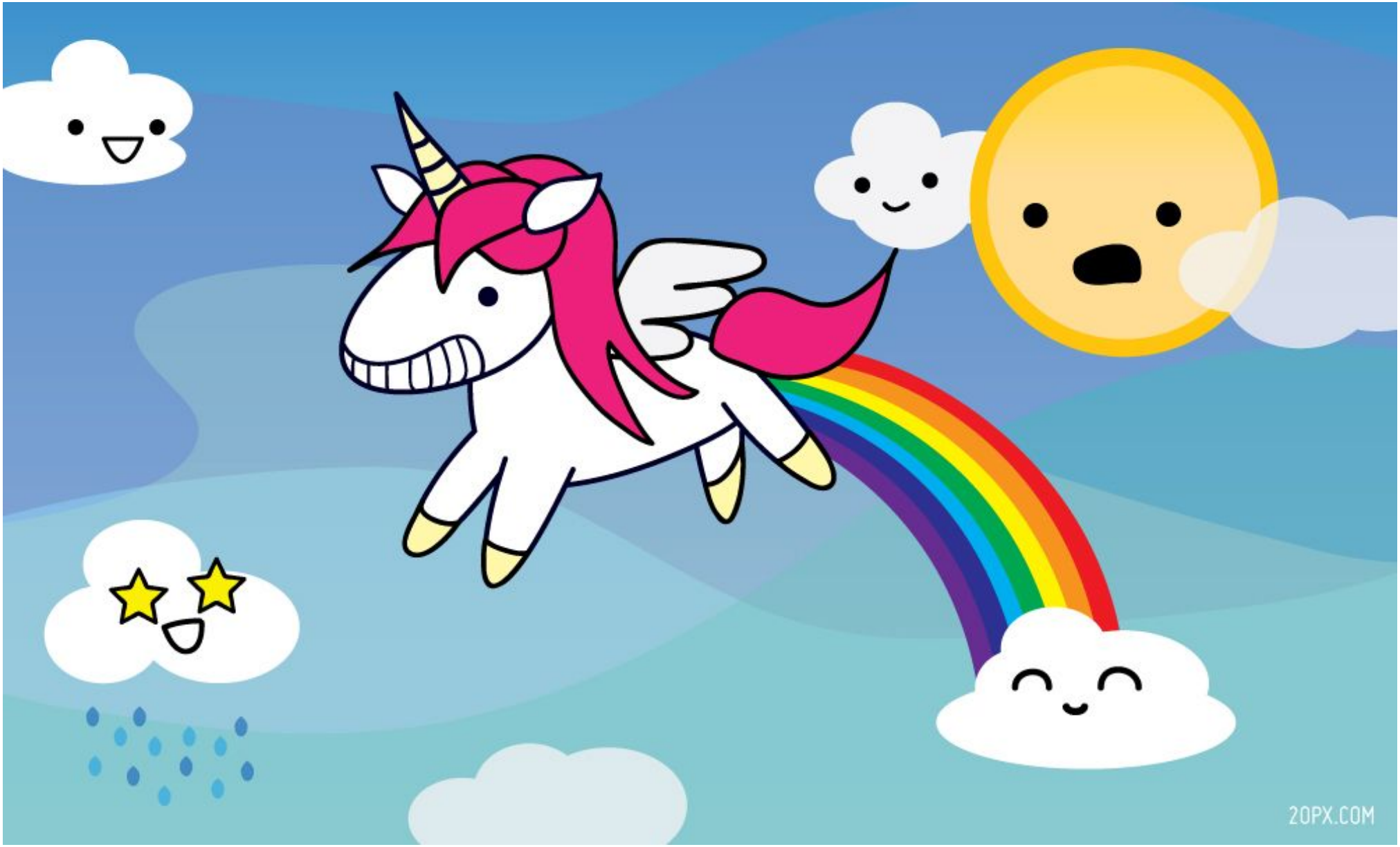


Layer 1: Blockchain, e.g. Bitcoin

Ecological Footprint of PoW Mining

Bitcoin Mining

Nakamoto's vision: spare CPU cycles used for mining



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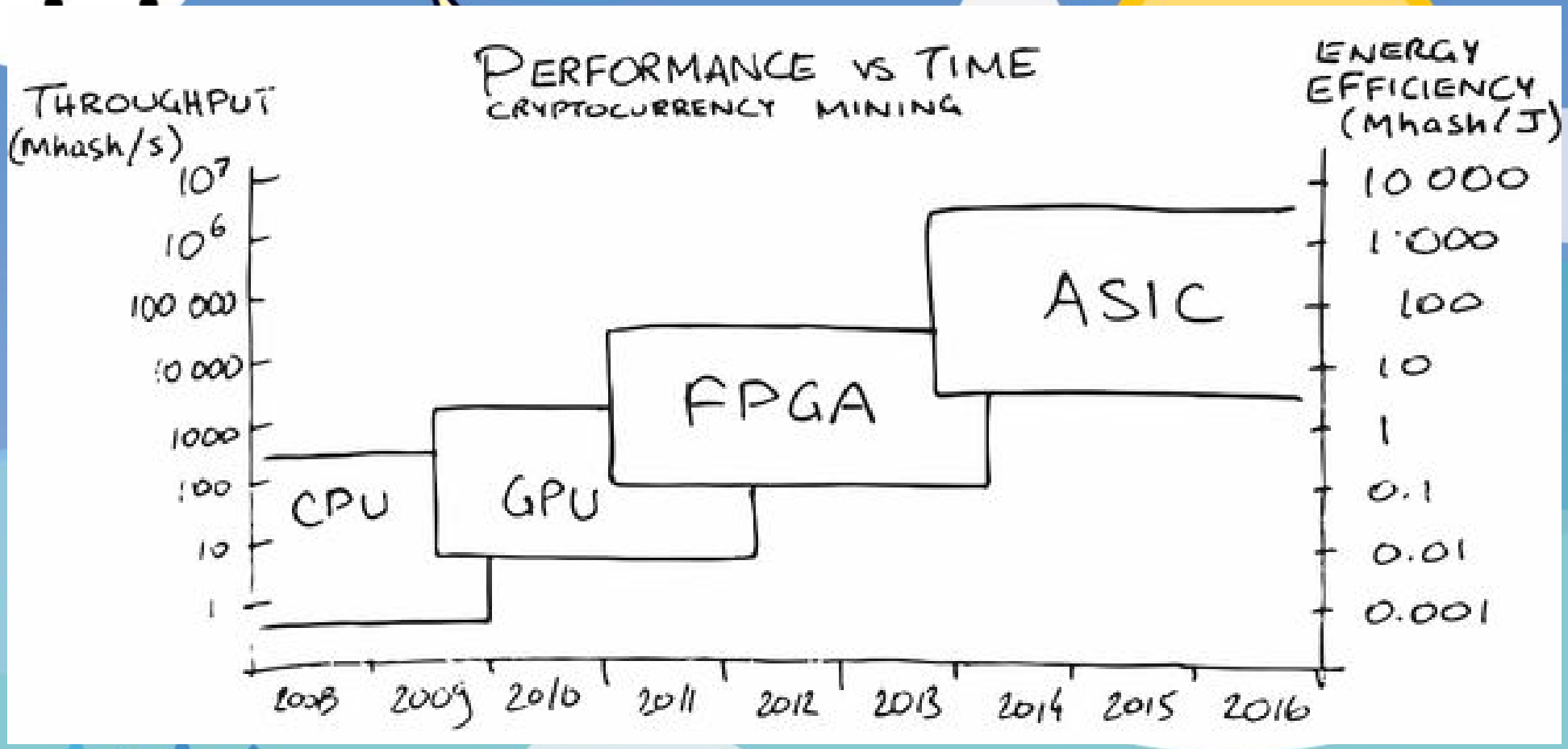


Bitcoin Mining

Bitcoin Sustainability

https://digiconomist.net/bitcoin-energy-consumption

Single Bitcoin Transaction Footprints

Carbon Footprint

462.90 kgCO2

Equivalent to the carbon footprint of 1,025,937 VISA transactions or 77,149 hours of watching Youtube.

Electrical Energy

829.92 kWh

Equivalent to the power consumption of an average U.S. household over 28.45 days.

Electronic Waste

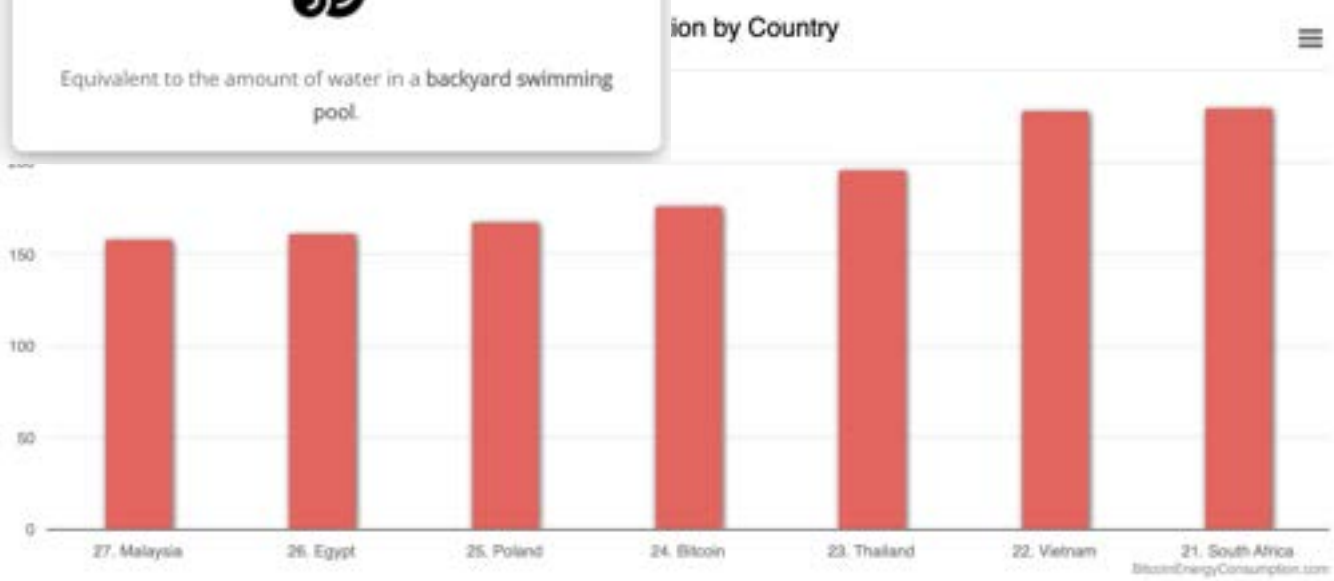
194.10 grams

Equivalent to the weight of 1.18 iPhones 12 or 0.40 iPads. (Find more info on e-waste here.)

Fresh Water Consumption

13,080 liters

Equivalent to the amount of water in a backyard swimming pool.



Can we have a more sustainable Blockchain?

Alternatives to Proof of Work Mining?

Proofs of (Useful) Work

(Bitcoin,old Ethereum, Primecoin. . .)

mining resource: work

Alternatives to Proof of Work Mining?

Proofs of (Useful) Work
(Bitcoin,old Ethereum, Primecoin. . .)
mining resource: work

Proofs of Stake
(Ethereum, Algorand,
Ourboros,. . .)
mining resource: (staked) coins

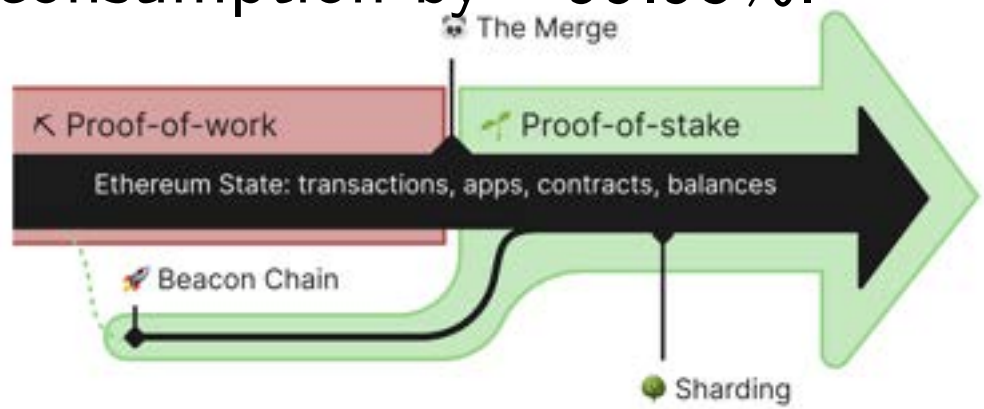
Alternatives to Proof of Work Mining?

Proofs of (Useful) Work

(Bitcoin,old Ethereum, Primecoin. . .)

mining resource: work

September 2022, "the Merge" reduced Ethereum's energy consumption by ≈99.95%.



Proofs of Stake

(Ethereum, Algorand, Ourboros,. . .)

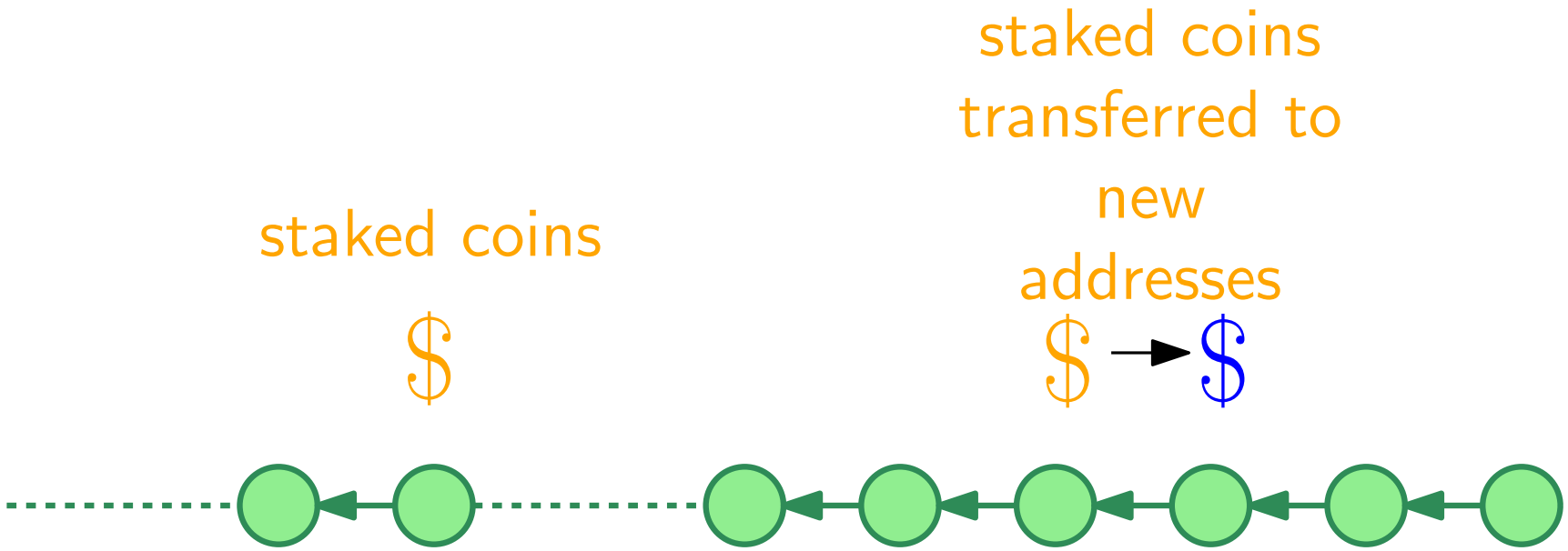
mining resource: (staked) coins

Proofs of Stake vs. Proofs of Work

- Is a PoStake based Blockchain still permissionless?
- How secure can a PoStake based Blockchain be?
- ...

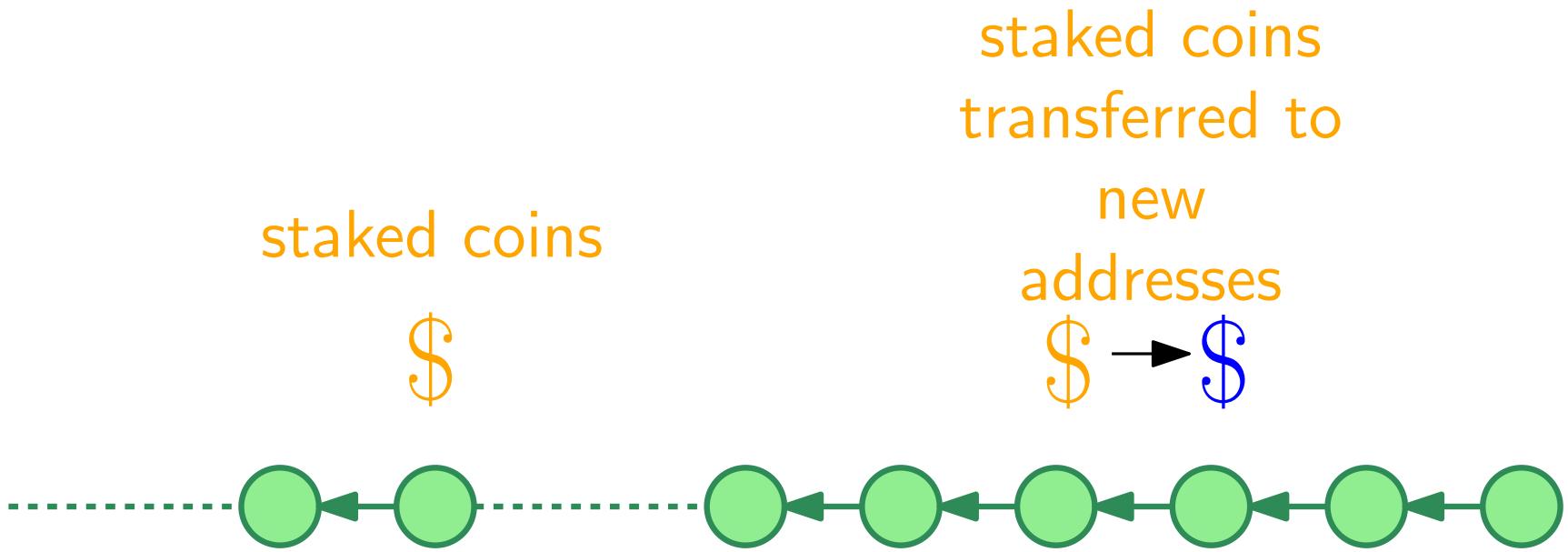
Proofs of Stake vs. Proofs of Work

Long range attack using "old keys"



Proofs of Stake vs. Proofs of Work

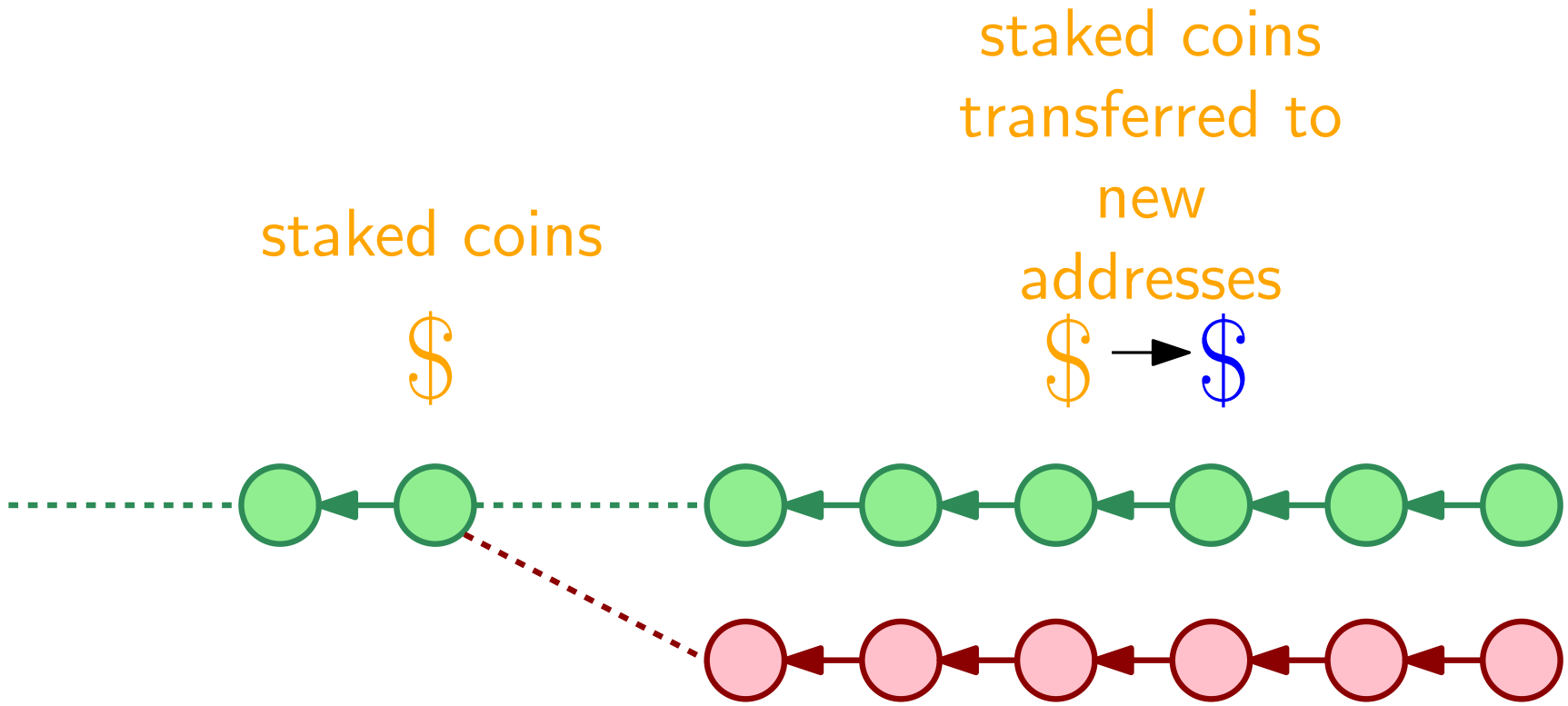
Long range attack using "old keys"



Adversary cheaply aquries $

Proofs of Stake vs. Proofs of Work

Long range attack using "old keys"

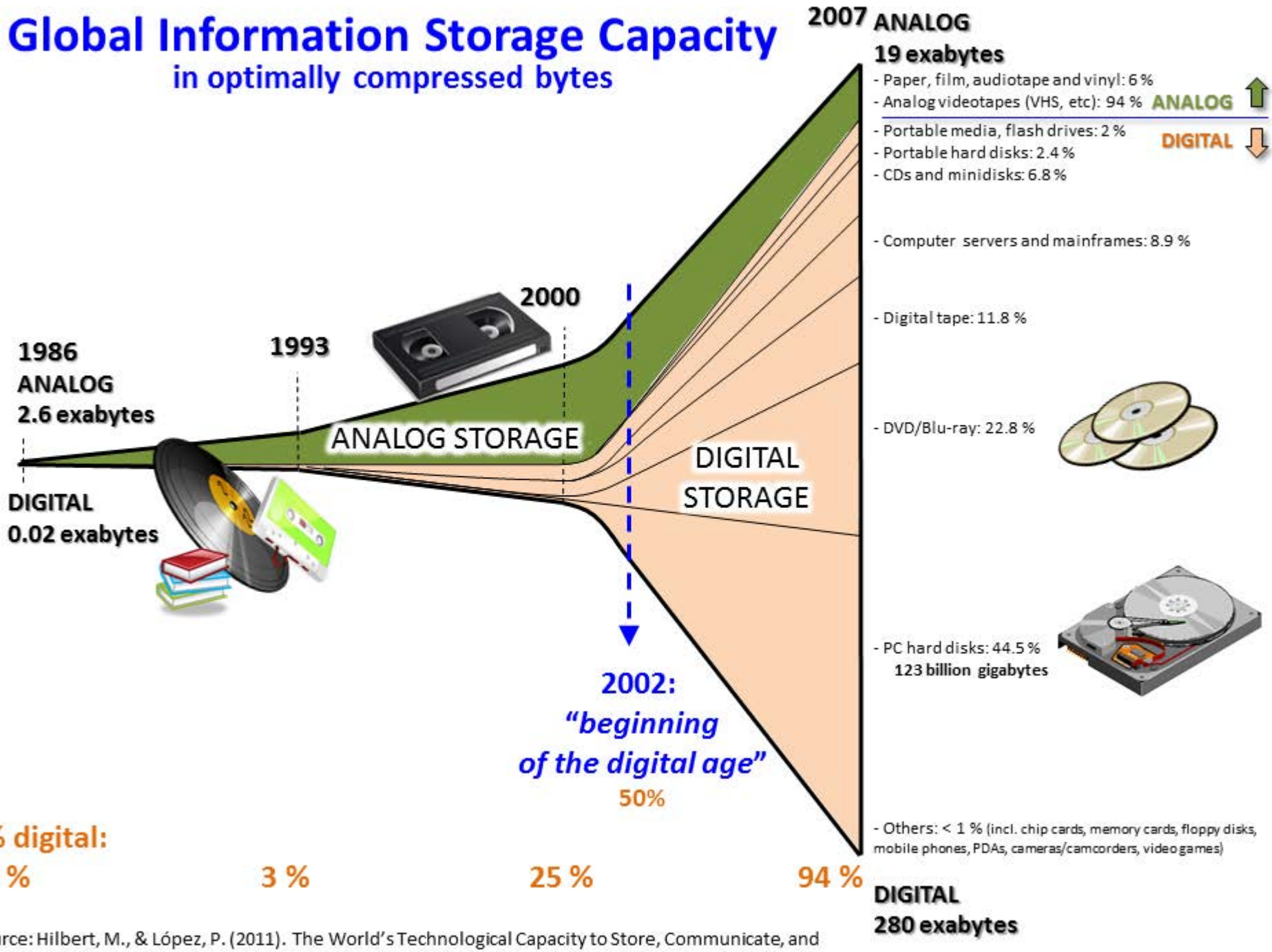


Adversary cheaply aquries $

Adversary bootstraps chain using $

Global Information Storage Capacity

in optimally compressed bytes



Source: Hilbert, M., & López, P. (2011). The World's Technological Capacity to Store, Communicate, and Compute Information. *Science*, 332(6025), 60 –65. http://www.martinhilbert.net/WorldInfoCapacity.html

Work vs. Space vs. Stake Mining/Farming

Work vs. Space vs. Stake Mining/Farming

Resource is

External

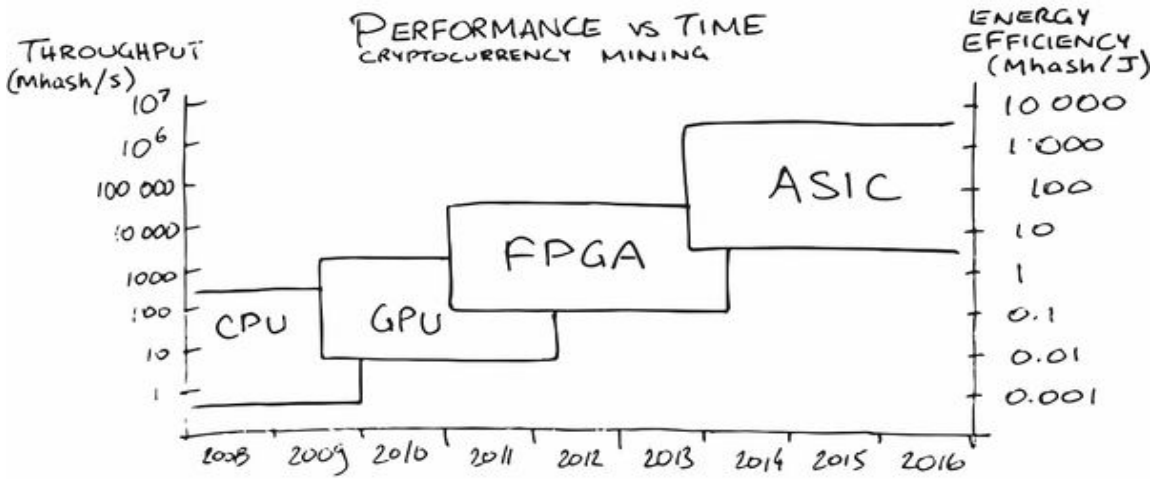
External

Internal

Work vs. Space vs. Stake Mining/Farming

	Resource is	Power consumption
	External	Huge
	External	Tiny
	Internal	Tiny

Work vs. Space vs. Stake Mining/Farming



	Resource is	Power consumption	Hardware
	External	Huge	Application Specific Integrated Circuits (ASIC)
	External	Tiny	General Purpose Disk Storage
	Internal	Tiny	None

Founded 2017 (CEO Bram Cohen)
Mainchain launched 2021

The Guardian, May 26, 2021

New cryptocurrency Chia blamed for hard drive shortages

Speculators buy up vital components as demand surges for rival to bitcoin that requires huge storage space

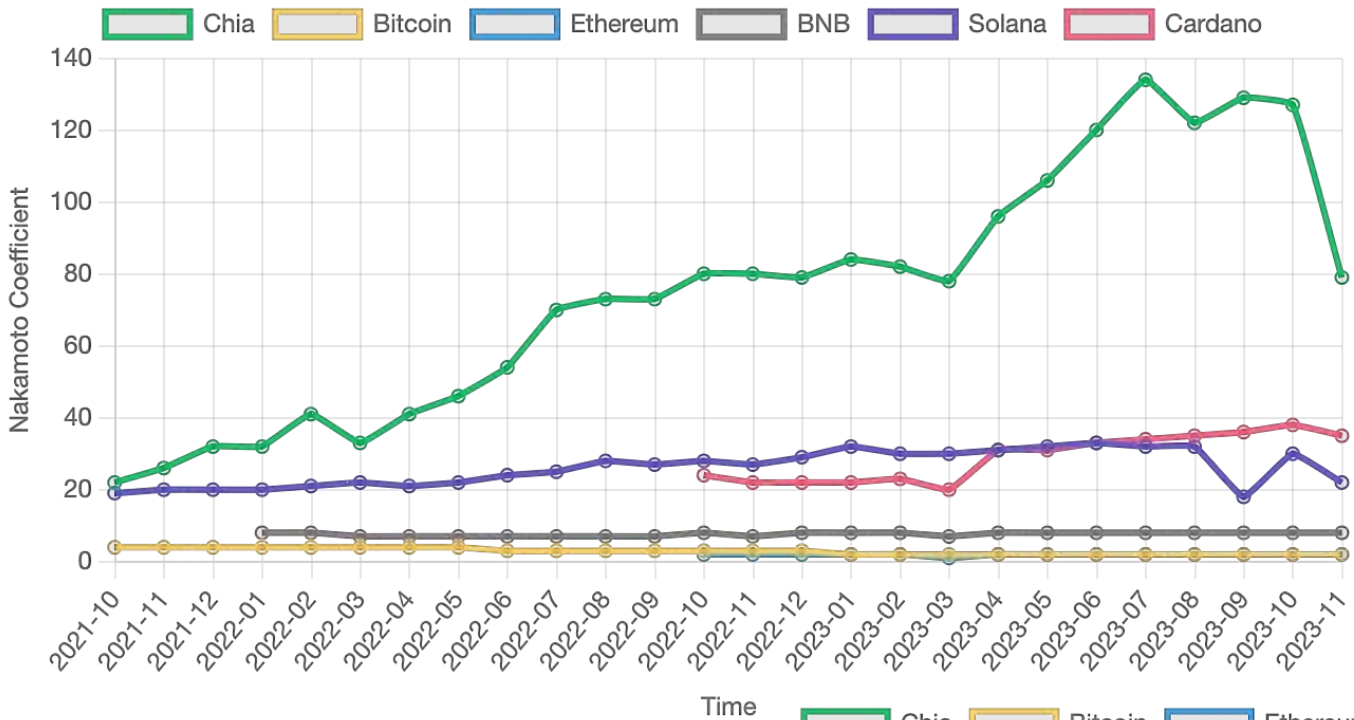
Circular Drive Initiative

Home Members FAQ News LinkedIn Resources

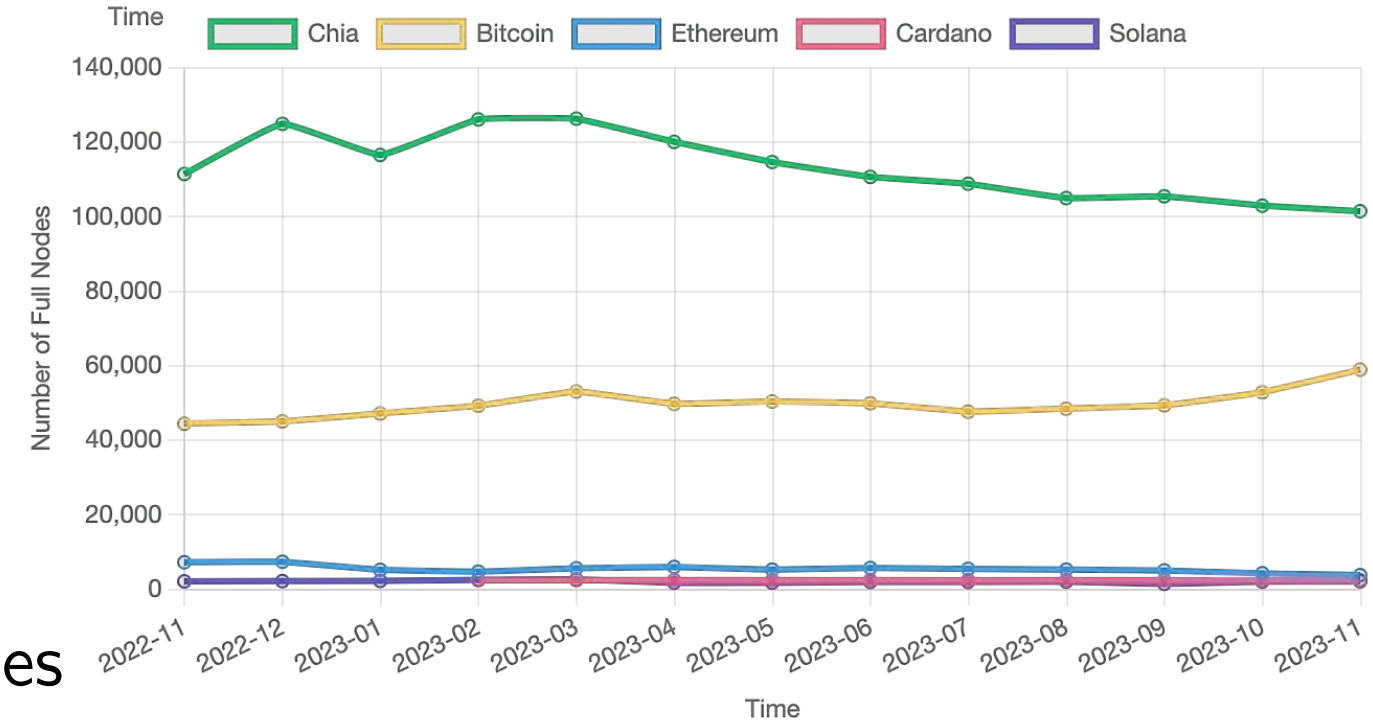
Driving the circular economy for storage

The Circular Drive Initiative (CDI) is a partnership of global leaders in digital storage, data centers, sustainability, and blockchain collaborating to reduce e-waste by enabling, driving, and promoting the secure reuse of storage hardware.

https://xch.farm/decentralization/



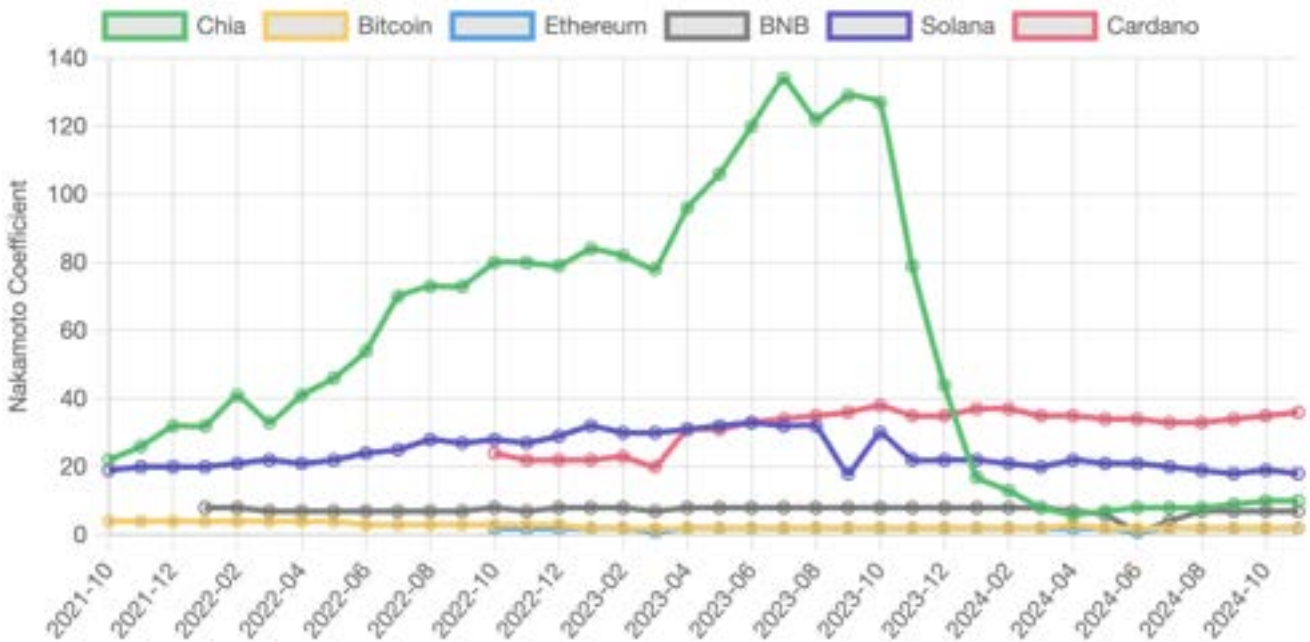
Nakamoto Coefficient

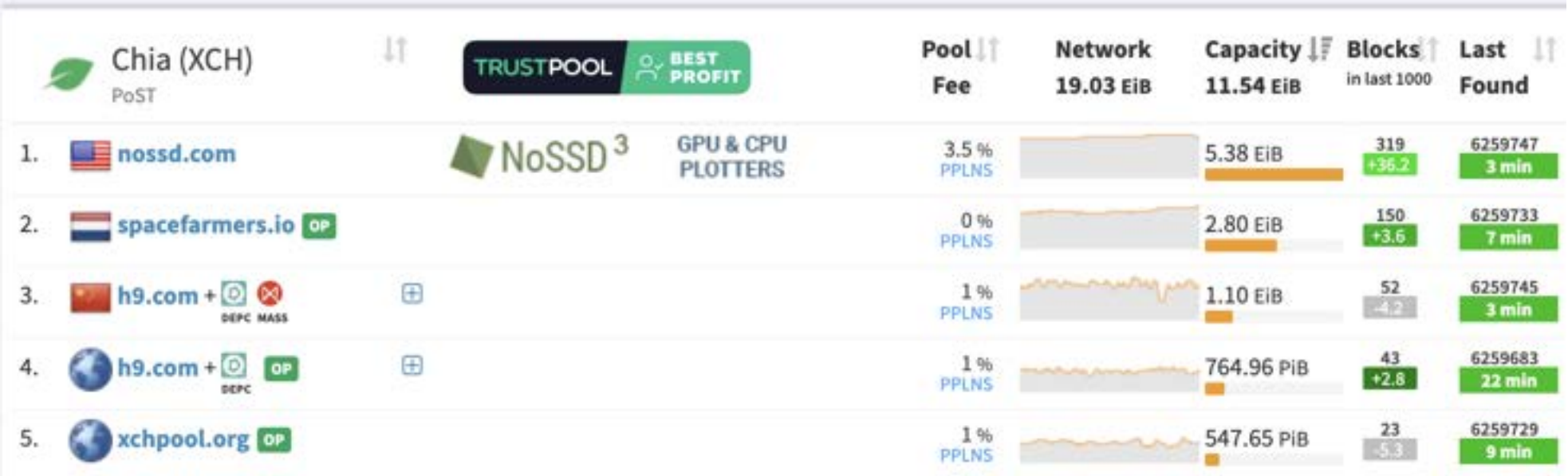


Number of Full Nodes

https://xch.farm/decentralization/

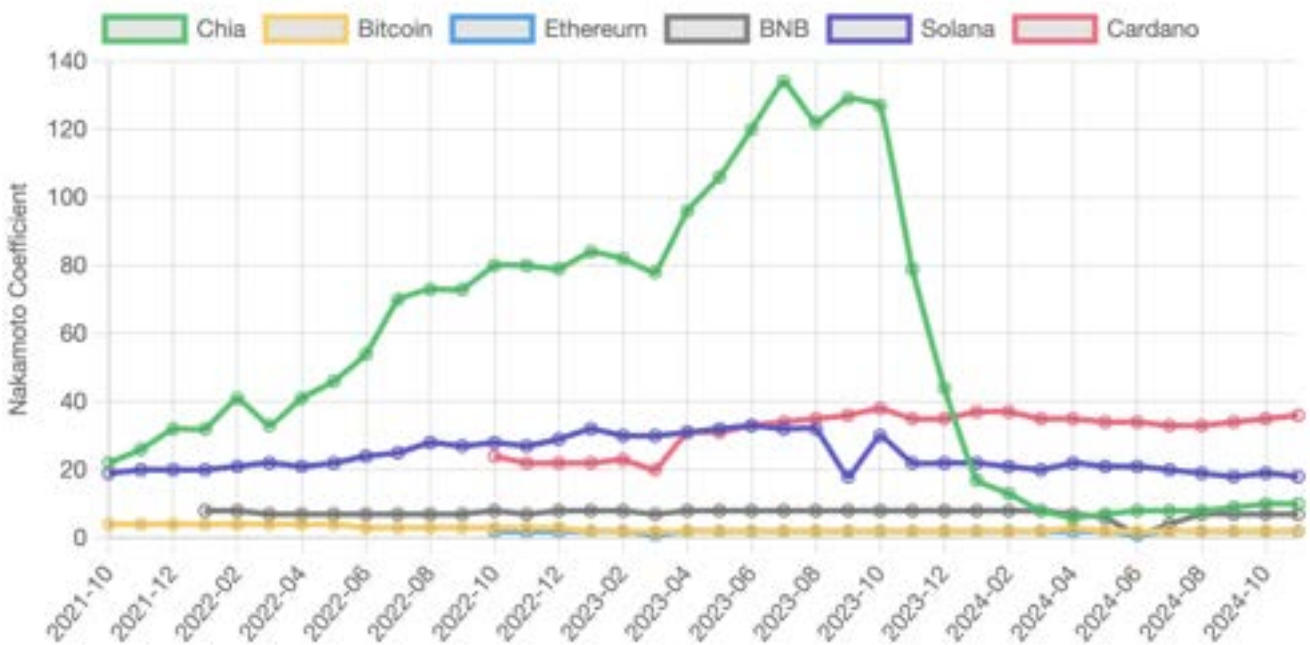
Nakamoto Coefficient





https://miningpoolstats.stream/chia

https://xch.farm/decentralization/



Nakamoto Coefficient

Chia Blog

Approaching the Next Generation of Proof of Space

August 8, 2024

by Chia Team

www.chia.net/2024/08/08/approaching-the-next-generation-of-proof-of-space/

Blockchains for Sustainability

Blockchains for Sustainability

How Blockchains Help Sustainability:

- **Traceable Supply Chains**: Verify ethical sourcing and reduce waste.
- **Carbon Tracking**: Monitor and verify emissions reductions.
- **Incentives for Green Practices**: Reward eco-friendly behavior via tokens.
- **Decentralized Energy**: Enable peer-to-peer renewable energy trading.
- **Circular Economy**: Streamline recycling and reuse.
- **Smart Contracts**: Ensure compliance with environmental standards.
- **Carbon Credit Trading**: Transparent, secure marketplace for carbon offsets.
- **Sustainability Transparency**: Reduce greenwashing with verifiable data.
- **Impact Tracking**: Verify sustainable investments and outcomes.
- **Waste Management**: Optimize recycling and reduce landfill waste.

Blockchains for Sustainability

Climate Warehouse: Helping Countries Leverage Climate Markets and Carbon Pricing

World Bank
310.000 Abonnenten
Abonnieren
125
Teilen
Herunterladen

https://youtu.be/7k9U60scEK4

Proofs of Space

Proofs of Space

73735	45963	78134	63873
02965	58303	90708	20025
98859	23851	27965	62394
33666	62570	64775	78428
81666	26440	20422	05720
15838	47174	76866	14330
89793	34378	08730	56522
78155	22466	81978	57323
16381	66207	11698	99314
75002	80827	53867	37797
99982	27601	62686	44711
84543	87442	50033	14021
77757	54043	46176	42391
80871	32792	87989	72248
30500	28220	12444	71840

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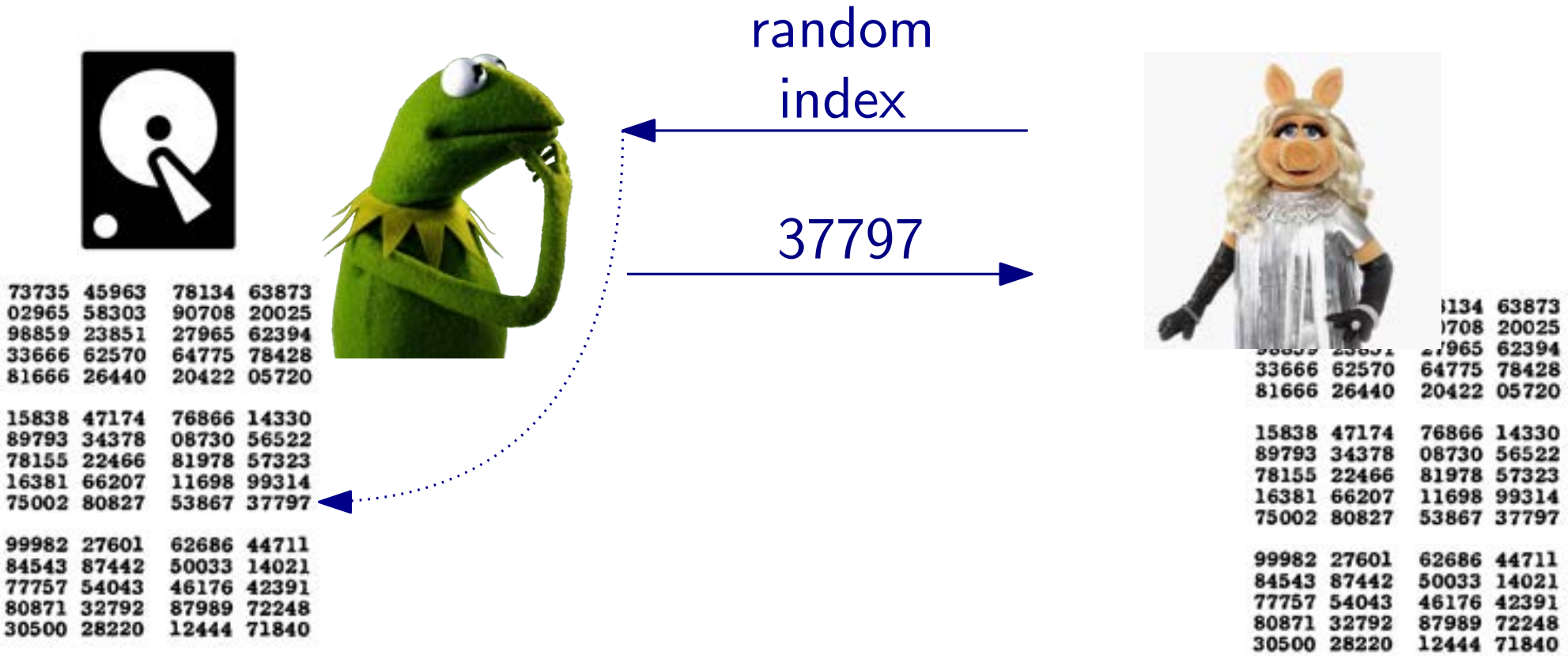


Proofs of Space

73735 45963 78134 63873
02965 58303 90708 20025
98859 23851 27965 62394
33666 62570 64775 78428
81666 26440 20422 05720

TOO MUCH COMMUNICATION

99982 27601 62686 44711
84543 87442 50033 14021
77757 54043 46176 42391
80871 32792 87989 72248
30500 28220 12444 71840

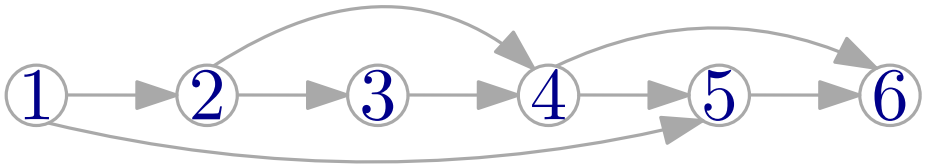
Proofs of Space




Stefan Dziembowski, Sebastian Faust, Vladimir Kolmogorov, Krzysztof Pietrzak: Proofs of Space. CRYPTO 2015

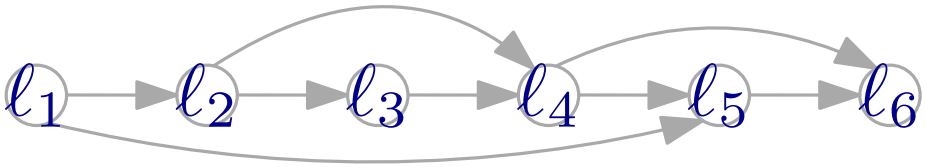
Proofs of Space

https://www.pebbling-game.at/



Proofs of Space

$$\ell_4 := hash(\ell_2, \ell_3)$$



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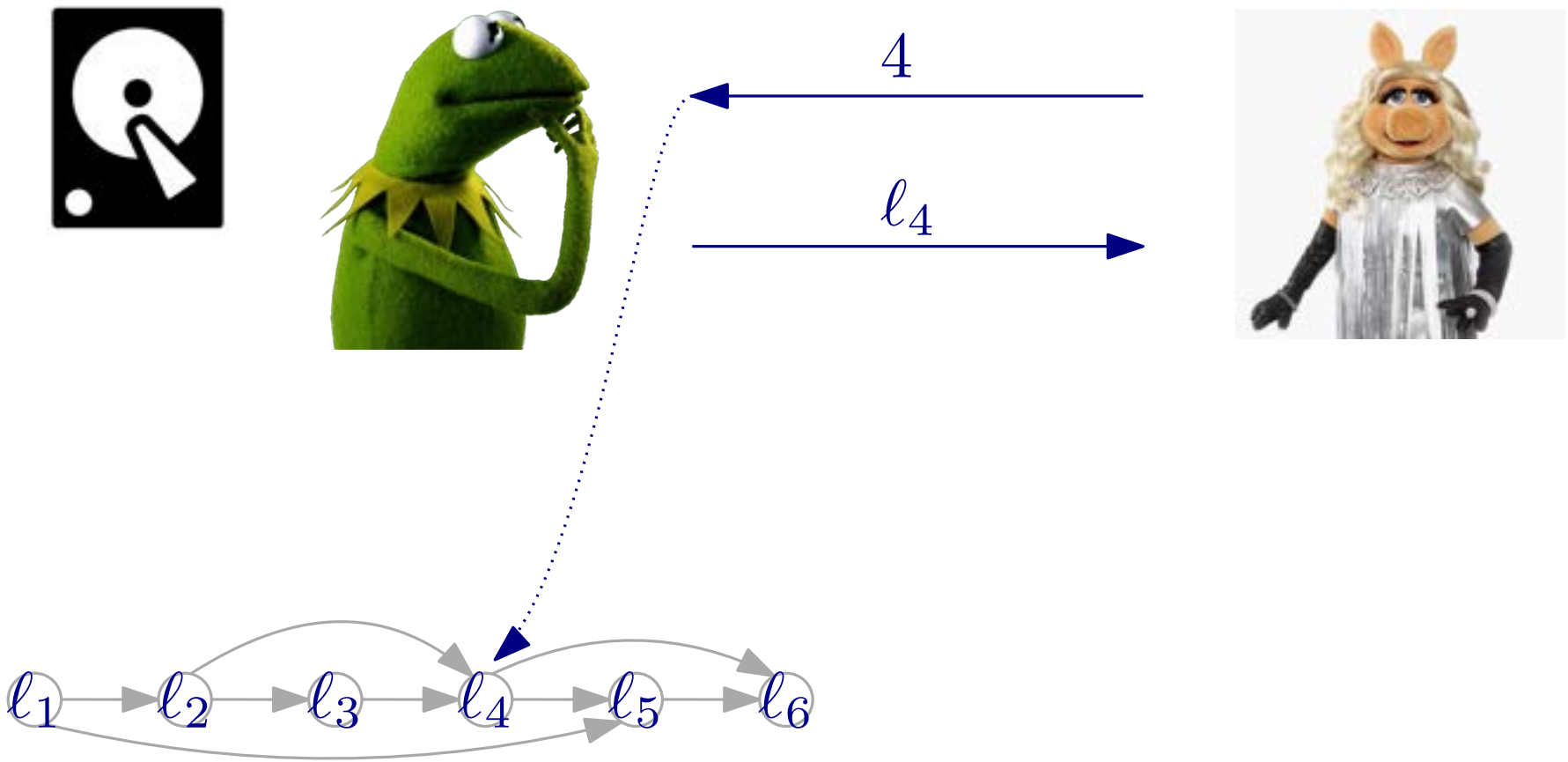
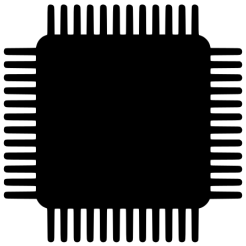
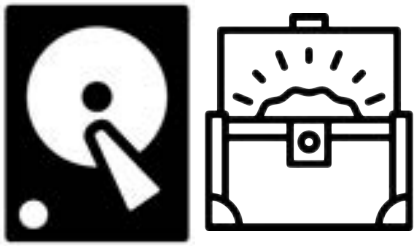


The Main Problem with Efficient Proof Systems



N Proofs of Work N times as costly as one



N Proofs of Space/Stake/... as cheap as 1

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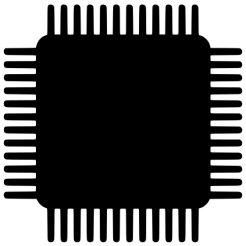

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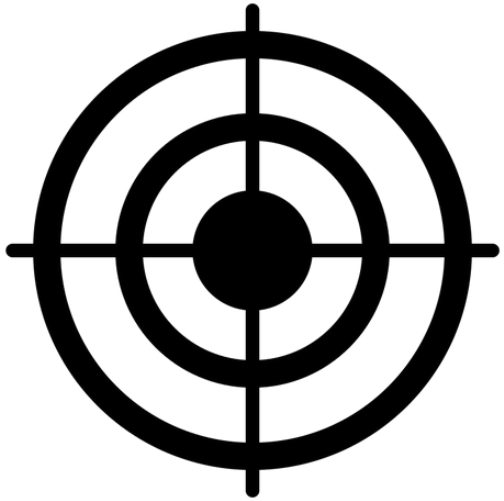
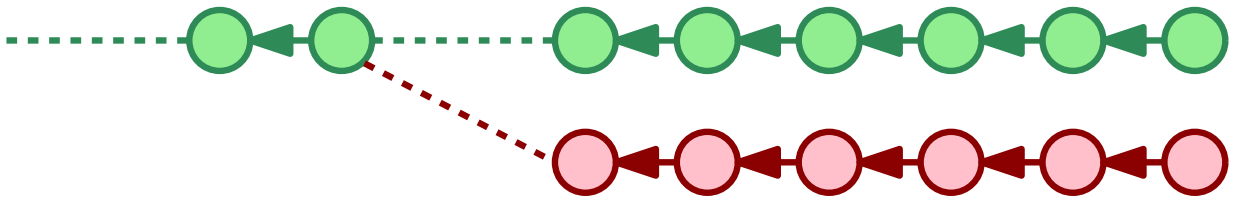


N Proofs of Space/Stake/... as cheap as 1

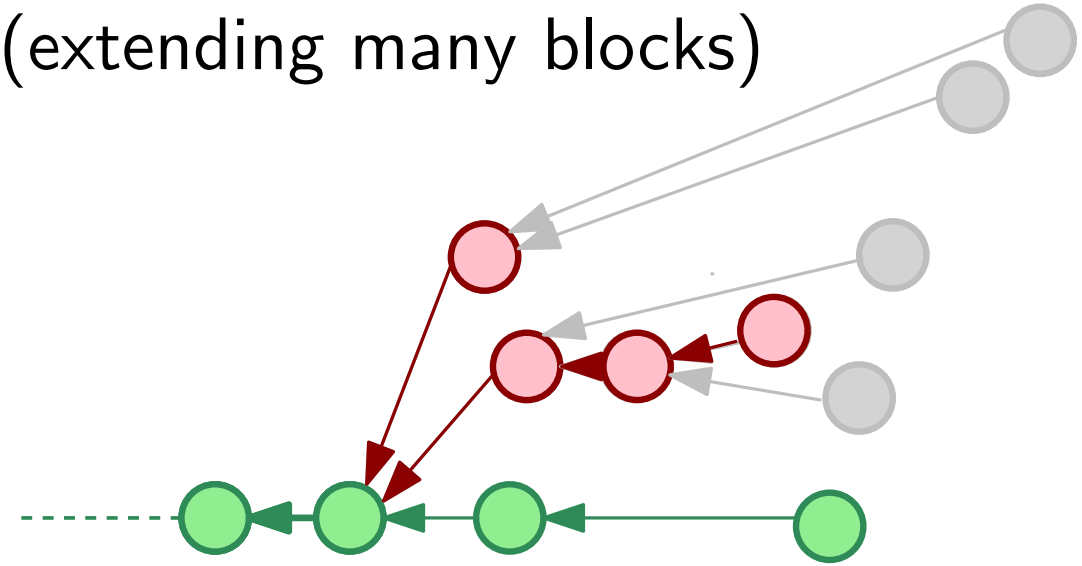
The 3 Issues with Efficient Proofs

1) Bootstrapping (Long range forks, seeing the future)



2) Digging (grinding block)

3) Double dipping (extending many blocks)



Proofs of Space and Time (early Chia proposal)

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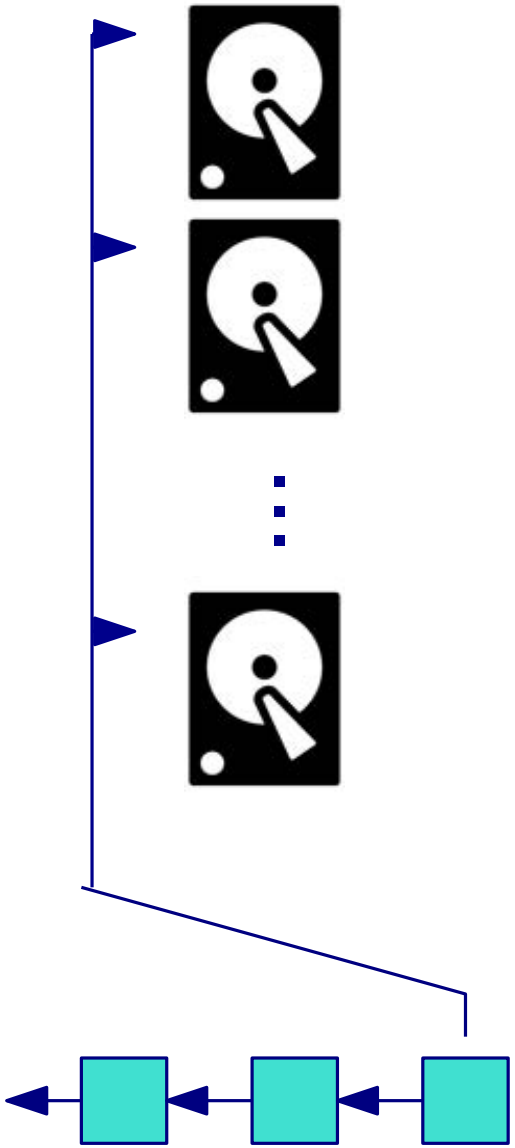

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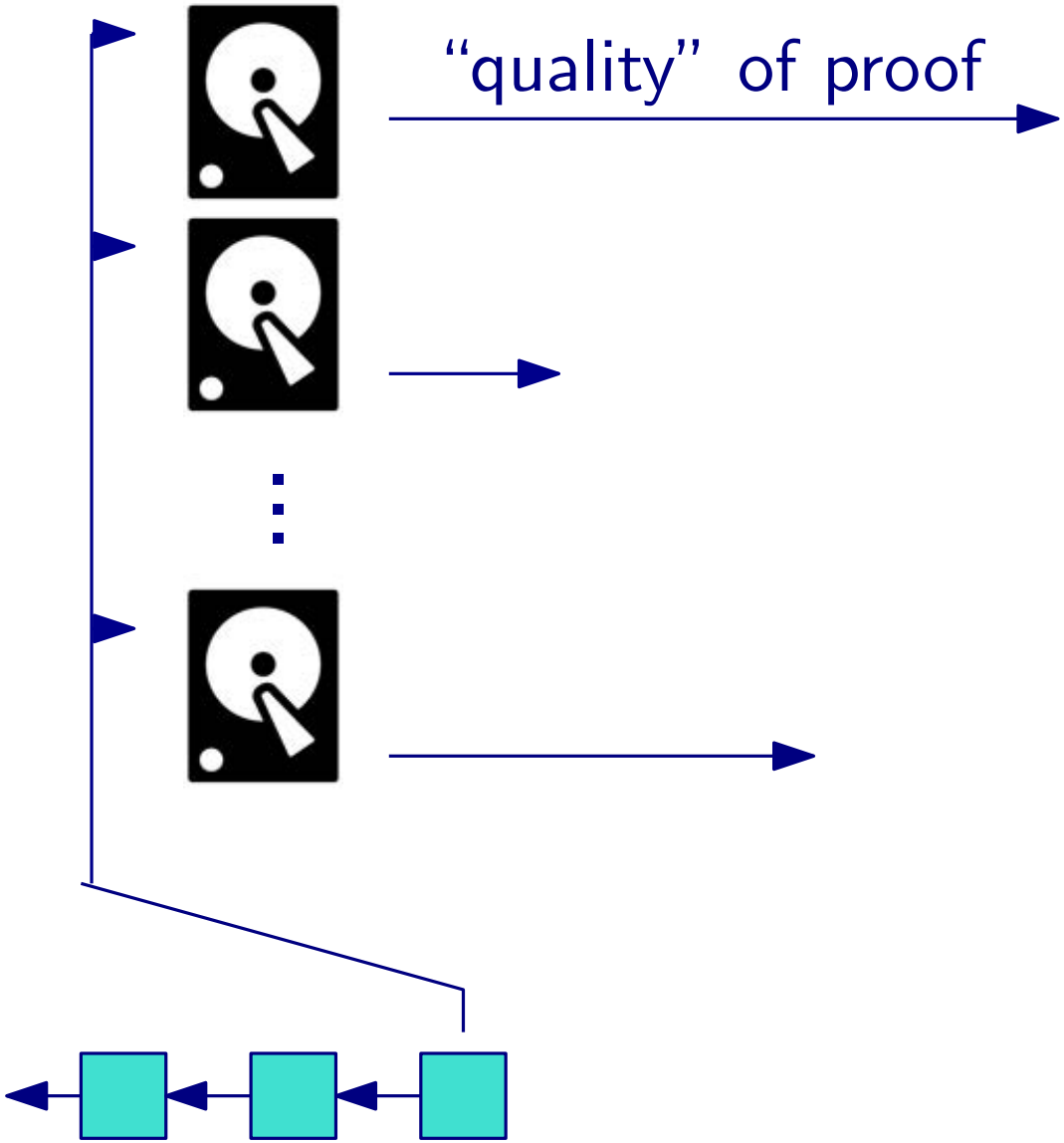

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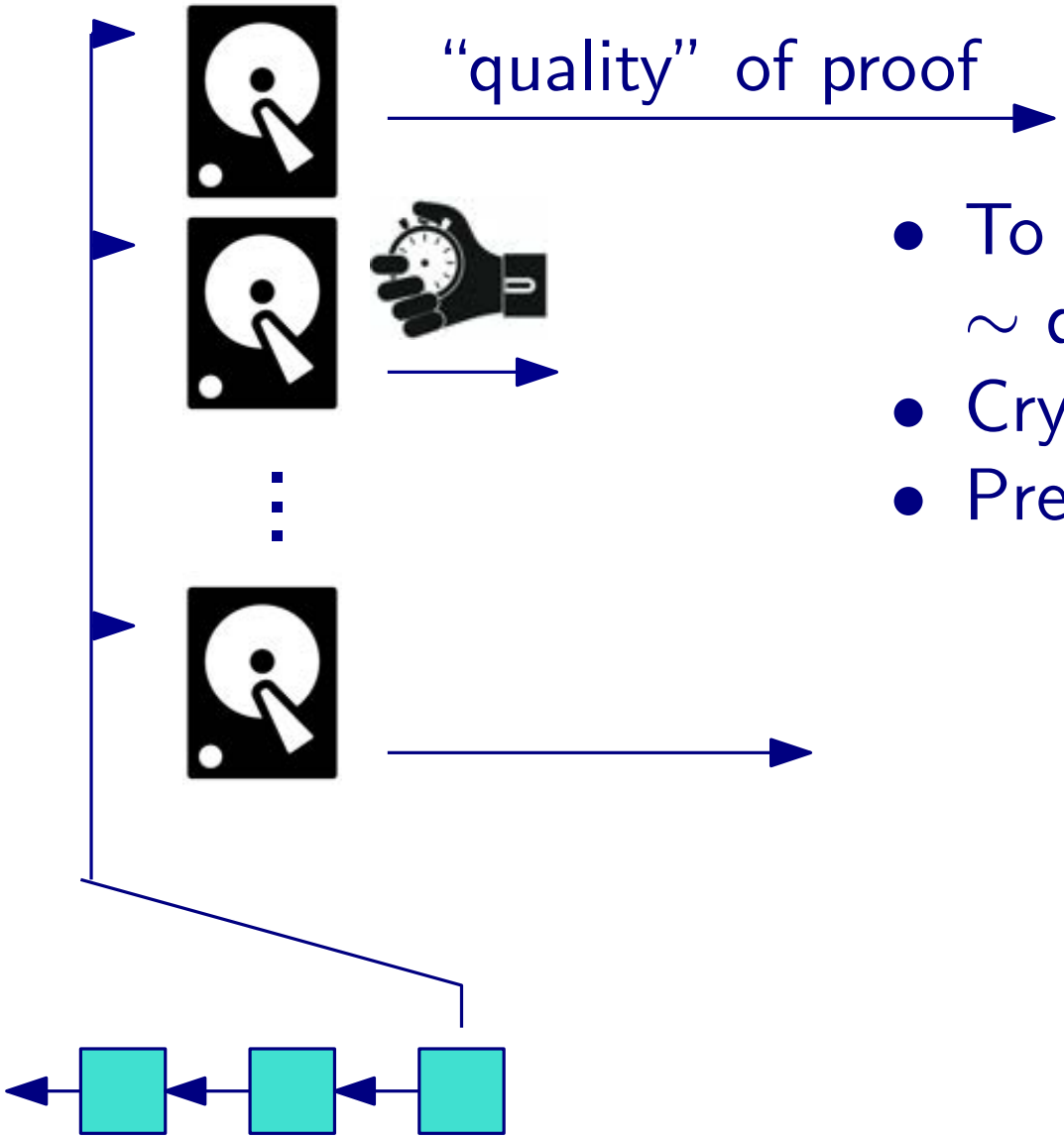

- To complete block wait for $\sim$ quality time
- Cryptographically enforced
- Prevents bootstrapping

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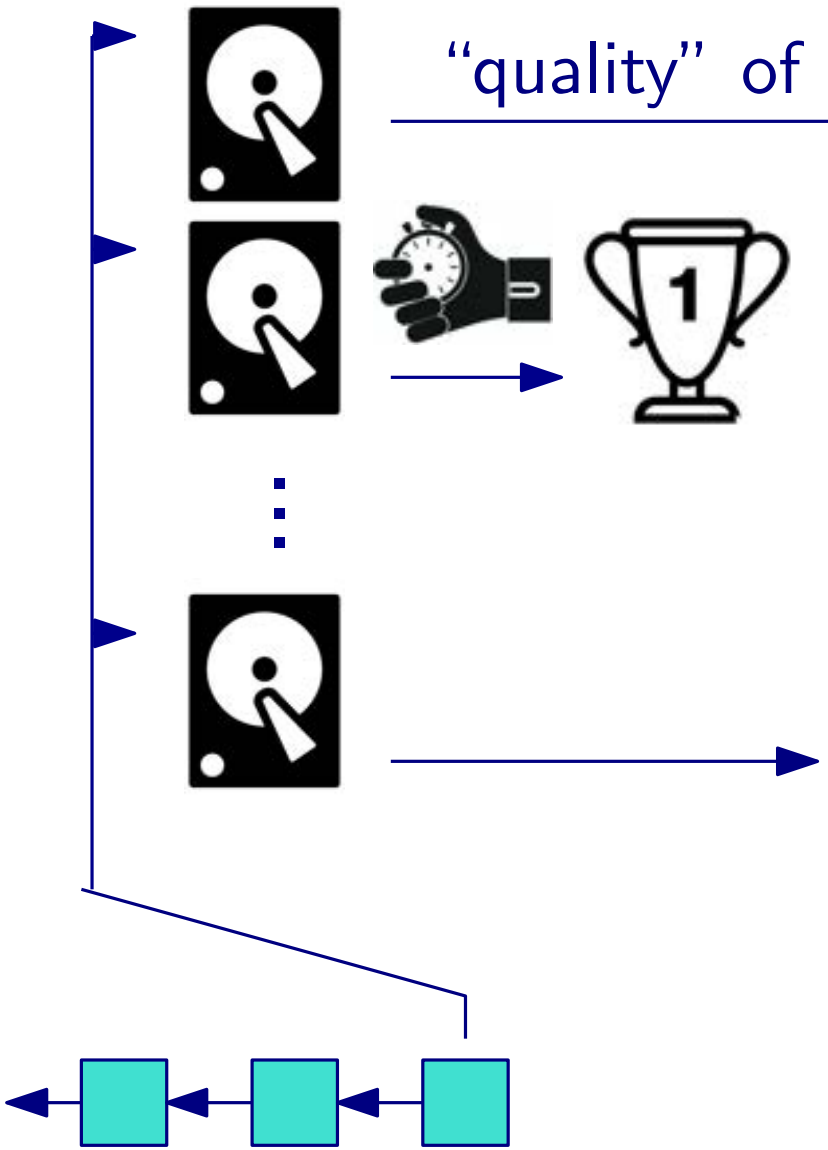

- To complete block wait for $\sim$ quality time
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Verifiable Delay Function

A VDF is a function that requires a large amount of time to compute

The difficulty input controls how long the VDF takes to solve

Verification( *)*

A proof is used to quickly verify the output came from a given input

Simple Verifibale Delay Function [ITCS'19]

VDF$(x, T) = x^{2^T}$ in a group of unknown order

Proving $\sigma = x^{2^T}$ in RSA group $\mathbb{Z}_N^*, N = p \cdot q$

$$x \; x^2 \; x^{2^2} \; x^{2^3} \ldots \qquad \mu \; (= x^{2^{T/2}}) \qquad \ldots \; x^{2^{T-1}} \; x^{2^T}$$

$$(x, y, T, N)$$

$\mathcal{P}$

claim

$y = x^{2^T} \bmod N$

$\mu \; (= x^{2^{T/2}})$ →

← random r

$\mathcal{V}$

new claim $y' = x'^{2^{T/2}} \bmod N$ where

$x' := \mu^r \cdot y \qquad y' := (x^r \cdot \mu)^{2^{T/2}}$

SUPRA NATIONAL

We are Supranational.

A product and service company developing hardware accelerated cryptography for verifiable and confidential computing.

VDF ALLIANCE

The VDF Alliance is a collection of academic, non-profit, and corporate collaborators building open source hardware for the blockchain ecosystem

HELP US BUILD