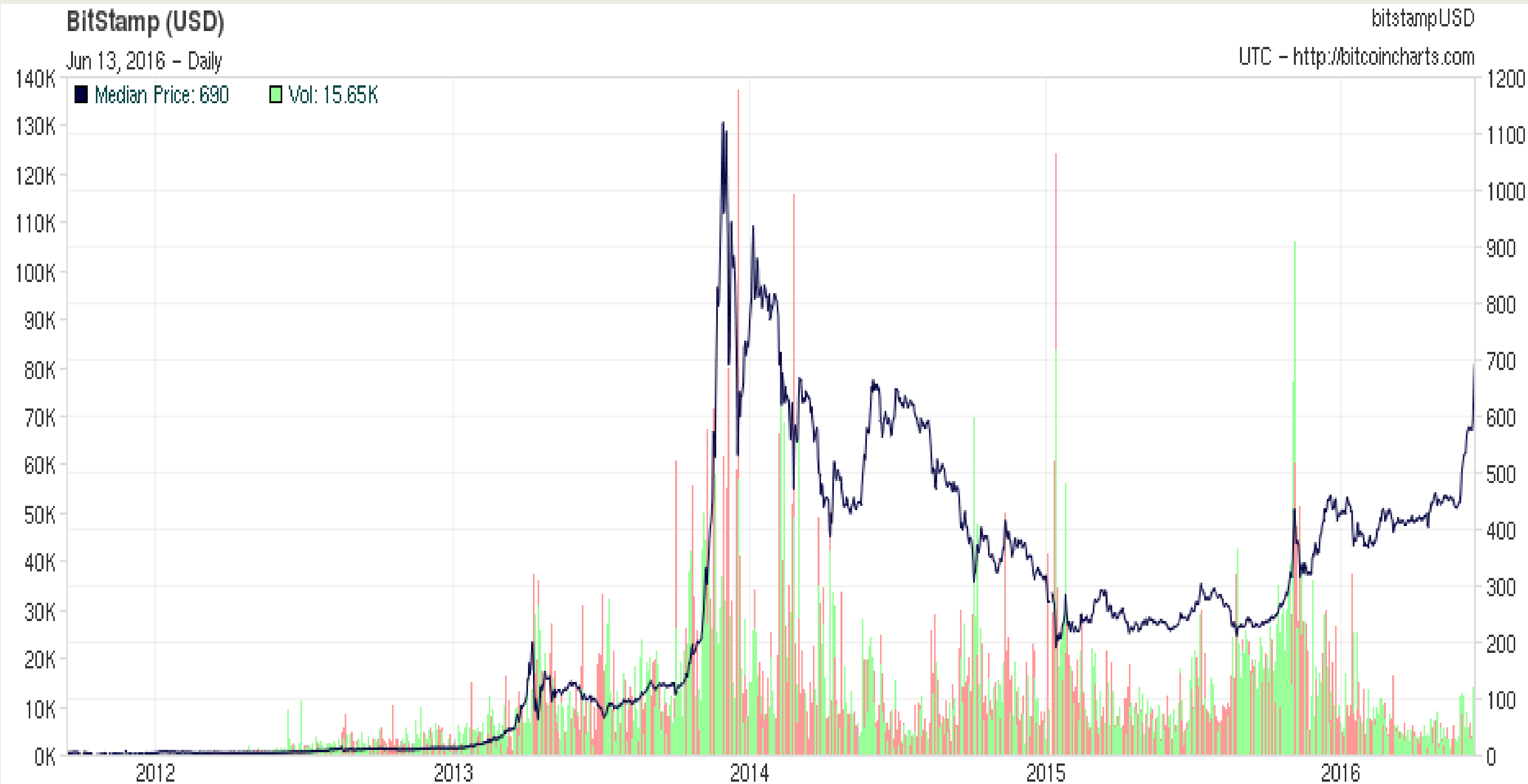
Analyzing Bitcoin Security

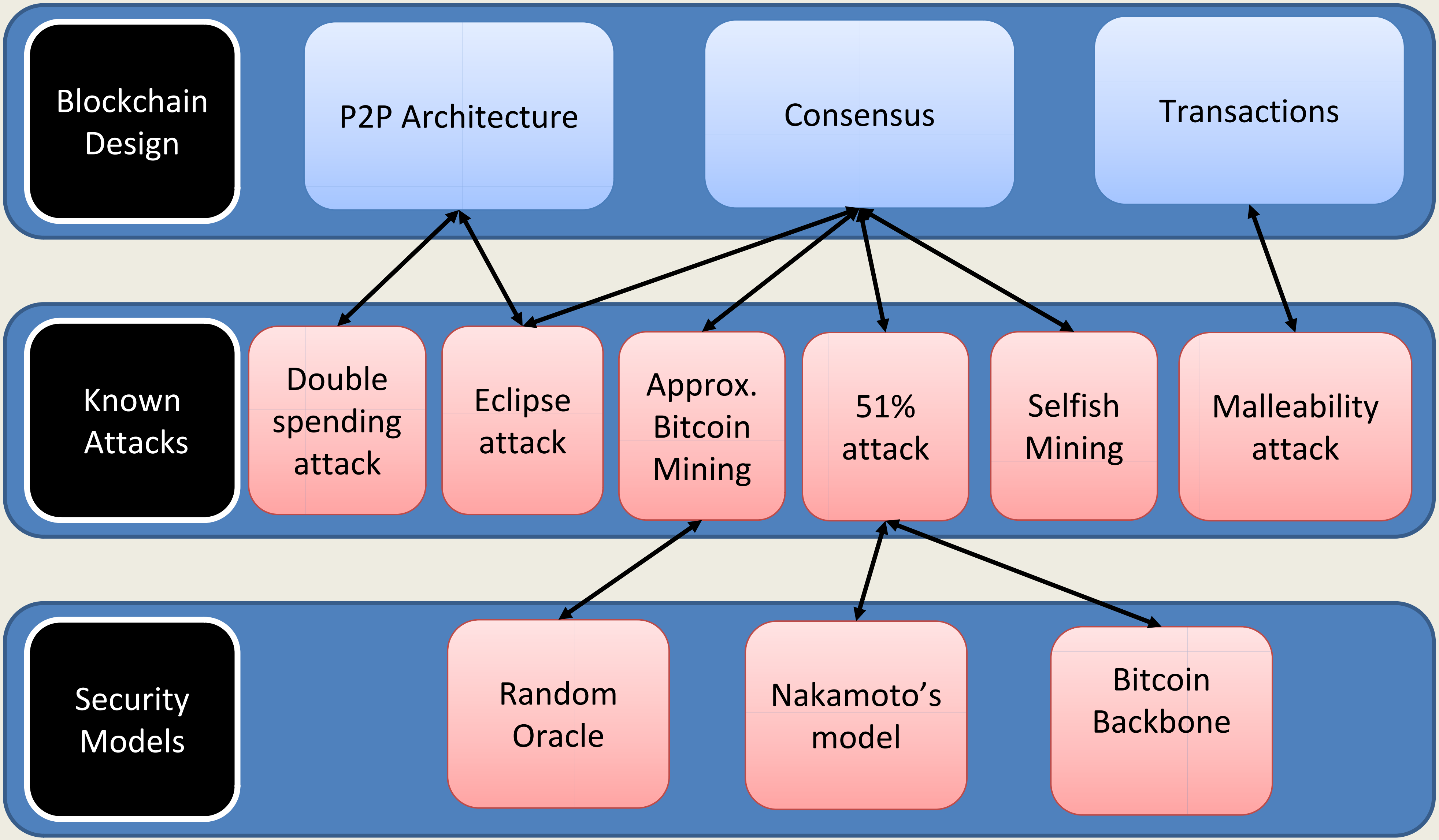
Philippe Camacho
philippe.camacho@dreamlab.net

Universidad Católica, Santiago de Chile
15 of June 2016

Bitcoin matters



Map



Blockchain Design
P2P Architecture
Consensus
Transactions
Known Attacks
Double spending attack
Eclipse attack
Approx. Bitcoin Mining
51% attack
Selfish Mining
Malleability attack
Security Models
Random Oracle
Nakamoto’s model
Bitcoin Backbone

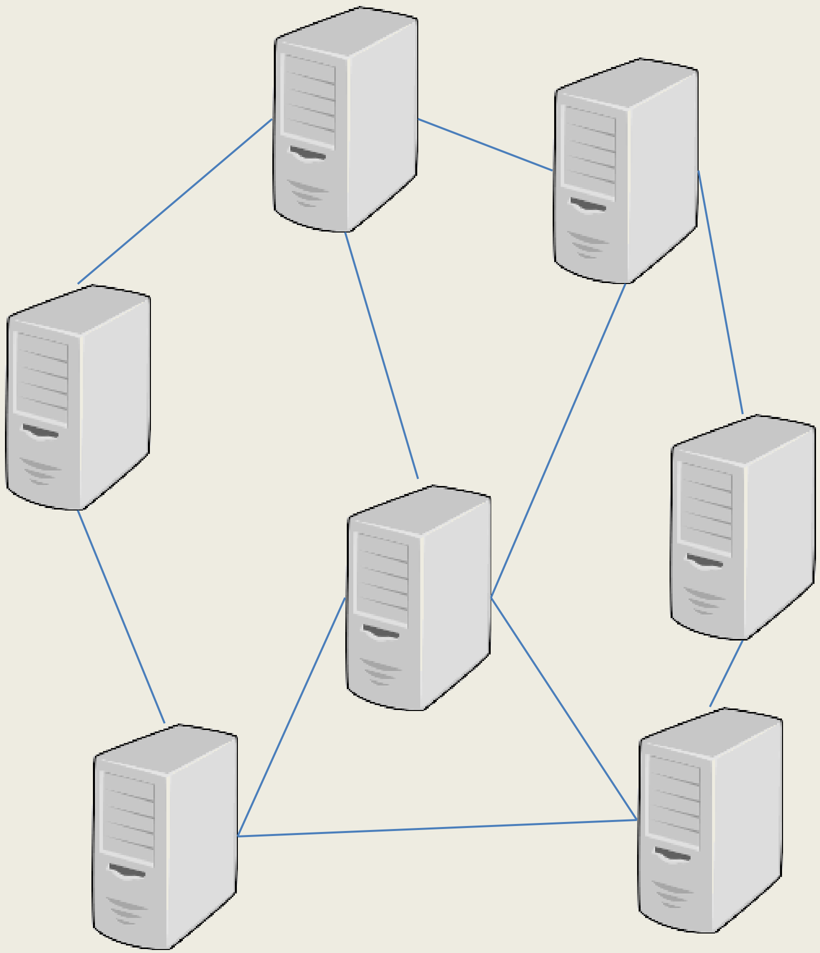
An open question (until 2008)

Is it possible to create (digital) money without a centralized authority?

Who wants some satoshis?

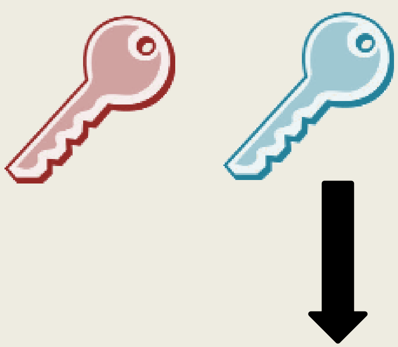
- What kinds of problems are hard to solve when building a decentralized digital cash system?

P2P Network

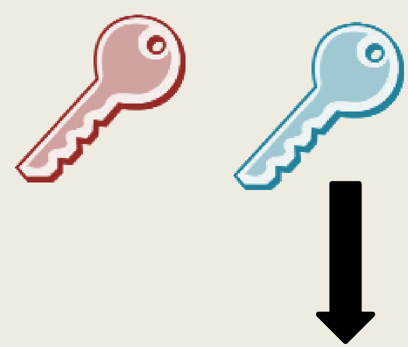


- TCP/IP
- No authentication
- 8 outgoing connections
- Up to 117 incoming connections
- Hardcoded IP addresses + DNS seeders to get first list of peers
- Probabilistic algorithm to choose peers
- Specific data structure to store peers list
- Gossip protocol to broadcast transactions

Bitcoin addresses



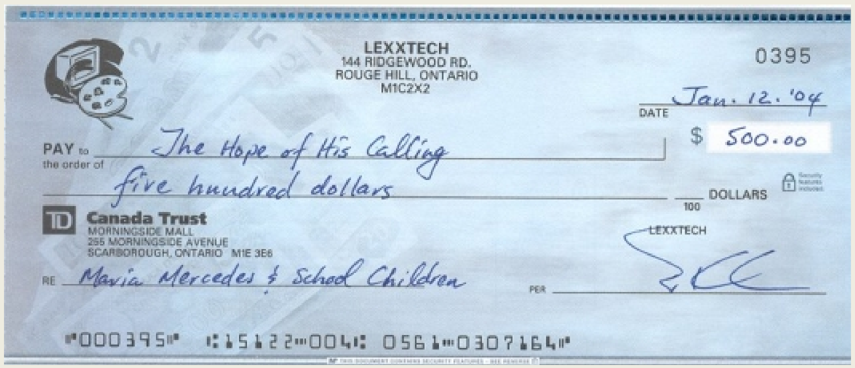
3Nxwenay9Z8Lc9JBiywExpnEFiLp6Afp8v



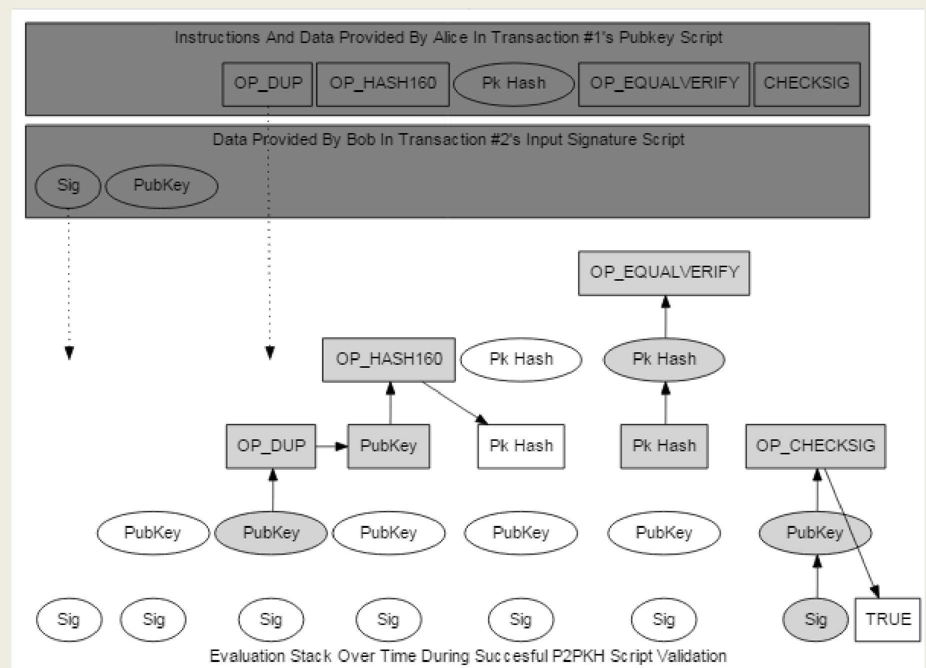
3J5KeQSVBUEs3v2vEEkZDBtPLWqLTuZPuD

Bitcoin transactions

- Conceptually very simple



- In practice quite complicated (more on this later)



Double spending attack

3NDQz8rZ3CnmsiBGrATk8SCpDXF2sAUiuM

1BTC

3Nxwenay9Z8Lc9JBiywExpnEFiLp6Afp8v

1BTC

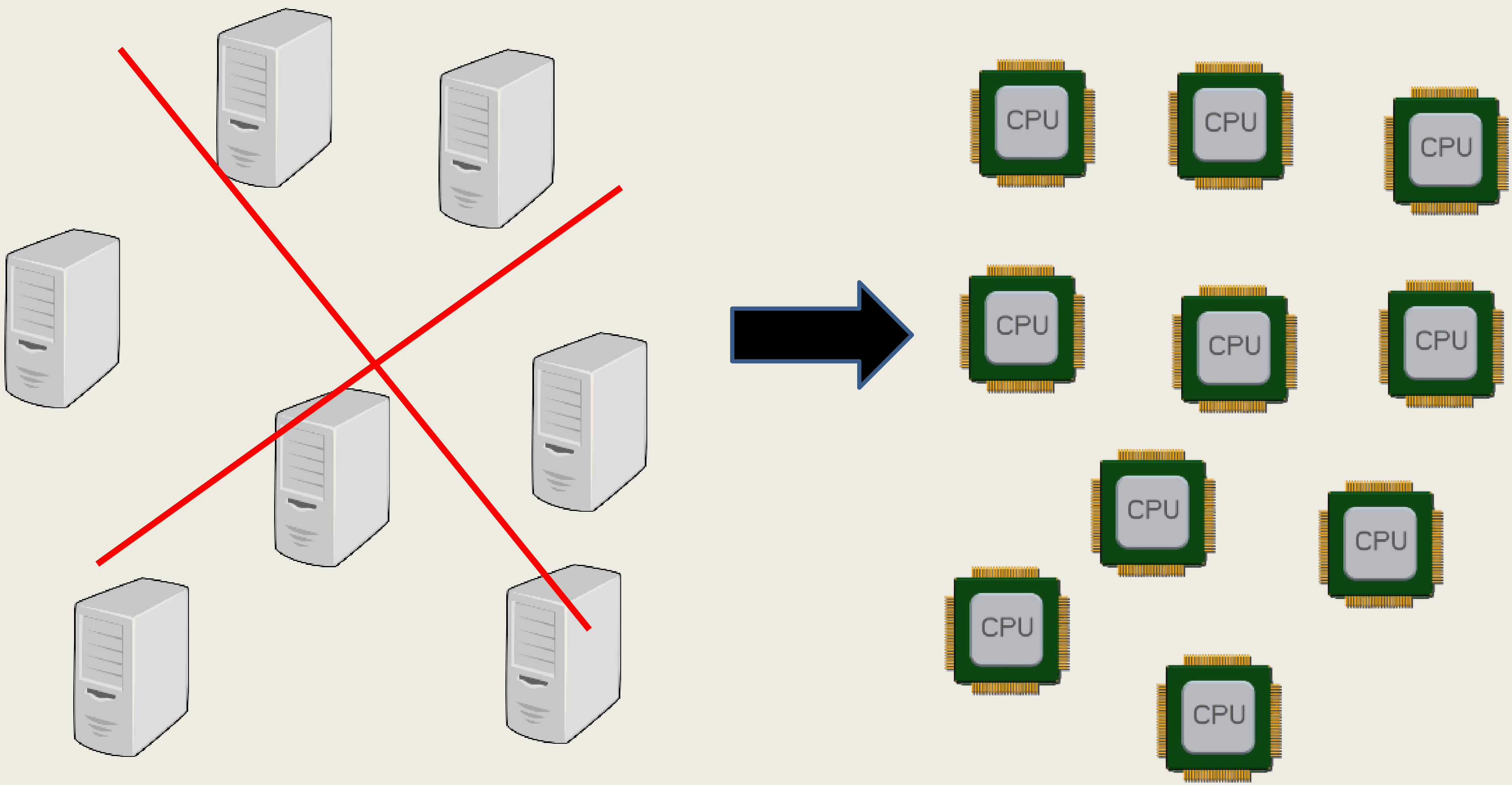
3J5KeQSVBUEs3v2vEEkZDBtPLWqLTuZPuD

How does Bitcoin prevent the double-spending attack?

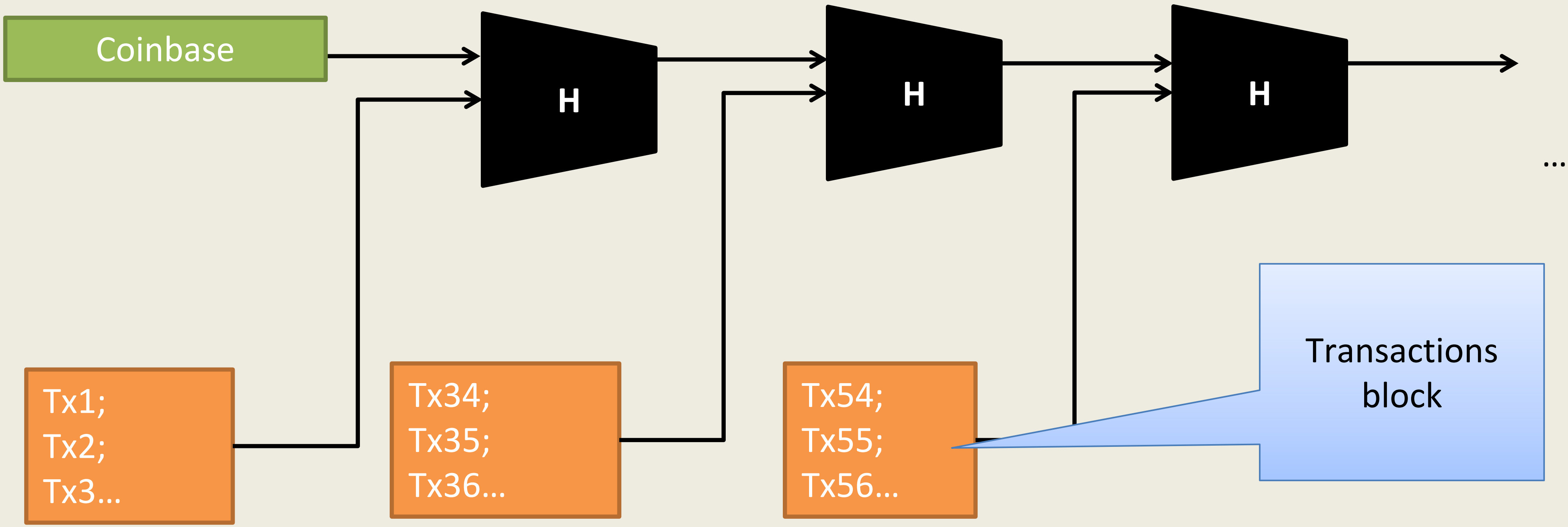
- **Idea**
  - Have participants of the network vote to establish the “official” ordered list of transactions
  - Check the validity of each transaction with this ledger
- **Challenge**
  - We are in an open network => Sybil attack is always possible

Consensus

Instead of voting with your IP, vote with your CPU



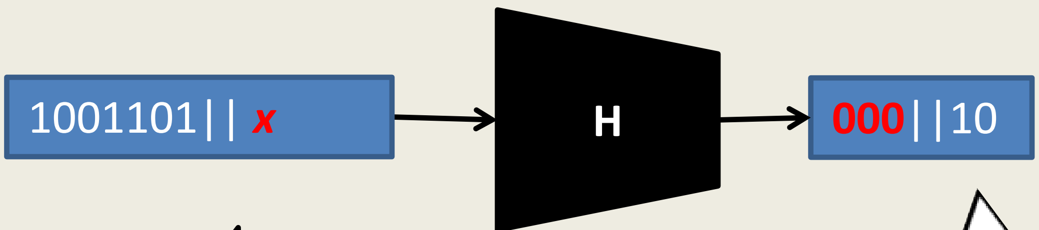
The Blockchain



Who wants some satoshis?

- Who will extend the next block ?
  Or how to agree in a fair way on the participant that will extend the chain?

Proof of Work **[Back2002]**



Find value ***x*** so that the output begins with **3** zeros.

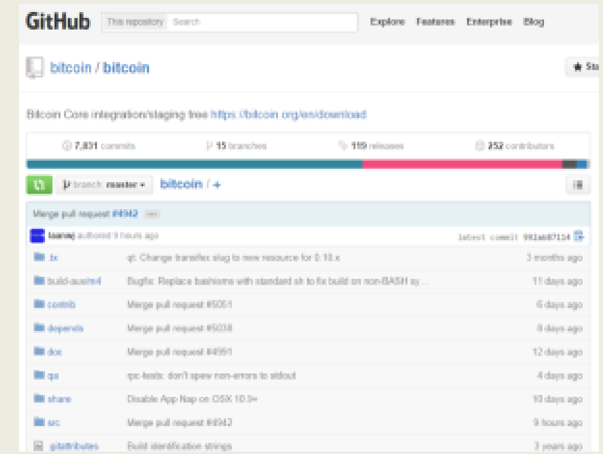
The «only way» to compute this value so that the output starts with n zeros is to try at random around 2^n times.

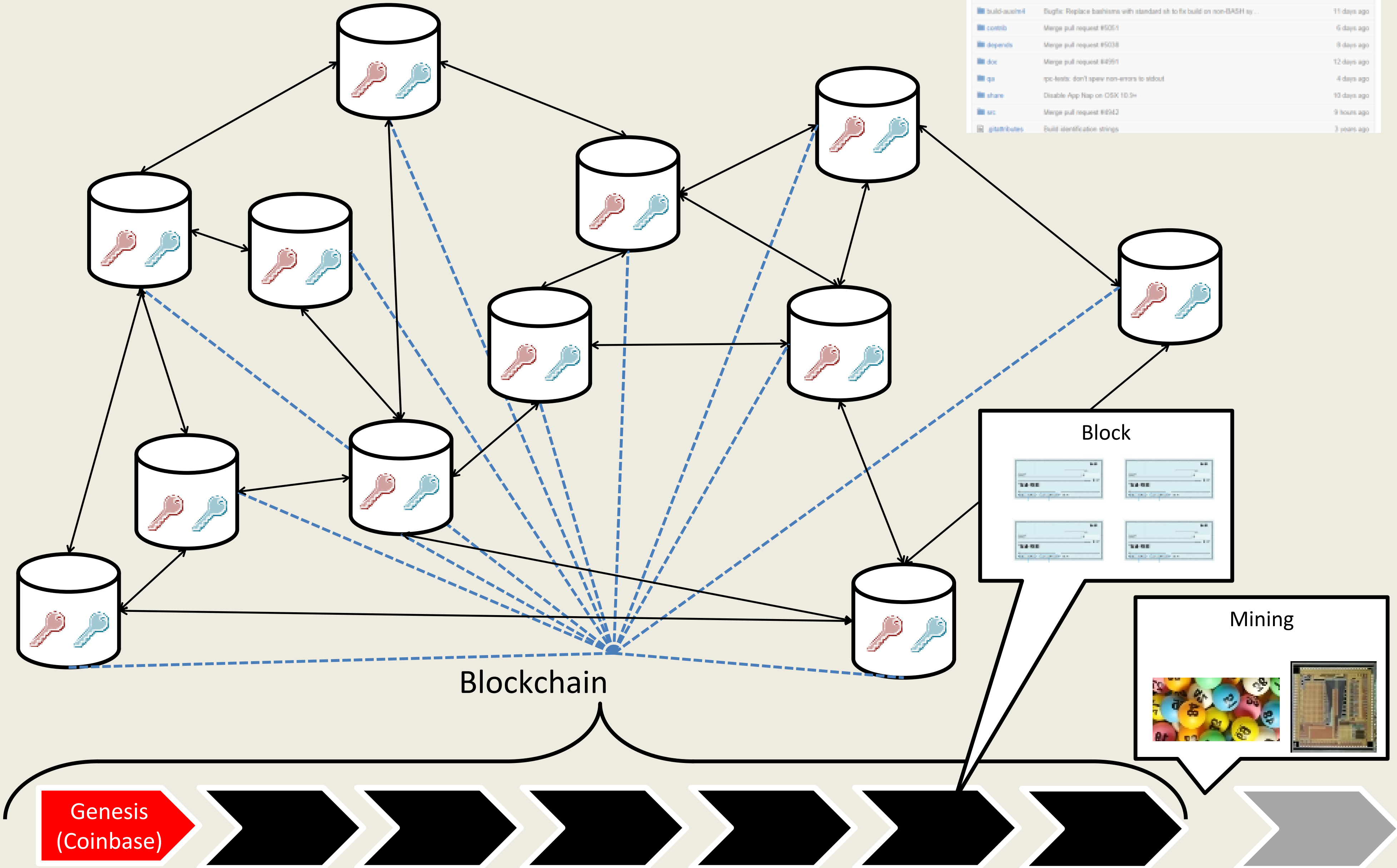
00000	10000
00001	10001
00010	10010
00011	10011
00100	10100
00101	10101
00110	10110
00111	10111
01000	11000
01001	11001
01010	11010
01011	11011
01100	11100
01101	11101
01110	11110
01111	11111

On the limits of the Random Oracle

- Approximate Bitcoin Mining **[LH2015,VDR2015]**
- Patent pending AsicBoost.com
- Enable to increase profitability of miners by 20%~30%

in 1 slide

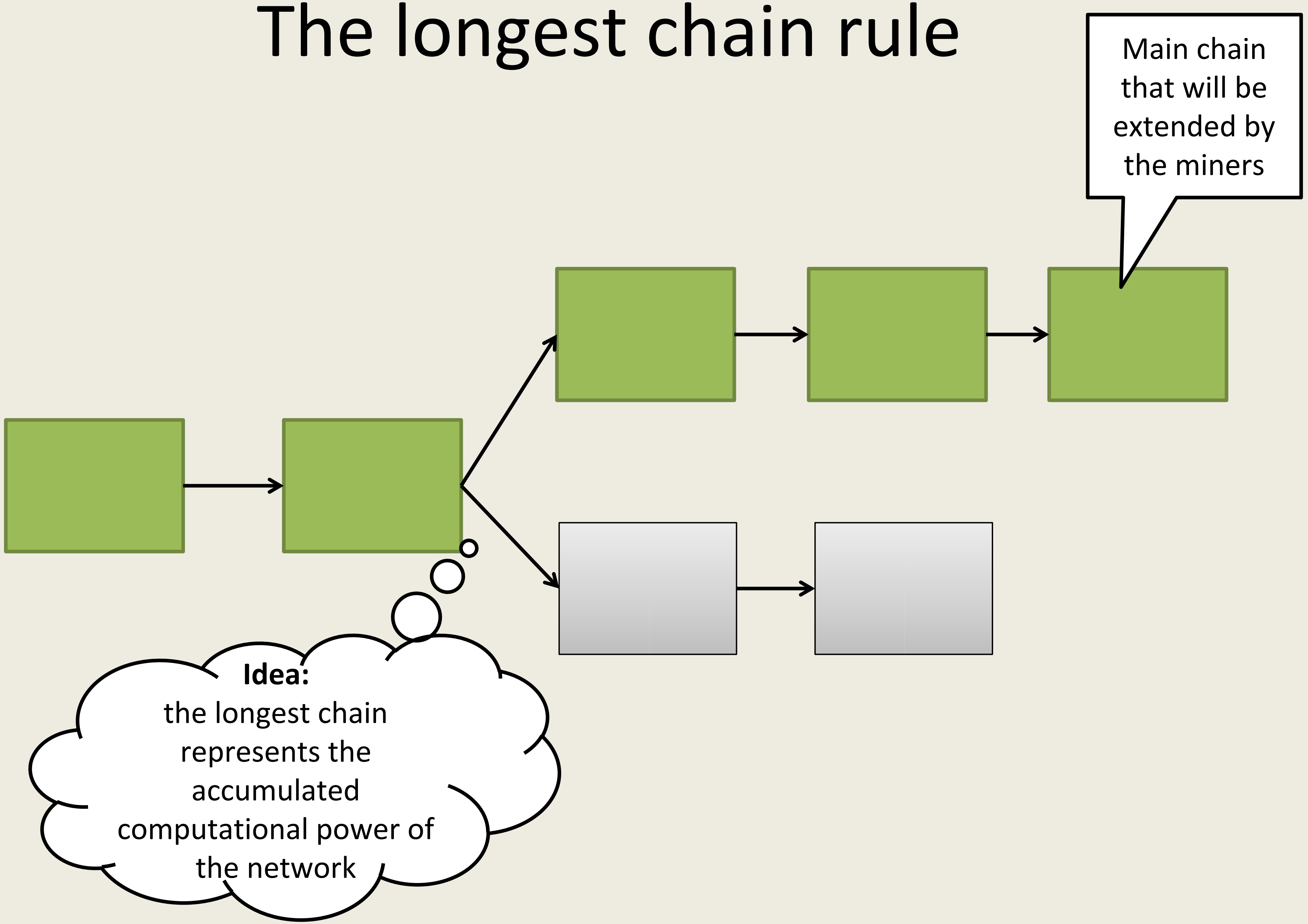

GitHub
bitcoin / bitcoin


Block
Mining
Blockchain
Genesis
(Coinbase)

Who wants some satoshis?

- What happens if two miners produce a block at almost the same time?

The longest chain rule



Who wants some satoshis?

- How are bitcoins created?
- Why would people spend their computational power to protect the network?

Incentive

- Each block mined that
ends up in the main chain
will be awarded with 12.5 BTC (*)

- Hence the metaphor «Mining»

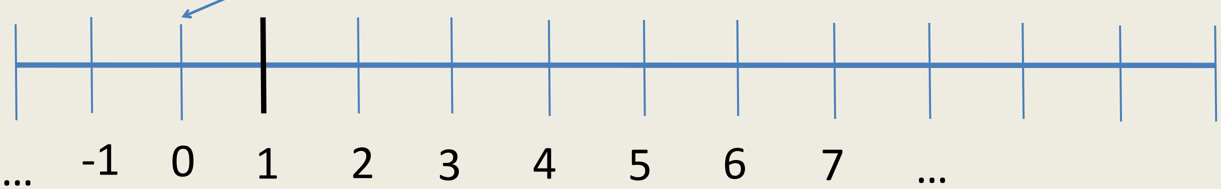
(*) It was 50 BTC at the beginning,
halving every 210000 blocks

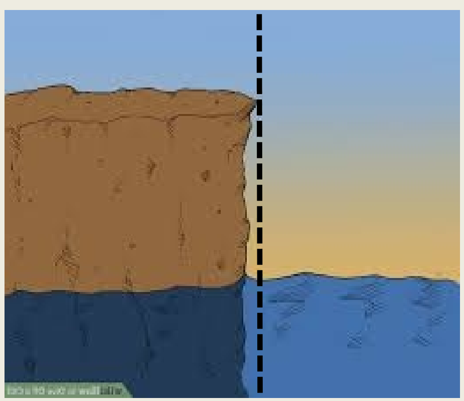
The Monkey at the Cliff

What is the probability that the monkey, sooner or later, will fall off the cliff?

$P[Left] = 1 - \alpha = \beta$

$P[Right] = \alpha$





We call this probability P_1

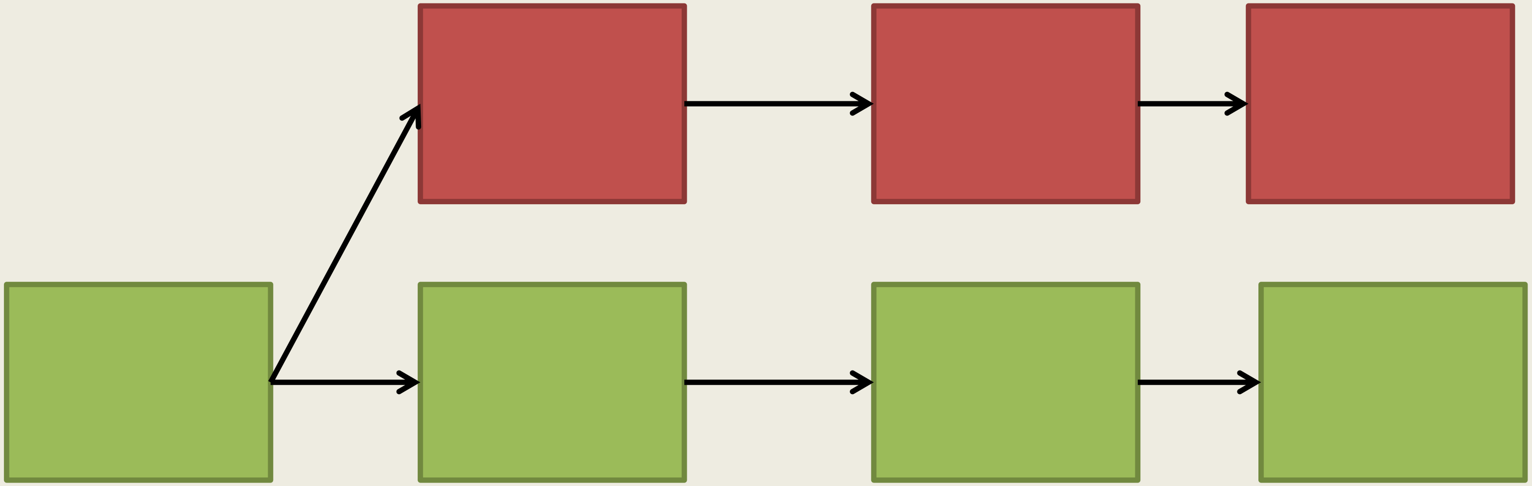
We have that $P_k = P_1^k$

Theorem: If $\alpha > \beta$ then $P_1 = 1$

If $\alpha < \beta$ then $P_1 = \frac{\alpha}{\beta}$ and $P_k = \frac{\alpha}{\beta}$

51% attack **[Nakamoto2008]**

I will try to catch up with 3 blocks and rewrite the history of transactions

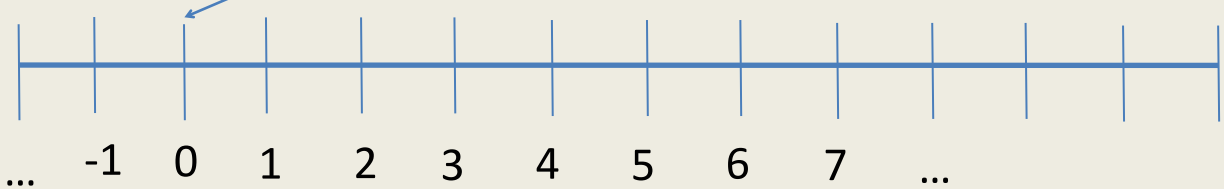


51% attack

$1 - \alpha = \ \beta$

α

Computational power of the adversary



What is the probability that the adversary catches up with k blocks, sooner or later?

k is the number of confirmations

We have that $P_k = P_1^k = \left(\frac{\alpha}{\beta}\right)^k$

Decreases exponentially fast in k

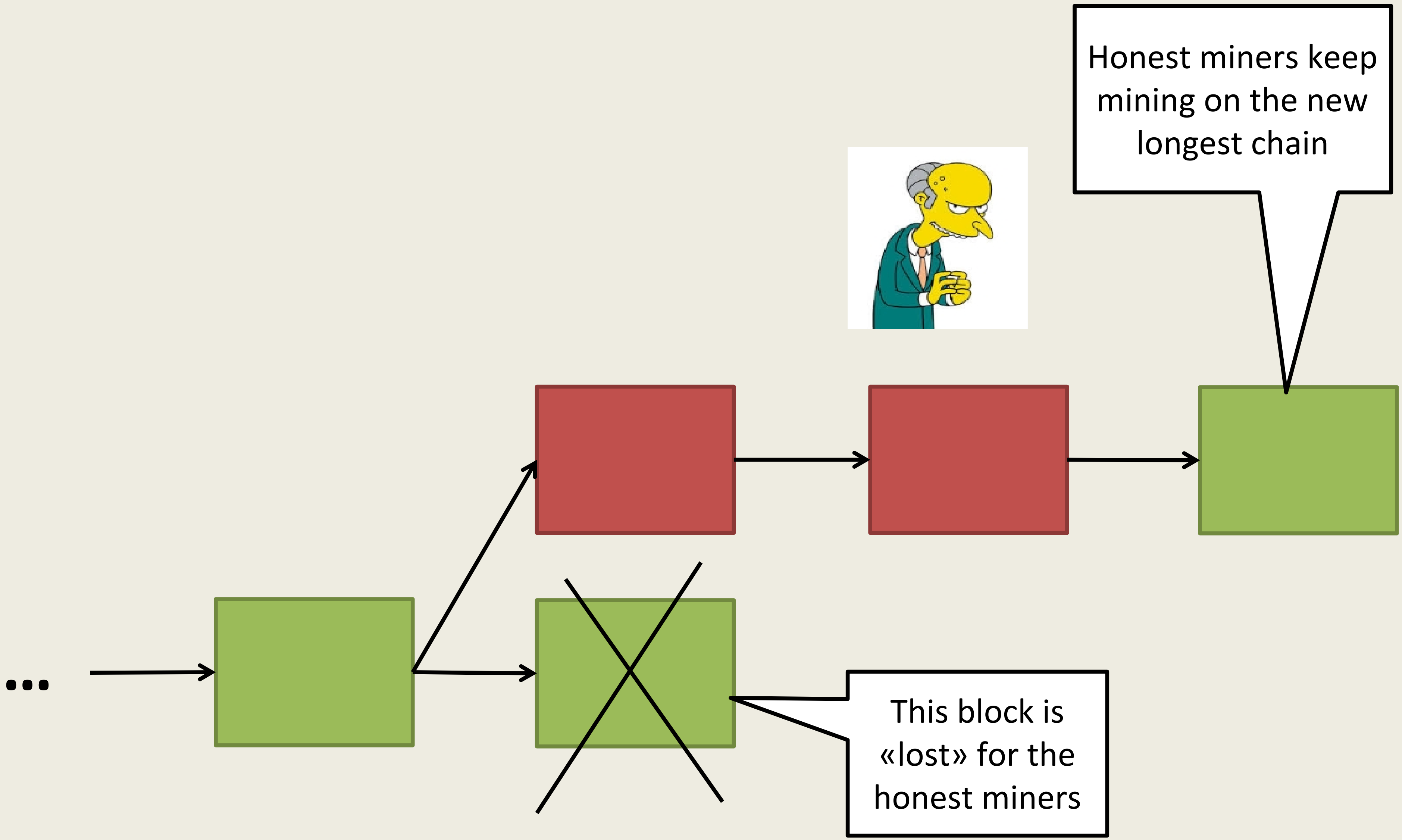
Who wants some satoshis?

- What are some implicit assumptions in the previous analysis?

Selfish Mining Attack **[ES2014]**

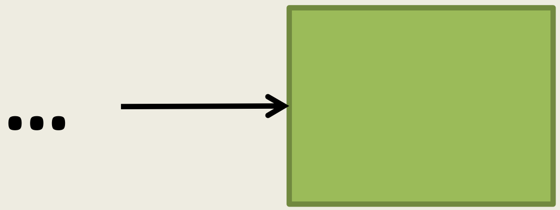
- **Idea:** The attacker will mine his blocks *privately* and release them at the right time so that honest miners *waste their computational power*.

Selfish Mining Attack



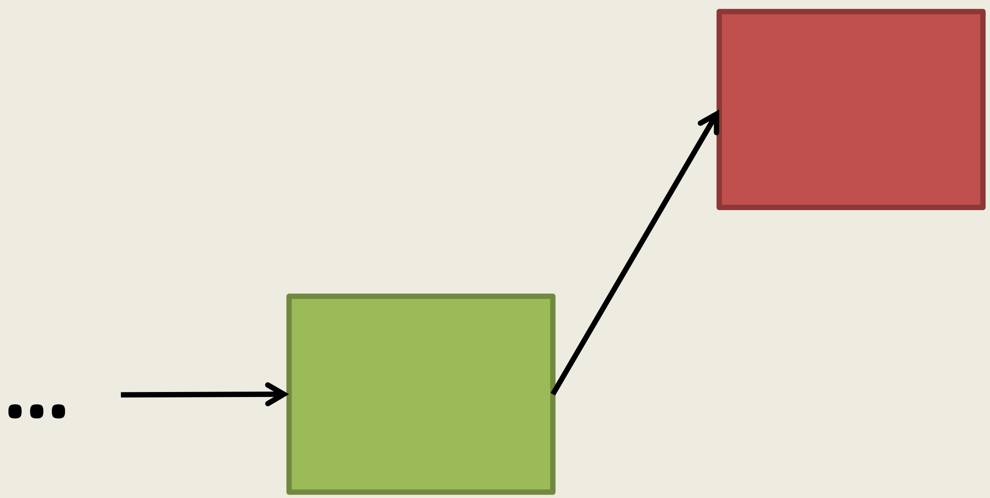
Selfish Mining Attack

State 0: only a single public chain



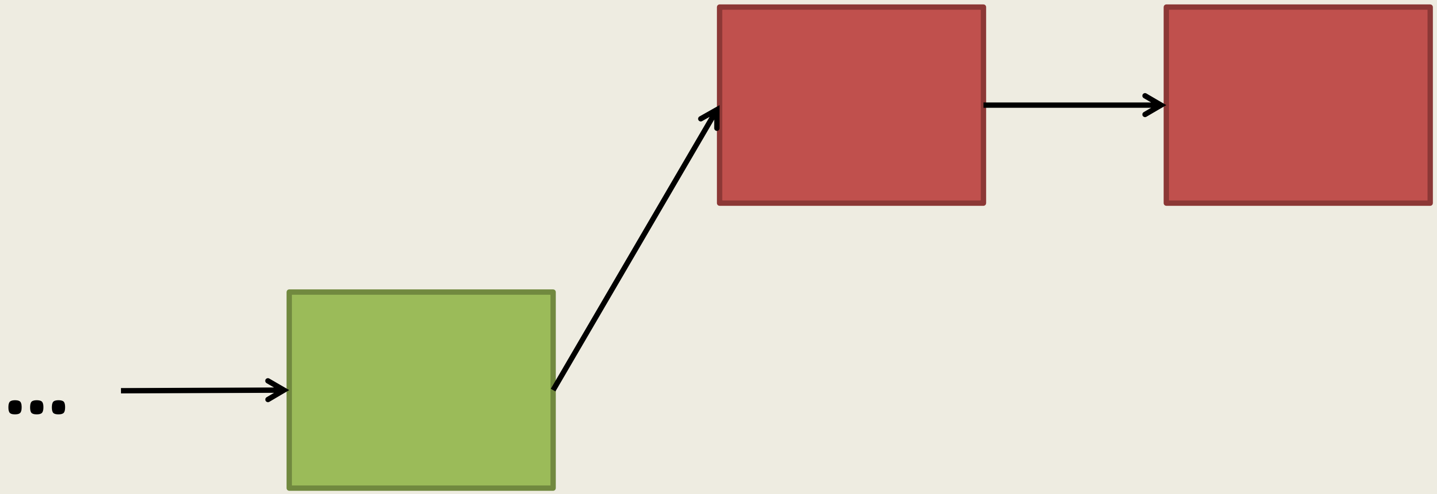
Selfish Mining Attack

State 1: Adversary manages to mine a block. The block is kept *private*.



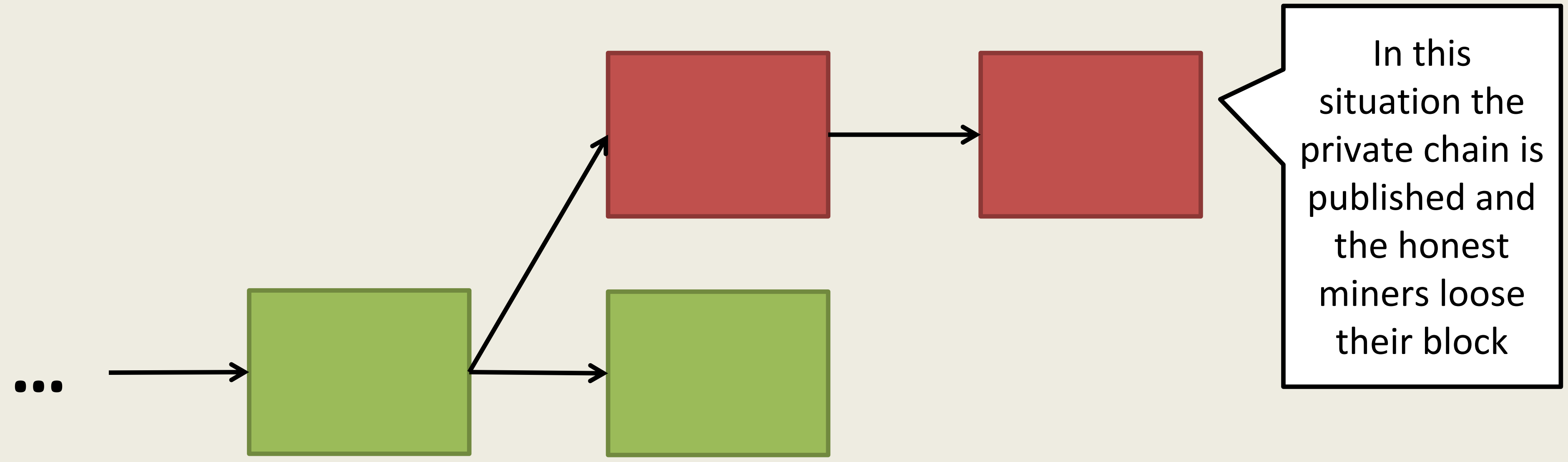
Selfish Mining Attack

State 2: Adversary manages to mine a block. The block is kept *private*.



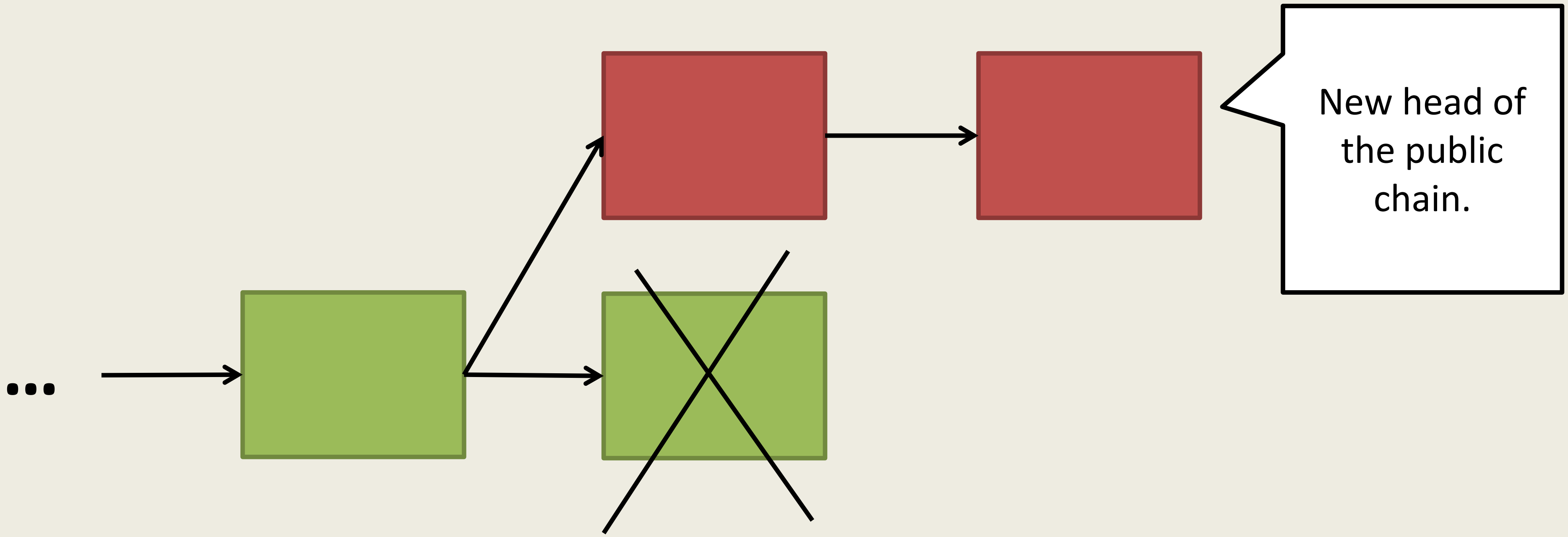
Selfish Mining Attack

State 2: Honest miners find a block



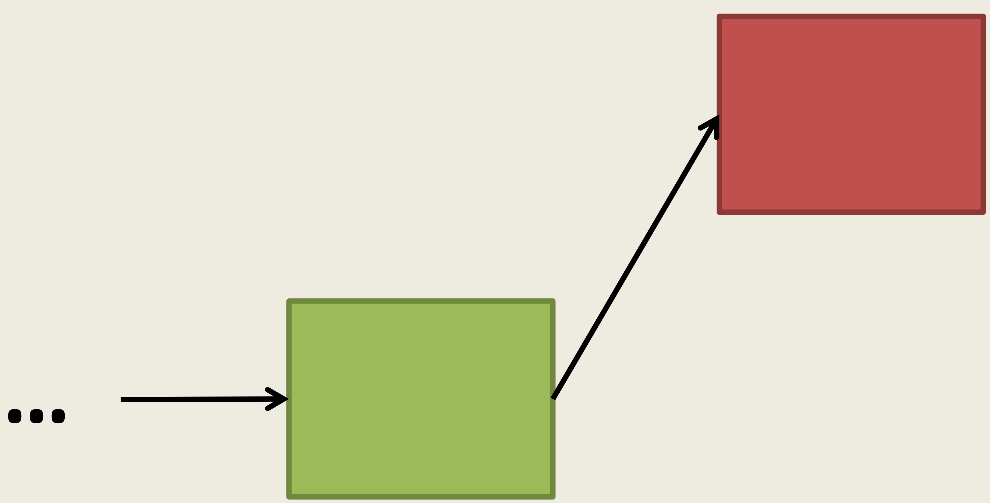
Selfish Mining Attack

State 0: After releasing the private chain, back to state 0.



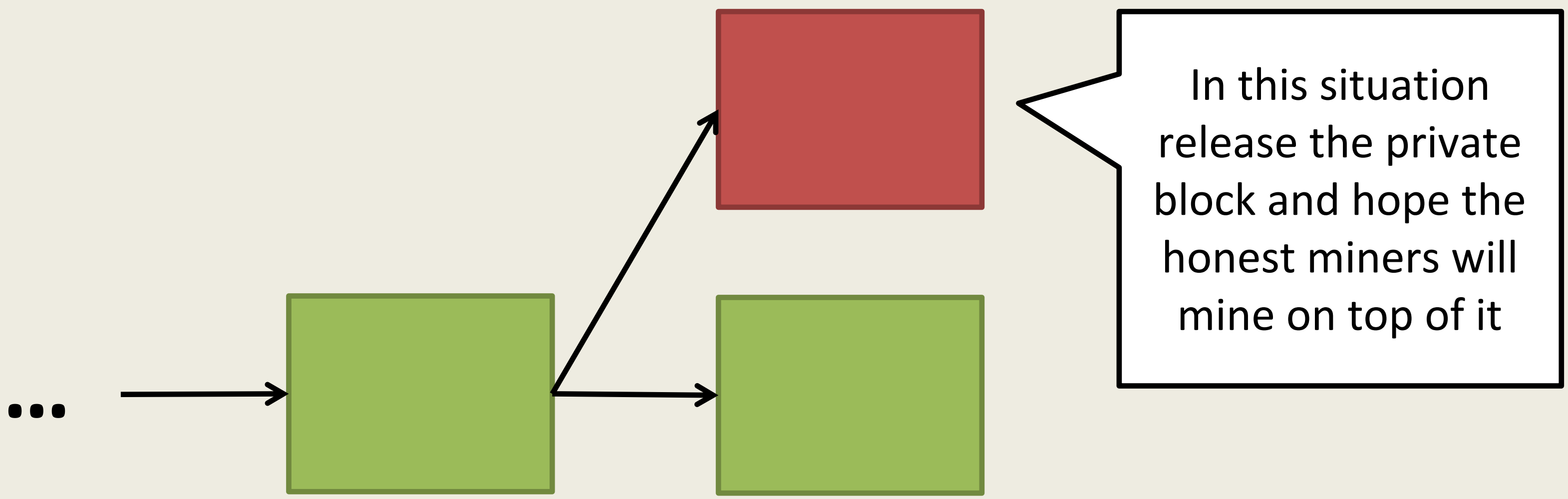
Selfish Mining Attack

State 1: Adversary manages to mine a block. The block is kept *private*.



Selfish Mining Attack

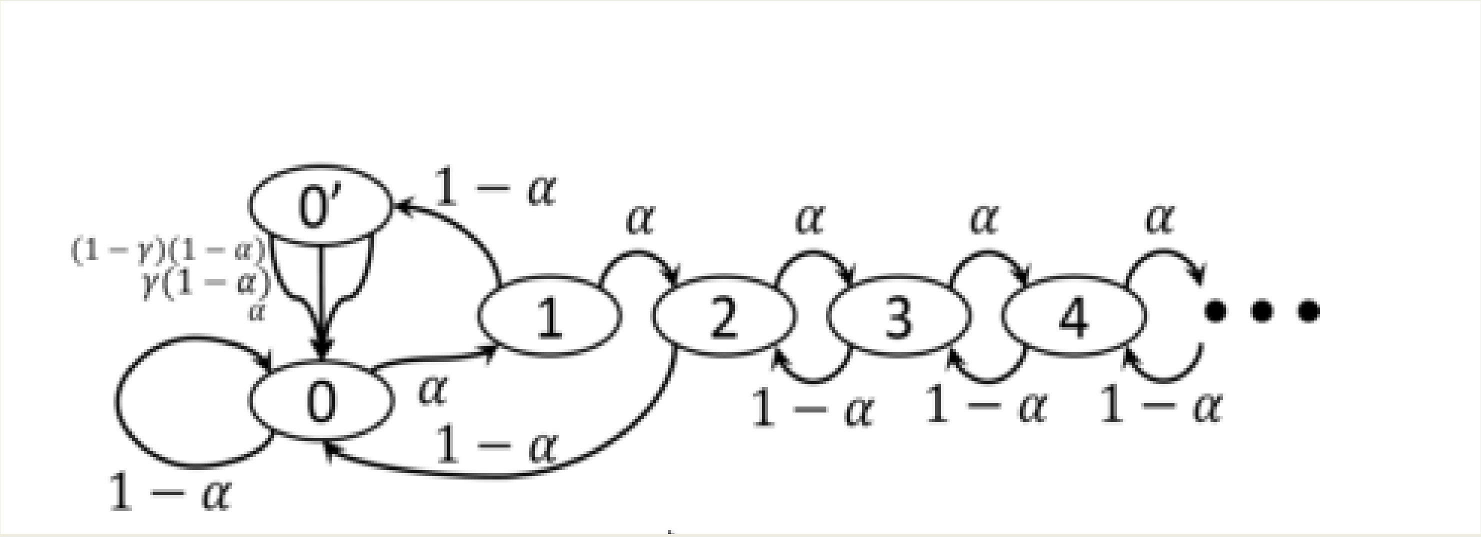
State 0': Honest miners and adversary's chain are competing



Selfish Mining Attack

α: Adversary's computational power

γ: Portion of honest miners that will mine on top of adversary's block



http://arxiv.org/pdf/1311.0243v1.pdf

Selfish Mining Attack

- Now we can compute the relative gain of the adversary

$$R_A = \frac{r_a}{r_a + r_h} = \frac{\alpha(1-\alpha)^2\big(4\alpha + \gamma(1-2\alpha)\big) - \alpha^3}{1 - \alpha(1 + (2-\alpha)\alpha)}$$

Who wants some satoshis?

- If everything were “fine”,
  how much should R_a be equal to?

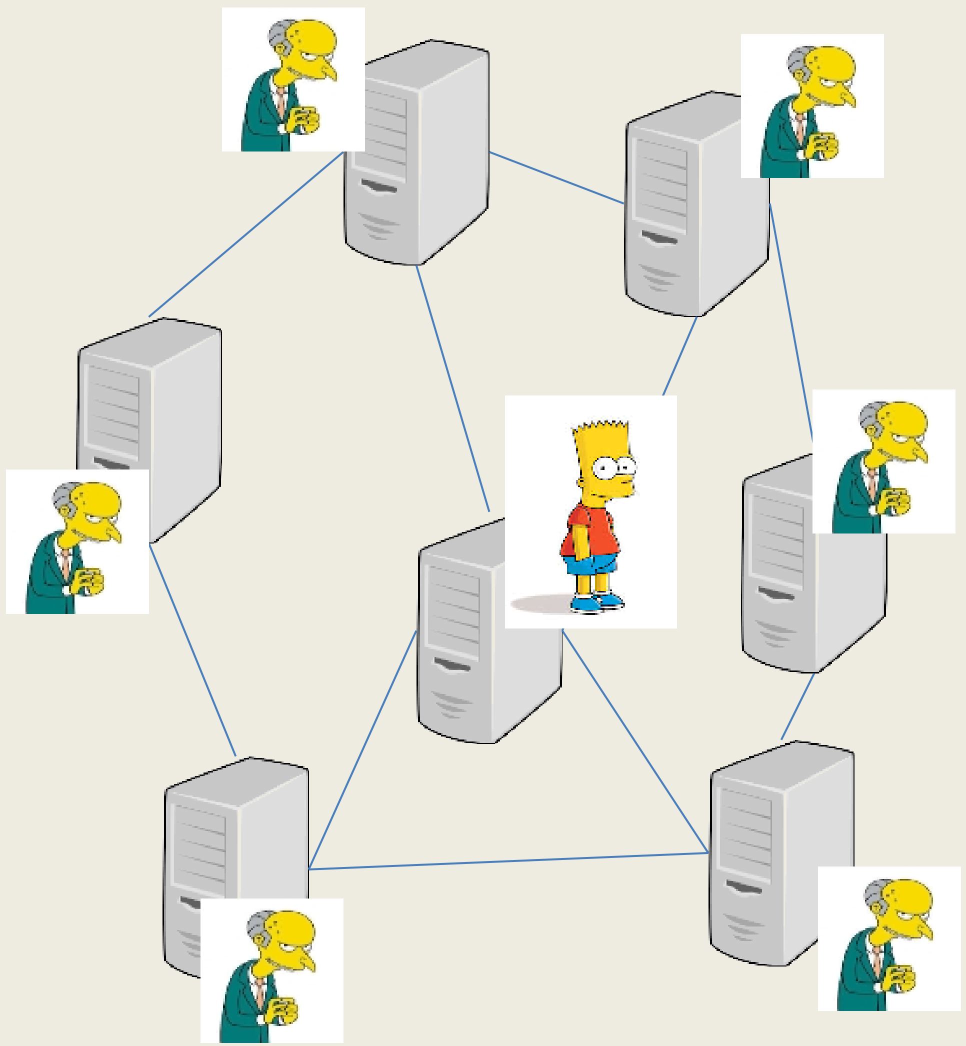
$$R_A = \frac{r_a}{r_a + r_h} = ???$$

Selfish Mining Attack

Majority is not enough!

- **Results:**
  - $\alpha > {}^{1}/_{4}$:
    the selfish mining strategy is more profitable than the honest strategy
  - Depending on γ this can be worse
    (i.e. the selfish mining strategy is always profitable
- **What is the problem?**
  - If miners are rational then they will prefer to join the adversary's pool => soon the adversary's pool will be

Eclipse Attack **[HKZG2015]**



The attacker surrounds the victim in the P2P network so that it can filter his view on the events.

Eclipse Attack

- **Mainly an implementation problem**
  - It is possible to populate the tables of peers of the victim
- **But with huge consequences as this attack can be used to leverage others**
  - Selfish mining
  - 51%
  - Double spending

Transaction Malleability

version		01 00 00 00
input count		01
input	previous output hash (reversed)	48 4d 40 d4 5b 9e a0 d6 52 fc a8 25 8a b7 ca a4 25 41 eb 52 97 58 57 f9 6f b5 0c d7 32 c8 b4 81
	previous output index	00 00 00 00
	script length	
	scriptSig	script containing signature
	sequence	ff ff ff ff
output count		01
output	value	62 64 01 00 00 00 00 00
	script length	
	scriptPubKey	script containing destination address
block lock time		00 00 00 00

- **Step 1:**
  Compute the unsigned transaction
- **Step 2:**
  Compute the signature of the transaction
- **Step 3:**
  Put the signature inside the transaction
- **Step 4:**
  Compute the hash of the signed transaction => this is the transaction ID

http://www.righto.com/2014/02/bitcoins-hard-way-using-raw-bitcoin.html

Transaction Malleability

version		01 00 00 00
input count		01
input	previous output hash (reversed)	48 4d 40 d4 5b 9e a0 41 eb 52 97 58 57 f9
	previous output index	00 00 00 00
	script length	
	scriptSig	script containing signature
	sequence	ff ff ff ff
output count		01
output	value	62 64 01 00 00 00 00 00
	script length	
	scriptPubKey	script containing destination address
block lock time		00 00 00 00

Problem: signature algorithm is probabilistic (ECDSA)
=> very easy to create «identical» transactions with different hashes

- **Step 1:**
  Compute the unsigned transaction
- **Step 2:**
  Compute the signature of the transaction
- **Step 3:**
  Put the signature inside the transaction
- **Step 4:**
  Compute the hash of the signed transaction => this is the transaction ID

http://www.righto.com/2014/02/bitcoins-hard-way-using-raw-bitcoin.html

Privacy with Bitcoin

«Standard» user id is replaced

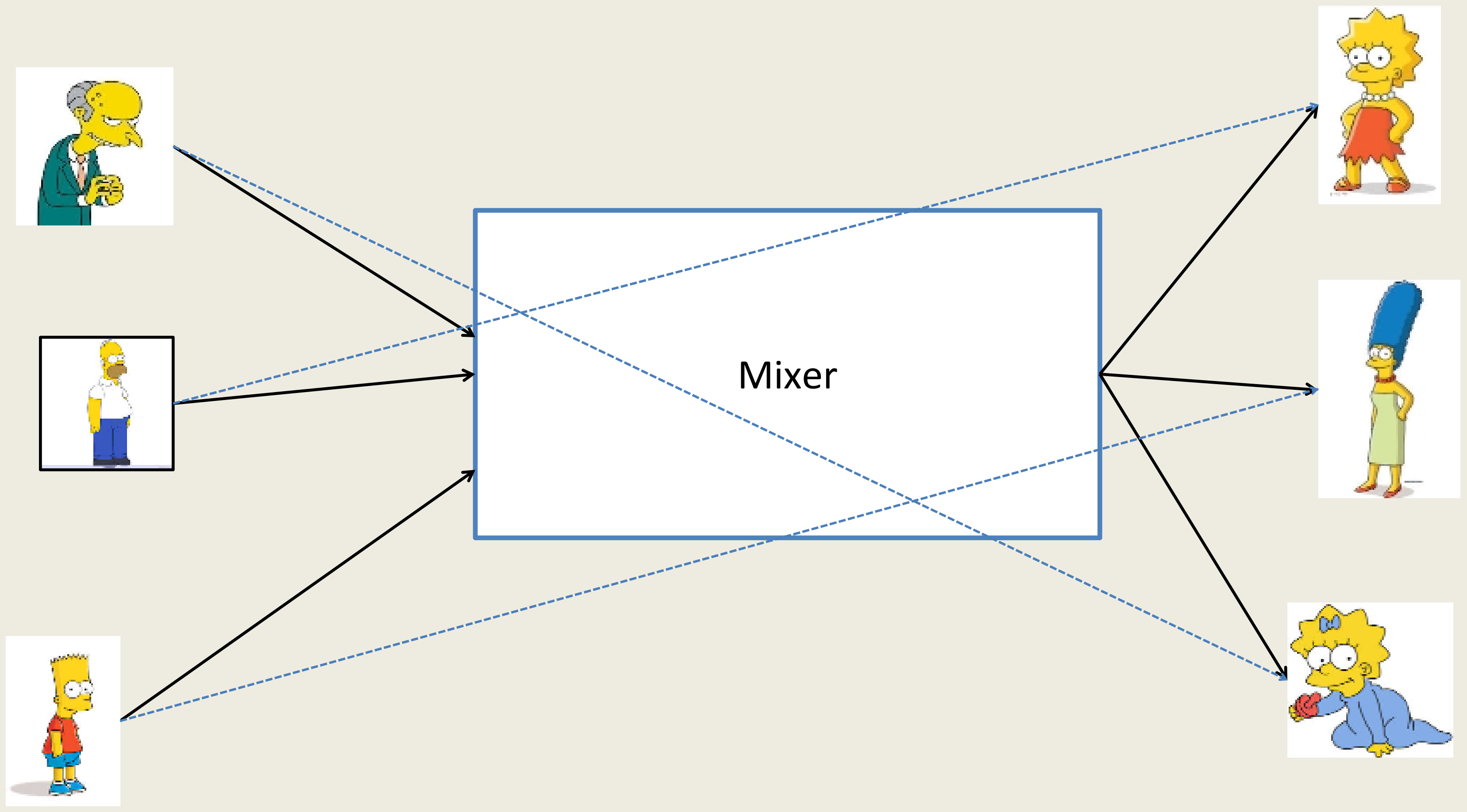
by a random looking sequence.

Bitcoin address
31uEbMgunupShBVTewXjtqbBv5MndwfXhb

However Bitcoin is not totally anonymous

Anonymity = **Pseudonymity** + **Unlinkability**

Improving Anonymity with mixers



Other initiatives: Zerocash **[BCG+2014]**

- + Uses of near to practical «universal» zero-knowlege proofs (ZK-SNARKs)
- + Provides a much higher level of anonymity than mixers
- - Requires to change bitcoin source code
- - Requires a trusted setup

Bitcoin Backbone protocol **[GKL2014]**

- **Purpose:** models the problem that occurs when the time of mining a block becomes small
- **Security model**: synchronous setting (*)

(*) Asynchronous setting is even more complex and analyzed in [PSS2016].

Bitcoin Backbone protocol

- **Common prefix property:**
  - Let f be the expected blocks mined per network synchronization round
  - if $\beta > \lambda\, \alpha$ where $\lambda > 1$ and $\lambda^2 - f\lambda + 1 \geq 0$
    then two honest participants will have the same chain if k blocks are pruned (i.e. the probability that it does not happen drops exponentially in k)

Bitcoin Backbone protocol

- **Chain quality property:**
  - if $\beta > \lambda\,\alpha$ where $\lambda > 1$ then the ratio of blocks in the chain of any honest player that are contributed by honest players is at least $\left(1 - \frac{1}{\lambda}\right)$

Caution: this definition does not exclude selfish mining attacks.

Open problems

- Anonymity
- Selfish Mining
- Alternatives to PoW
- Scalability
- Avoiding centralization in mining
- ASIC resistance proof of work
- Useful proof of work
- …

Thank you!

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