CS 731: Blockchain Technology And Applications

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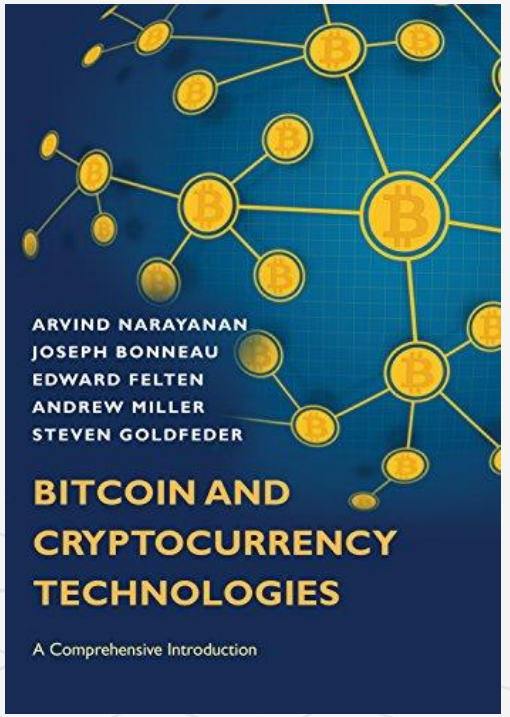
Acknowledgement

- The material of this lecture material is mostly due to Prof. Arvind Narayanan's Lecture at Princeton and his book on Bitcoin (Chapter 8 mostly)



Alternative Mining Puzzles

Puzzles are the core of Bitcoin

- Incentive system steers participants
- Basic features of Bitcoin's puzzle (recap)
  The puzzle is difficult to solve, so attacks are costly
  … but not too hard, so honest miners are compensated
- What other features could a puzzle have?

This lecture

- Alternative puzzle designs
  Used in practice, and speculative

- Variety of possible goals
  ASIC resistance, pool resistance, intrinsic benefits...

- Essential security requirements

Essential Puzzle Requirements

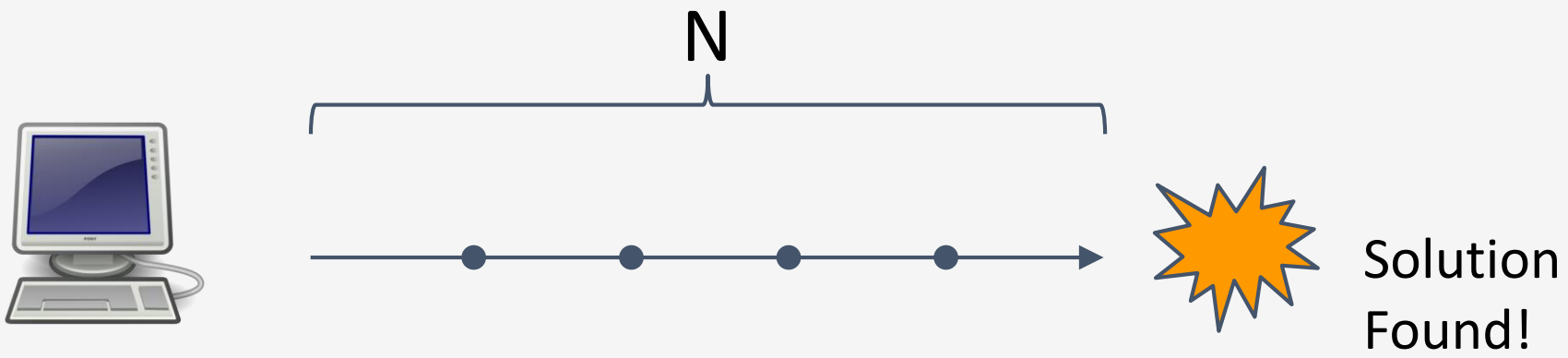
Puzzle requirements

- Cheap to Verify
- Adjustable difficulty
…

- Chance of winning is proportional to hashpower
  - Large players get only proportional advantage
  - Even small players get proportional compensation

Bad puzzle: a sequential puzzle

Consider a puzzle that takes N steps to solve
a “Sequential” Proof of Work

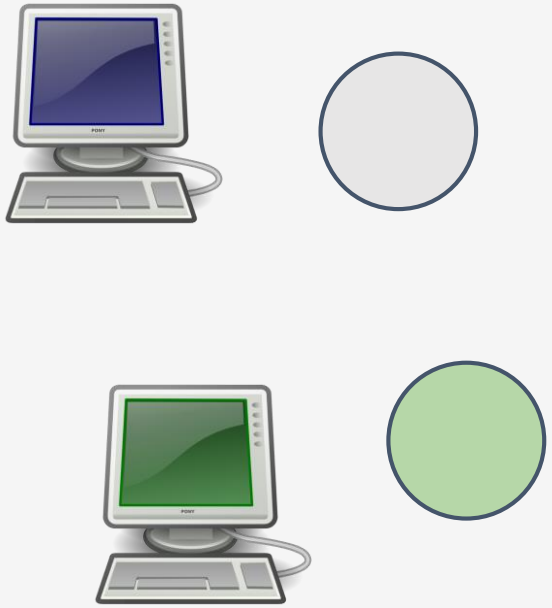


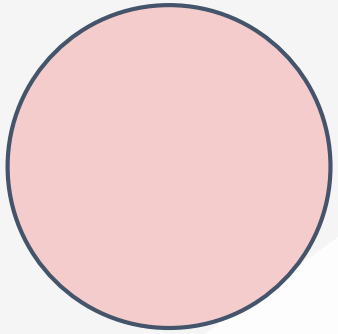
Bad puzzle: a sequential puzzle

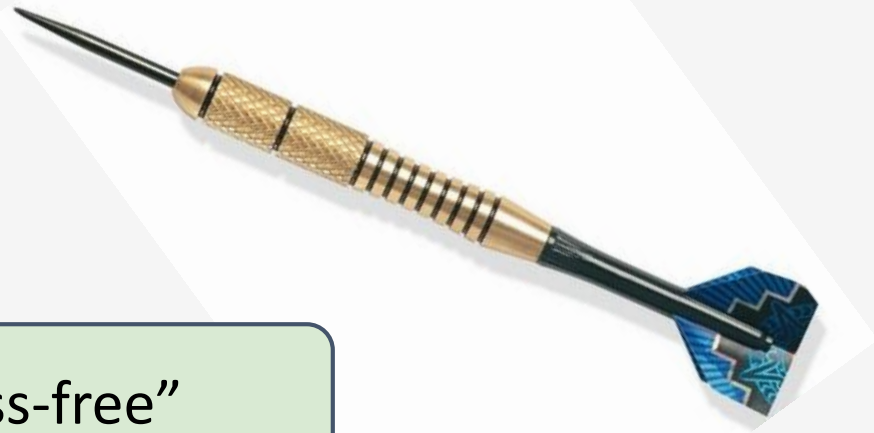
Problem: fastest miner **always** wins the race!

Solution Found!

Good puzzle → Weighted sample







This property is sometimes called “progress-free”

ASIC Resistant Puzzles

ASIC resistance - Why? (1 of 2)

Goal: Ordinary people with idle laptops, PCs, or even mobile phones can mine!

Lower barrier to entry

Approach: reduce the gap between custom hardware and general purpose equipment

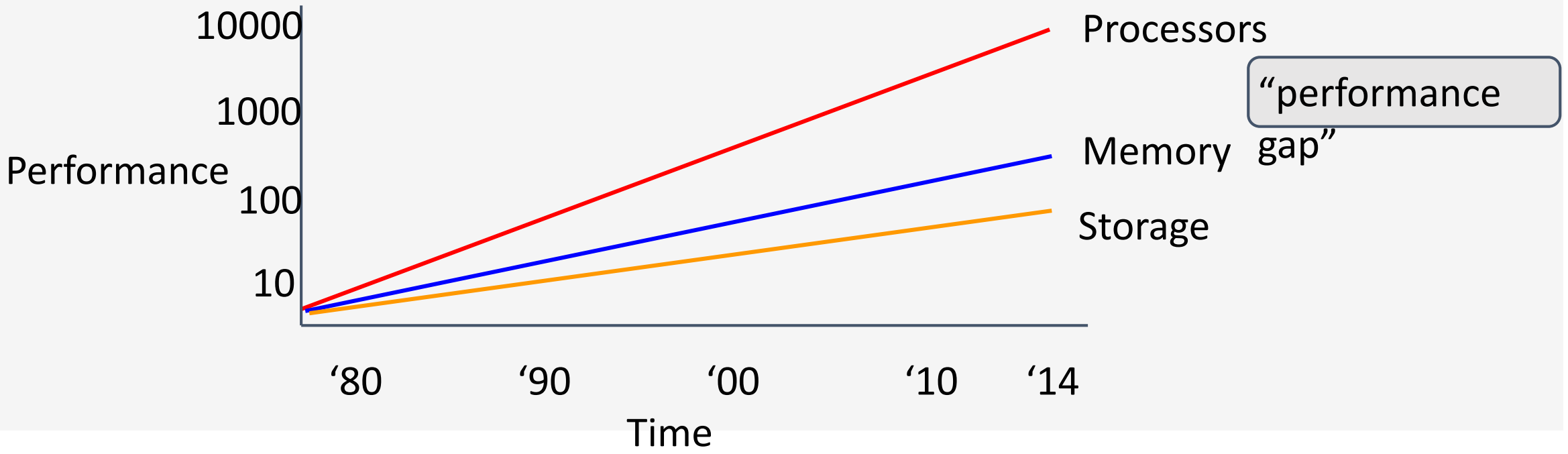
ASIC resistance - Why? (2 of 2)

Goal: Prevent large manufacturers from dominating the game
- "Burn-in" advantage
- In-house designs

Approach: reduce the "gap" between future hardware and the custom ASICs we already have

Memory hard puzzles

Premise: the cost and performance of memory is more stable than for processors



scrypt

Colin Percival, 2009

- Memory hard hash function
  Constant time/memory tradeoff
- Most widely used alternative Bitcoin puzzle
- Also used elsewhere in security (Password-hashing)

1. Fill memory with random values
2. Read from the memory in random order

scrypt - step 1 of 2 (write)

Input: **X**

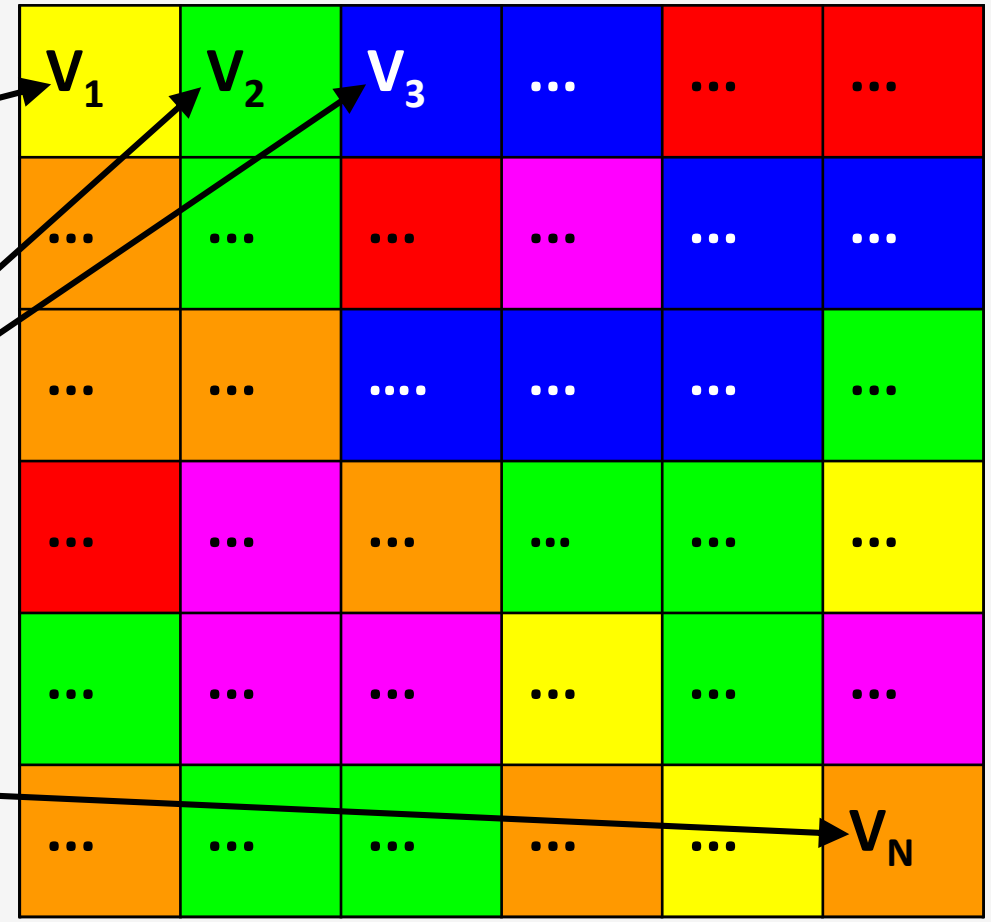
$V_1 = H(X)$

$V_2 = H(V_1) = H(H(X))$

$V_3 = H(V_2) = H^3(X)$

…

$V_N = H^N(x)$



scrypt - step 2 of 2 (read)

Input: X

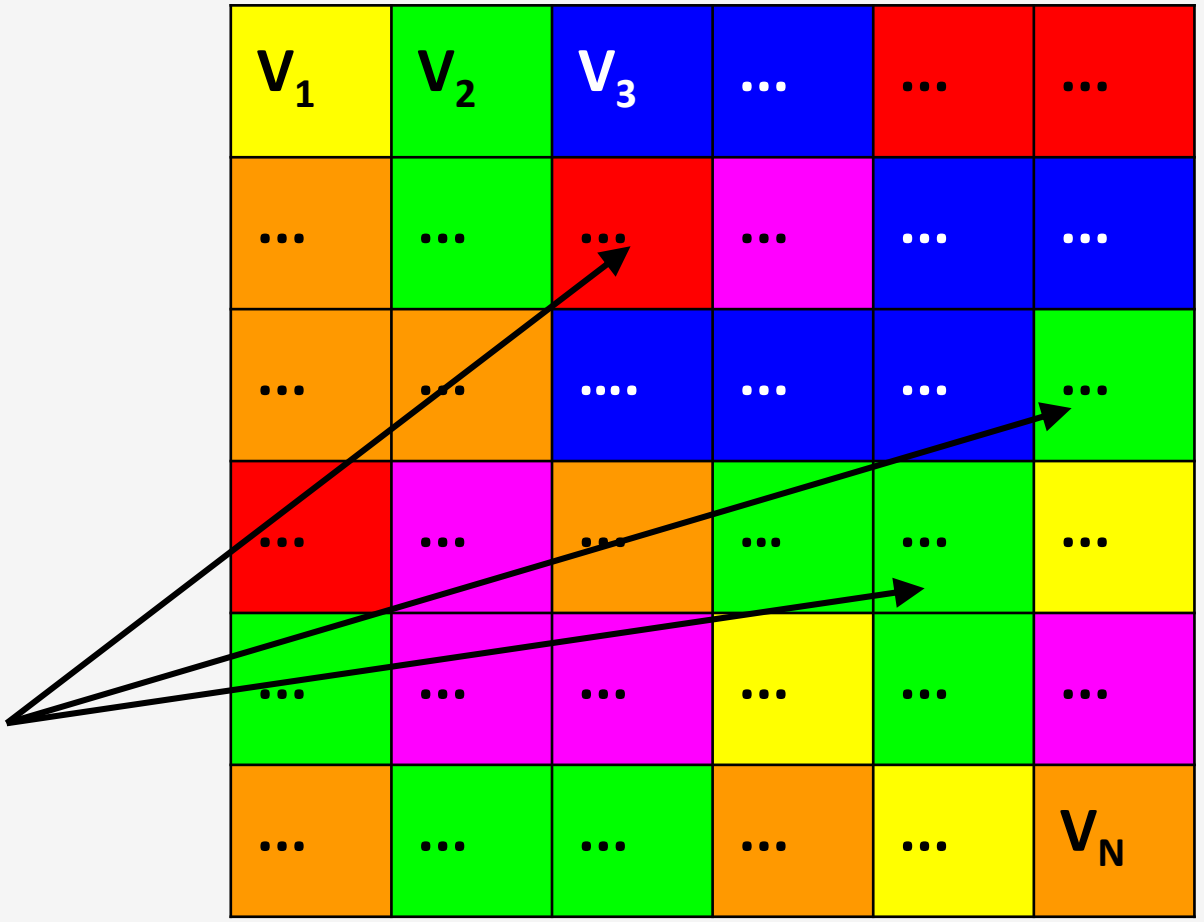
$\mathbf{A := H^{N+1}(X)}$

For N iterations:

$\mathbf{i := A \quad mod\ N}$

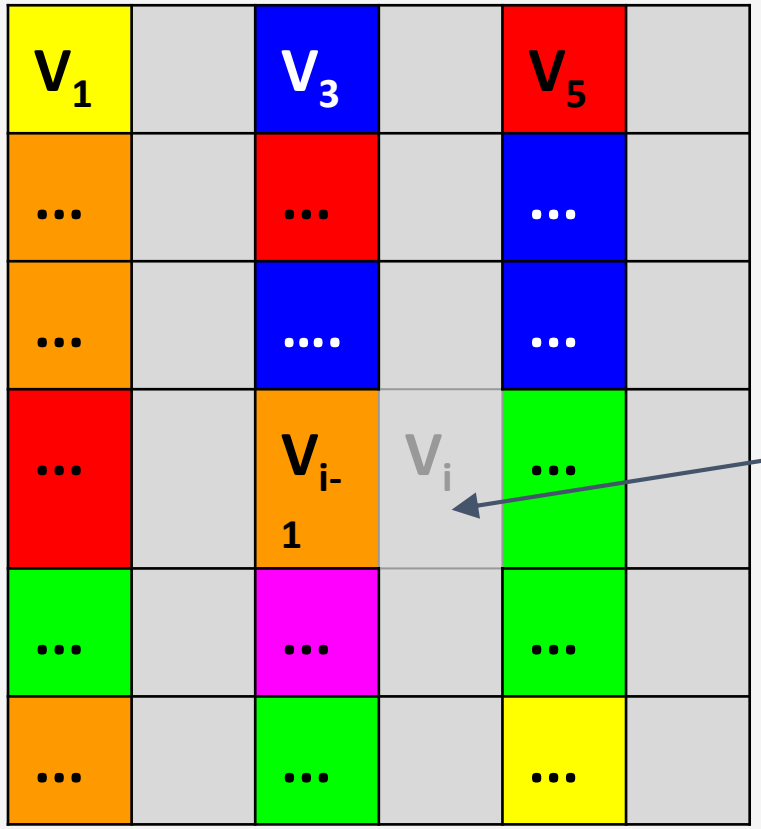
$\mathbf{A := H(A\ xor\ V_i)}$

Output: A



scrypt - time/memory tradeoff

Why is this memory-hard?
Reduce memory by half, 1.5x the # steps



Need to access V_i where i is even?

Access V_{i-1}

Compute $V_i = H(V_{i-1})$

scrypt

Disadvantages:

Also requires N steps, N memory to check

Is it actually ASIC resistant?

scrypt ASICs *are* already available

http://zeusminer.com/

Cuckoo hash cycles

John Tromp, 2014

Memory hard puzzle that's cheap to verify

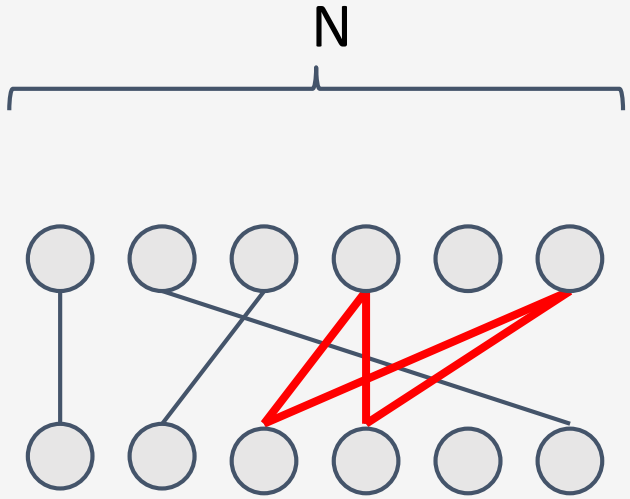
Input: X

For i = 1 to E:

```
  a := H0(X + i)
     b := N + H1(X + i)
   edge(a mod N, b mod N)
```

Is there a cycle of size K?

If so, Output: X, K edges



Even more approaches

- More complicated hash functions

X11: 11 different hash functions combined

- Moving target

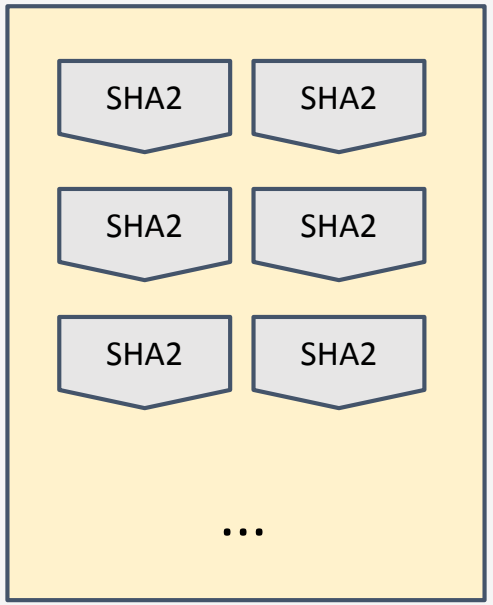
Change the puzzle periodically

Counter argument: SHA2 is fine

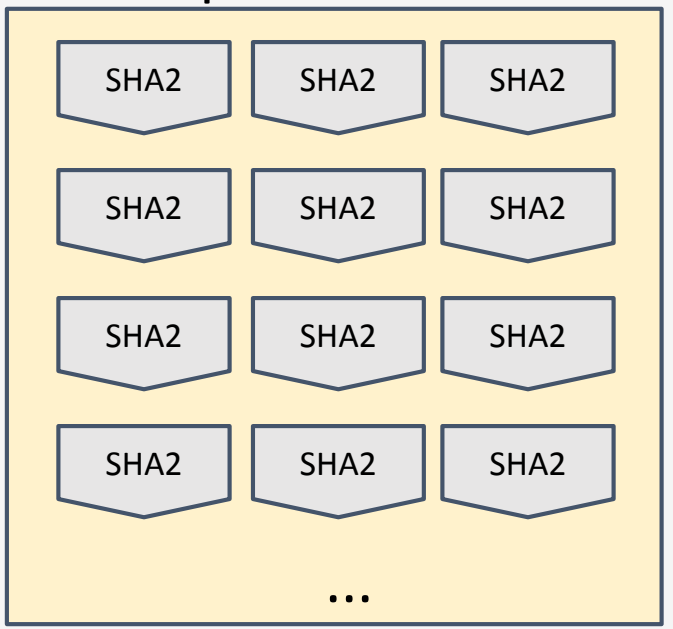
Bitcoin Mining ASICs aren't changing much
Big ASICs only marginally more performant than small ones

Ordinary SHA2 Circuit

Affordable ASIC



Expensive ASIC



Proof-of-useful-work

Recovering wasted work

Recall:

between 150 MW - 900 MW power consumed (as of mid-2014)

Natural question:

Can we recycle this and do something useful?

Candidates - needle in a haystack

- Natural choices:

- Protein folding (find a low energy configuration)
- Search for aliens (find an anomalous region of a signal)

These have been successful @Home problems

- Challenges:

- Randomly chosen instances must be hard

Who chooses the problem?

Primecoin

Sunny King, 2013

Puzzle based on finding large prime numbers

Cunningham chain:

$p_1, p_2, \ldots p_n$ where $p_{i+1} = 2. p_i + 1$

Each p_i is a large (probable) prime

p_1 is divisible by `H(prev || mrkl_root || nonce)`

Primecoin

- Many of the largest known Cunningham chains have come from Primecoin miners
- Hard problem? Studied by others (e.g., PrimeGrid)
- Usefulness? Maybe - at least one known use

Recovering wasted hardware

Estimate: more than $100M spent on customized Bitcoin mining hardware

This hardware investment is otherwise useless

Idea: a puzzle where hardware investment is useful, even if the work is wasted?

Permacoin - Mining with storage

Miller et al., 2014

Bitcoin

Permacoin

Side effect:
Massively distributed, replicated storage system

Permacoin

Assume we have a large file **F** to store

For simplicity: **F** is chosen globally, at the beginning, by a trusted dealer

Each user stores a random subset of the file

Storage-based puzzle

1. Build a Merkle tree, where each leaf is a segment of the file

2. Generate a public signing key pk, which determines a random subset of file segments

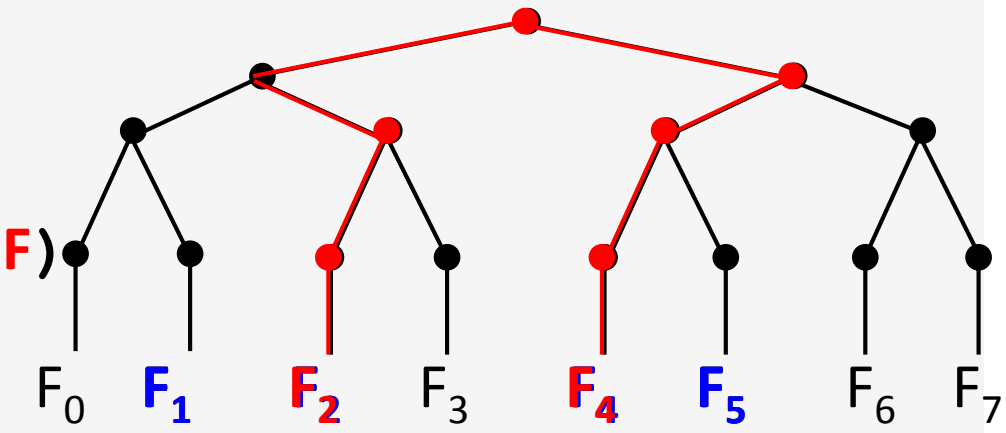
F_1 F_2 F_4 F_5

3. Each mining attempt:

F_2 F_4

a) Select a random nonce
b) h1 := H(prev || mrkl_root || PK || nonce)
c) h1 selects *k* segments from subset

d) h2 := H(prev || mrkl_root || PK || nonce || F)
e) Winner if h2 < TARGET



Reducing Bitcoin's "honesty" cost

"Honest" miners validate every transaction

Validation requires the UTXO database ~200MB

Maintaining the UTXO database doesn't pay

Idea: use Permacoin to reward UTXO storage

Summary

- Useful proof-of-work is a natural goal

(while maintaining security requirements)

- The benefit must be a pure public good
- Viable approaches include storage, prime-finding, others may be possible
- Realized benefit so far has been limited

Nonoutsourceable Puzzles

Large mining pools are a threat

- Bitcoin's core value is decentralization
- If power is consolidated in a few large pools, the operators are targets for coercion/hacking
- Position: large pools should be discouraged!
  Analogy to voting: It's illegal (in US) to sell your vote

Hacking, Distributed

It's Time For a Hard Bitcoin Fork

Ittay Eyal, and Emin Gün Sirer Friday June 13, 2014 at 02:05 PM

A Bitcoin mining pool, called GHash and operated by an anonymous entity called CEX.io, just reached 51% of total network mining power today. Bitcoin is no longer decentralized. GHash can control Bitcoin transactions.

Is This Really Armageddon?

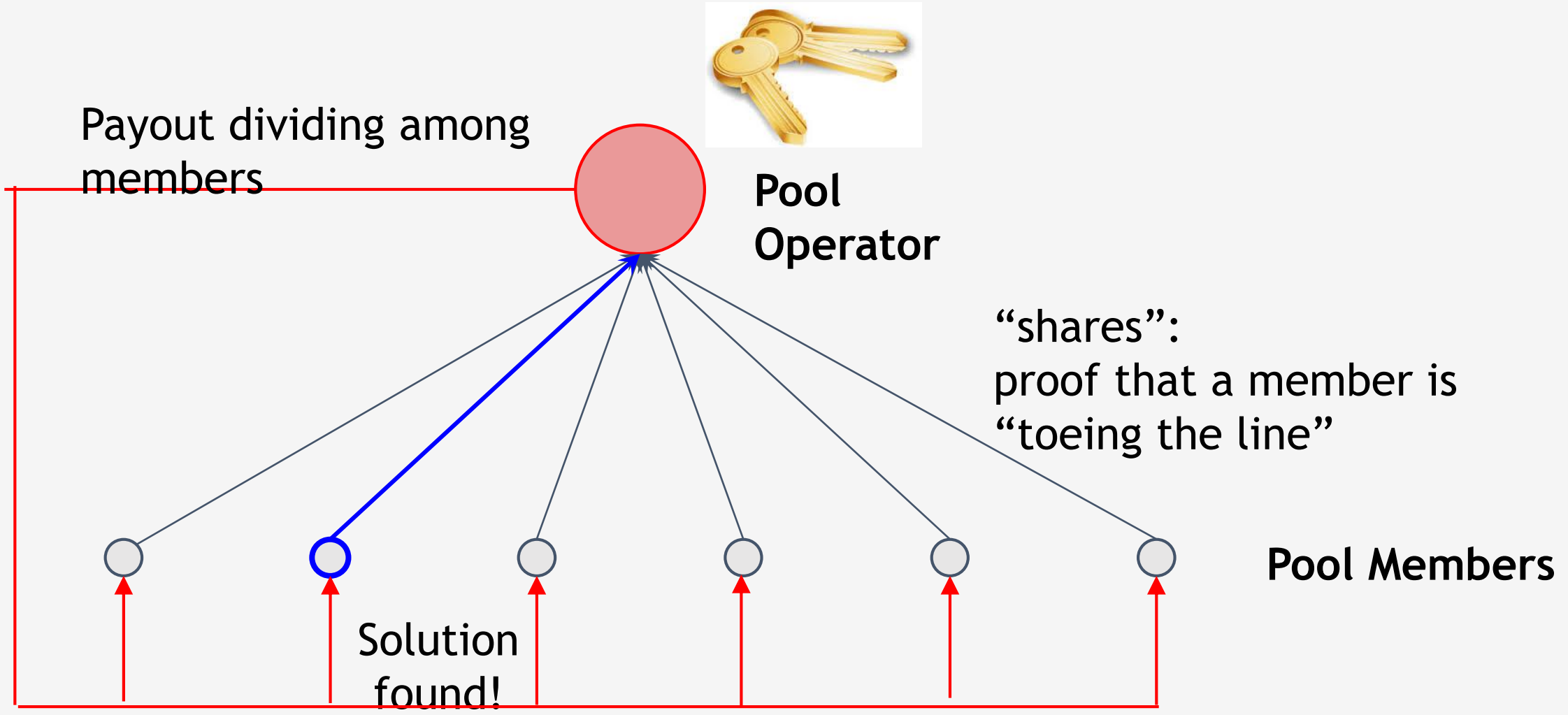
Yes, it is. GHash is in a position to exercise complete control over which

Observation:

Pool participants don’t trust each other

Pools only work because the “shares” protocol lets members ***prove*** cooperation

Standard Bitcoin mining pool



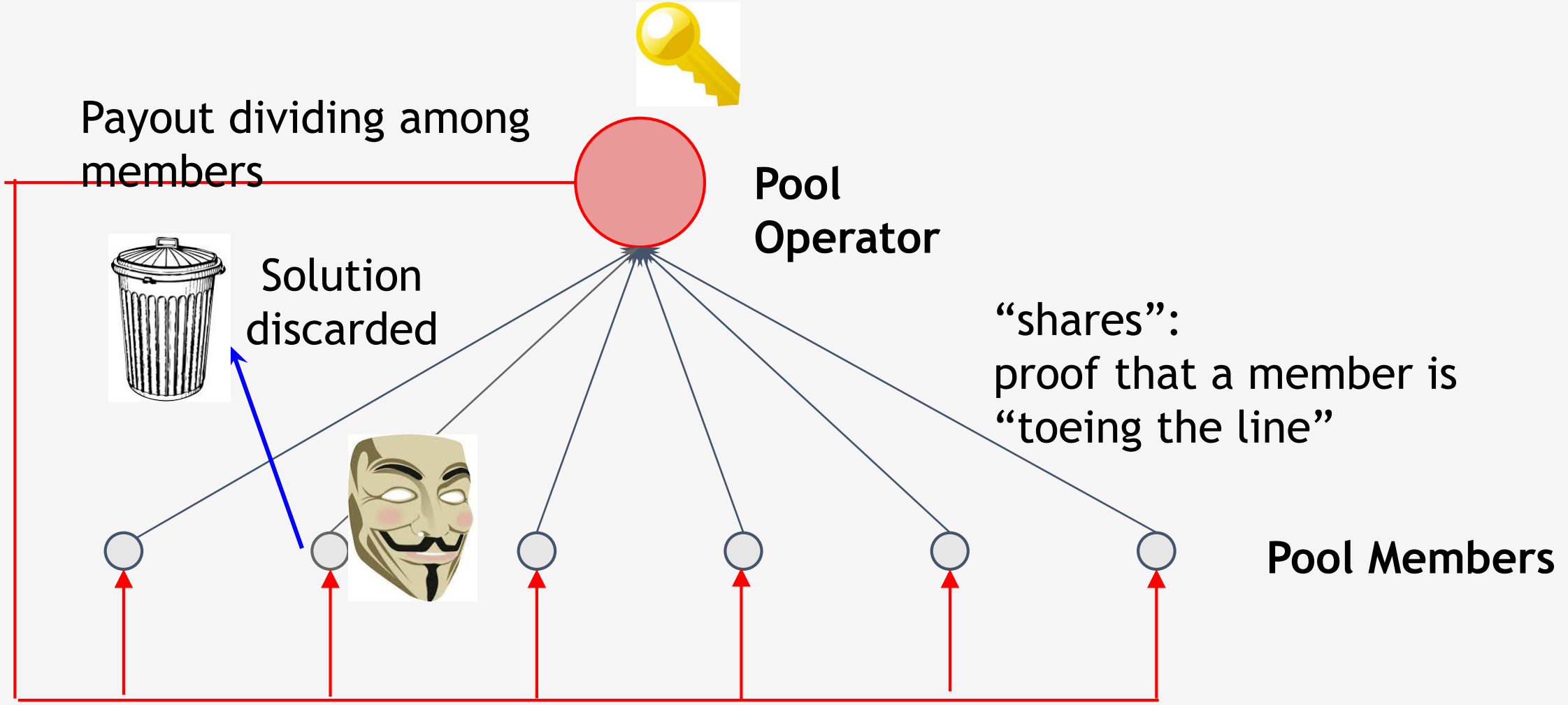
The Vigilante Attack

Suppose a Vigilante is angry with a large pool

He submits “shares” like normal….
… but if he finds a real solution, discards it

Pool output is reduced, Vigilante loses a little

The Vigilante Attack

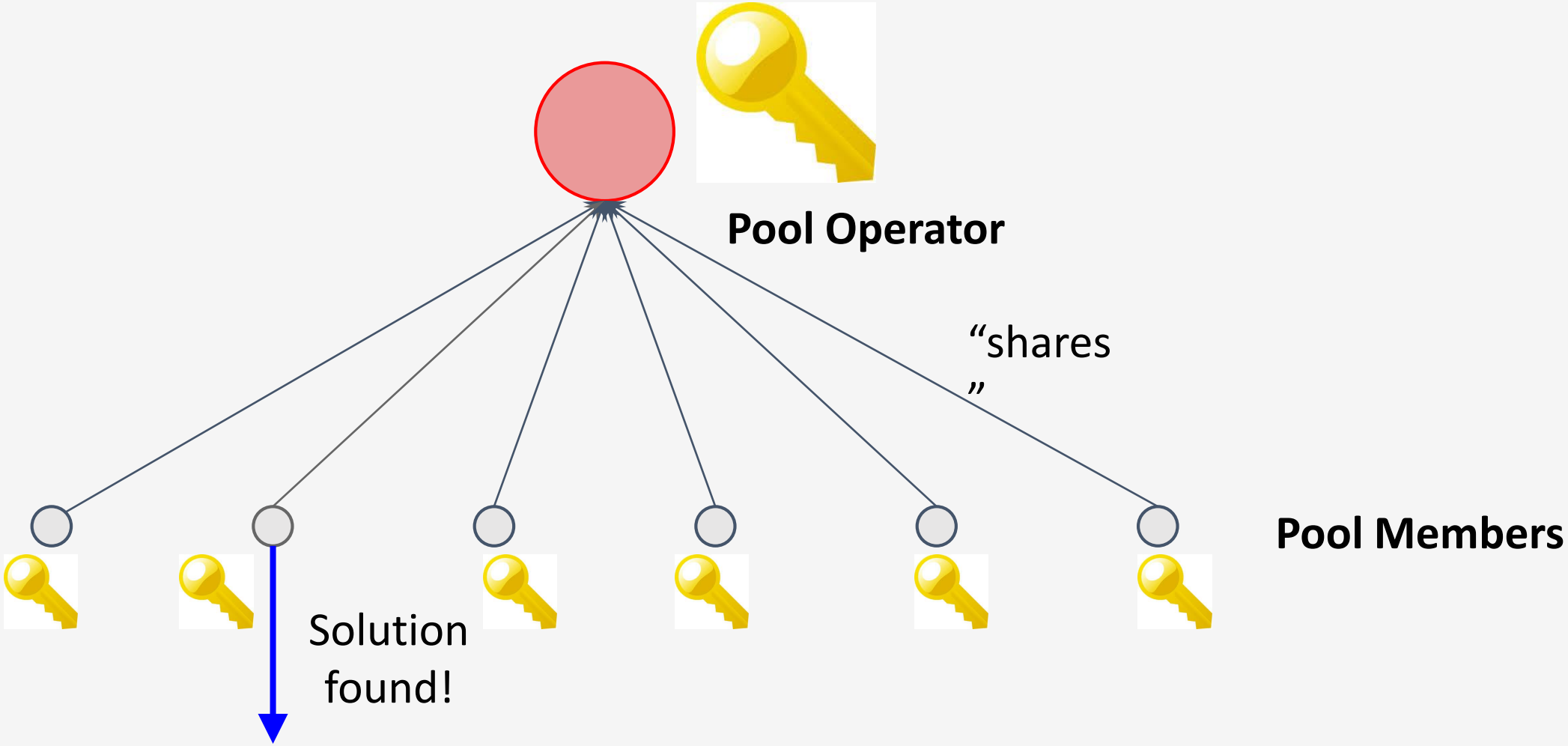


Encouraging the Vigilante

Whoever ***FINDS*** a solution spends the reward

Approach:
- searching for a solution requires ***SIGNING,*** not just hashing. (Knowledge of a private key)
- Private key can be used to spend the reward

Encouraging the Vigilante



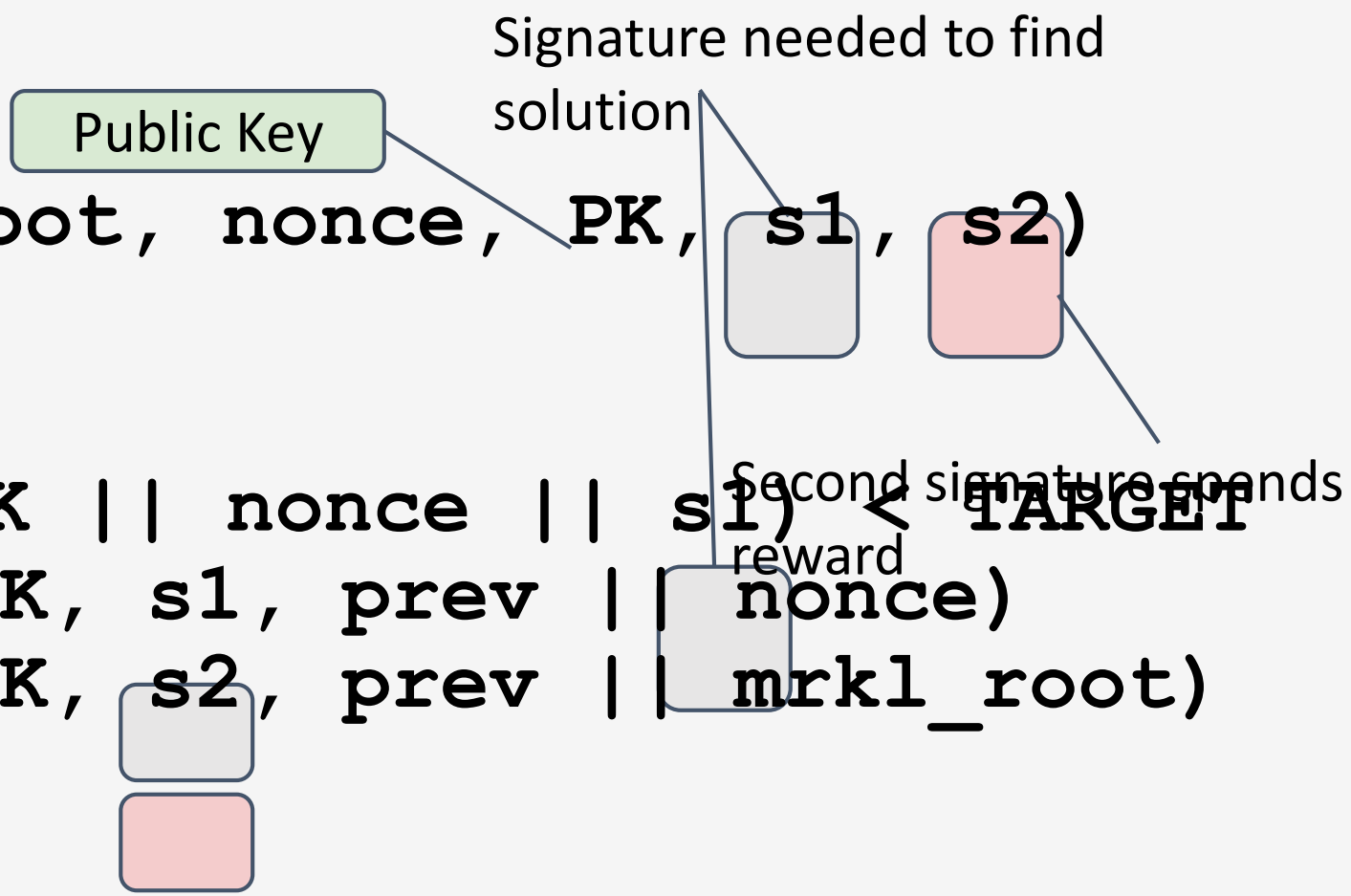
Nonoutsourceable puzzle

Solution:

```
(prev, mrkl_root, nonce, PK, s1, s2)
```

such that:

```
H(prev || PK || nonce || s1) < TARGET
VerifySig(PK, s1, prev || nonce)
VerifySig(PK, s2, prev || mrkl_root)
```



Nonoutsourceable puzzle concerns

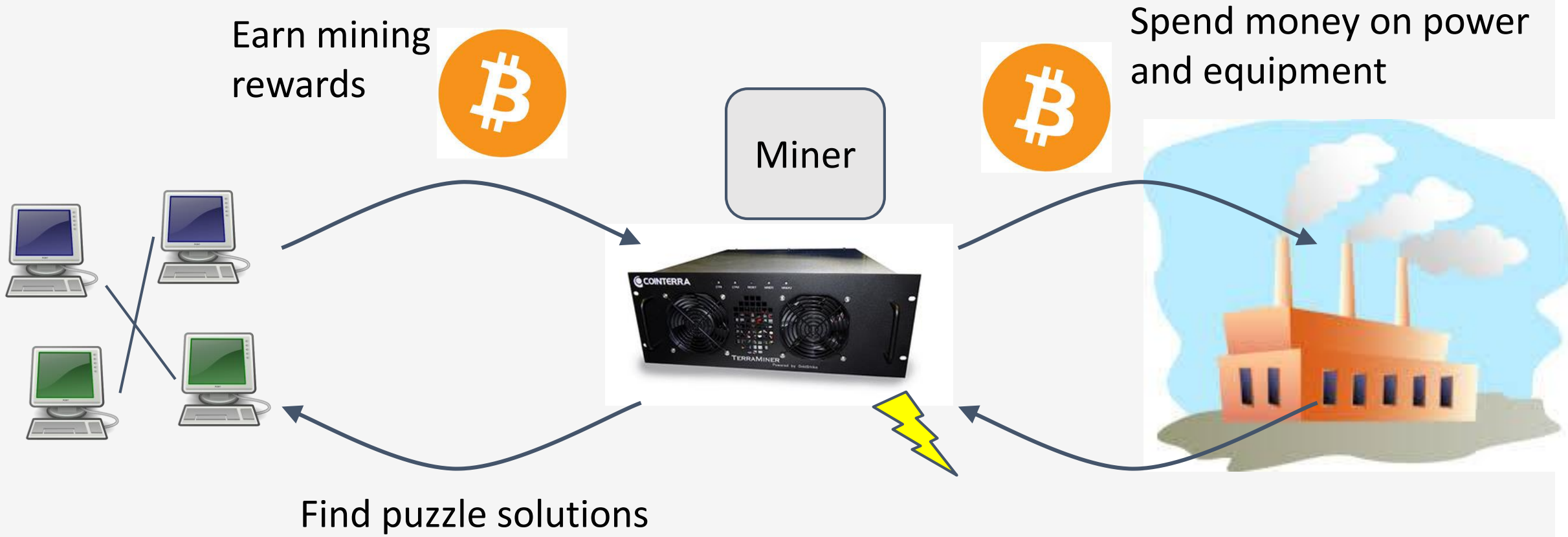
- This puzzle discourages ALL pools
including harmless decentralized P2Pools

- Other forms of outsourcing
might drive pool members to hosted mining

Proof-of-Stake
“Virtual Mining”

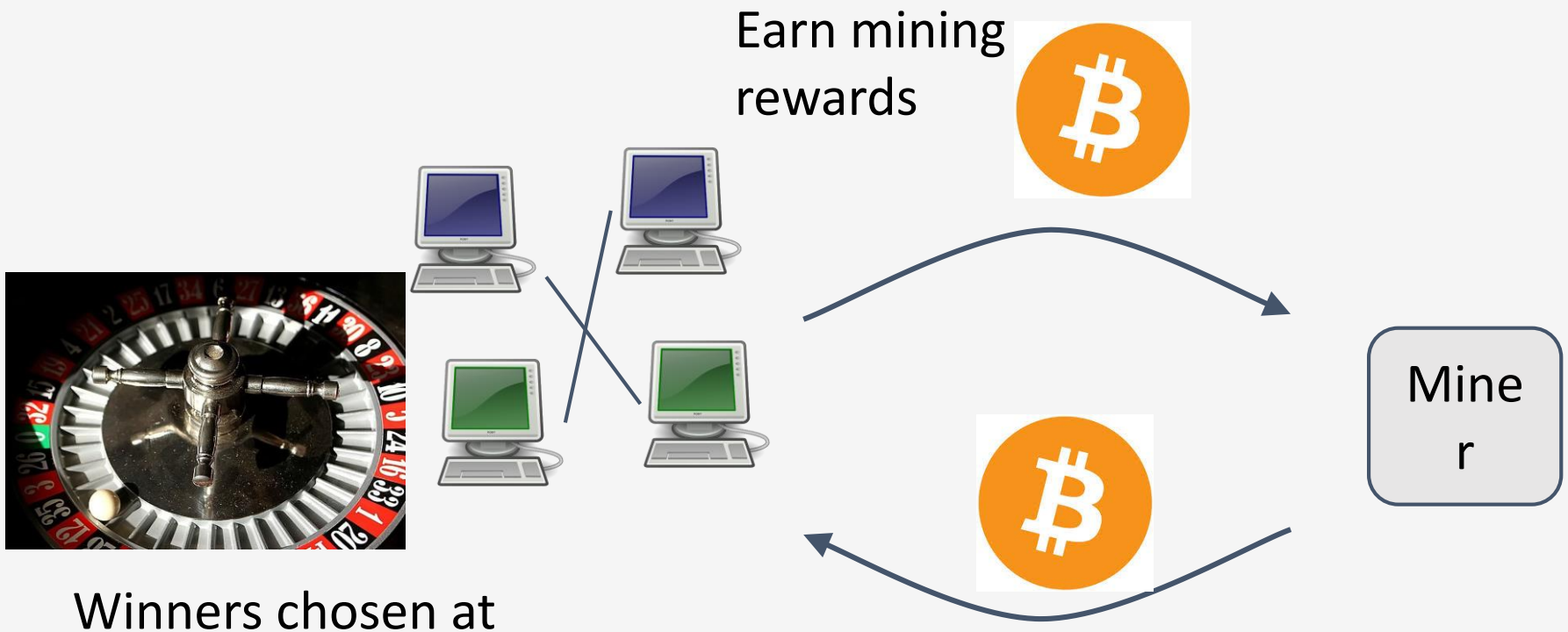
Mining has an unnecessary step

Proof-of-Work Mining:



Mining has an unnecessary step

Virtual Mining:

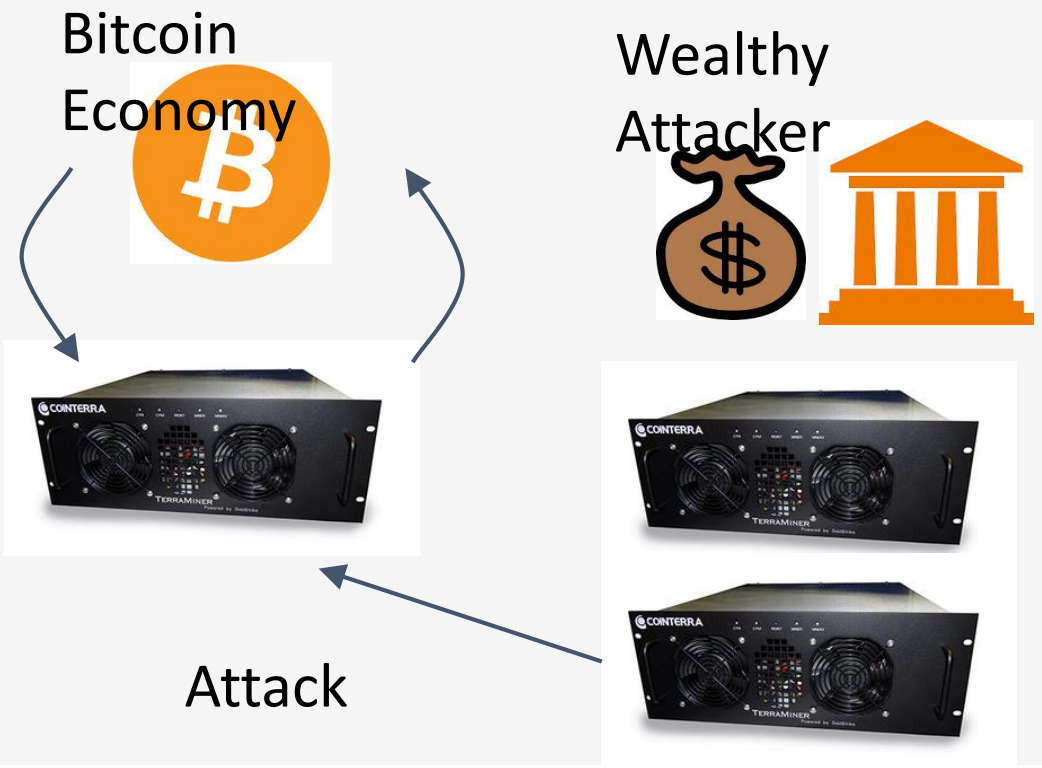


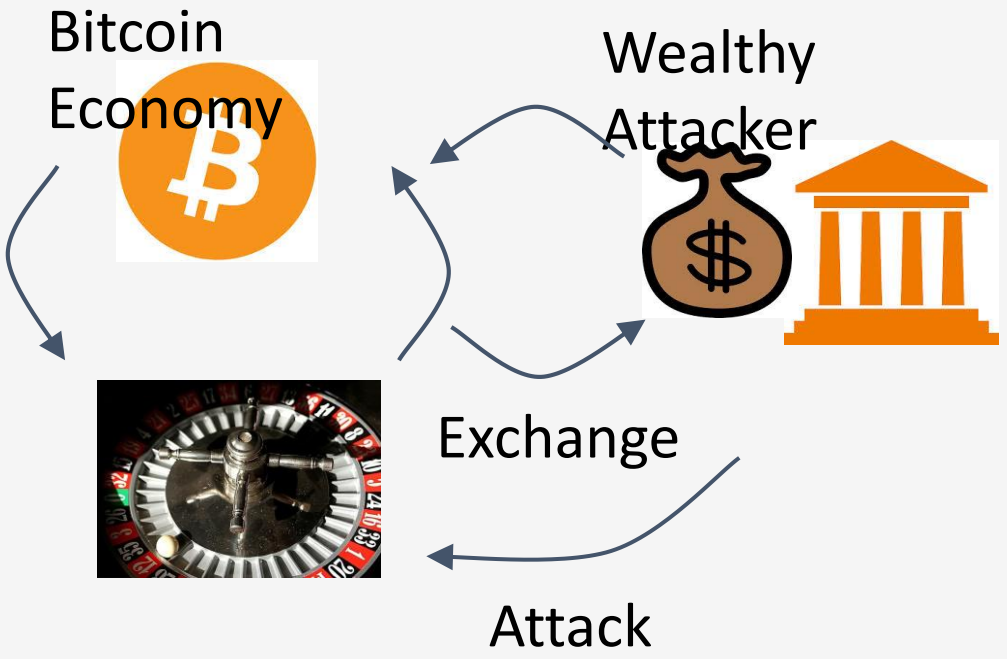
Potential benefits

- Lower overall costs
  - No harm to the environment
- Savings distributed to all coin holders
- Stakeholder incentives - good stewards?
- No ASIC advantage
- 51% attack is even harder

51% attack prevention

The Bitcoin economy is smaller than the world
Wealth *outside* Bitcoin has to move *inside*





Variations of Virtual Mining

- Proof-of-Stake: “Stake” of a coin grows over time as long as the coin is unused
- Proof-of-Burn: mining with a coin destroys it
- Proof-of-Deposit: can reclaim a coin after some time
- Proof-of-Activity: any coin might be win (if online)

Open Questions with Virtual Mining

Is there any security that can only be gained by consuming “real” resources?

- If so, then “waste” is the cost of security
- If not, then PoW mining may go extinct

Conclusion

- Many possible design goals
  - Prevent ASIC miners from dominating
  - Prevent large pools from dominating
  - Intrinsic usefulness
    - Eliminate the need for mining hardware at all
- Best tradeoff is unclear for now
- Outlook: alternatives will coexist for the near future