Lecture 8

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

Lecture 8.1:

Essential Puzzle Requirements

Puzzle requirements

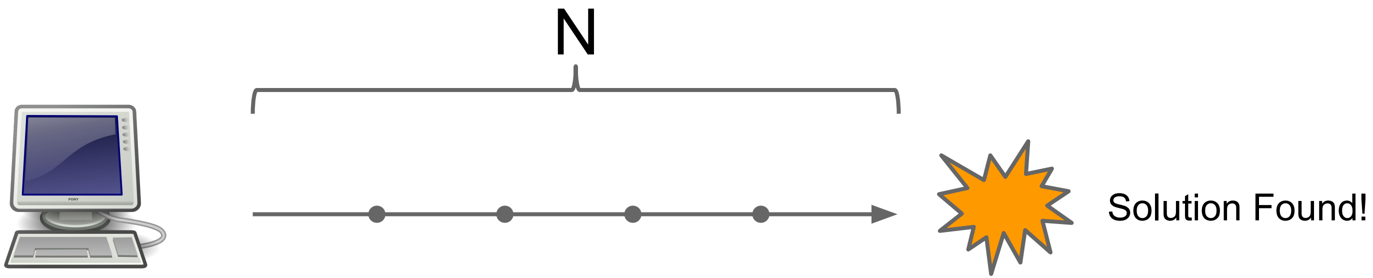
- Cheap to Verify
- Adjustable difficulty

…

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

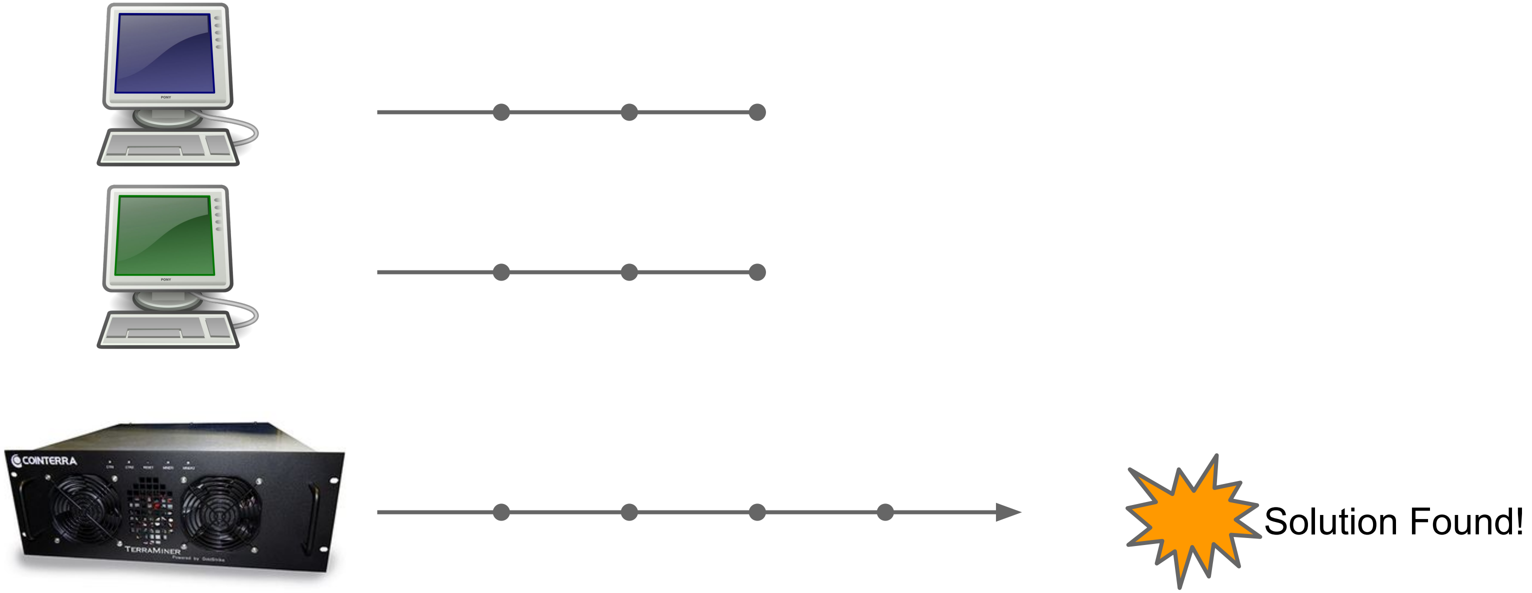
Bad puzzle: a sequential puzzle

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

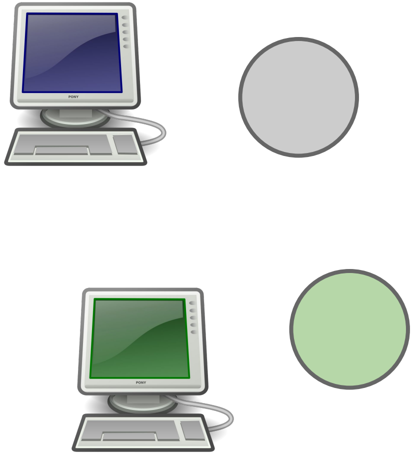


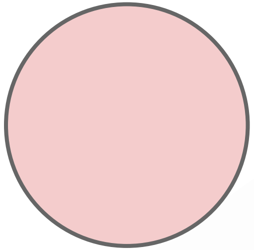
Bad puzzle: a sequential puzzle

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



Good puzzle → Weighted sample





This property is sometimes called “progress-free”

Lecture 8.2:

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)

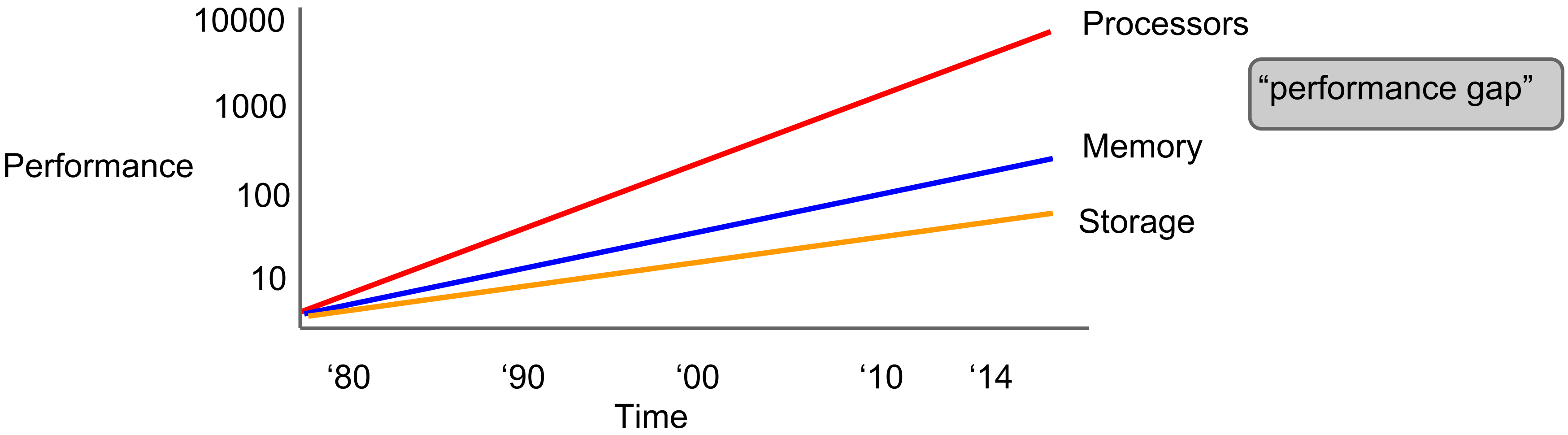
Goal: Prevent large manufacturers from dominating the game

- "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 (PW-hashing)

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

scrypt - step 1 of 2 (write)

Input: $\mathtt{x}$

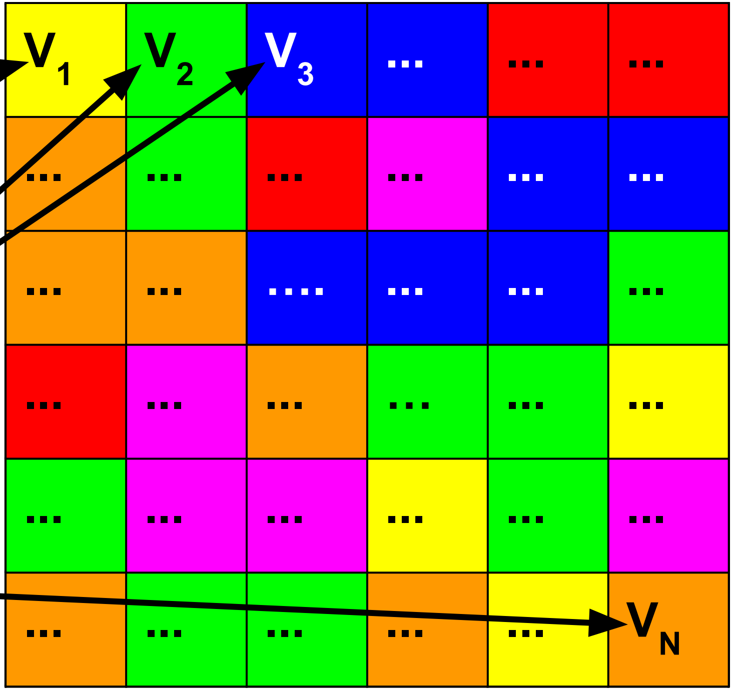
$V_1 = H(X)$

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

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

…

$V_N = H^N(x)$



scrypt - step 2 of 2 (read)

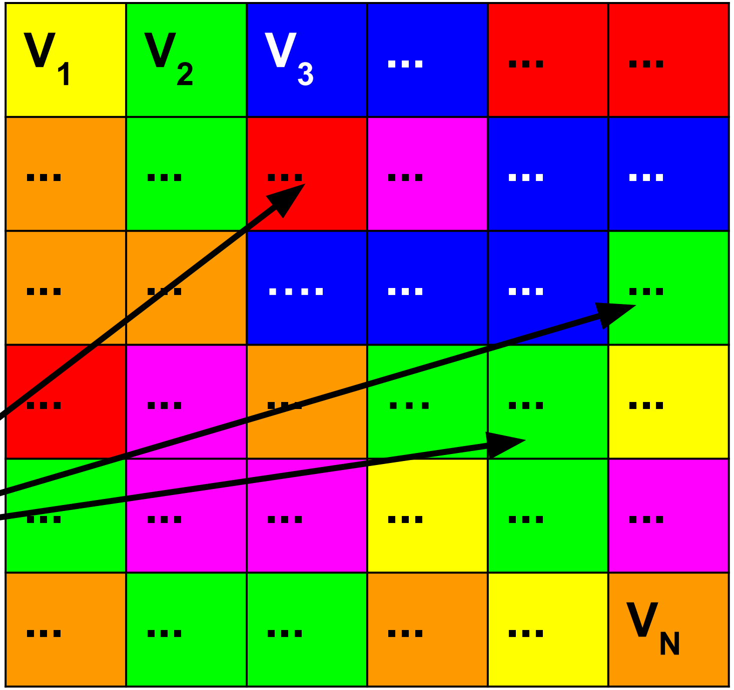
Input: X

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

For N iterations:

```
i := A    mod N
A := H(A xor V_i)
```

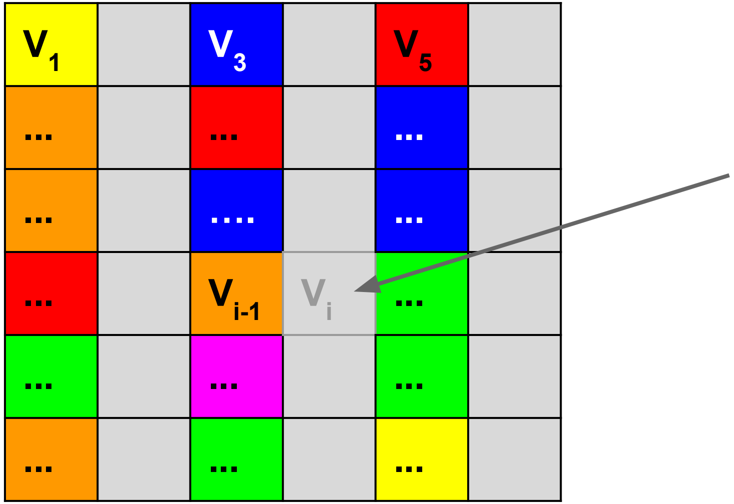
Output: A



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

Future: PW-hashing research

http://zeusminer.com/

Cuckoo hash cycles

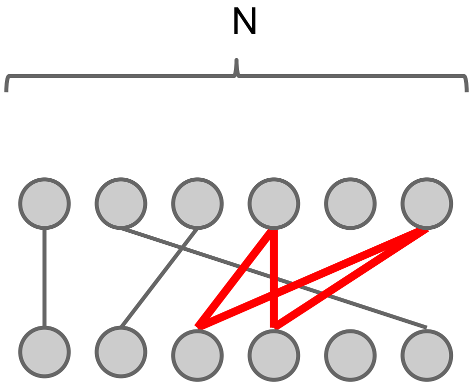
John Tromp, 2014

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

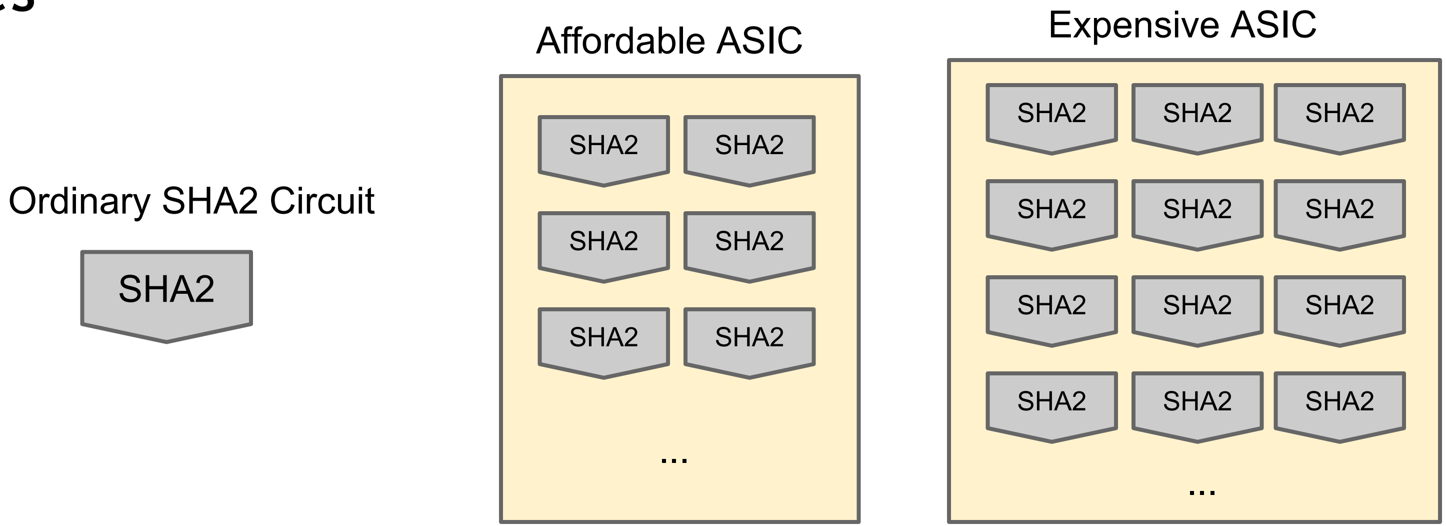
- More complicated hash functions
  X11: 11 different hash functions combined

- 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



Lecture 8.3:

Proof-of-useful-work

Recovering wasted work

Recall: (as of mid-2014)

between 150 MW - 900 MW power consumed

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:

$\mathbf{p_1, p_2, \ldots p_n}$ where $\mathbf{p_i = 2^i a + 1}$

Each $\mathbf{p_i}$ is a large (probable) prime

$\mathbf{p_1}$ 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

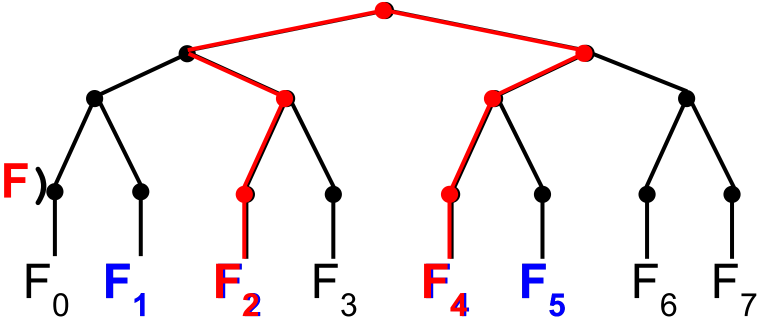
2. Generate a public signing key pk, which determines a random subset of file segments

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

Lecture 8.4:

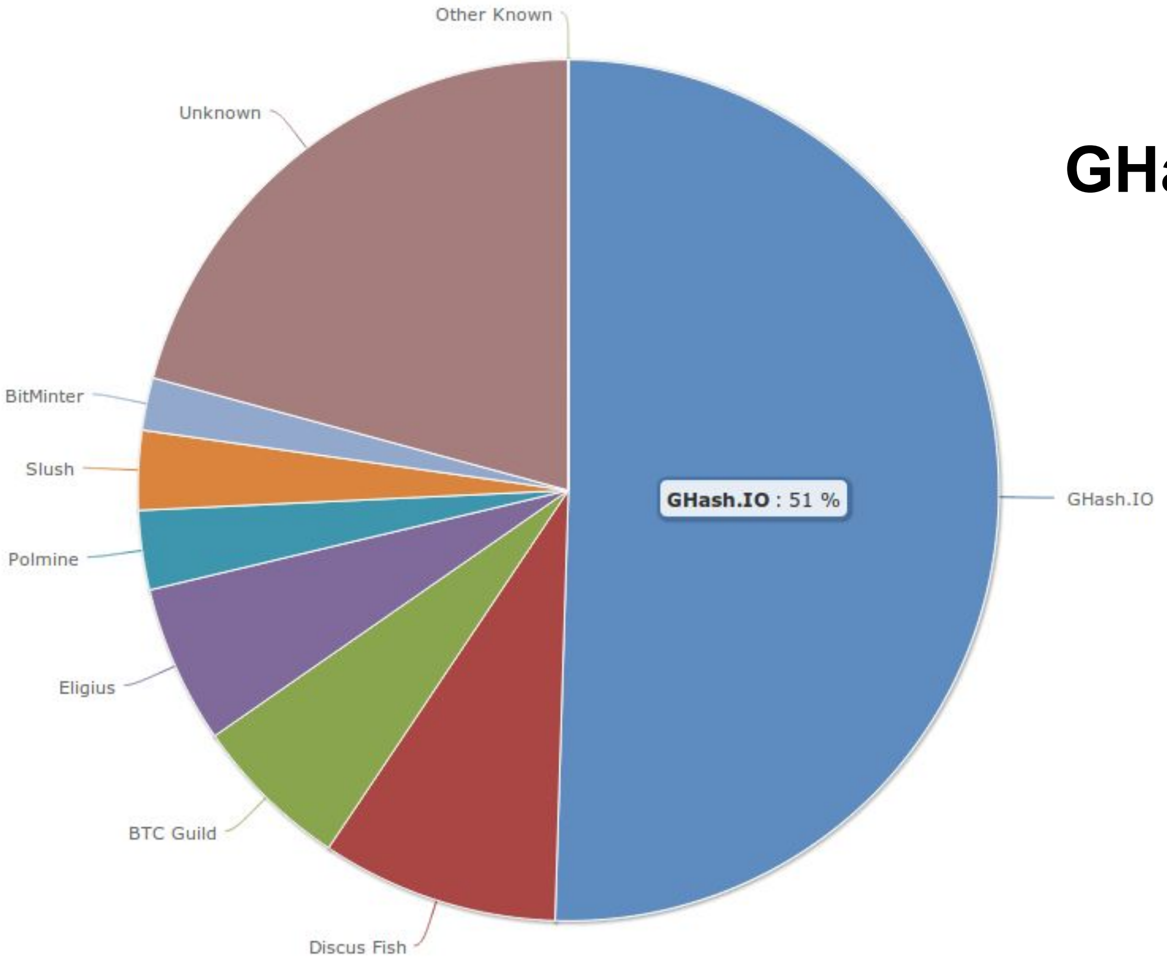
Nonoutsourceable Puzzles

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



June 12, 2014
GHash.IO large mining pool crisis

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?

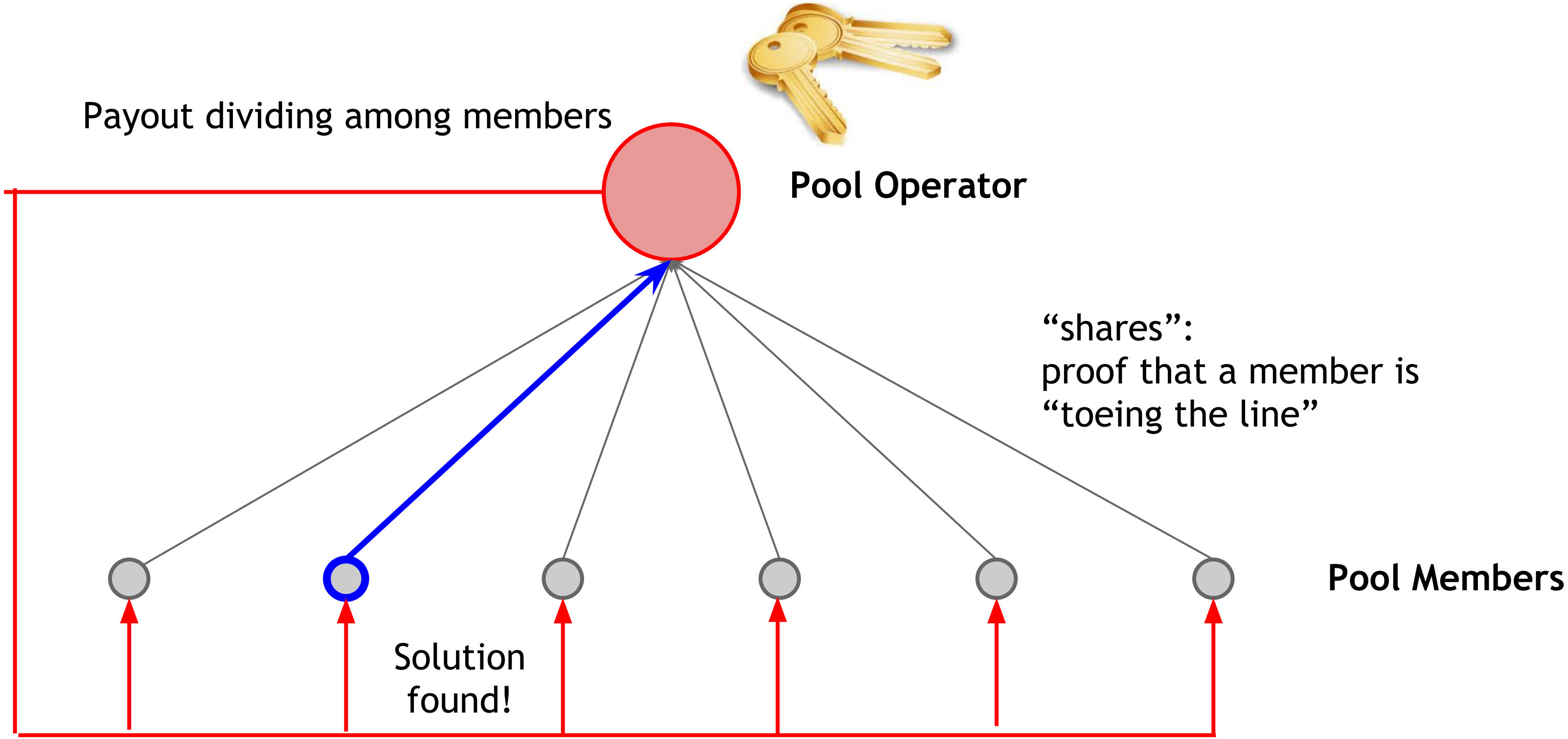
Yes, it is. GHash is in a position to exercise complete control over which

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

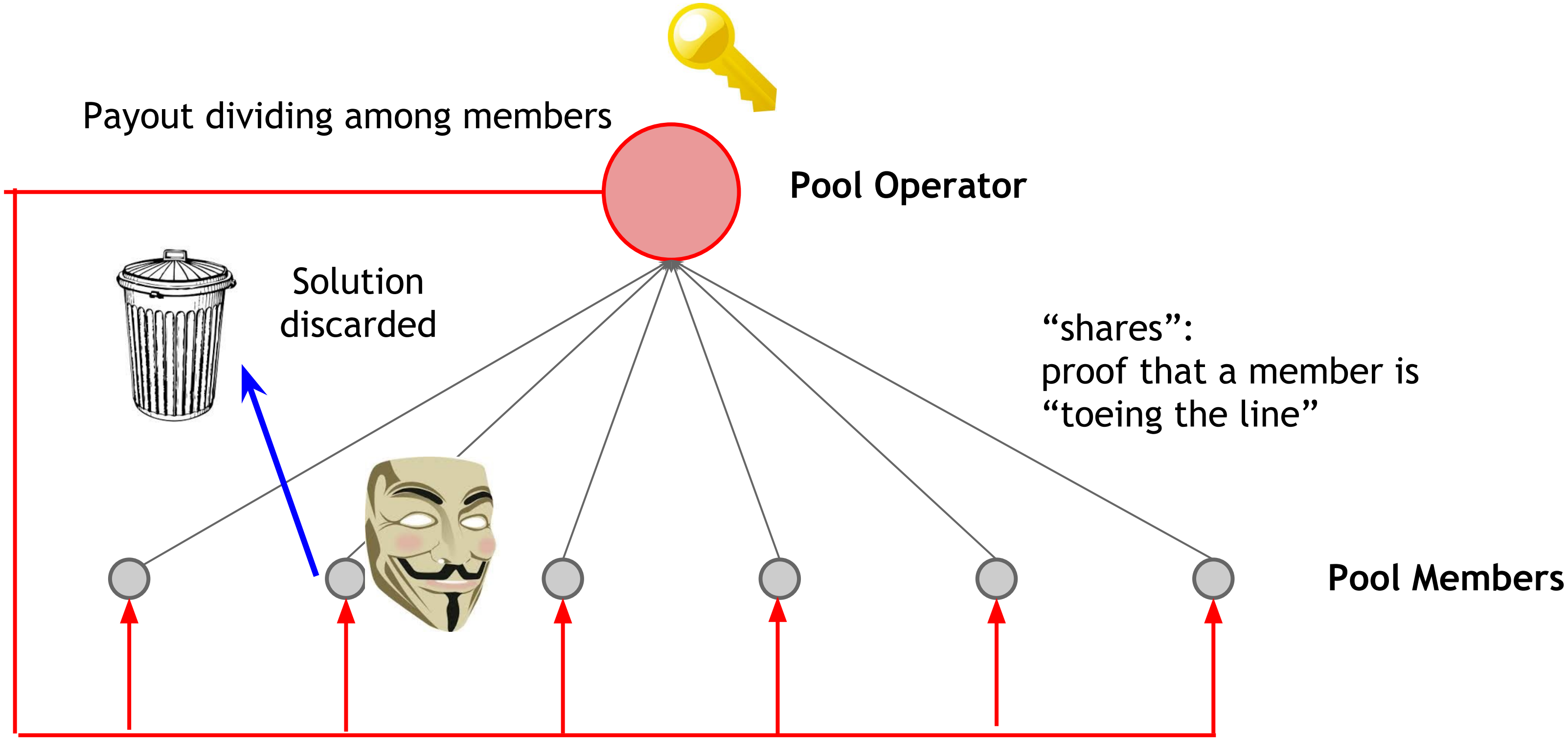
Suppose a Vigilante is angry with a large pool

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



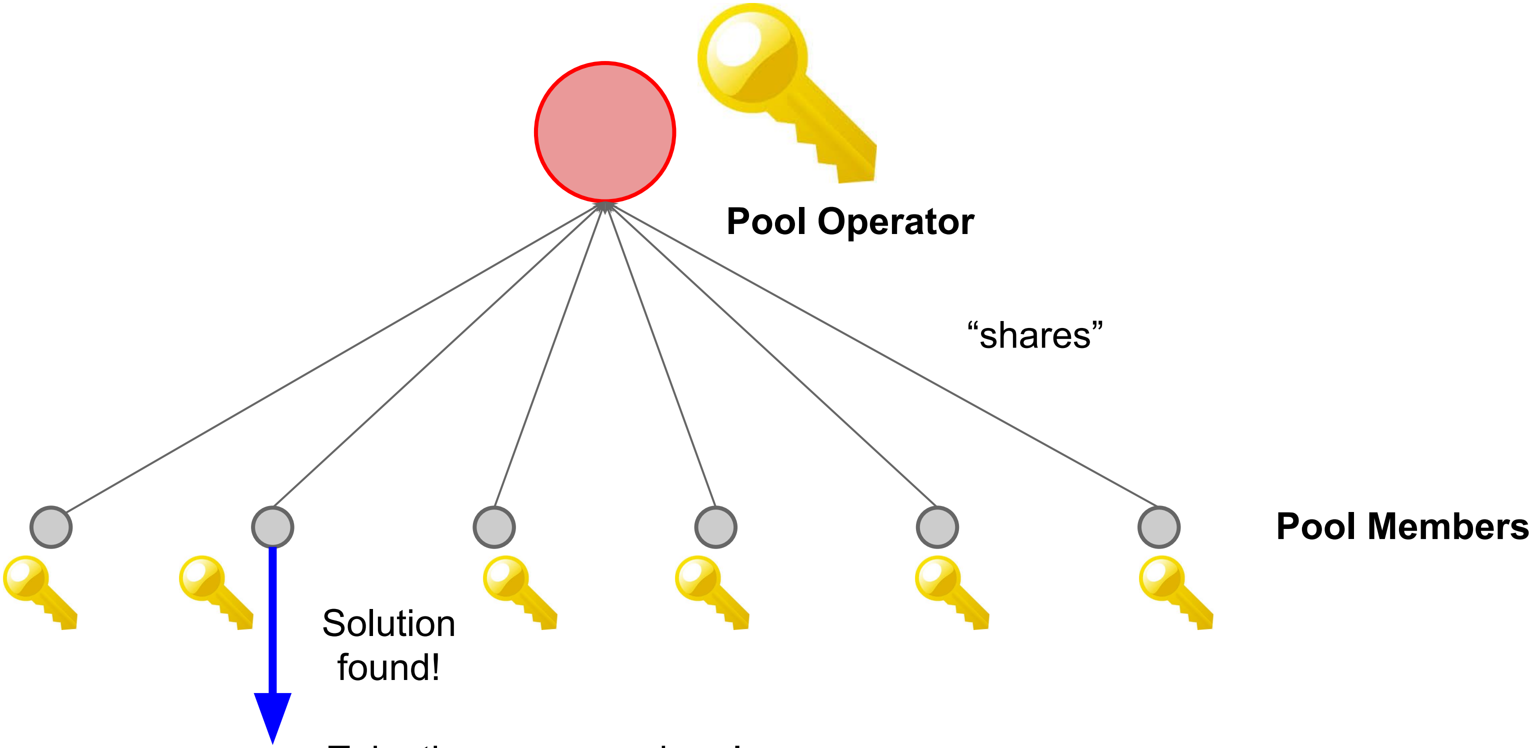
Encouraging the Vigilante

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



Take the money and run!
Also: evade detection

Nonoutsourceable puzzle

Signature needed to find solution

Public Key

Solution:

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

Second signature spends reward

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

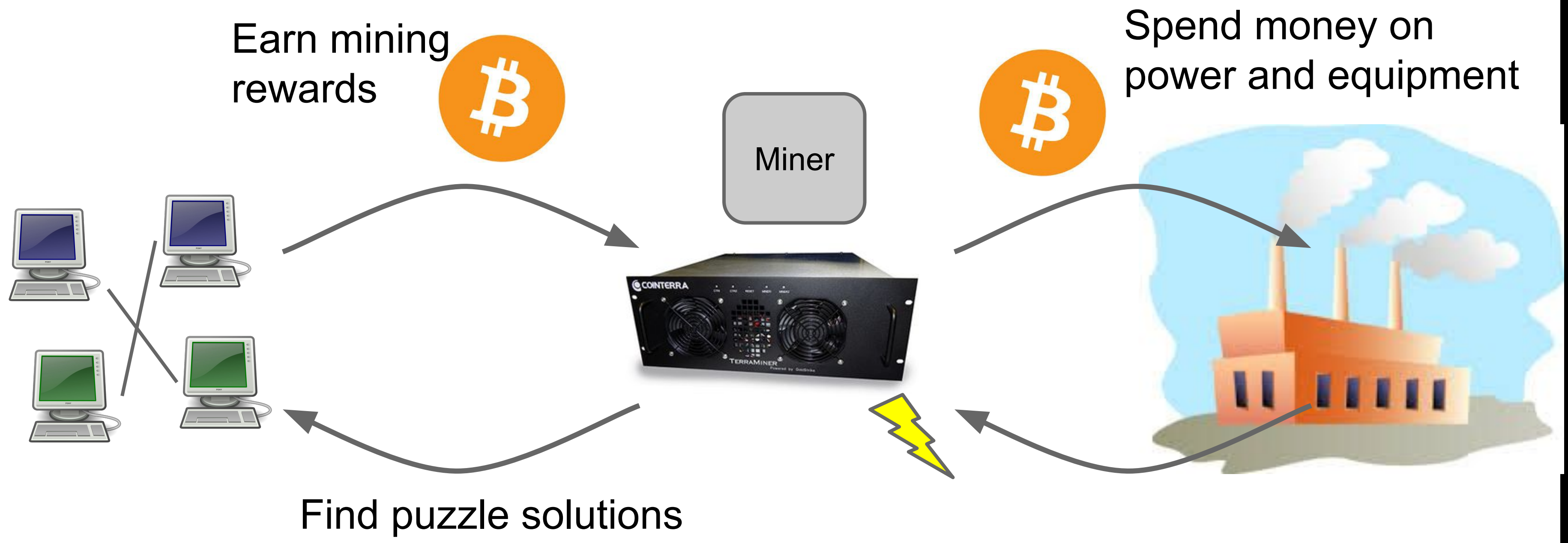
- Other forms of outsourcing
  might drive pool members to hosted mining

Lecture 8.5:

Proof-of-Stake
“Virtual Mining”

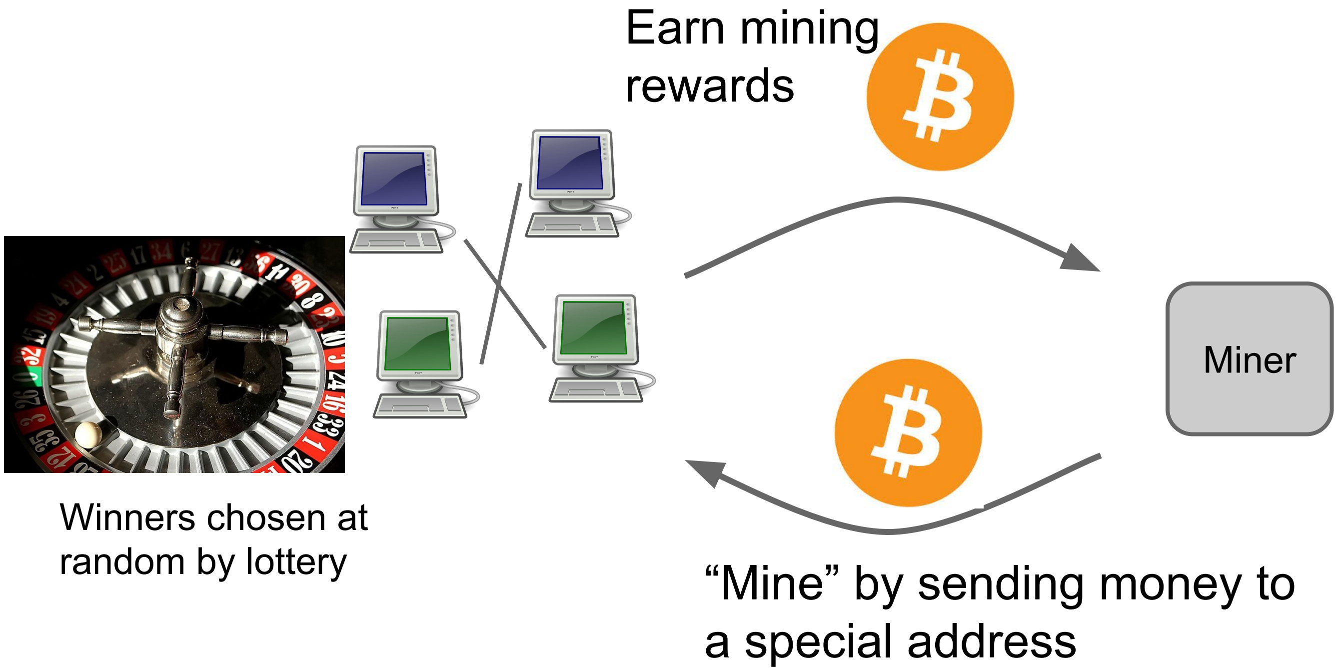
Mining has an unnecessary step

Proof-of-Work Mining:



Mining has an unnecessary step

Virtual Mining:



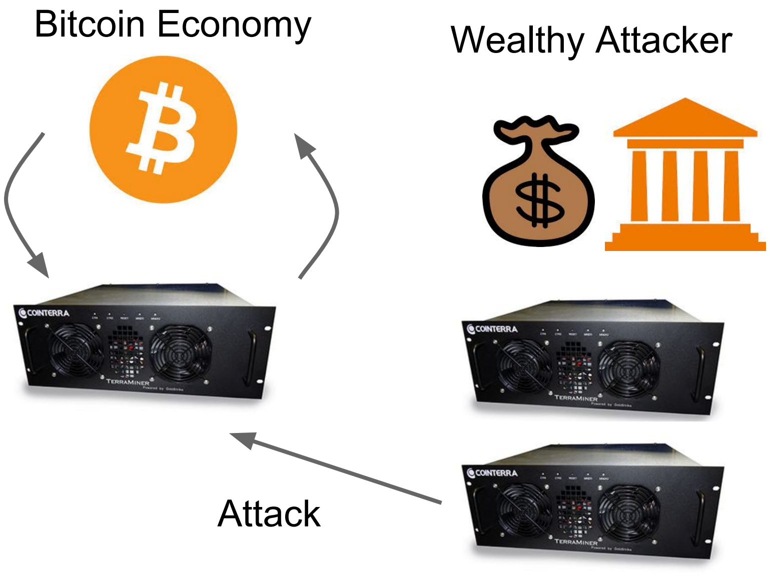
Potential benefits

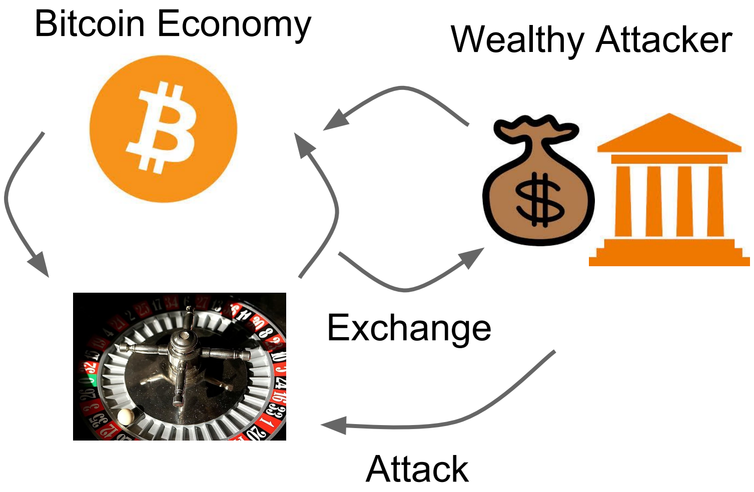
- Lower overall costs
  - No harm to the environment
  - Savings distributed to all coin holders
- Stakeholder incentives - good stewards?
- No ASIC advantage
- 51% attack is even harder

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

In the next lecture…

Bitcoin as a Platform

Applications beyond just currency:

- Lotteries
- Prediction markets
- Smart contracts
- Financial derivatives
- … and more

Incentive Design Heuristics

- Overall, participants are greedy, have short horizons, and distrust each other
- Greedy → wants coins
- If there’s a shortcut, it will be found
- Honest behavior when convenient, at best

Public goods constraint

Suppose the “useful” side effect benefits Bitcoin miners

We can imagine a market where the beneficiaries pay miners

Net result: more mining overall, no benefit

Bread pudding protocols

Use puzzles from one protocol in another

Ex: Instead of captcha, server requires client to do some mining before providing service

Useless work is still useless… but at least it's recycled

Be Careful What You Incentivize

Cobra Effect

Reward for dead cobras → cobra farms (unintended)