Lecture 11

Alternative Mining Puzzles

Puzzles are the core of Bitcoin

- Determine the incentive system, and nature of puzzles determines behavior of miners
- Basic features of Bitcoin’s proof-of-work puzzle (recap)
  - Puzzle is difficult to solve, so large-scale attacks are difficult
  - … but not too hard, so honest miners are compensated
- What other features could a puzzle have?

This lecture (and later)

- Alternative puzzle designs

  Used in practice, and research proposals

- Variety of possible goals

  ASIC resistance, pool resistance, environmental-friendliness, intrinsic benefits…

- Essential security requirements

Basic Puzzle Requirements

Puzzle requirements

- Cheap to Verify
  - since other users have to verify solutions
- Adjustable difficulty
  - E.g., due on increase in hash rate or more users
- In PoW puzzles, chance of winning should be proportional to computing power (e.g., hash power in Bitcoin)
  - Large players get only proportional advantage
  - Even small players get proportional compensation

Bad PoW puzzle: a *sequential* puzzle

Consider a puzzle that takes N steps to solve

a “Sequential” Proof of Work

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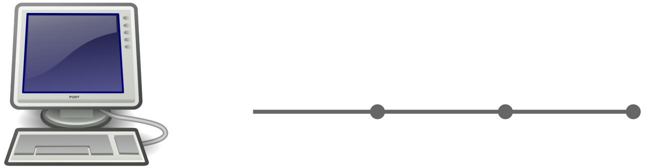

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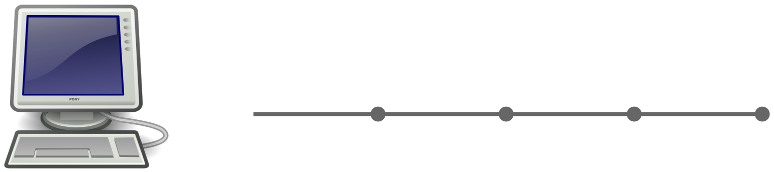

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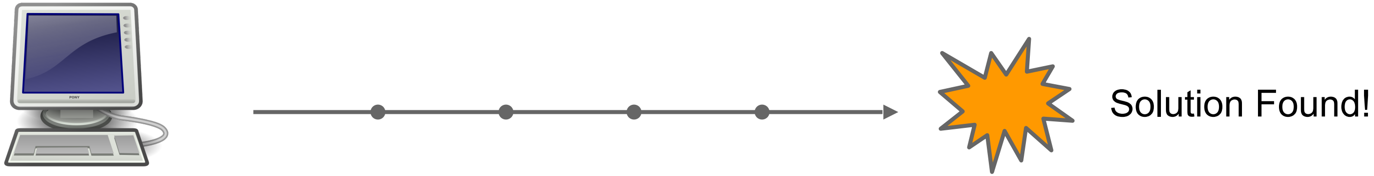

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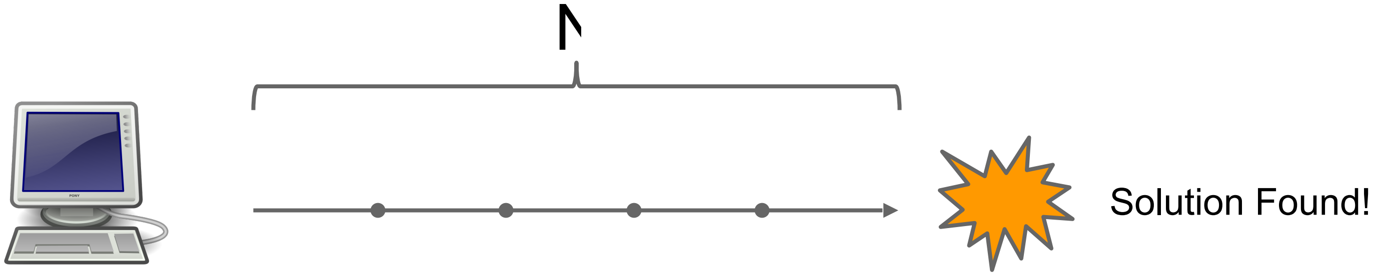

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Problem: fastest miner **always** wins the race!

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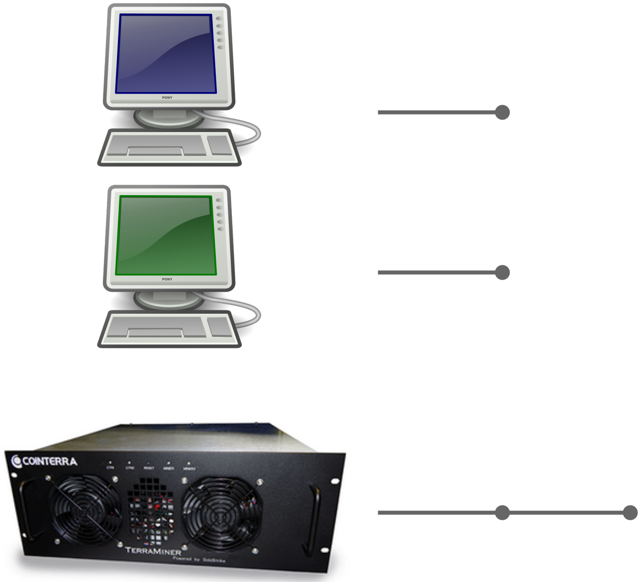

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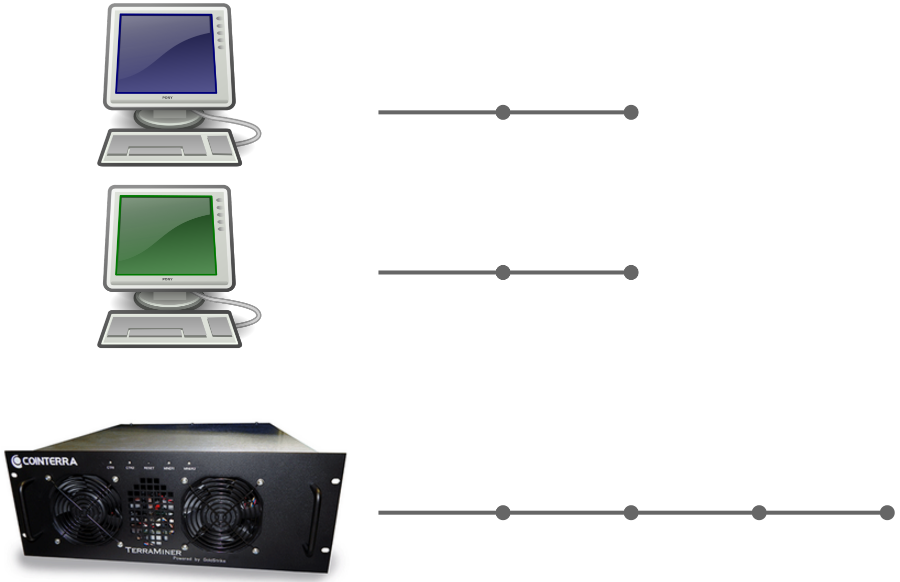

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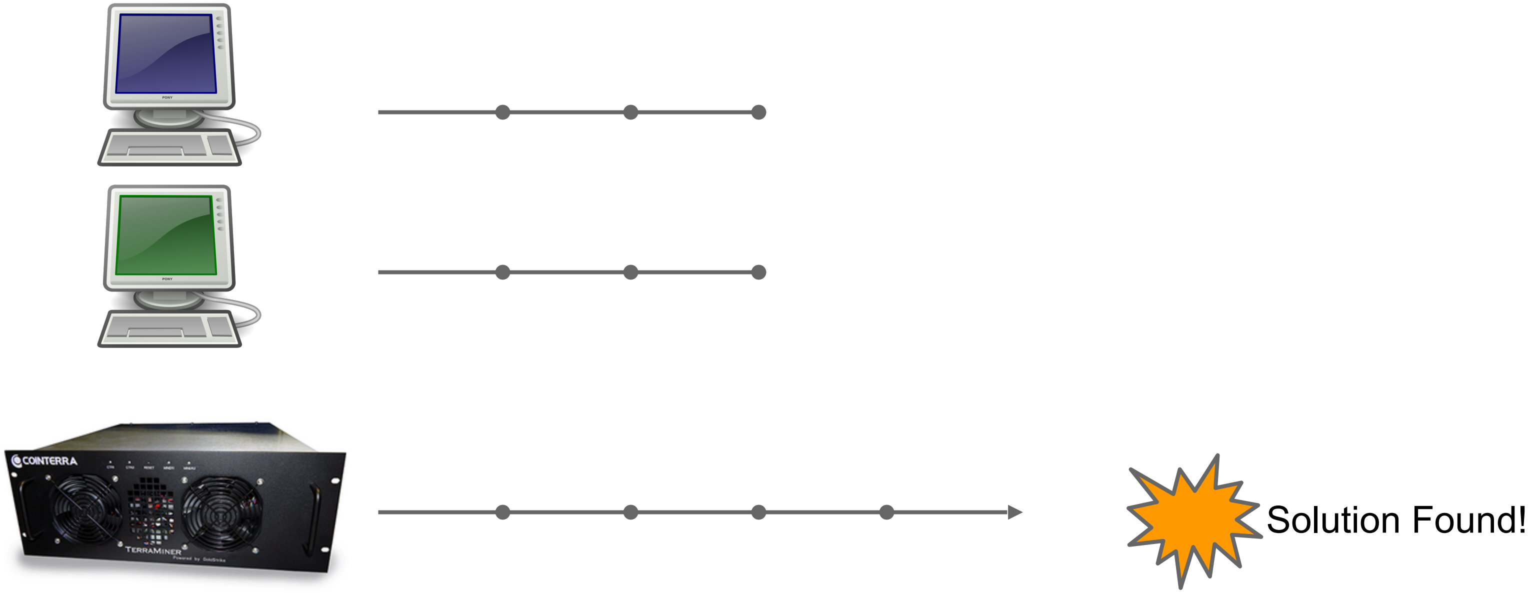
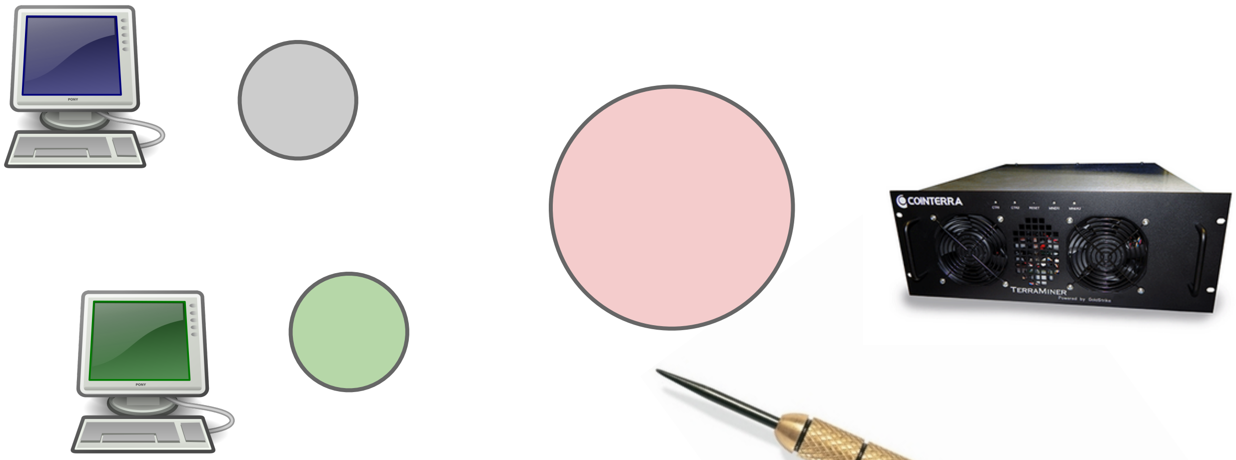


Good PoW puzzle → Weighted sample



This property is sometimes called “progress-free”

ASIC Resistant (PoW) Puzzles

ASIC resistance - Why? (1 of 2)

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

Lower barrier to entry

<u>Approach</u>: Reduce the gap between custom hardware and general purpose equipment

ASIC resistance - Why? (2 of 2)

Goal: Prevent large manufacturers from dominating the game

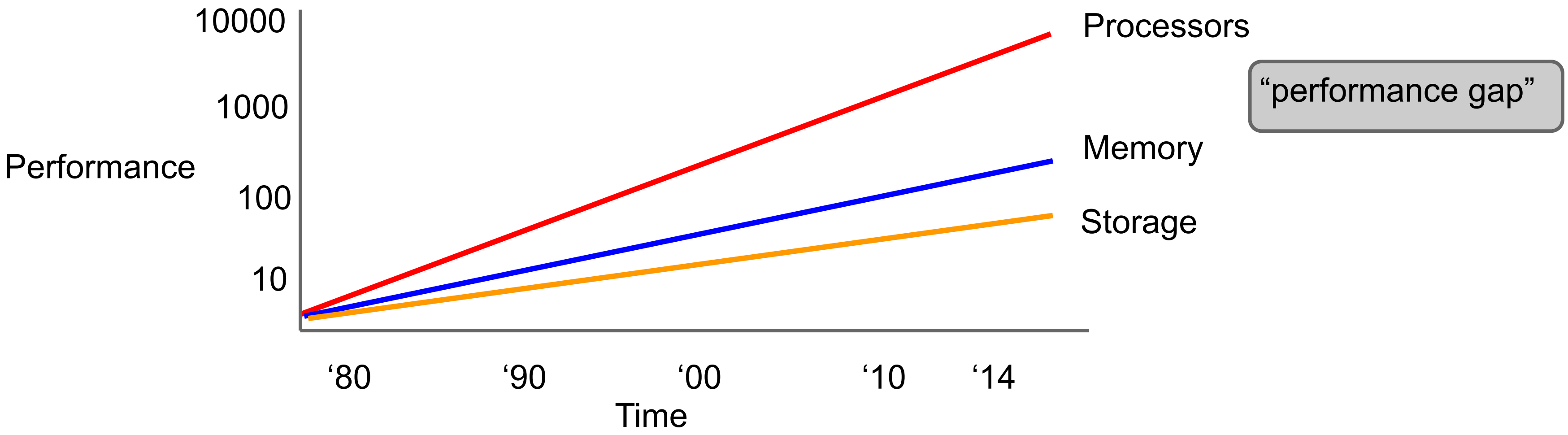
“Burn-in” advantage

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***
  - Memory consumes a large amount of on-chip area. High memory requirement => small number of hashing engines on special-purpose chips
- Widely used alternative PoW puzzle (e.g., Litecoin)
- Also used in Password-hashing

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

scrypt - step 1 of 2 (write)

Input: $\mathtt{x}$

$V_1 = H(X)$

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

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

…

$V_N = H^N(x)$

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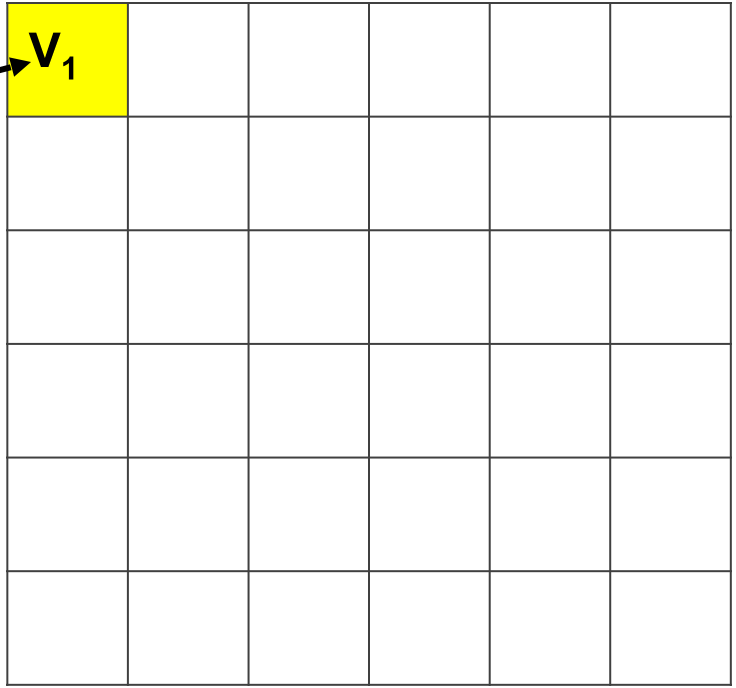

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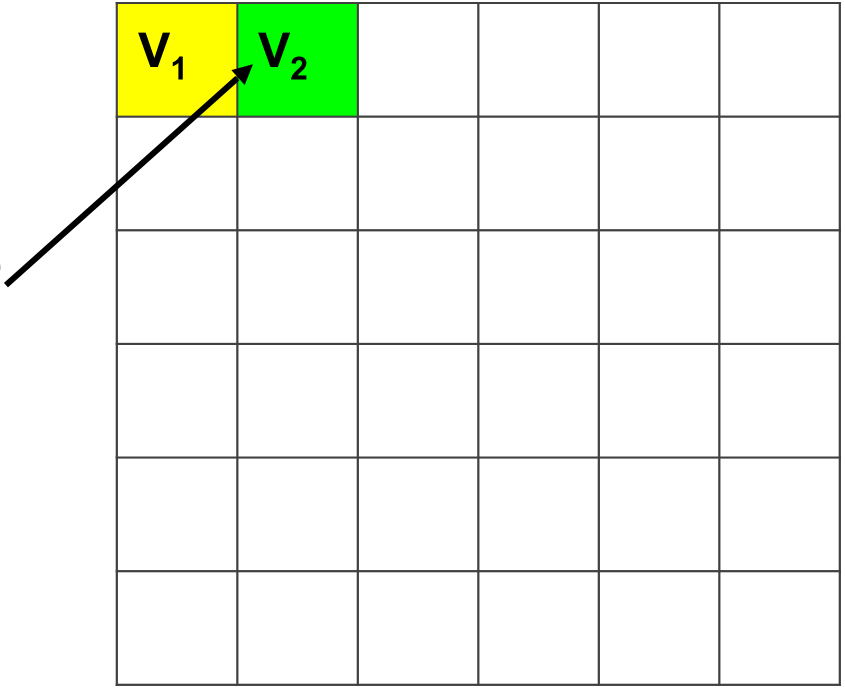

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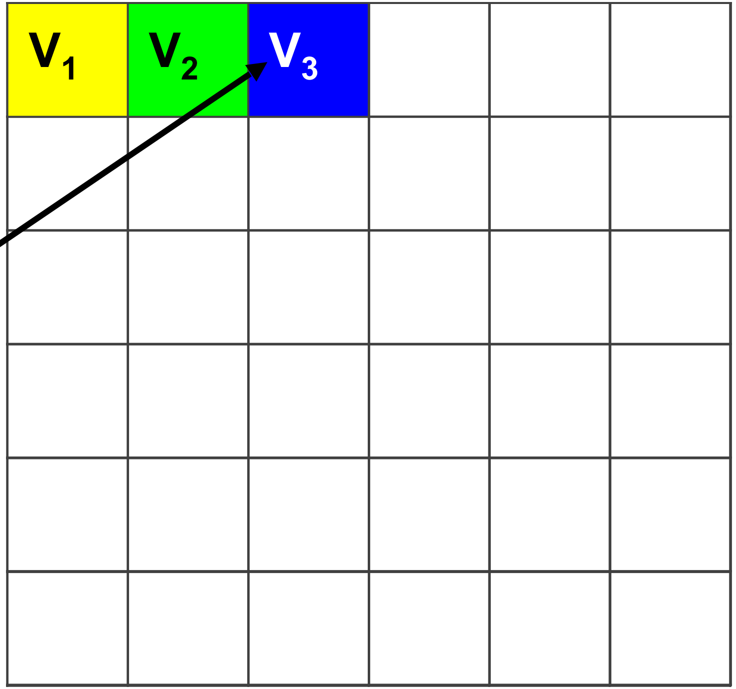

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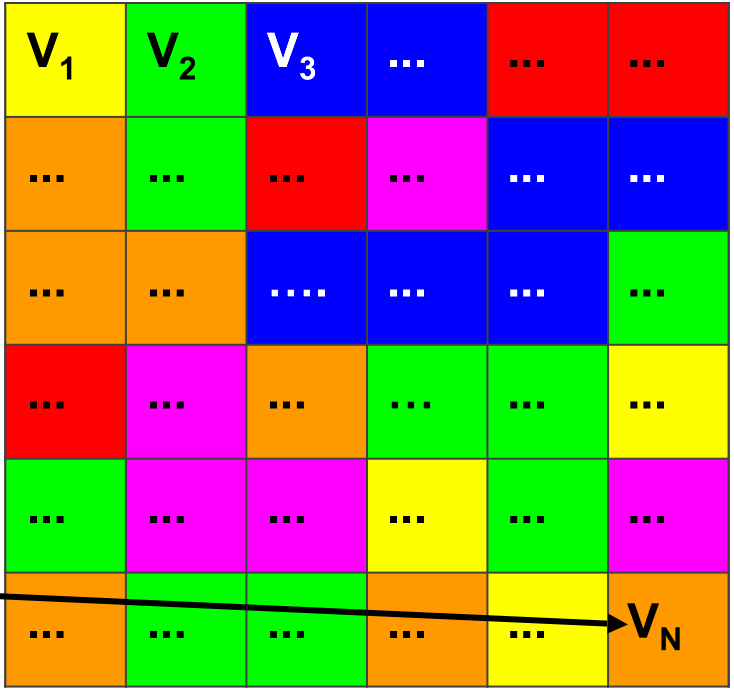

scrypt - step 2 of 2 (read)

Input: `x`

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

For N iterations:

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

Output: A

V_1	V_2	V_3	...	...	...
...	...	...	...	...	...
...	...	....	...	...	...
...	...	...	...	...	...
...	...	...	...	...	...
...	...	...	...	...	V_N

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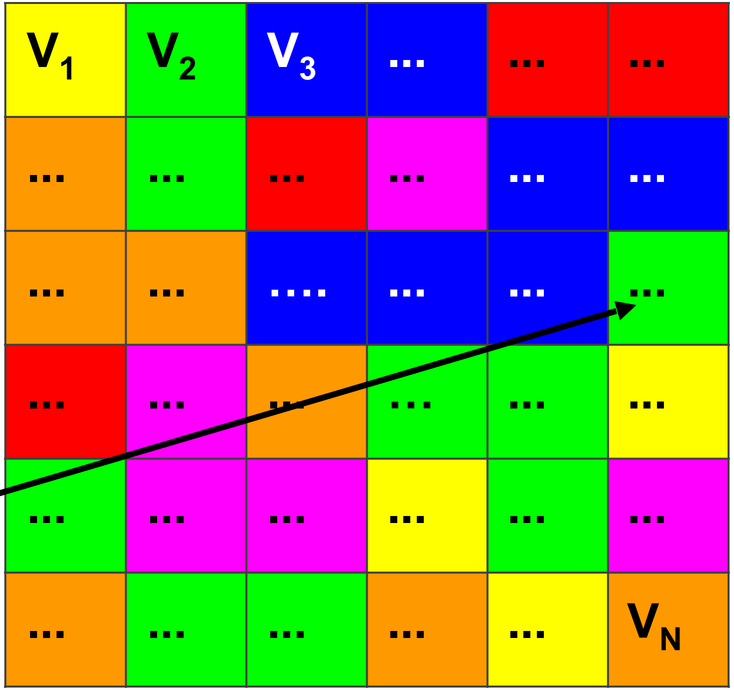

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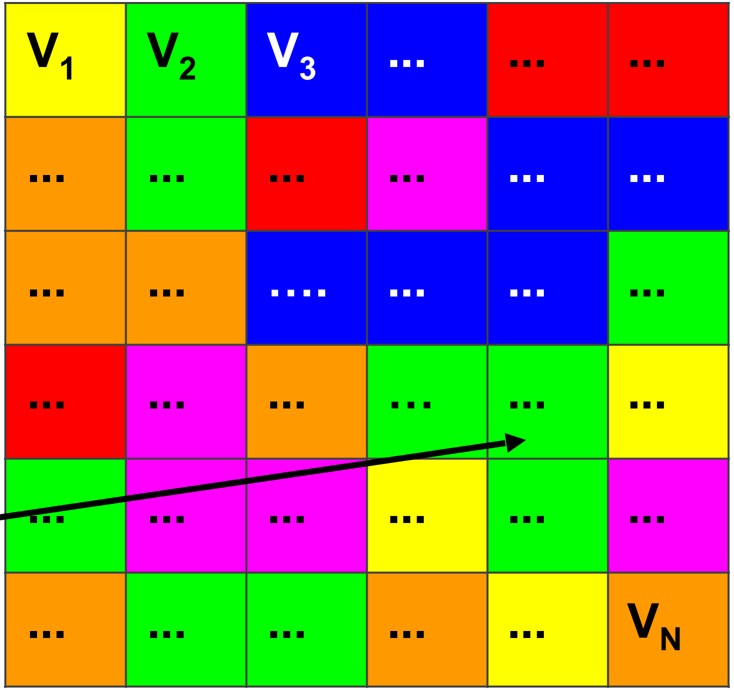

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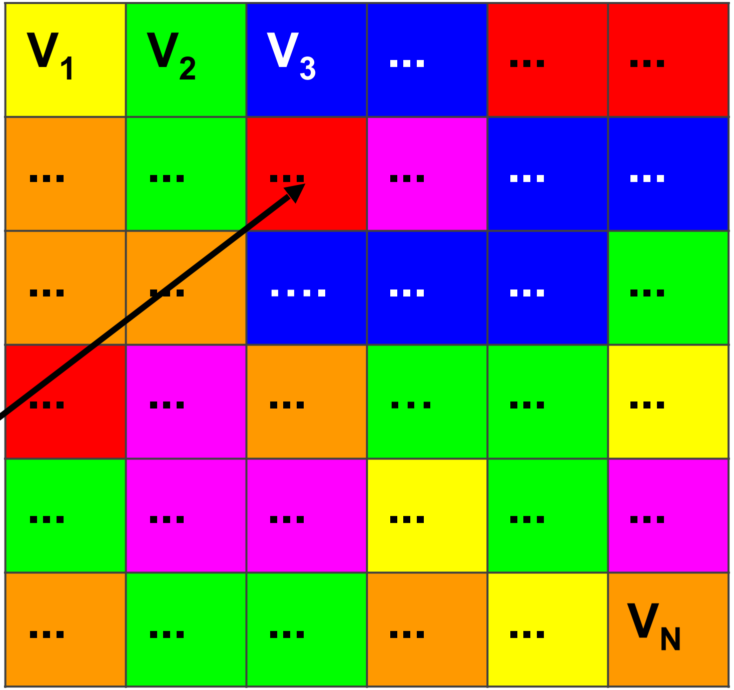
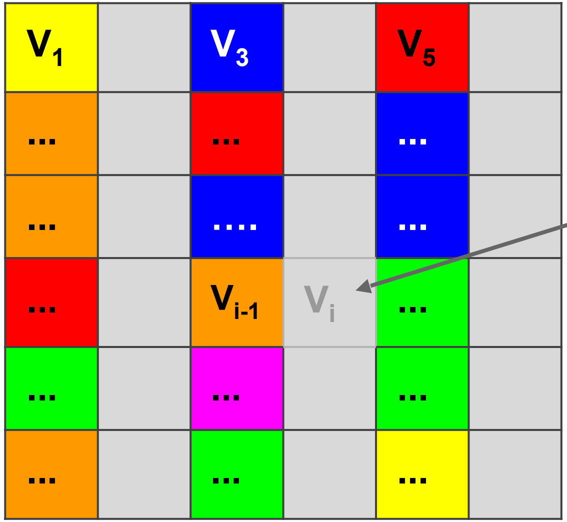


scrypt - time/memory tradeoff

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
- Exploit time-memory trade-offs, lower values of N, etc.

Academic research

- Many subsequent candidates: Argon2i (winner of PW-hashing contest), Ballon-Hashing, etc.
- Proofs of memory hardness in various models using graph pebbling techniques (see, e.g., Alwen-Serbeninko’15 and many subsequent works)
- See talk at Theory Seminar this Wednesday (Malone 228, 12-1pm) on this subject

Cuckoo hash cycles John Tromp, 2014

Memory hard puzzle that's cheap to verify

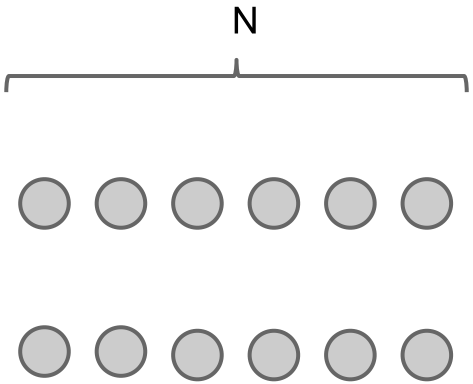
Input: X

For i = 1 to E:

$$\mathbf{a} := \mathbf{H}_0(\mathbf{X} + \mathbf{i})$$

$$\mathbf{b} := \mathbf{N} + \mathbf{H}_1(\mathbf{X} + \mathbf{i})$$

```
edge(a mod N, b mod N)
```



Is there a cycle of size K? If so, Output: X, K edges

Cuckoo hash cycles

John Tromp, 2014

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For i = 1 to E:

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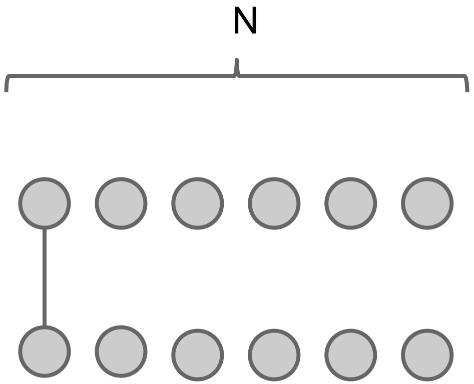

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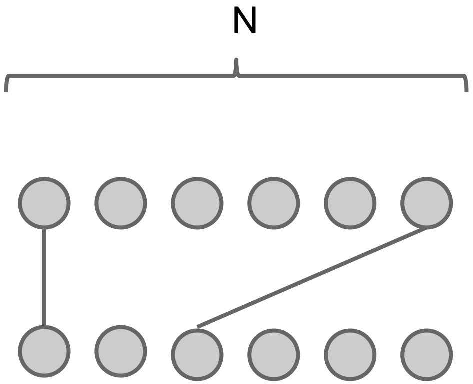

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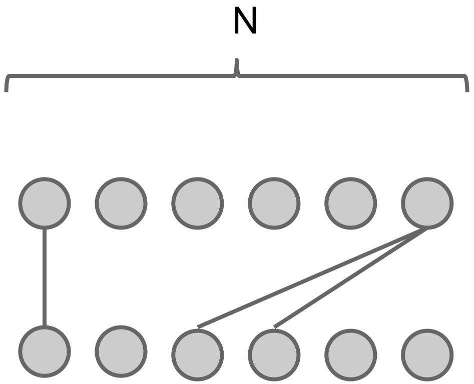

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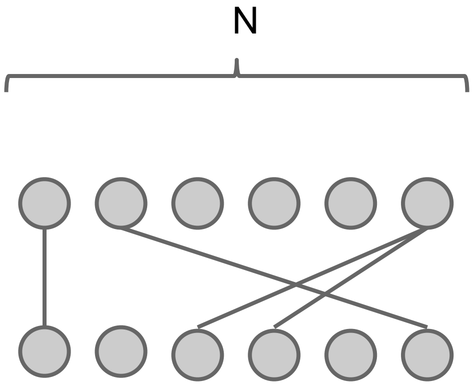

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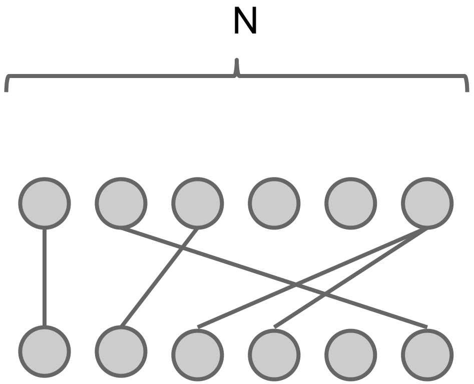

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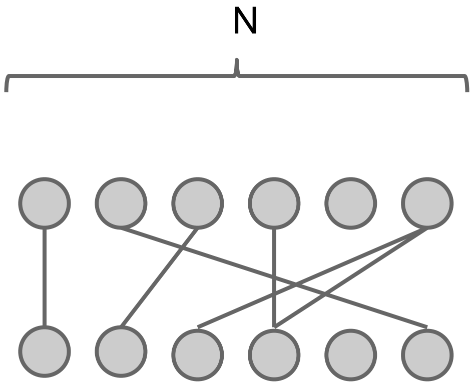

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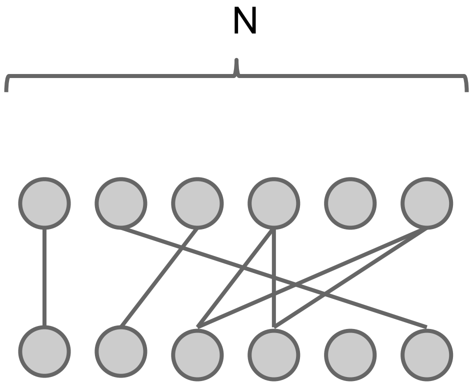

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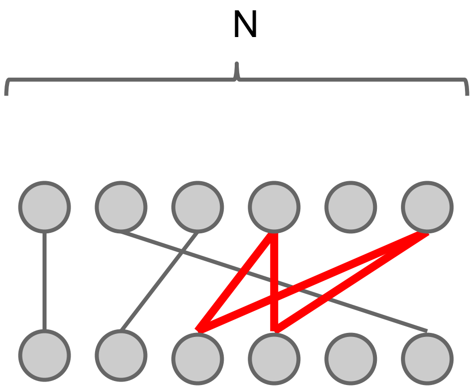


Even more approaches

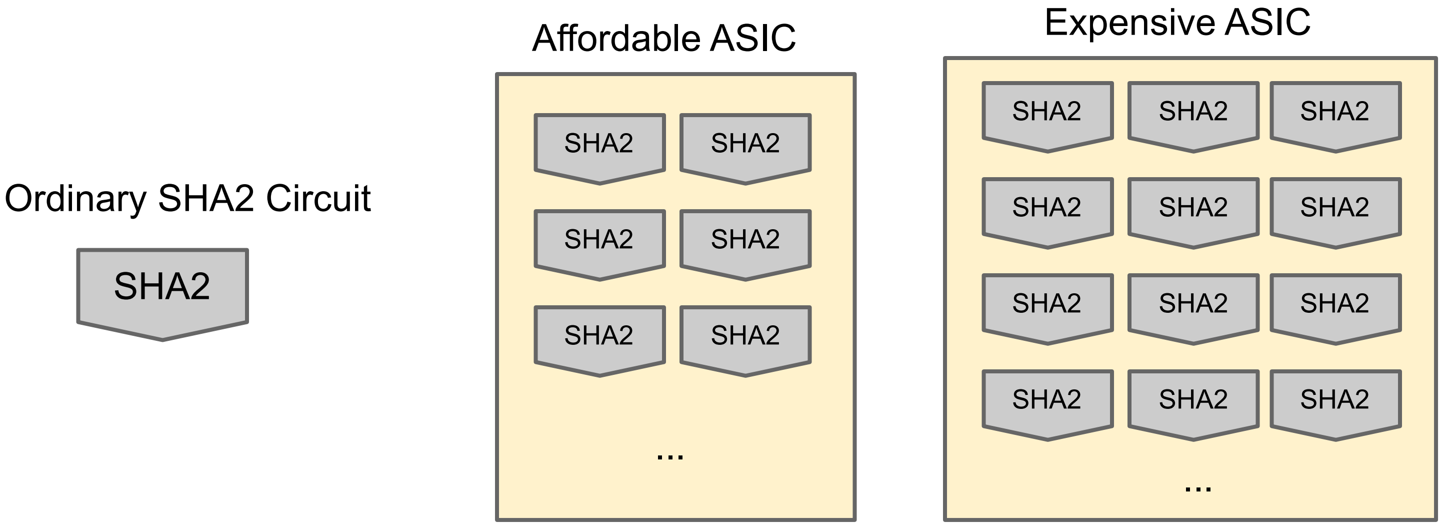
- More complicated hash functions
  - X11: 11 different hash functions combined (subsequent iterations: X13, X14, X15, X17)

- 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



Proof-of-useful-work

Recovering wasted work

Recall: power consumed by Bitcoin network in 2017 ~ power consumed by Denmark

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)
- 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 $p_i = 2^i a + 1$

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? Some applications to crypto (e.g., Young-Yung'98)

Recovering wasted hardware

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

This hardware investment is otherwise useless

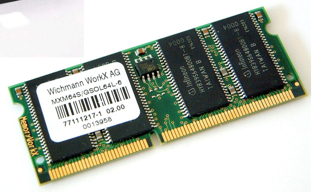
Idea: a puzzle where hardware investment is useful, even if the work is wasted?

Permacoin - Mining with storage

Miller et al., 2014

Bitcoin

Permacoin



Side effect:

Massively distributed, replicated storage system

Permacoin

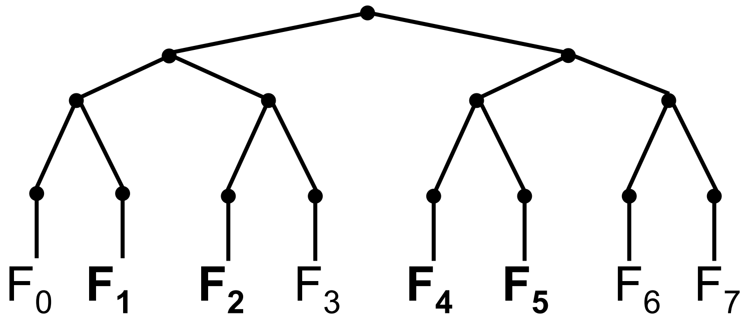
Assume we have a large file **F** to store

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

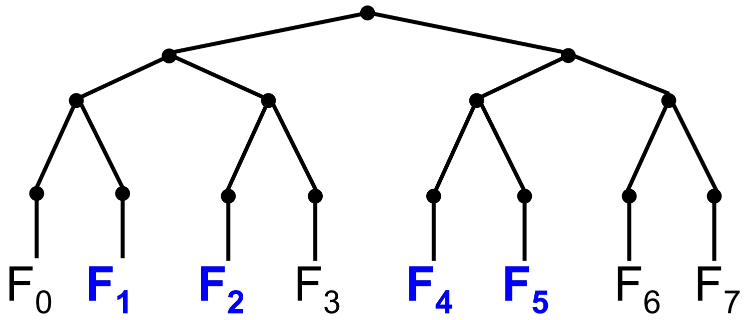


Storage-based puzzle

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



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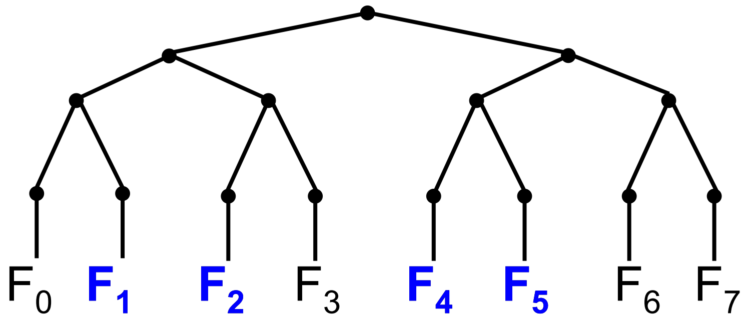
3. Each mining attempt:

```
a) Select a random nonce
b) h1 := H(prev || mrkl_root || PK || nonce)
```



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a) Select a random nonce
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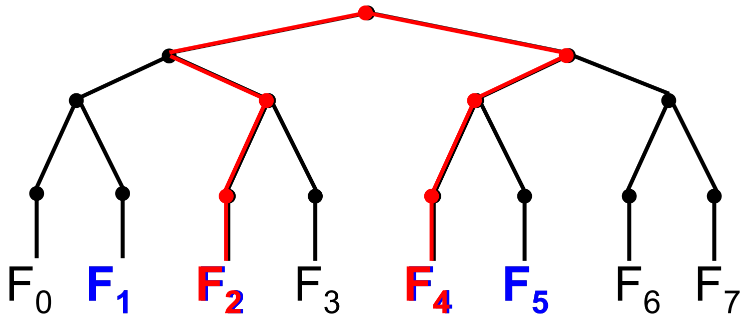
```



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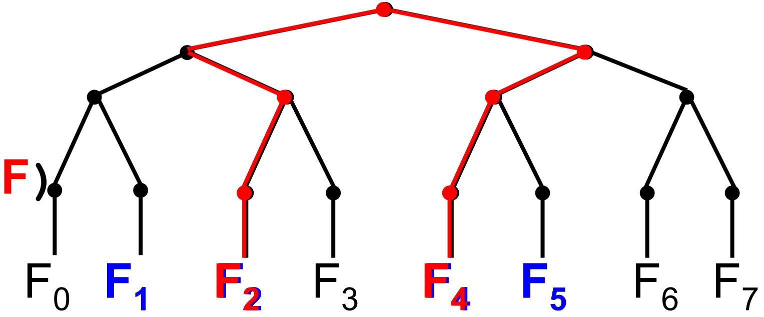
```
a) Select a random nonce
b) h1 := H(prev || mrkl_root || PK || nonce)
c) h1 selects k segments from subset
d) h2 :=
H(prev || mrkl_root || PK || nonce || F)
e) Winner if  h2 < TARGET
```



Reducing Bitcoin's "honesty" cost

"Honest" miners validate every transaction

Validation requires the UTXO database (GBs)

Maintaining the UTXO database doesn't pay

Idea: use Permacoin to reward UTXO storage

Proofs of Space

- Require non-trivial storage (as opposed to computational power) to solve a puzzle
  [Dziembowski et al. CRYPTO'15, Ateniese et al. SCN'14]

- More environmental-friendly
- Used in SpaceMint (see also Burstcoin)

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

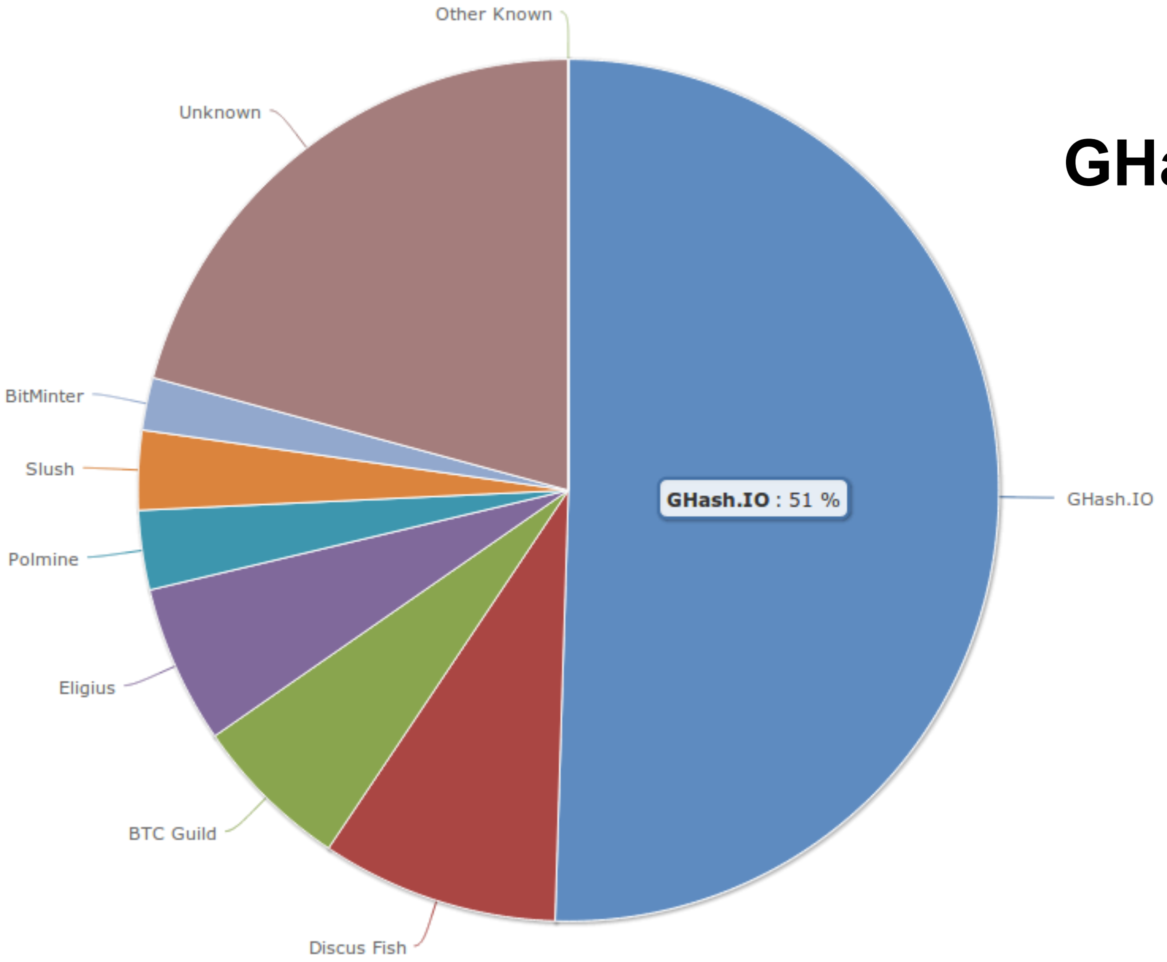
Nonoutsourceable Puzzles

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



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?

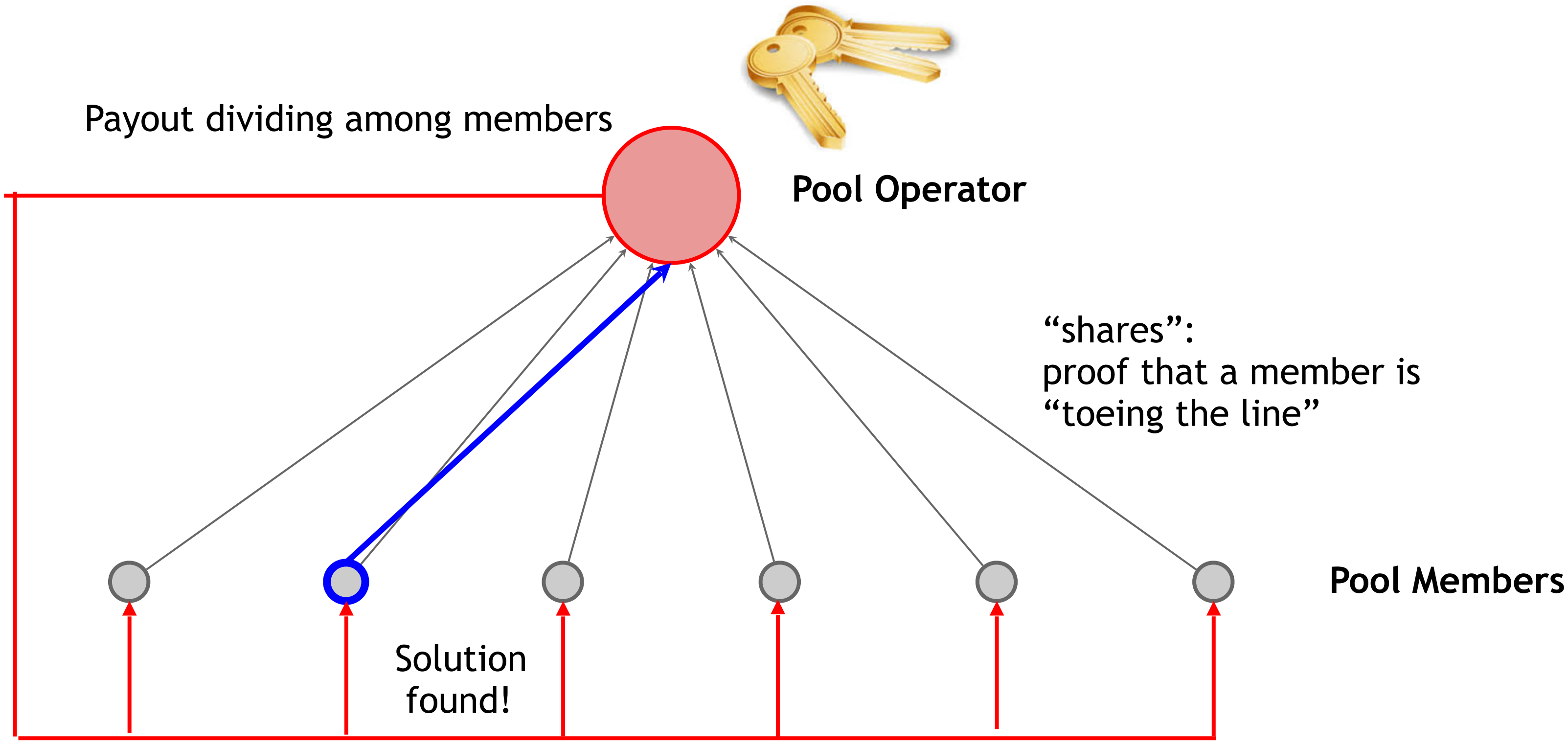
Yes, it is. GHash is in a position to exercise complete control over which

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

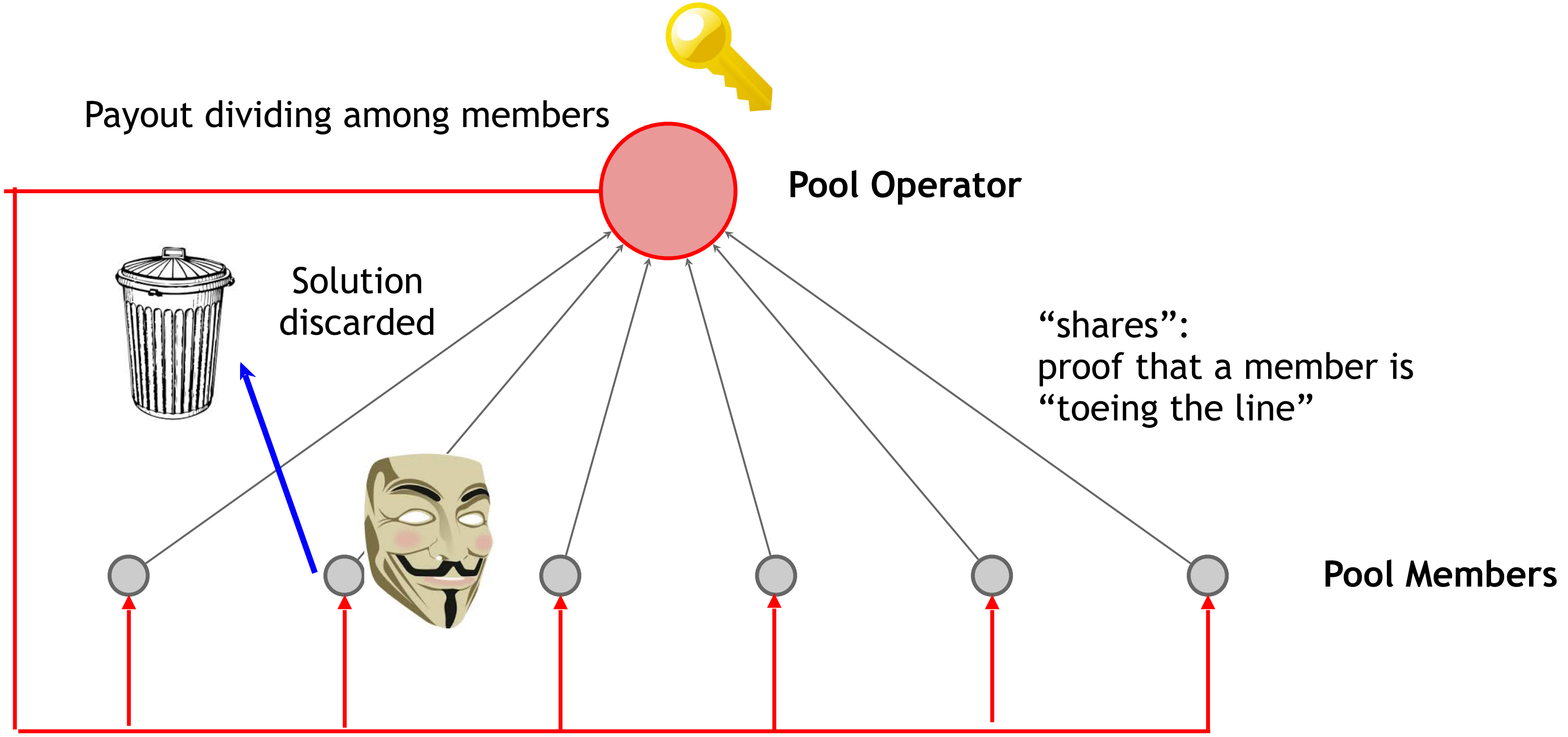
Suppose a Vigilante is angry with a large pool

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



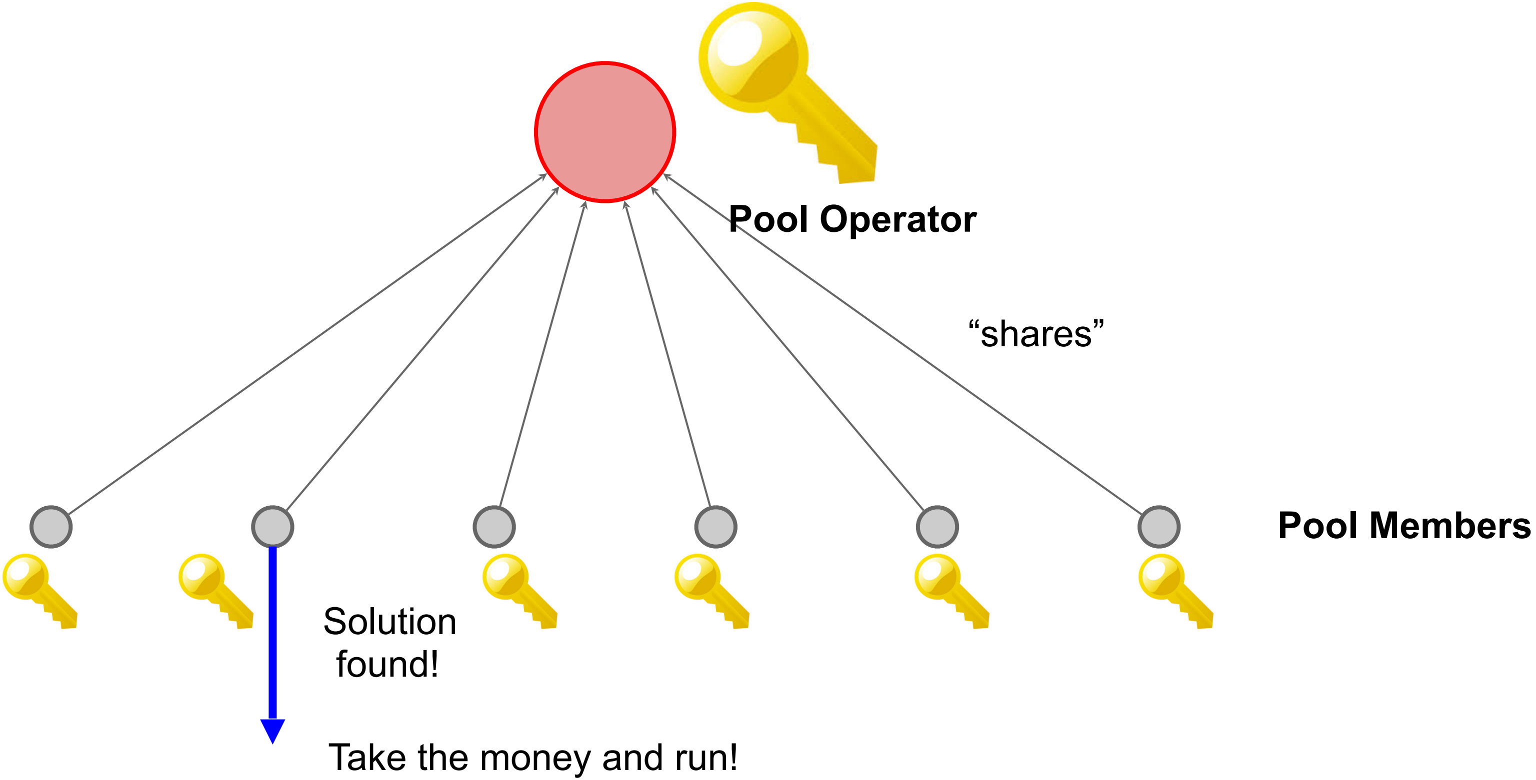
Encouraging the Vigilante

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



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

Public Key

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

Signature needed to find solution

Public Key

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

Signature needed to find solution

Public Key

Solution:

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

Second signature spends reward

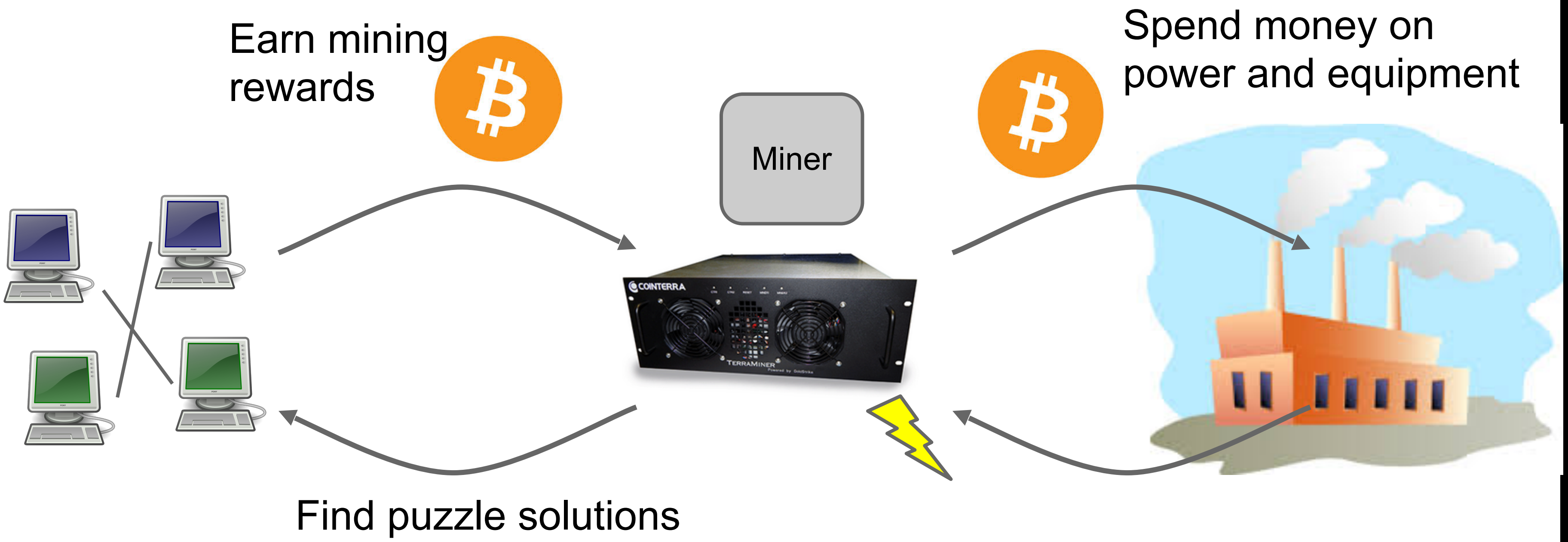
such that:

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

Proof-of-Stake
“Virtual Mining”

Bitcoin Mining has an unnecessary step

Proof-of-Work Mining:



Bitcoin Mining has an unnecessary step

Proof of Stake:

- Creator of next block chosen at random based on current stake in the system
- Assuming all the money owned/used by miners is in the system, this mechanism cuts the middle man (equipment manufacturer)

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 argument

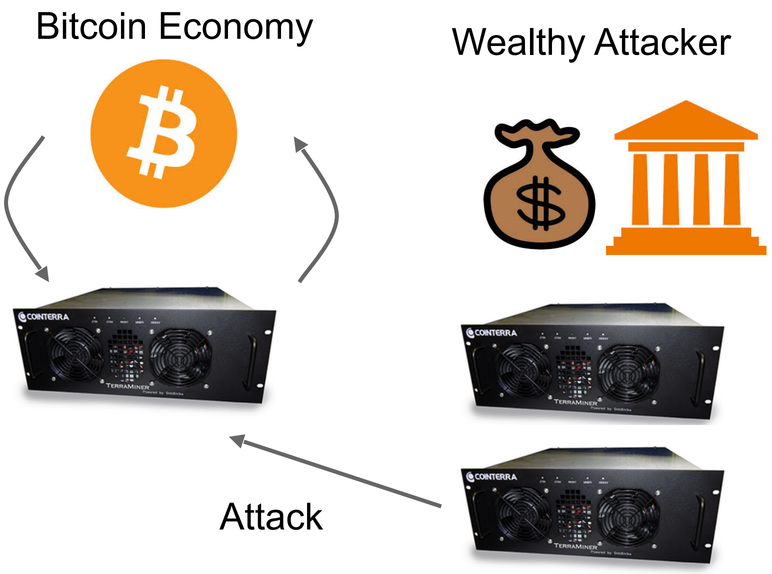
The Bitcoin economy is smaller than the world

Wealth *outside* Bitcoin has to move *inside*

51% attack prevention argument

The Bitcoin economy is smaller than the world

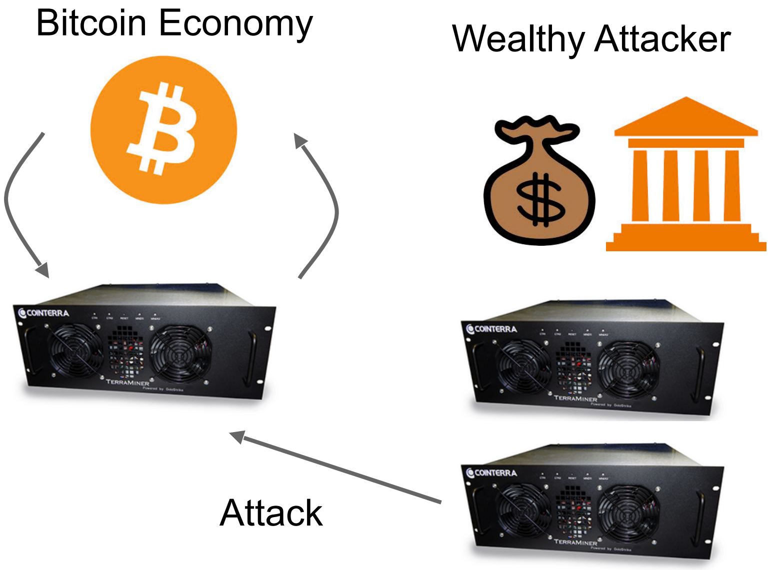
Wealth *outside* Bitcoin has to move *inside*

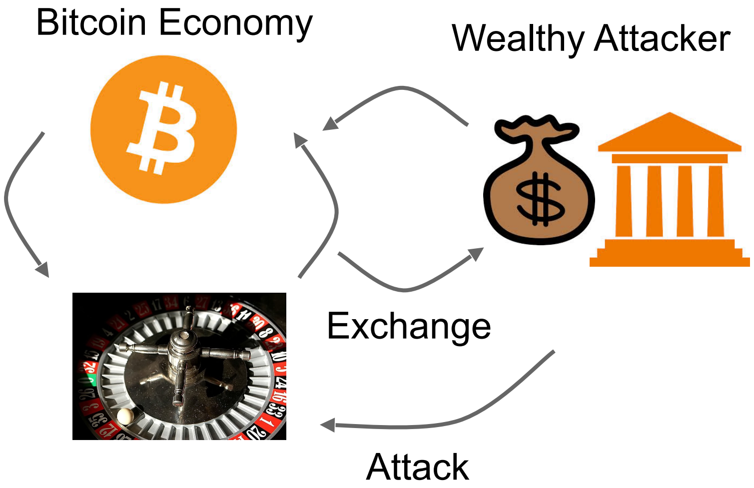


51% attack prevention argument

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 (but potentially some upper limit)

- 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)

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

Examples of PoS based Cryptocurrencies

- Peercoin
- Blackcoin
- Nxt
- Neucoin
- …

Examples of secure PoS systems

- Algorand [Full version: Chen-Micali’17]

- Ourboros [Kiayias-Russel-David-Oliynykov’17]

- Snow white [Daian-Pass-Shi’17]

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
- Further research required to understand the best tradeoffs
- Many competing systems already co-exist