pay-to-sudoku

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Zcash

Live demo

- Live demos always fail without exception
  - Network will go offline
  - Laptop will start on fire
  - SHA256 collisions destroy Bitcoin network
  - Miners switch to dogecoin

Paying for the solution to a sudoku puzzle

- Alice wants the solution to a puzzle, **P**.

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Redeem script:

OP_???
OP_???
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Problems

- The script (and the solution) could be gigantic for larger puzzles.
- Bitcoin's scripting system isn't expressive enough.
- Everyone else discovers the solution.
- If somebody tries to spend the script, someone else can spend it using their solution first.

Paying for the solution to a sudoku puzzle

- Alice wants to pay Bob to solve a puzzle.


```
OP_IF
    bob_pubkey
    OP_CHECKSIGVERIFY
    OP_SUDOKU...
OP_ELSE
    400000
    OP_CHECKLOCKTIMEVERIFY
    alice_pubkey
    OP_CHECKSIGVERIFY
OP_ENDIF
```

Problems

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- ~~If somebody tries to spend the script, someone else can spend it using their solution first.~~

Zero-knowledge contingent payments

- Gregory Maxwell described them in 2011
- Relies on two processes:
  - An interactive zero-knowledge proving scheme
  - An atomic swap over the blockchain
- Achieves
  - Privacy of the solution (and the problem)
  - Small transaction size

HTLC (Hashed Timelock Contract)

Alice

Bob

SHA256(K)

K

HTLC (Hashed Timelock Contract)

Alice	Bob
SHA256(K)	**K**

```
OP_SHA256
h_key
OP_EQUAL
OP_IF
    bob_pubkey
    OP_CHECKSIG
OP_ELSE
    future_block_height
    OP_CHECKLOCKTIMEVERIFY
    OP_DROP
    alice_pubkey
    OP_CHECKSIGVERIFY
OP_ENDIF
```

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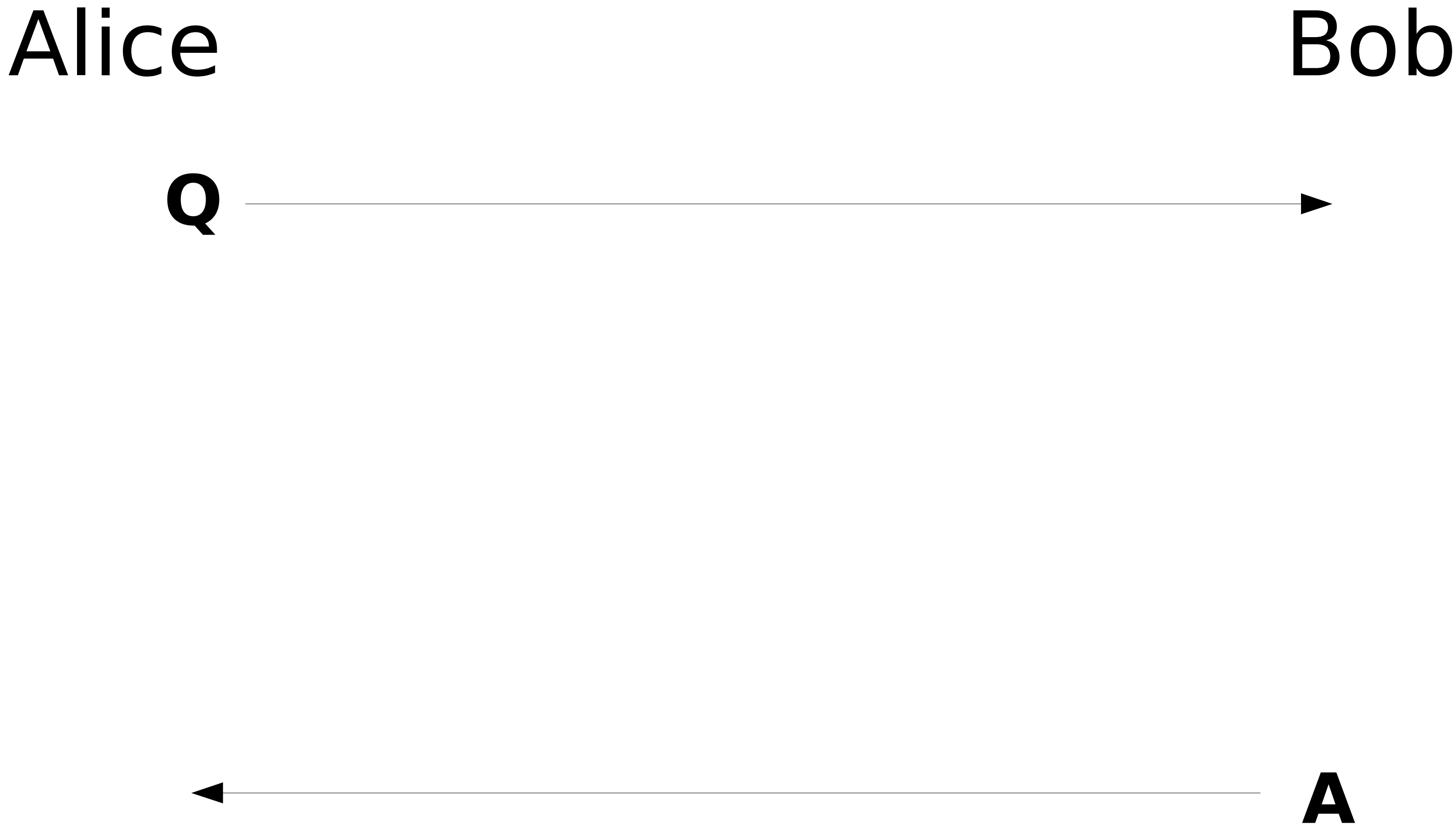
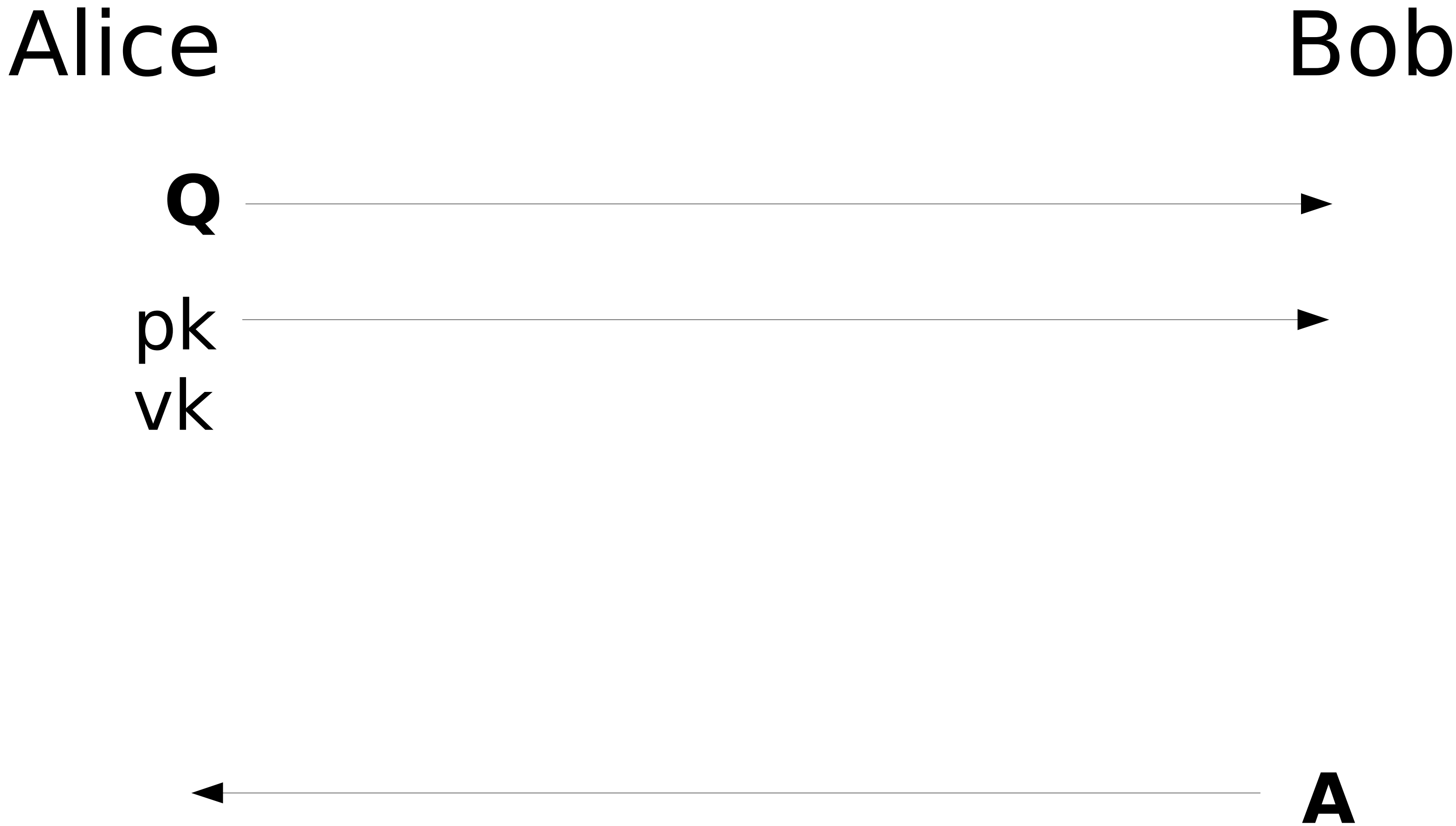
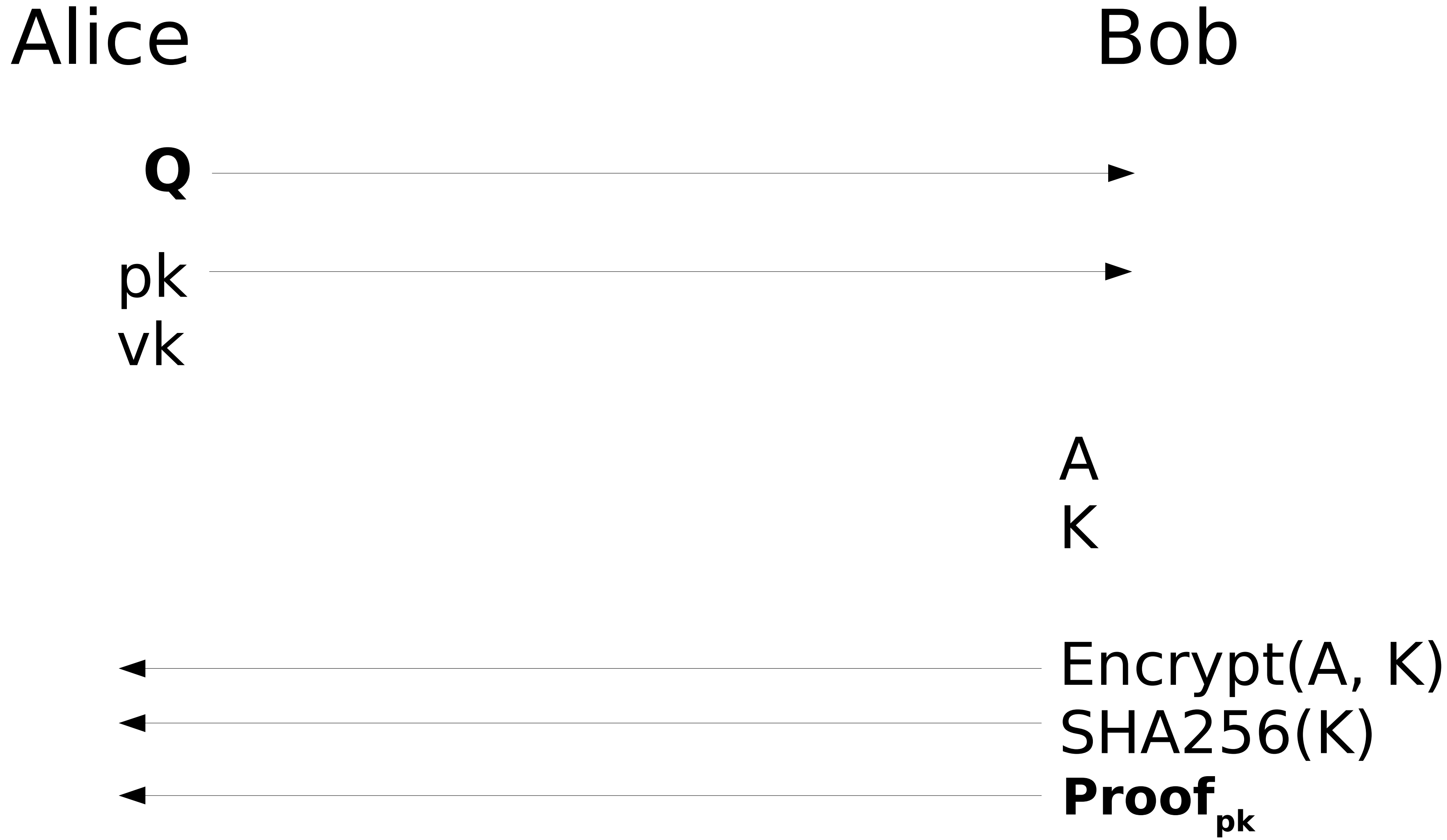
```

- Bob must disclose K to get the money
- Alice gets her money back if Bob doesn't provide K
- The transaction is not that big.

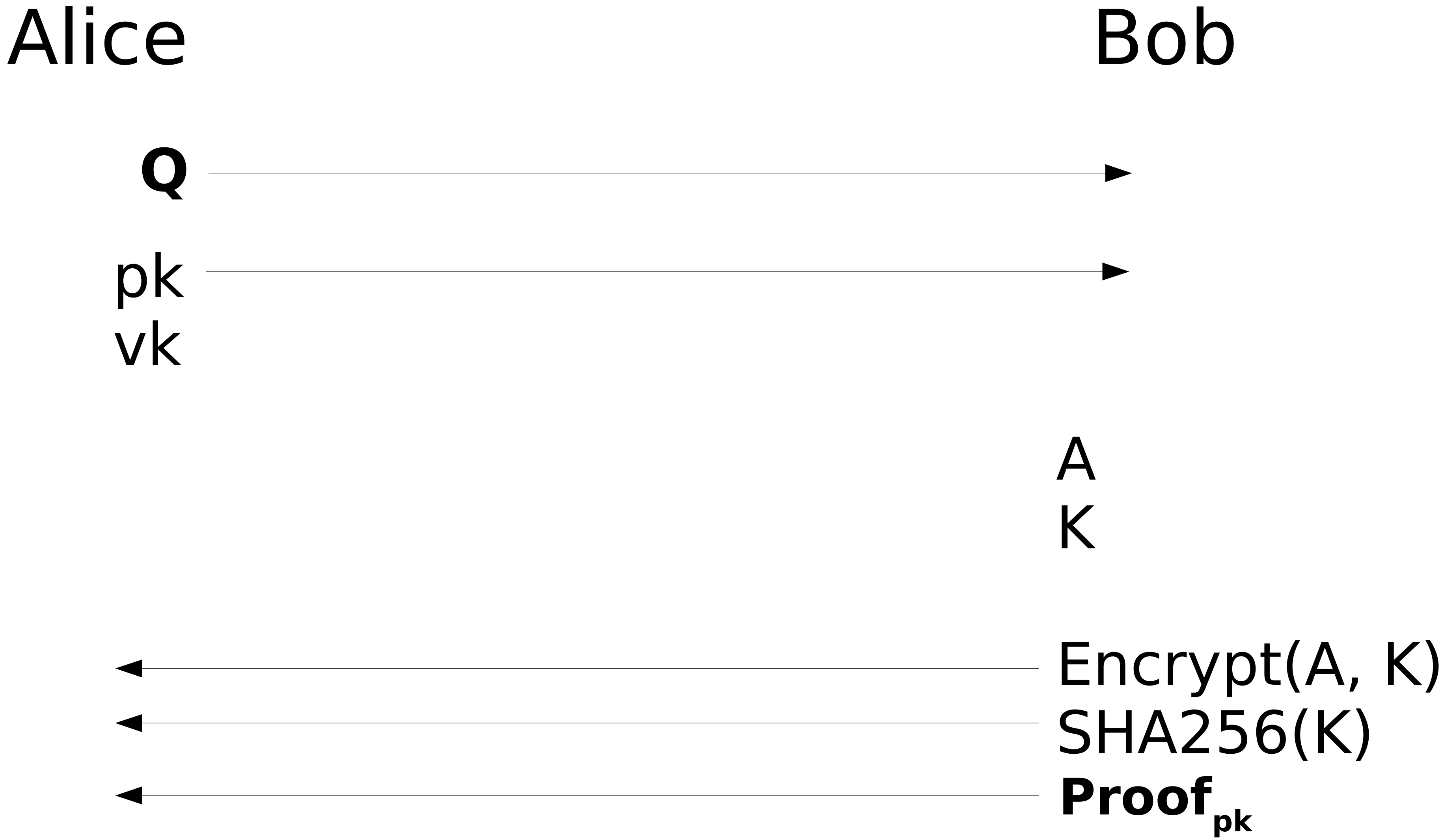

Alice
Bob
Q
A


Alice
Bob
Q
pk
vk
A


Alice
Bob
Q
pk
vk
A
K
Encrypt(A, K)
SHA256(K)
Proof pk

Zero-knowledge proof

- Given a question **Q**, a hash **H**, and an encrypted answer **E**
- I know answer **A** and key **K**
- Such that
  - **A** answers **Q**
  - **E** is Encrypt(**A**, **K**)
  - **H** is SHA256(**K**)



Alice uses a HTLC to pay Bob in exchange for **K**.
Alice decrypts with K to get the solution.

Pros and cons

- Pro: The transaction is *atomic*, *trustless*, and *private*.
- Pro: The transaction is small and completely prunable.
- Pro: We can do it on Bitcoin today!

Pros and cons

- Con: The transaction is interactive.
- Con: Constructing the zero-knowledge proof can take seconds to minutes depending on the complexity of the circuit.
- Con: The proving key can be tens to hundreds of megabytes in size depending on the complexity of the circuit.

Circuit Statistics

- 16x16 sudoku:
  - Proving key: 68MB
    - Only needs to be computed once, so cost can be amortized.
  - Proving time: 10 to 20 seconds
  - Proof: 288 bytes (sent off chain)
  - Verification time: 40ms
  - Circuit cost:
    - **Encrypt(A, K)** (81.86%)
      - ChaCha20 would be a 3x improvement over the current cipher.
    - **SHA256(K)** (10.23%)
      - Could use RIPEMD-160?
    - Solution validity (4.42%)
      - Mostly unoptimizable

Wrapping up

- Code: https://github.com/zcash/pay-to-sudoku
- Thanks:
  - Gregory Maxwell
  - Pieter Wuille
  - Madars Virza
  - Andrew Poelstra
  - Zcash Company