MixCoin: Anonymity for BitCoin with Accountable Mixes

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The Graduate Center, CUNY

May 27, 2016

BitCoin

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- Users have pseudononymous addresses
- Transactions can often be easily linked
- If one transaction is linked to user, then all of their addresses may be exposed

Background: BitCoin

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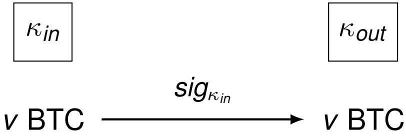

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- Transactions are recorded on the blockchain
- Blockchain is a decentralized, publicly verifiable ledger
- Records all past messages exchanged between users on that Blockchain
- No transactions are truly anonymous, because they are always publicly visible on the blockchain

Background: BitCoin Mixes

Used to preserve privacy for some BitCoin users. Multiple clients send coins to a mixing address, which forwards them randomly to a fresh address for each client.

Mixing Services

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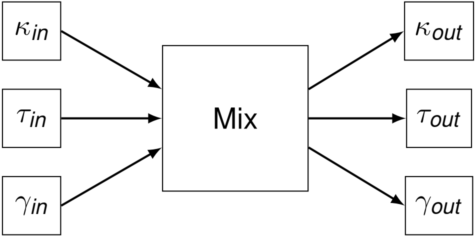
- Take a user's coins and randomly exchange them for other user's coins
- Obfuscates ownership

Alice owns N bitcoins at address κ_{in}, which is linkable to her real-world identity. She wishes to tranfer her funds to address κ_{out} in a way which is difficult to link to κ_{in} for a fee.
She sends her funds to a mix M which holds them for an agreed time period before sending an equal value to κ_{out}.



The Downside of Mixes

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- Open question of linking attacks between inputs and outputs

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No protection from theft!

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- Alice could falsely accuse the mix of theft to undermine its reputation
- Accusations of theft cannot be proven, hence it is difficult to determine which mixes are honest
- A malicious mix is able to link the in and out addresses, potentially undermining Alice's anonymity

Various Solutions

- ZeroCoin

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  - Provides strong anonymity
  - Requires advanced cryptography
  - Substantial modifications to BitCoin

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- Zerocash
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- CoinJoin, CoinSwap
  - Backwards-compatible with BitCoin
  - Practical complications, smaller anonymity sets

Solution: MixCoin!

- Build on the framework of mixes

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- Build on the framework of mixes
- Add cryptographic accountability layer

MixCoin: Accountability

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- Alice can publish this warranty if the mix fails to deliver her coin

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- Paying for mixing services incentives honest behavior
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- MixCoin uses randomized, all-or-nothing fees

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- Single-use mix addresses
- Passive adversaries can't determine which mix a user is interacting with
- Anonymity set: All users who are interacting with any mix at the same time

MixCoin: Mix networks for BitCoin

- Chains multiple mixes together

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- Chains multiple mixes together
- Provides strong anonymity against an active attacker who can break mix indistinguishability

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- MixCoin is a protocol for mixing with accountability
- The mix gives Alice a signed warranty which she can use to unabiguously prove that the mix has misbehaved

- There is no way to prove that a mix is not storing records which could deanonymize its clients
- Alice can send her coins through a series of mixes which all must collude to deanonymize her final address

Assumptions

- Availability of multiple mixes M_i

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- Mix M_i represented by warranty-signing key K_{M_i}
- Each mix's warranty-signing key is used consistently
- Alice able to negotiate with mix over an anonymous, confidential channel (Tor hidden service)

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- κ_{out}, the address where Alice is transferring her funds
- ρ, the mixing fee
- n, a nonce used to determine payment of randomized mixing fees
- w, the number of blocks the Mix requires to confirm Alice's payment

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- Deadlines are specified as block numbers in the BitCoin block chain.
- $w = 6$ is a common standard

Step 1

Alice contacts Mix over a secure channel and proposes the mixing parameters

Step 2

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2. The mix rejects Alice's request

Note that κ_{out} and κ_{esc} should be fresh addresses created specifically for mixing

Step 3

Alice transfers the value v to κ_{esc} by time deadline t_1

Step 4

1. The mix transfers an equal value to κ_{out} by time t_2

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2. The mix fails to transfer v to κ_{out} by time t_2

Step 5

1. If the protocol is successful, *A* and *M* destroy their records

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2. If Alice detects theft, she publicizes

$$\{v, t_1, t_2, w, \kappa_{esc}, \kappa_{out}, \rho, n\}_{K_M}$$

Mixing Fees

Fixed mixing fees undermine the goal of indistinguishable transfers and limit the anonymity set

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- Expected mixing rate is ρ

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- Call this a *beacon*
- This computation can be performed by anybody if Alice's warranty is published (hence cheating is detectable!)

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    - Assuming the exact set of future transactions is included in each block
    - Also utilizes the nonce *n* specified by Alice, used to solove the proof-of-work puzzle

Beacon from BitCoin blocks

The mix computes

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- B_i is the Merkle root of block i in the BlockChain

Merkle Trees

- double-SHA256 (SHA256 applied twice)

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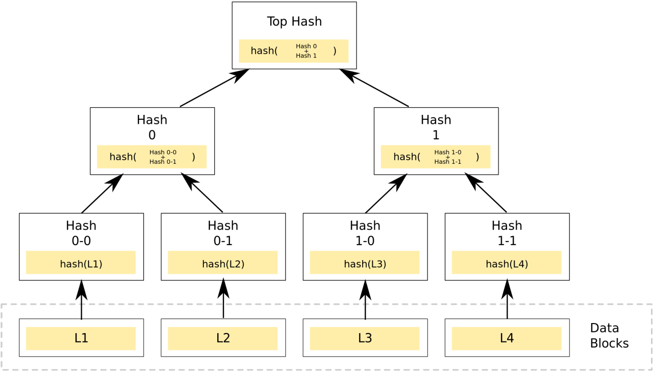

Figure: From Wikipedia

The MixCoin Protocol

$A \xrightarrow{anon} M$
$\langle v, t_1, t_2, w, \kappa_{out}, \rho, n \rangle$

- *M* accepts terms
  $A \xleftarrow{anon} M$
  $\{v, t_1, t_2, w, \kappa_{esc}, \kappa_{out}, \rho, n\}_{K_M}$
  - *A* by time t_1:
    Transfer $\kappa_{in} \xrightarrow{v} \kappa_{esc}$
    - $X = \text{Beacon}(t_1, w, n)$
  - *M* aborts protocol $\perp$
- *M* rejects terms
  $A \xleftarrow{anon} M$
  $\perp$
  - *A* destroys κ_{out}

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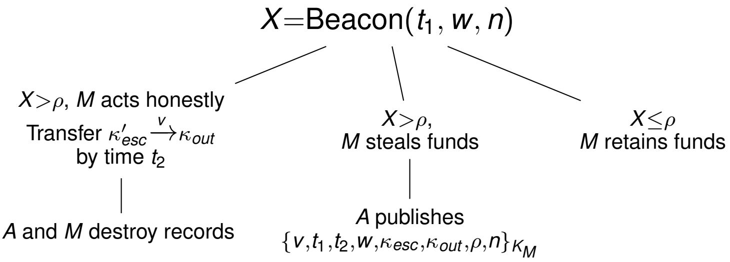

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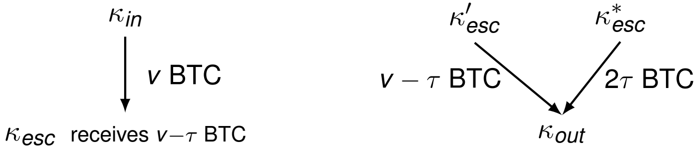

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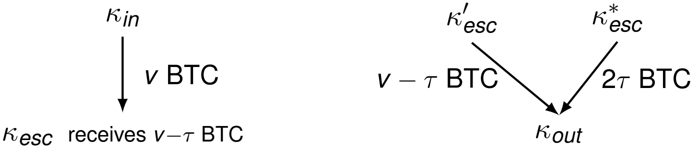

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- Execute the MixCoin protocol through these mixes in reverse order
- Instruct M_i to forward her funds to escrow address $\kappa_{esc_{i+1}}$ which she previously received from M_{i+1}
- Alice obtains N signed warranties, transfers funds to κ_{esc_1}

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- Each chunk should travel through an independently-chosen random mix of sequences.

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- What is this ρ?

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- $\bar{t}$ is the average time period (in blocks) that the mix holds funds during a mixing round
- Expected value of absconding is $\mathbf{E}[\text{abscond}] = Q\bar{t}$

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- Expected payoff from choosing to continue defined recursively
- Under steady state conditions, optimal decision the same in every round
- If mix chooses to continue, it will do so indefinitely
- Mix is discounting future earnings at a rate of r per block
- Net value of indefinite honest behavior:

$$\frac{\rho Q}{r}$$

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- To incentivize honest behavior, we need:

$$\frac{\rho}{r} > \bar{t}$$

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- Then, all this says is that the expected value of fees collected by a mix during the time it holds funds is greater than the amount those funds would yield during the same time period if invested

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- If $r \approx 20\%$ available to mix, then a mix time $\bar{t} \approx 1$ hour yields lower bound $\rho_{min} \approx 2^{-15}$
- A chunk taking a path through 10 consecutive mixes leaves a fee rate of $\approx 2^{-12}$

Anonymity Properties: Passive Adversary

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- Best case scenario: Passive Adversary
- Say adversary can determine with high probability which Bitcoin transactions are mix traffic
- Adversary still may not be able to link escrow addresses to specific mixes due to their one-time nature
- This property is called *mix indistinguishability*

Anonymity Properties: Active Adversary

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- The client which sends the chunk to κ'_{esc}, eventually sent to κ_{out}, learns that Alice interacted with *M*
- Active adversary can exploit this in a *flooding attack*

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Anonymity Properties: Active Adversary

Second attack:

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- All of these transaction fees can then be linked to *M*

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- If 25% of mixes are comprimised, there is a 2^{-20} chance of routing a chunk through a chain of ten comprimised mixes

Acknowledgements

I would like to thank Dr. Rosario Gennaro for teaching this course.

Bibliography

Mixcoin: Anonymity for BitCoin with Accountable Mixes, Joseph Bonneau, Arvind Narayanan, Andrew Miller, Jeremy Clark, Joshua A. Kroll, Edward W. Felten. International Financial Cryptography Association 2014, LCNS 8437, pp.486-504.