Peer-to-Peer Payment System

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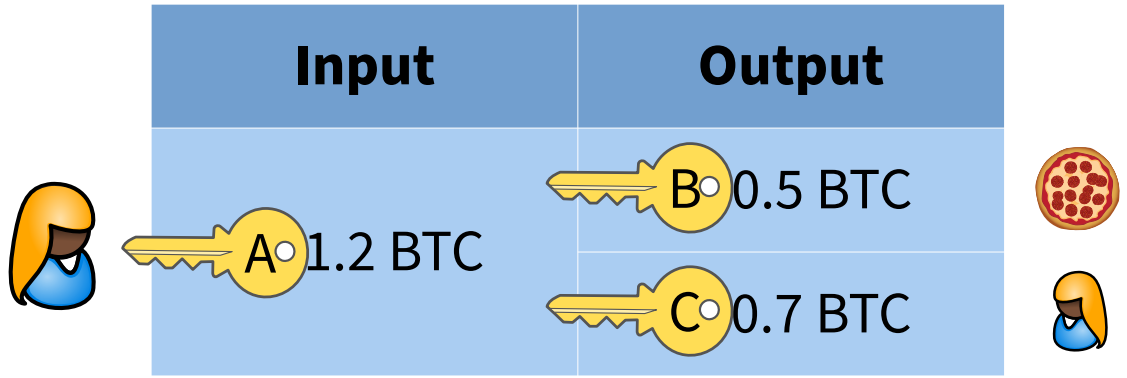

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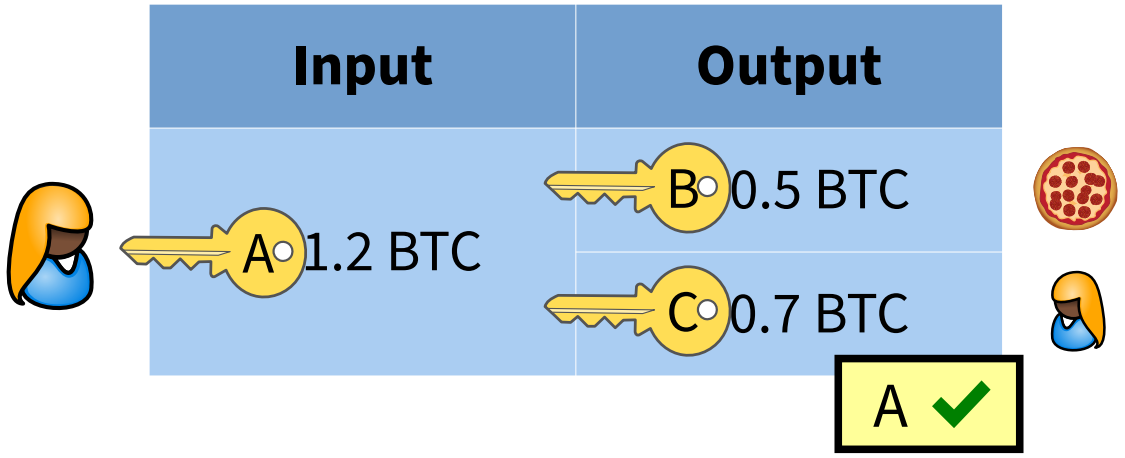

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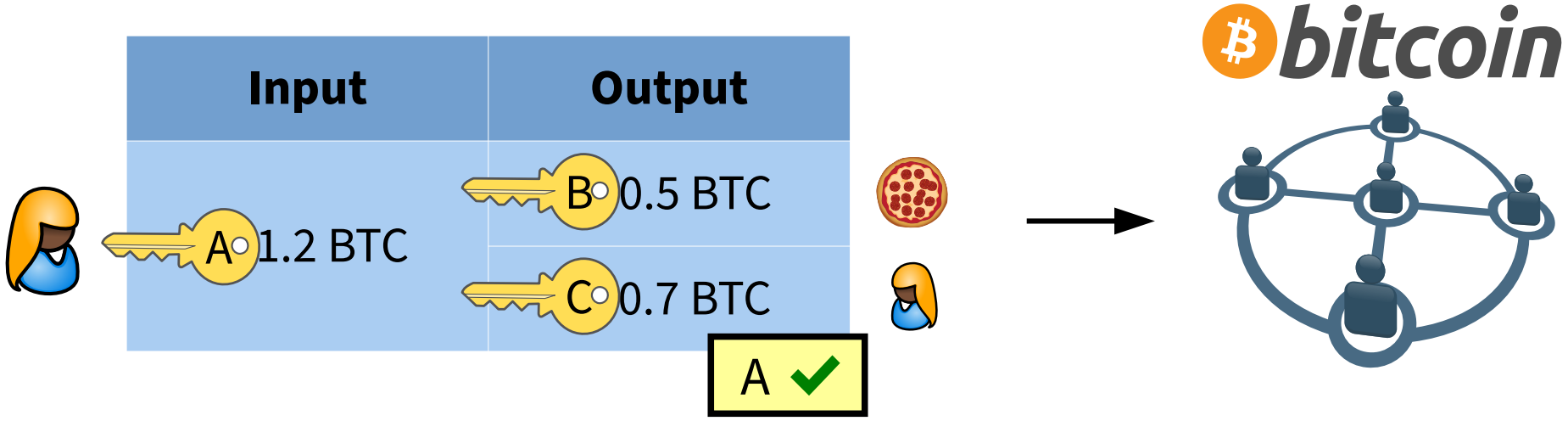

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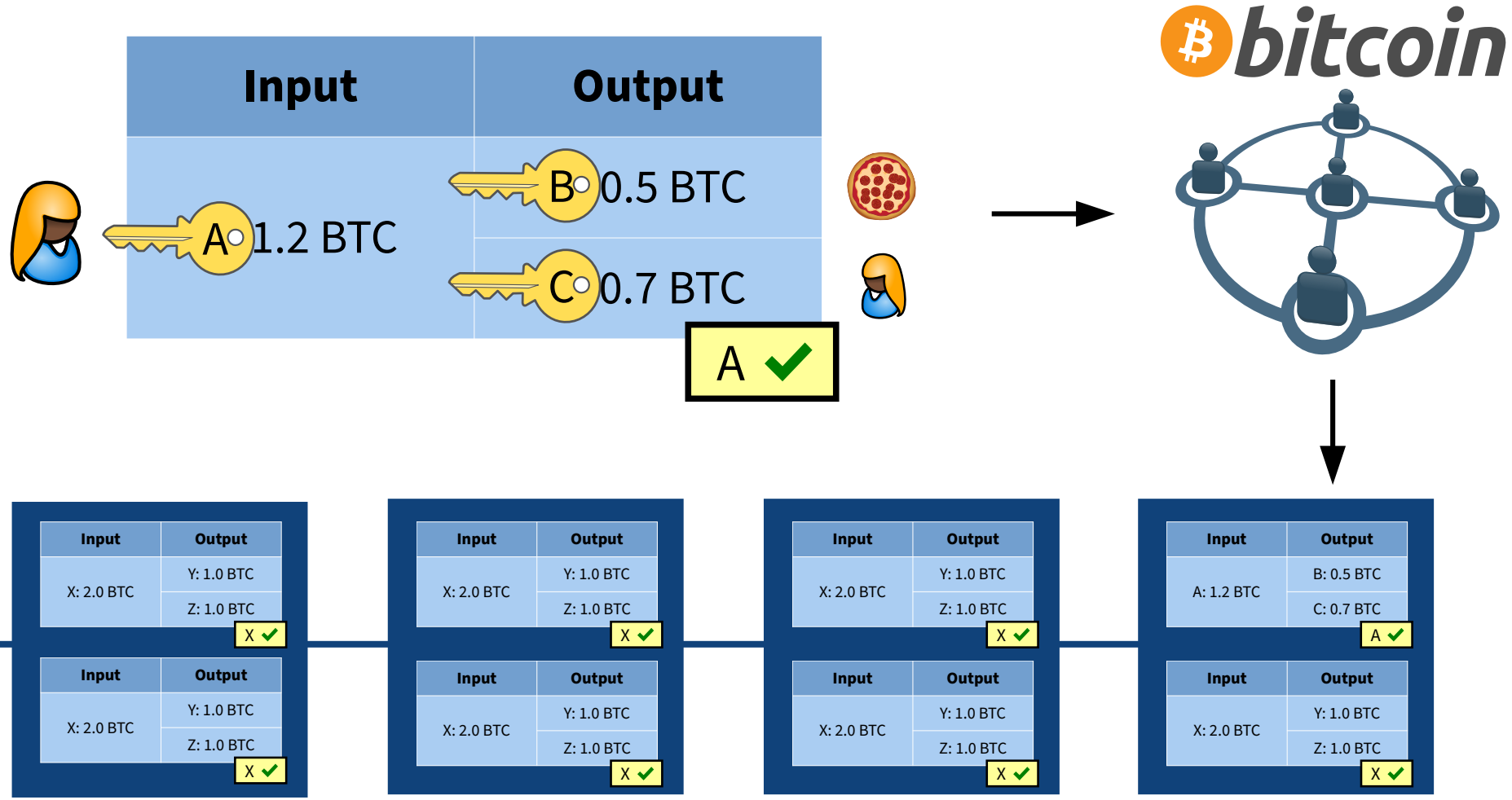

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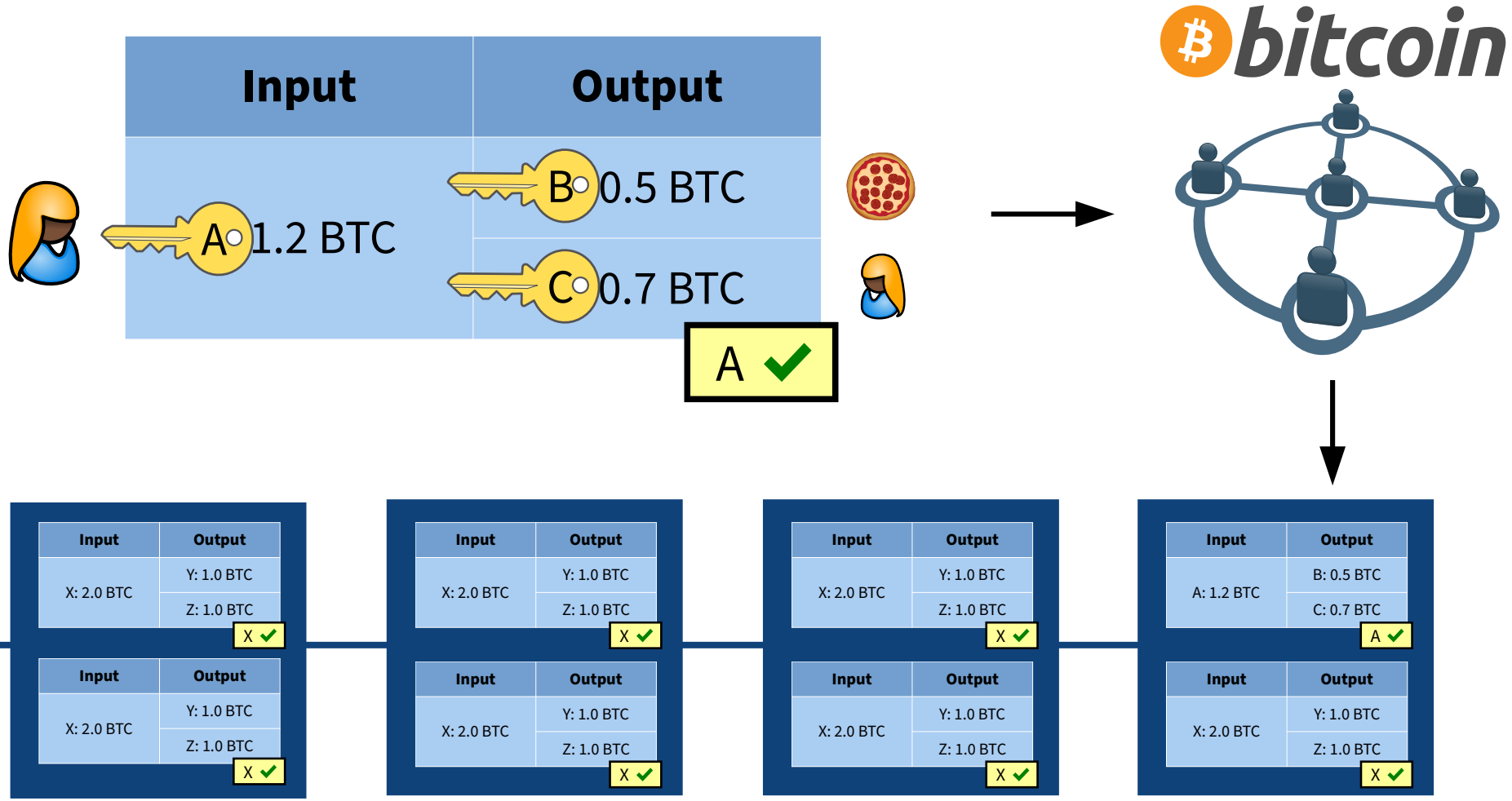

blockchain = **public** ledger of transactions

Main Privacy Issues (Transaction Layer)

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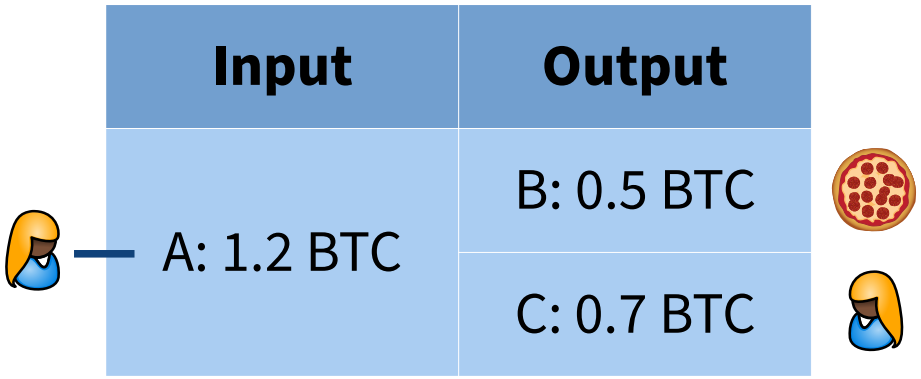

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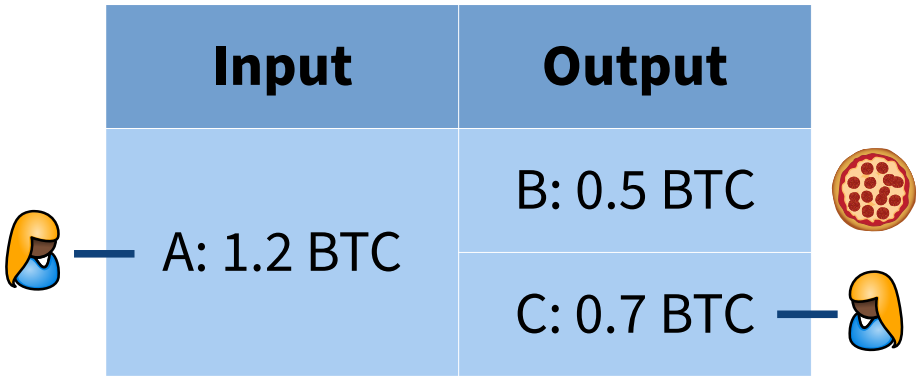

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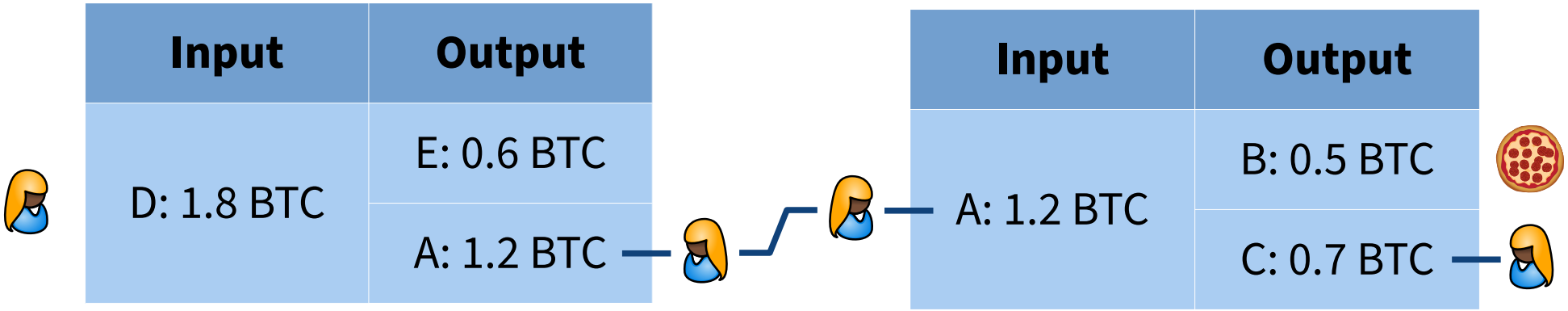

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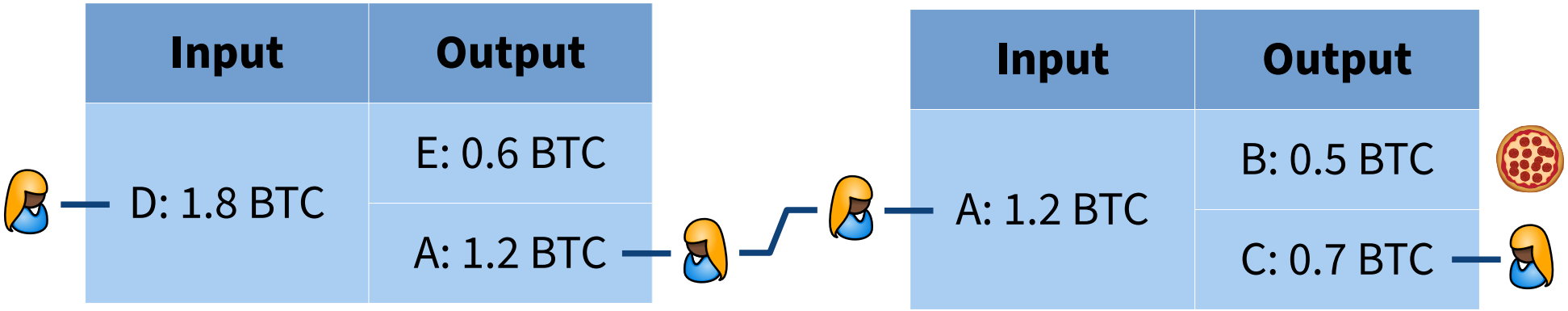
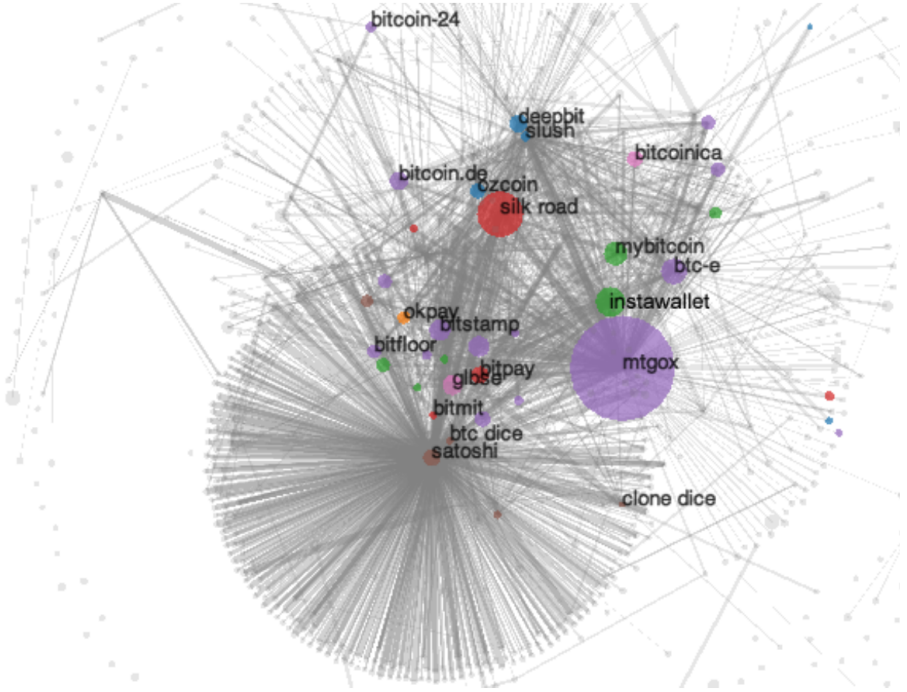
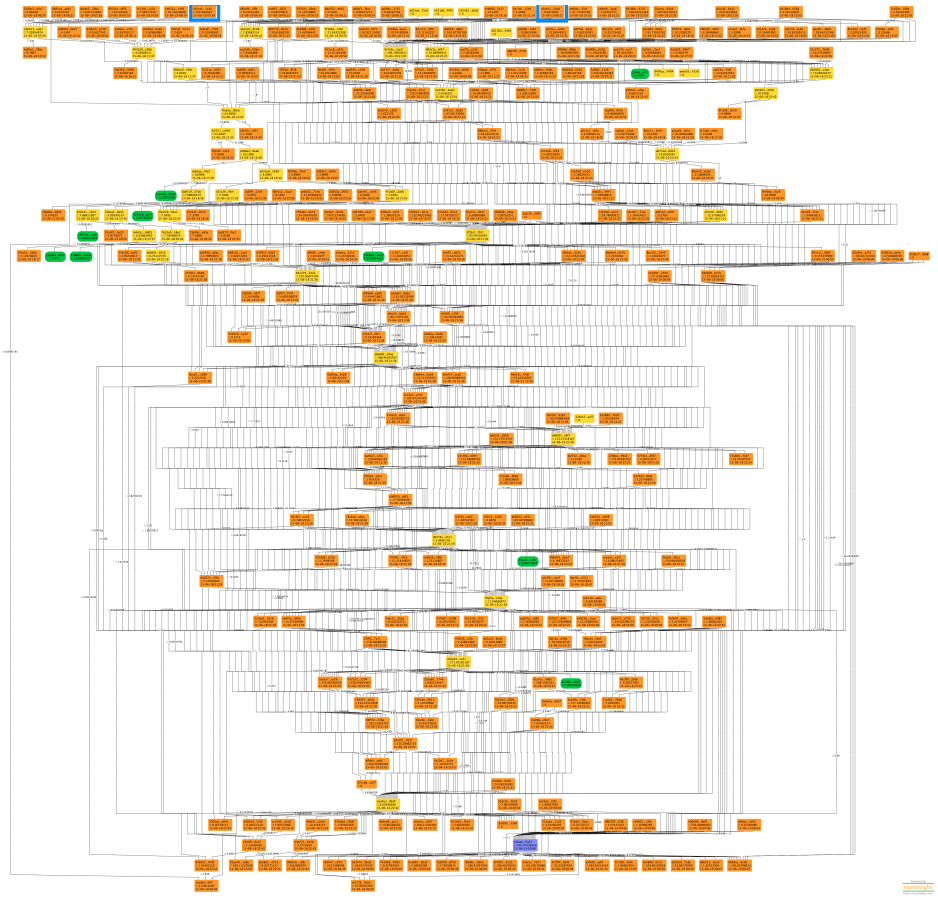


Transaction Graph Analysis



[Meiklejohn et al. 2013]



BitIodine [Spagnuolo, Maggi, Zanero 2013]

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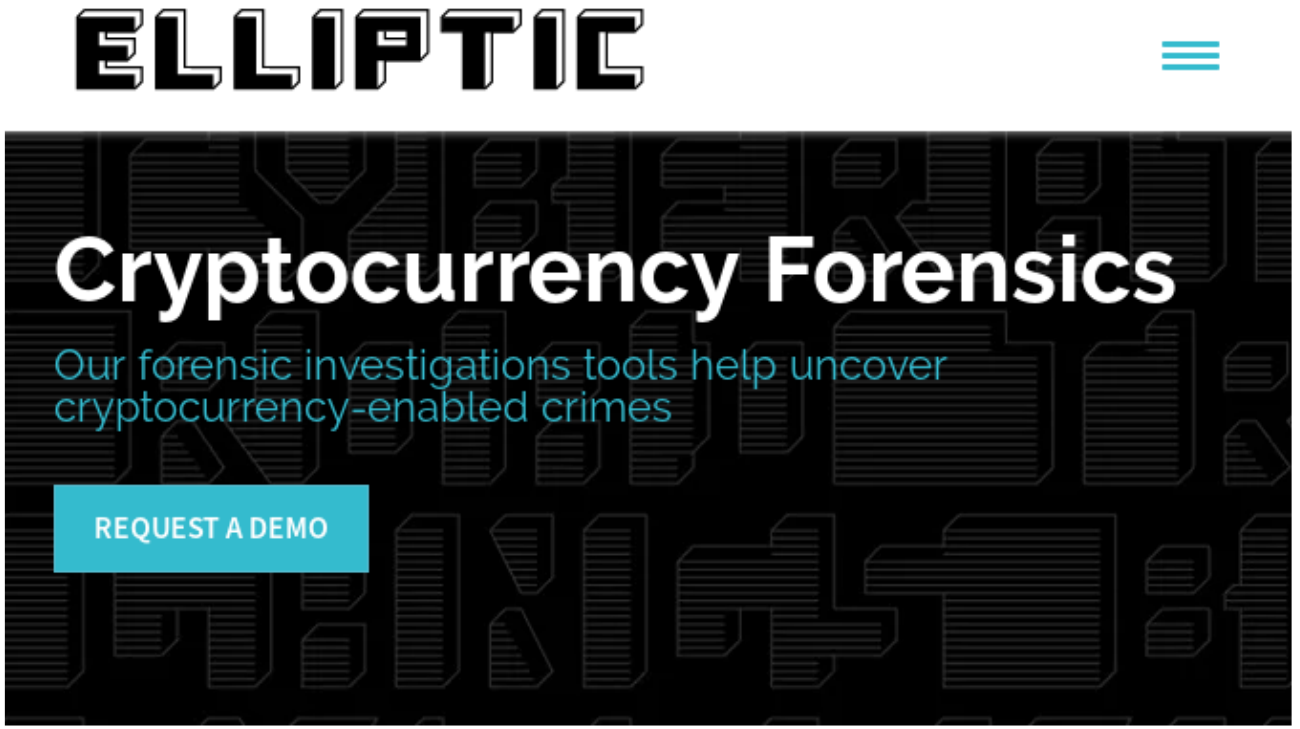

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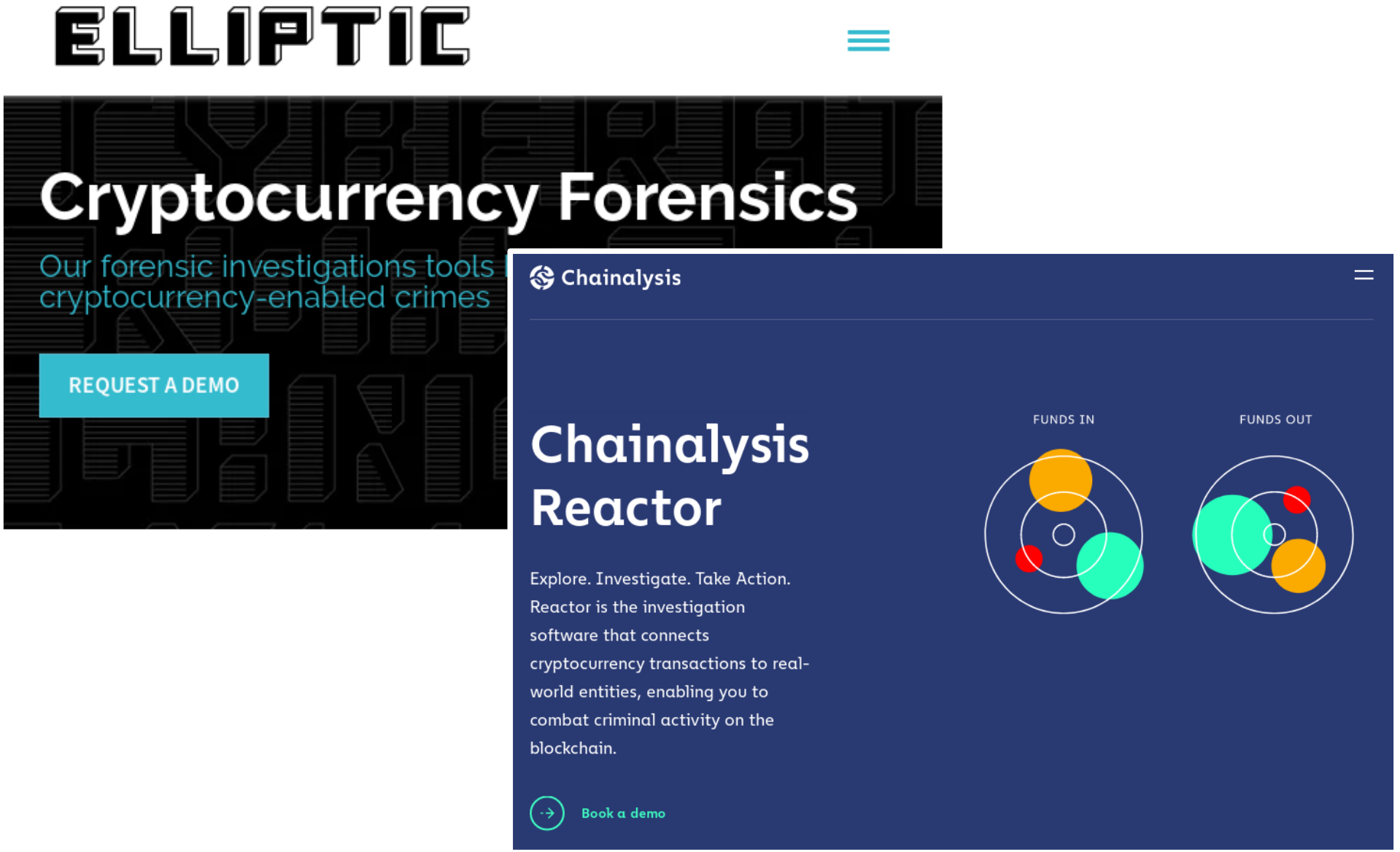
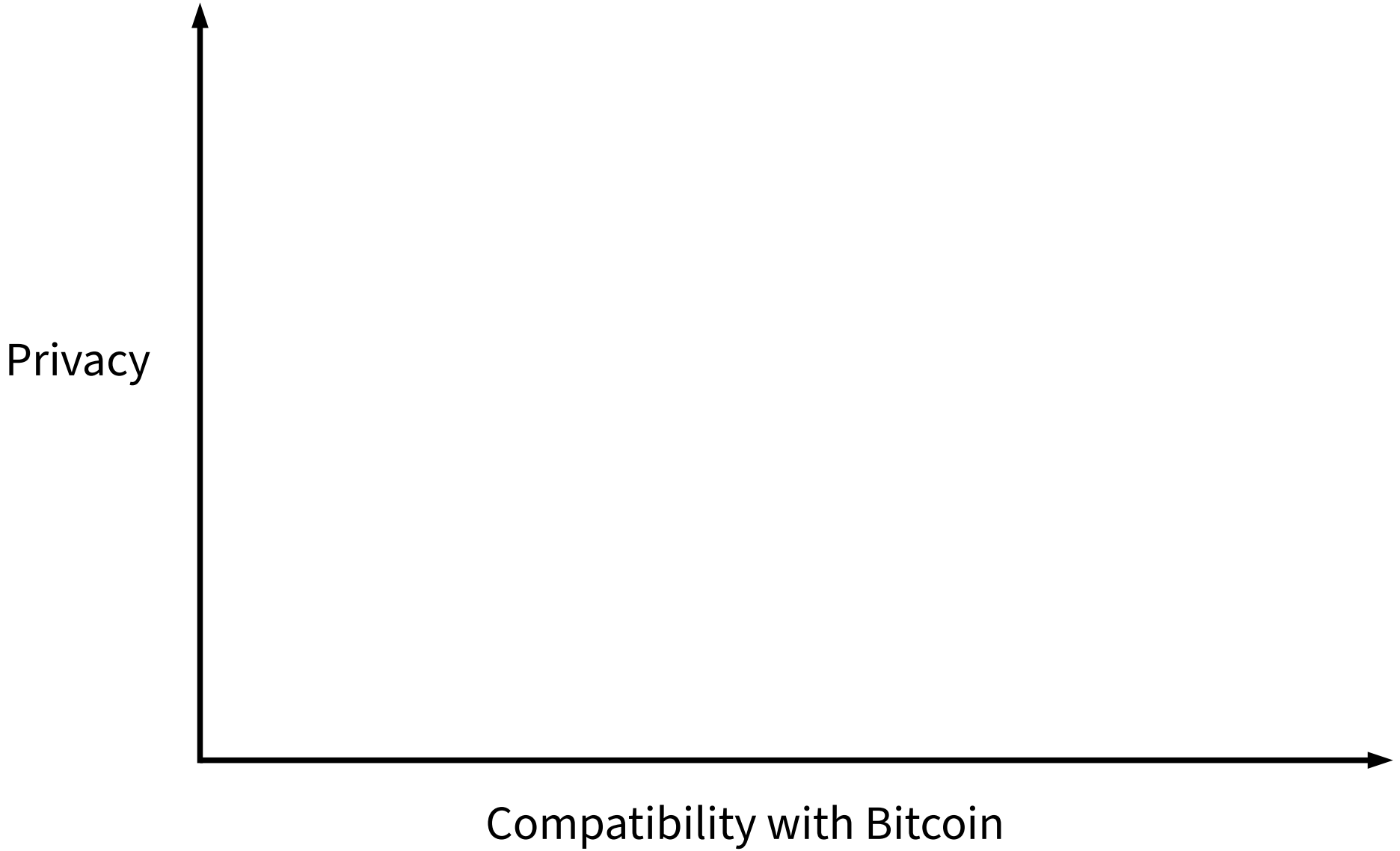


Improving Privacy

Big Picture of Privacy Technologies



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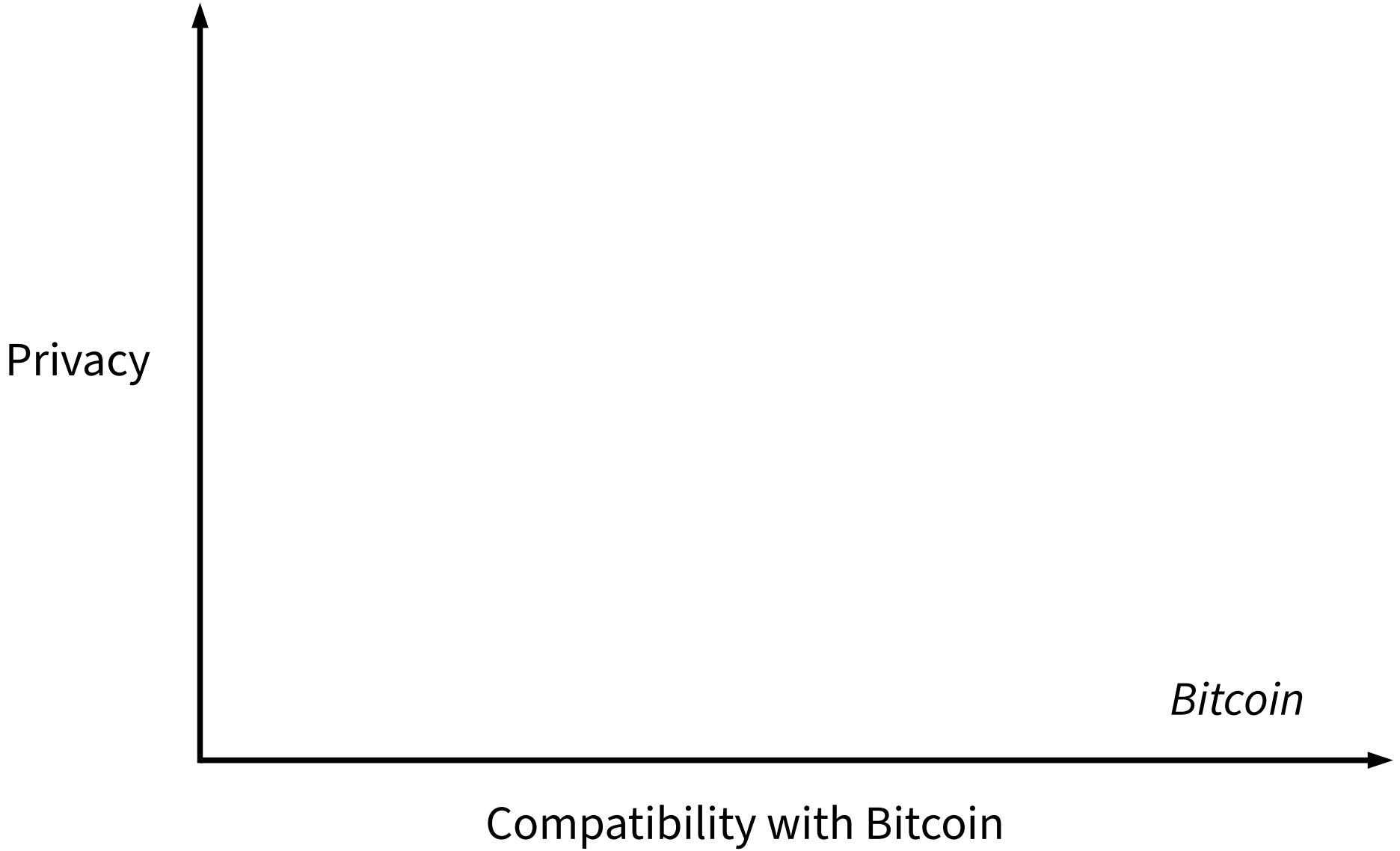

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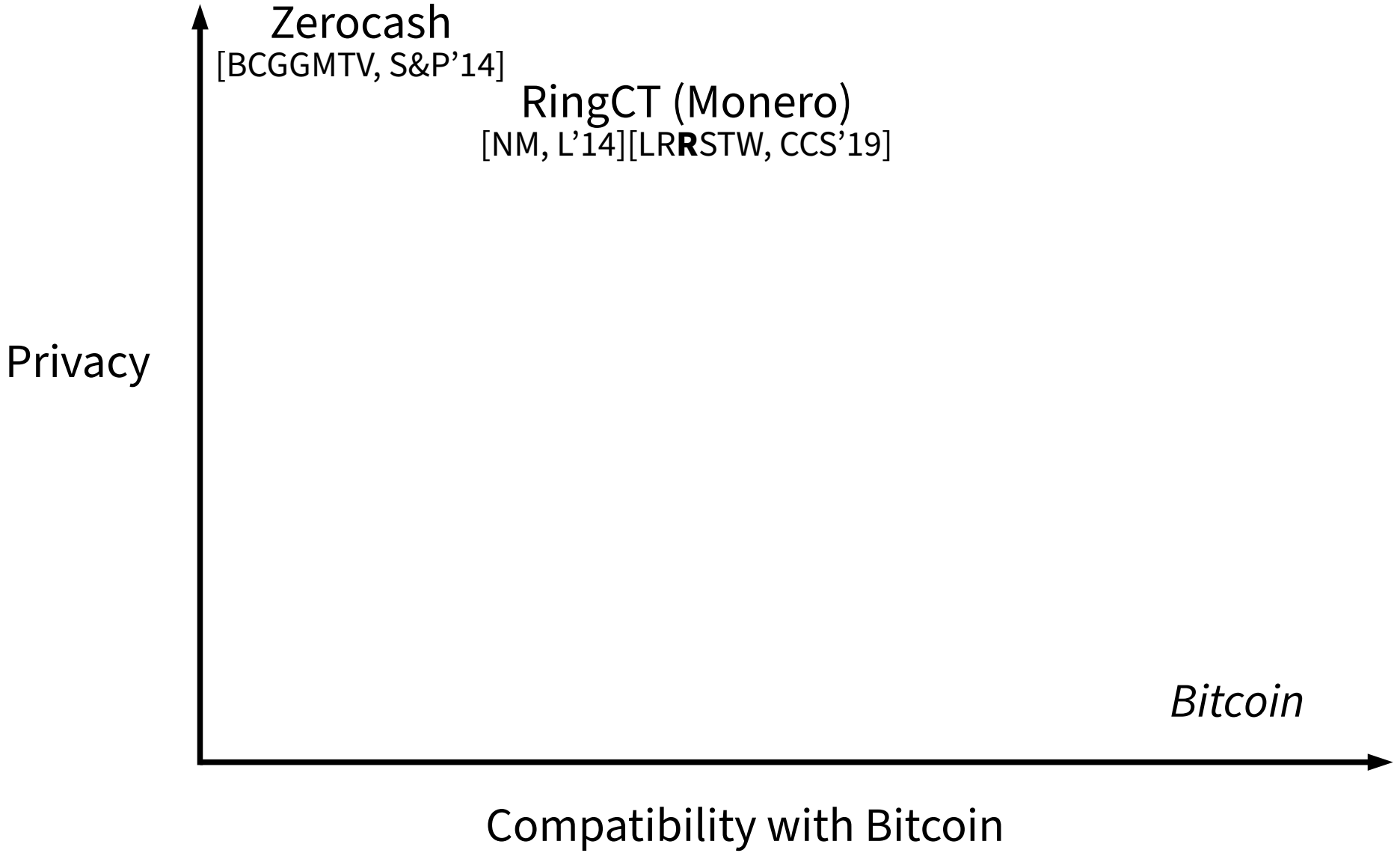

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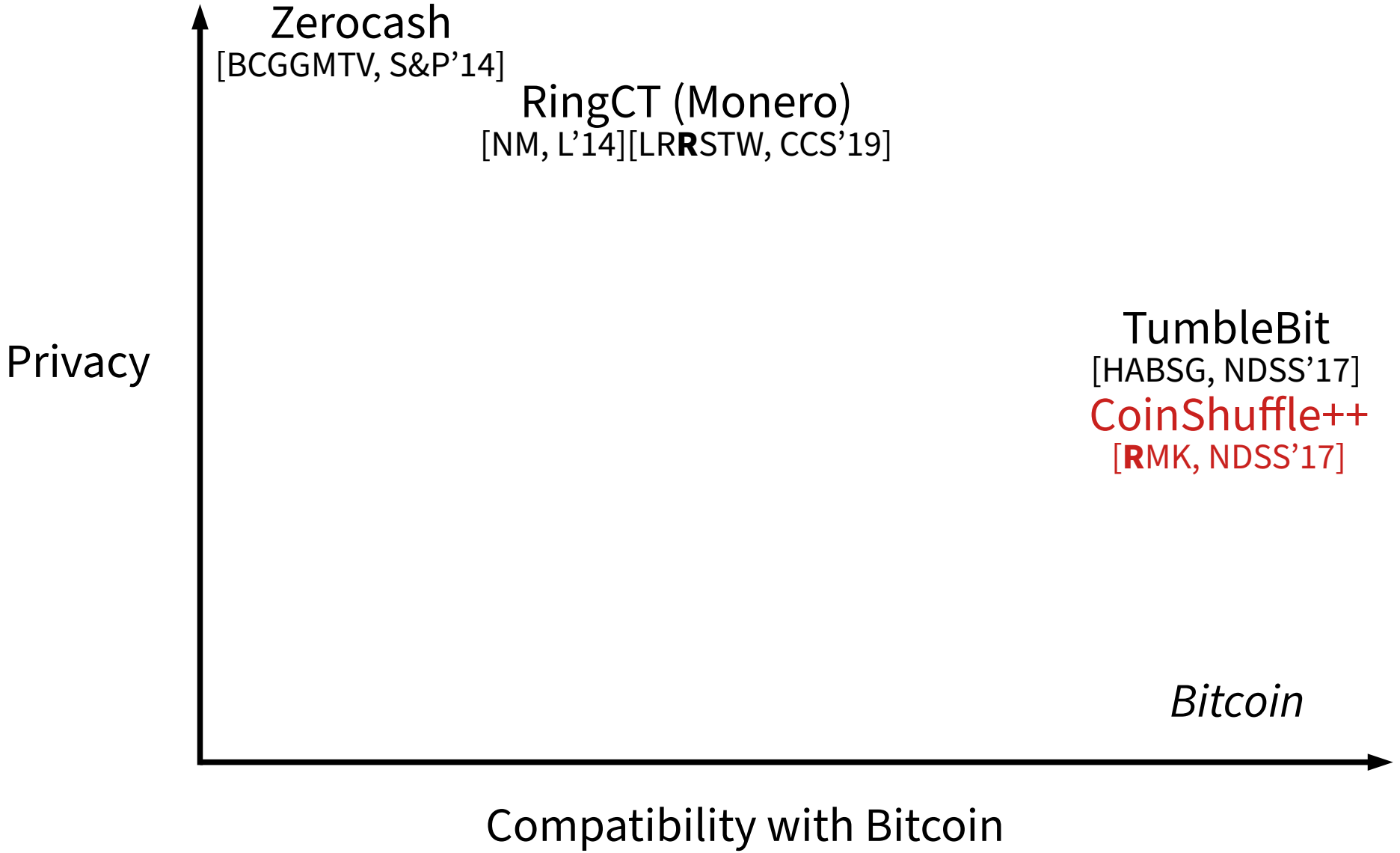

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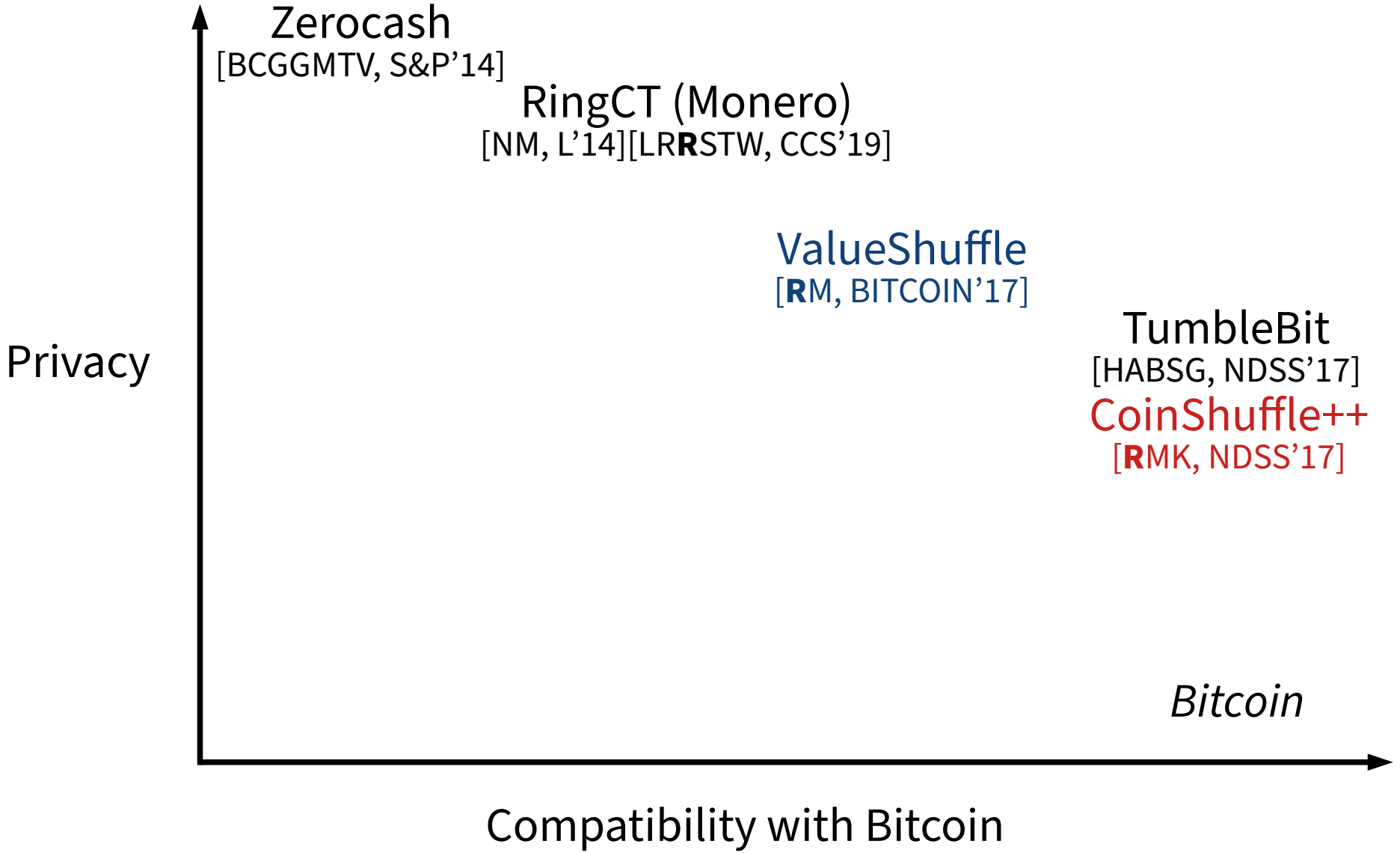
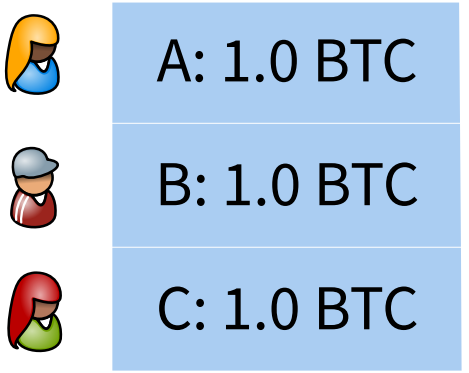


Coin Mixing



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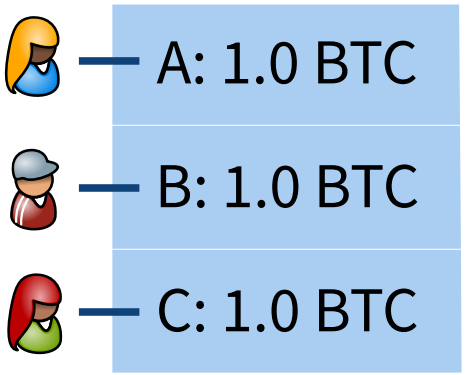

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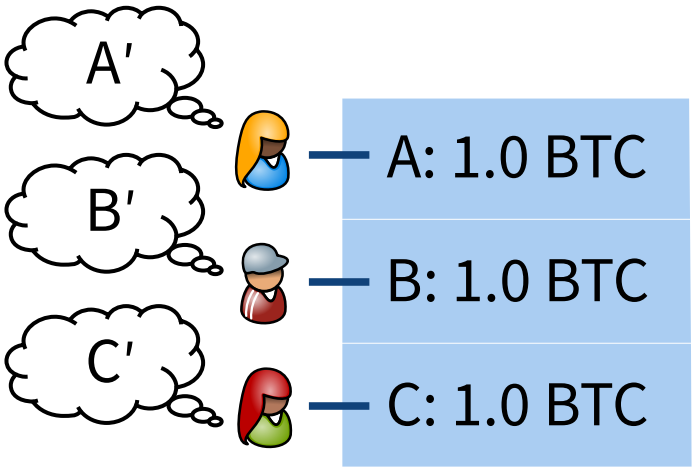
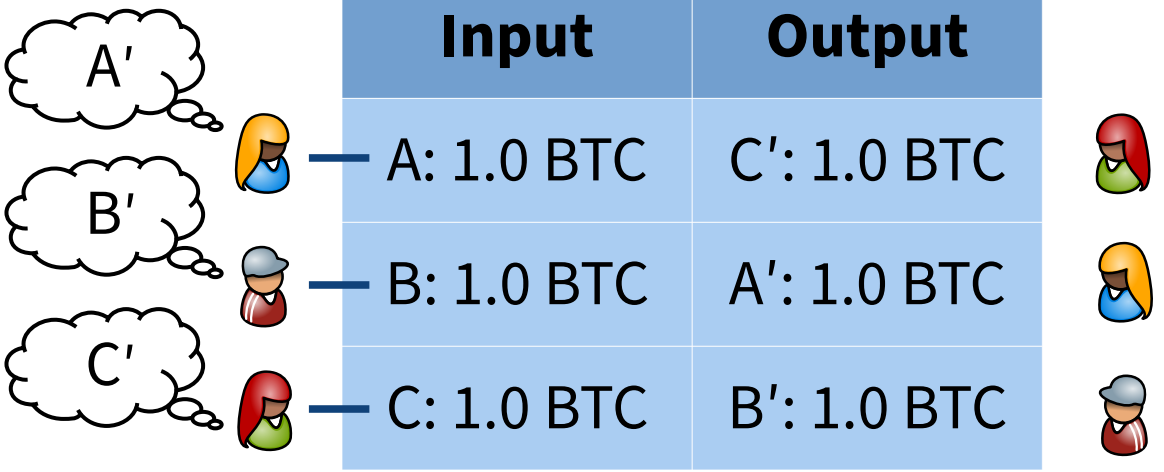


Coin Mixing

Multi-input multi-output transaction



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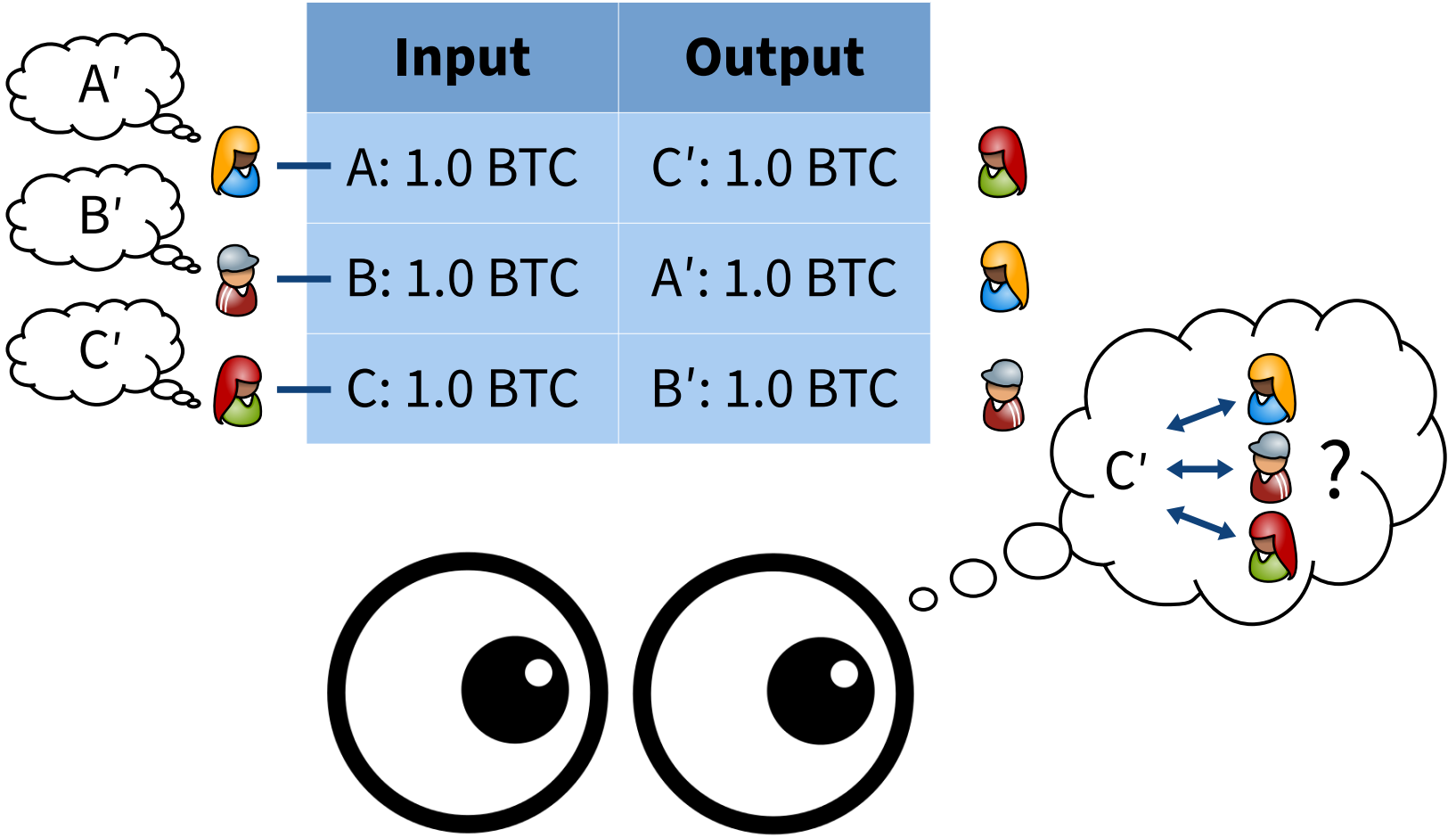

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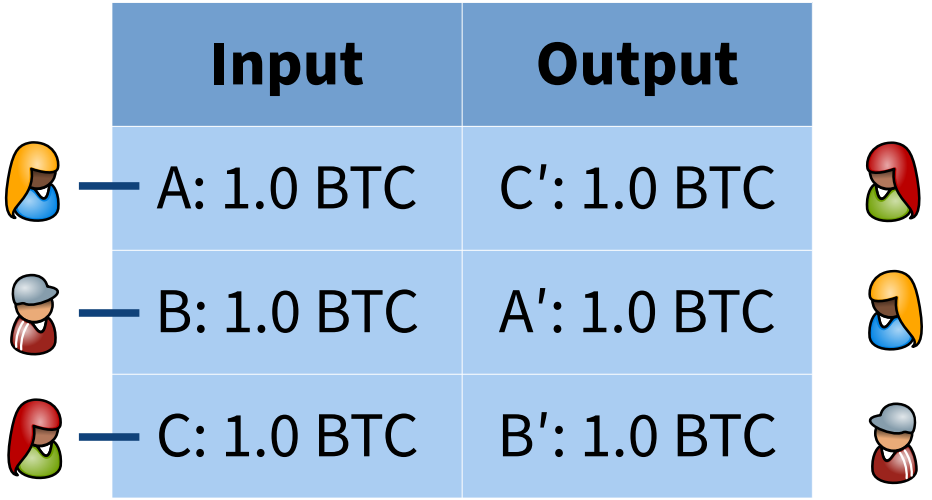

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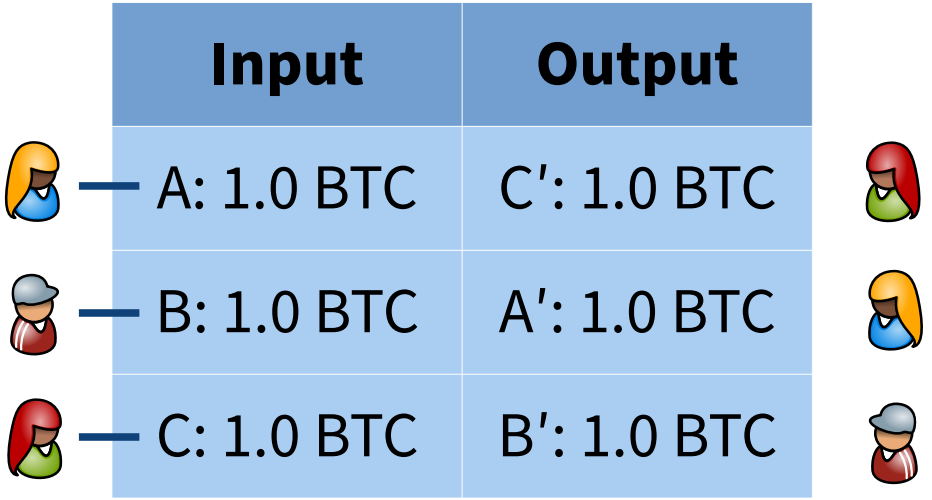

Fully compatible with Bitcoin

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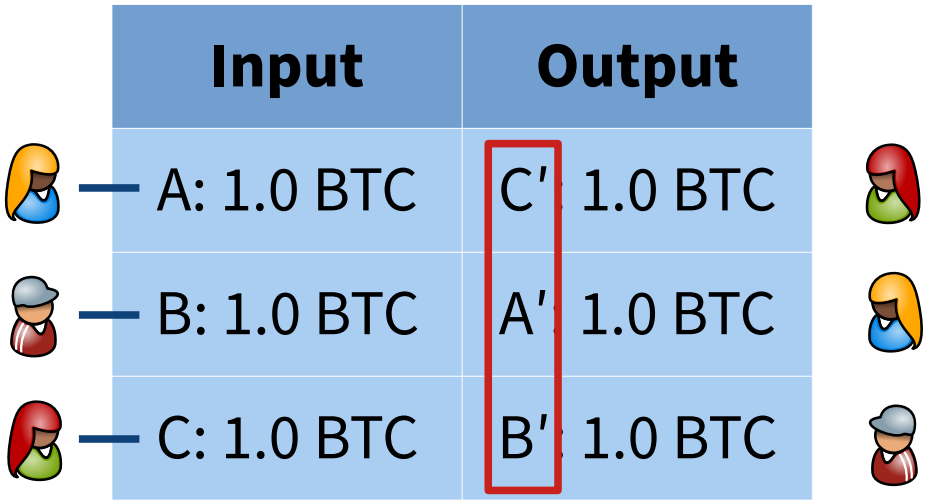

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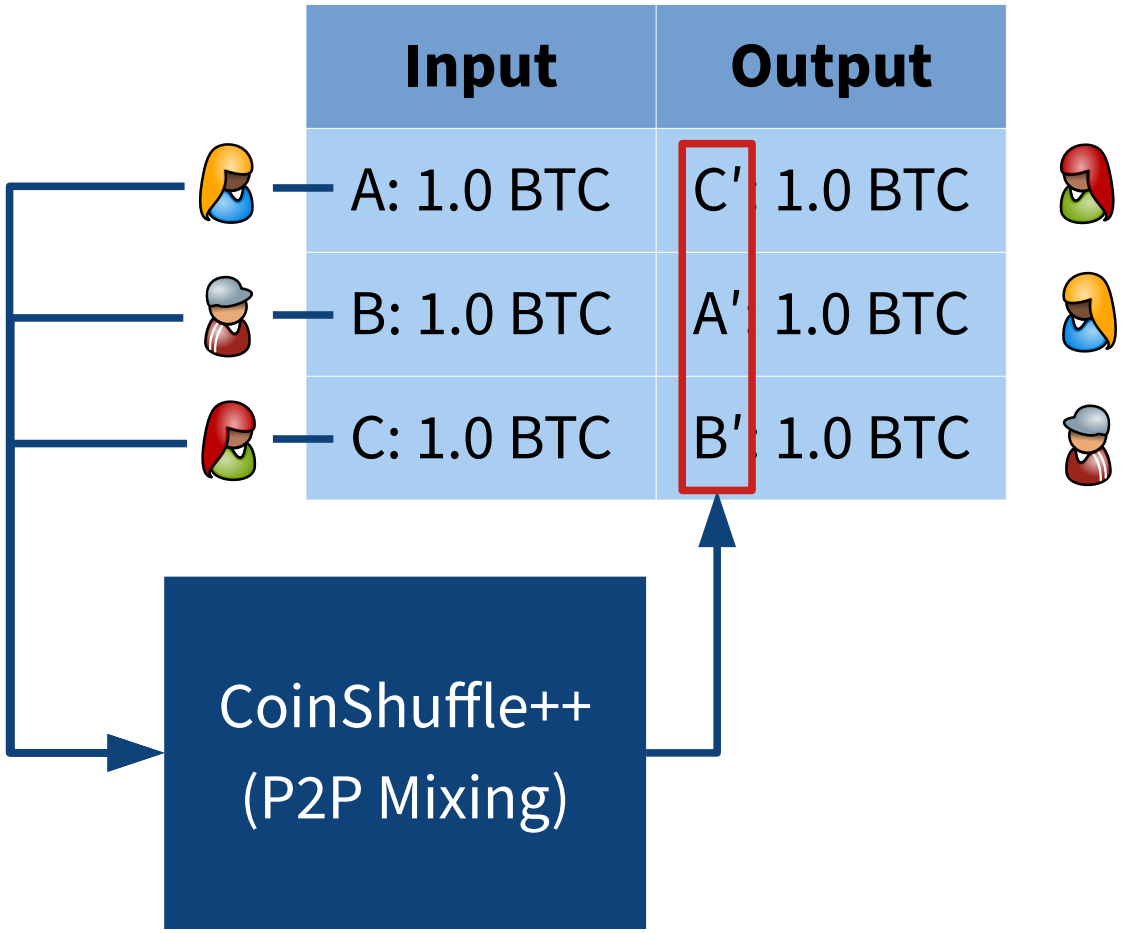
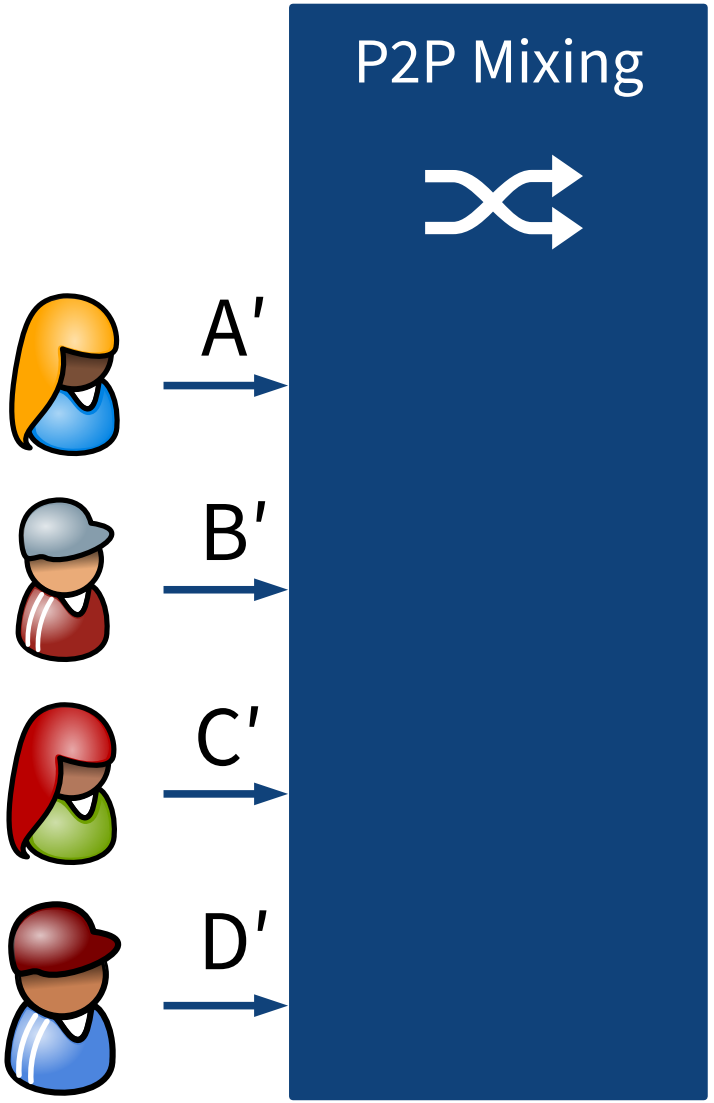


P2P Mixing



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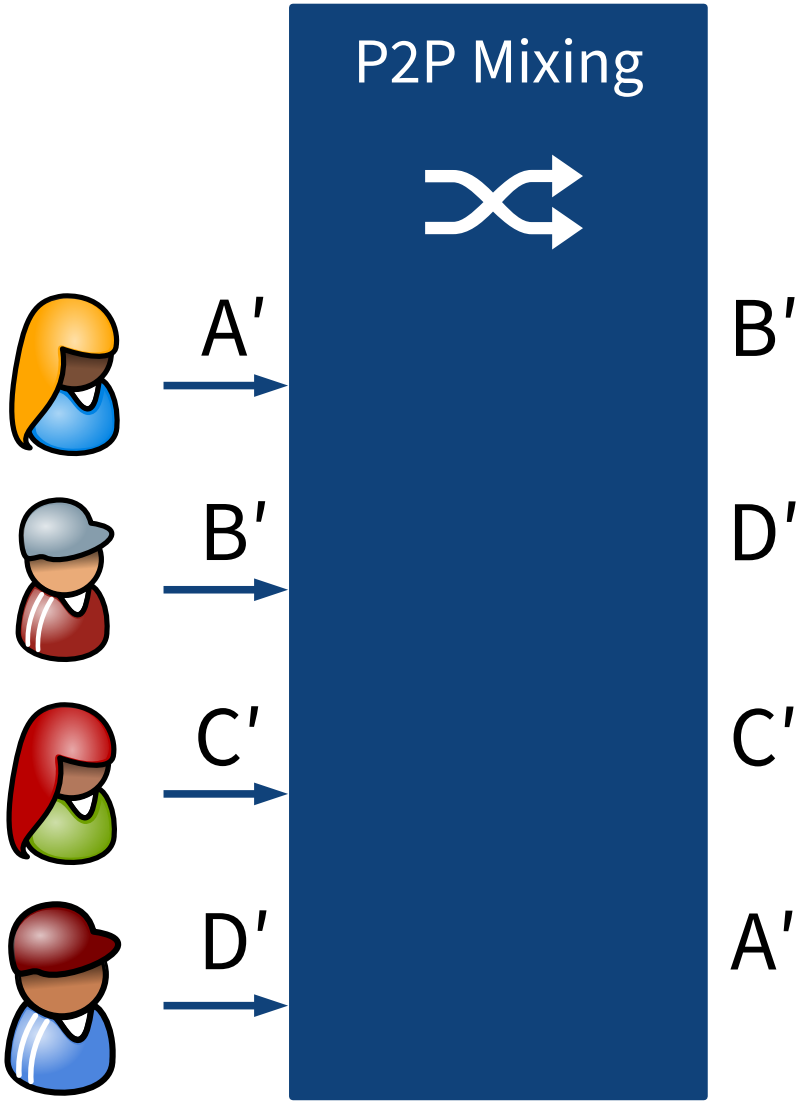

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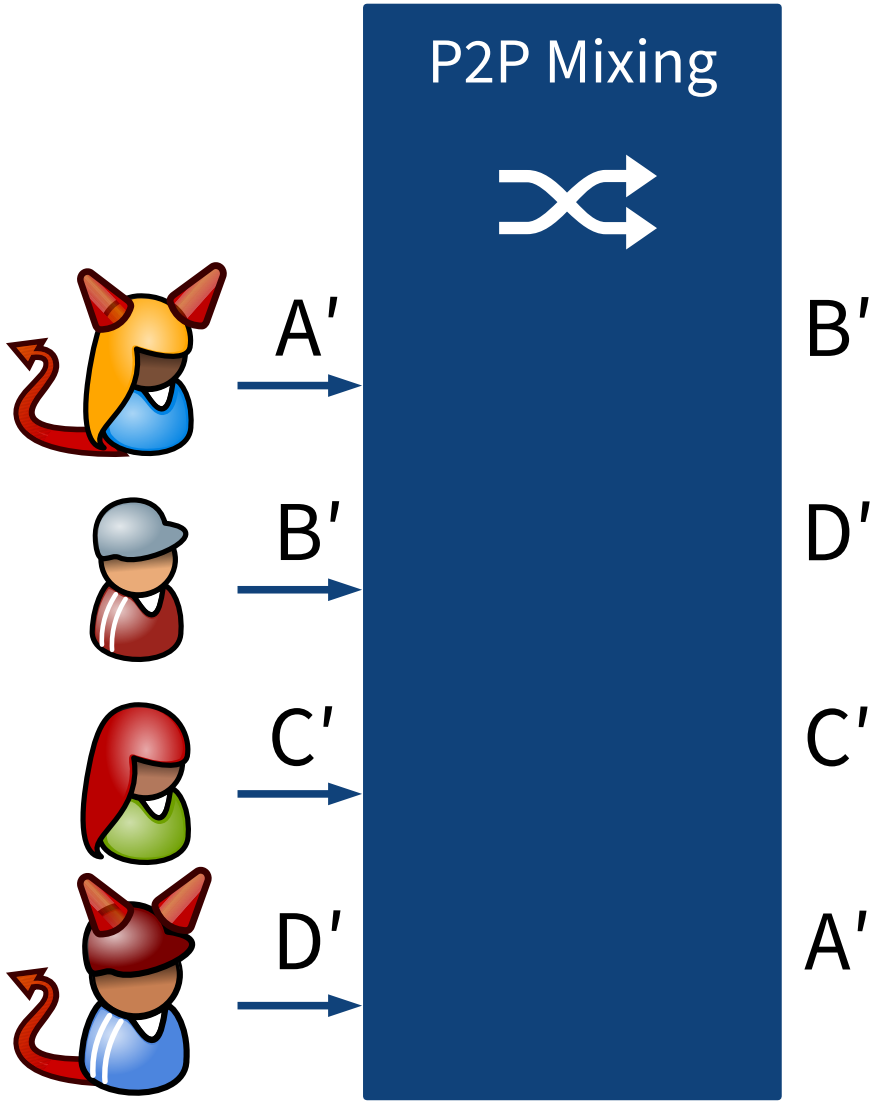

P2P Trust Model

No mutual trust,
no third-party routers.

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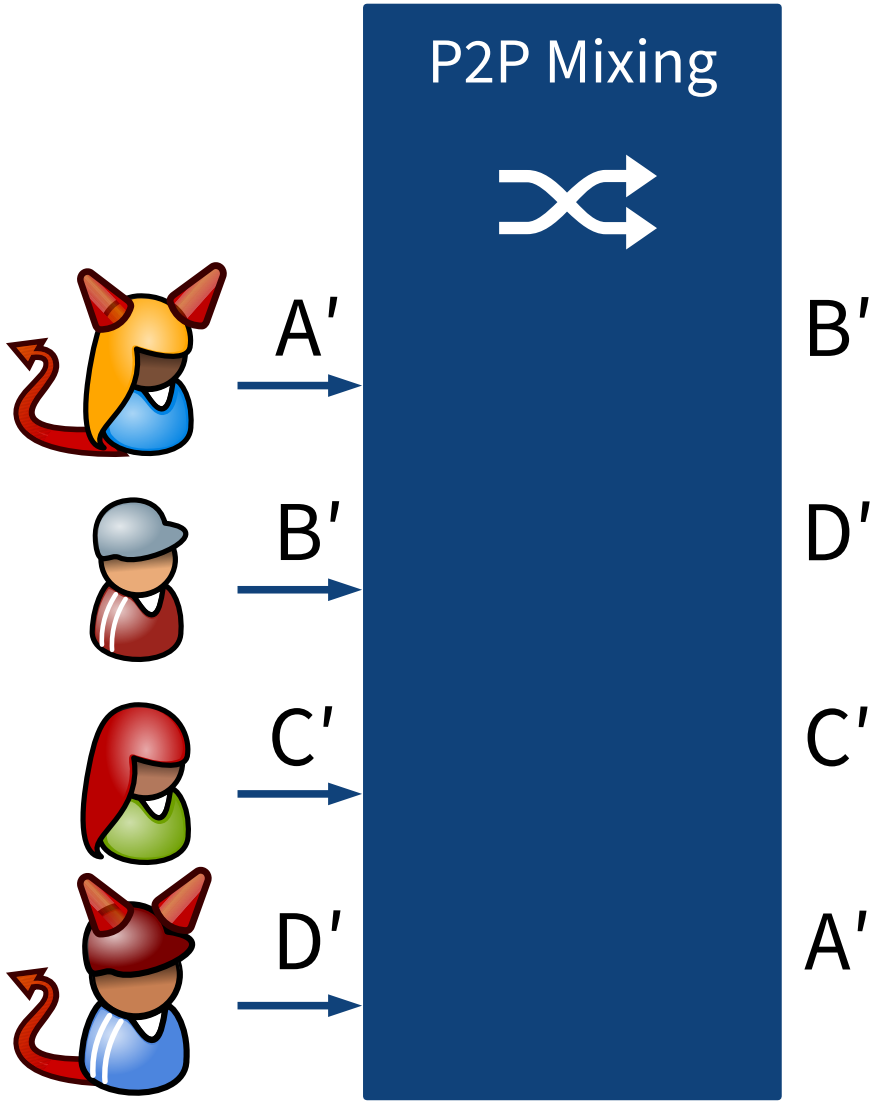

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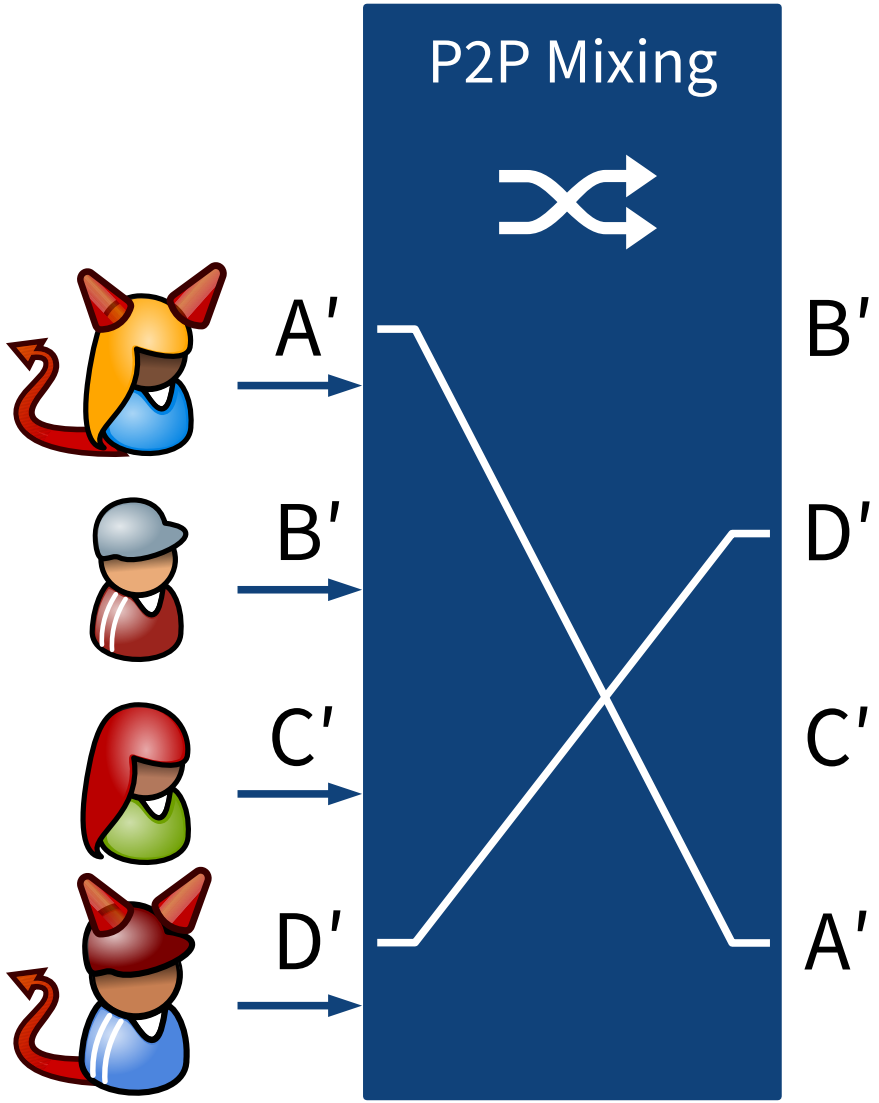

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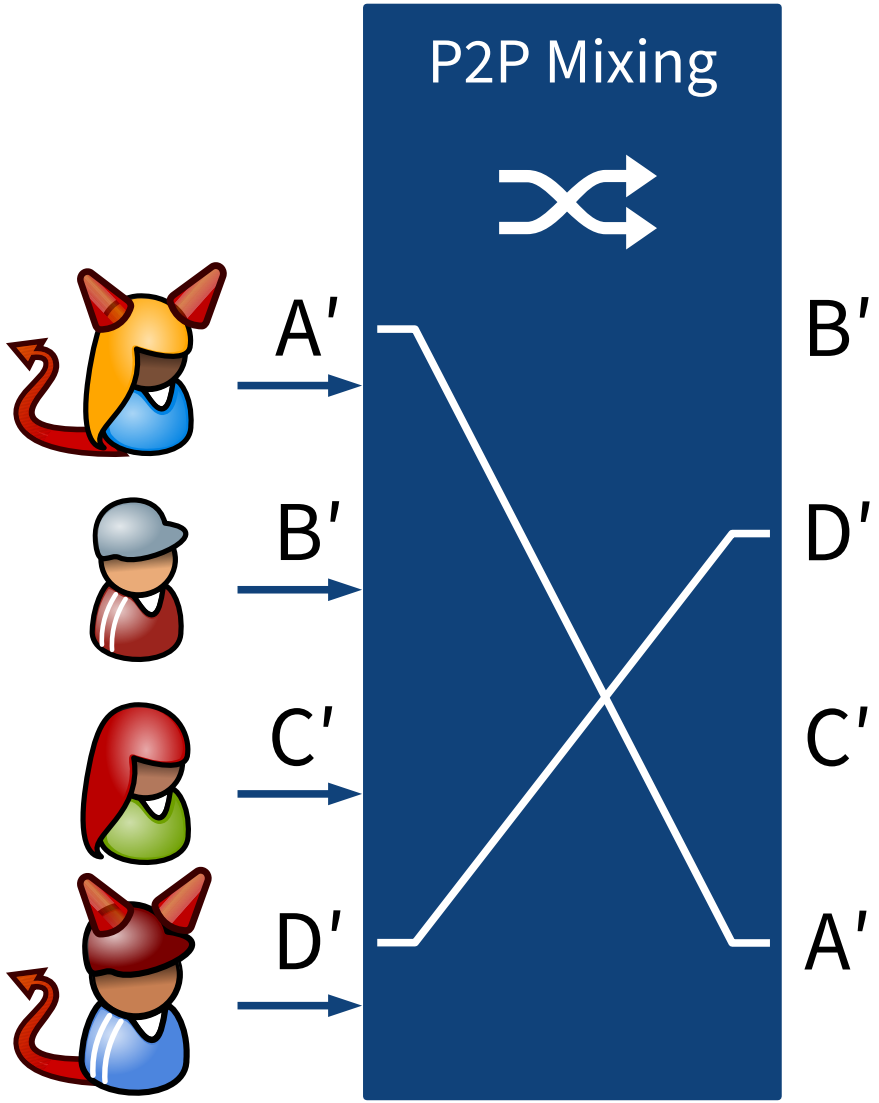

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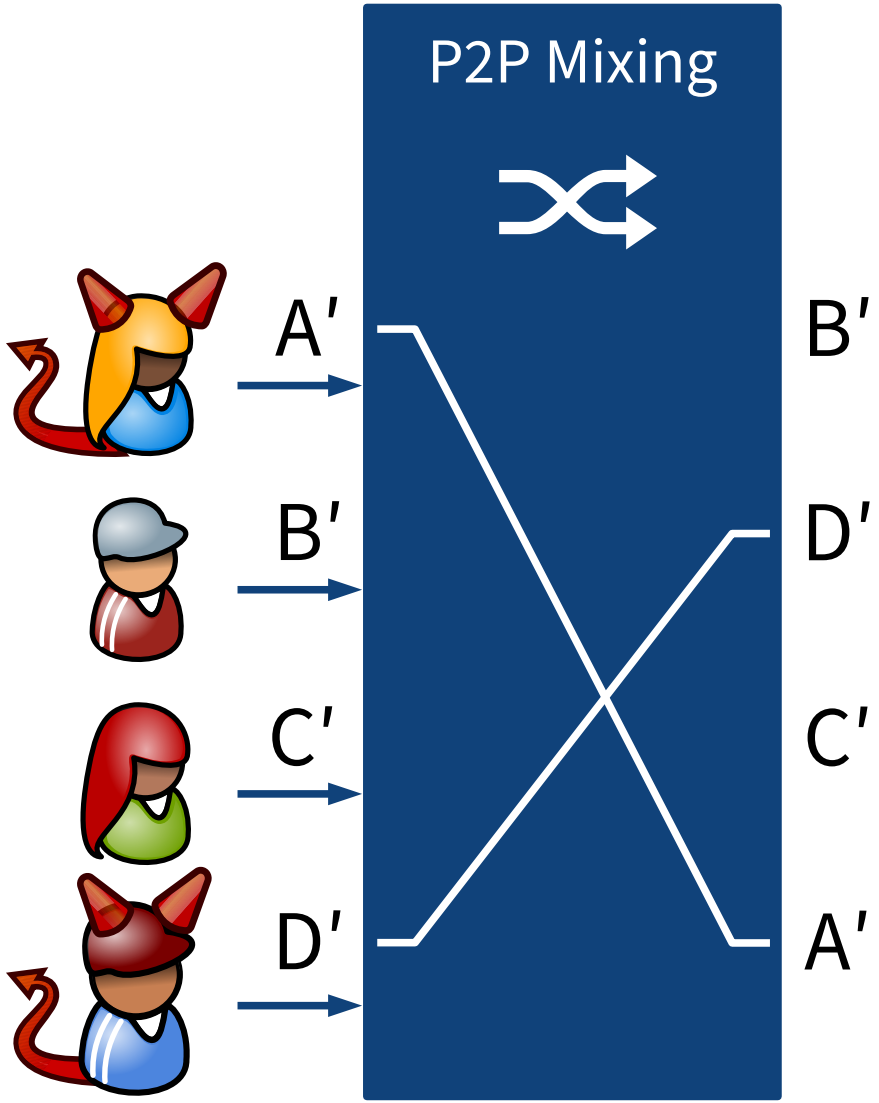

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(Bulletin board to facilitate broadcasts.)

CoinShuffle++

An Efficient P2P Mixing Protocol based on DC-nets

DC-net [Chaum, CRYPTO’88]

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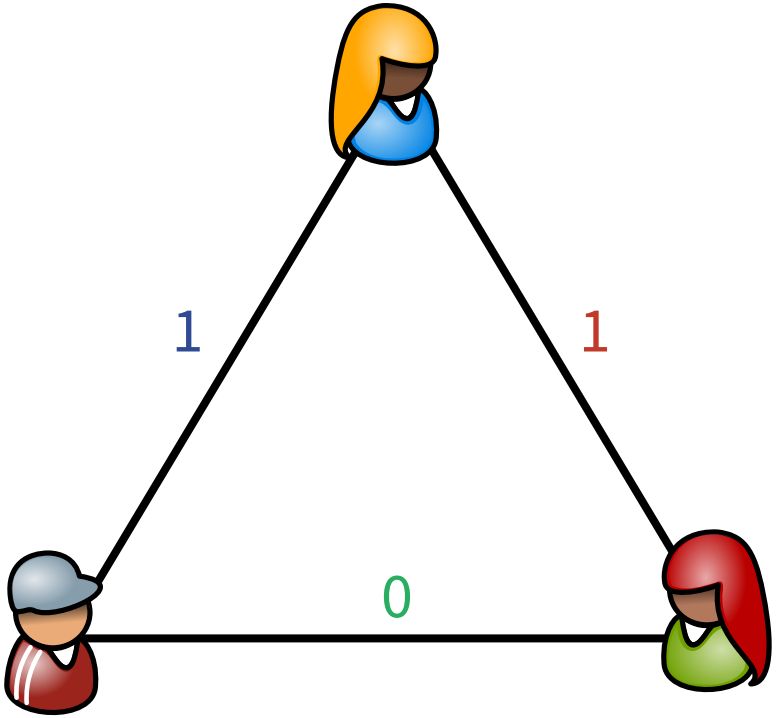

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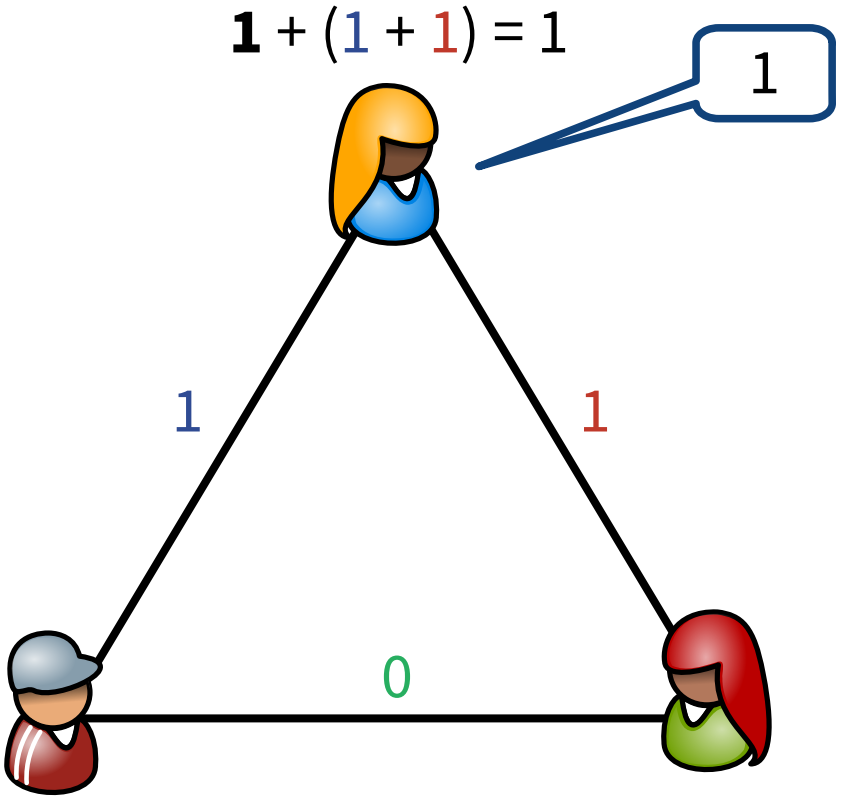

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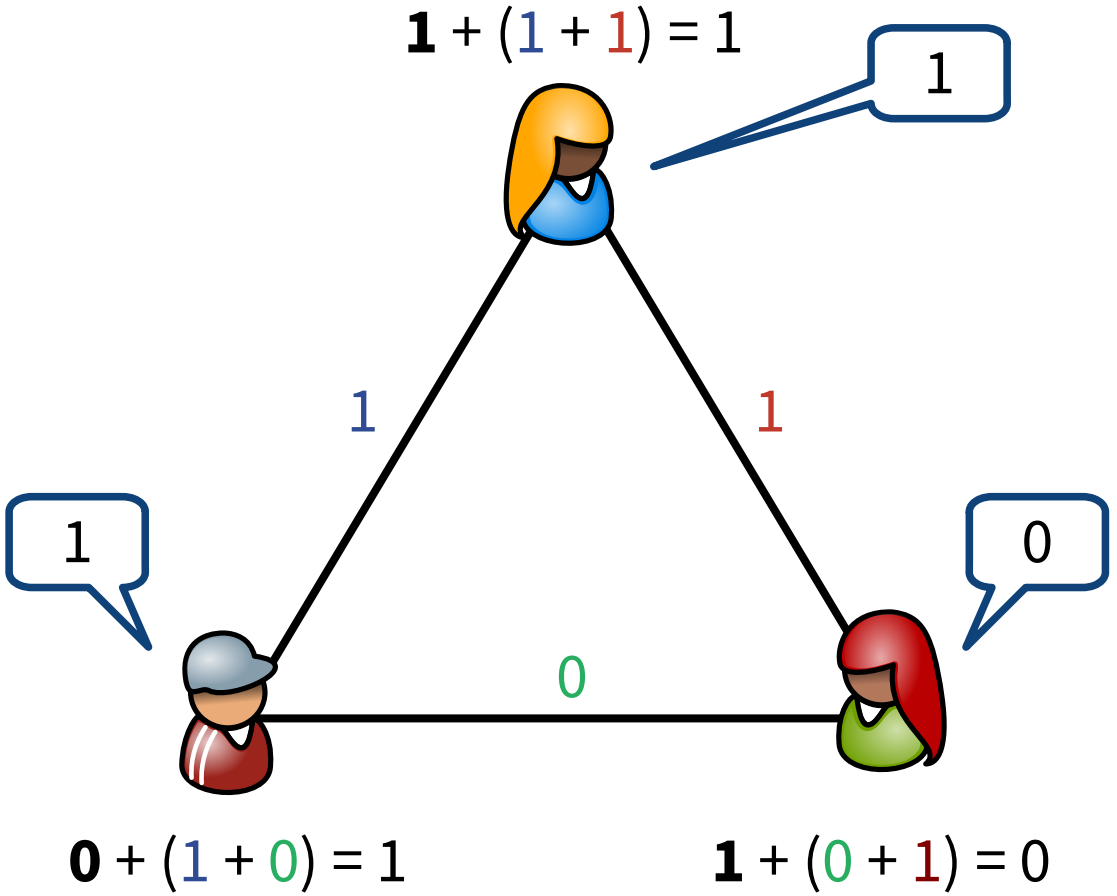

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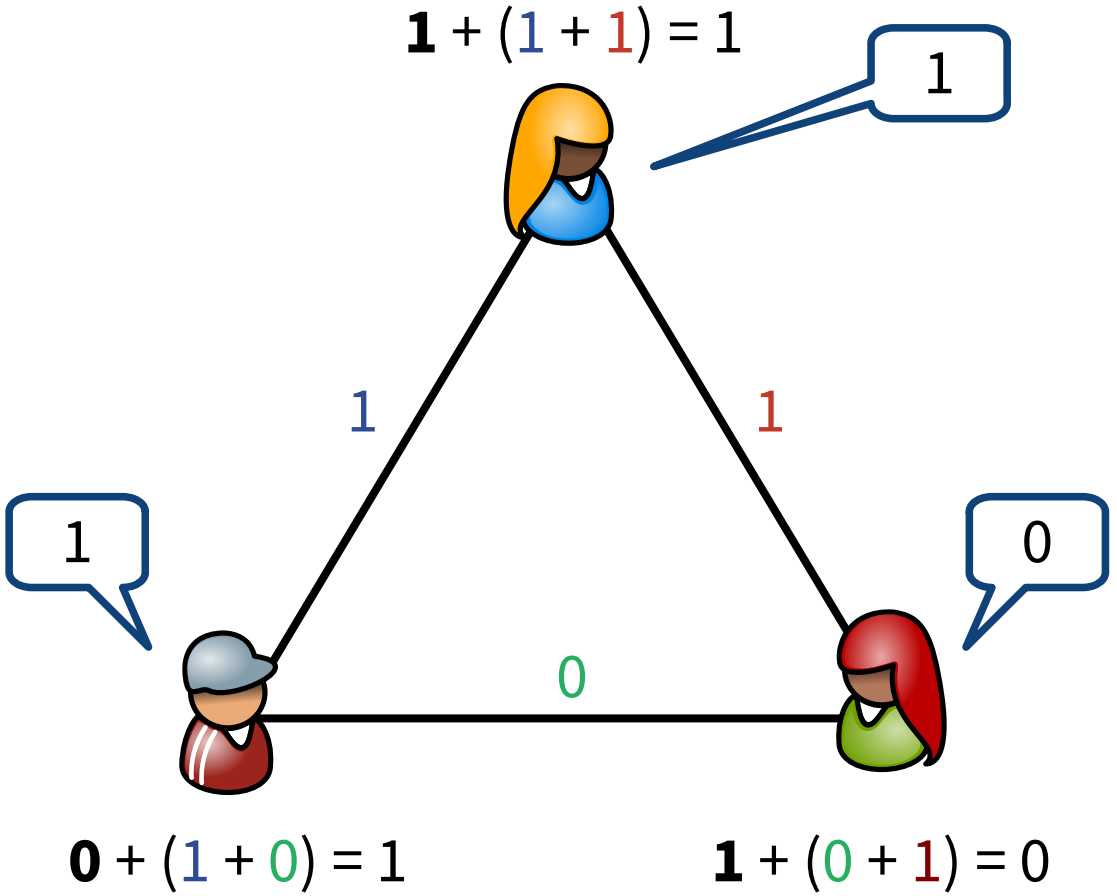
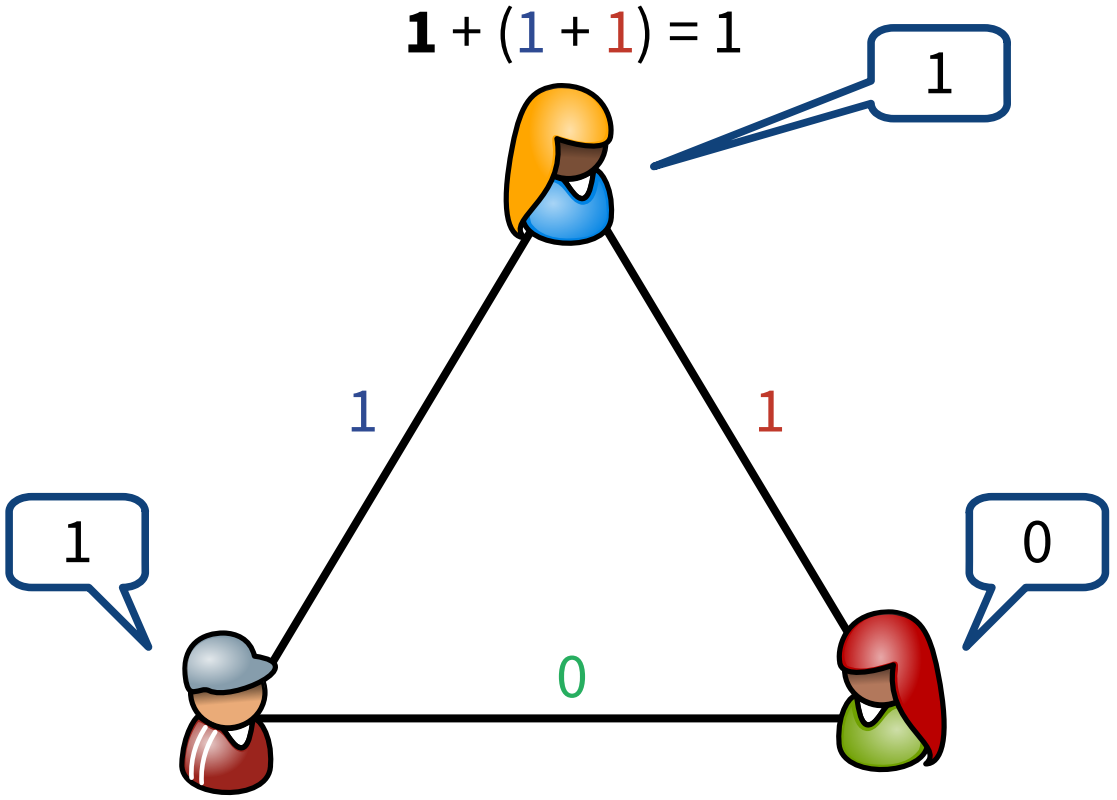


1 + 1 + 0

DC-net [Chaum, CRYPTO'88]



1 + 1 + 0 = [**1** + (1 + 1)] + [**0** + (1 + 0)] + [**1** + (0 + 1)]

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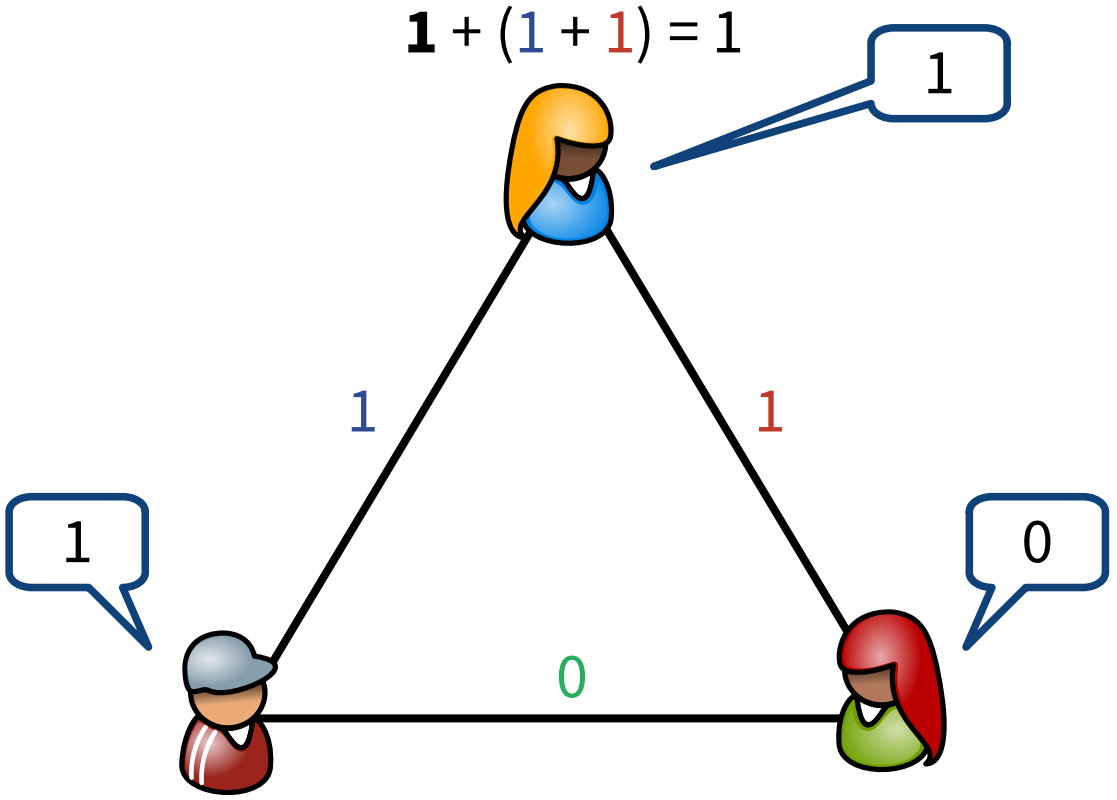

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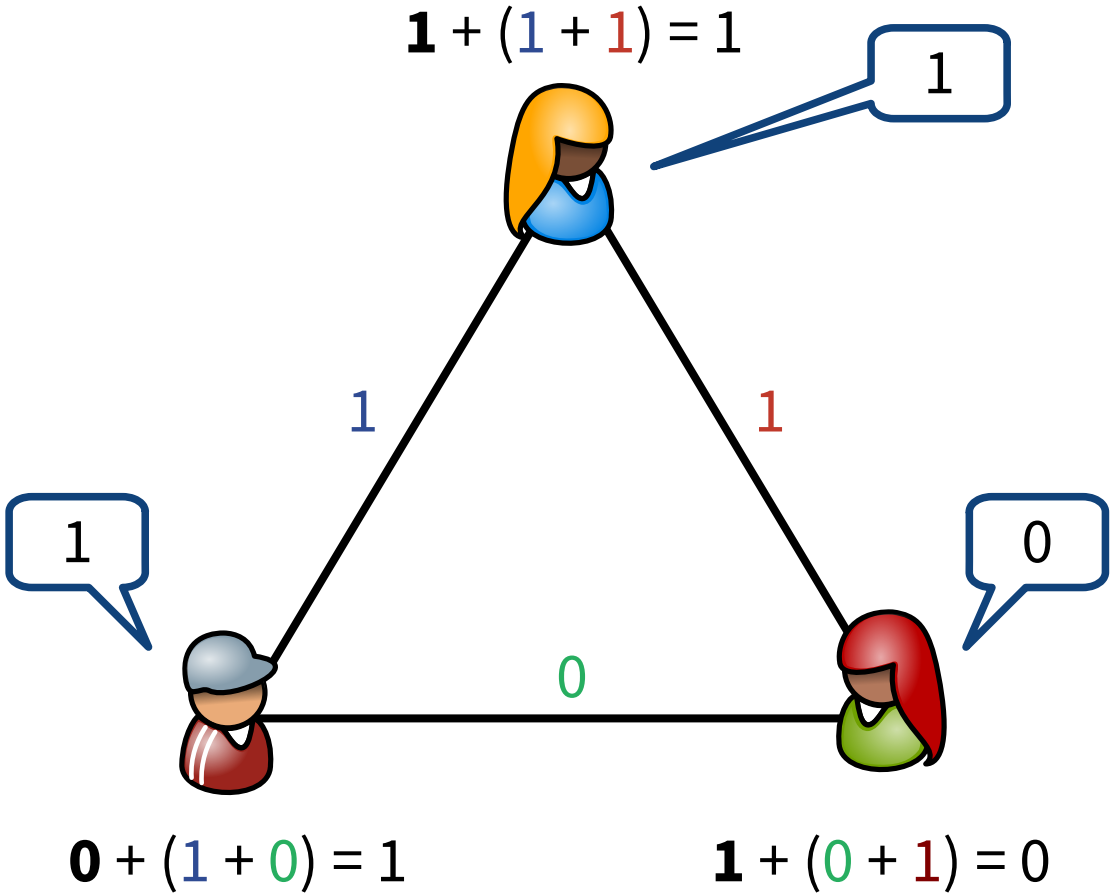

$$1 + 1 + 0 = [\mathbf{1} + (1 + 1)] + [\mathbf{0} + (1 + 0)] + [\mathbf{1} + (0 + 1)] = \mathbf{1} + \mathbf{1} + 0 = 0$$

DC-nets in Practice

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- Obtain shared symmetric keys: perform key exchange

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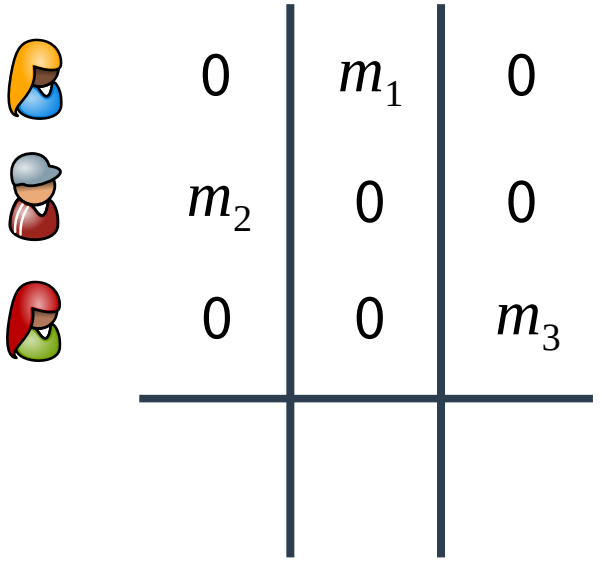

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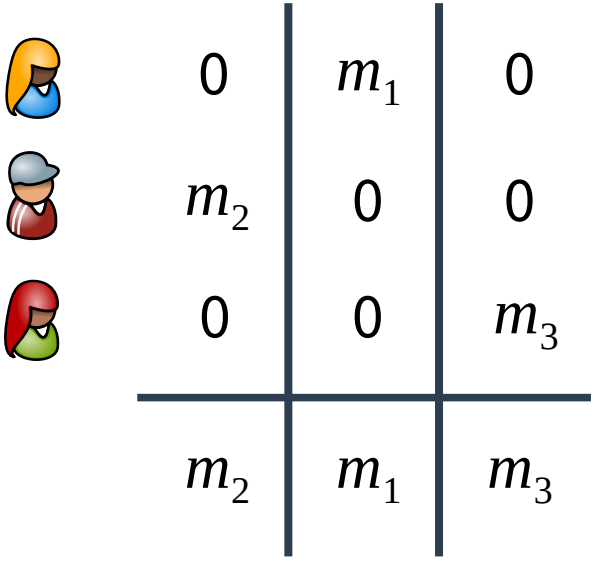

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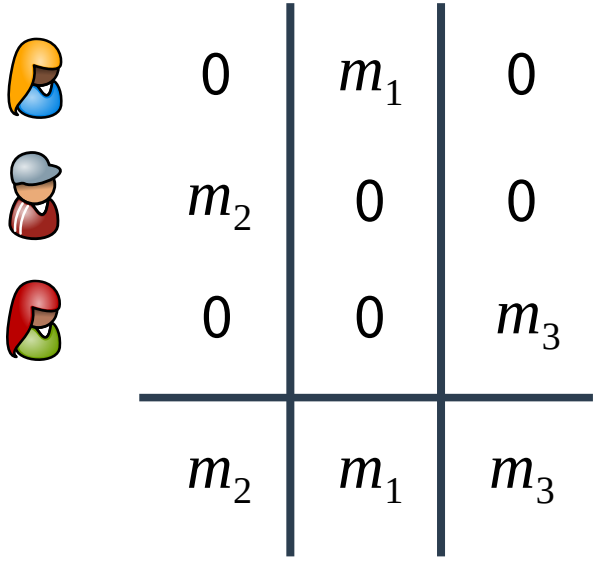


Needs anonymous slot assignment!

Multiple Messages (based on [BB, EC'89])


User 1: $m_1 \mid m_1^2 \mid m_1^3 \mid \cdots \mid m_1^n$


User 2:


User 3:


User *n*:

Multiple Messages (based on [BB, EC'89])


User 1:


User 2:


User 3:


User *n*:

m_1	m_1^2	m_1^3	$\cdots$	m_1^n
m_2	m_2^2	m_2^3	$\cdots$	m_2^n
m_3	m_3^2	m_3^3	$\cdots$	m_3^n
$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$
m_n	m_n^2	m_n^3	$\cdots$	m_n^n

Multiple Messages (based on [BB, EC'89])


User 1:


User 2:


User 3:


User *n*:

m_1	m_1^2	m_1^3	$\cdots$	m_1^n
m_2	m_2^2	m_2^3	$\cdots$	m_2^n
m_3	m_3^2	m_3^3	$\cdots$	m_3^n
$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$
m_n	m_n^2	m_n^3	$\cdots$	m_n^n
$\sum_{i=1}^{n} m_i$	$\sum_{i=1}^{n} m_i^2$	$\sum_{i=1}^{n} m_i^3$	$\cdots$	$\sum_{i=1}^{n} m_i^n$

Multiple Messages (based on [BB, EC'89])


User 1: m_1 m_1^2 m_1^3 $\cdots$ m_1^n


User 2: m_2 m_2^2 m_2^3 $\cdots$ m_2^n


User 3: m_3 m_3^2 m_3^3 $\cdots$ m_3^n

$\vdots$ $\vdots$ $\vdots$ $\ddots$ $\vdots$


User *n*: m_n m_n^2 m_n^3 $\cdots$ m_n^n

$$\sum_{i=1}^{n} m_i \quad \sum_{i=1}^{n} m_i^2 \quad \sum_{i=1}^{n} m_i^3 \quad \cdots \quad \sum_{i=1}^{n} m_i^n$$

Messages can be recovered from the power sums.

Disruption

User 1:

User 2:

User 3:

User *n*:

$$
\begin{array}{|c|c|c|c|c|}
\hline
m_1 & m_1^2 & m_1^3 & \cdots & m_1^n \\
m_2 & m_2^2 & m_2^3 & \cdots & m_2^n \\
m_3 & m_3^2 & m_3^3 & \cdots & m_3^n \\
\vdots & \vdots & \vdots & \ddots & \vdots \\
m_n & m_n^2 & m_n^3 & \cdots & m_n^n \\
\hline
 & & & \cdots & \\
\hline
\end{array}
$$

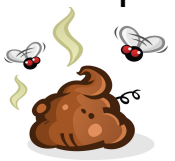
Disruption

User 1:

User 2:

User 3:

User *n*:

m_1	m_1^2	m_1^3	$\cdots$	m_1^n
			$\cdots$	
m_3	m_3^2	m_3^3	$\cdots$	m_3^n
$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$
m_n	m_n^2	m_n^3	$\cdots$	m_n^n
			$\cdots$	

Disruption

User 1:

User 2:

User 3:

User *n*:

m_1	m_1^2	m_1^3	$\cdots$	m_1^n
m_3	m_3^2	m_3^3	$\cdots$	m_3^n
$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$
m_n	m_n^2	m_n^3	$\cdots$	m_n^n

Disruption

User 1:

User 2:

User 3:

User *n*:

m_1	m_1^2	m_1^3	$\cdots$	m_1^n
m_3	m_3^2	m_3^3	$\cdots$	m_3^n
$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$
m_n	m_n^2	m_n^3	$\cdots$	m_n^n

Malicious user stays anonymous!

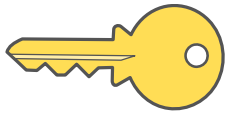
IN CASE OF
DISRUPTION
BREAK ANONYMITY

Flowchart of CoinShuffle++

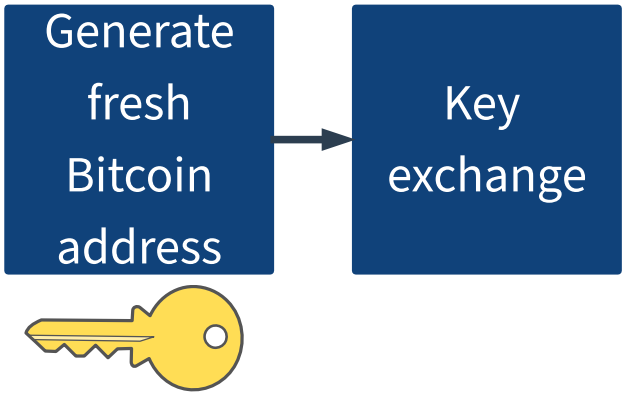
Generate fresh Bitcoin address

Flowchart of CoinShuffle++

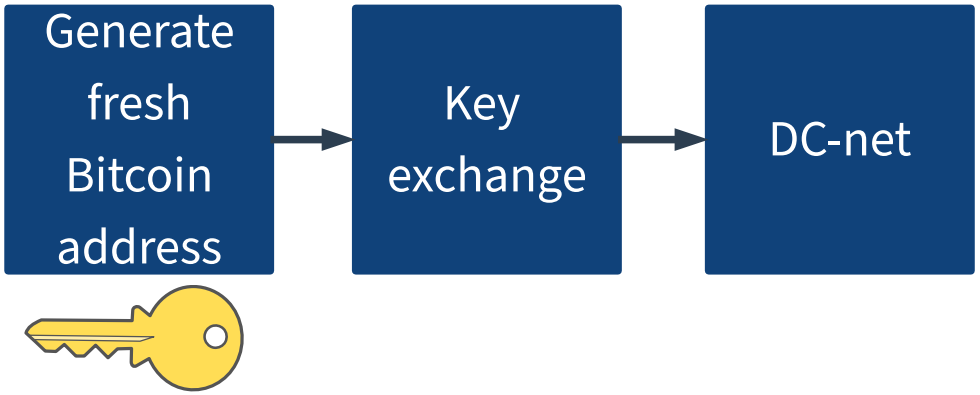
Generate fresh Bitcoin address



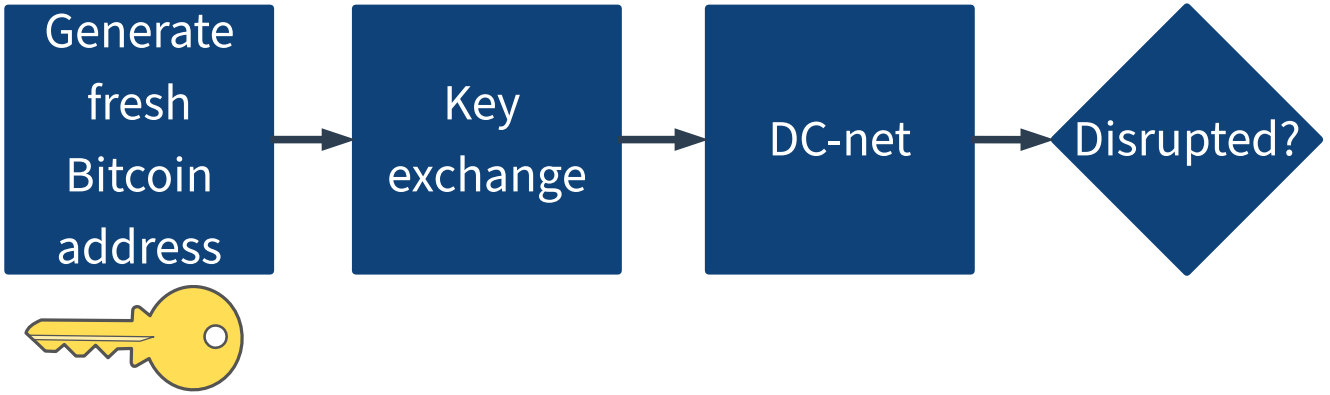
Flowchart of CoinShuffle++



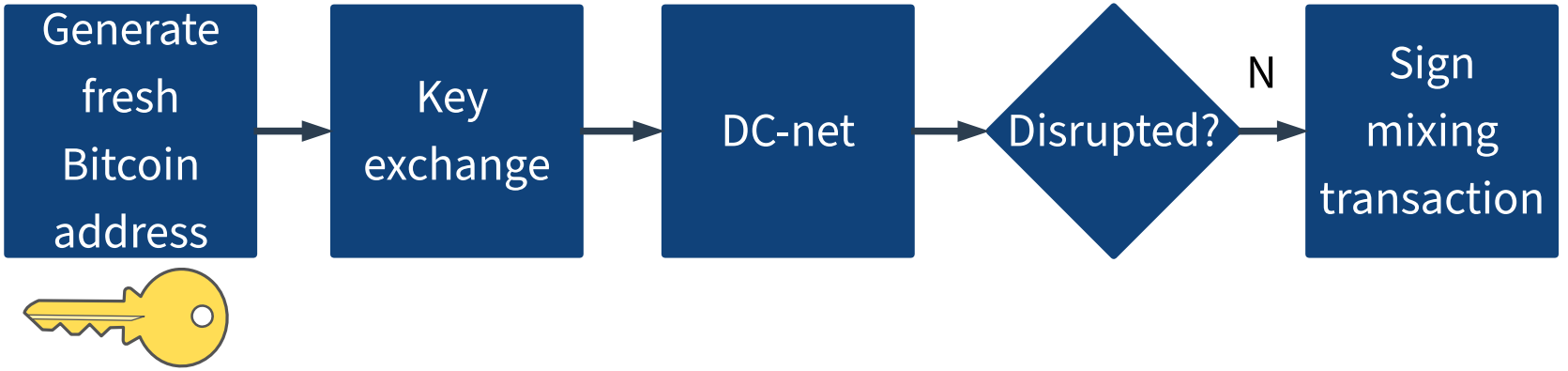
Flowchart of CoinShuffle++



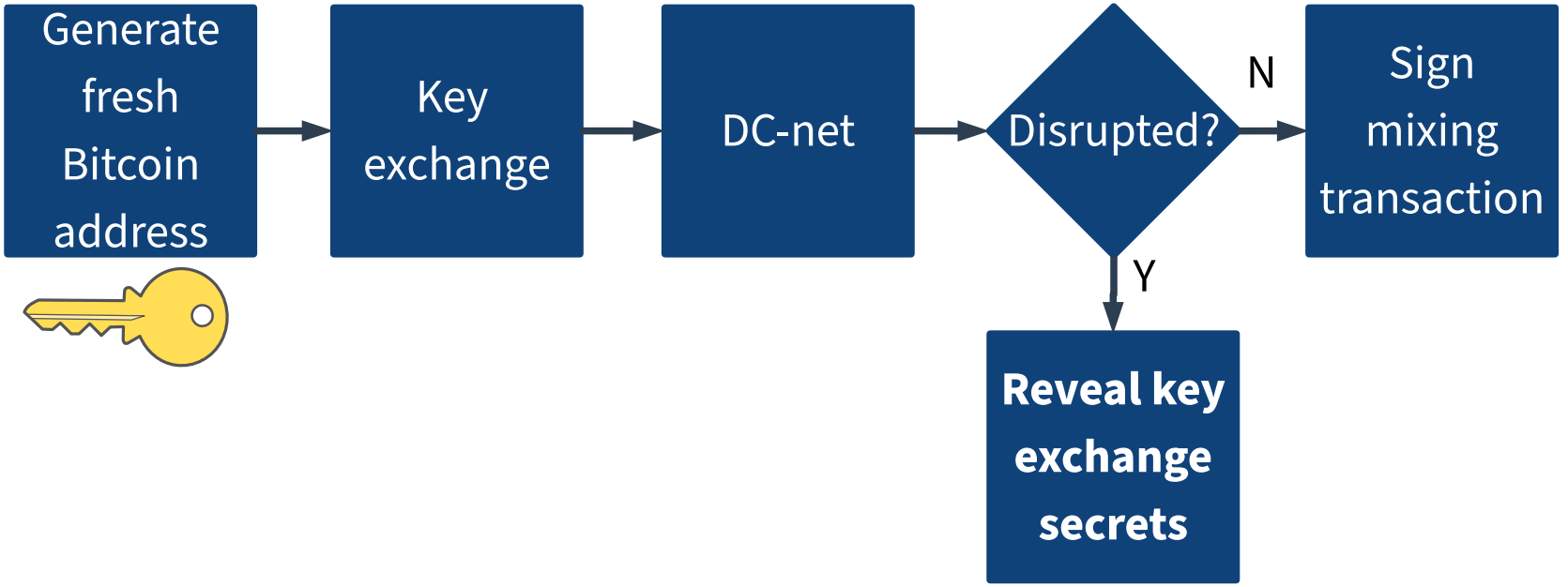
Flowchart of CoinShuffle++



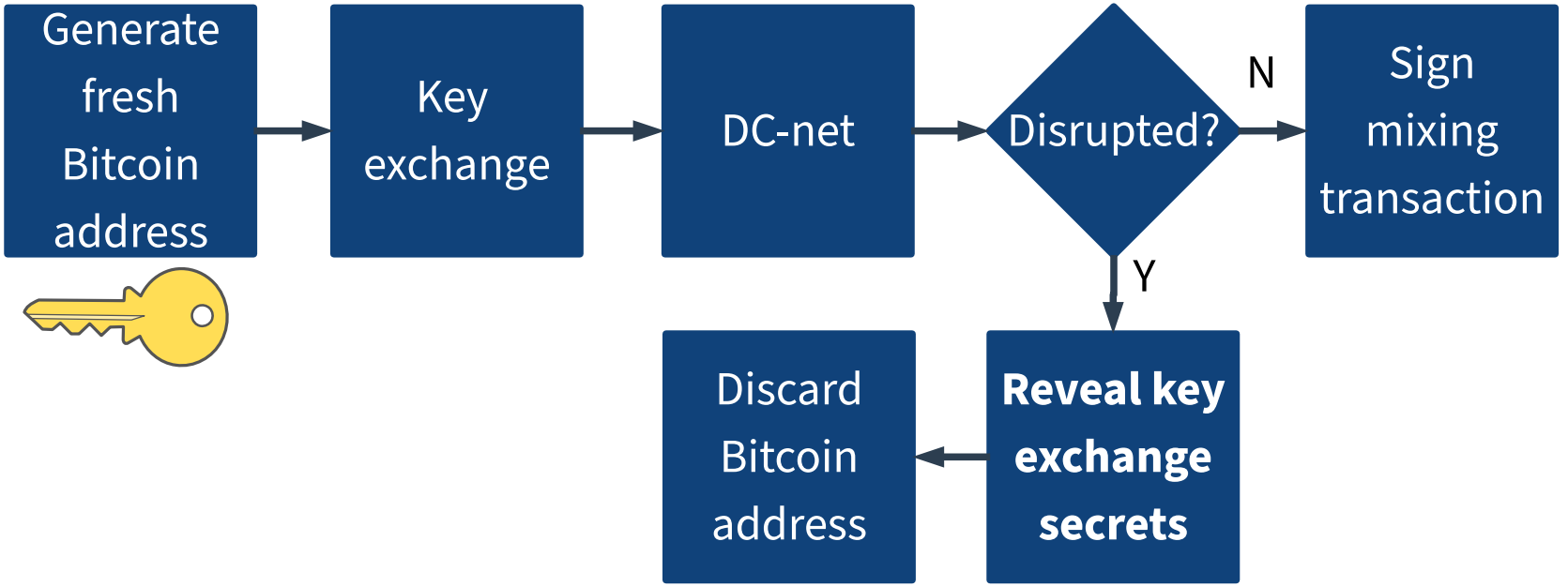
Flowchart of CoinShuffle++

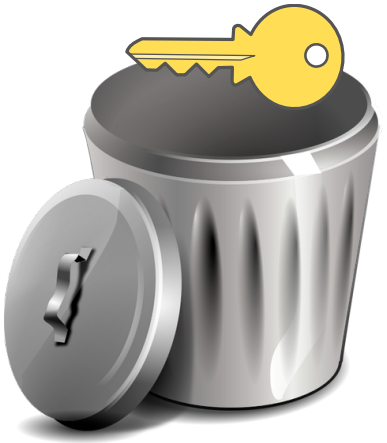


Flowchart of CoinShuffle++

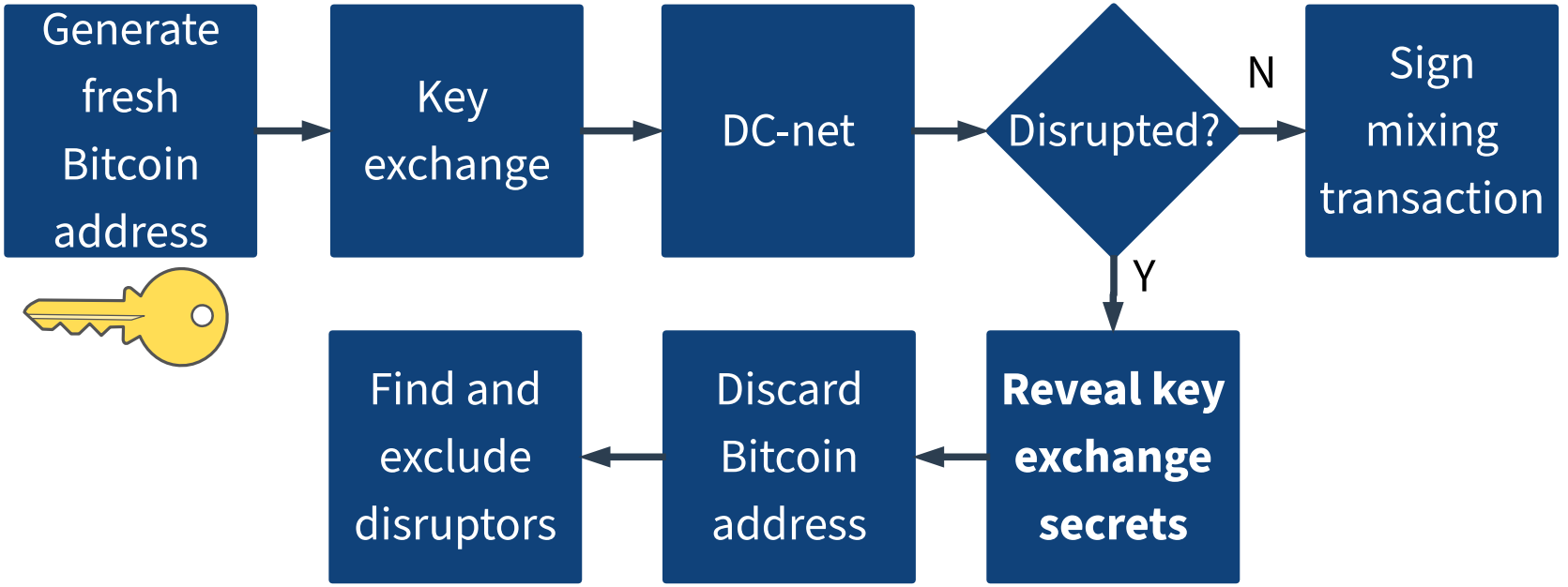


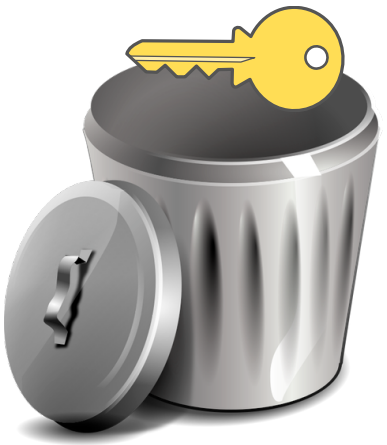
Flowchart of CoinShuffle++



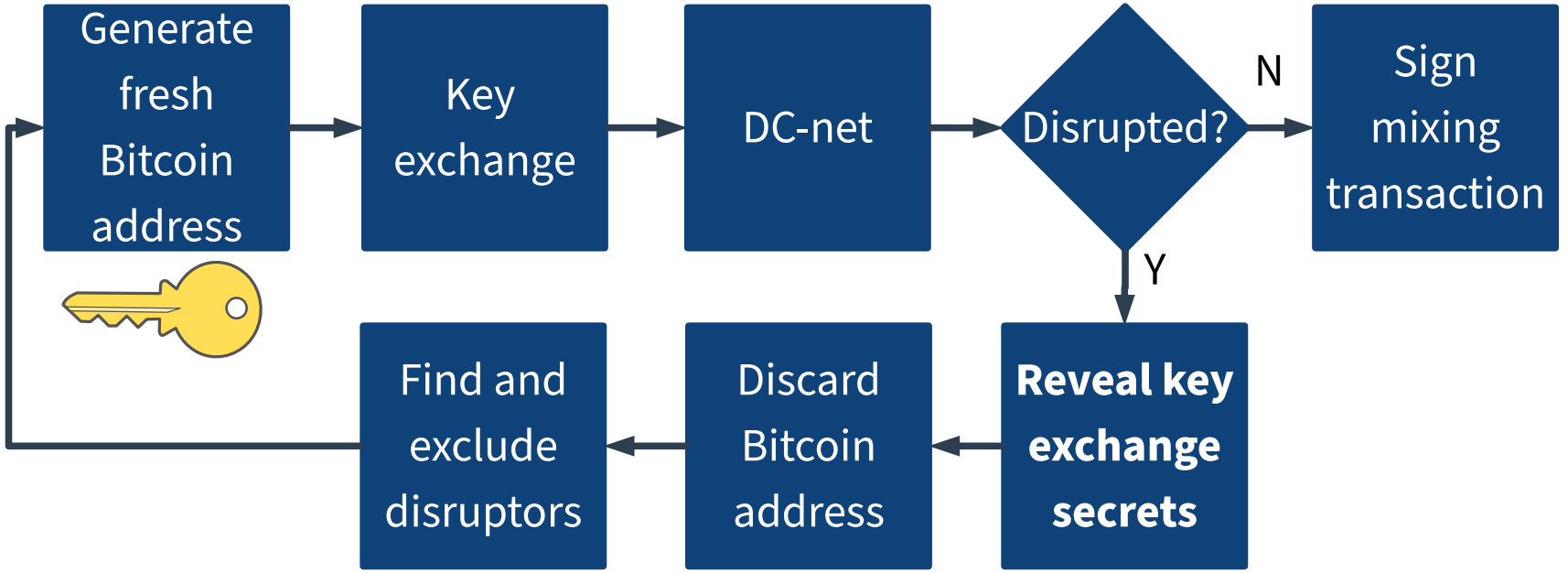


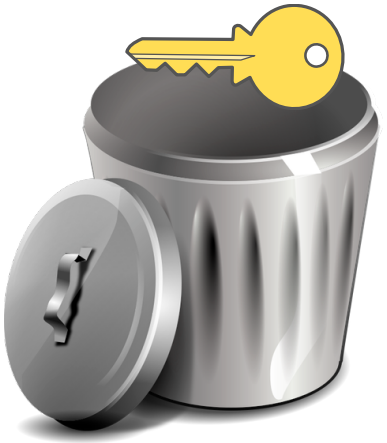
Flowchart of CoinShuffle++



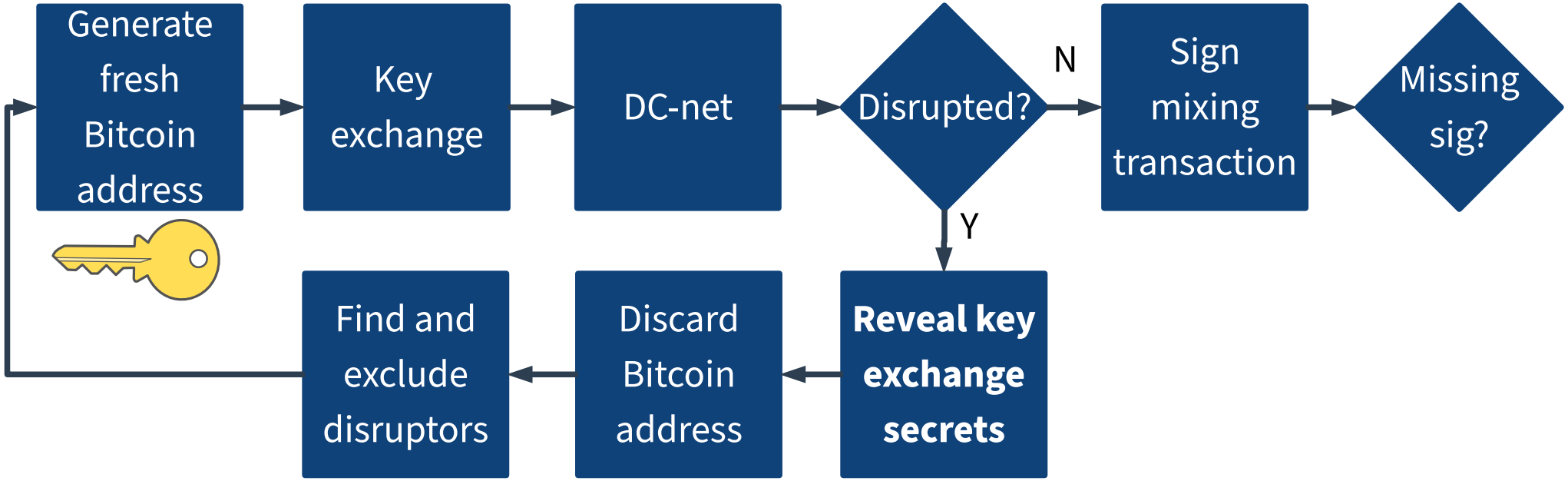


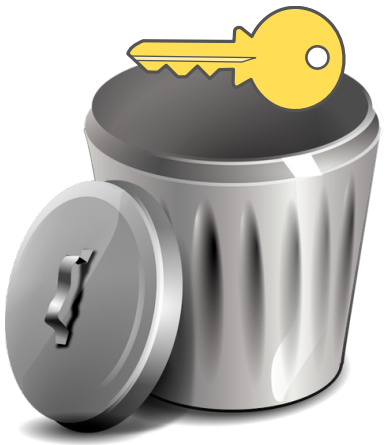
Flowchart of CoinShuffle++



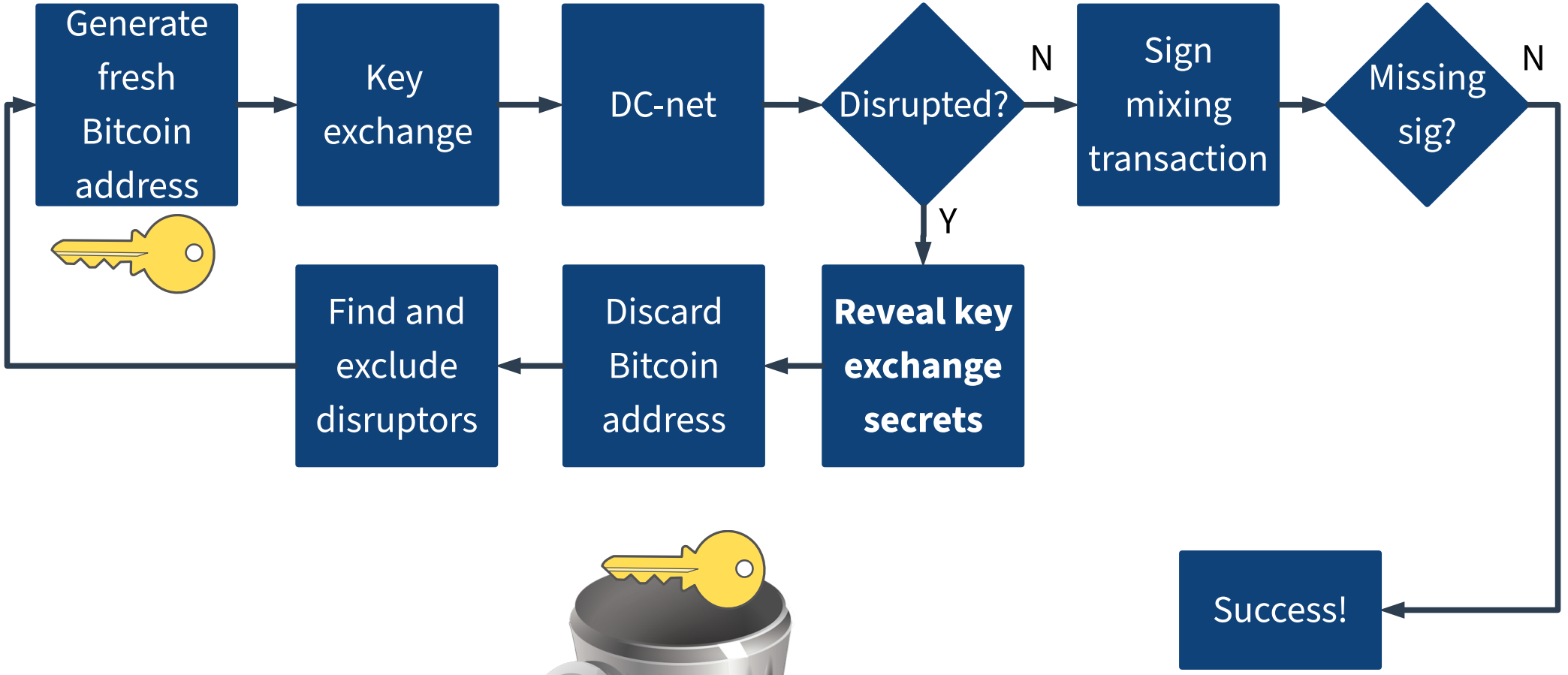


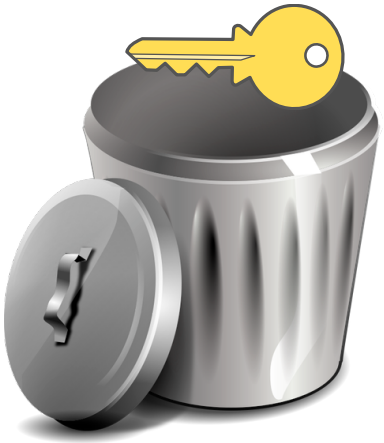
Flowchart of CoinShuffle++



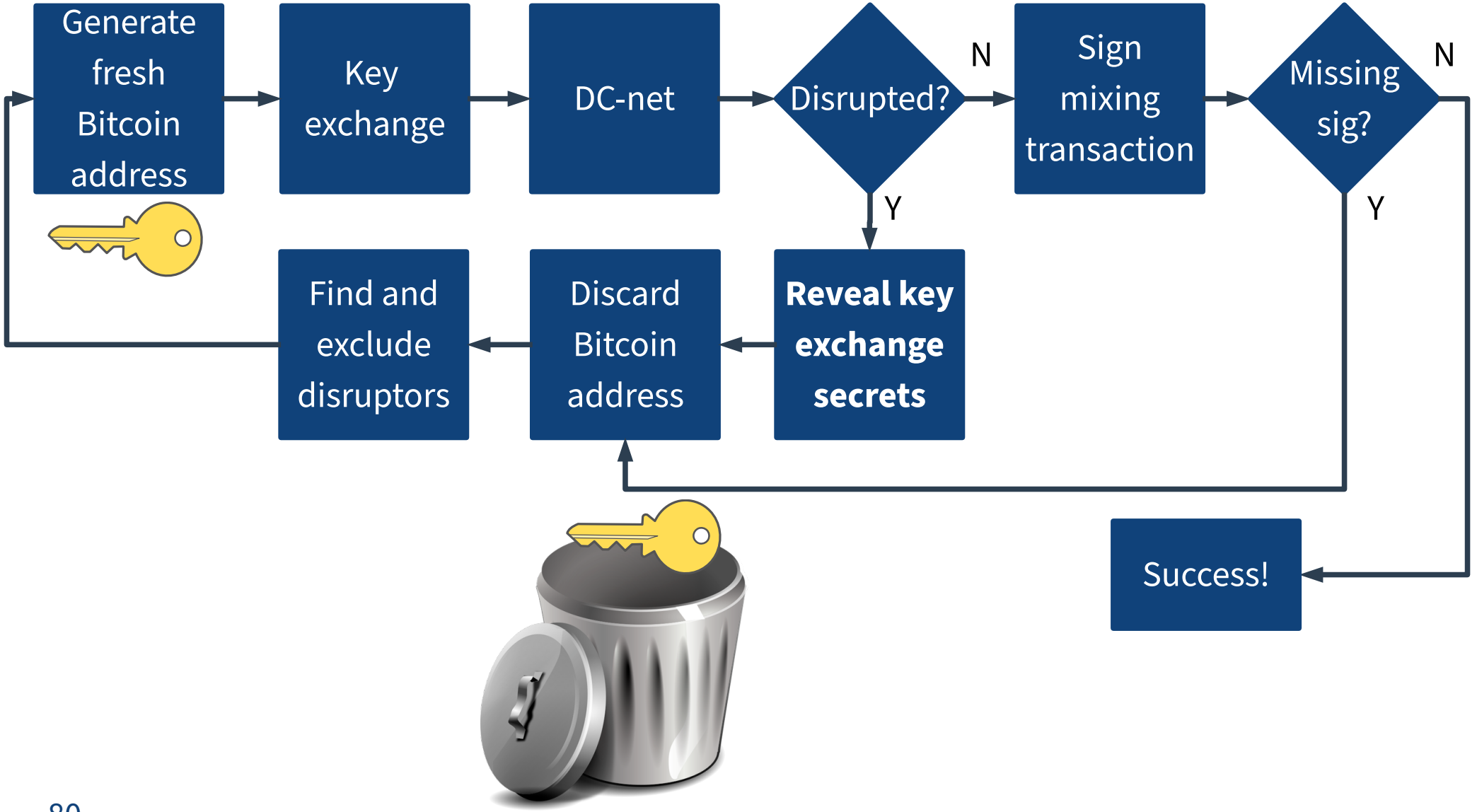


Flowchart of CoinShuffle++

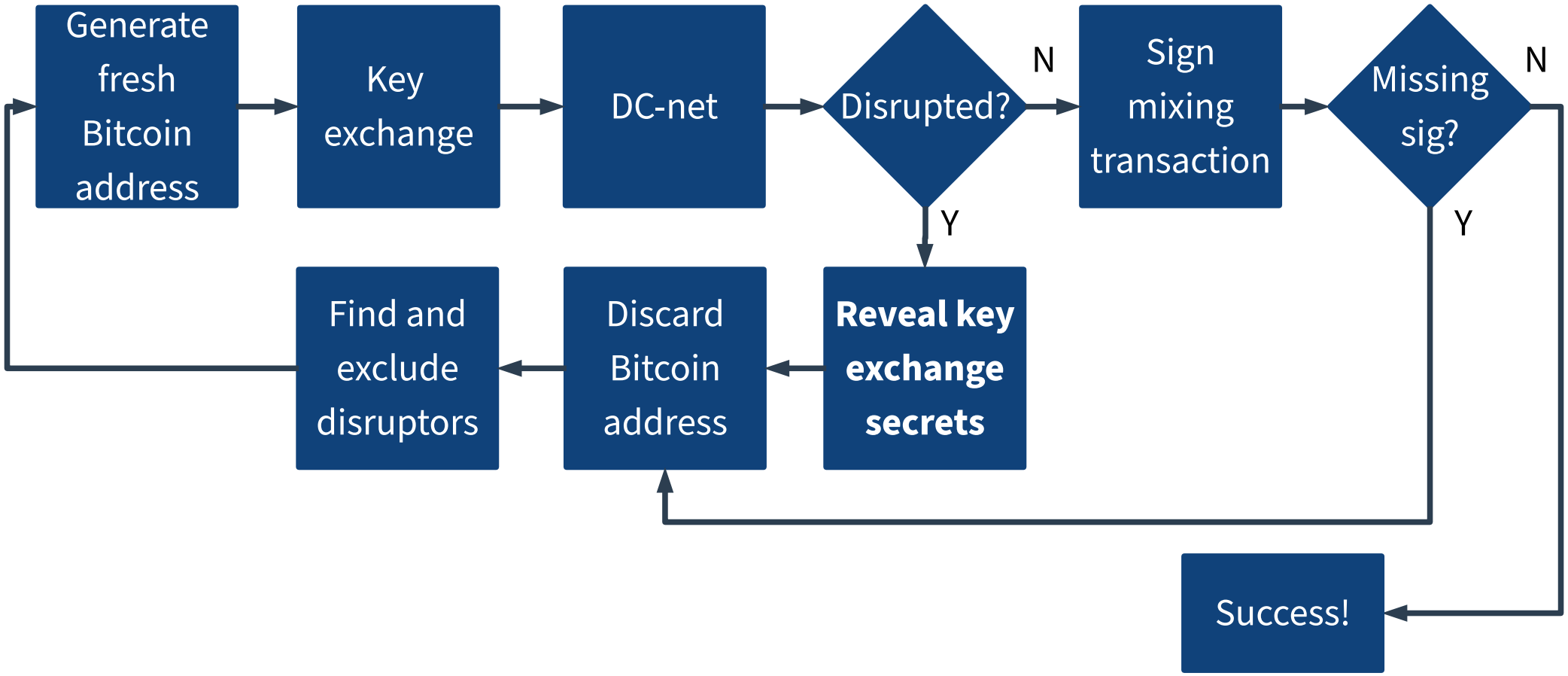




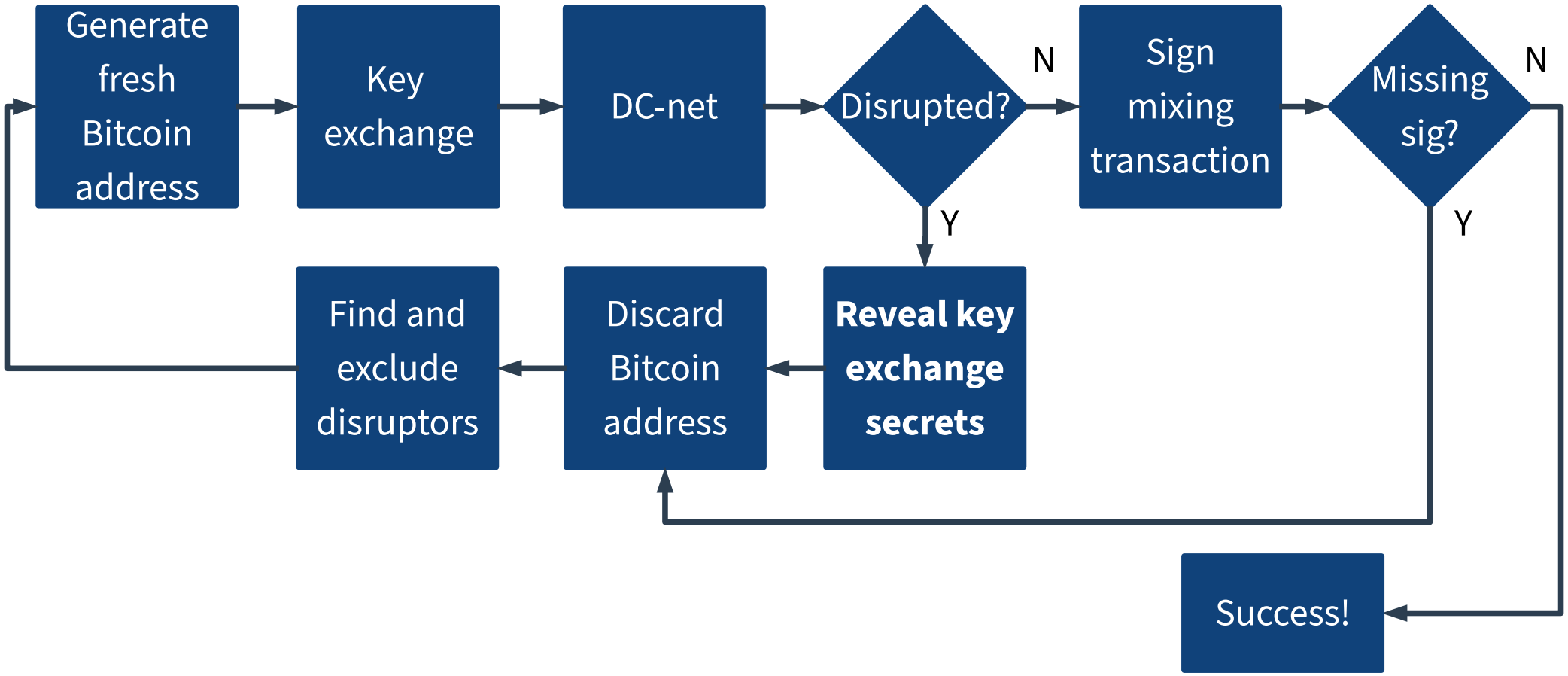
Flowchart of CoinShuffle++



Flowchart of CoinShuffle++



Flowchart of CoinShuffle++

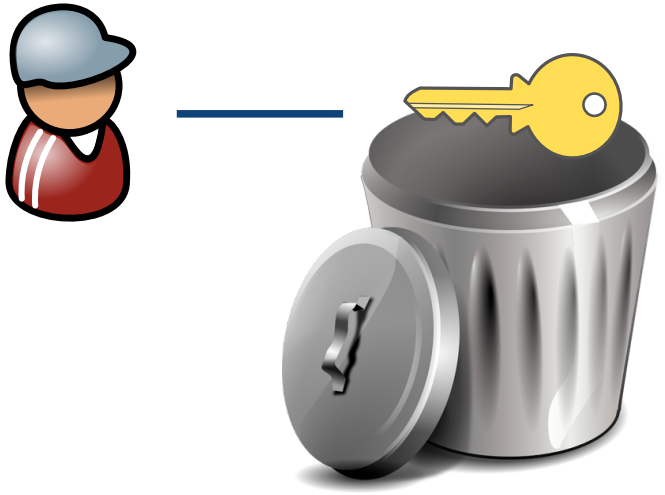


CoinShuffle++ provides anonymity and termination.

Side Topic: Are Fresh Messages Needed?

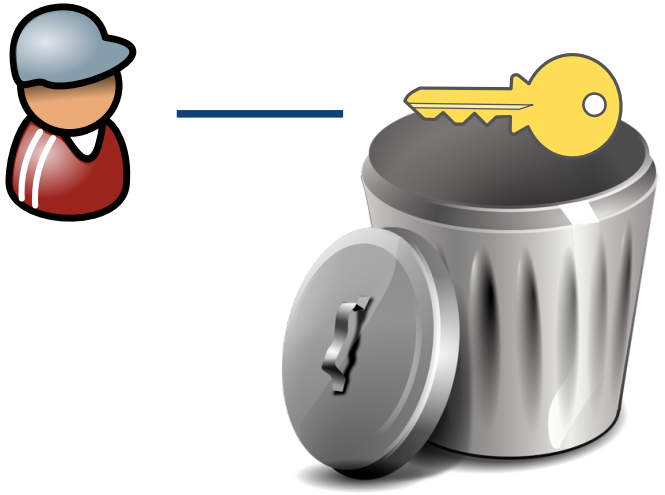
“Fresh” vs. “Fixed” Input Messages

Fresh:



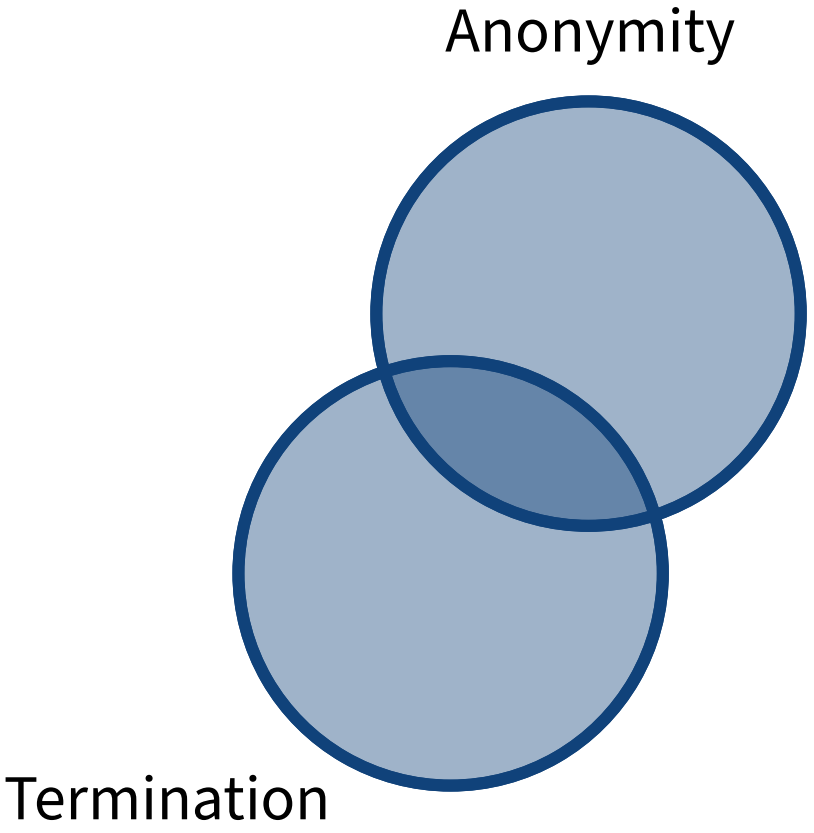
“Fresh” vs. “Fixed” Input Messages

Fresh:



Fixed:

Features of P2P Mixing Protocols



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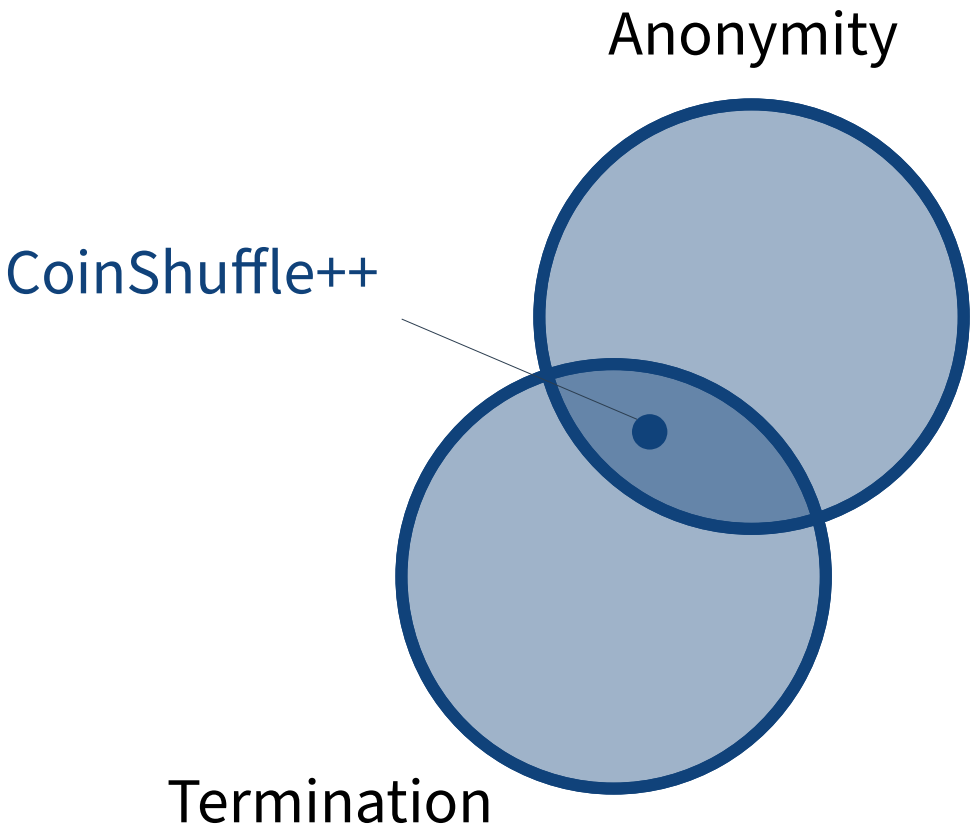

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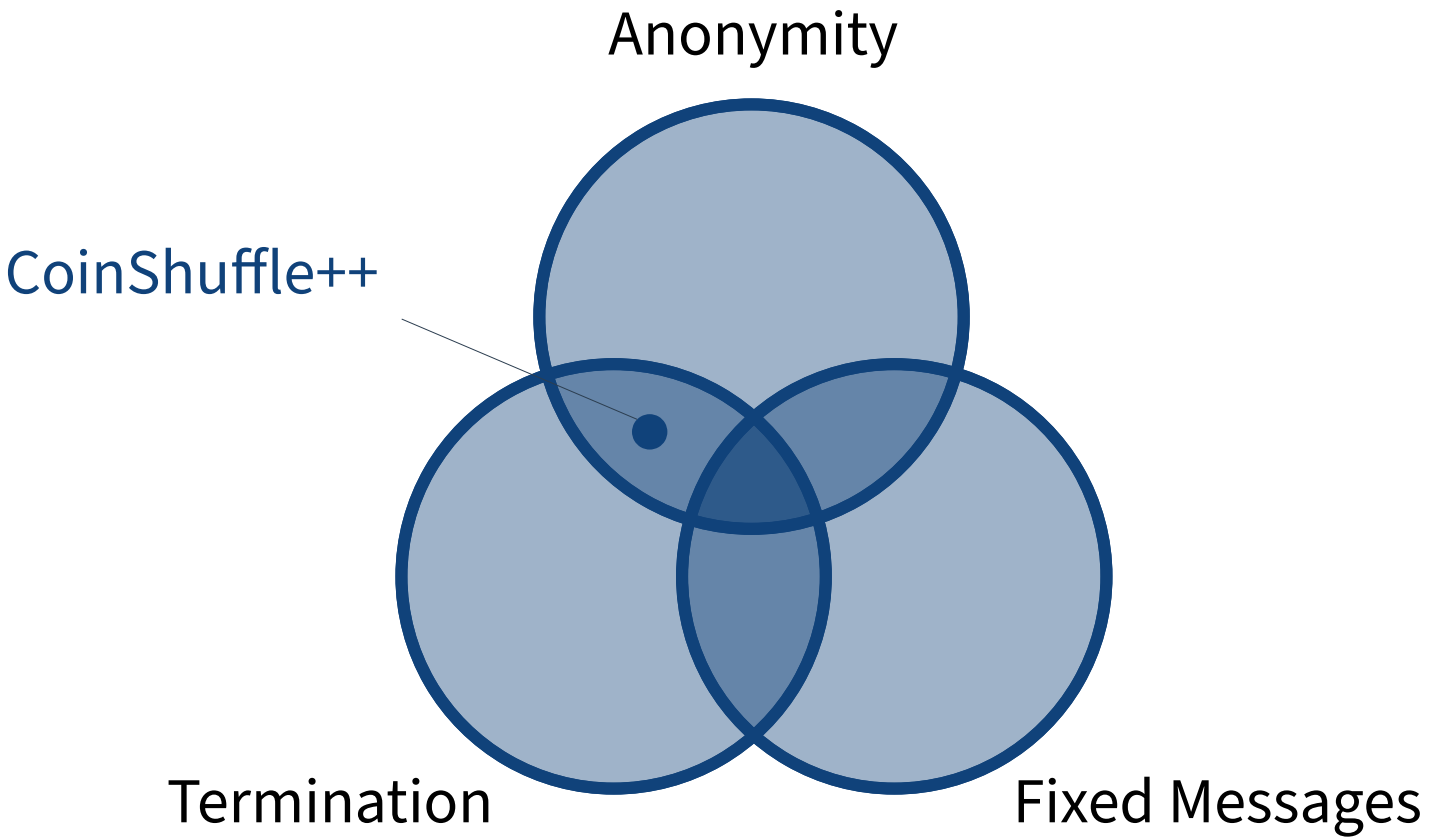
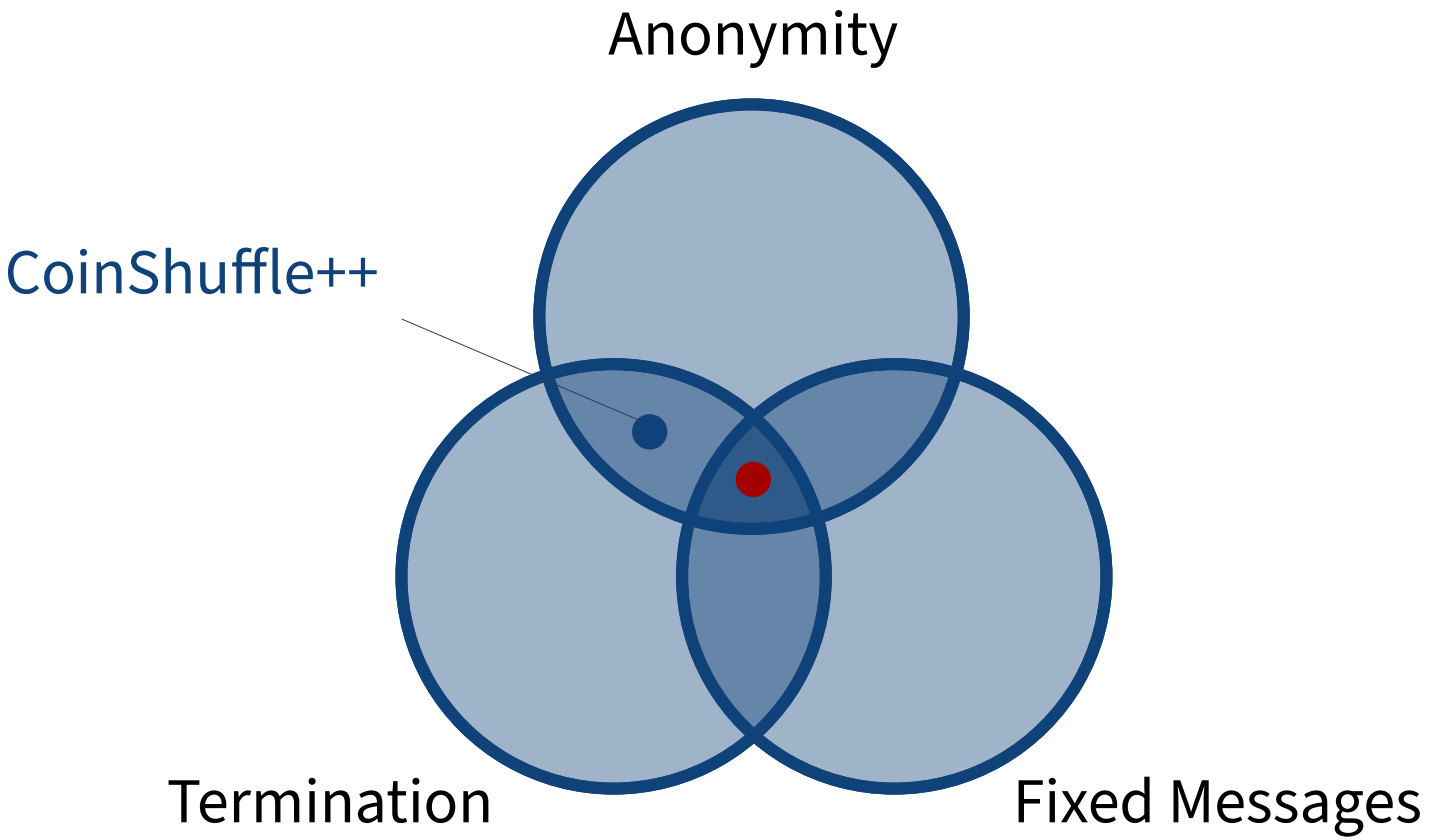
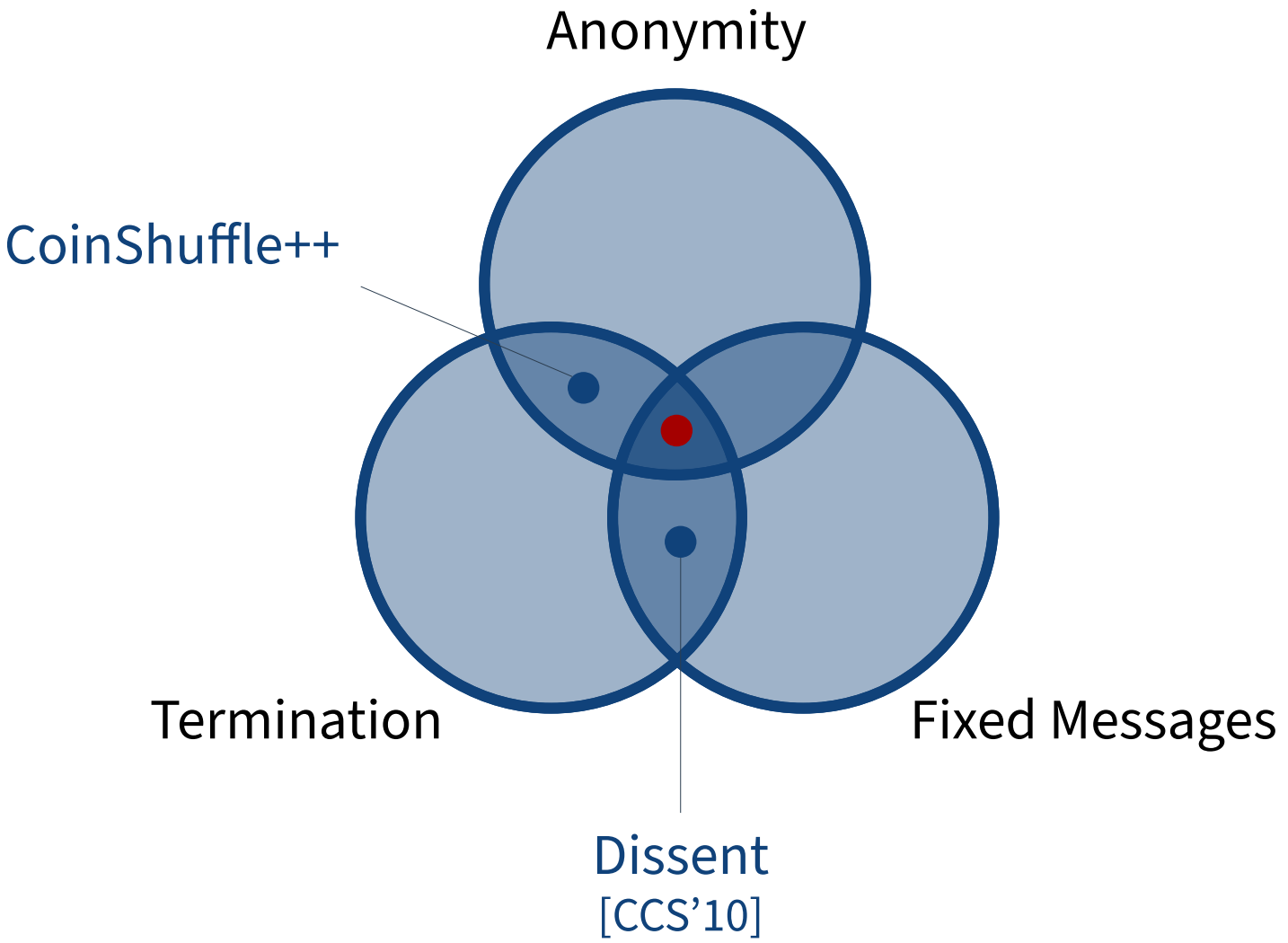


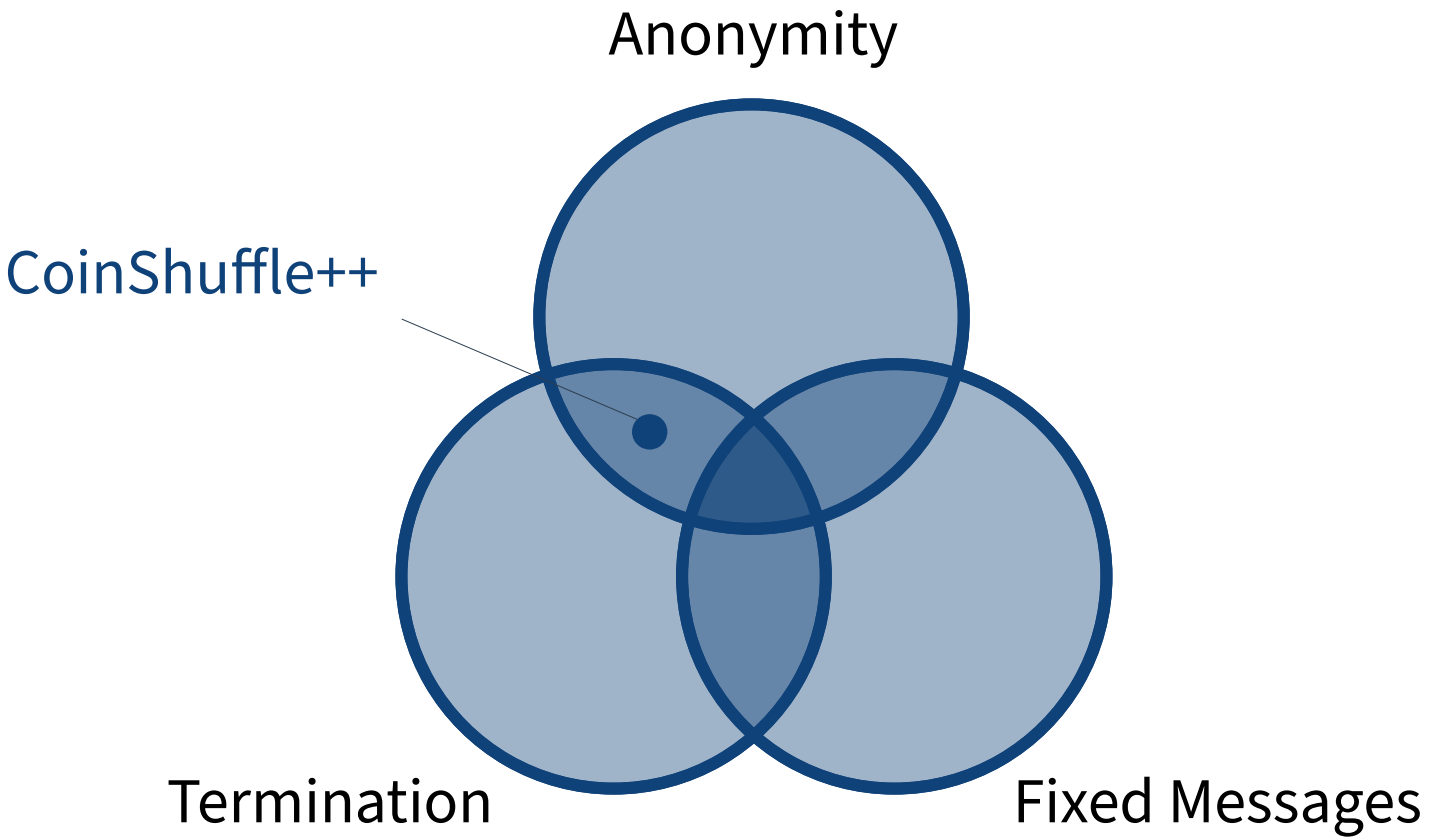
Features of P2P Mixing Protocols



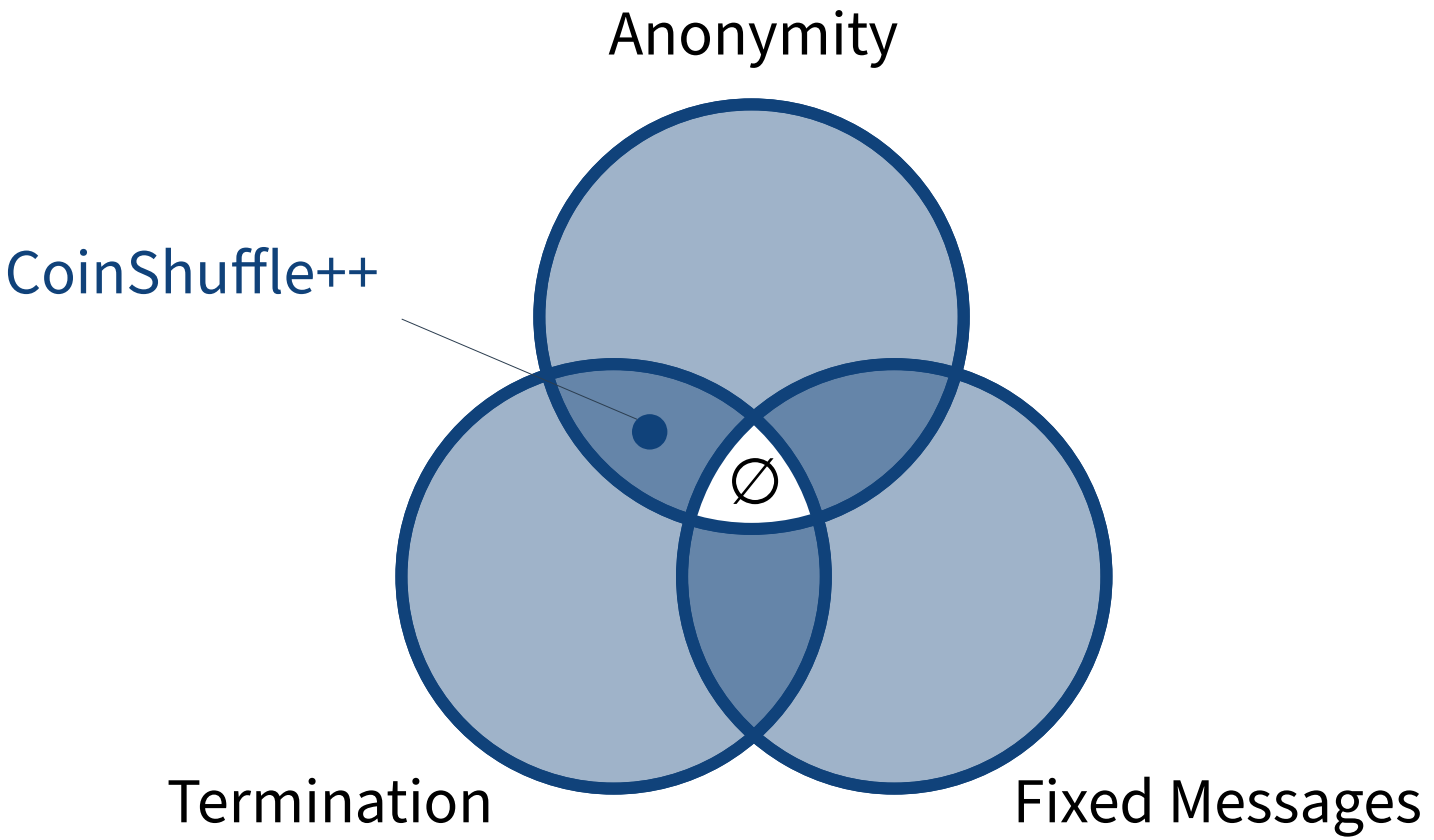
Features of P2P Mixing Protocols



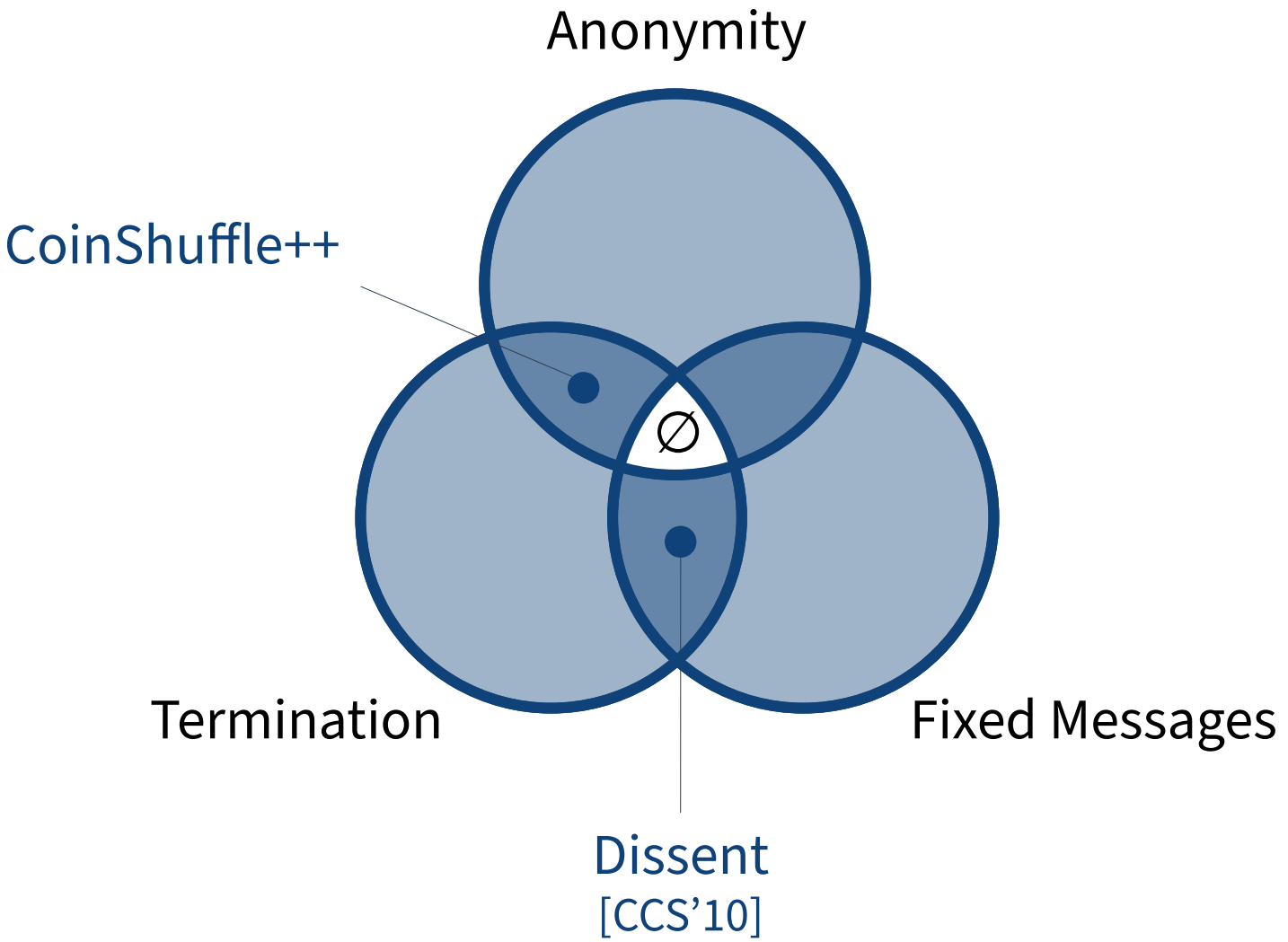
P2P Mixing Trilemma



P2P Mixing Trilemma



P2P Mixing Trilemma



Attack on “Dissent” Protocol

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- Dissent proceeds in broadcast rounds

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- Outcome of the protocol is revealed to users in last broadcast

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- Outcome of the protocol is revealed to users in last broadcast
- Also network attacker sees the outcome in the last broadcast

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Run 1:

Attack on “Dissent” Protocol

- Dissent proceeds in broadcast rounds
- Outcome of the protocol is revealed to users in last broadcast
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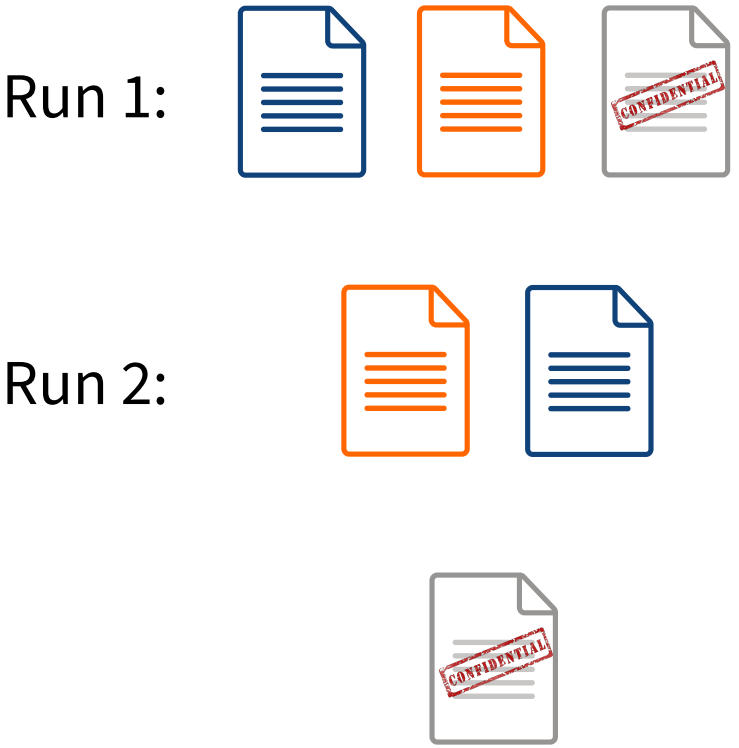
Run 1:

Run 2:

Attack on “Dissent” Protocol

- Dissent proceeds in broadcast rounds
- Outcome of the protocol is revealed to users in last broadcast
- Also network attacker sees the outcome in the last broadcast



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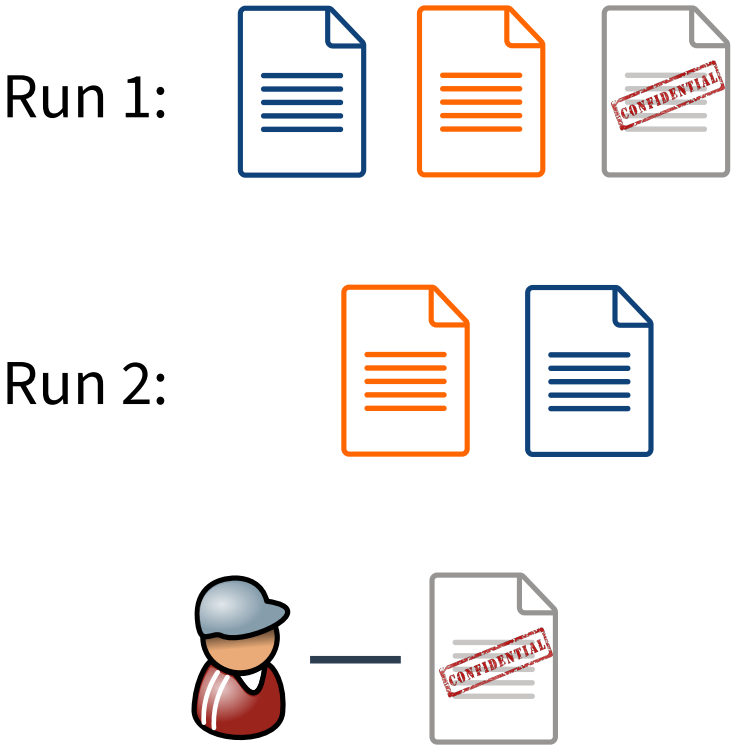
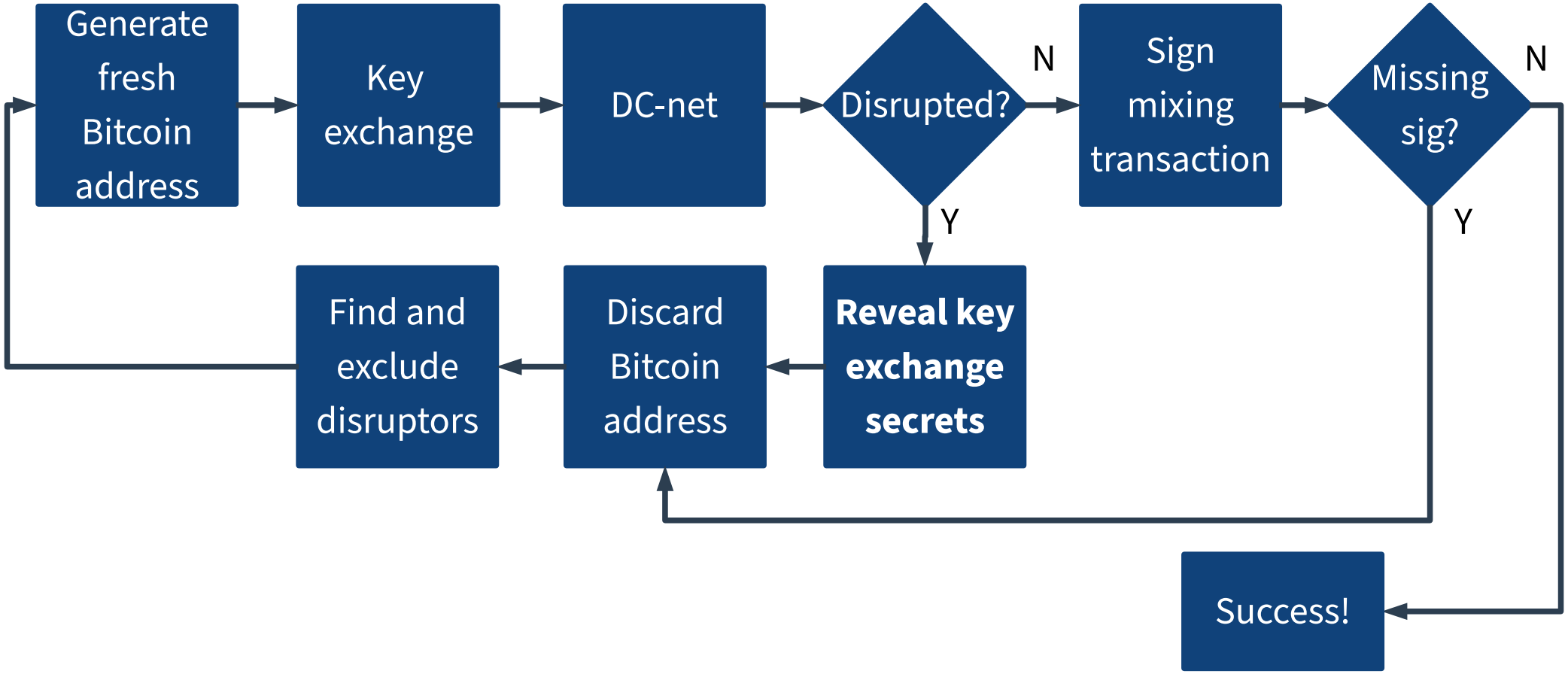


Efficiency of CoinShuffle++

Broadcast Rounds (Naive)



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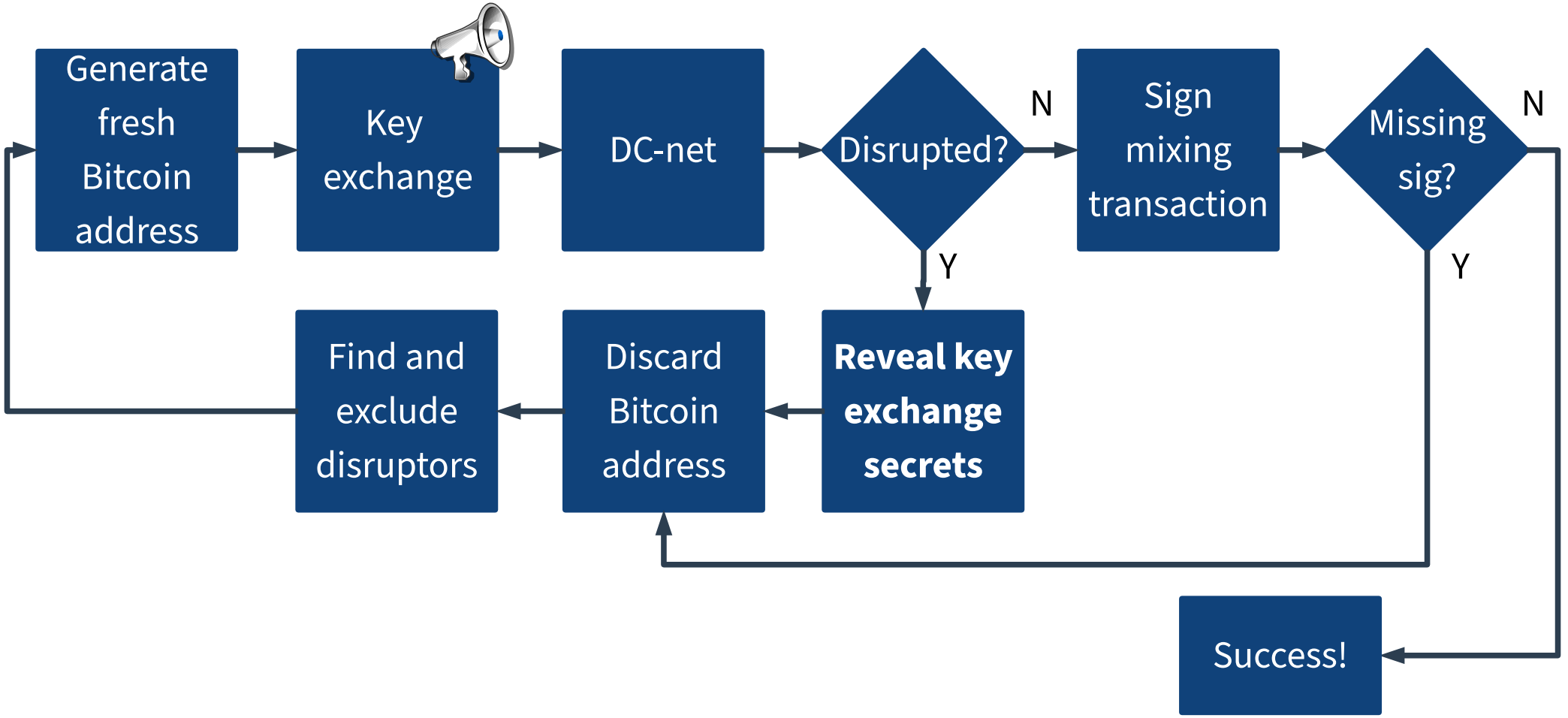
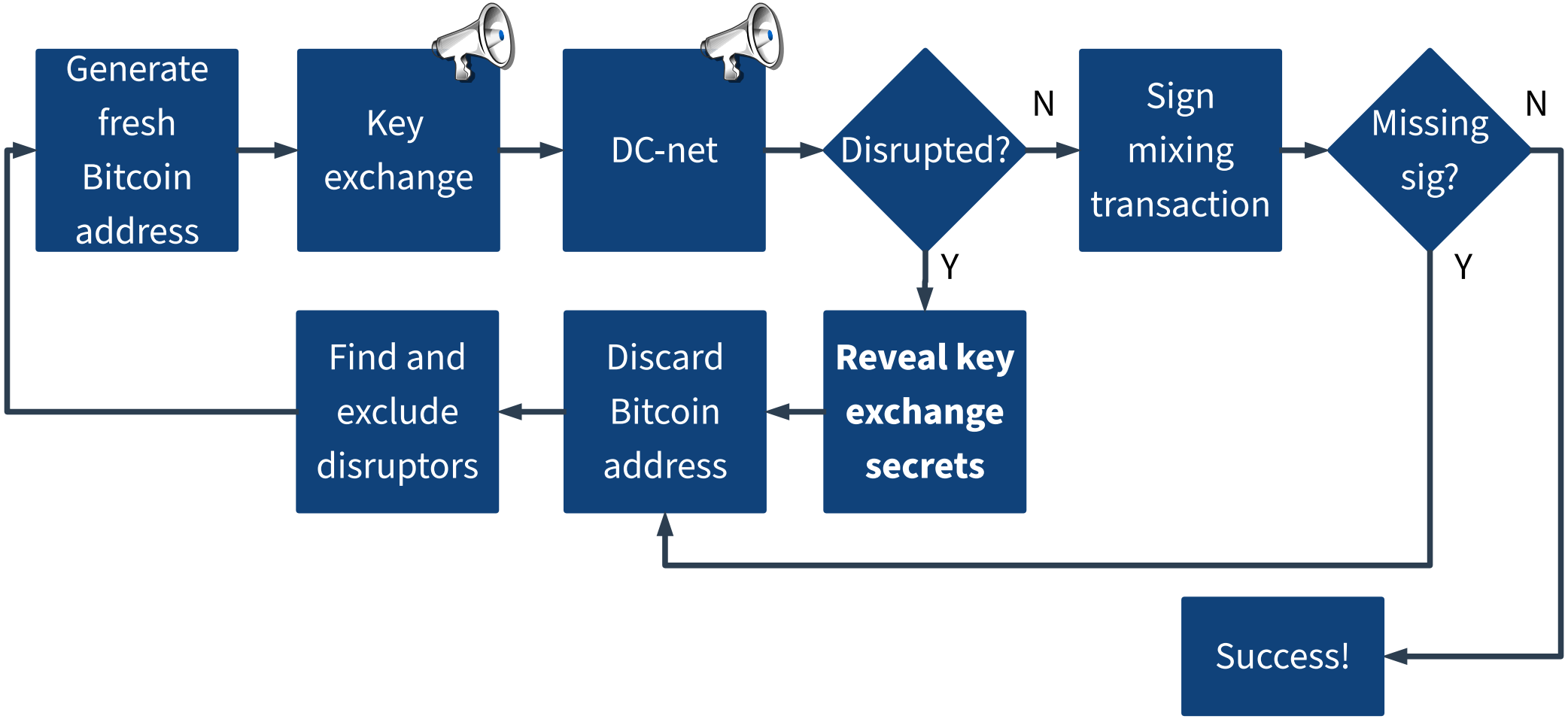


Broadcast Rounds (Naive)



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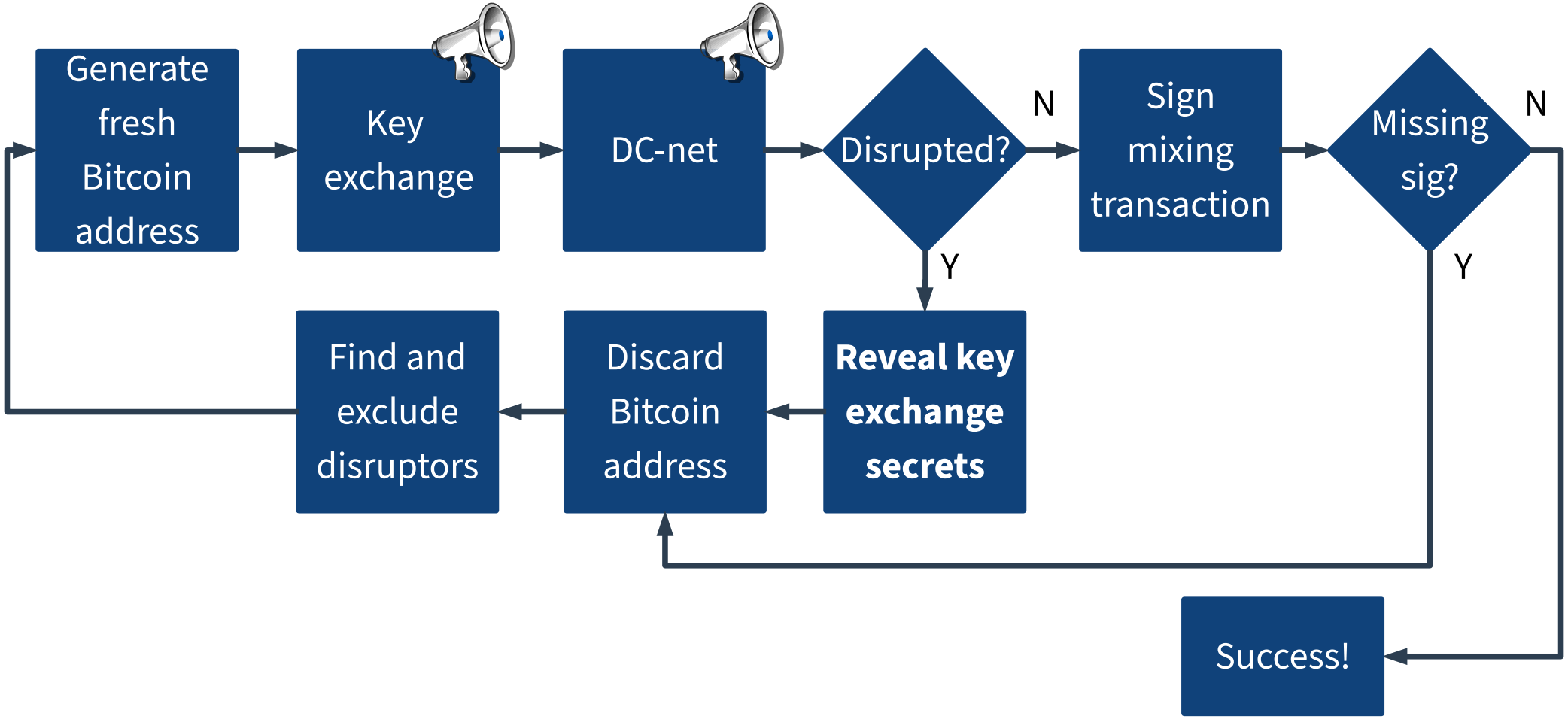

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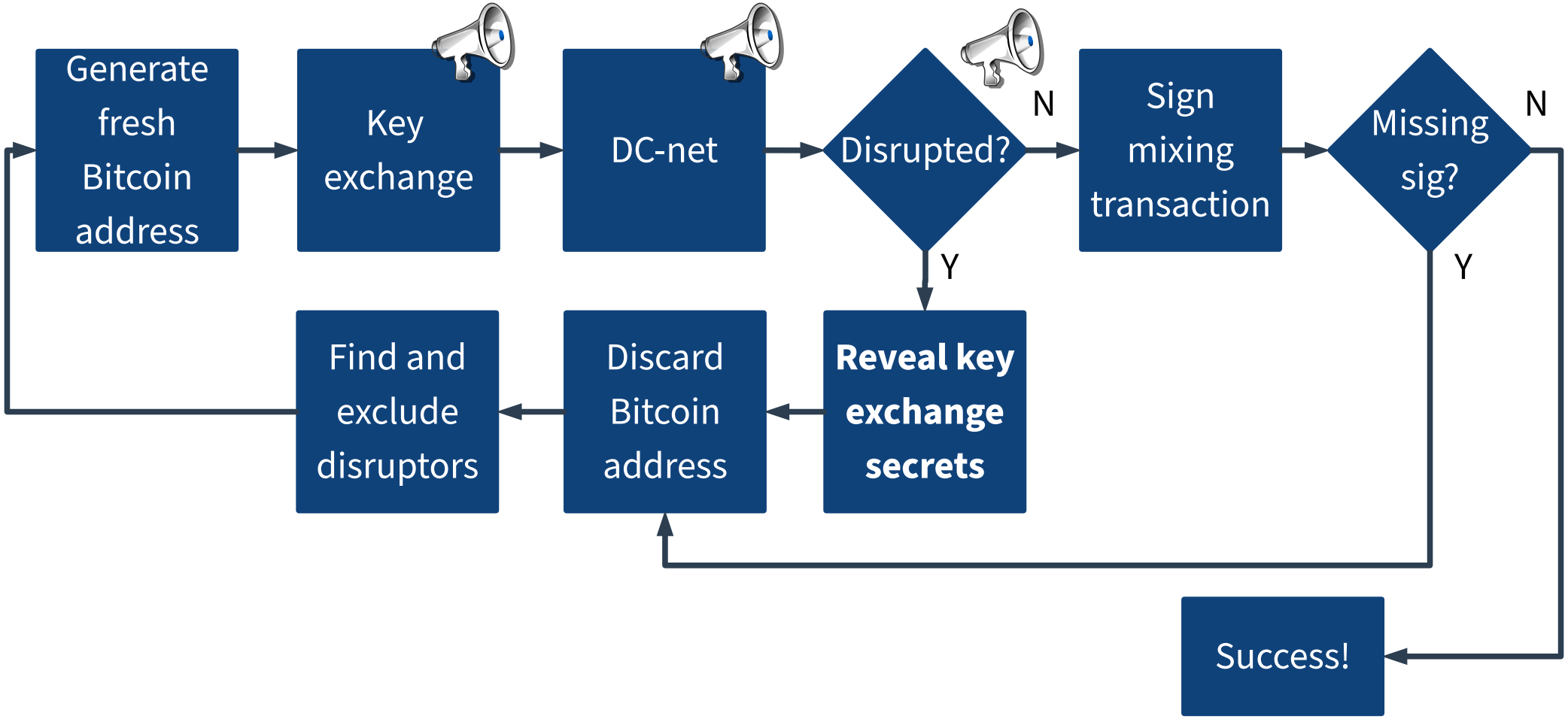

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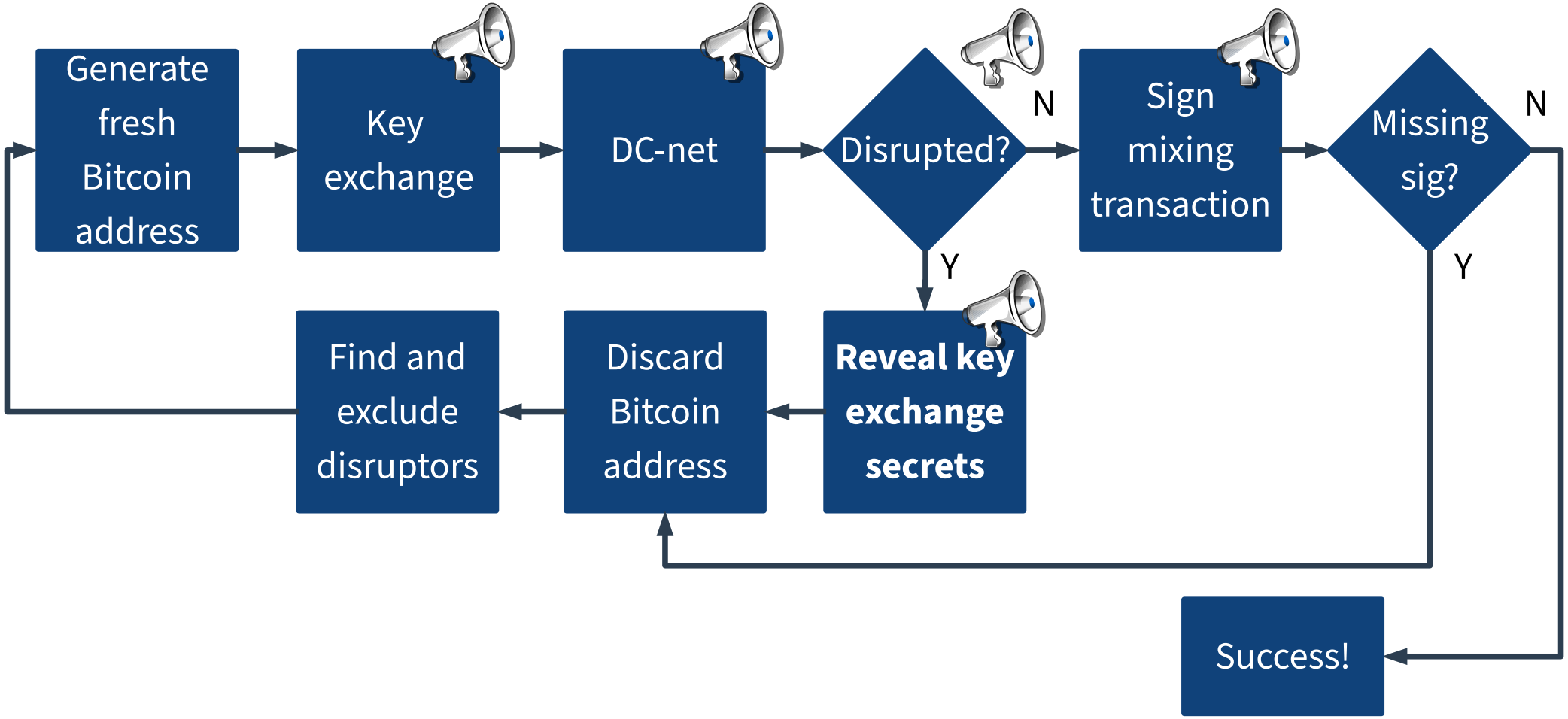
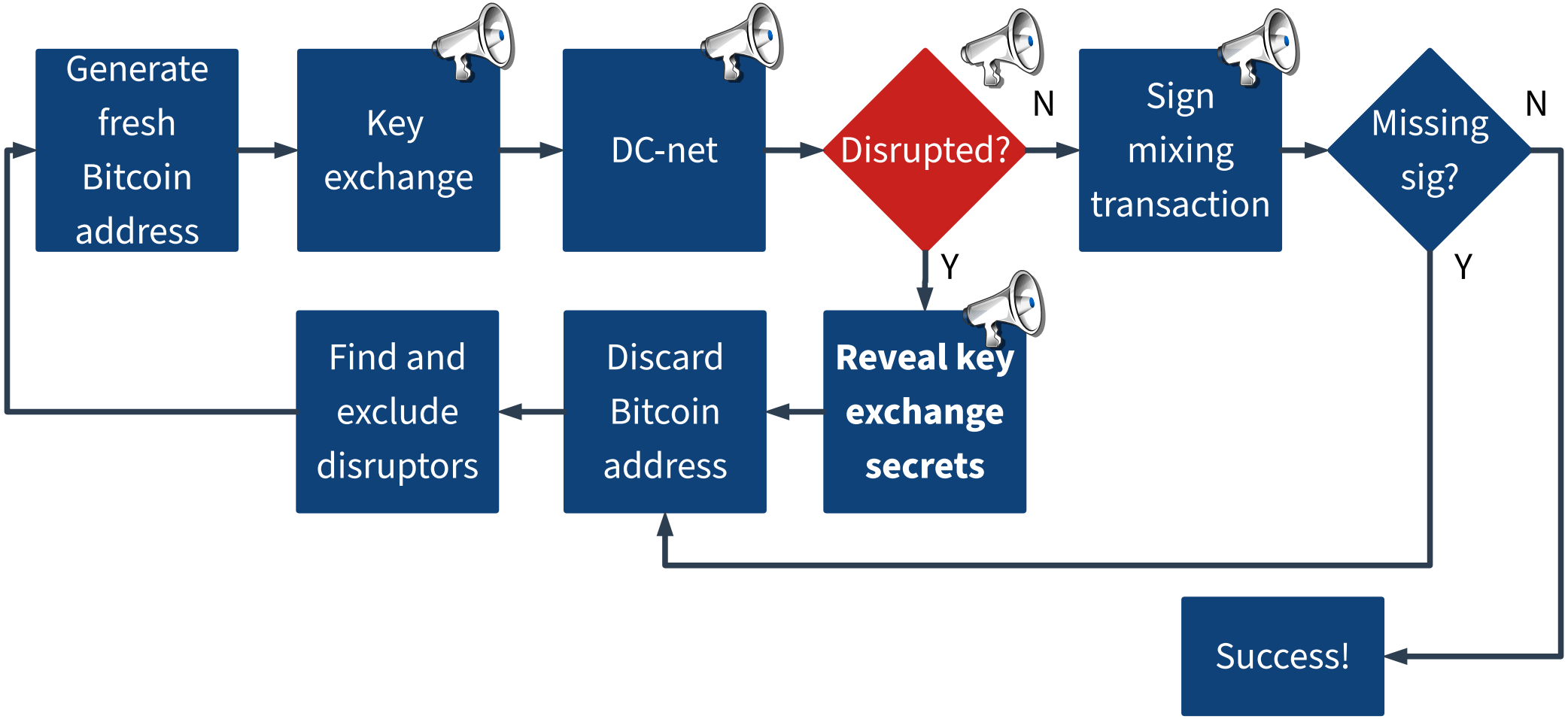
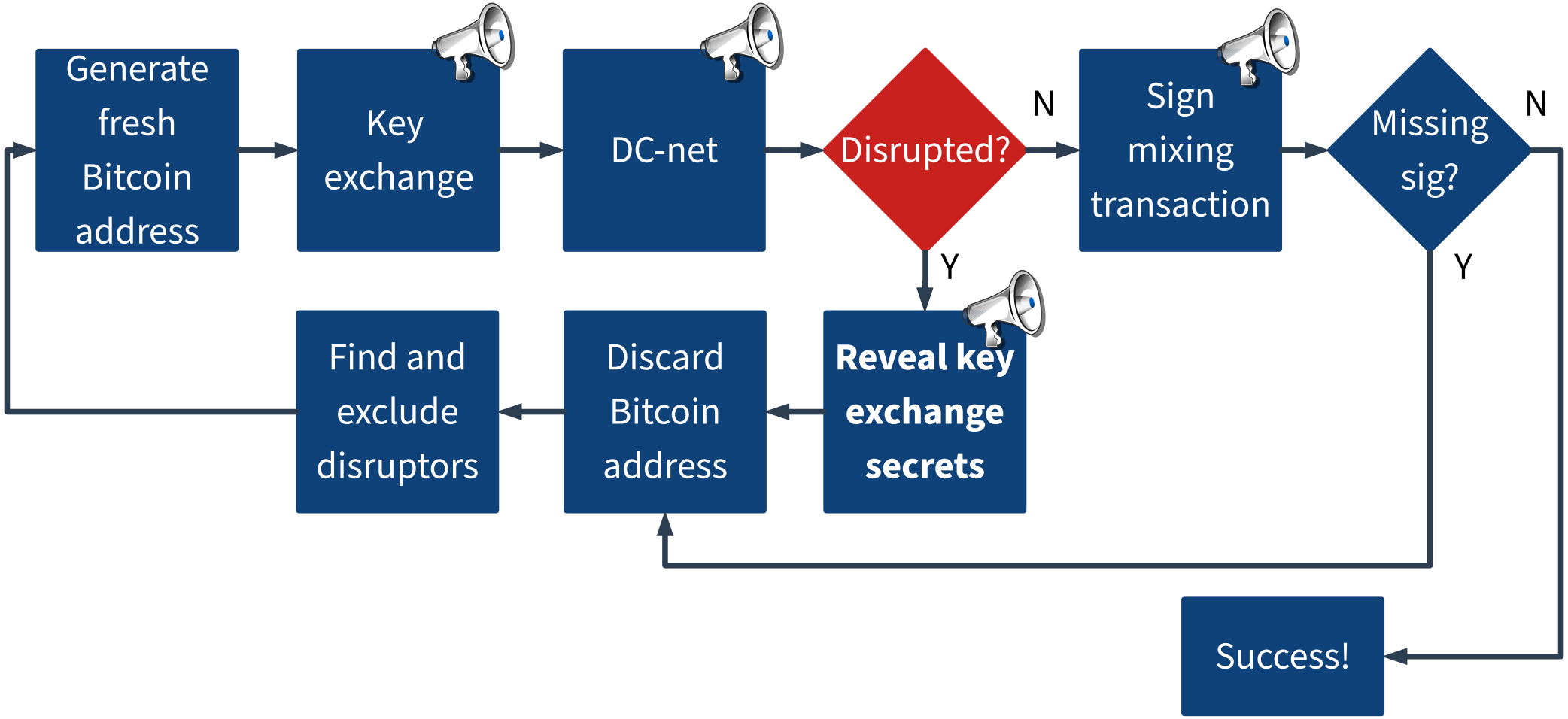


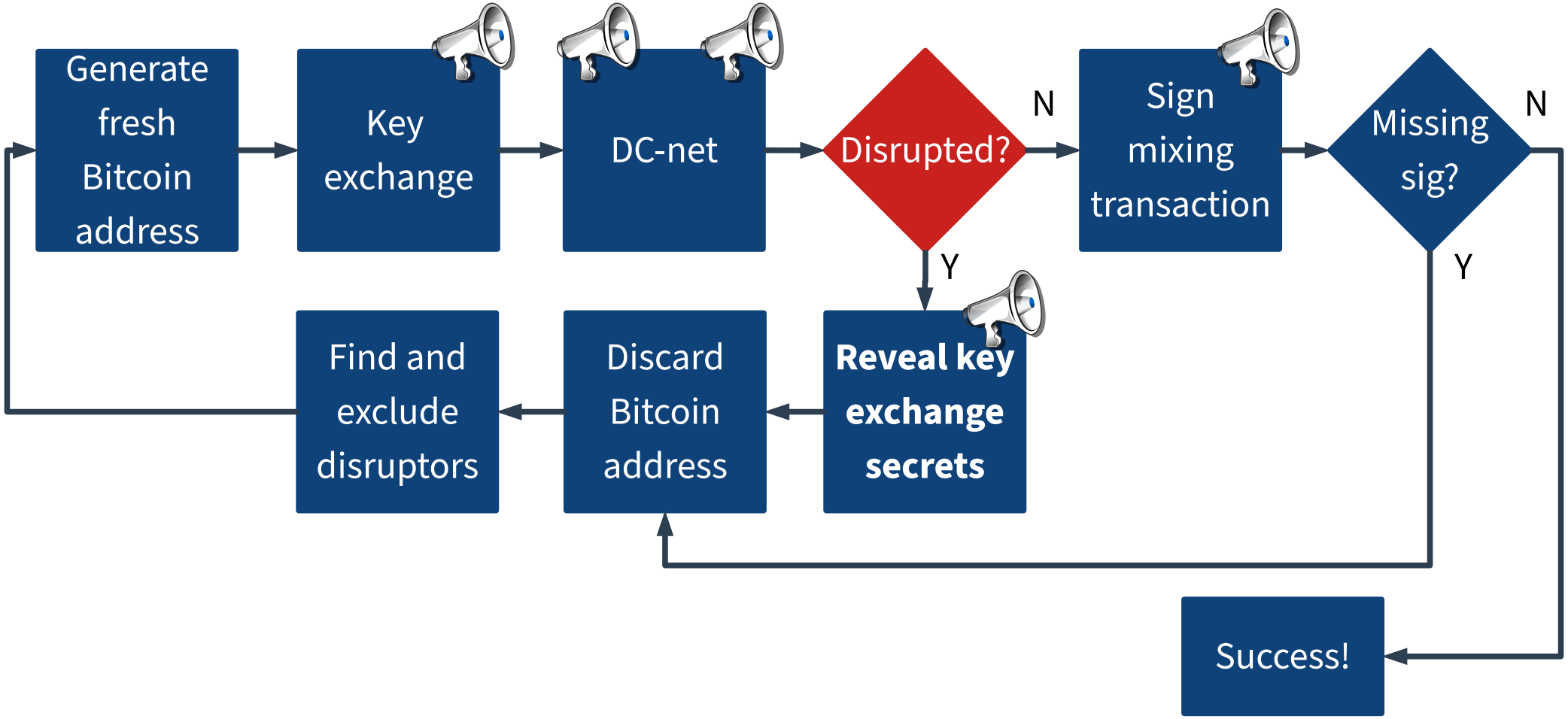
Broadcast Rounds (CoinShuffle++)



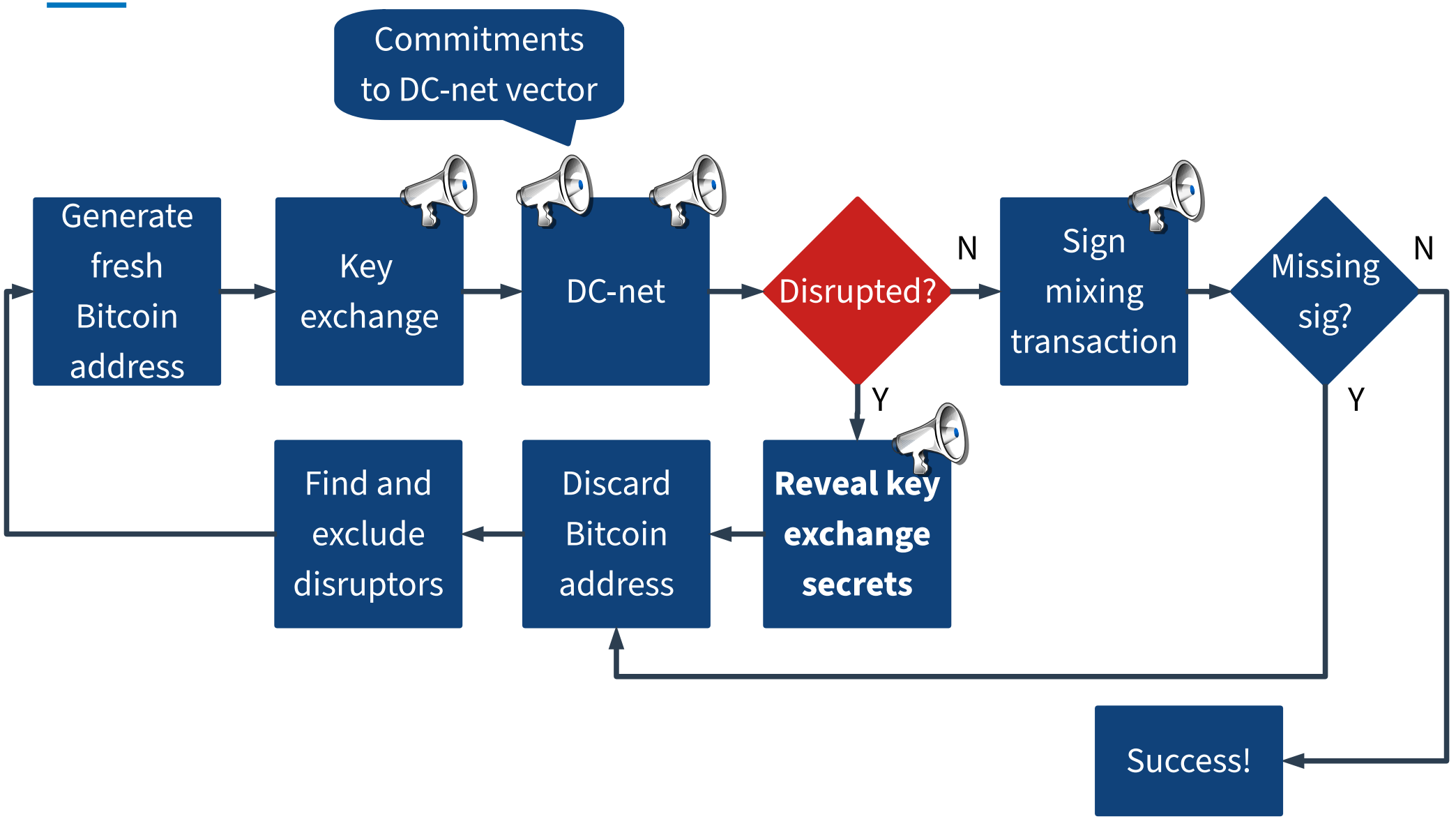
Broadcast Rounds (CoinShuffle++)



Broadcast Rounds (CoinShuffle++)



Broadcast Rounds (CoinShuffle++)



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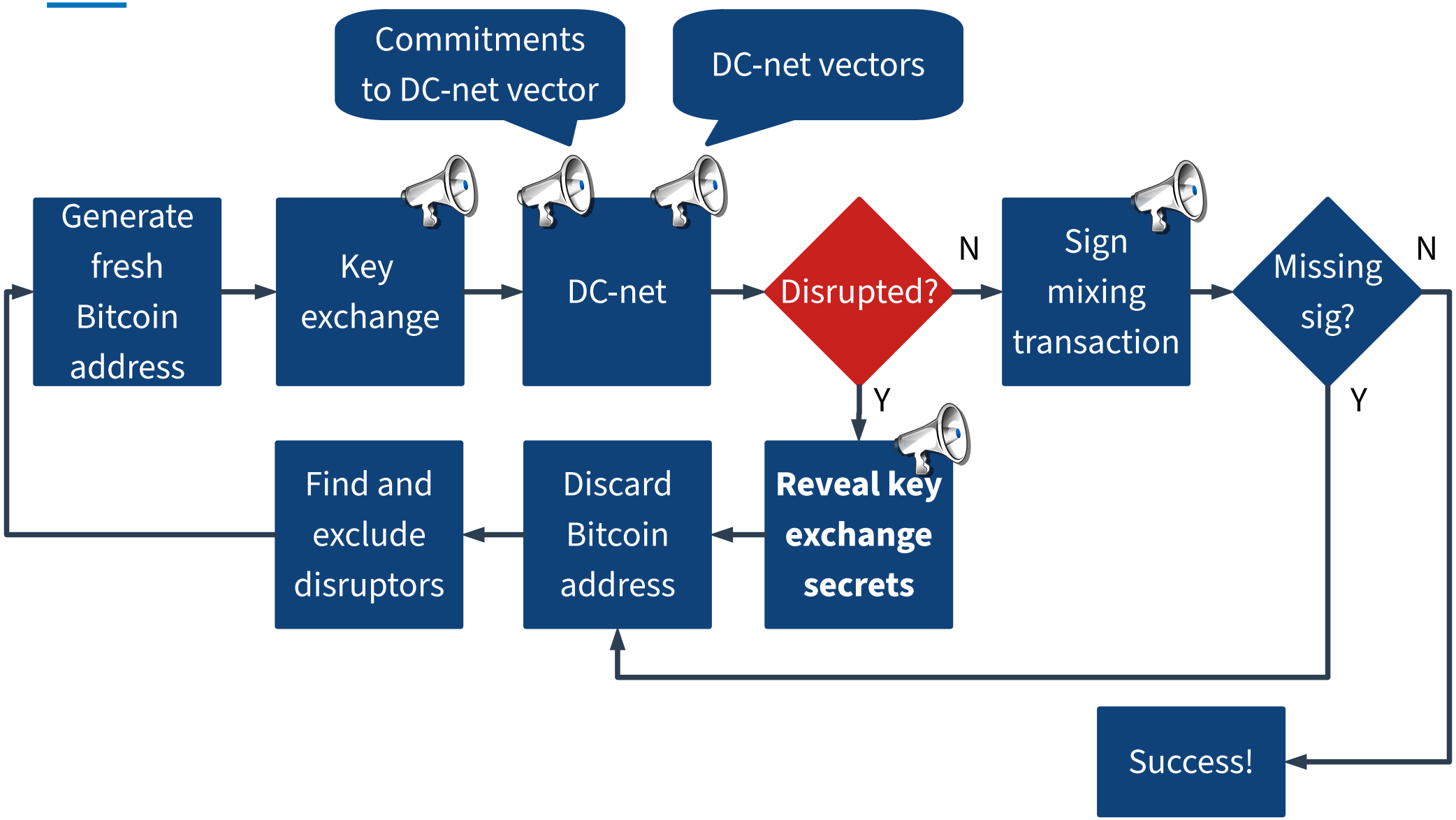

Justification (Informal)

There is a honest user whose message is disrupted.

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All honest users' messages are disrupted.

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Using hash-based commitments,
in the random oracle model without further computational assumptions
against a ppt attacker, with overwhelming probability:

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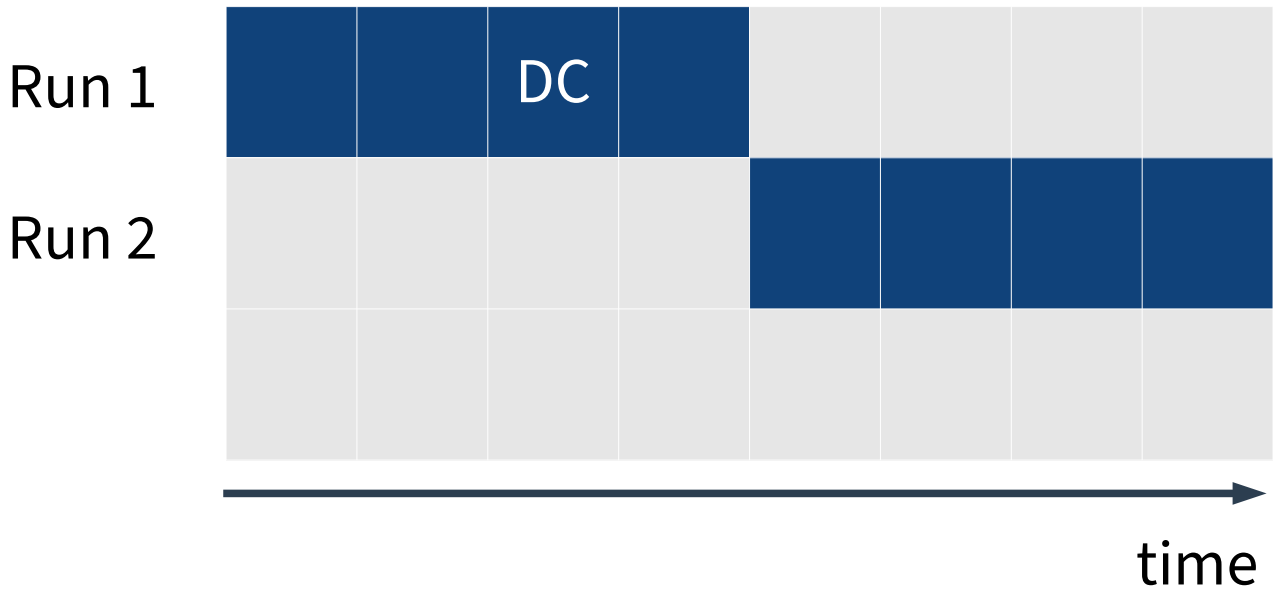
Example Execution (simple)



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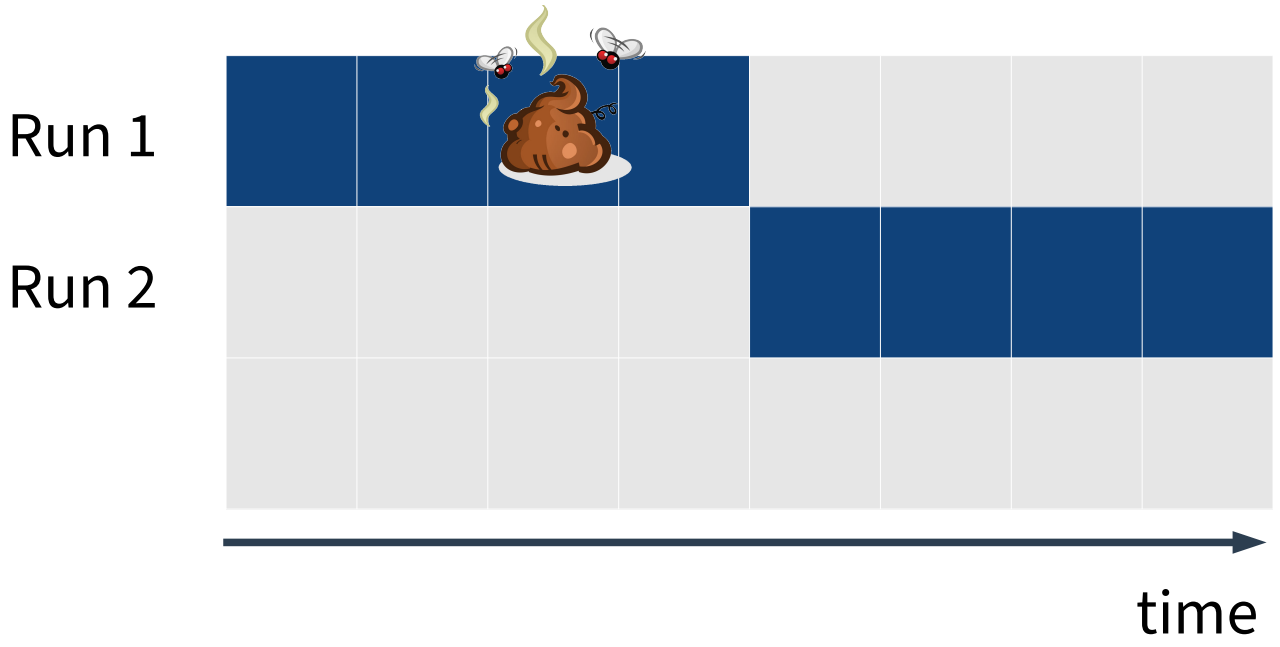

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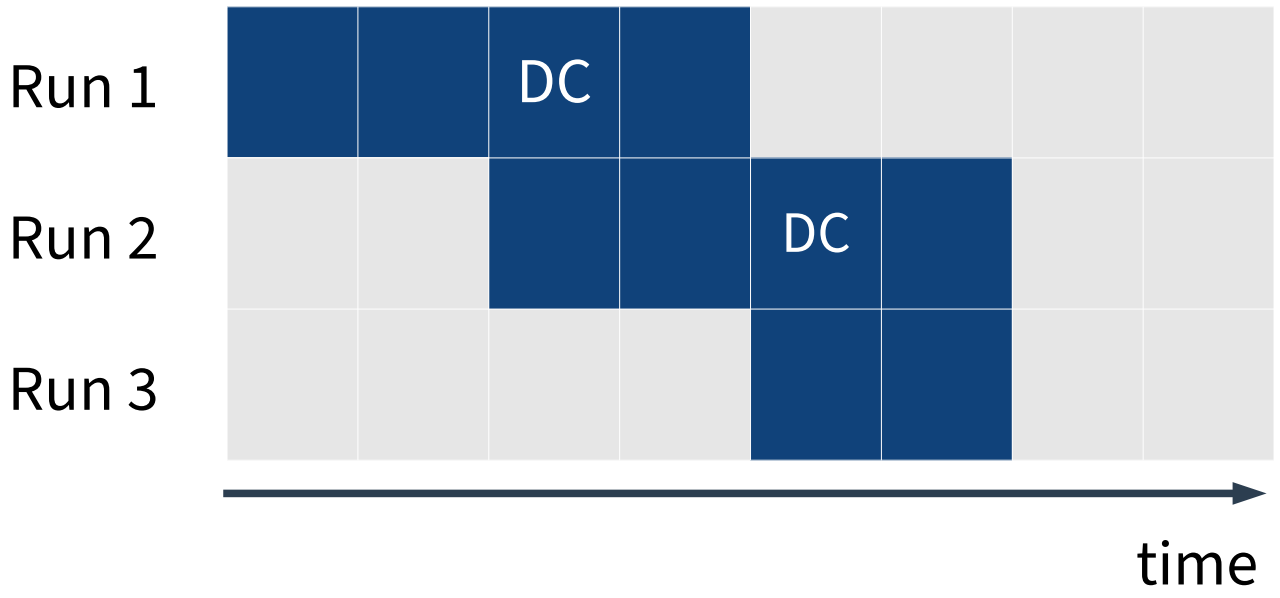

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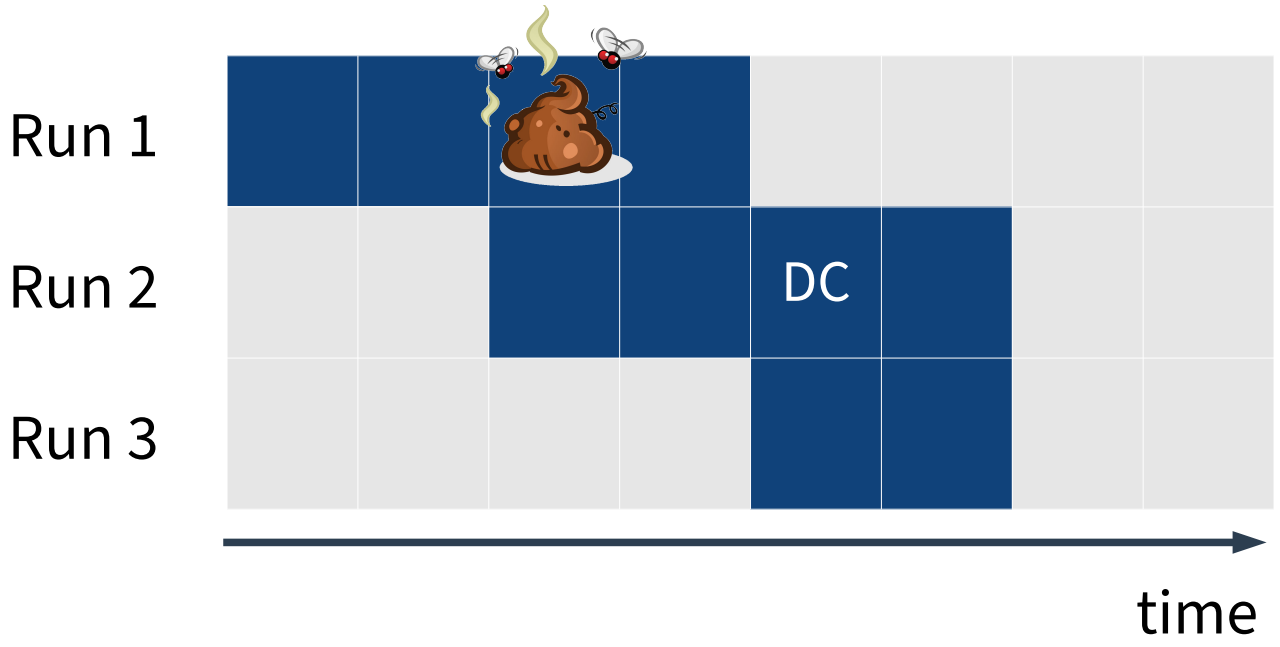

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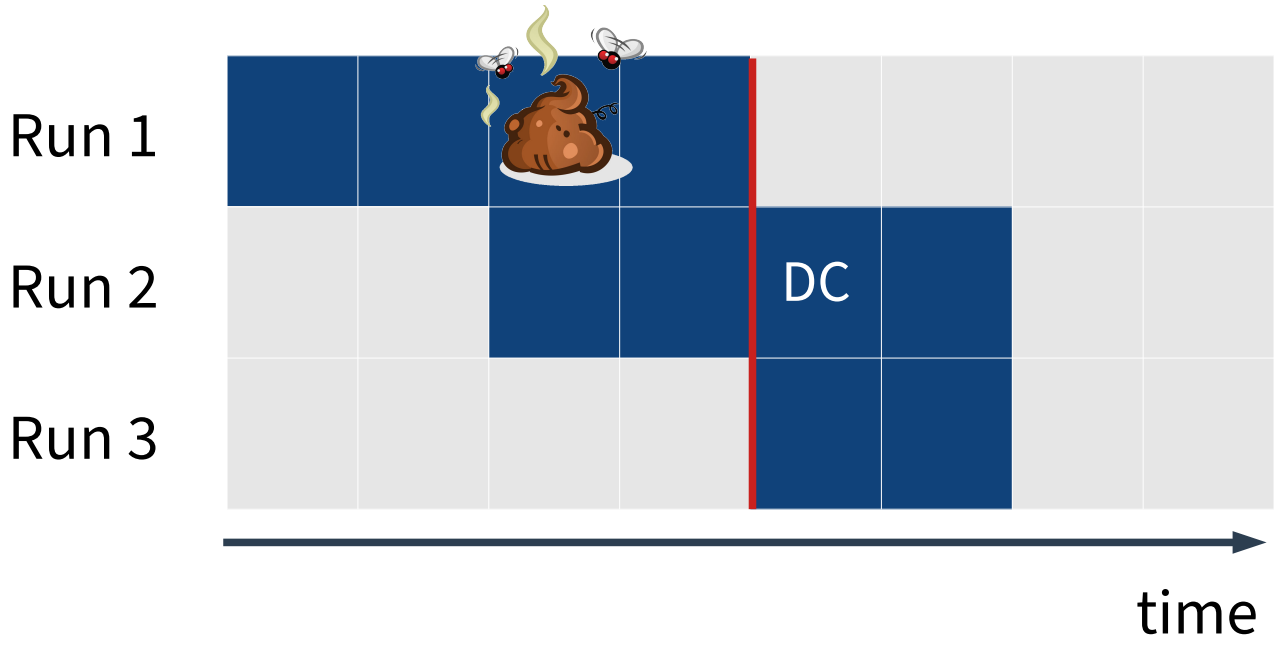

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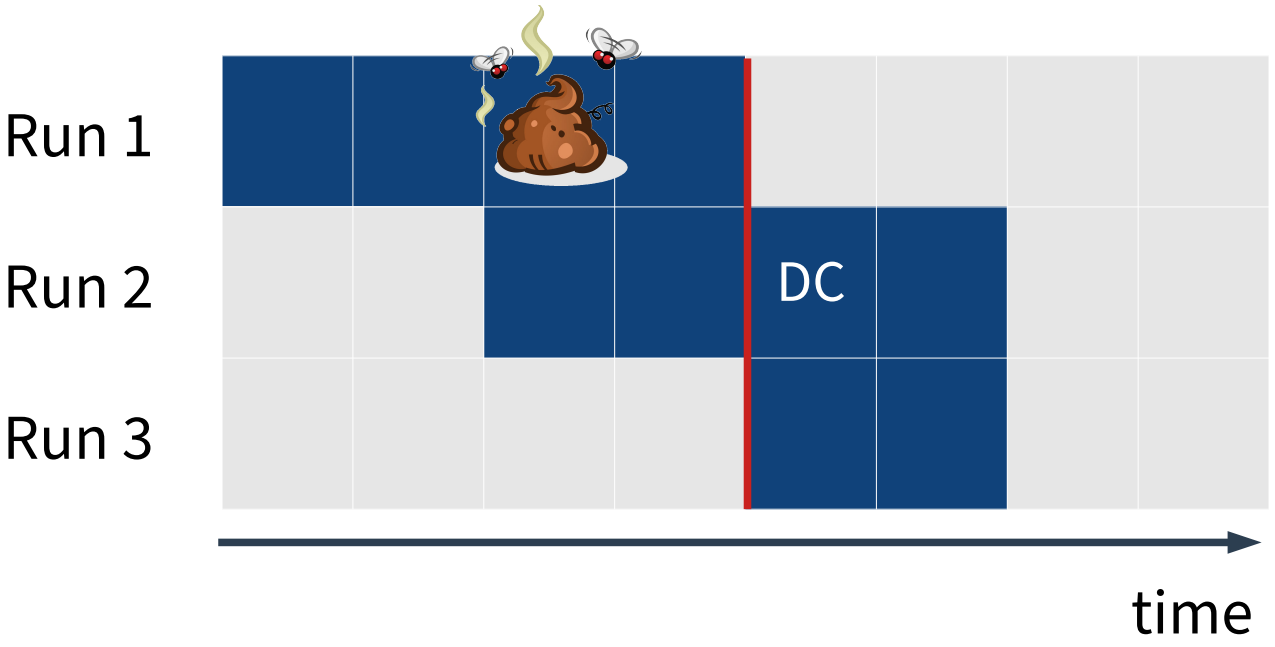

Let *f* be the number of malicious users.

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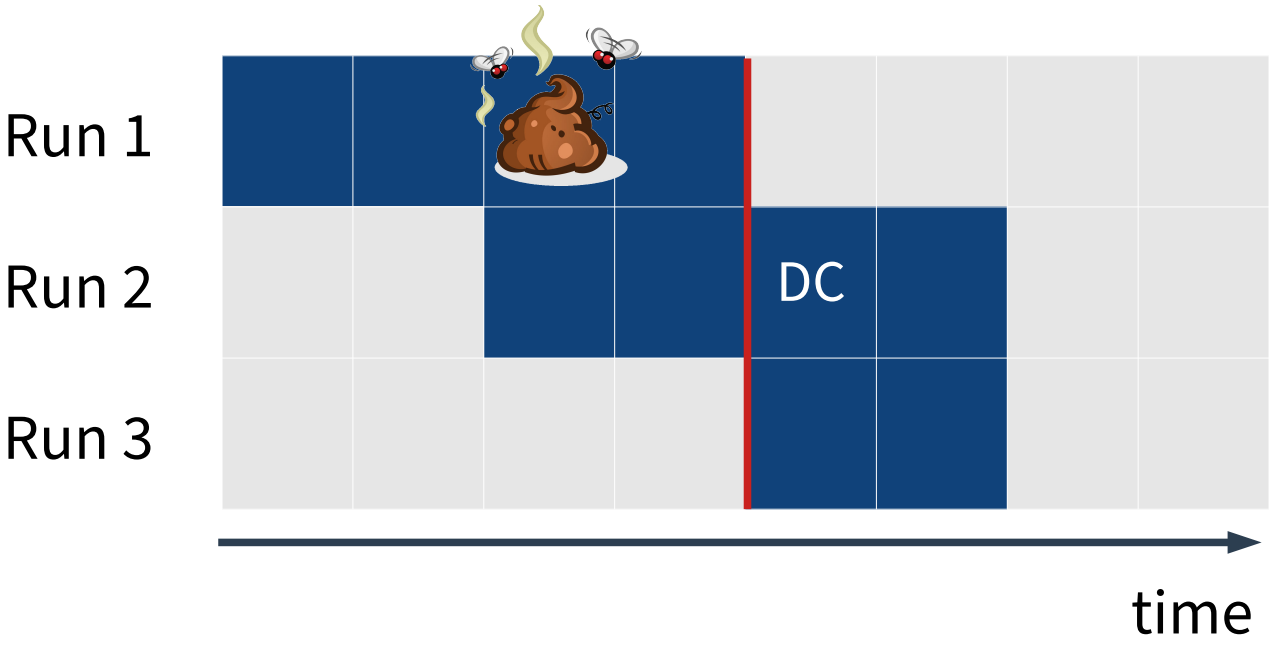

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CoinShuffle++ needs $4 + 2f$ broadcast rounds.

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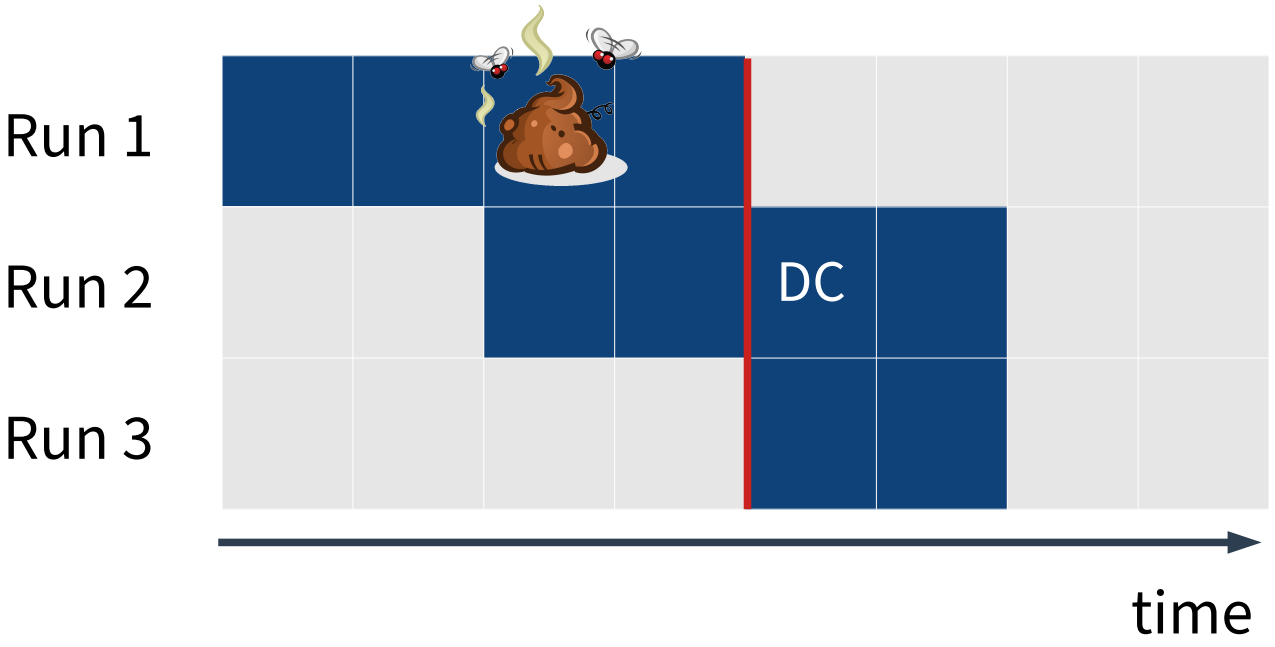

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Previous work: $O(nf)$

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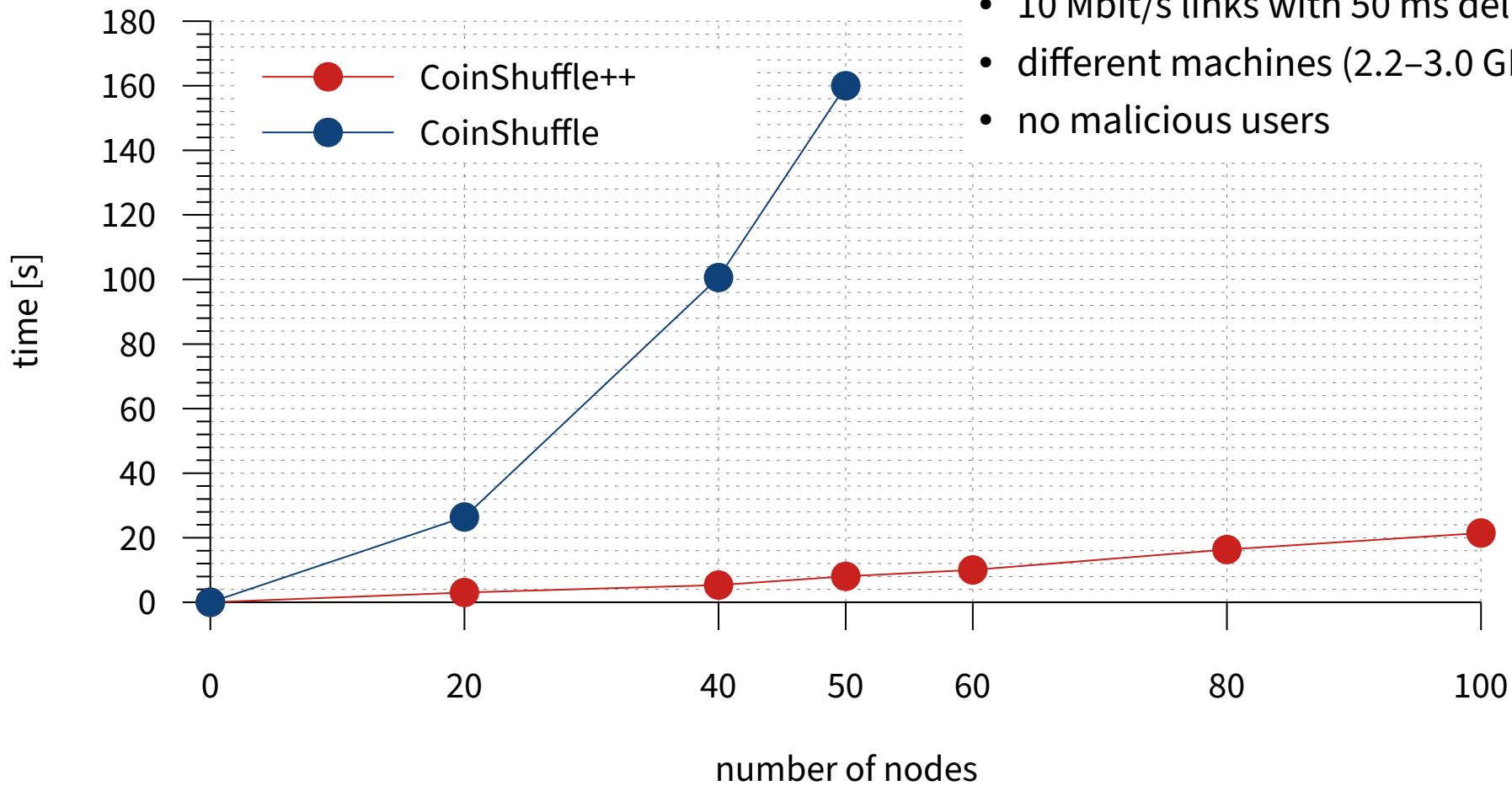

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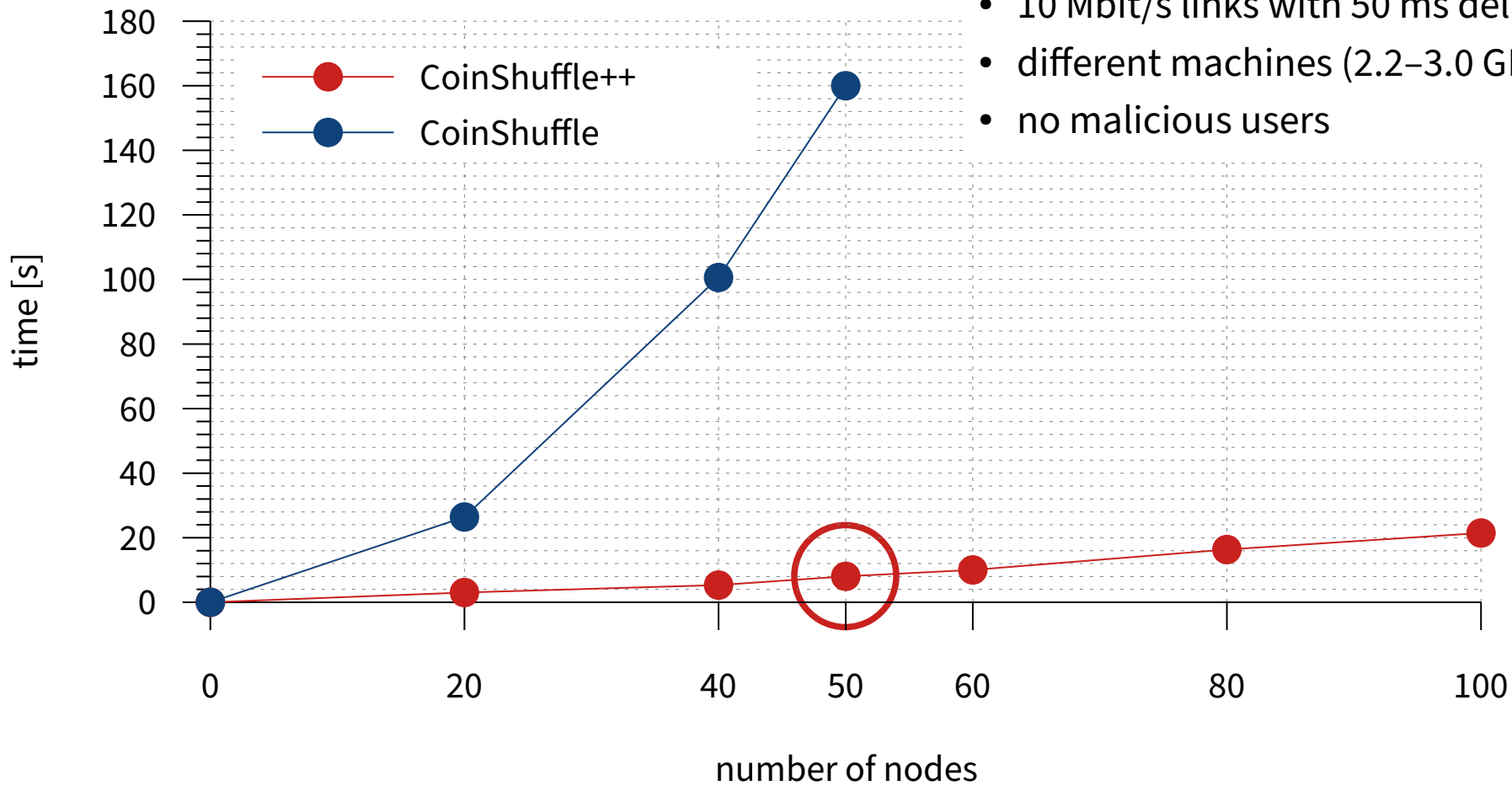

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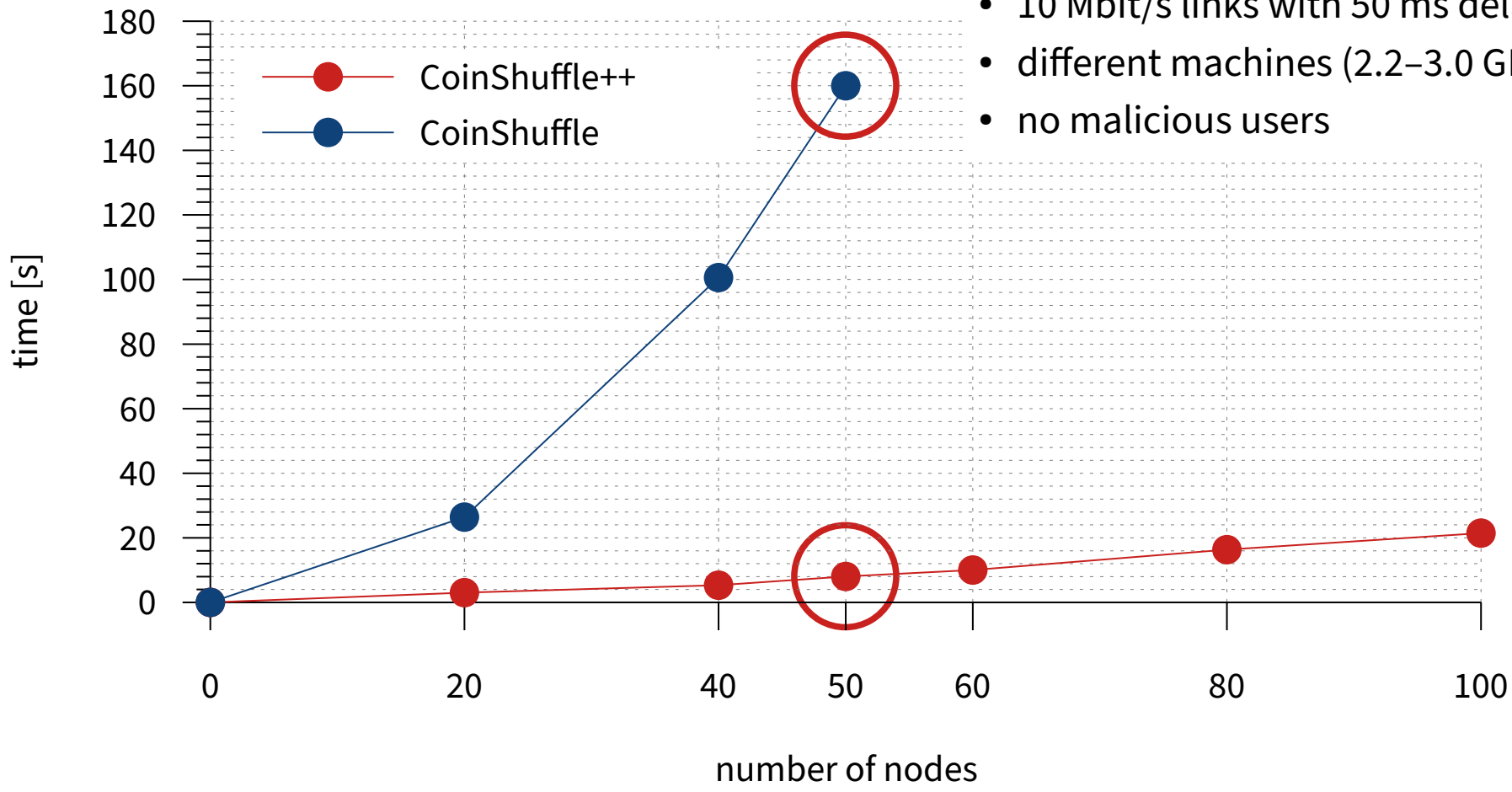

Limitations of CoinShuffle++

1. Handling Unequal Inputs

	Input	Output	
	A: 1.0 BTC	C′: 1.0 BTC	
	B: **1.2** BTC	A′: 1.0 BTC	
	C: 1.0 BTC	B′: **1.2** BTC	

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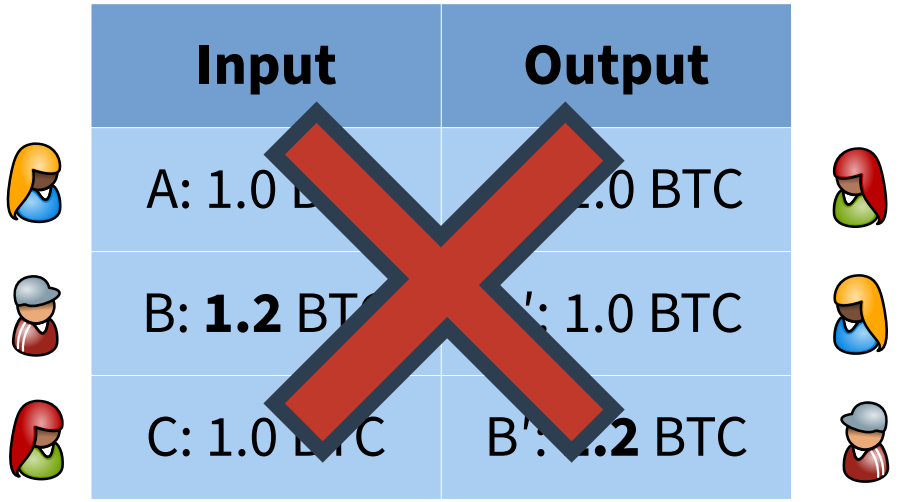
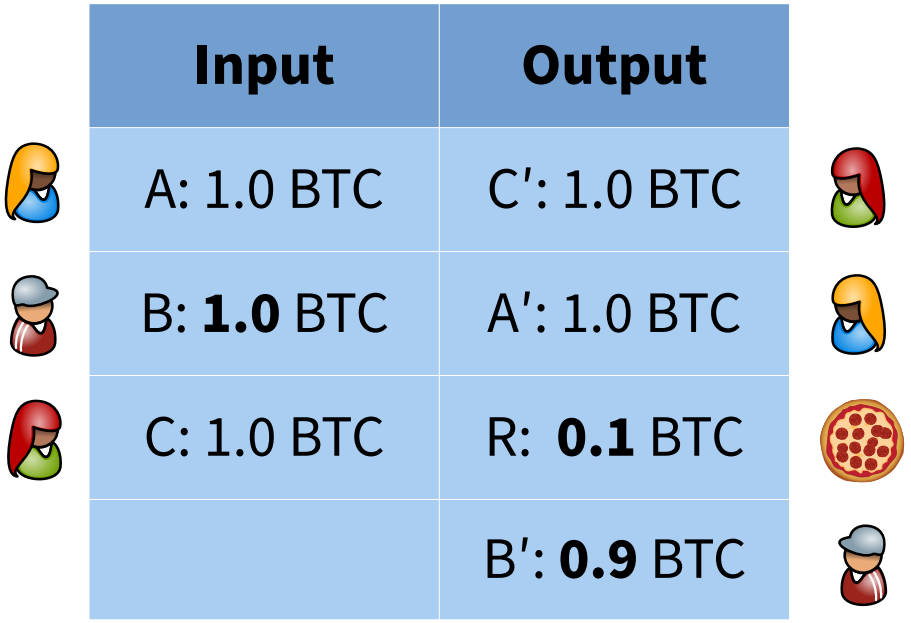


2. Mixing and Paying Simultaneously



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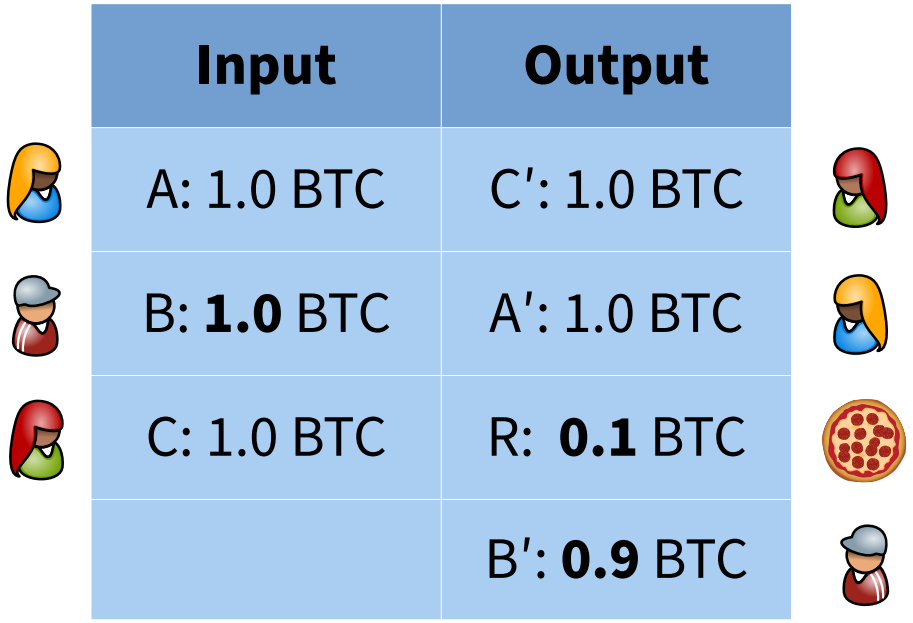

One of Bob's input messages to P2P mixing protocol:

(R, 0.1)

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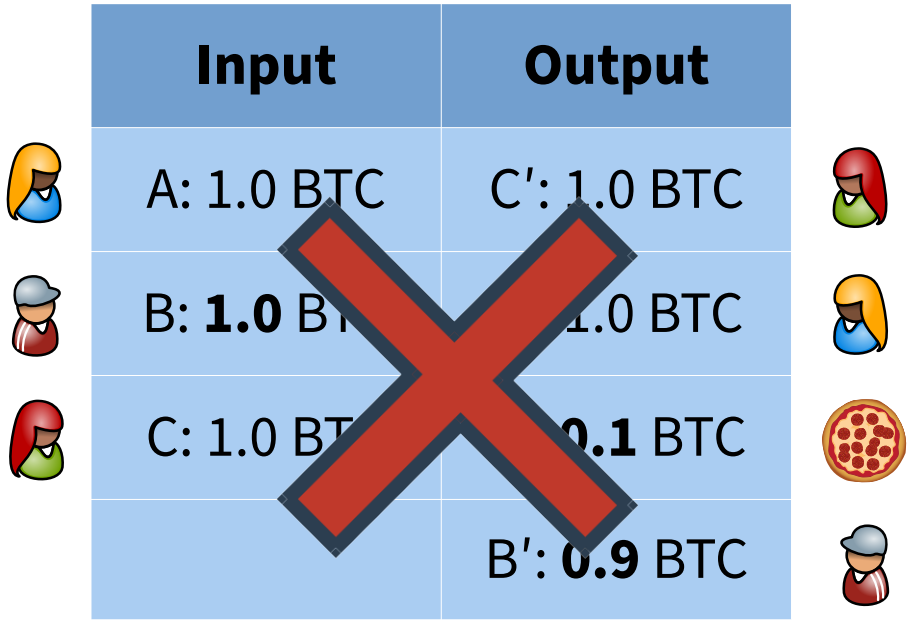

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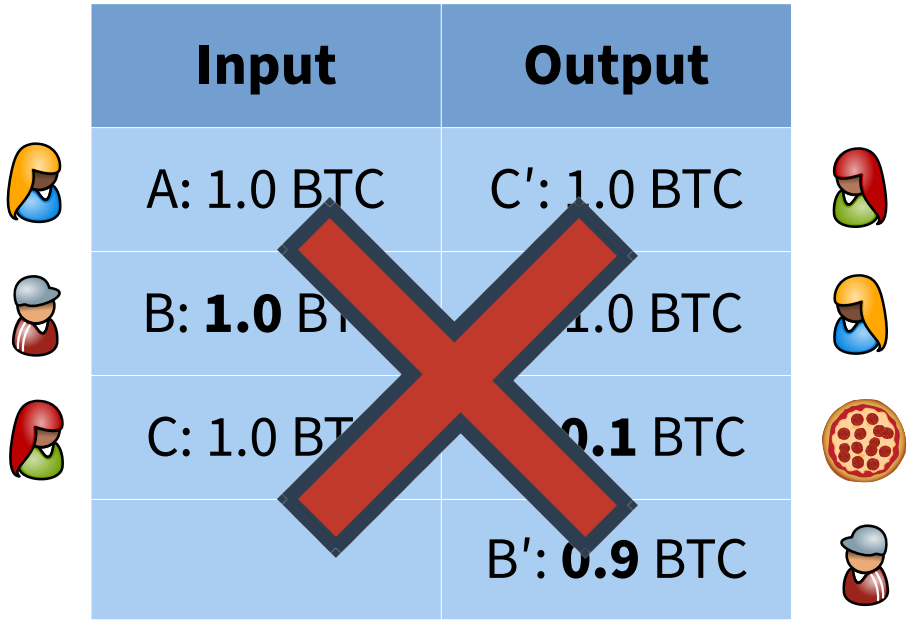

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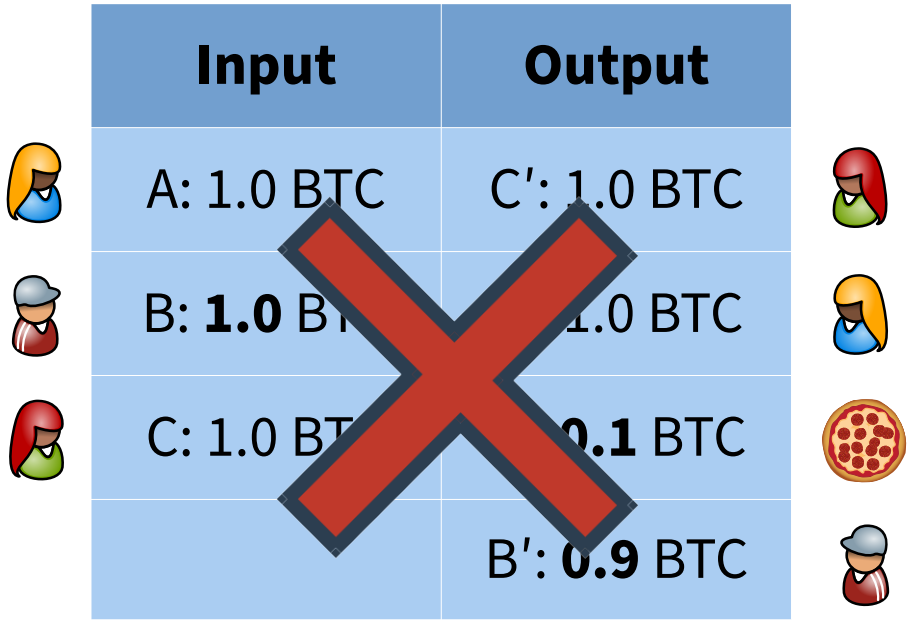

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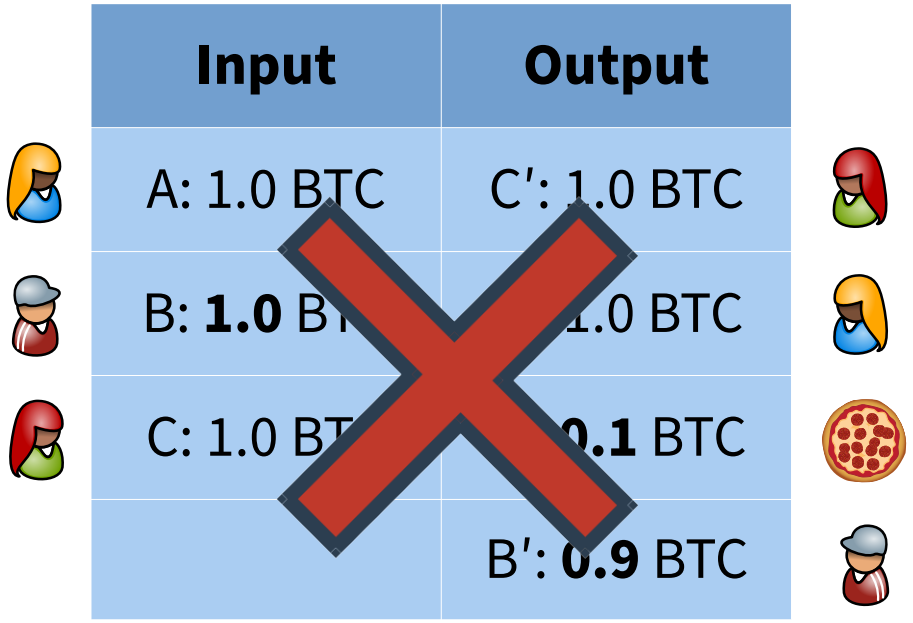

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Solution:

ValueShuffle