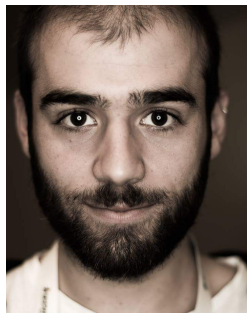
The security of Mimblewimble

Georg Fuchsbauer

joint work with

Michele Orrù



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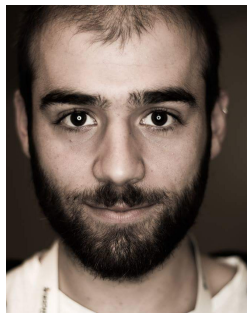
Michele Orrù  and Yannick Seurin 

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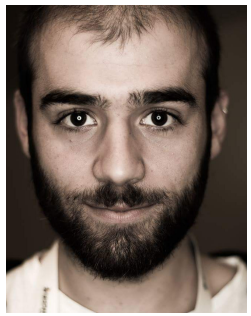
Michele Orrù  and Yannick Seurin 

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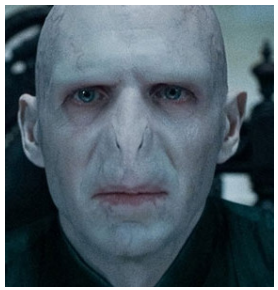
F, Orrù: **Non-interactive Mimblewimble transactions, revisited.** ASIACRYPT'22

What is it?

- **Cryptocurrency scheme**

- proposed by "Tom Elvis Jedusor" in 2016



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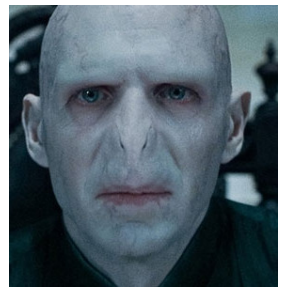

```
MIMBLEWIMBLE
Tom Elvis Jedusor
19 July, 2016

\****/
Introduction
/****\

Bitcoin is the first widely used financial system for which all the necessary
data to validate the system status can be cryptographically verified by anyone
However, it accomplishes this feat by storing all transactions in a public
database called "the blockchain" and someone who genuinely wishes to check
this state must download the whole thing and basically replay each transaction
check each one as they go. Meanwhile, most of these transactions have not
```

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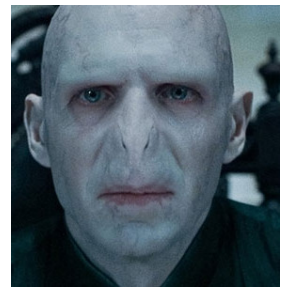

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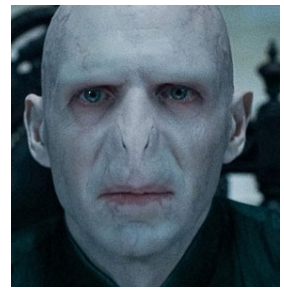

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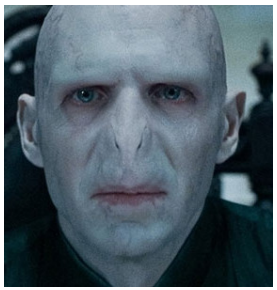

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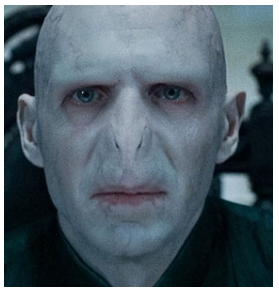
What is it?

- **Cryptocurrency scheme**
  - **Privacy** (all amounts hidden; input/output relation blurred)
  - **Scalability** (forget about spent tx's)

- proposed by "Tom Elvis Jedusor" in 2016



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Applications

Implemented by several cryptocurrencies (since 2019):

#	Name	Price	1h %	24h %	7d %	Market Cap
1273	Beam BEAM	$0.03445	▲0.28%	▼0.51%	▼11.47%	$5,194,030
1435	Grin GRIN	$0.03167	▼0.08%	▼1.60%	▼6.82%	$3,110,211

Non-interactive TXs

Main **drawback**: transactions are *interactive*

2020: David Burkett, Gary Yu:
Non-interactive transactions

Non-interactive TXs

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2020: David Burkett, Gary Yu:
Non-interactive transactions

2021: Fixed by Burkett, F, Orrù

Analyzed by F, Orrù

Non-interactive TXs

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Non-interactive TXs

#	Name	Price	1h %	24h %	7d %	Market Cap
247	MimbleWimbleCoin MWC	$16.77	▲0.76%	▲0.42%	▼3.92%	$183,788,914
1273	Beam BEAM	$0.03445	▲0.28%	▼0.51%	▼11.47%	$5,194,030
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Non-interactive TXs

2022: Implemented in

Litecoin ("Mimblewimble extension blocks")

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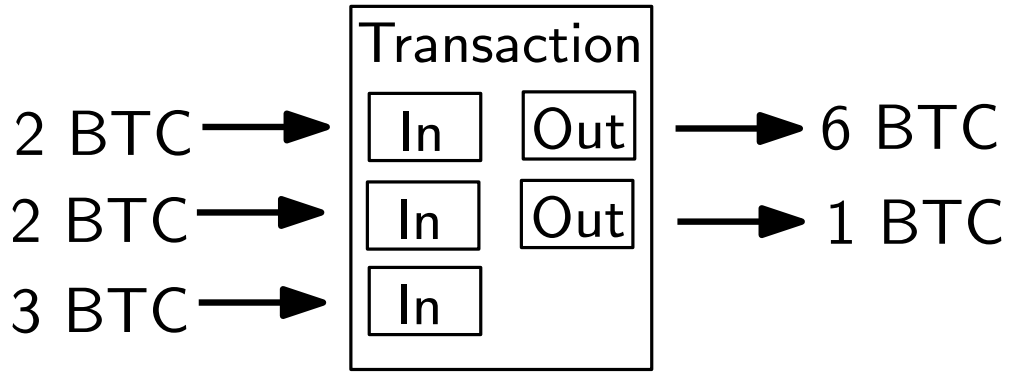
#	Name	Price	1h %	24h %	7d %	Market Cap
1	Bitcoin BTC	$63,990.10	▼0.12%	▼0.44%	▼3.86%	$1,261,608,323,848
2	Ethereum ETH	$3,468.64	▼0.12%	▼0.99%	▼3.53%	$424,131,839,729
⋮						
19	Polygon MATIC	$0.5682	▼0.88%	▼0.66%	▼8.52%	$5,627,473,007
20	Litecoin LTC	$74.63	▼0.17%	▲0.50%	▼5.63%	$5,573,047,076

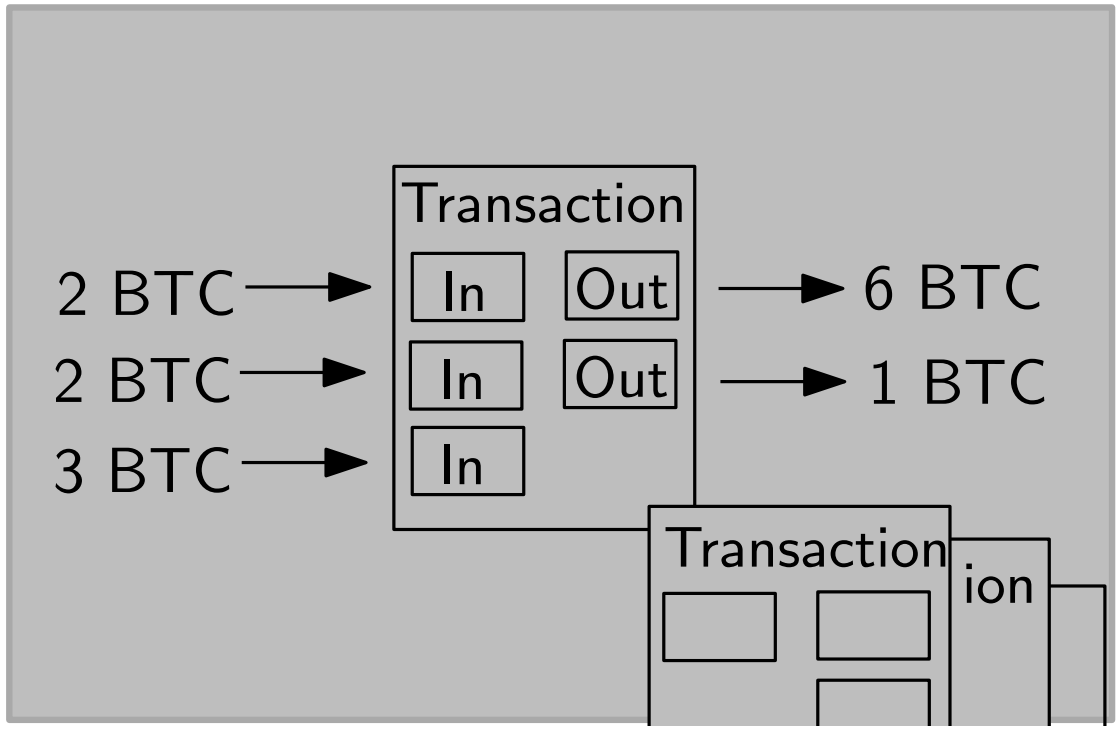
Bitcoin

- **Transactions**



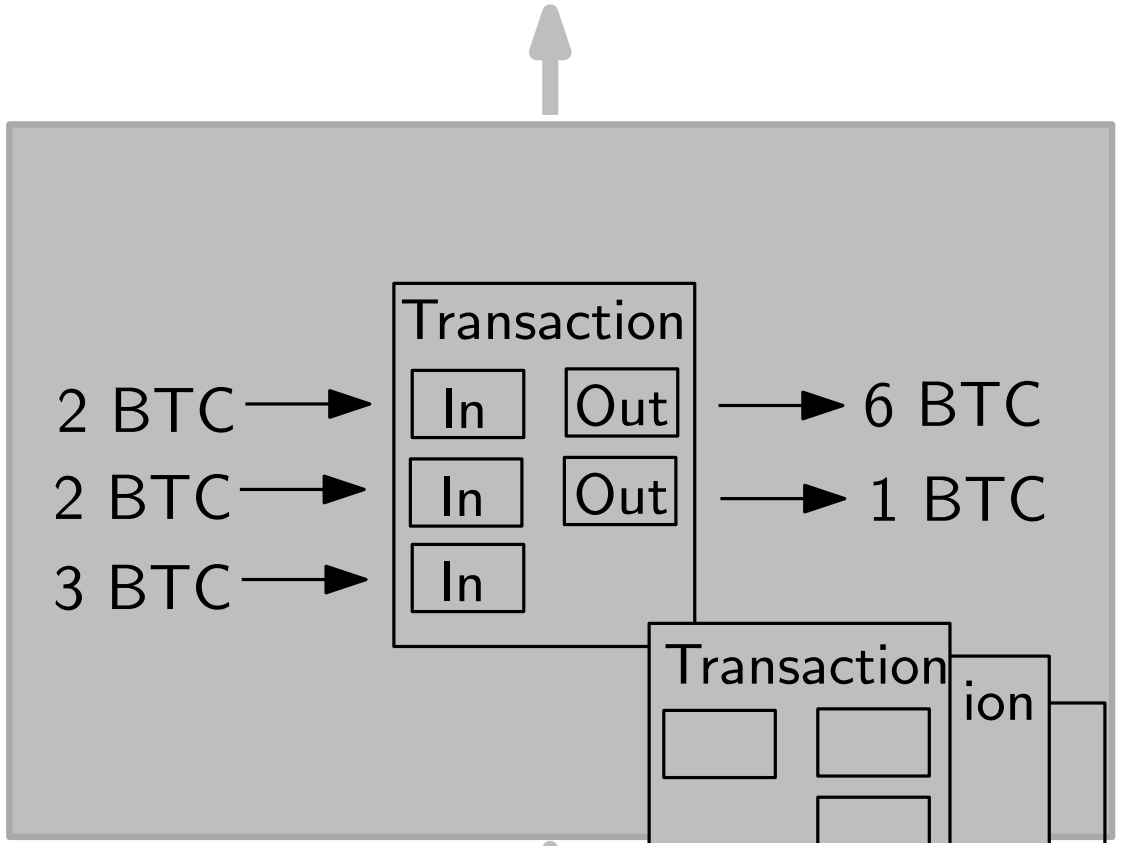
Bitcoin

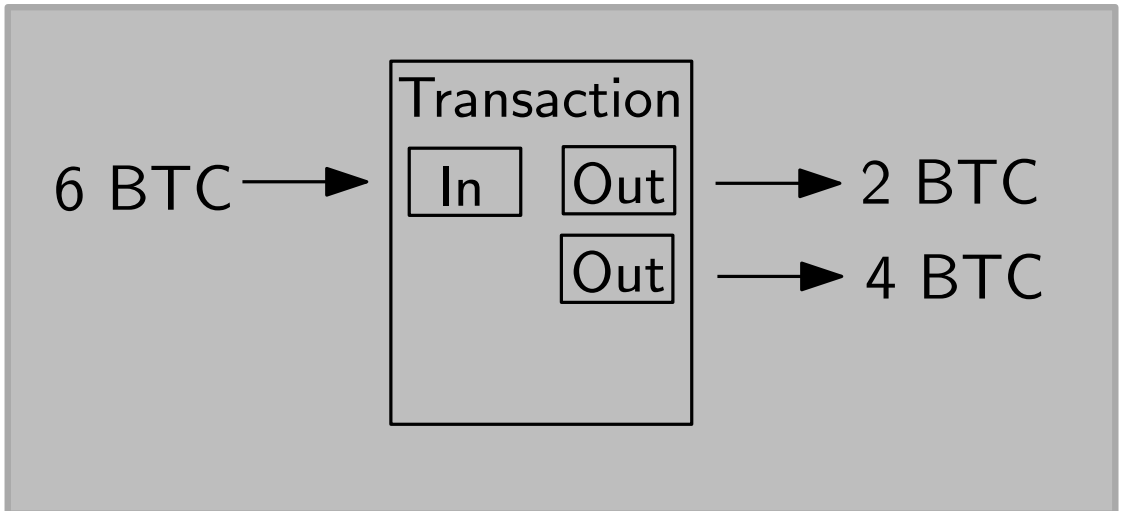
- **Block**



Bitcoin

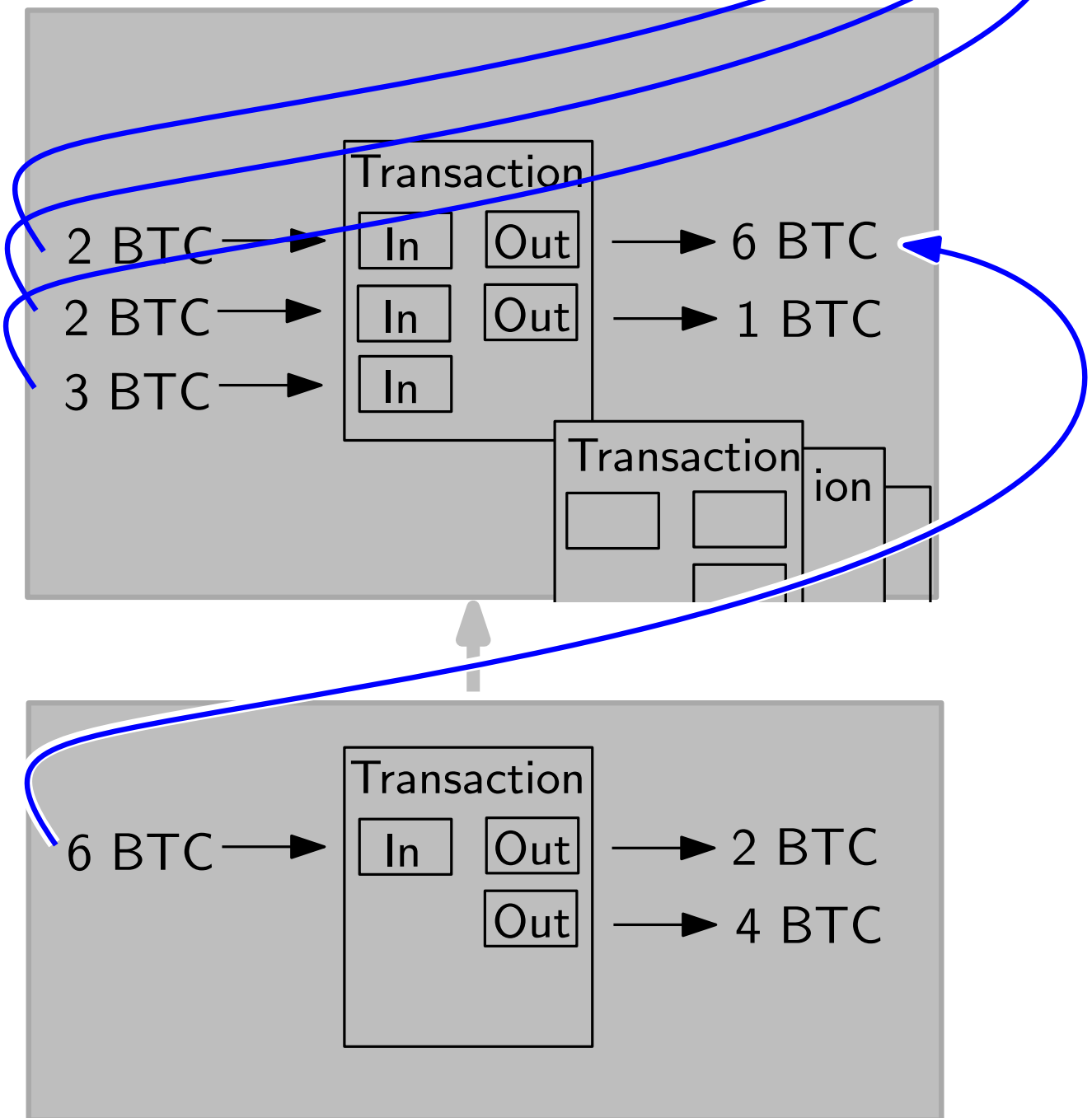
- **Blockchain**





Bitcoin

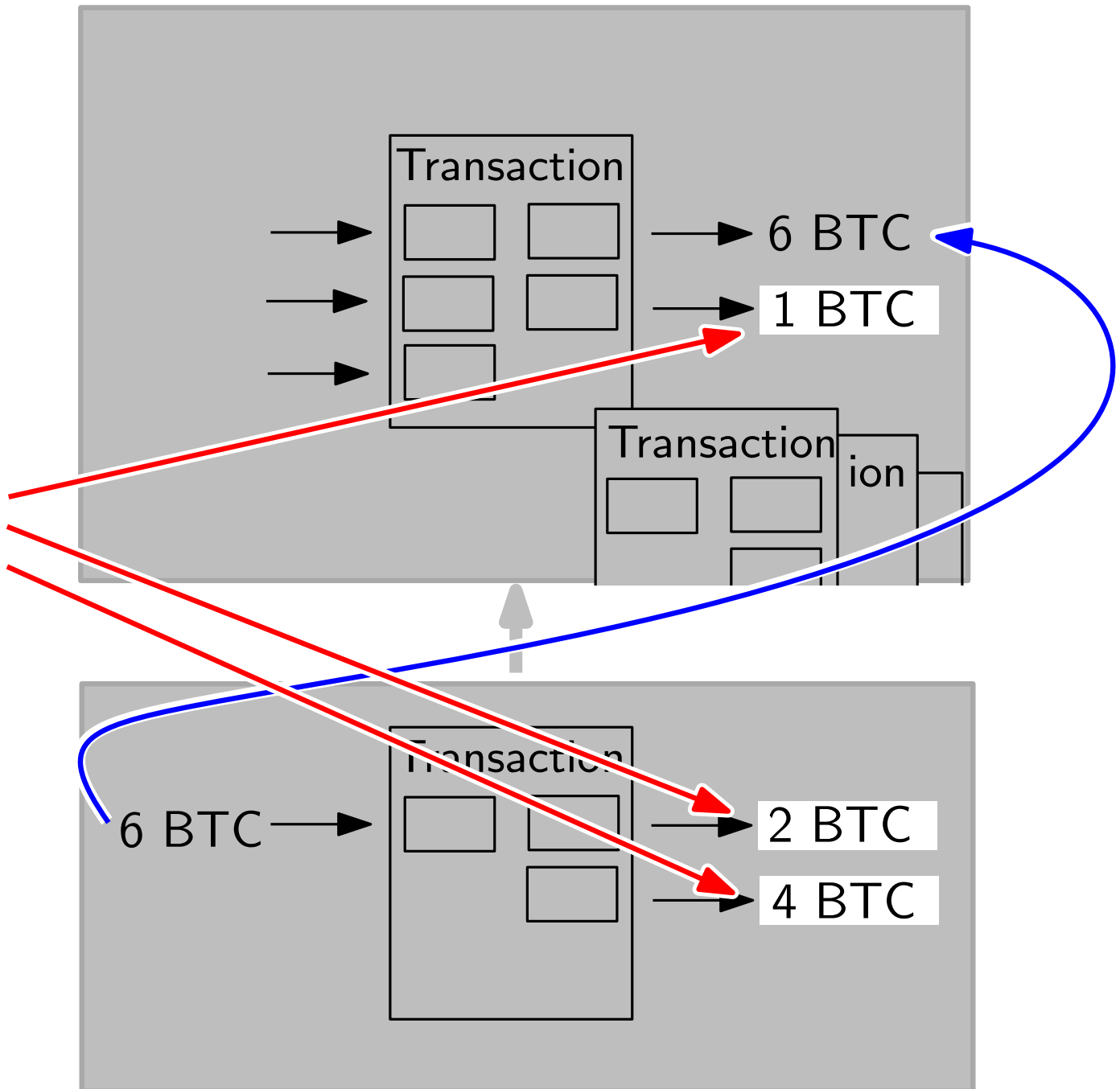
- Reference to previous output



Bitcoin

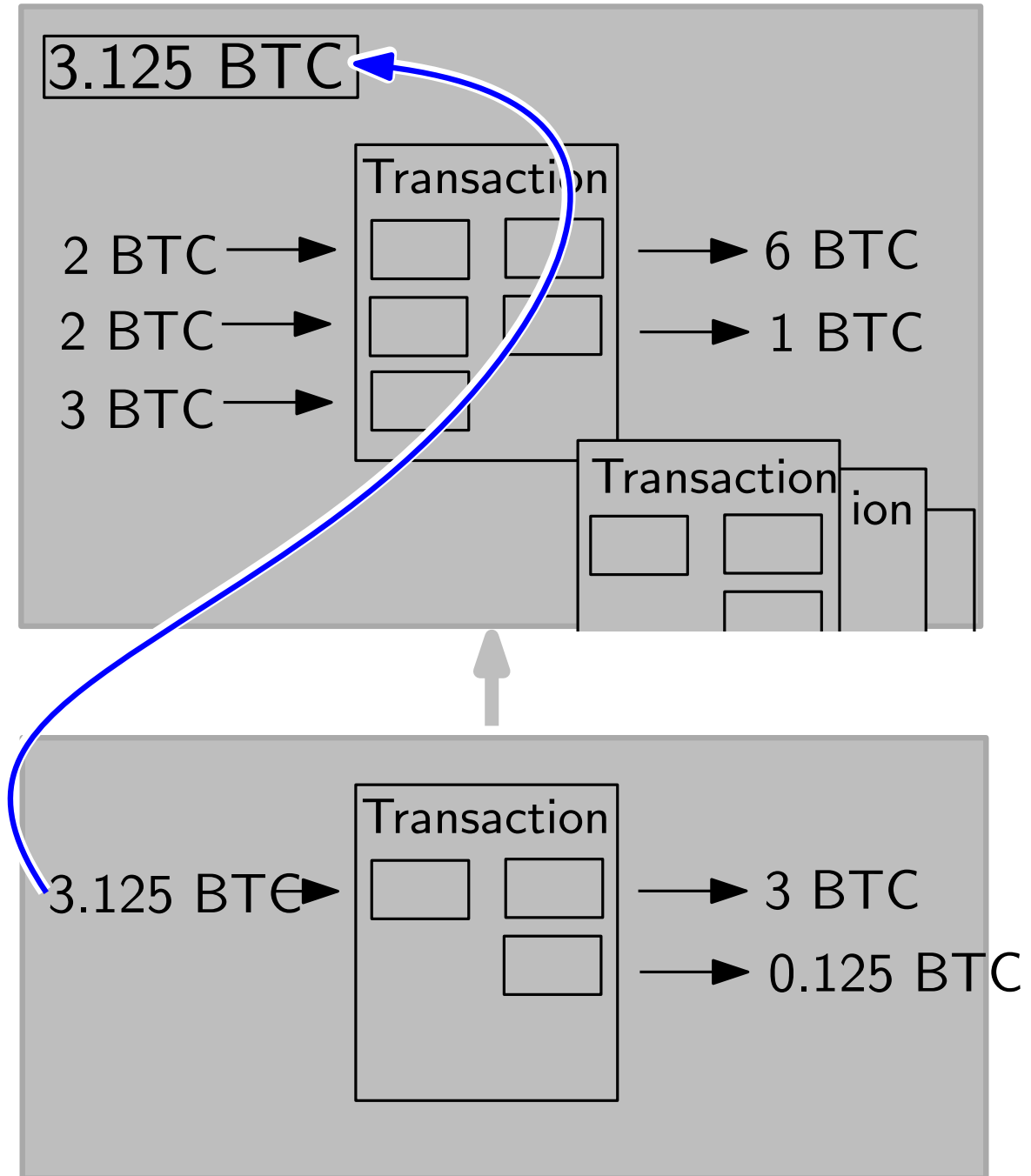
Unspent transaction outputs (UTXO's)

= existing money in system



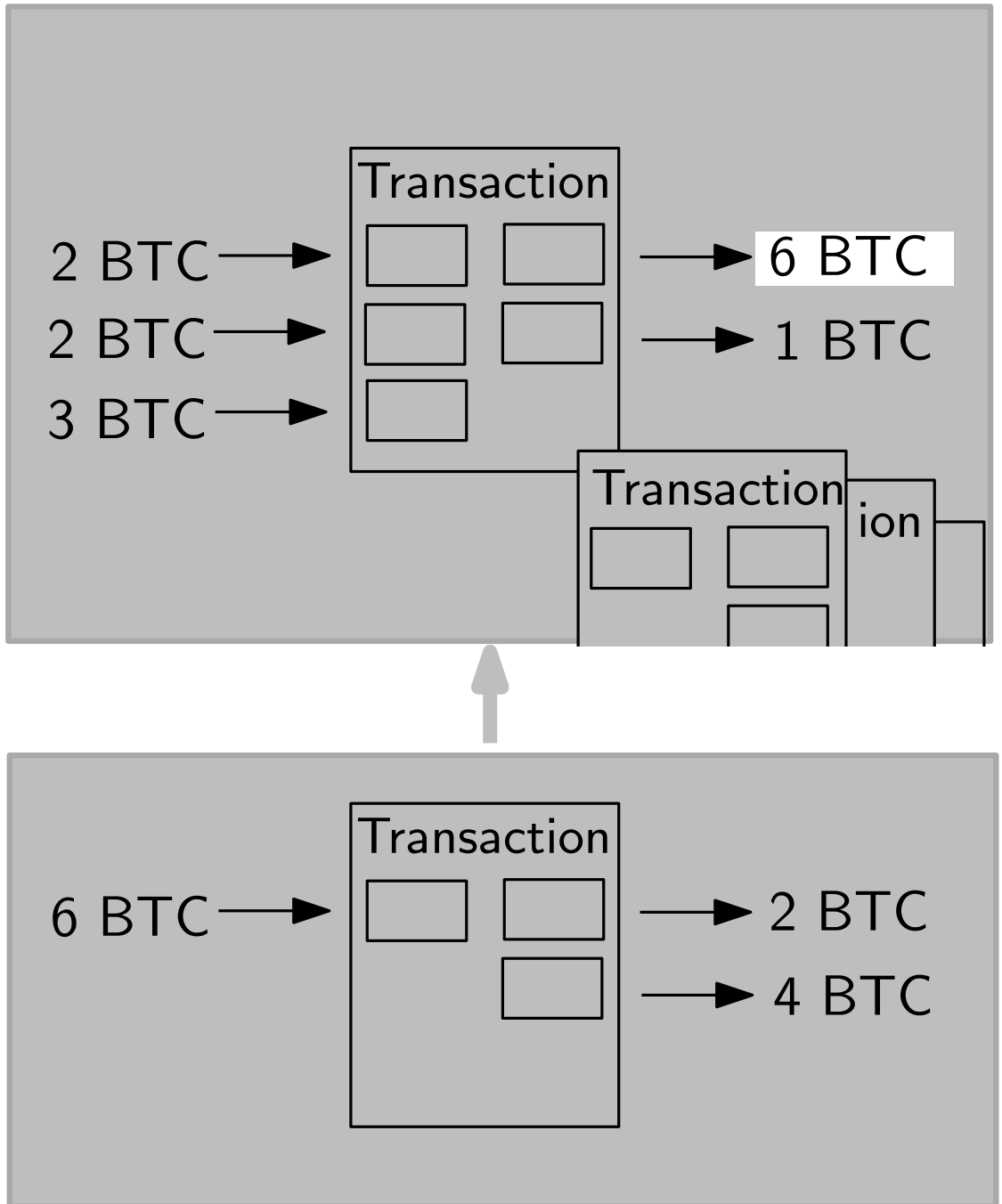
Bitcoin

- **Coinbase transaction**



Bitcoin

- **Owning**
  an output



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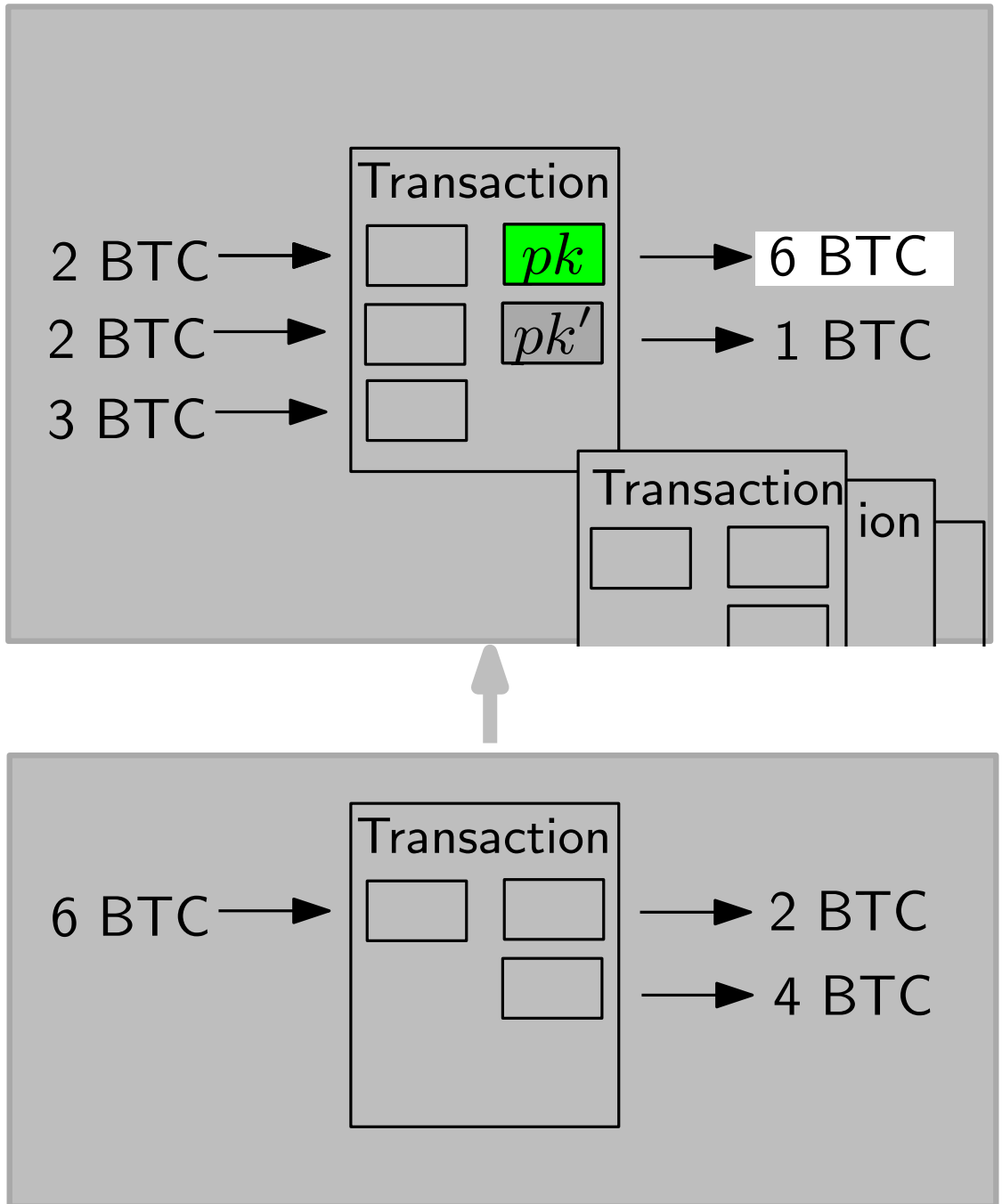

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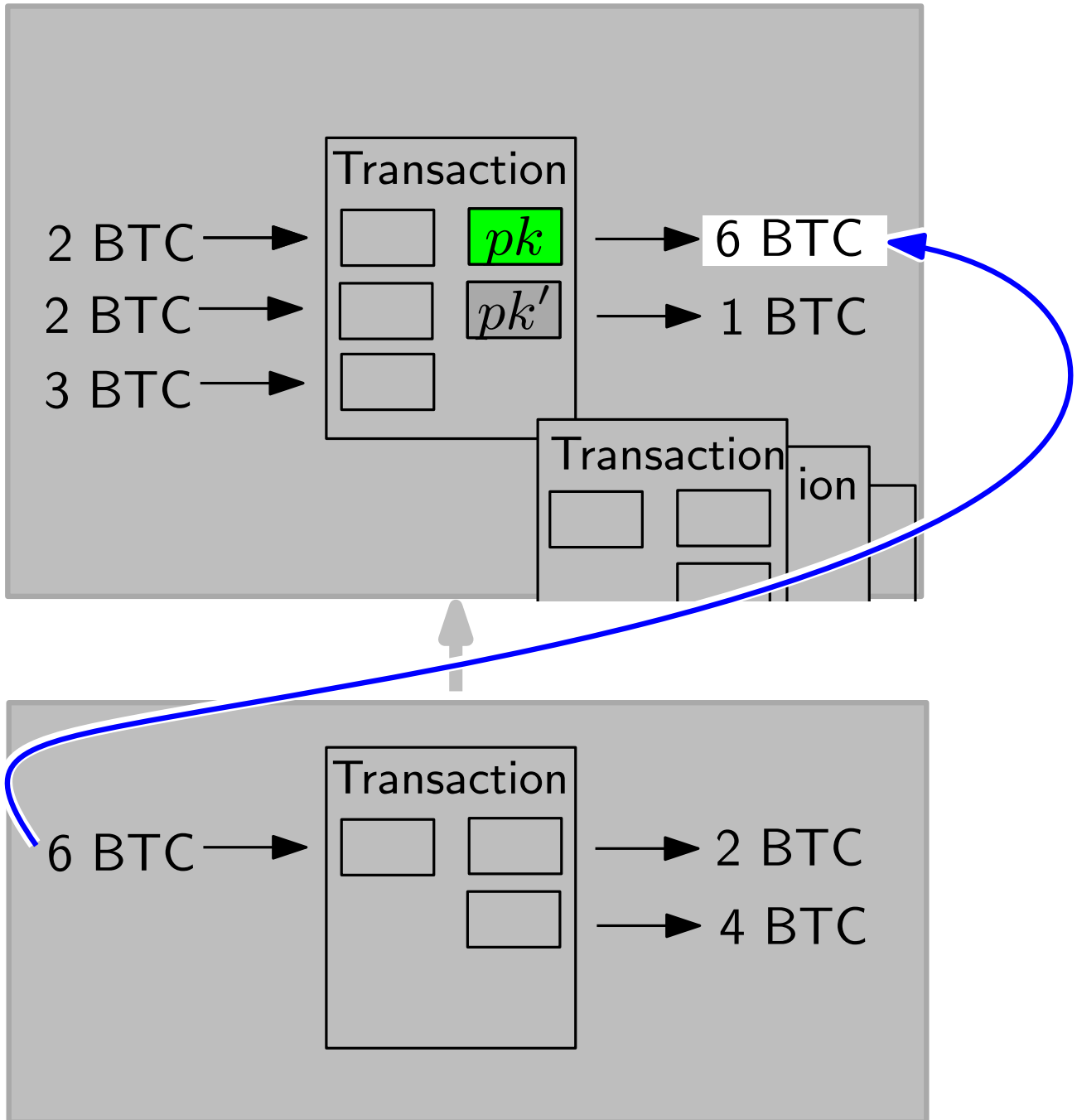
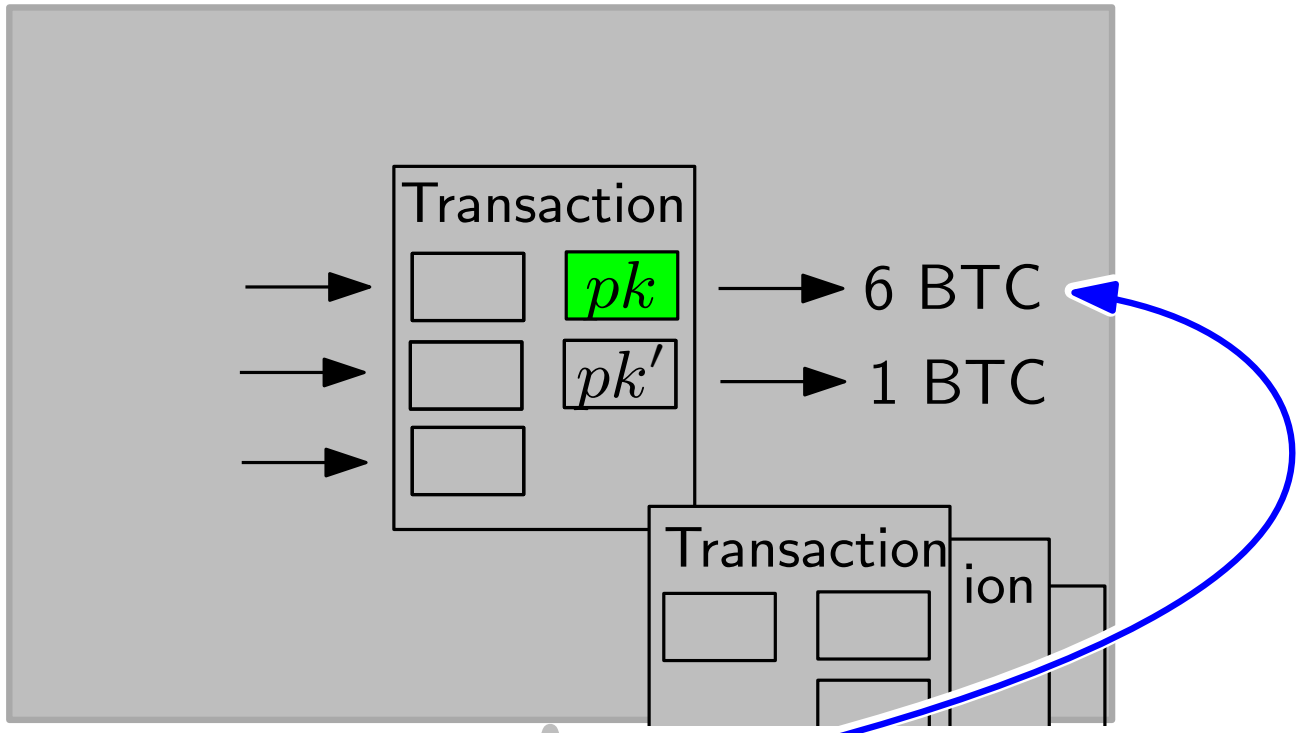
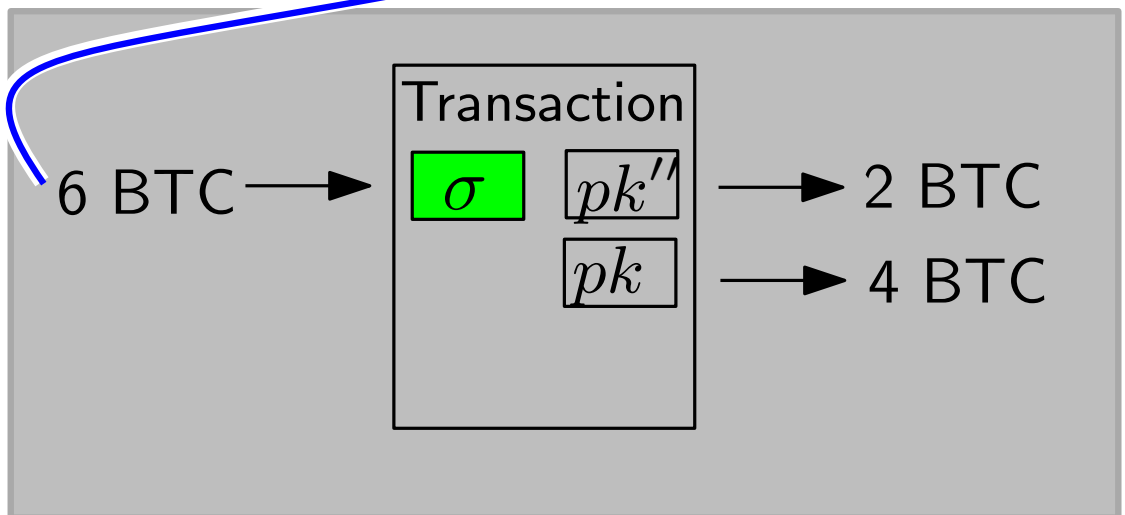


Bitcoin



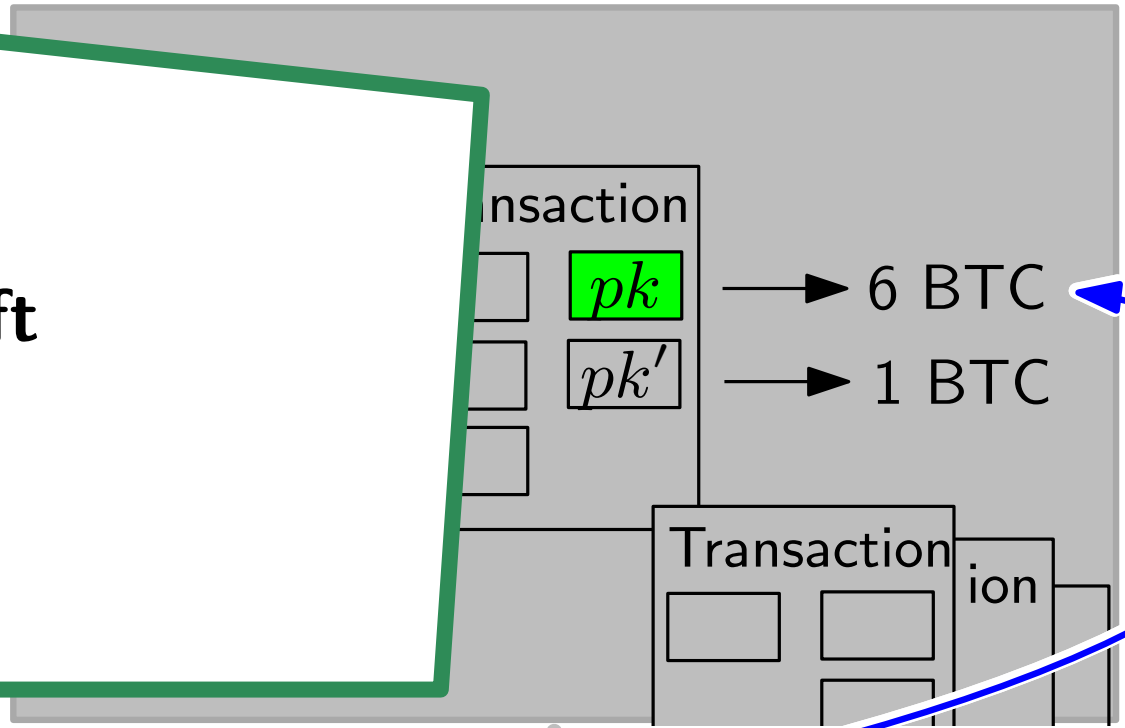
σ is **signature** under pk on tx



Bitcoin

Security

- signatures
  $\Rightarrow$ **no theft**



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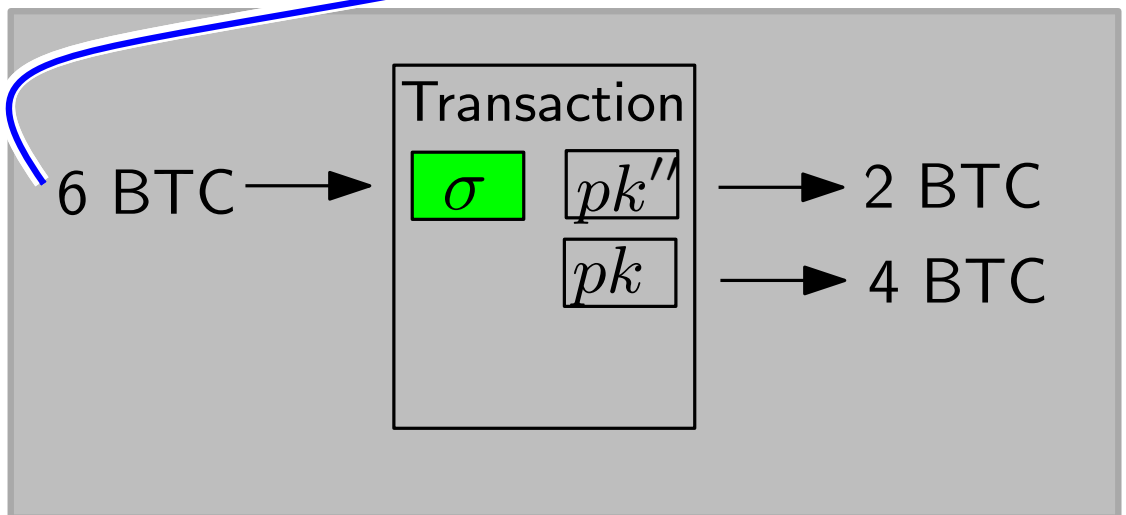
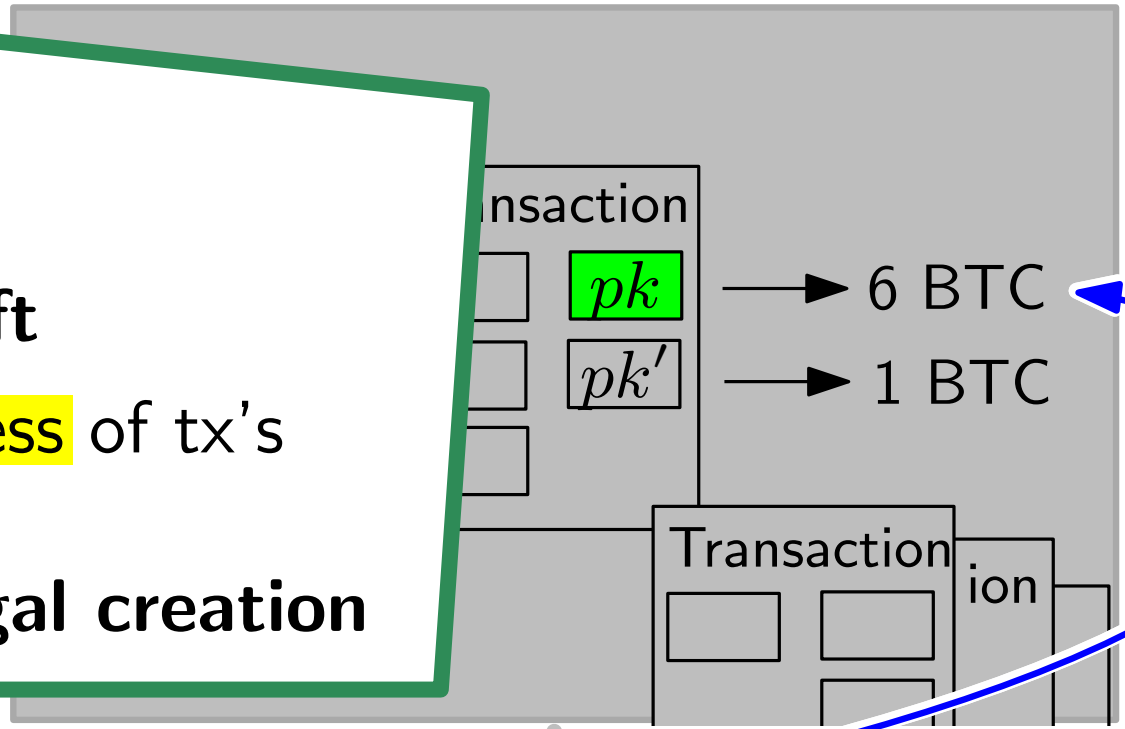


Bitcoin

Security

- signatures
  $\Rightarrow$ **no theft**
- balancedness of tx's checkable
  $\Rightarrow$ **no illegal creation**



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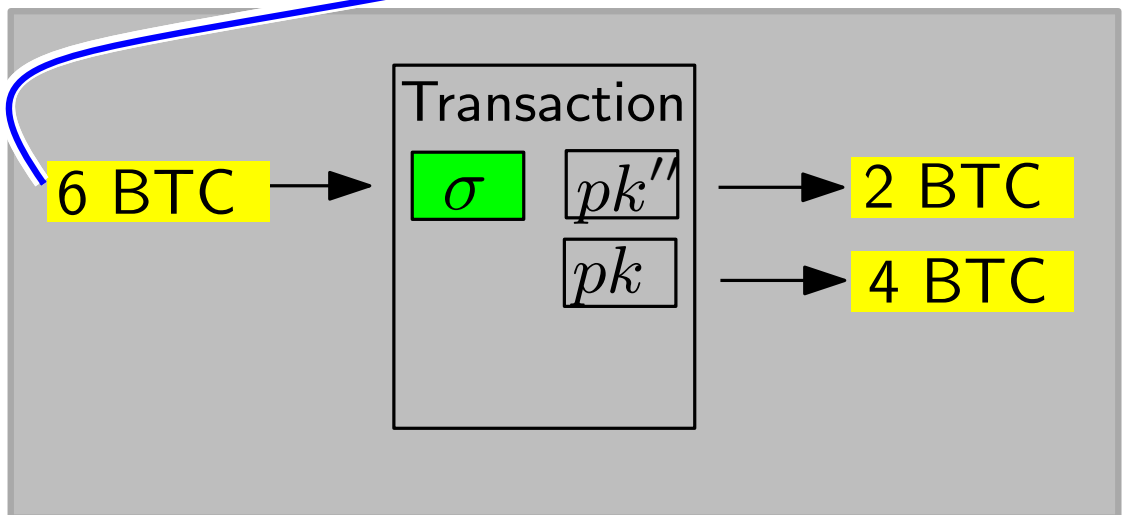

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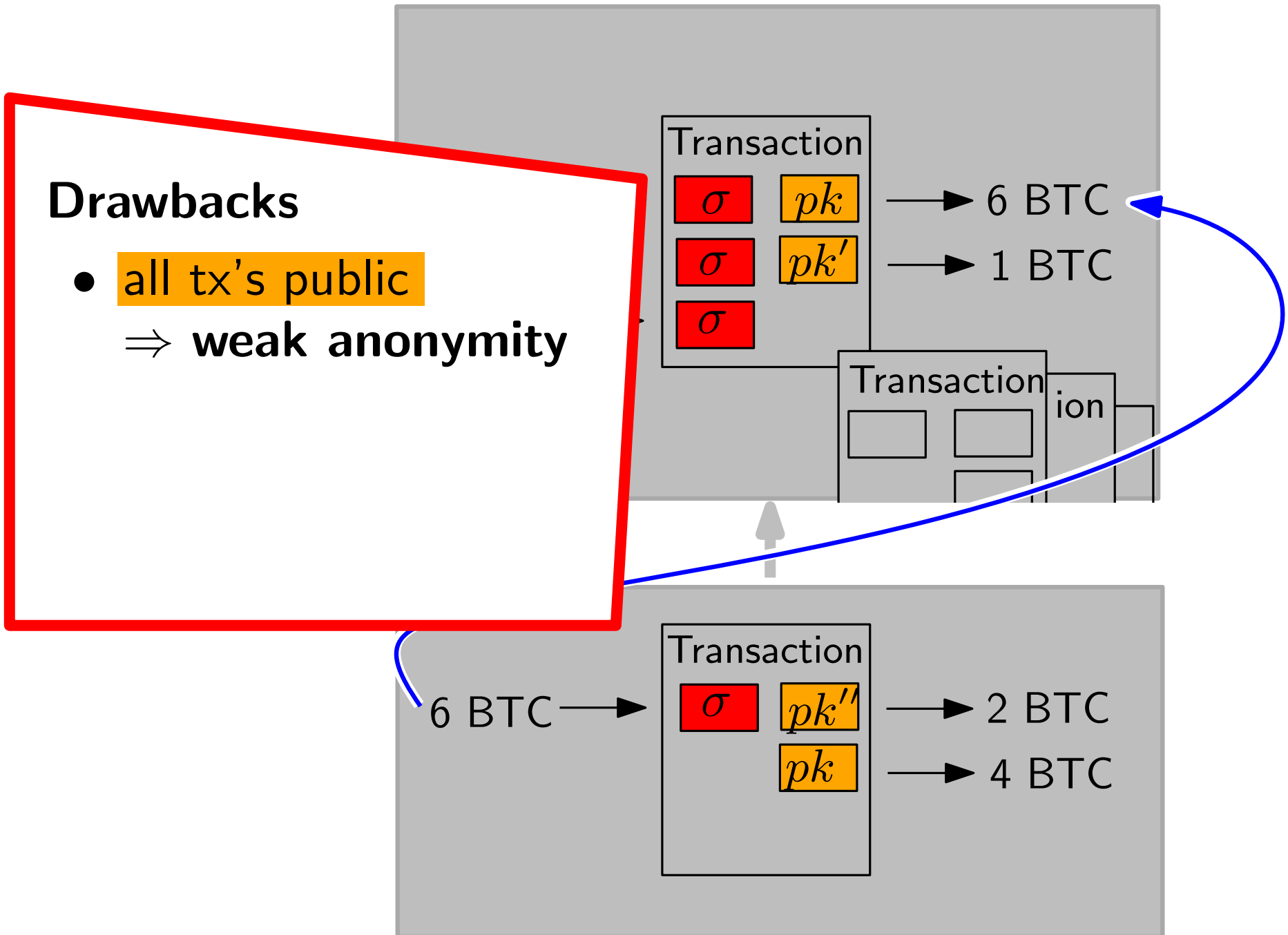
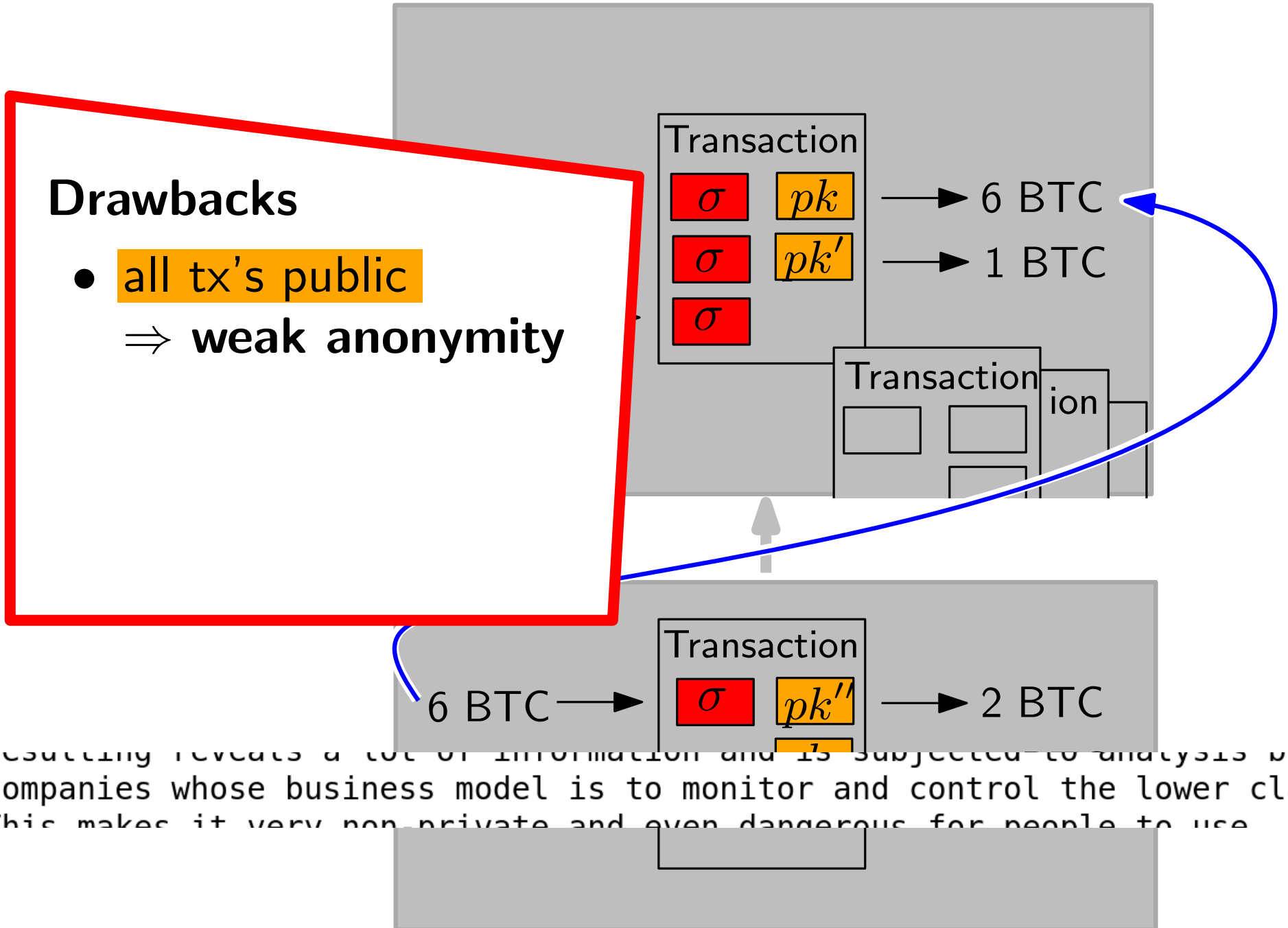

Drawbacks
• all tx's public
⇒ weak anonymity
Transaction
σ
σ
σ
pk
pk'
6 BTC
1 BTC
Transaction
ion
6 BTC
Transaction
σ
pk''
pk
2 BTC
4 BTC

Bitcoin

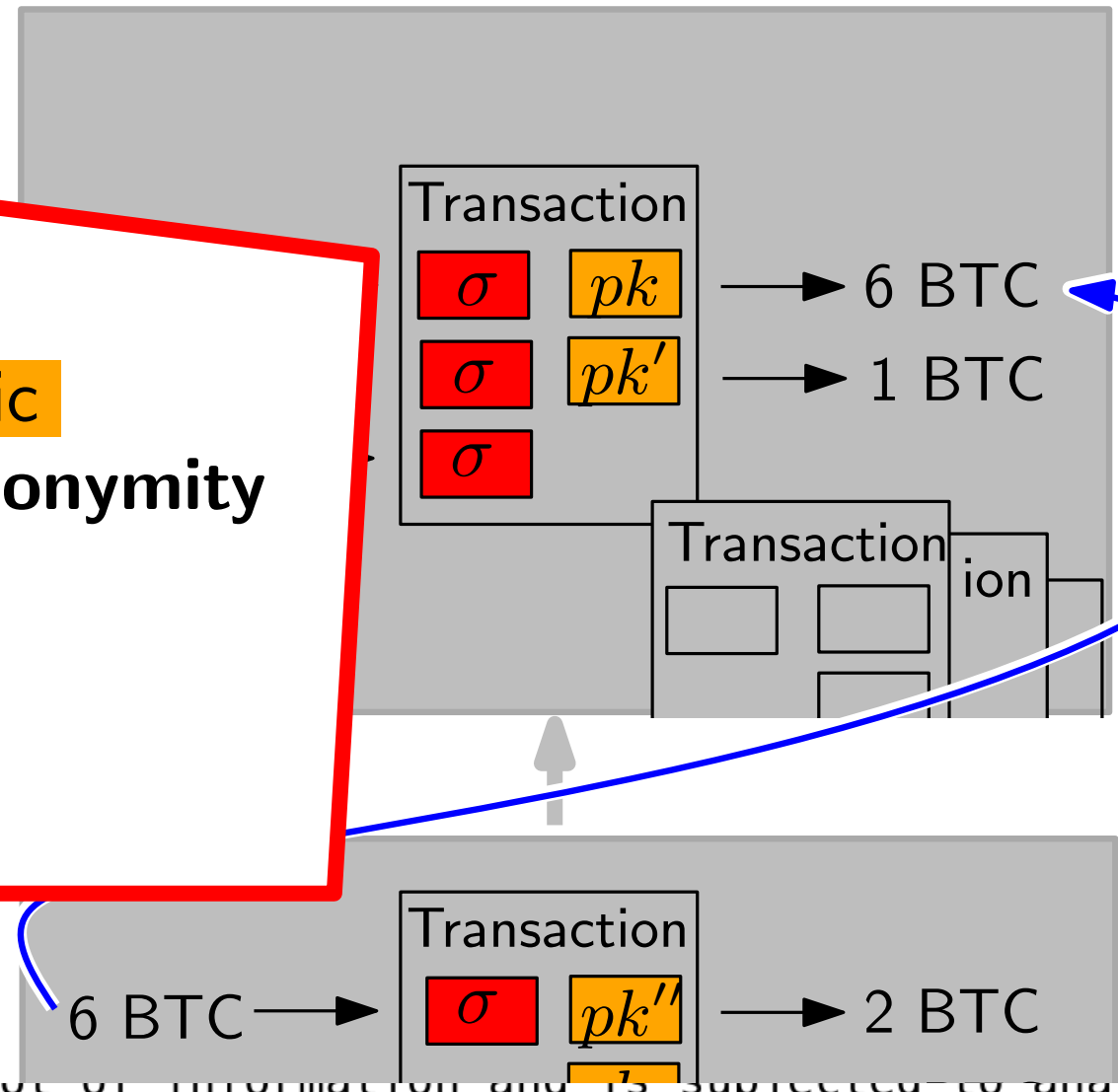


resulting reveals a lot of information and is subjected to analysis by many companies whose business model is to monitor and control the lower classes. This makes it very non-private and even dangerous for people to use

Bitcoin

Drawbacks

- all tx's public
  $\Rightarrow$ **weak anonymity**



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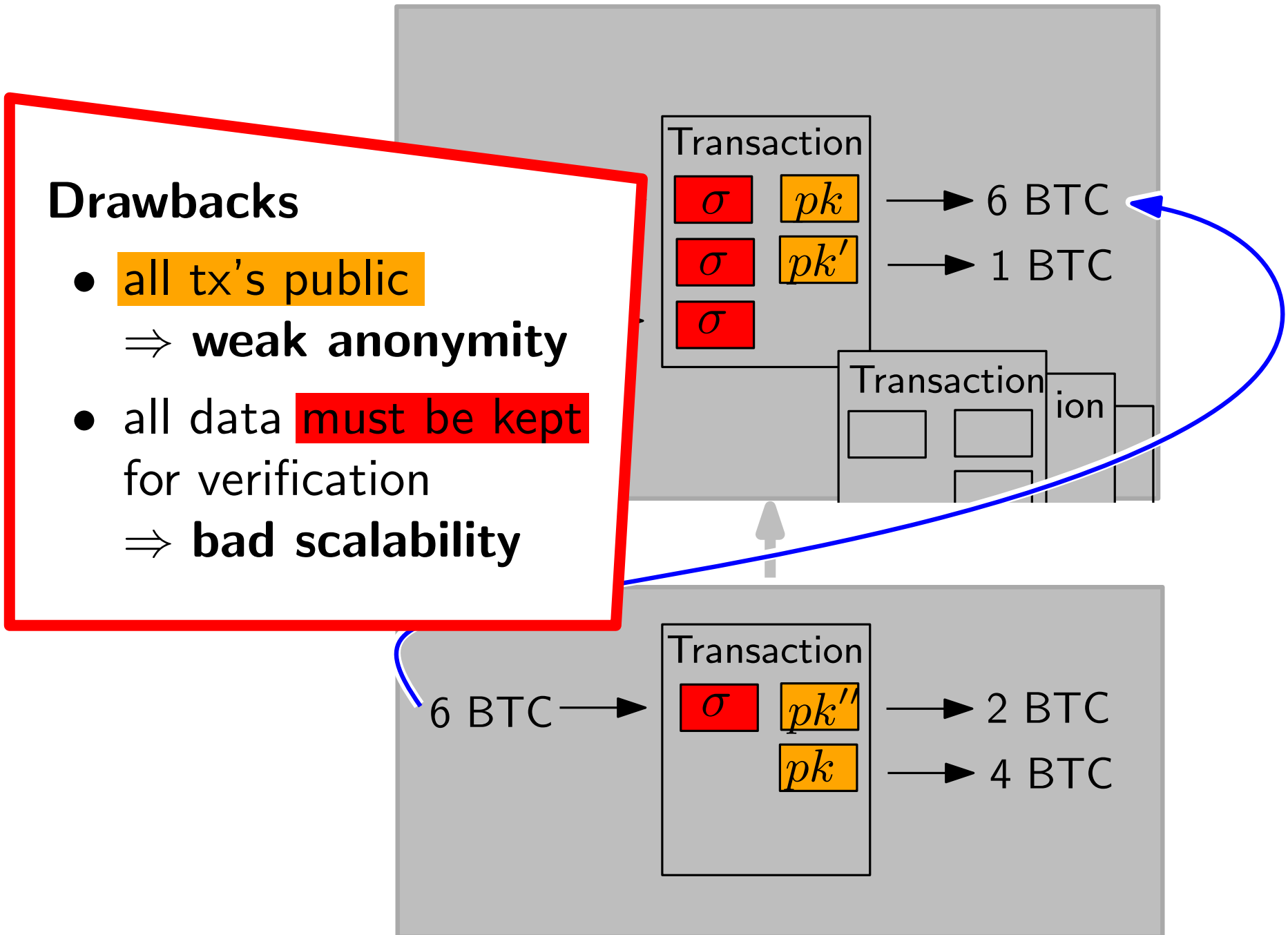
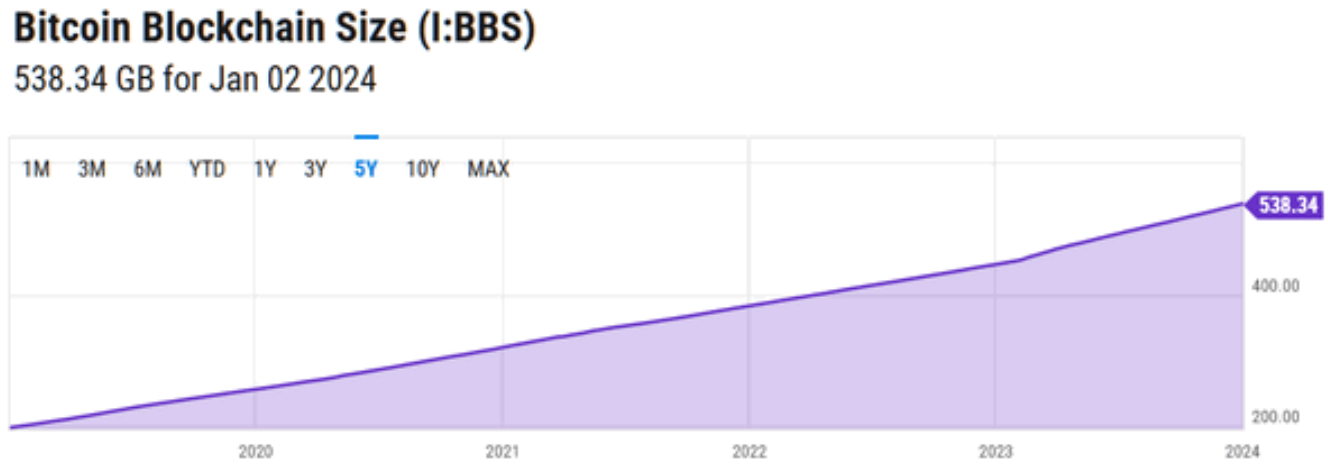

Drawbacks
• all tx's public
⇒ weak anonymity
• all data must be kept for verification
⇒ bad scalability
Transaction
σ
pk
σ
pk′
σ
6 BTC
1 BTC
Transaction
ion
6 BTC
Transaction
σ
pk″
pk
2 BTC
4 BTC

Scalability

Blockchain size:

$> 500\,\text{GB}$



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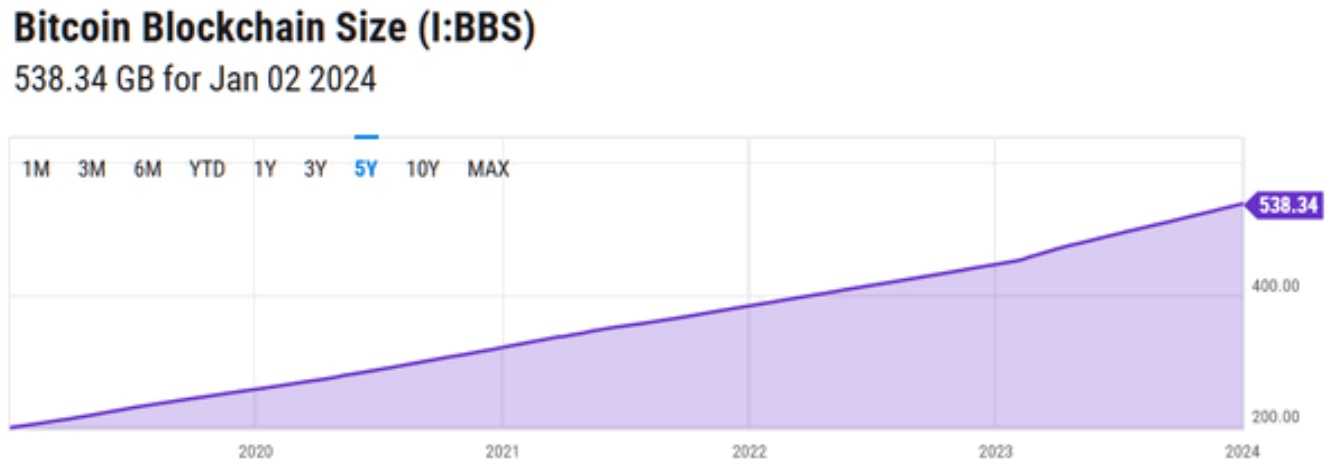
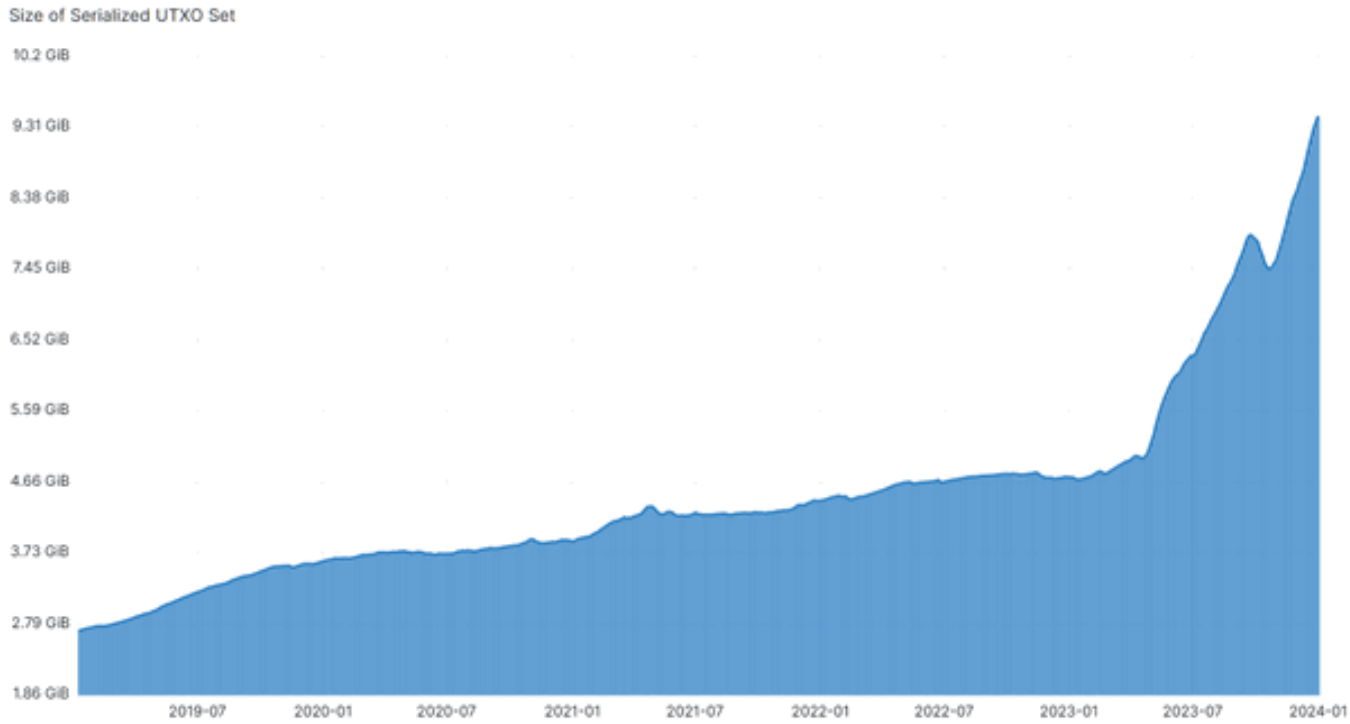
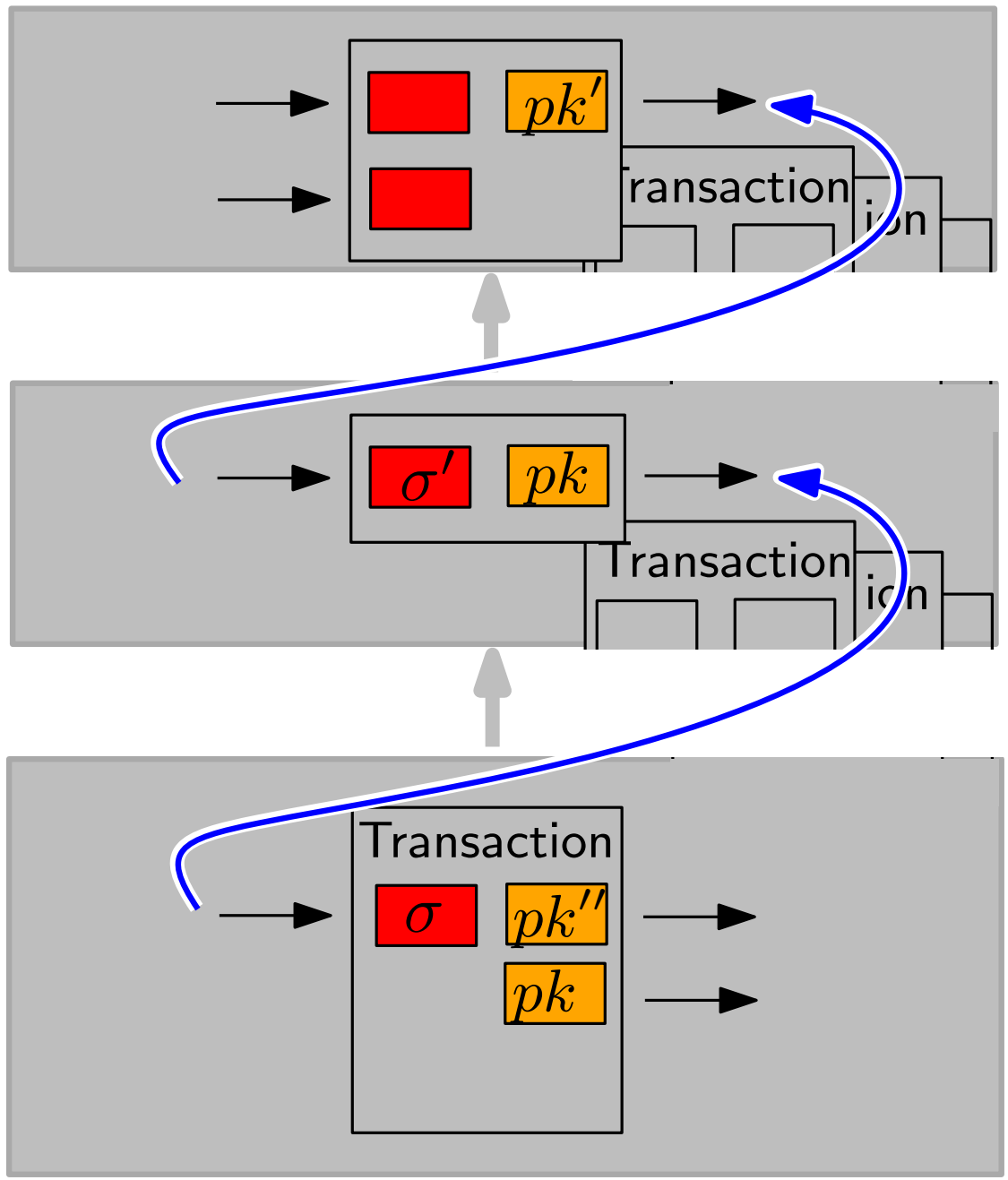


Size of UTXO set:
$< 10\,\text{GB}$

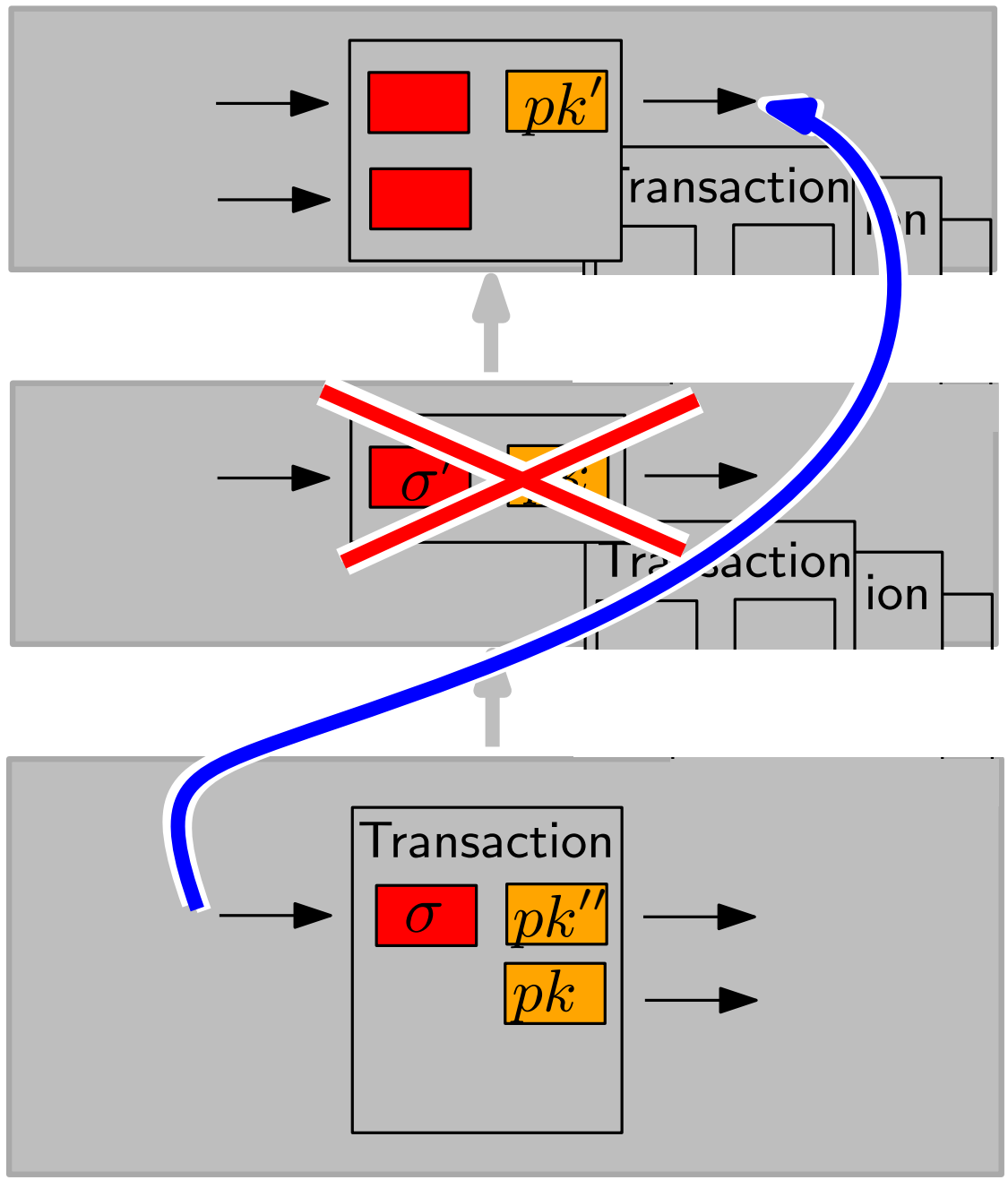


Scalability



Scalability

“cut-through”

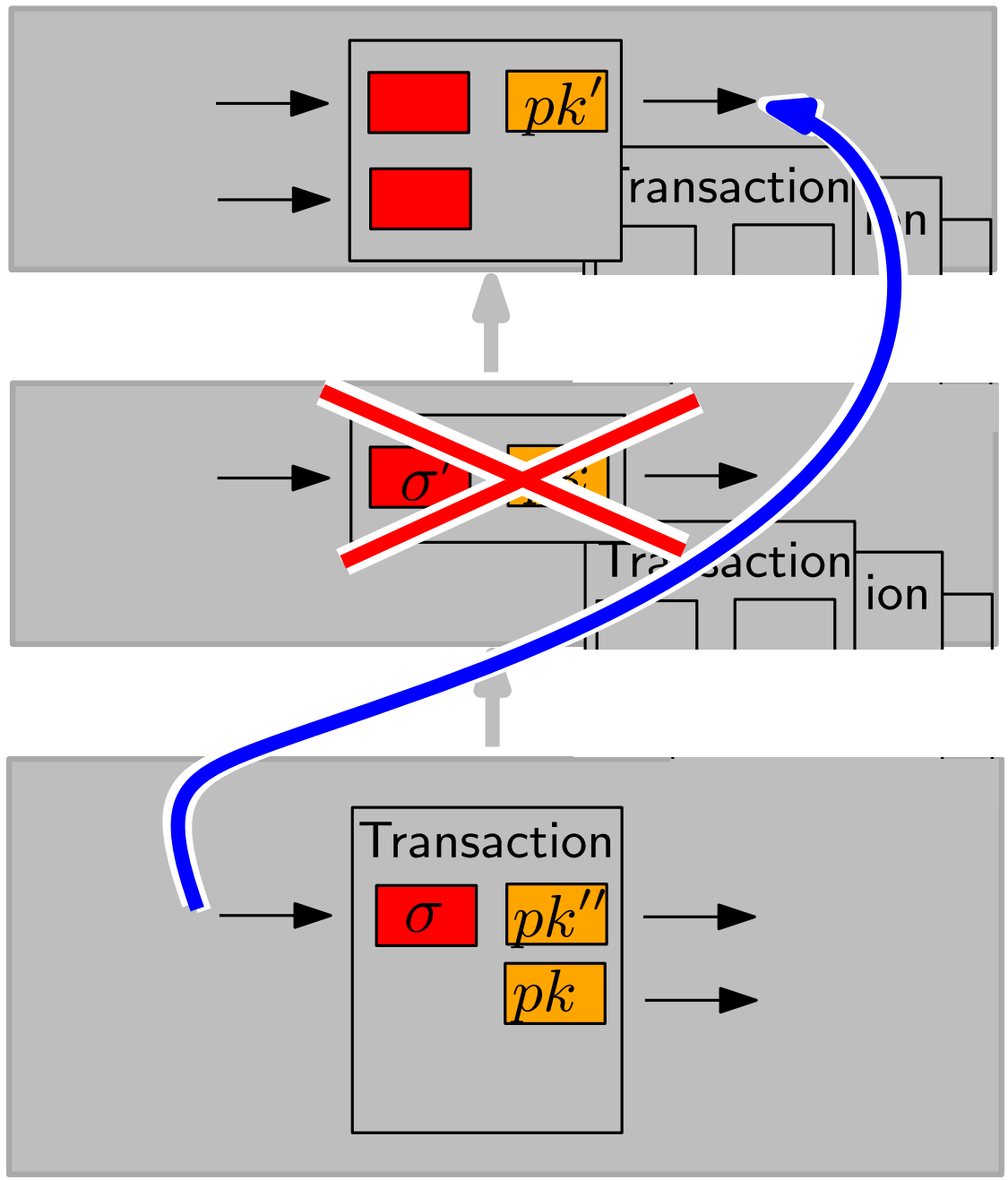


Scalability

“cut-through”

not possible
in Bitcoin:

σ' is needed
to verify validity



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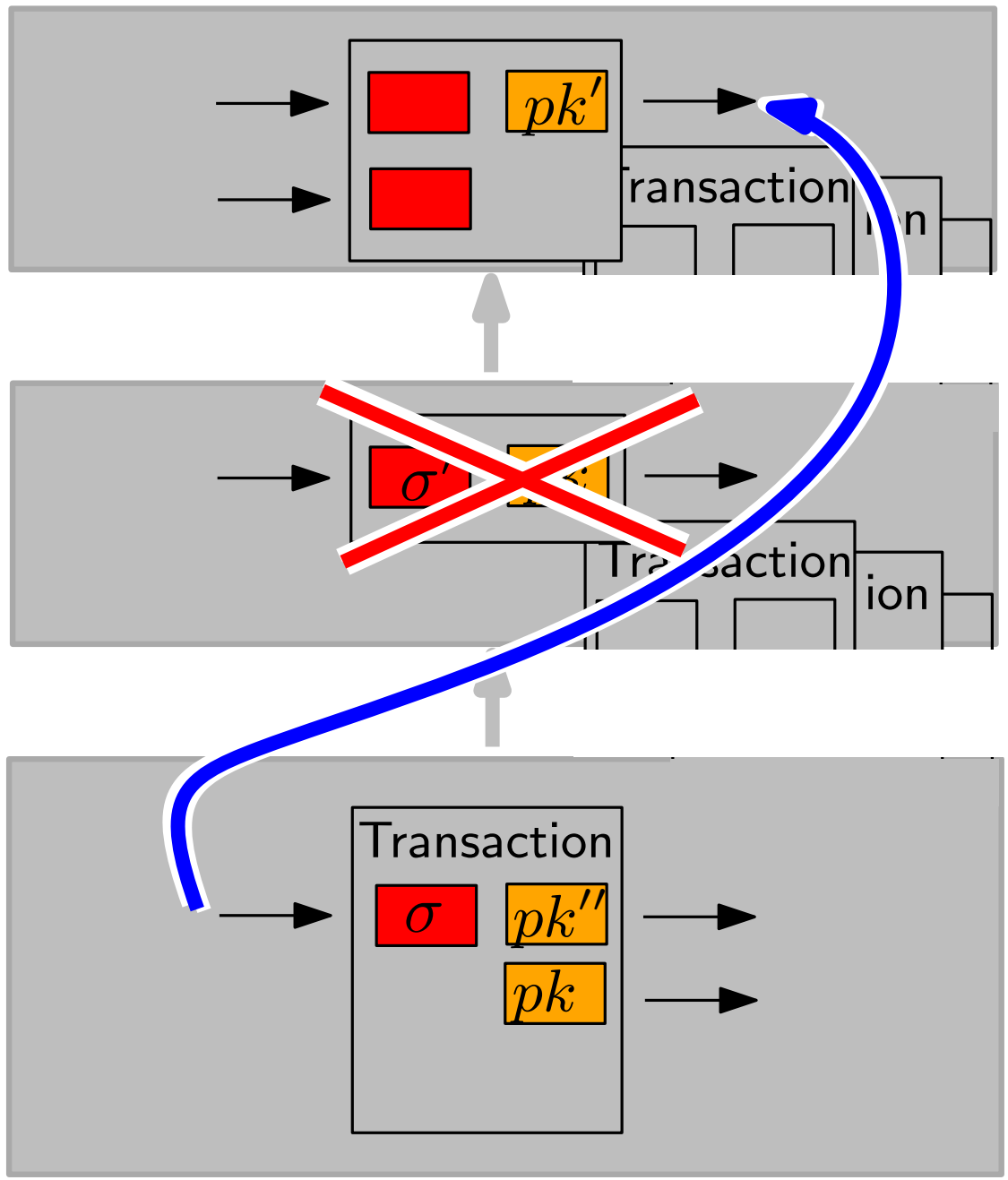
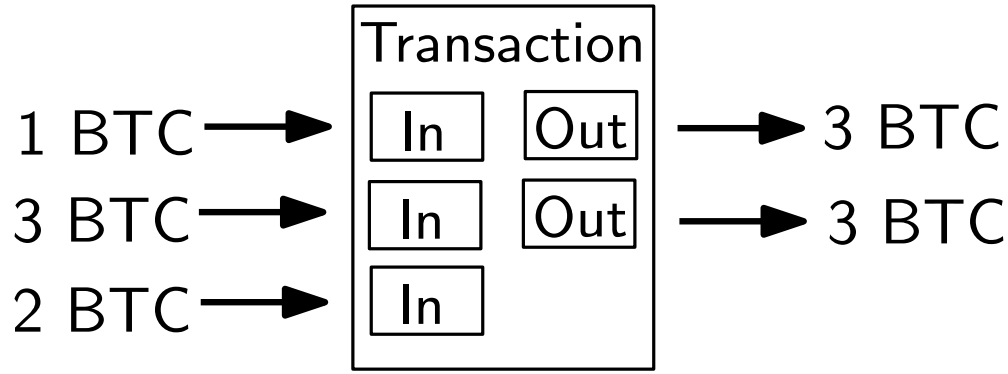
$\Rightarrow$ **Mimblewimble**



Anonymity



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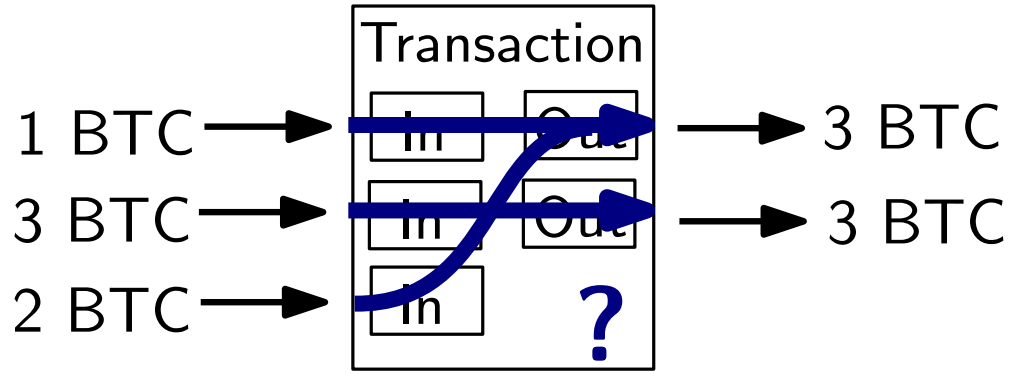
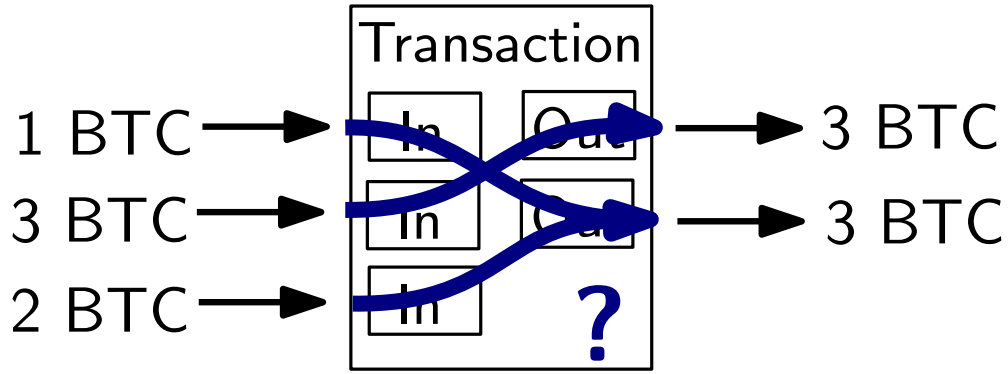


Anonymity



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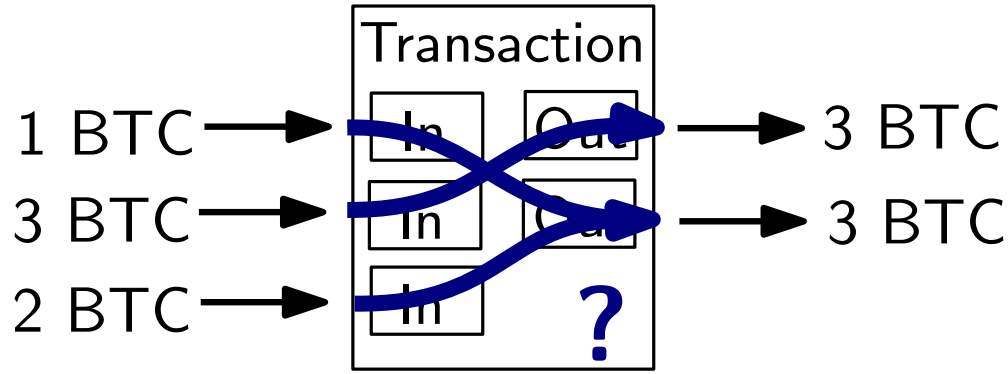
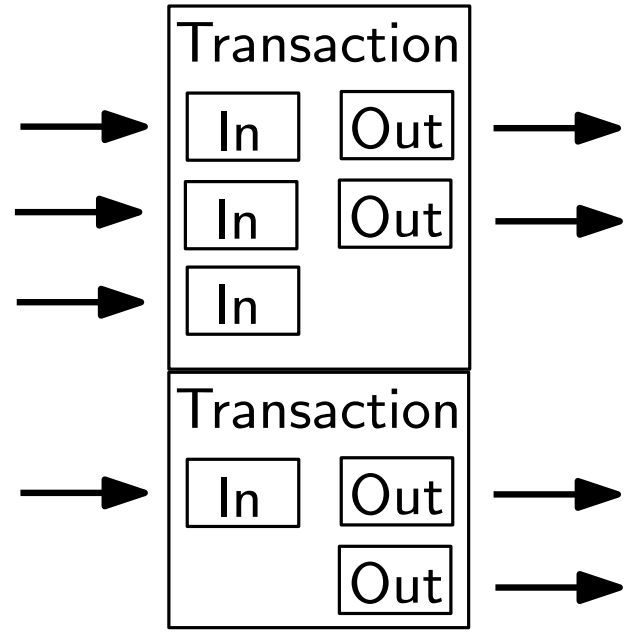


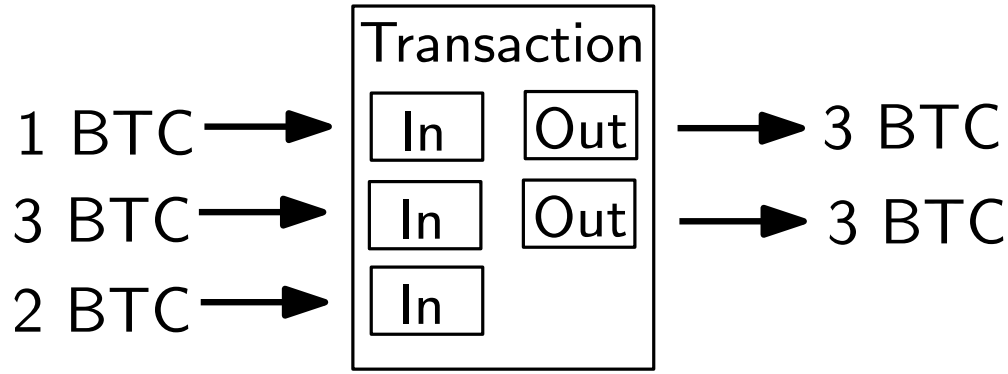
- **CoinJoin** [Maxwell'13]
  - no *link* between inputs and outputs

Anonymity



- **CoinJoin** [Maxwell'13]
  - no *link* between inputs and outputs
  - join many transactions?
  - in Bitcoin: only interactively, since all inputs must sign tx

Anonymity



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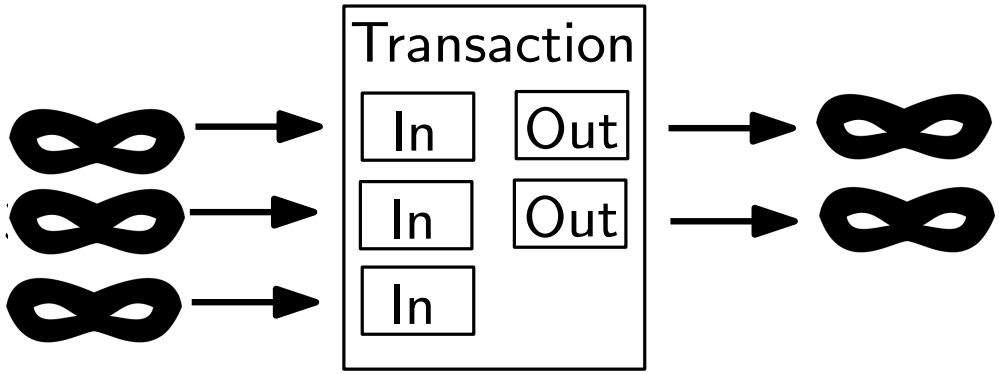

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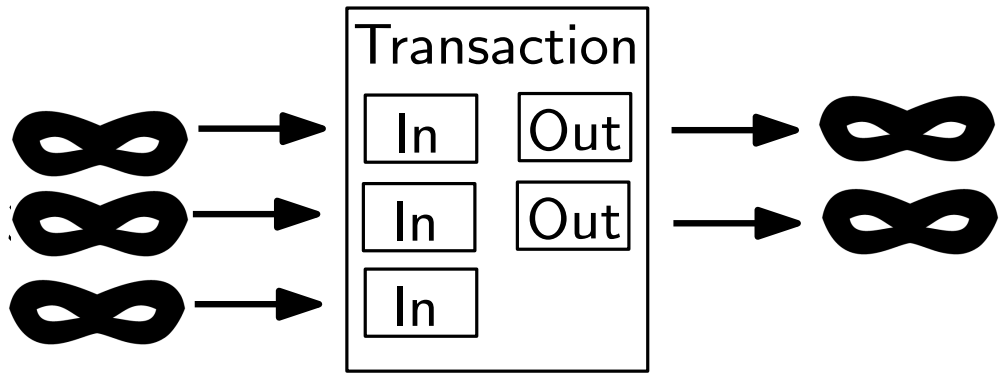
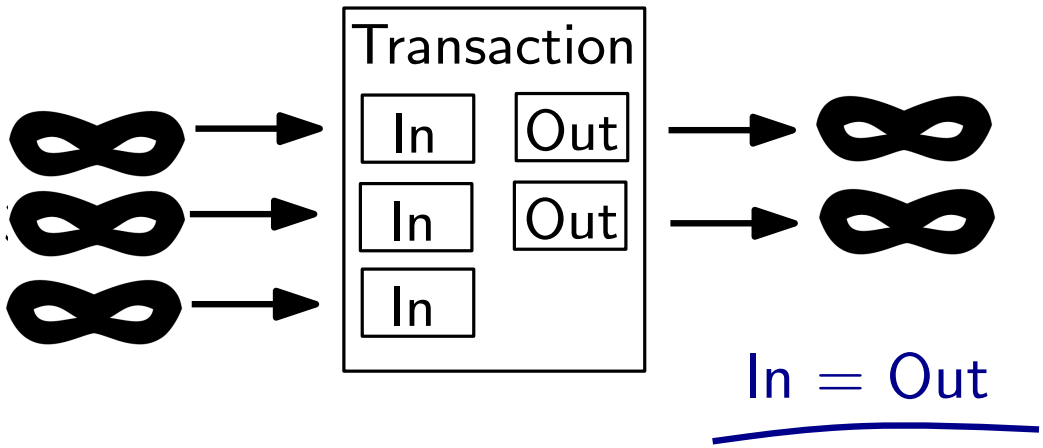


- **Confidential Transactions** [Maxwell]
  - hide the input and output *amounts*
  - not compatible with Bitcoin
  - balancedness verifiable?

Anonymity



- **Confidential Transactions** [Maxwell]
  - hide the input and output *amounts*
  - not compatible with Bitcoin
  - balancedness verifiable?

(by default in MONERO)

Anonymity

How can we get

- **Confidential transactions** (check balancedness)
- **Coin-join** (non-interactively)
- **Cut-through** (post-confirmation)

while **maintaining verifiability?**

- **Confider**
  - hide th
  - not co
  - balanc

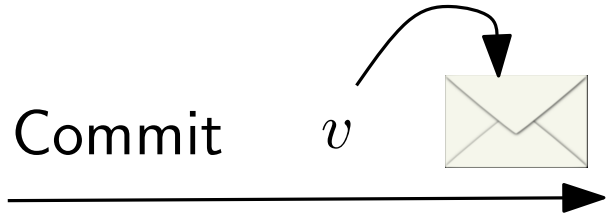
Anonymity

- **Confider**
  - hide th
  - not co
  - balanc

Pedersen commitment

Commitment

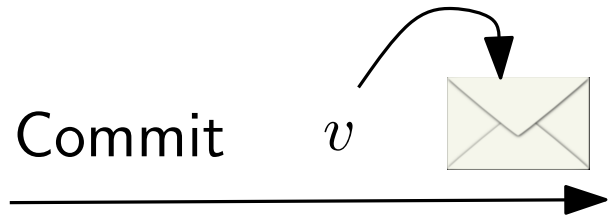
- "digital envelope"



Pedersen commitment

Commitment

- "digital envelope"

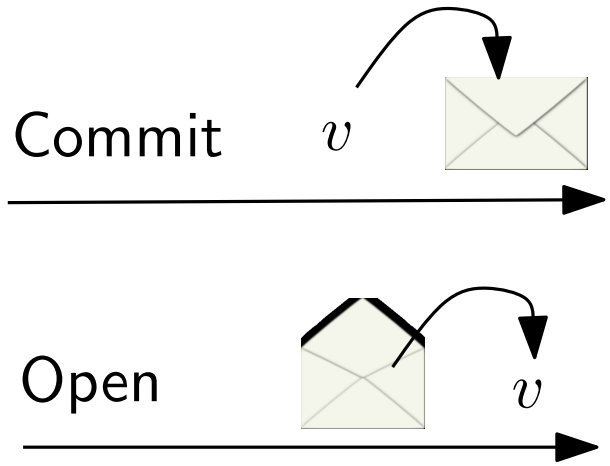


- **hiding:** commitment hides v

Pedersen commitment

Commitment

- "digital envelope"

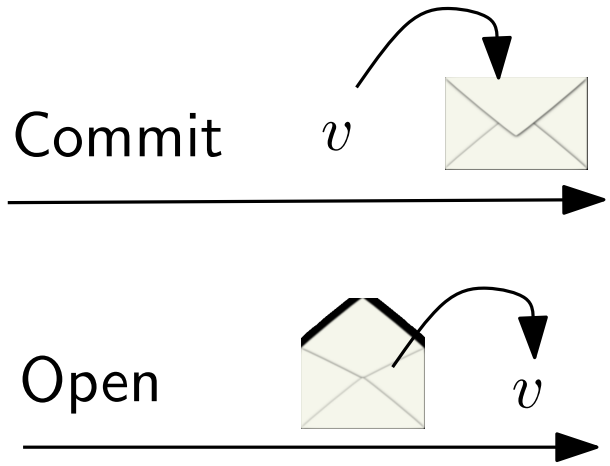


- **hiding:** commitment hides v

Pedersen commitment

Commitment

- "digital envelope"



- **hiding:** commitment hides v
- **binding:** Alice can open commitment only to one value

Pedersen commitment

Commitment

- "digital envelope"

Commit v

Open

Pedersen

$G, H \in \mathbb{G}$

pick random r

$C := vH + rG$

reveal v and r

Pedersen commitment

Commitment

- "digital envelope"

Commit v

Open

Pedersen

$G, H \in \mathbb{G}$

pick random r

$C := vH + rG$

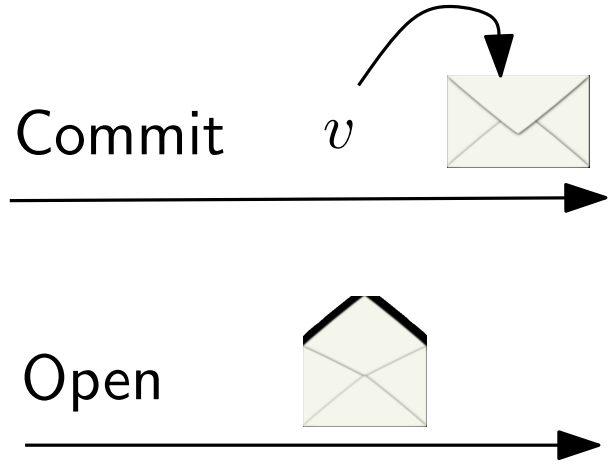
reveal v and r

- **hiding:** for any v exists r so that C commits v

Pedersen commitment

Commitment

- "digital envelope"



Pedersen

$G, H \in \mathbb{G}$

pick random r

$C := vH + rG$

reveal v and r

- **binding:** from $v \neq v', r, r'$ with

$$vH + rG = C = v'H + r'G$$

$$\Rightarrow \text{ compute } \log_G H$$

Pedersen commitment

Commitment

- "digital envelope"

Commit v

Open

Pedersen

$G, H \in \mathbb{G}$

pick random r

Com$(v; r) := vH + rG$

reveal v and r

- commitments are **homomorphic**:

$$\textbf{Com}(v_1; r_1) + \textbf{Com}(v_2; r_2) = (v_1 H + r_1 G) + (v_2 H + r_2 G)$$

Pedersen commitment

Commitment

- "digital envelope"

Commit v

Open

Pedersen

$G, H \in \mathbb{G}$

pick random r

Com$(v; r) := vH + rG$

reveal v and r

- commitments are **homomorphic**:

$$\begin{aligned}\textbf{Com}(v_1; r_1) + \textbf{Com}(v_2; r_2) &= (v_1 H + r_1 G) + (v_2 H + r_2 G) \\ &= (v_1 + v_2)H + (r_1 + r_2)G \\ &= \textbf{Com}(v_1 + v_2; r_1 + r_2)\end{aligned}$$

Pedersen commitment

Commitment

- "digital envelope"

Commit v

Open

Pedersen

$G, H \in \mathbb{G}$

pick random r

Com$(v; r) := vH + rG$

reveal v and r

- commitments are **homomorphic**:

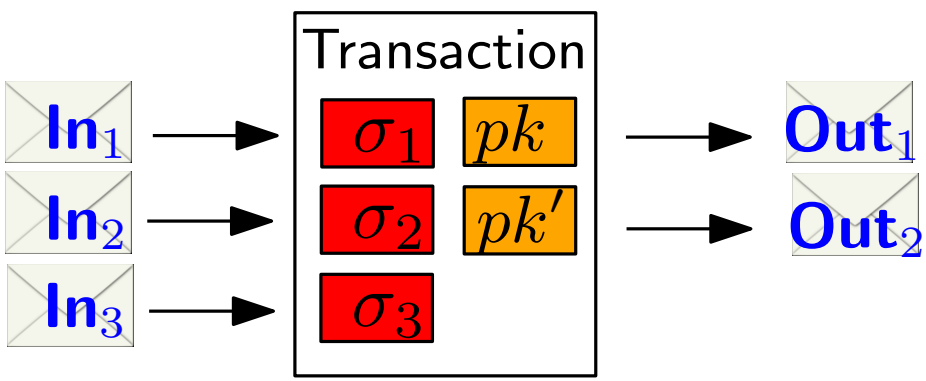
$$\begin{aligned}\textbf{Com}(v_1; r_1) + \textbf{Com}(v_2; r_2) &= (v_1 H + r_1 G) + (v_2 H + r_2 G) \\ &= (v_1 + v_2)H + (r_1 + r_2)G \\ &= \textbf{Com}(v_1 + v_2; r_1 + r_2)\end{aligned}$$

e.g.: $\textbf{Com}(1; 5) + \textbf{Com}(1; 10) - \textbf{Com}(2; 15) = \mathbf{0}$

Confidential Transactions

[Back, Maxwell '13 – '15]

- use *commitments* to amounts

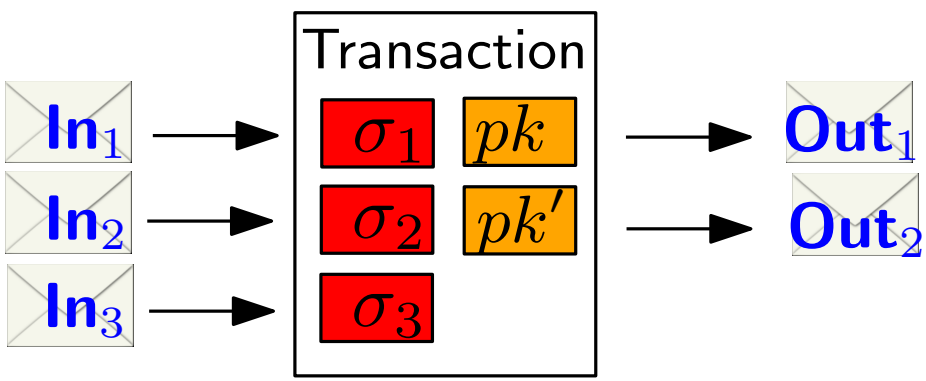


$$C = vH + rG$$

Confidential Transactions

[Back, Maxwell '13 – '15]

- use *commitments* to amounts
- ensure that transactions do not create money?



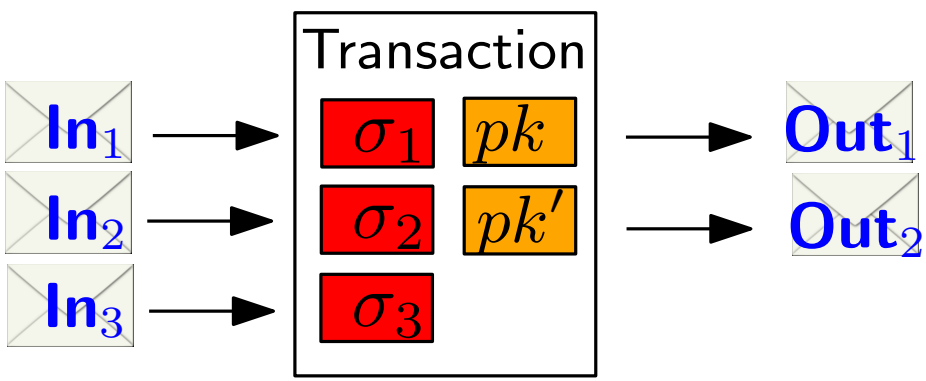
$$C = vH + rG$$

$$\mathbf{Out}_1 + \ldots + \mathbf{Out}_n - \mathbf{In}_1 - \ldots - \mathbf{In}_\ell = 0$$

Confidential Transactions

[Back, Maxwell '13 – '15]

- use *commitments* to amounts
- ensure that transactions do not create money?



$$C = vH + rG$$

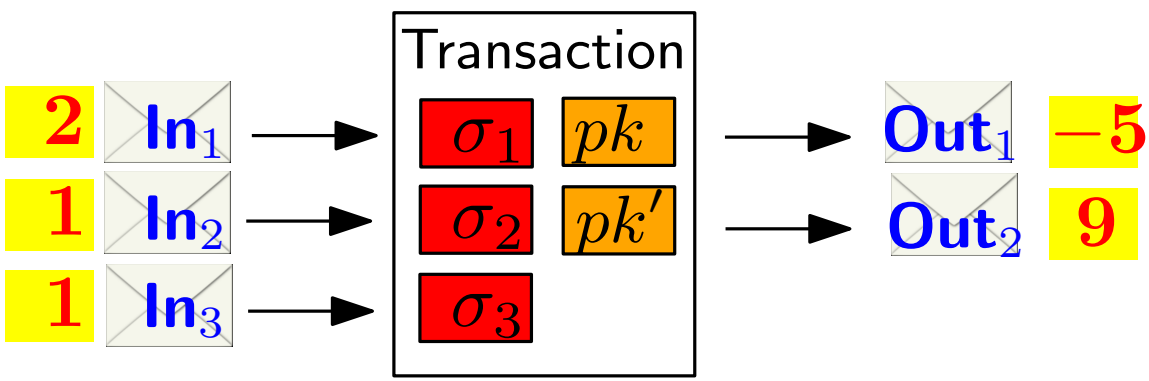
$$\sum \mathbf{Out} - \sum \mathbf{In} = 0$$

$$\begin{aligned}
&\sum C_i^{\text{out}} - \sum C_i^{\text{in}} \\
&= \sum (v_i^{\text{out}} H + r_i^{\text{out}} G) - \sum (v_i^{\text{in}} H + r_i^{\text{in}} G) \\
&= (\underbrace{\sum v_i^{\text{out}} - \sum v_i^{\text{in}}}_{\stackrel{!}{=}0}) H + (\underbrace{\sum r_i^{\text{out}} - \sum r_i^{\text{in}}}_{\stackrel{!}{=}0}) G
\end{aligned}$$

Confidential Transactions

[Back, Maxwell '13 – '15]

- use *commitments* to amounts
- ensure that transactions do not create money?



$$C = vH + rG$$

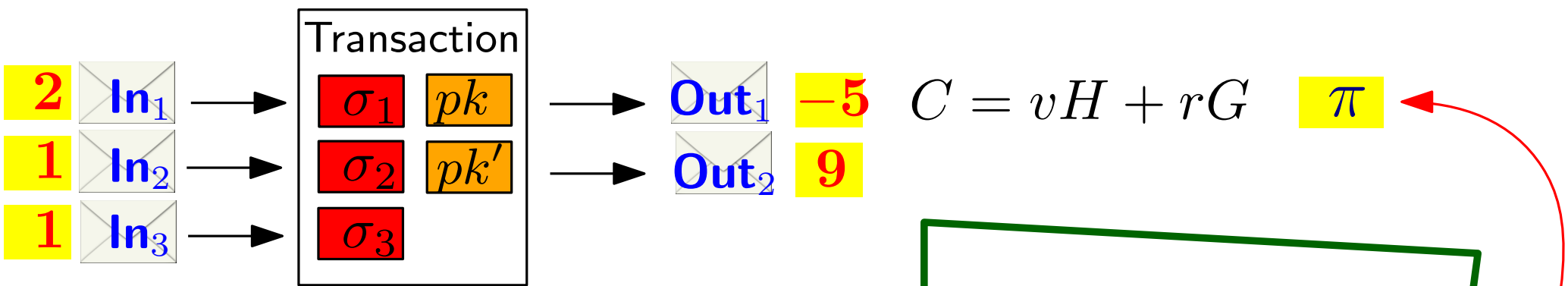
$$\sum \textbf{Out} - \sum \textbf{In} = 0$$

- negative amounts!

Confidential Transactions

[Back, Maxwell '13 – '15]

- use *commitments* to amounts
- ensure that transactions do not create money?



- negative amounts!

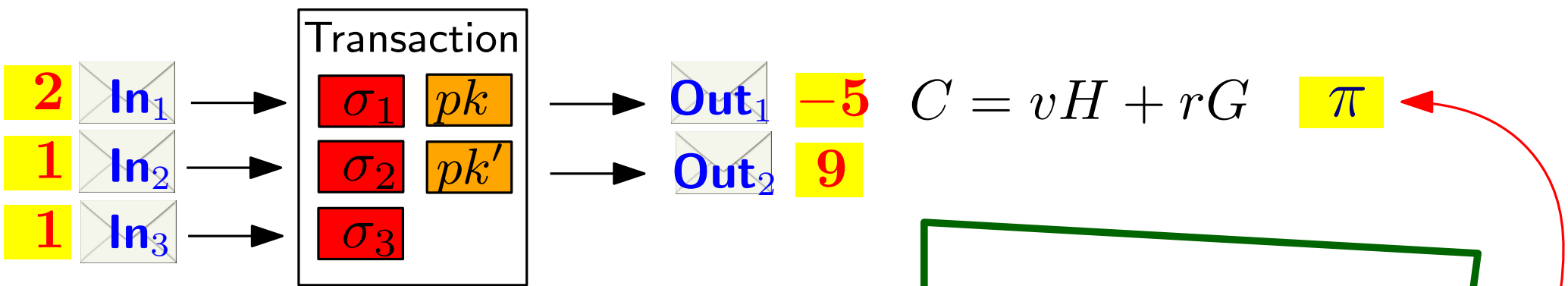
Range proofs

– add proofs that committed values are in $\in [0, 2^{64}]$

Confidential Transactions

[Back, Maxwell '13 – '15]

- use *commitments* to amounts
- ensure that transactions do not create money?



$$\sum \mathbf{Out} - \sum \mathbf{In} = 0$$

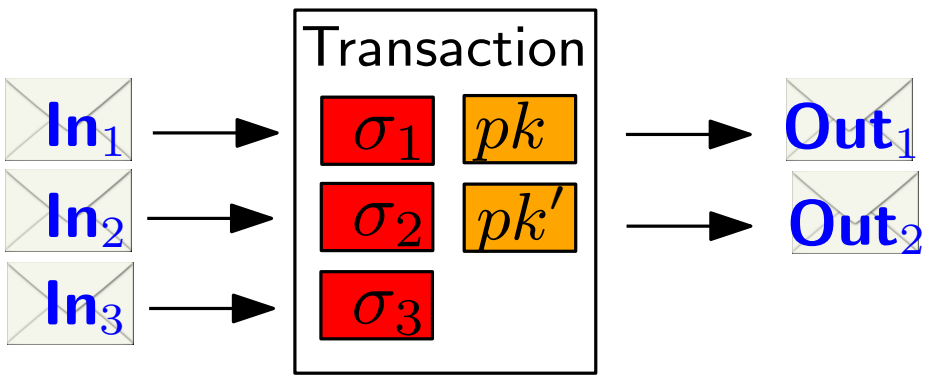
- negative amounts!

Range proofs

– add proofs that committed values are in $\in [0, 2^{64}]$

Confidential Transactions

Confidential transaction

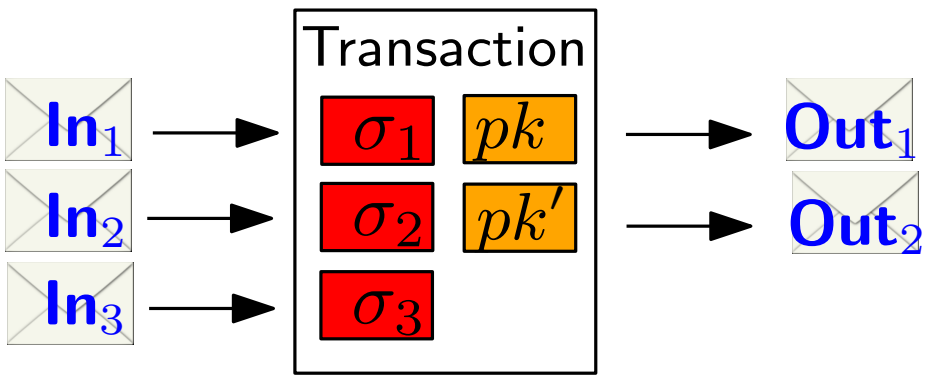


$$C = vH + rG, \quad \pi$$

$$\sum \mathbf{Out} - \sum \mathbf{In} = 0$$

Confidential Transactions

Confidential transaction



$$C = vH + rG, \quad \pi$$

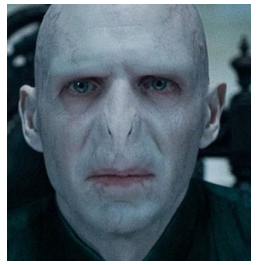
$$\sum \mathbf{Out} - \sum \mathbf{In} = 0$$

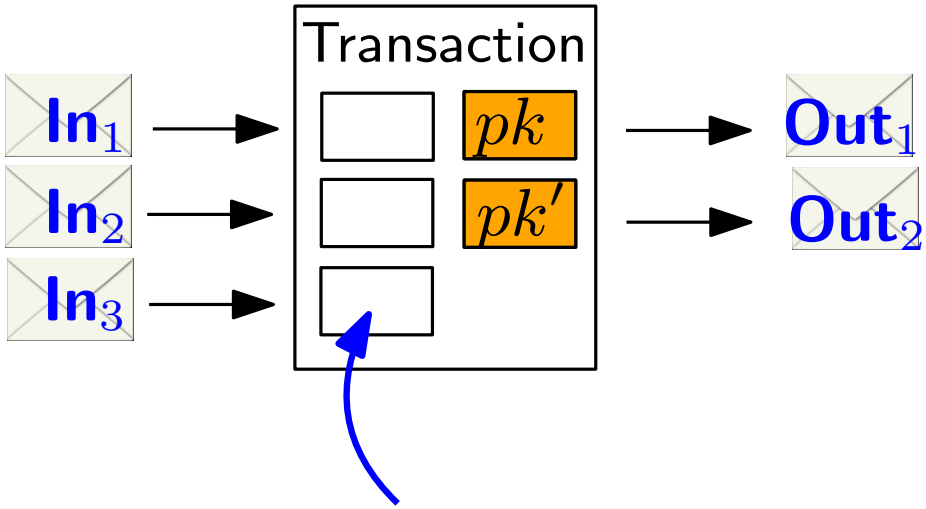
Signatures $\Rightarrow$

- no non-interactive CoinJoin
- no Cut-Through

Mimblewimble

[Jedusor '16]





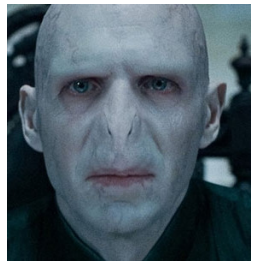
$$C = vH + rG, \quad \pi$$

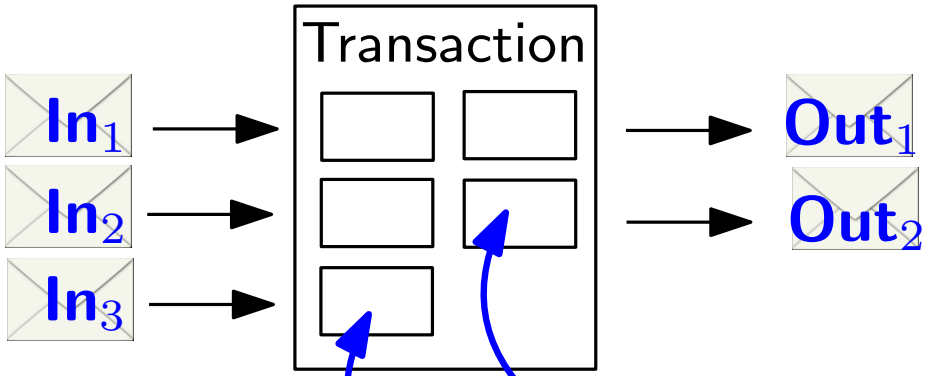
$$\sum \mathbf{Out} - \sum \mathbf{In} = 0$$

no more signatures!

Mimblewimble

[Jedusor '16]





$$C = vH + rG, \quad \pi$$

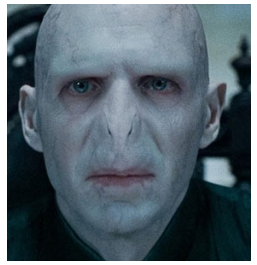
$$\sum \textbf{Out} - \sum \textbf{In} = 0$$

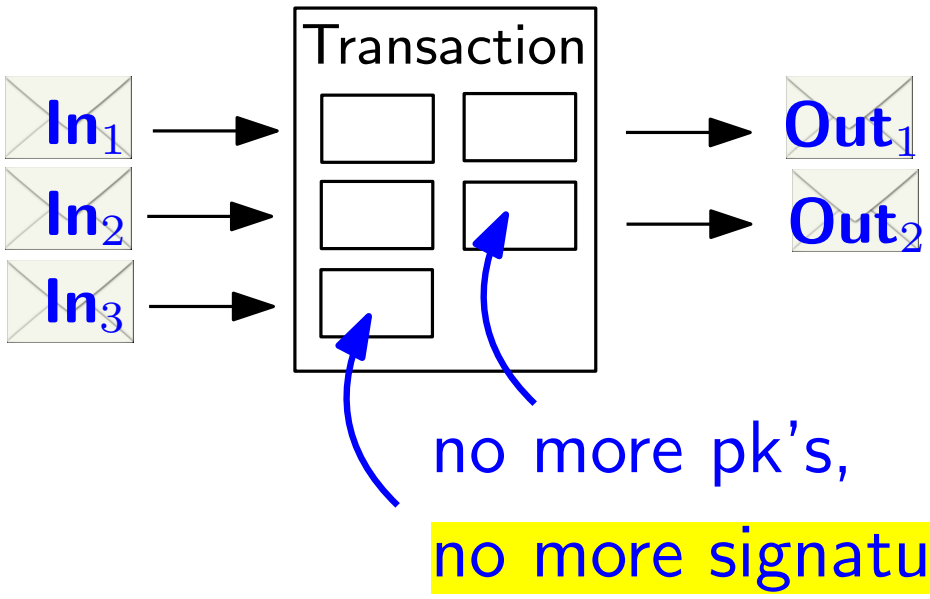
no more pk's,

no more signatures!

Mimblewimble

[Jedusor '16]





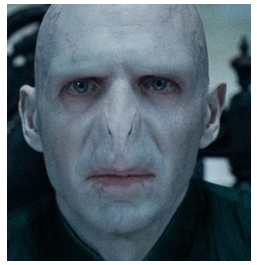
secret key!

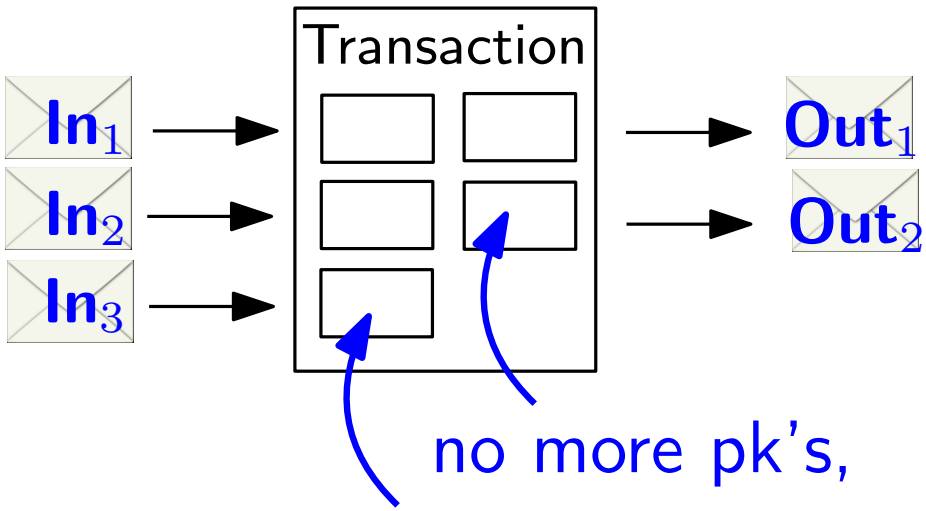
$$C = vH + rG, \quad \pi$$

$$\sum \mathbf{Out} - \sum \mathbf{In} = 0$$

Mimblewimble

[Jedusor '16]





secret key!

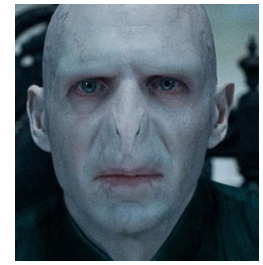
$$C = vH + rG, \quad \pi$$

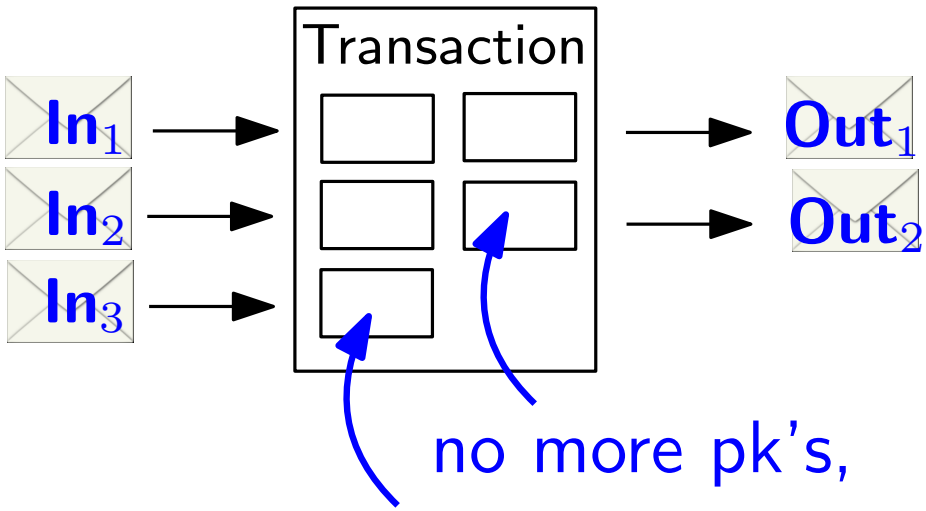
$$\sum \mathbf{Out} - \sum \mathbf{In} = \mathbf{0}$$

But: sender knows sum of output r's

Mimblewimble

[Jedusor '16]





secret key!

$$C = vH + rG, \quad \pi$$

$$\sum \mathbf{Out} - \sum \mathbf{In} = 0$$

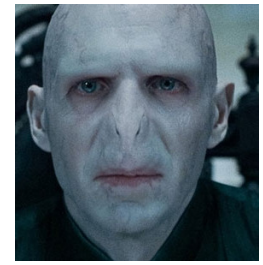
no more pk's,

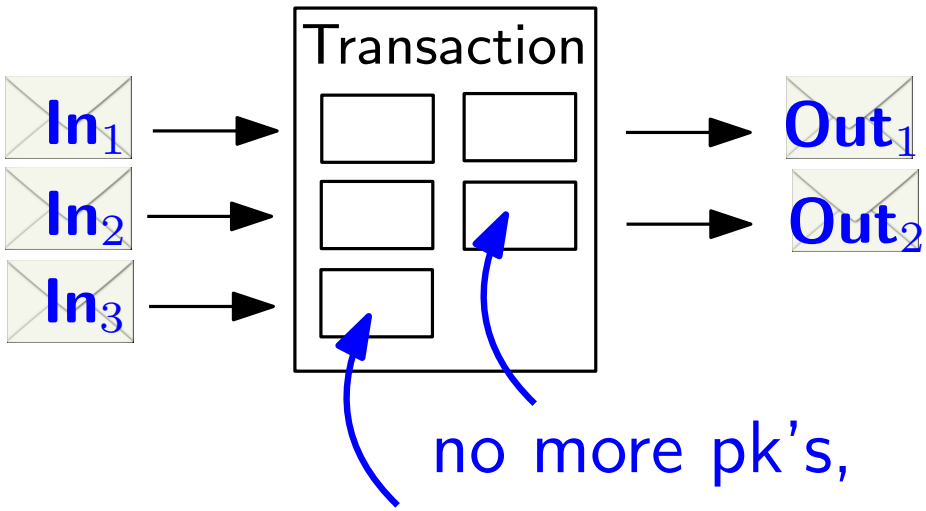
no more signatures!

$$\begin{aligned}
&\sum C_i^{\text{out}} - \sum C_i^{\text{in}} \\
&= \sum (v_i^{\text{out}} H + r_i^{\text{out}} G) - \sum (v_i^{\text{in}} H + r_i^{\text{in}} G) \\
&= (\underbrace{\sum v_i^{\text{out}} - \sum v_i^{\text{in}}}_{\stackrel{!}{=}0}) H + (\underbrace{\sum r_i^{\text{out}} - \sum r_i^{\text{in}}}_{=:x}) G
\end{aligned}$$

Mimblewimble

[Jedusor '16]





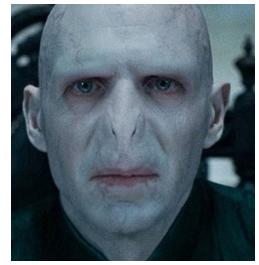
$$C = vH + rG, \quad \pi$$

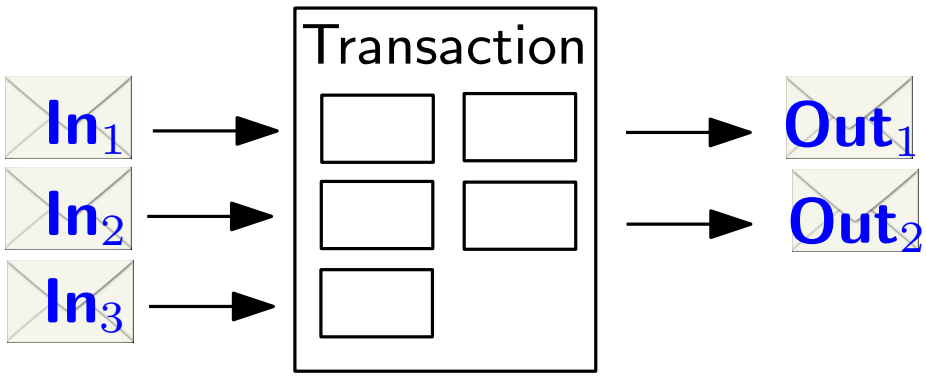
$$\sum \textbf{Out} - \sum \textbf{In} = 0H + xG$$

$$\begin{aligned}
&\sum C_i^{\text{out}} - \sum C_i^{\text{in}} \\
&= \sum (v_i^{\text{out}} H + r_i^{\text{out}} G) - \sum (v_i^{\text{in}} H + r_i^{\text{in}} G) \\
&= (\underbrace{\sum v_i^{\text{out}} - \sum v_i^{\text{in}}}_{\stackrel{!}{=}0}) H + (\underbrace{\sum r_i^{\text{out}} - \sum r_i^{\text{in}}}_{=:x}) G
\end{aligned}$$

Mimblewimble

[Jedusor '16]





secret key!

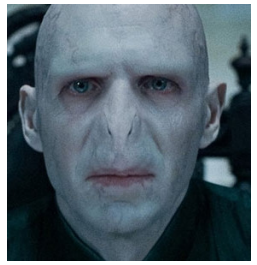
$$C = vH + rG, \quad \pi$$

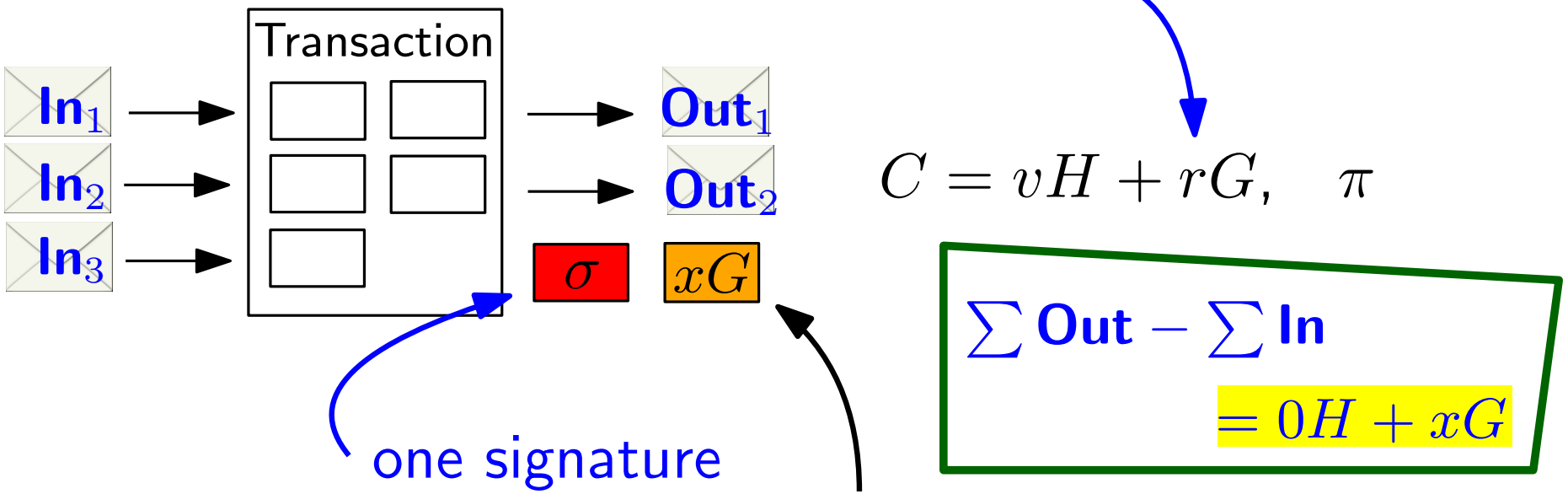
$$\sum \textbf{Out} - \sum \textbf{In} = 0H + xG$$

$\Rightarrow$ prove that $\sum \text{Out} - \sum \text{In}$ is commitment to 0

Mimblewimble

[Jedusor '16]



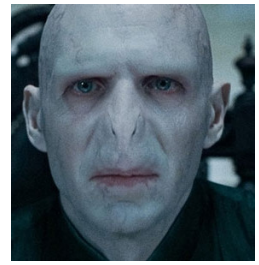


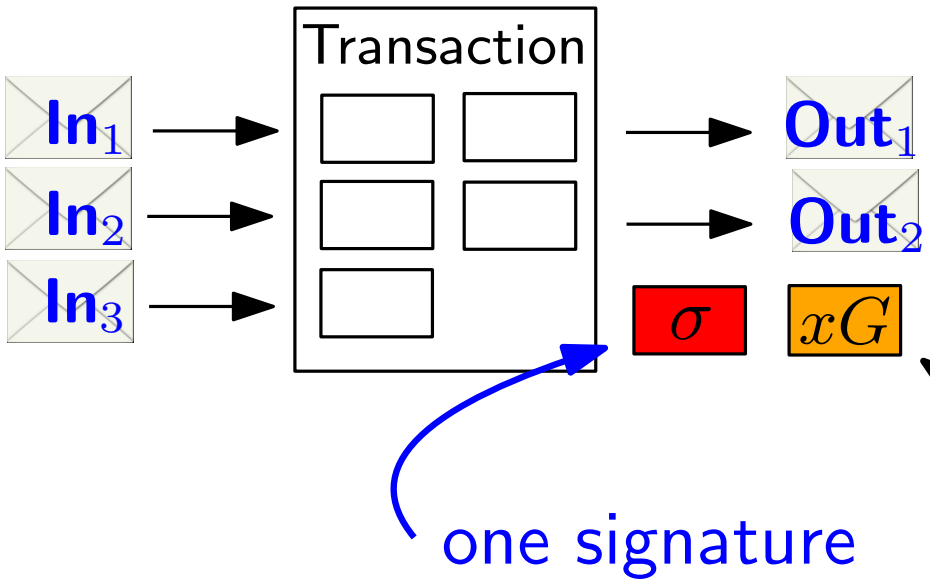
"proves" that $\overbrace{\sum \text{Out} - \sum \text{In}}$

is commitment to 0

Mimblewimble

[Jedusor '16]





secret key!

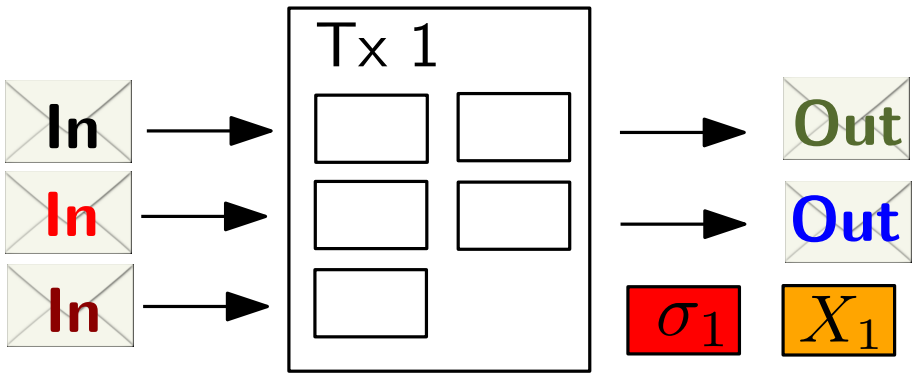
$$C = vH + rG, \quad \pi$$

$$\sum \textbf{Out} - \sum \textbf{In} = 0H + xG$$

one signature

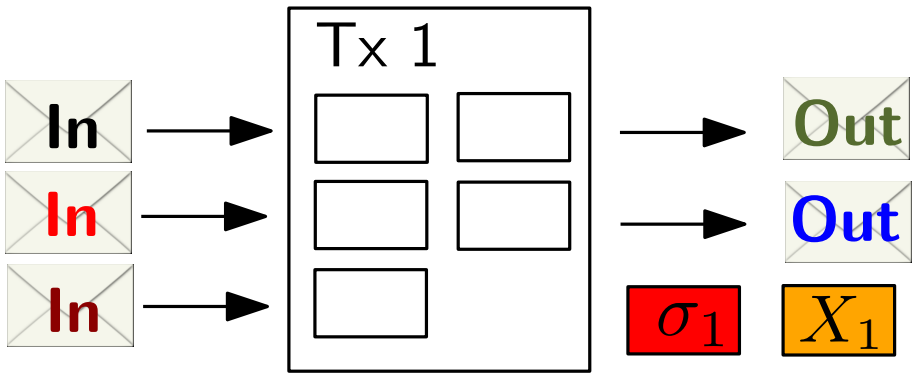
"proves" that $\overbrace{\sum \text{Out} - \sum \text{In}}$ is commitment to 0

Mimblewimble

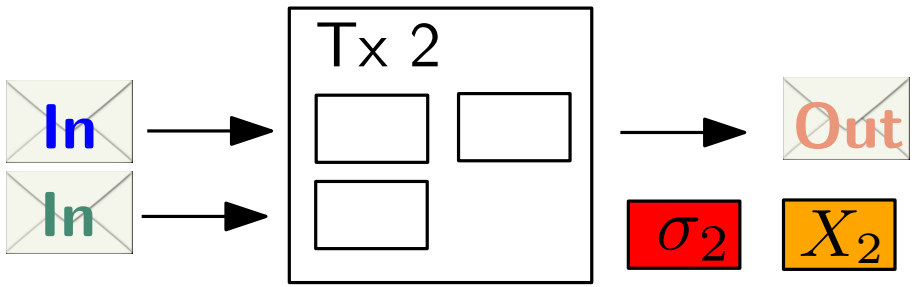


- $\sum \mathbf{Out}_1 - \sum \mathbf{In}_1 = X_1$
- σ_1 valid for X_1

Mimblewimble



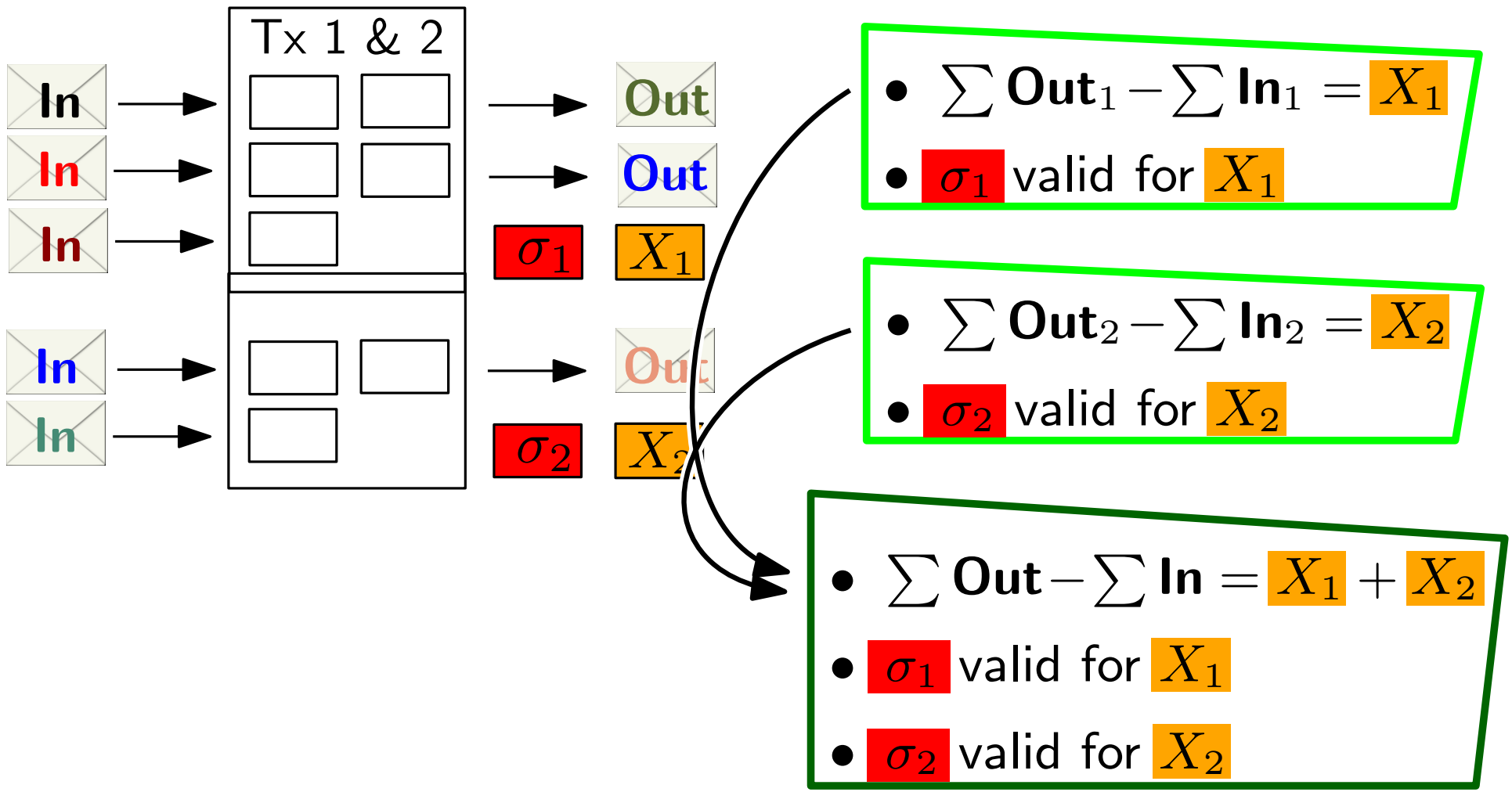
- $\sum \mathbf{Out}_1 - \sum \mathbf{In}_1 = X_1$
- σ_1 valid for X_1



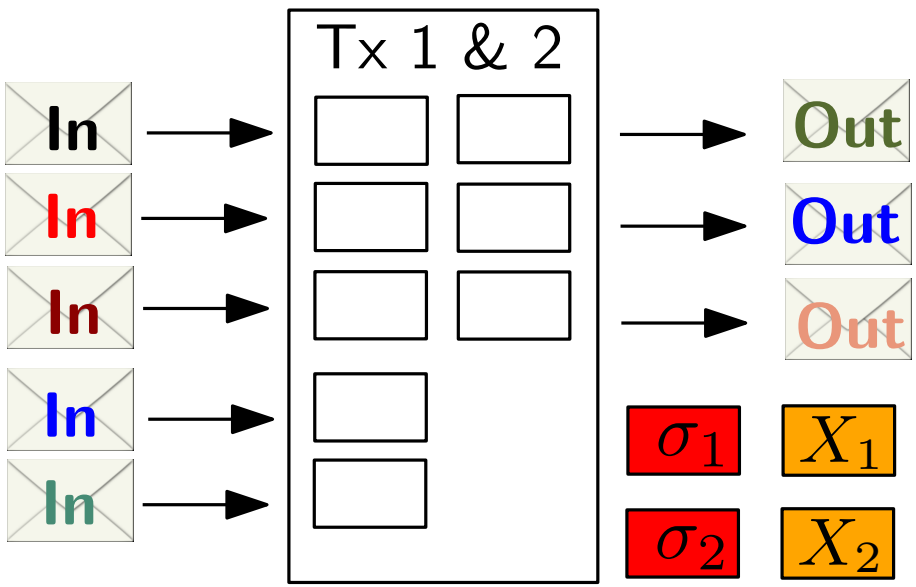
- $\sum \mathbf{Out}_2 - \sum \mathbf{In}_2 = X_2$
- σ_2 valid for X_2

Mimblewimble

Non-interactive CoinJoin

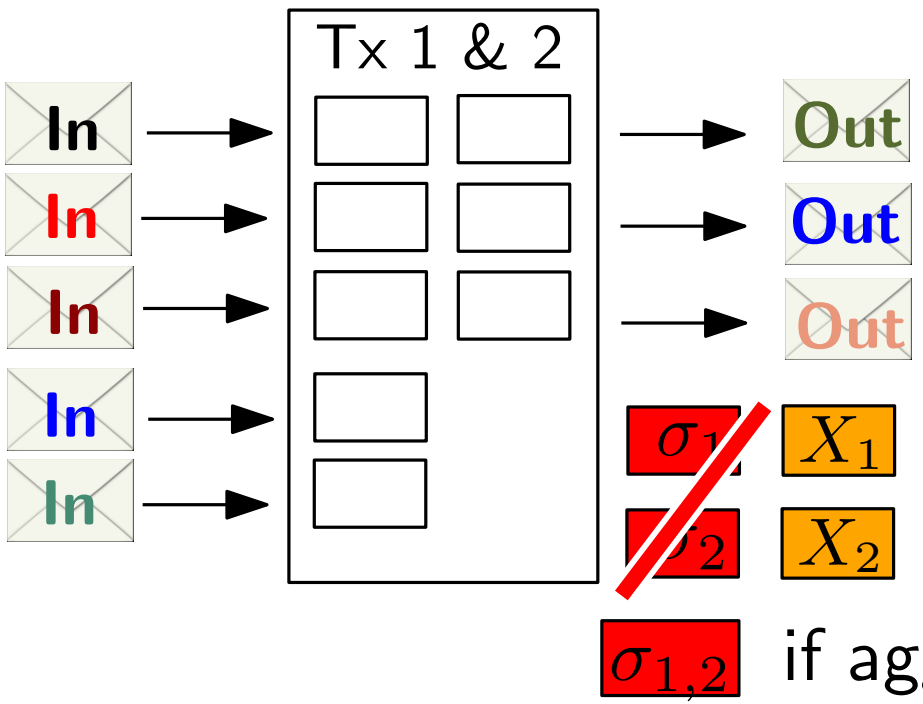


Mimblewimble



- $\sum$ **Out** $-\sum$ **In** $= X_1 + X_2$
- σ_1 valid for X_1
- σ_2 valid for X_2

Mimblewimble

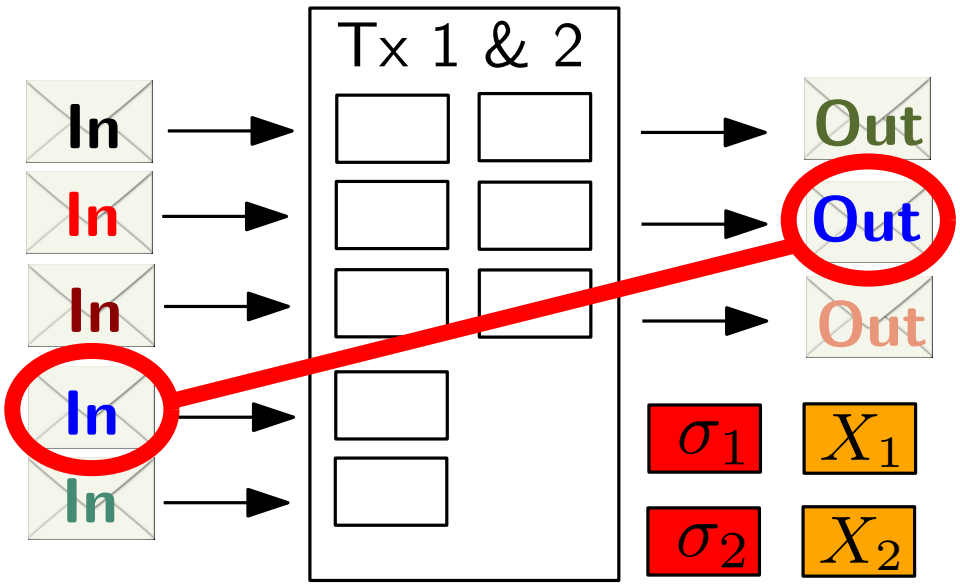


- $\sum \textbf{Out} - \sum \textbf{In} = X_1 + X_2$
- σ_1 valid for X_1
- σ_2 valid for X_2

$\sigma_{1,2}$ if aggregate signature scheme (BLS)

Mimblewimble

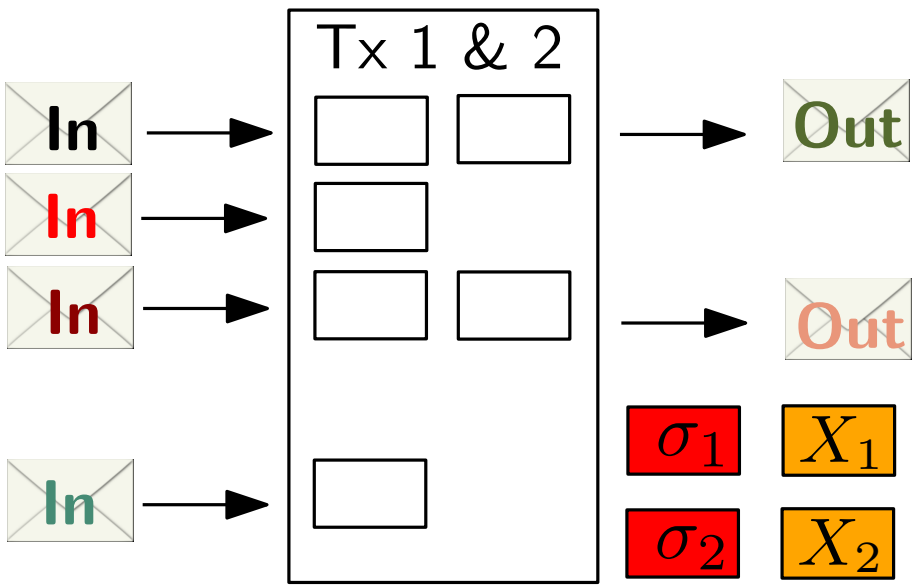
Post-confirmation Cut-Through



- $\sum$ **Out** $-\sum$ **In** $= X_1 + X_2$
- σ_1 valid for X_1
- σ_2 valid for X_2

Mimblewimble

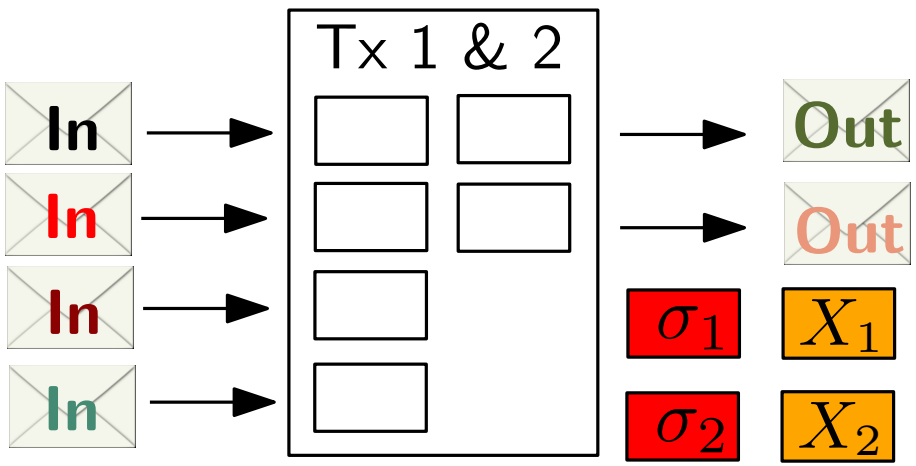
Post-confirmation Cut-Through



- $\sum$ **Out** $-\sum$ **In** $= X_1 + X_2$
- σ_1 valid for X_1
- σ_2 valid for X_2

Mimblewimble

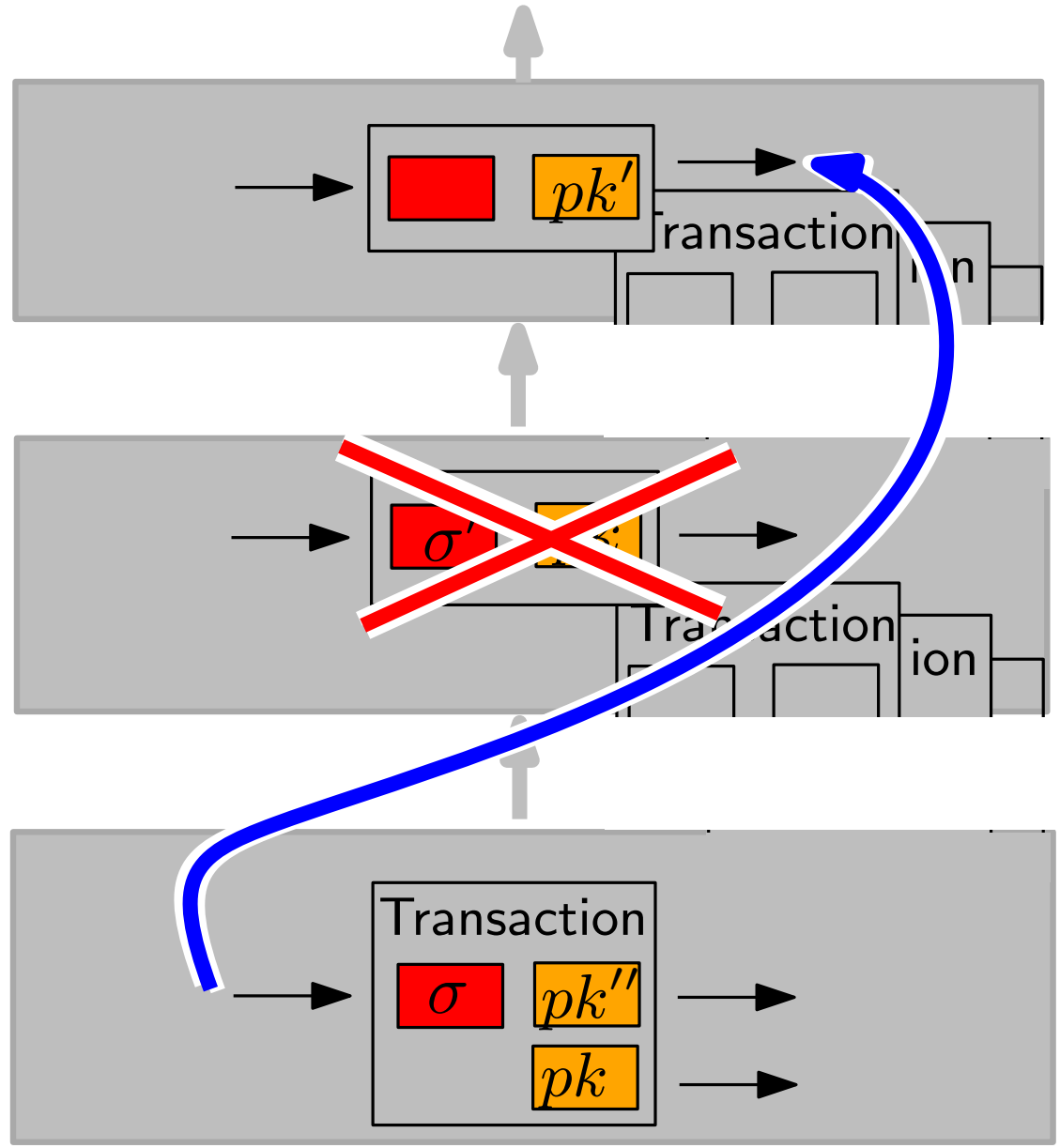
Post-confirmation Cut-Through



- $\sum$ **Out** $-\sum$ **In** $= X_1 + X_2$
- σ_1 valid for X_1
- σ_2 valid for X_2

Scalability

“cut-through”



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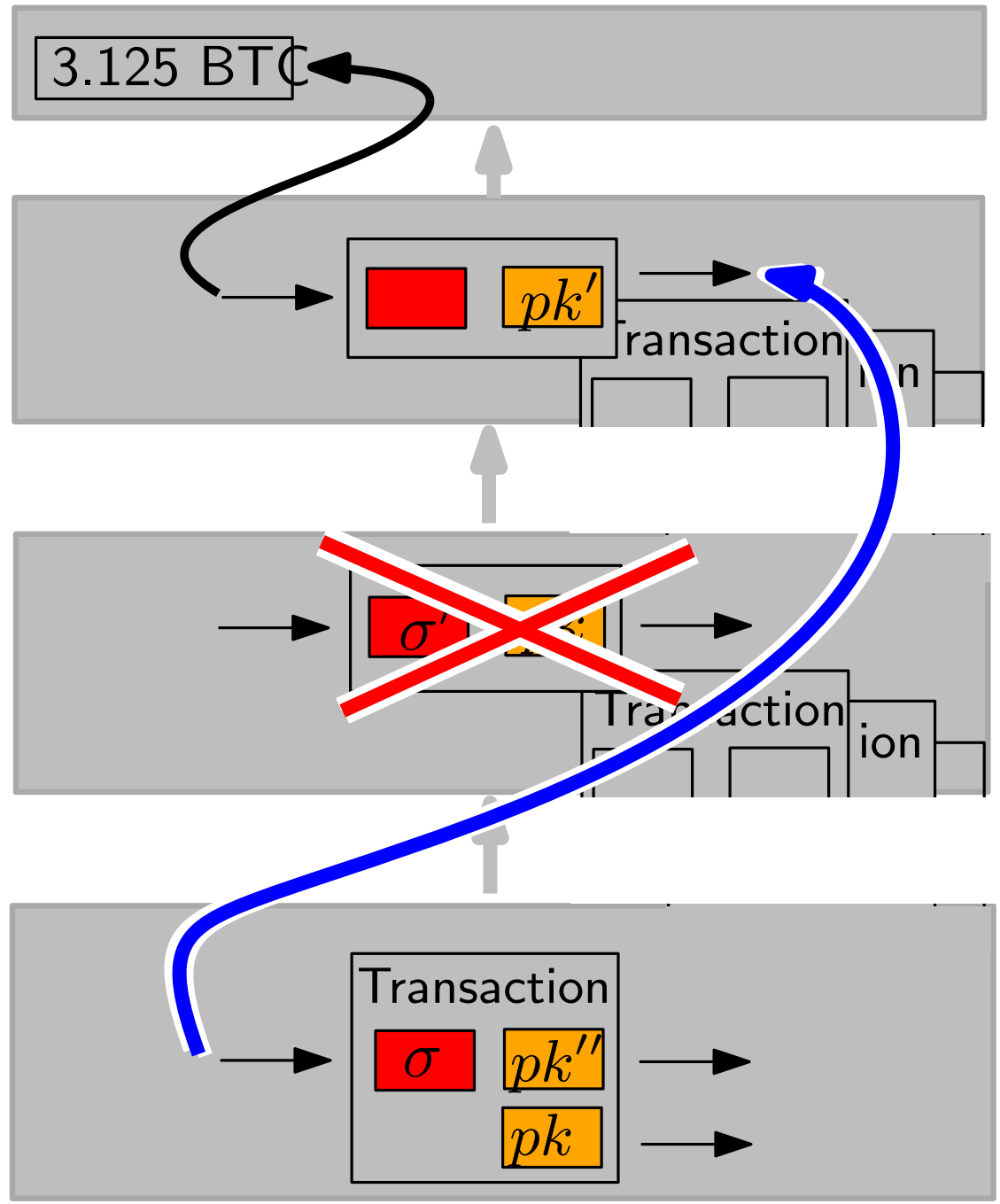

Scalability

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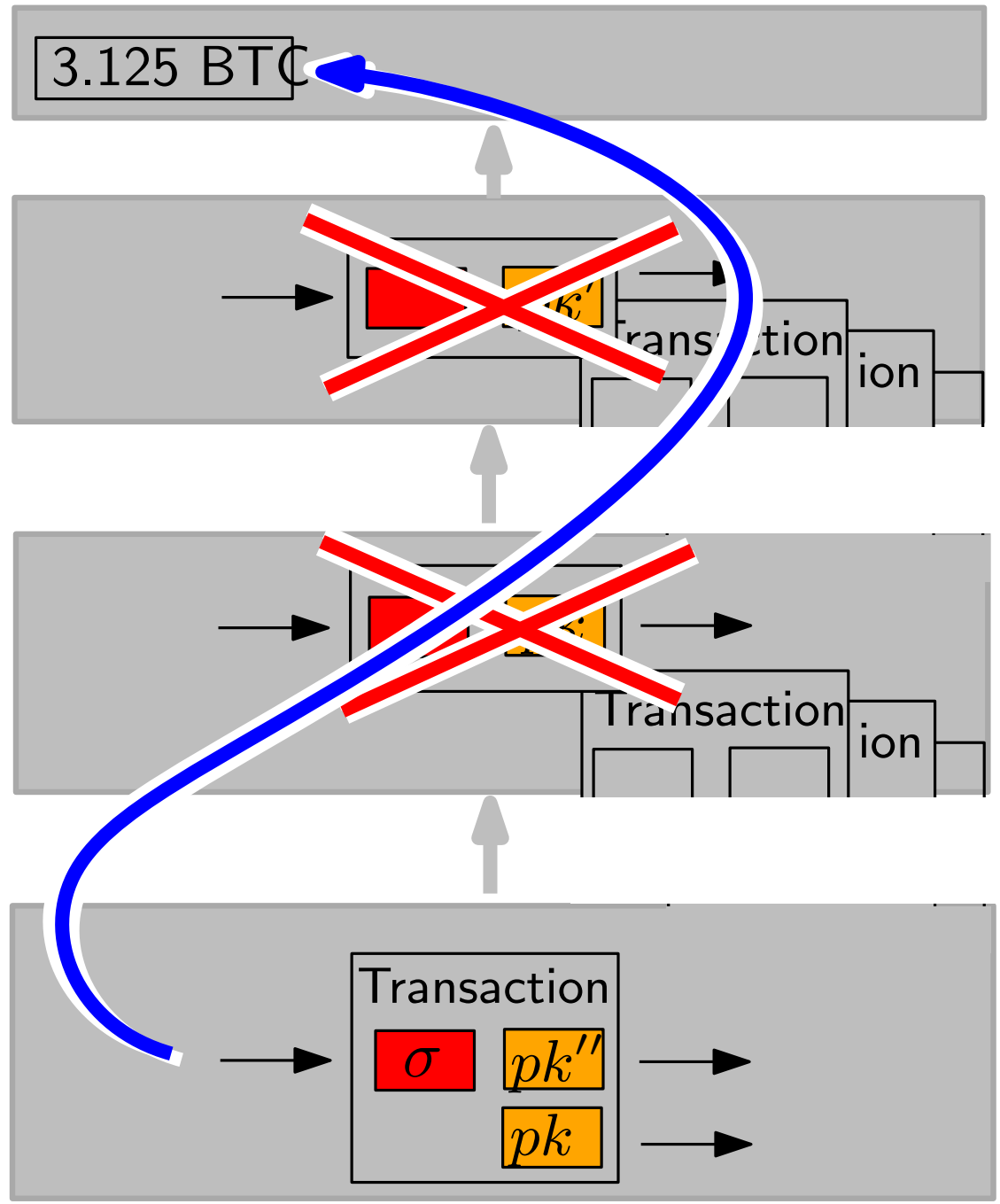
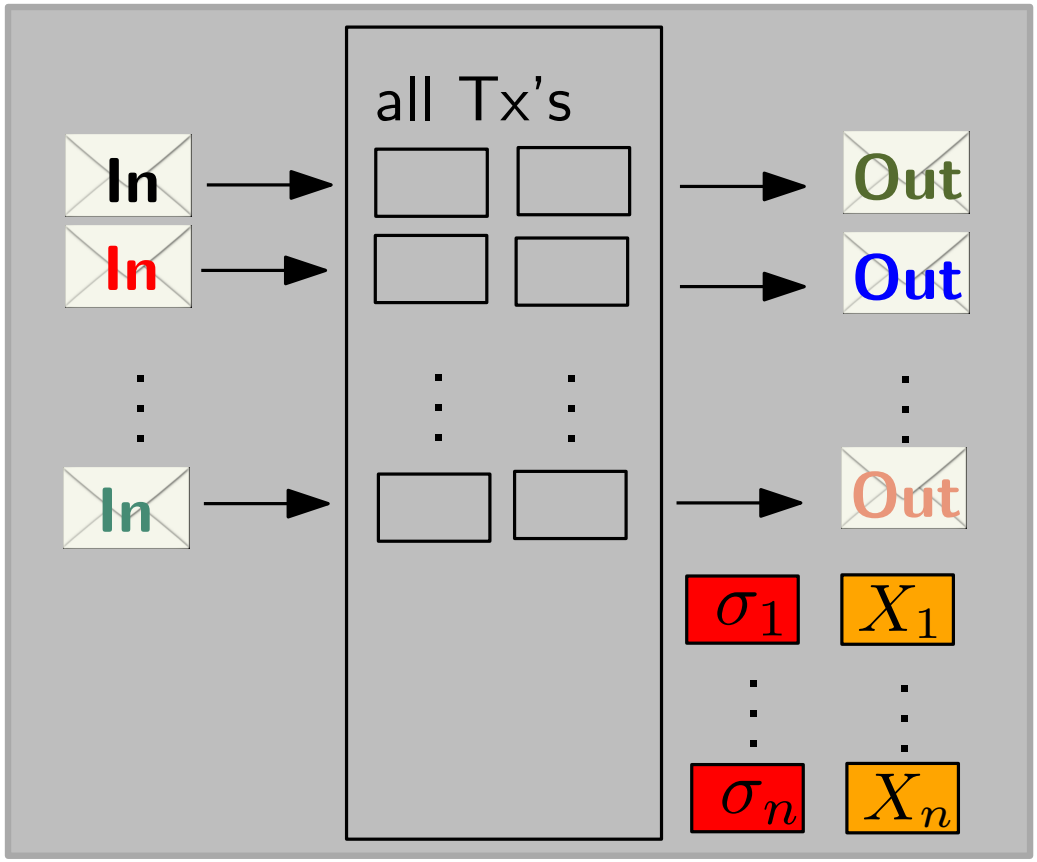


Mimblewimble

Cut through all transactions in blockchain



- $\sum$ **Out** $-\sum$ **In** $= \sum X_i$
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Mimblewimble

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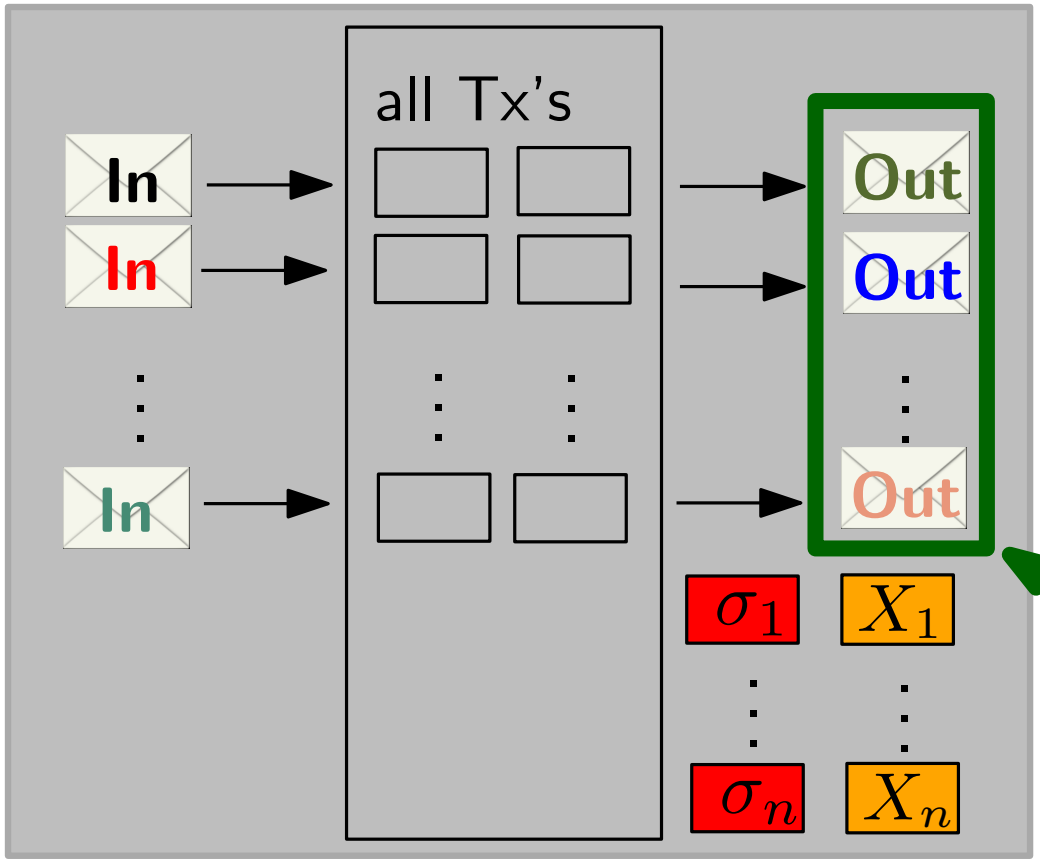

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UTXO set

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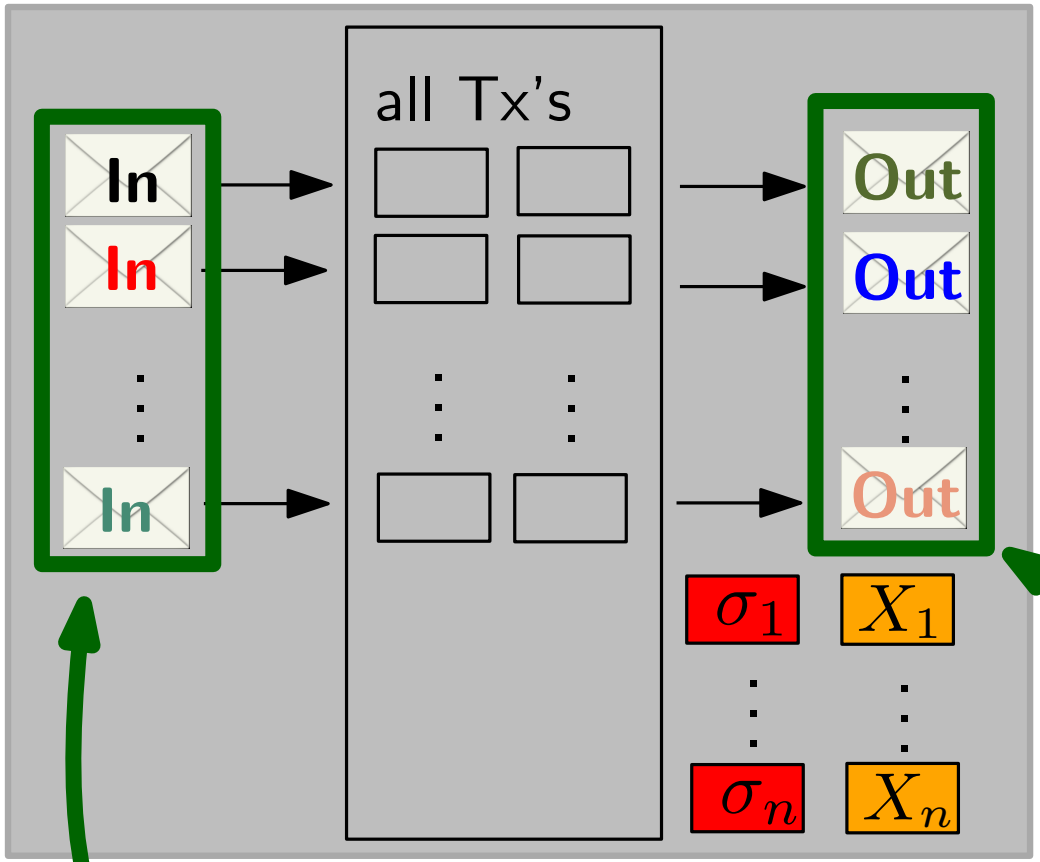

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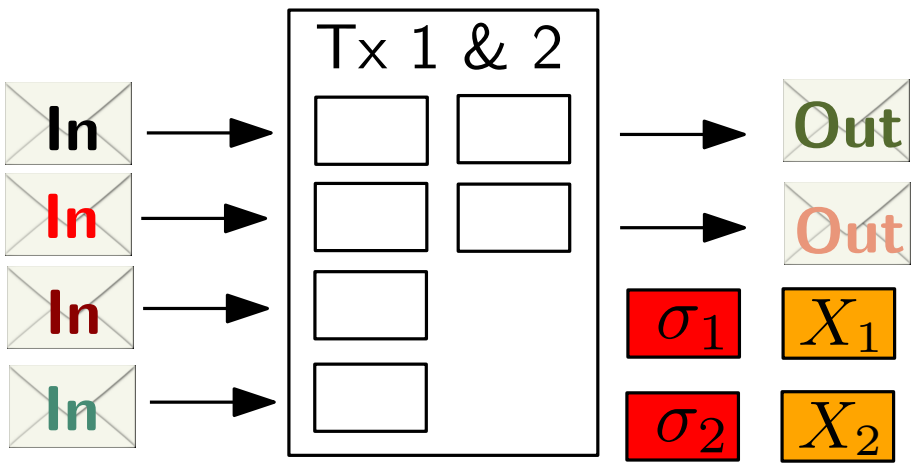
UTXO set

Only coinbase transactions

Mimblewimble

Privacy?



- $\sum$ **Out** $-\sum$ **In** $= X_1 + X_2$
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Mimblewimble

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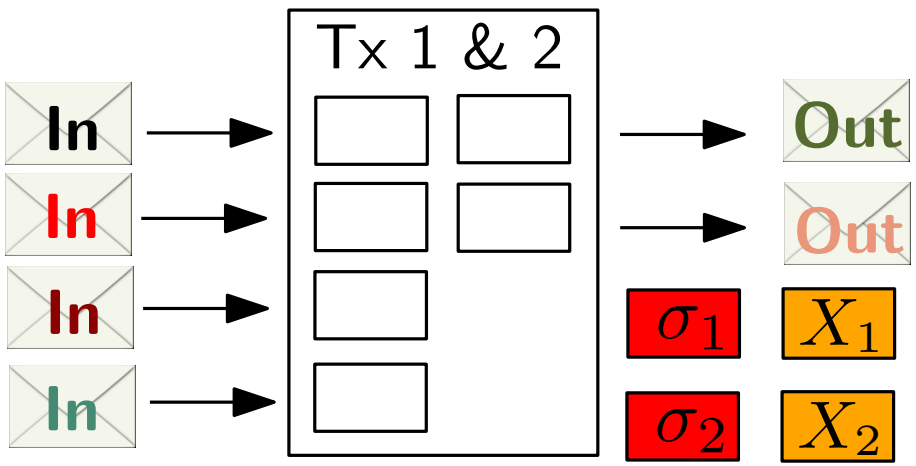

- $\sum \textbf{Out} - \sum \textbf{In} = X_1 + X_2$
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- Shuffle inputs and outputs

Mimblewimble

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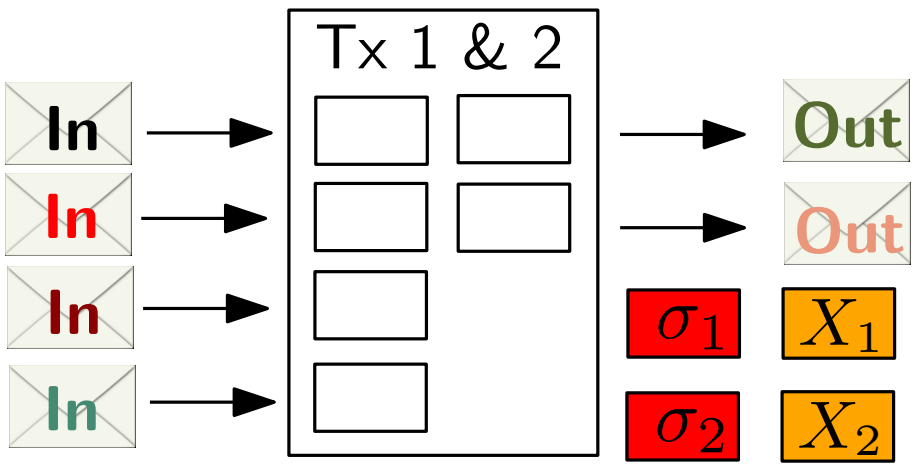

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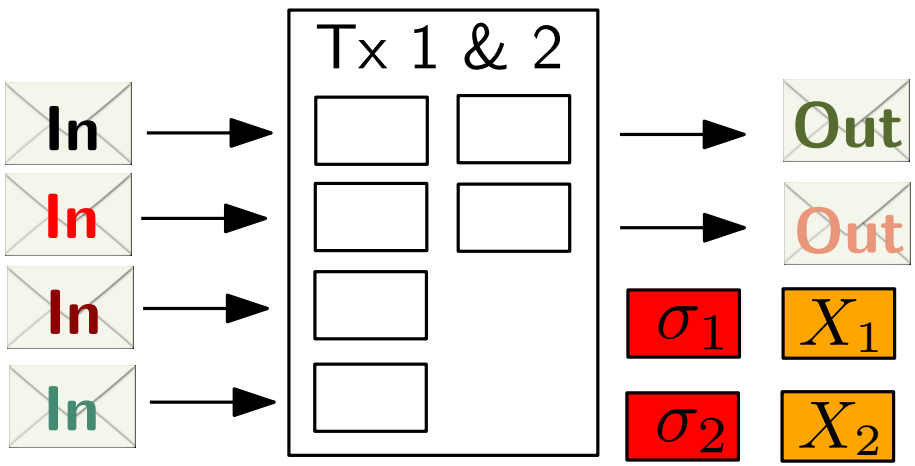

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- No! We have $\sum \mathbf{Out}_i - \sum \mathbf{In}_i = X_i \Rightarrow$ solve subset-sum

Mimblewimble

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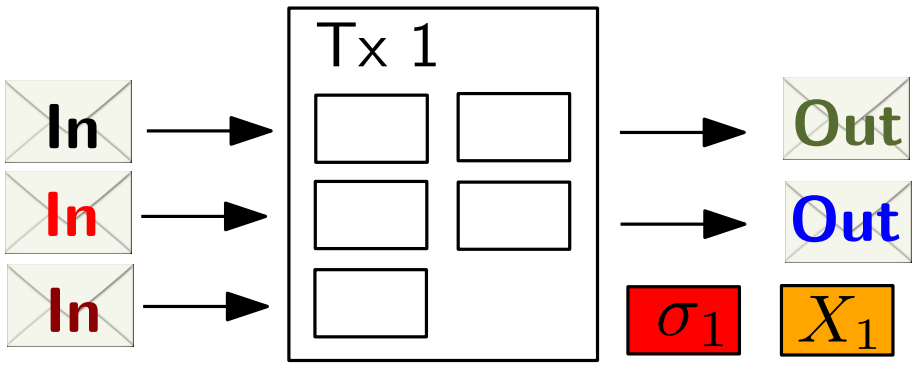

- $\sum \mathbf{Out}_1 - \sum \mathbf{In}_1 = X_1$
- σ_1 valid for X_1

Kernel offset:

- Choose random t_i, set $X_i := \sum \mathbf{Out}_i - \sum \mathbf{In}_i - t_i G$

Mimblewimble

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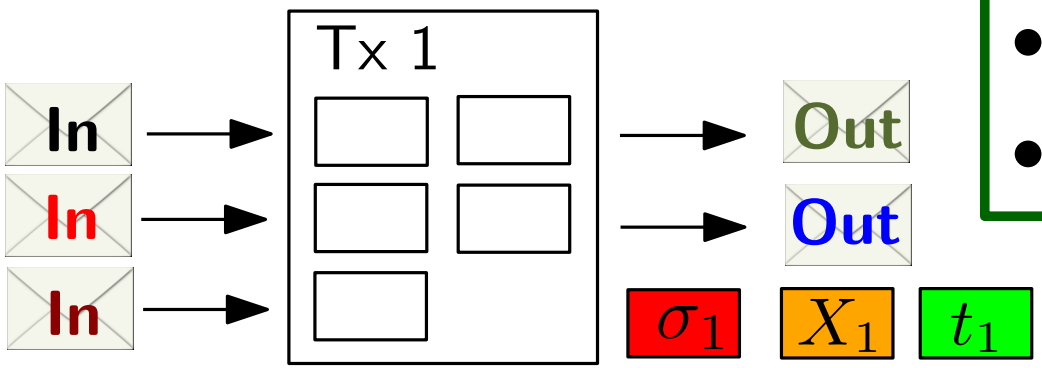

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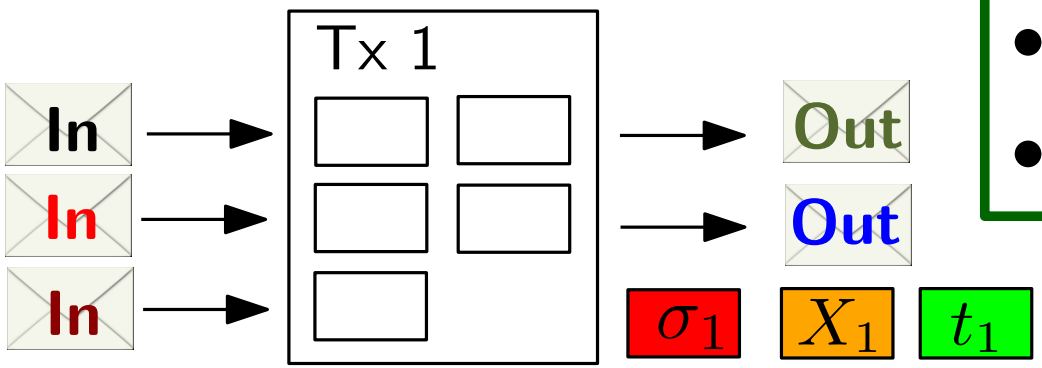

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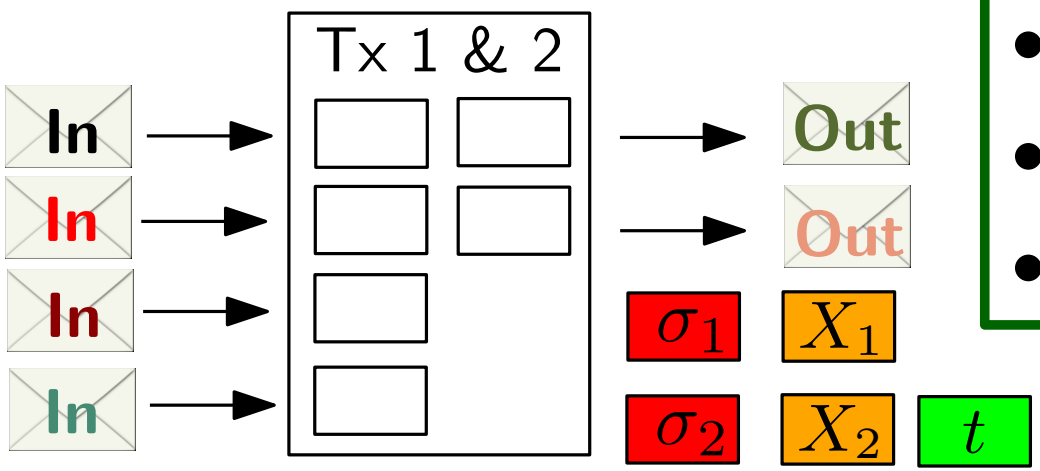

- $\sum \mathbf{Out} - \sum \mathbf{In} = X_1 + X_2 + tG$
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Mimblewimble

How are transactions actually created?

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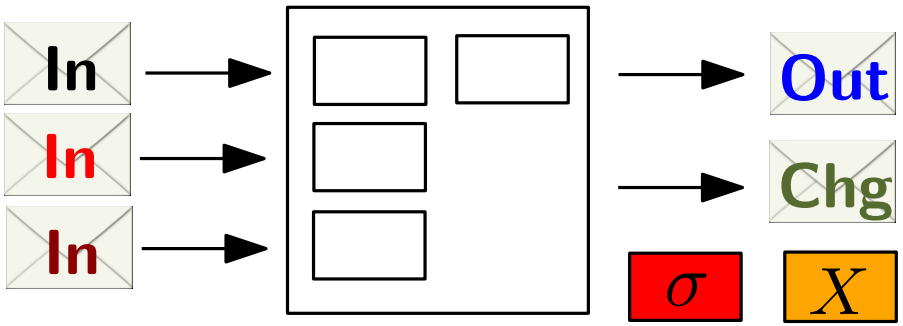

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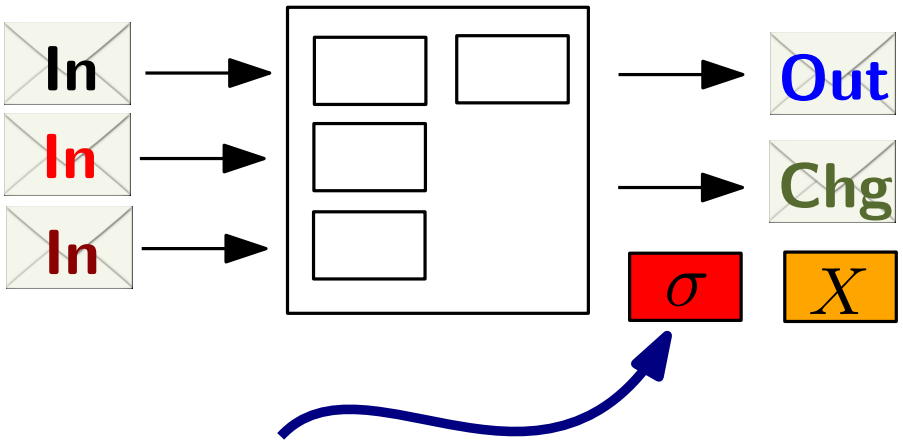

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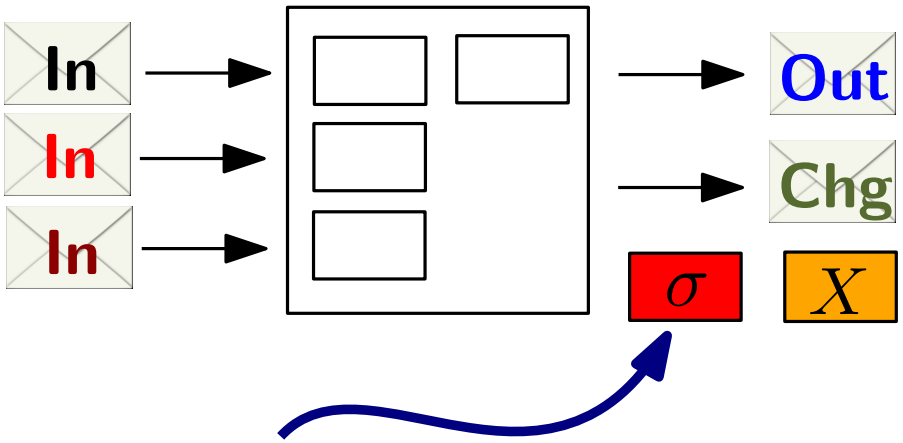

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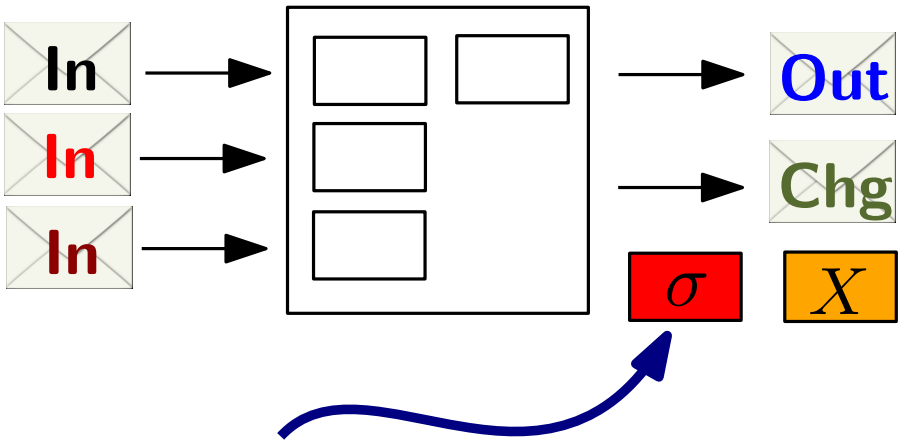

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signature under key $r_{\text{Out}} + r_{\text{Chg}} - \sum r_{In}$

known by sender

known by receiver

Threshold-signing for key $r_{\text{Out}}G + (r_{\text{Chg}} - \sum r_{In})G$

Mimblewimble

[FOS19]

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  - inflation-resistance
  - coin-theft-resistance
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Mimblewimble

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- **Instantiations:** proof that
  - Pedersen + Schnorr
  - Pedersen + (aggregate) BLS

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