# Blockchains & Distributed Ledgers

## Lecture 07

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Slide credits: AK

# Lecture Overview

- Anonymity & Privacy in blockchain protocols.
    - Bitcoin and CoinJoin transactions.
    - Mix-nets
    - group and ring signatures.
        - Cryptonote/Monero
    - Zero-knowledge proofs & SNARKs
        - Zcash.

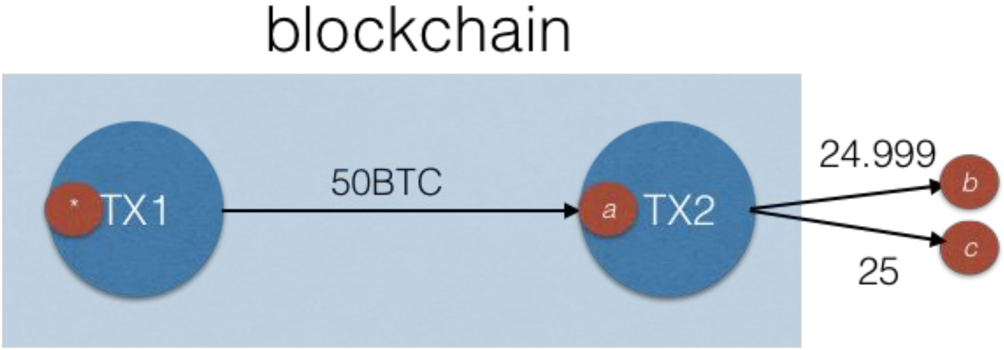
# Pseudonymity vs. Anonymity

- Pseudonymity: identities are substituted by tags that are independently assigned to each identity.
- Anonymity: any action performed is manifested within a set of indistinguishably acting participants. (The anonymity set)

# Privacy and Bitcoin

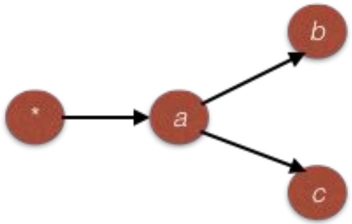
- Users can create accounts -practically- without cost and without association to previous accounts.
- Essentially they can create an unlimited number of pseudonyms.

# Transaction Graph Analysis

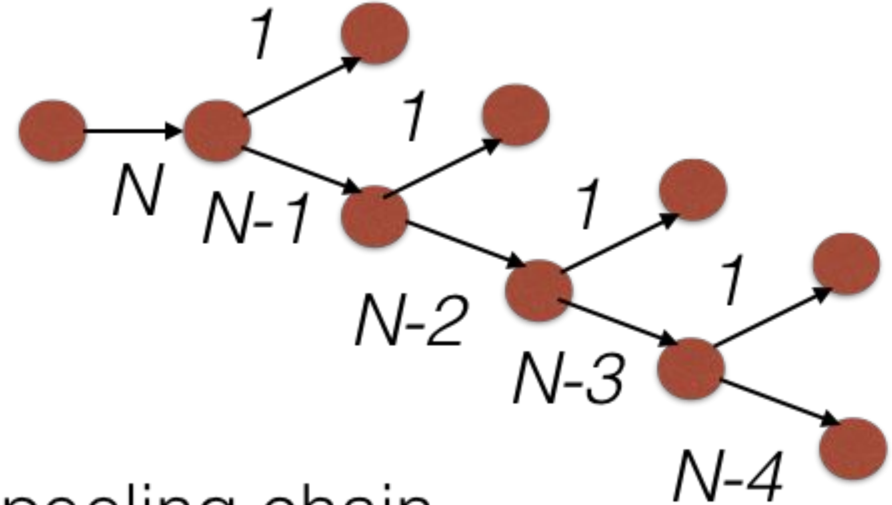



coinbase transaction

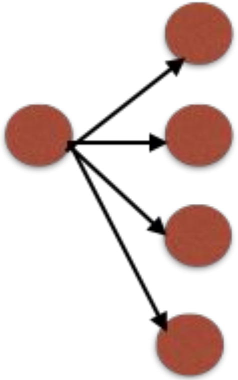
account *a* moves 50 BTC to accounts *b* and *c* (minus fees)



# Common Behaviours




peeling chain



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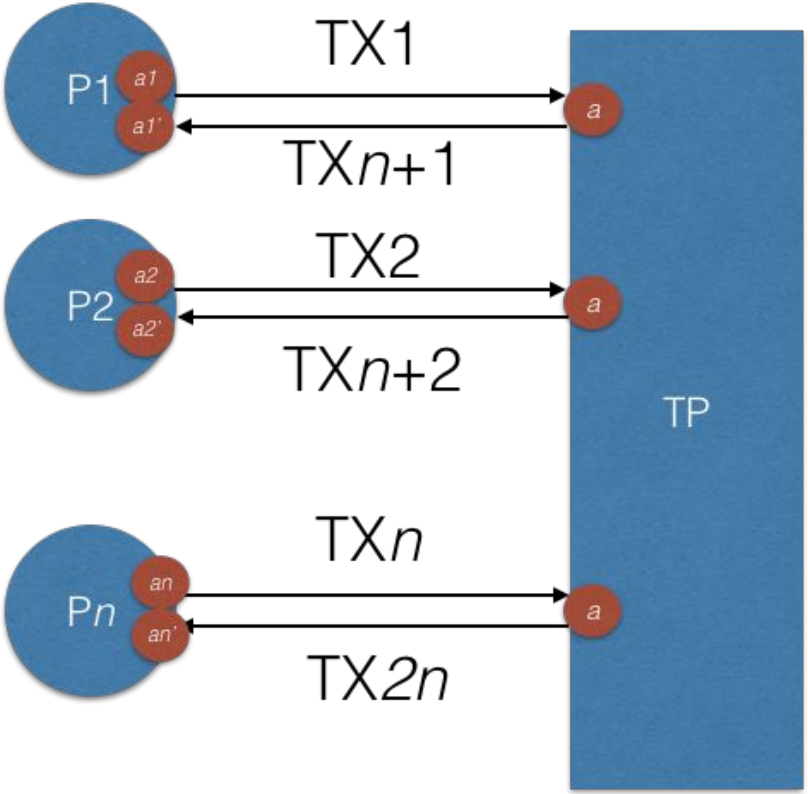
# Fungibility and Privacy

- Coins are interchangeable.
- Since each “satoshi” has its whole history in the bitcoin blockchain, its fungibility is debatable.

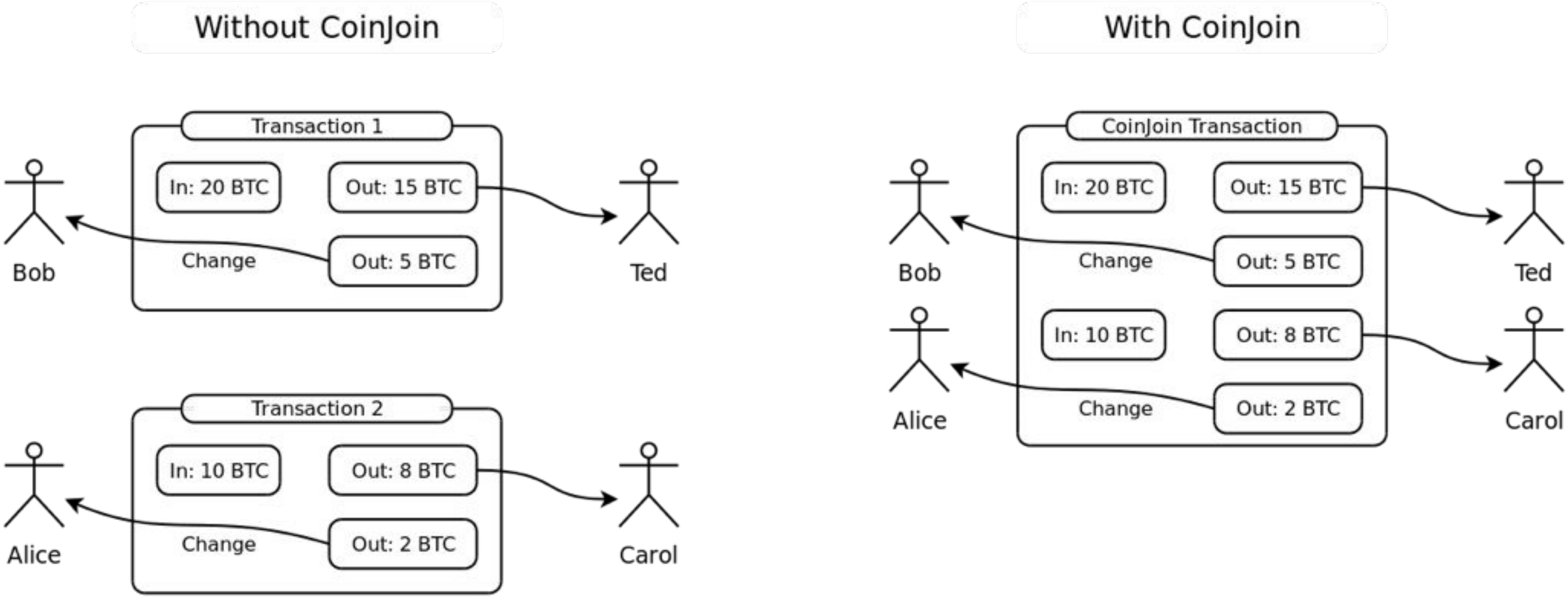
# Anonymising Transactions




Anonymity set of size $n$

TP may disappear with the money

# CoinJoin



Without CoinJoin
Transaction 1
In: 20 BTC
Out: 15 BTC
Out: 5 BTC
Change
Bob
Ted
Transaction 2
In: 10 BTC
Out: 8 BTC
Out: 2 BTC
Change
Alice
Carol
With CoinJoin
CoinJoin Transaction
In: 20 BTC
Out: 15 BTC
Out: 5 BTC
Change
In: 10 BTC
Out: 8 BTC
Out: 2 BTC
Change
Bob
Ted
Alice
Carol

# Using Multiple Input Transactions

- parties broadcast a1’,a2’, …, a*n*’ accounts to each other.
- The *i*-th party broadcasts a signature from account a*i* to pay the account a’*i* from the set of accounts a1’,a2’, …, a*n*’. When all *n* signatures are broadcasted then the multiple input transaction can be posted on the blockchain.
- If any of the *n* parties abort the protocol the transaction cannot be validated.
- **Questions**: how to ensure that the adversary cannot do a correlation between a*i* and a*i’*? in case of an abort how to restart the protocol without the offending party?

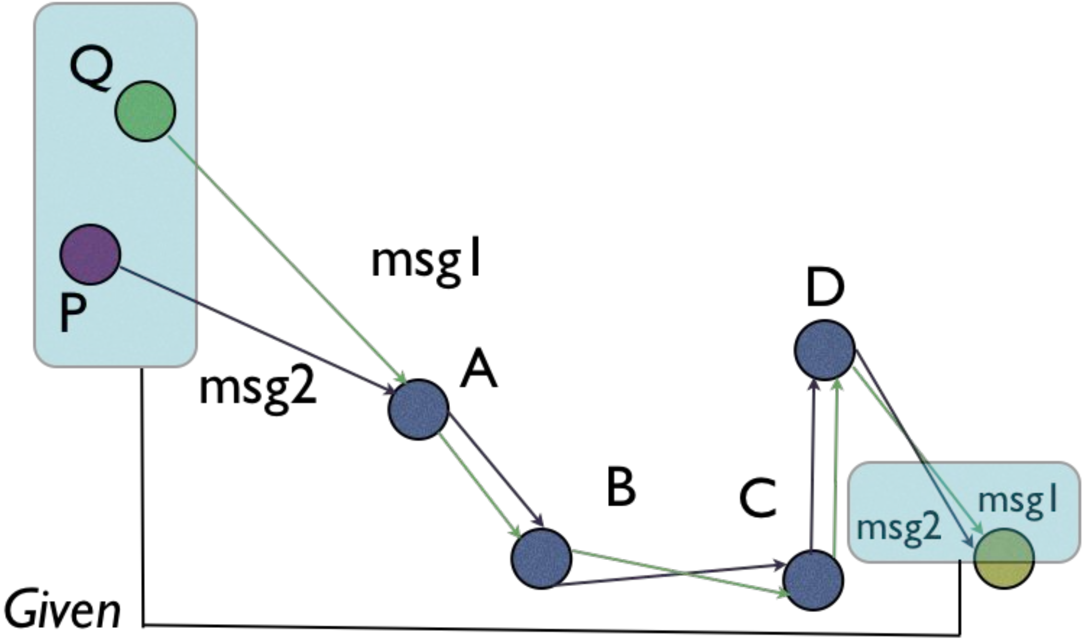
# Passive vs Active Attacks

- A “passive” adversary would just observe the transaction in the blockchain. In this case, an anonymity set of size *n* protects each participant.
- However, an “active" adversary participates in a protocol execution; the correlation between participants is apparent due to the broadcast.

# Mix-net

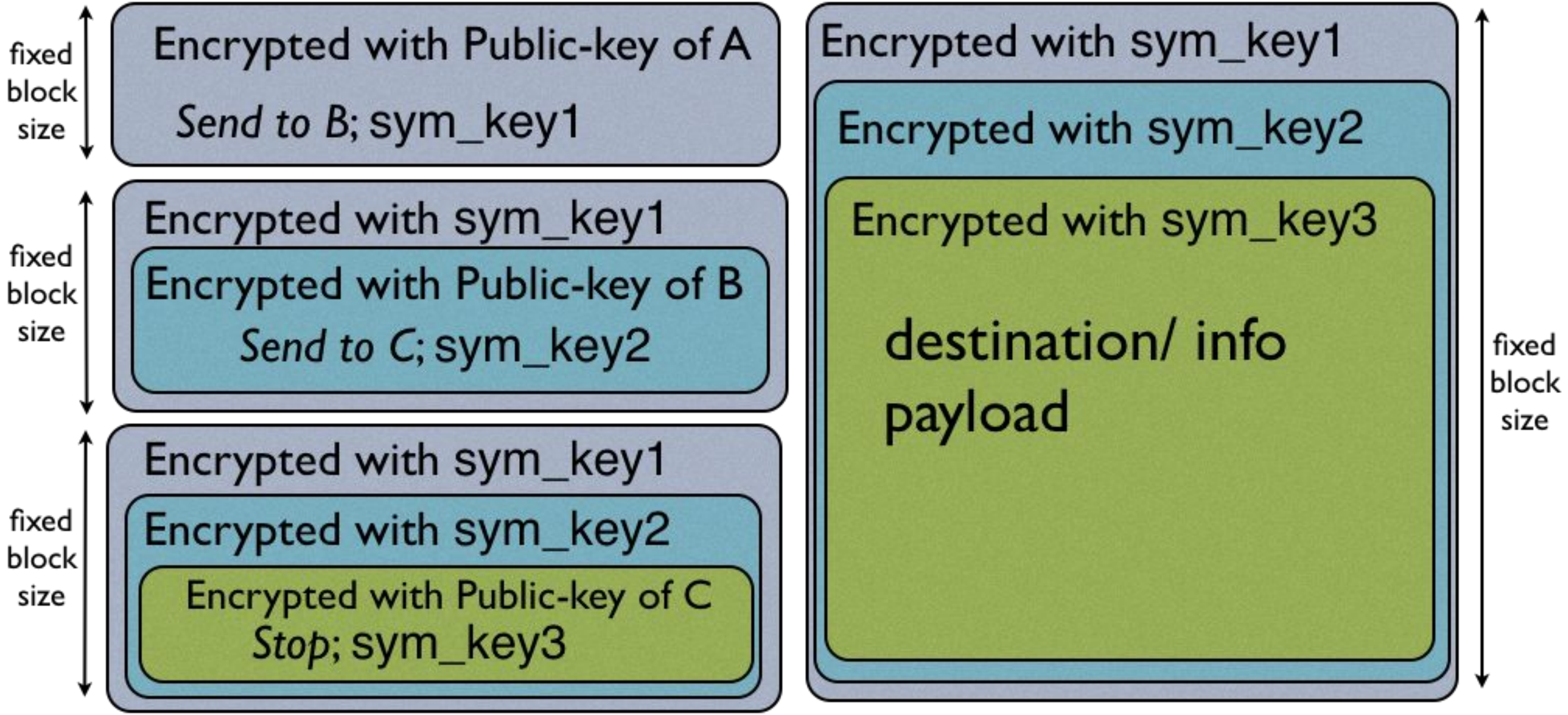
- Facilitates a sender-anonymous broadcast.
  - Decryption mix-nets.
  - Re-encryption mix-nets.

# Mix-net, 2

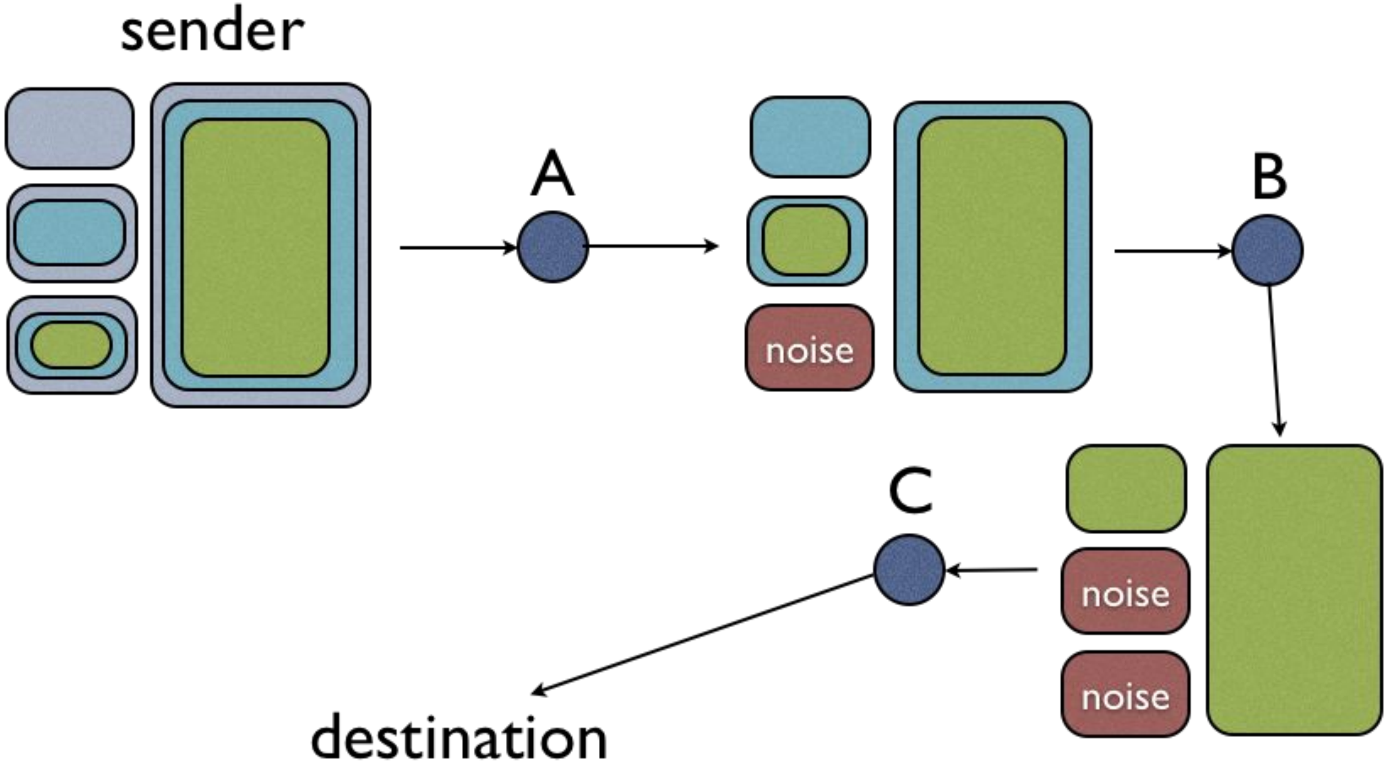



Not possible to relate whether P send msg1 or msg2 and similarly for Q (as long as there is one honest mix)

# Decryption Mix-net



# Routing via a Mix-net

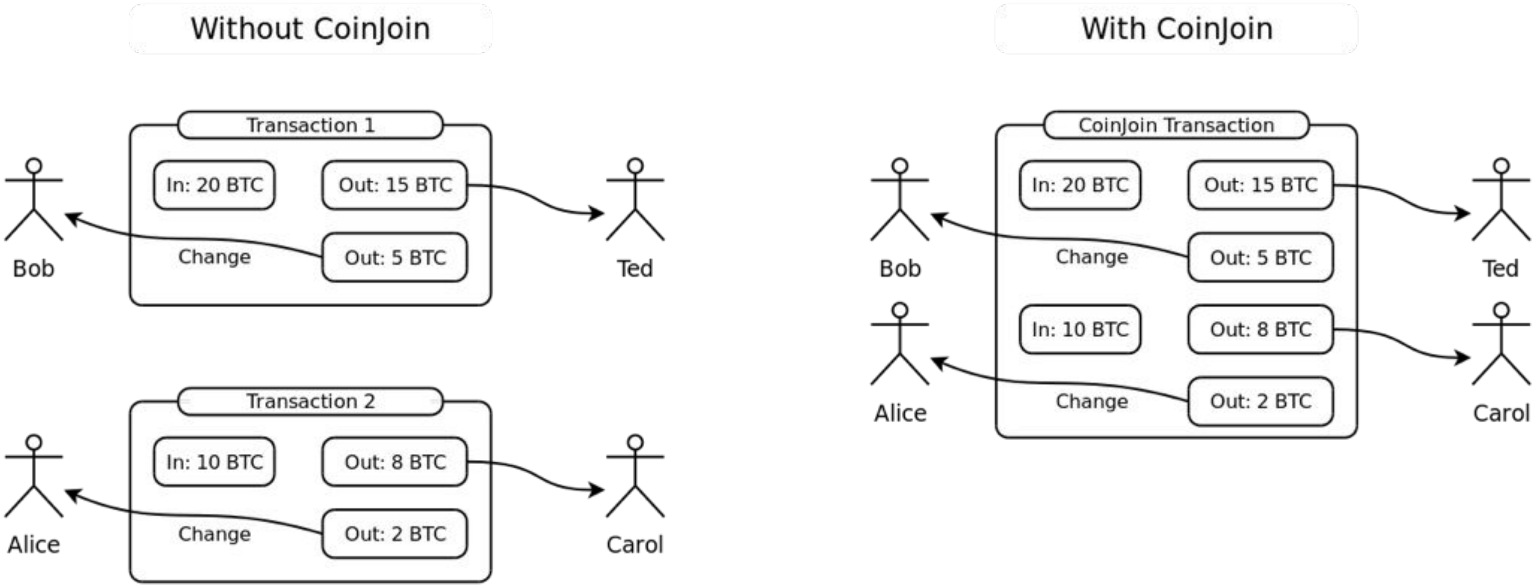


# Mix-net for Coinjoin transactions

- Parties broadcast their public-keys (the association between public-keys and accounts a1,a2, …, an is public).
- Parties engage in a decryption mix-net in sequence so that the last party P*n* obtains the sequence of accounts a1’,a2’, …, a*n*’. P*n* broadcasts the accounts to all.
- Note that each step is performed by a designated party Pi, hence any abort can be attributed to that party. A repeat session may exclude the party Pi.

# Hiding Coin Balances

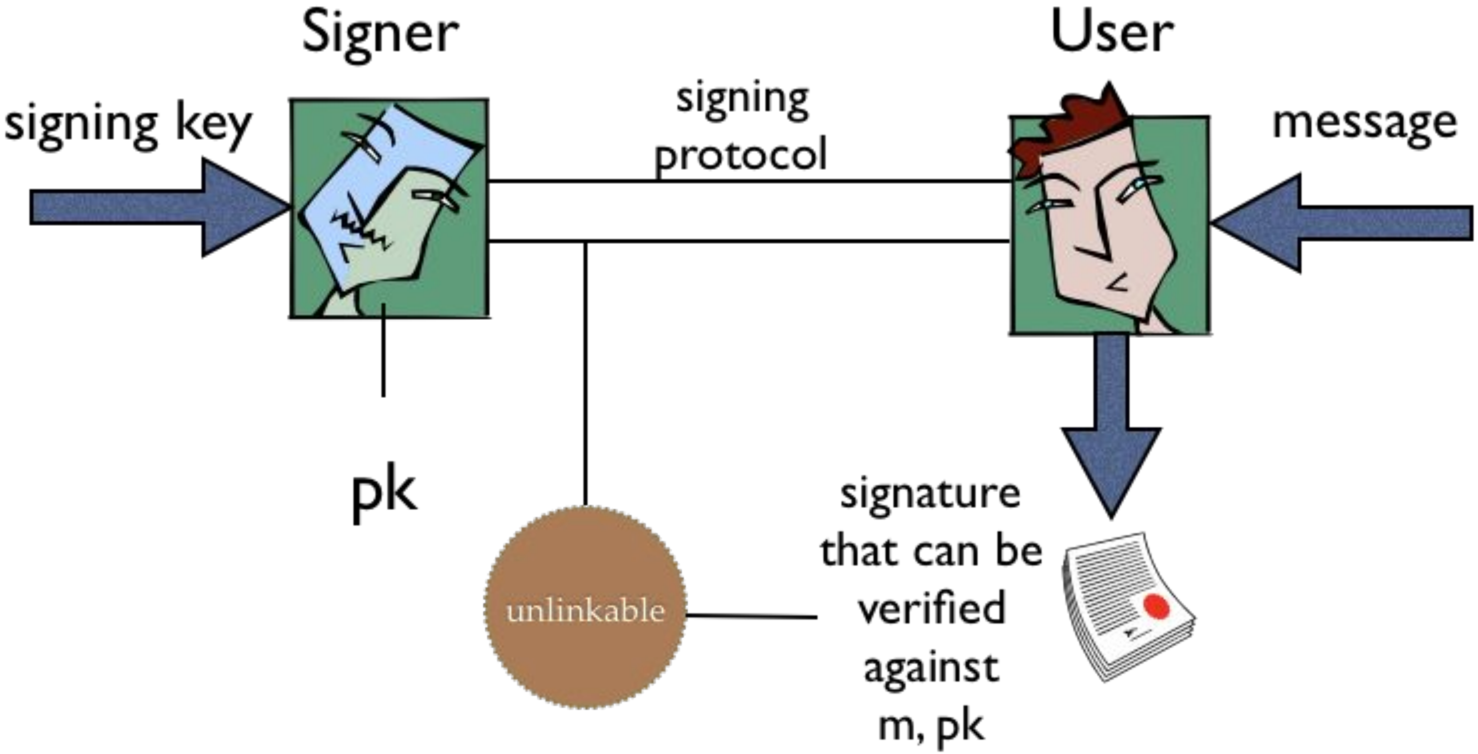
balances
are visible:



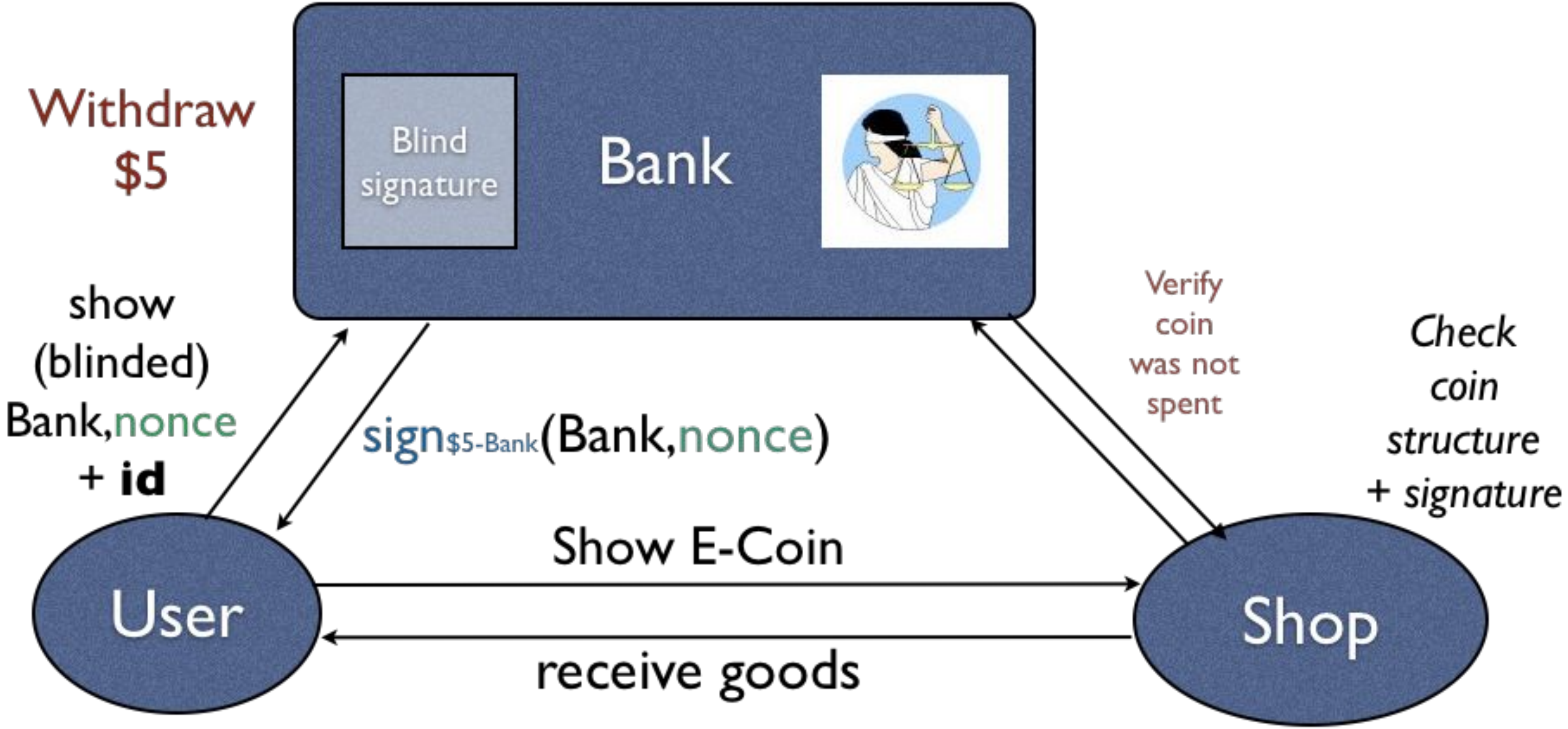
# Coordination

- Coinjoin & similar techniques require coordination and message passing between the parties engaged in the transaction.
- Is it possible to improve that?

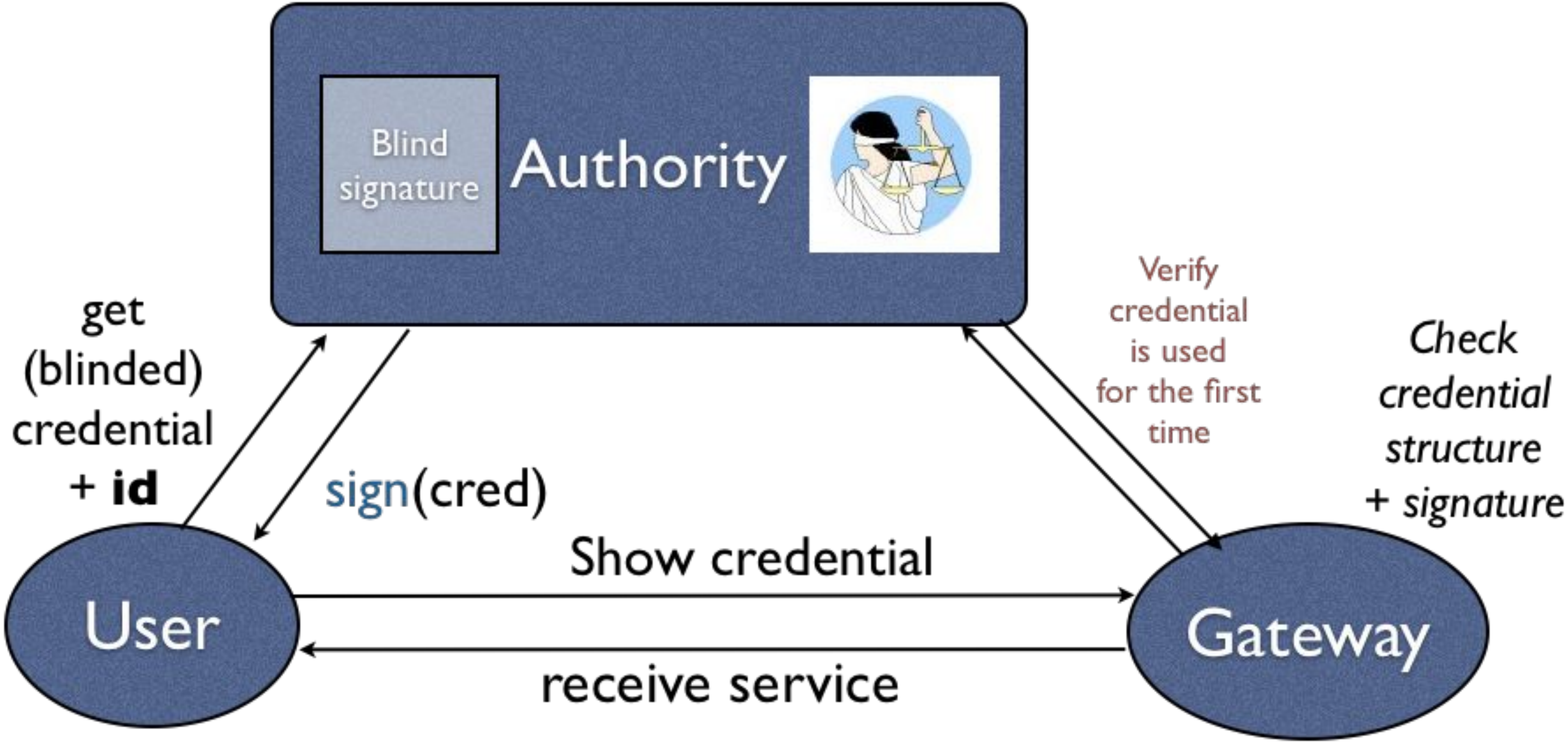
# Blind-Signatures



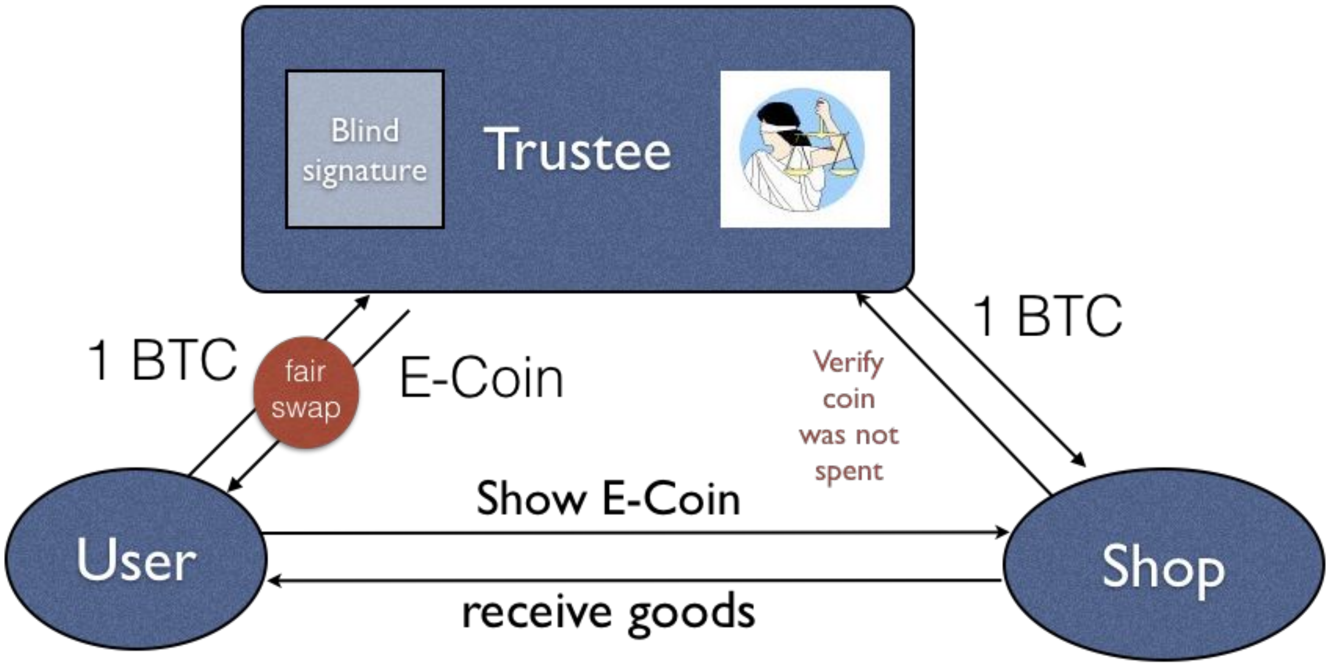
# Chaum’s E-cash



# Anonymous Credentials



# Anonymizing Bitcoin Payments via E-cash




**Note**: Trustee is trusted to honor its e-coins.

# Fair Swaps

- Alice and Bob would like to exchange secrets so that either none of them gets output or both.
  - Classical problem!
  - Impossible to solve under standard network assumptions!
  - Going around the impossibility: (i) optimistic fair exchange (ii) resource-based fair exchange (iii) fair swaps with penalties.
- [Construction] using a smart contract that both parties fund to accept their secrets. Key requirements: (i) parties lock up funds, (ii) secret submission can be verified by the contract code

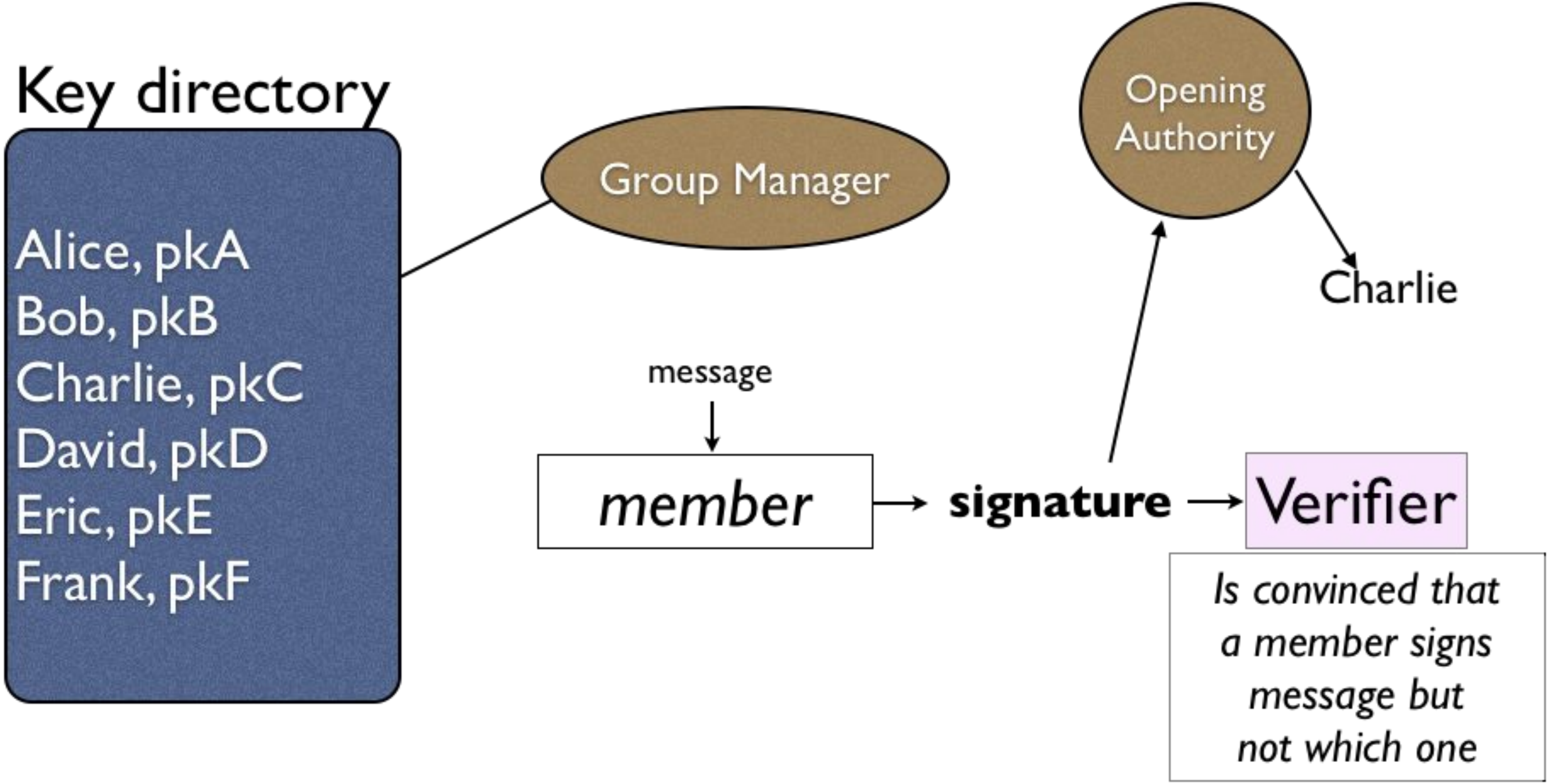
# Challenges

- Using a trustee eases coordination requirements but introduces a single point of failure.
  - further enhance penalty mechanisms (along the lines of fair swaps of values) so that the trustee pays for any conceivable deviation.
  - or… use alternative techniques.

# Anonymity and Digital Signatures

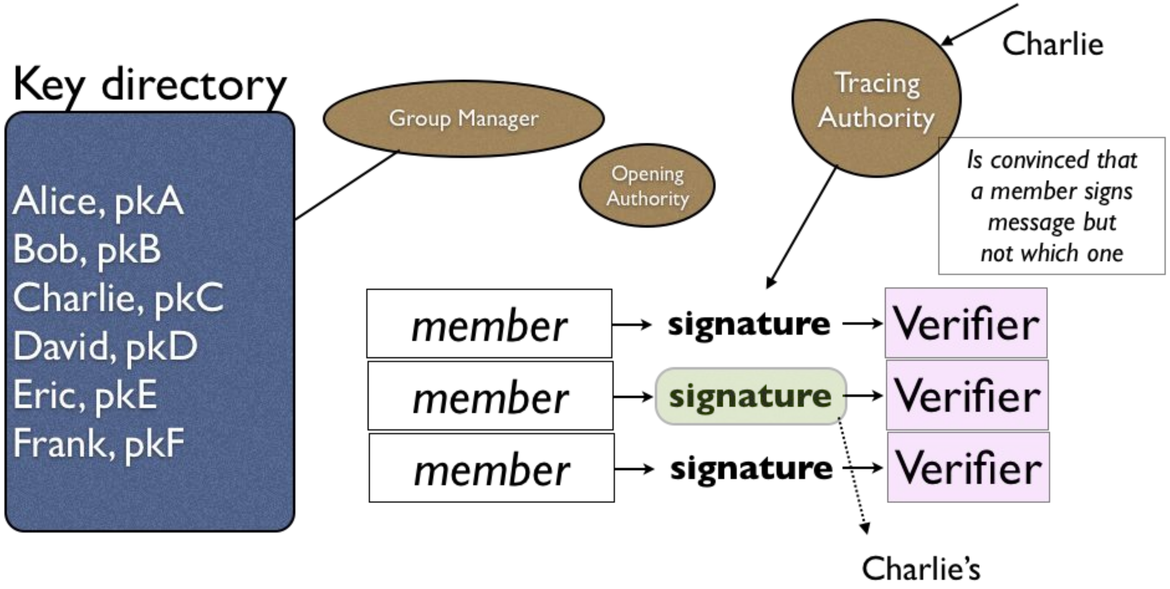
- So far all digital signatures identify the signer.
  - Is it possible to hide the sender within a group?

# Group Signatures

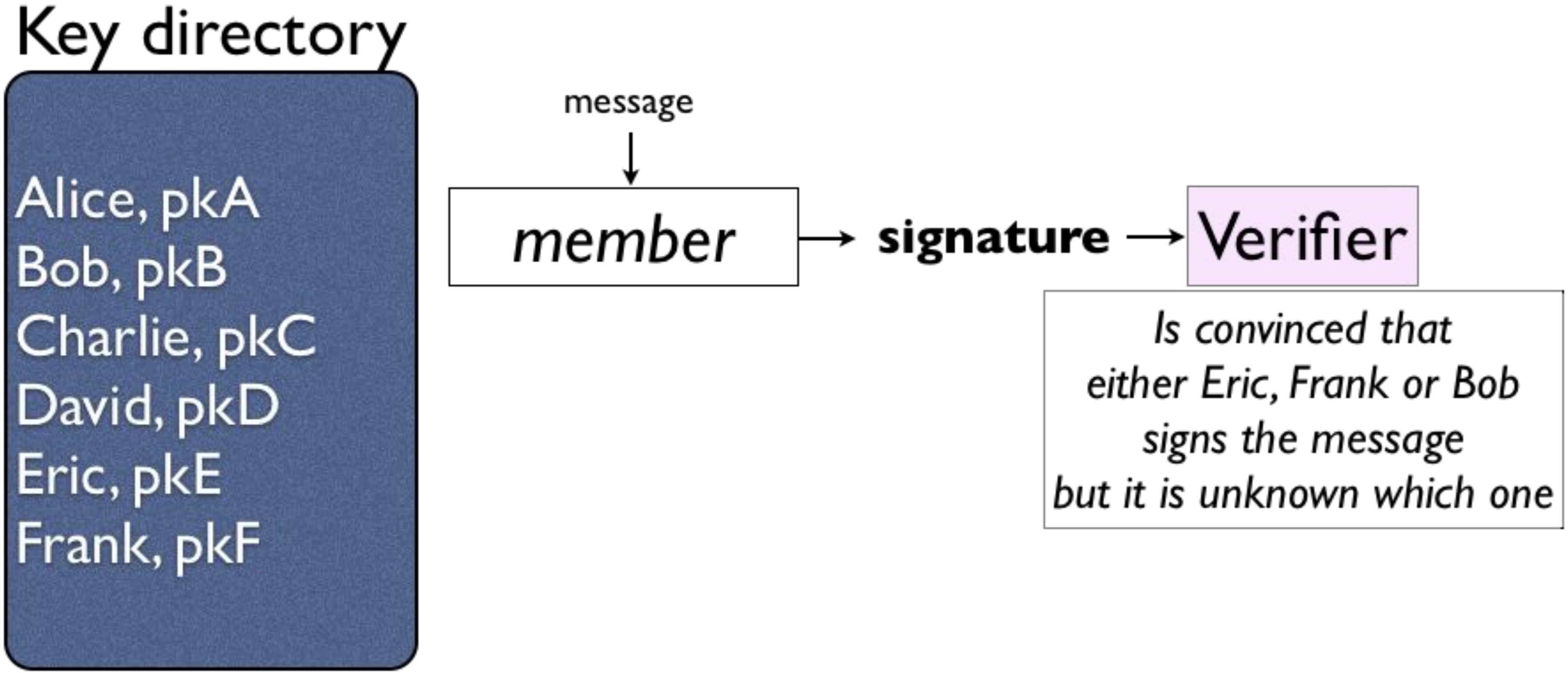


# Traceable Signatures

Traceable Signatures



# Ring Signatures



# Monero/Cryptonote

- Uses “stealth” addresses and linkable ring signatures to provide better anonymity.
- For each payment an anonymity set is selected with accounts of the same monetary value.
- A ring signature is issued on behalf of that set, suitably restricted so that an account can only be used twice (linkable).
- Stealth addresses enable the sender to create unlinkable addresses for the receiver which subsequently the receiver can detect.

# Is Monero Anonymous?

- There is potentially more uncertainty in terms of transactions compared to a bitcoin-like blockchain.
- Nevertheless, it is not obvious how to quantify the level of anonymization.
- De-anonymization is feasible in a number of cases. (e.g., imagine the attacker “spraying” the ledger with transactions so that it commands a good number of selected accounts)

# Increasing and Safeguarding the anonymity set, I

- A larger anonymity set is most preferable.
- However in the techniques we have seen so far, transaction preparation work increases linearly with the anonymity set.
- **Ideal:** use the set of all possible unspent transaction outputs.

# Increasing the anonymity set, II

$$\langle \rho, sn, \psi = \underbrace{\text{Commit}(\rho, sn)}_{\text{public}} \rangle$$

The commitment value is associated with a deposit to the ledger ("minting" a coin for $1).

Spending a coin, requires announcing the *sn* and proving that it was committed before in the ledger; (withdrawing $1)

$$\underbrace{\exists i : \psi_i}_{\text{existential quantifier over all commitments in the blockchain}} = \text{Commit}(\rho, sn)$$

# Increasing the anonymity set, III

Organize all commitments and serial numbers in a Merkle tree.

Prove that there is a leaf in the Merkle tree that contains the commitment

$$\psi_i = \mathrm{Commit}(\rho, sn)$$

Statement representation and witness size logarithmic in the number of coins.

# Challenges

- How is it possible to prove efficiently statement referring to the leaf of a Merkle tree?
  - a possible solution: use “ZK-snarks”
- Transferring a coin from one user to another is not properly specified (one cannot simply transfer $\rho$).

# ZK-Snarks

- Zero-knowledge succinct arguments of knowledge.
  - like zero-knowledge proofs, but with:
    - *computational* soundness: it depends on the security of a “common reference string”; this is structured cryptographic information that is assumed to be honestly sampled.
    - succinctness: the proof size and the verifier’s running time is efficient proportionally to the *statement* only.

# Constructing ZK

- There exist a SNARK for any NP-relation R.
- The actual proof sizes are small (hundreds of bytes)
- Verification **does not** depend on the running time of *R.*

# Zerocash

$$\langle a_{\mathbf{pk}}, \underbrace{v}_{\text{value}}, \underbrace{s}_{\text{random}} \rangle$$

$(a_{\mathbf{pk}}, a_{\mathbf{sk}})$

account
public/secret
key

$$k = \mathrm{Commit}(\rho, a_{\mathsf{pk}} || s)$$

$$sn = \mathsf{PRF}^{\mathsf{sn}}_{a_{\mathbf{sk}}}(s)$$

$$\psi = \mathrm{Commit}(\rho', v || k)$$

coin : $\langle a_{\mathsf{pk}}, v, s, \rho, \rho', \psi \rangle$

The double commitment enables verifying that the value *v* is properly encoded in the coin without revealing information about the owner

# Zerocash "Pour" Operation

given coin $\langle a_{\mathsf{pk}}, v, s, \rho, \rho', \psi \rangle$

produce two new coins with values $v_1 + v_2 = v$

$a^1_{\mathsf{pk}}, a^2_{\mathsf{pk}}$

set $k_i = \mathrm{Commit}(\rho_i, a^i_{\mathsf{pk}} || s_i)$

$\psi_i = \mathrm{Commit}(\rho'_i, v_i || k_i)$

Reveal $\psi_1, \psi_2$ and prove that the Merkle tree has a commitment corresponding to a coin $\langle a_{\mathsf{pk}}, v, s, \rho, \rho', \psi \rangle$ that is split properly and $a_{\mathsf{sk}}$ is known

Serial number of spent coin is revealed and marked as spent

Include a public-key encryption of opening the commitment that the recipient can use to decrypt the coin secret values.

# How to obtain a CRS?

- Trusted computation is needed.
  a. Use secure multiparty computation (topic of our next lecture)
  b. Use updateable reference strings (URS) instead and outsource the update operation.
  c. Use alternatives to SNARKs that do not require it (disadvantage: performance would be worse)