Blockchains & Distributed Ledgers

Lecture 08

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Lecture Overview

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

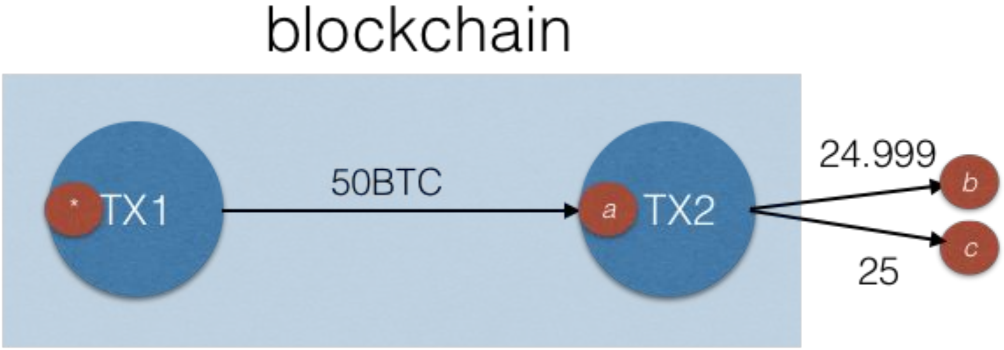
Pseudonymity vs. Anonymity

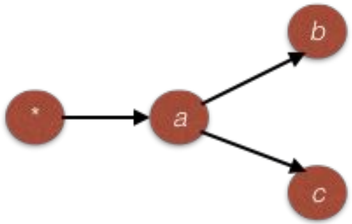
- Pseudonymity: identities are substituted by tags that are independently assigned to each identity.
- Anonymity: any action performed is manifested within a set of indistinguishably acting participants. (The anonymity set)

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

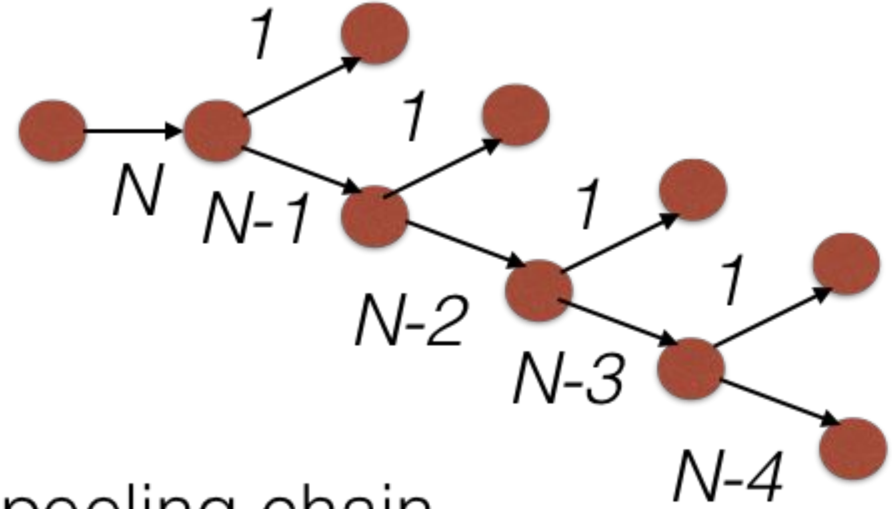




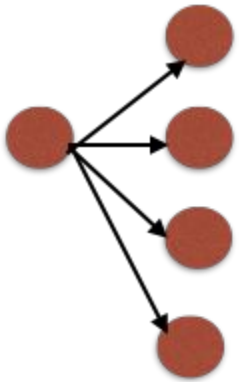
coinbase transaction

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

Common Behaviours



peeling chain



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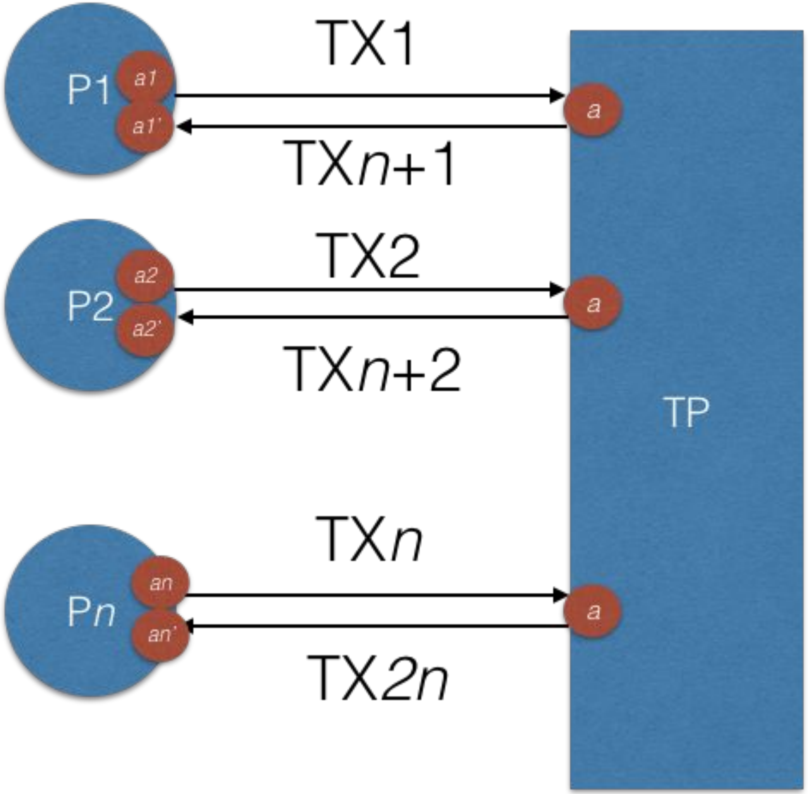
Fungibility and Privacy

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

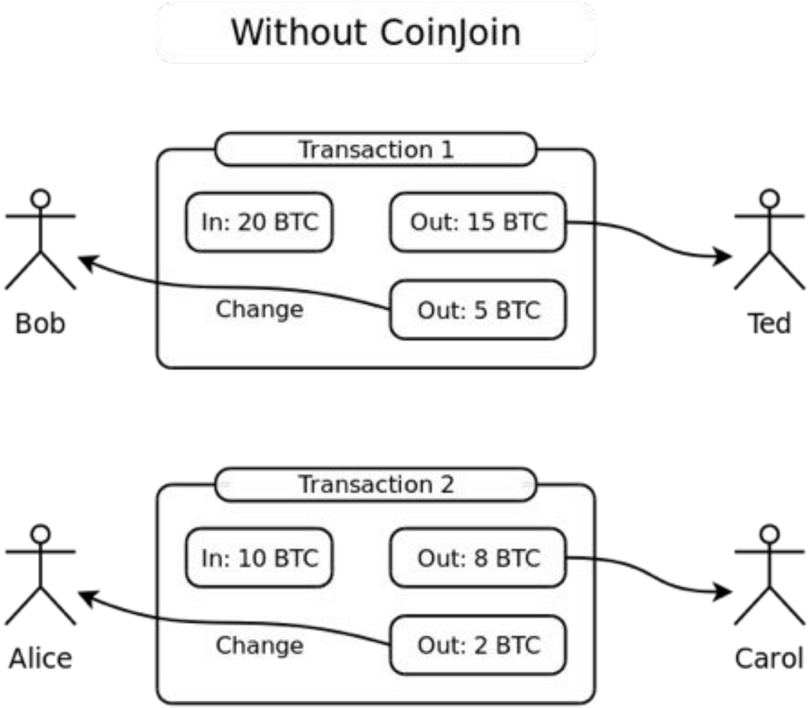
Anonymising Transactions



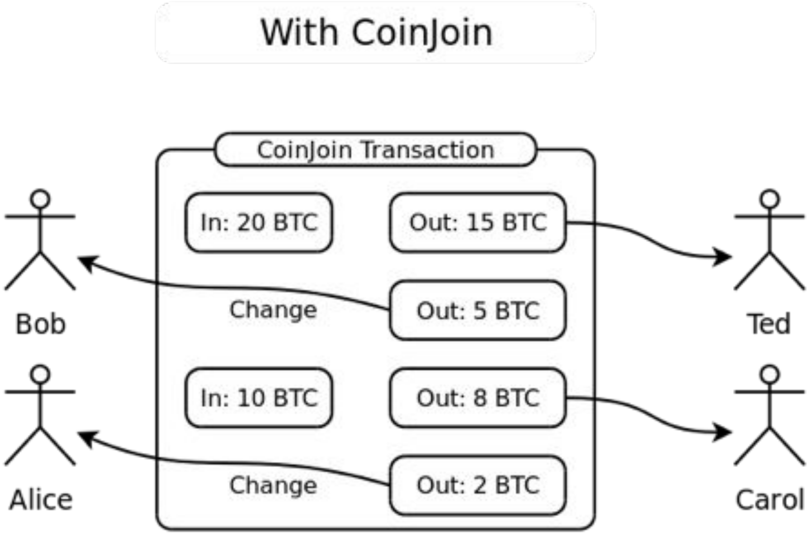
Anonymity set of size *n*

TP may disappear with the money

CoinJoin



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



With CoinJoin
CoinJoin Transaction
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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?

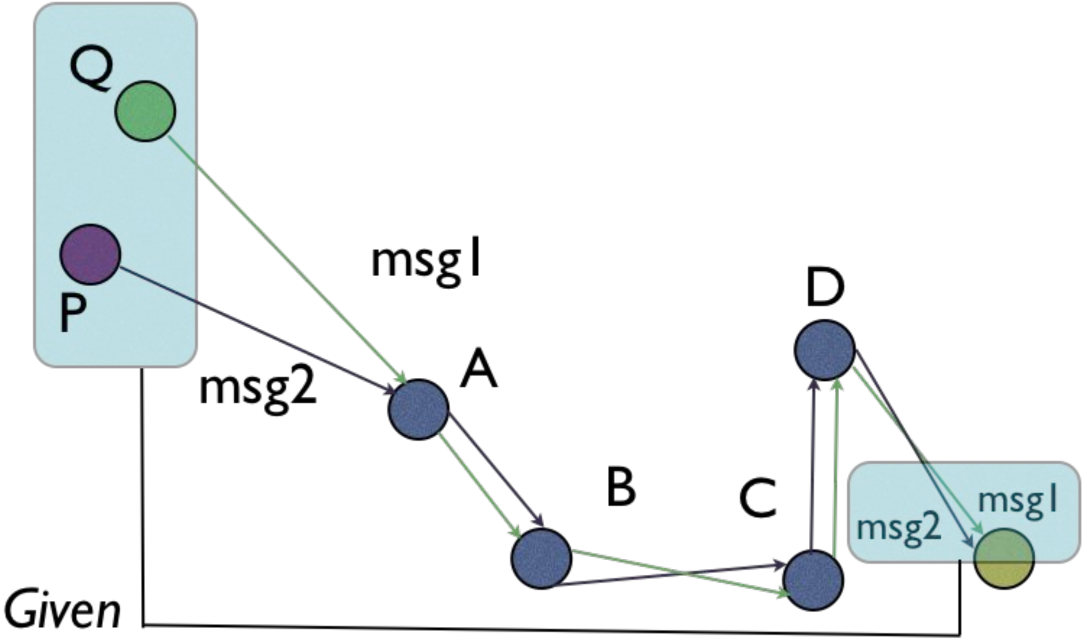
Passive vs Active Attacks

- 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

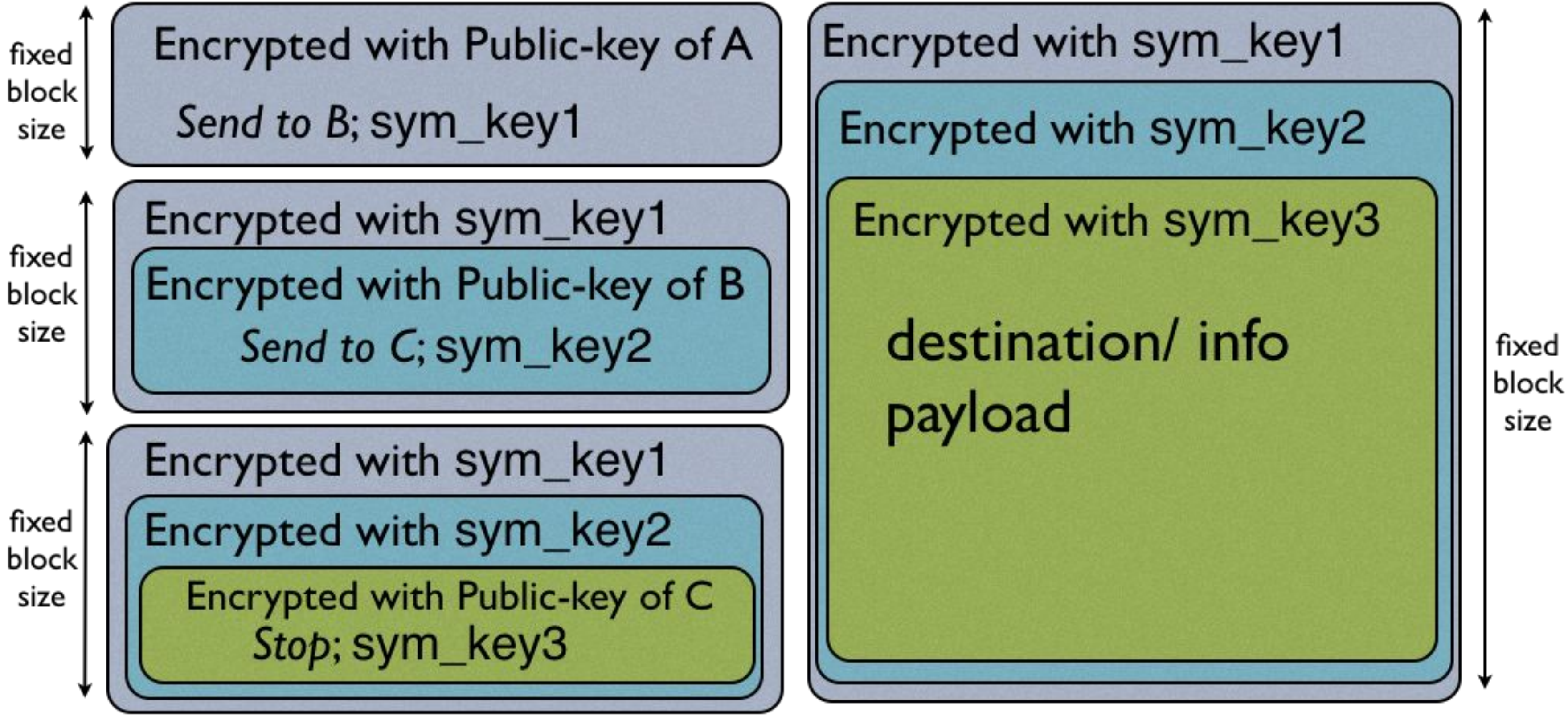
- Facilitates a sender-anonymous broadcast.
  - Decryption mix-nets.
  - Re-encryption mix-nets.

Mix-net, 2

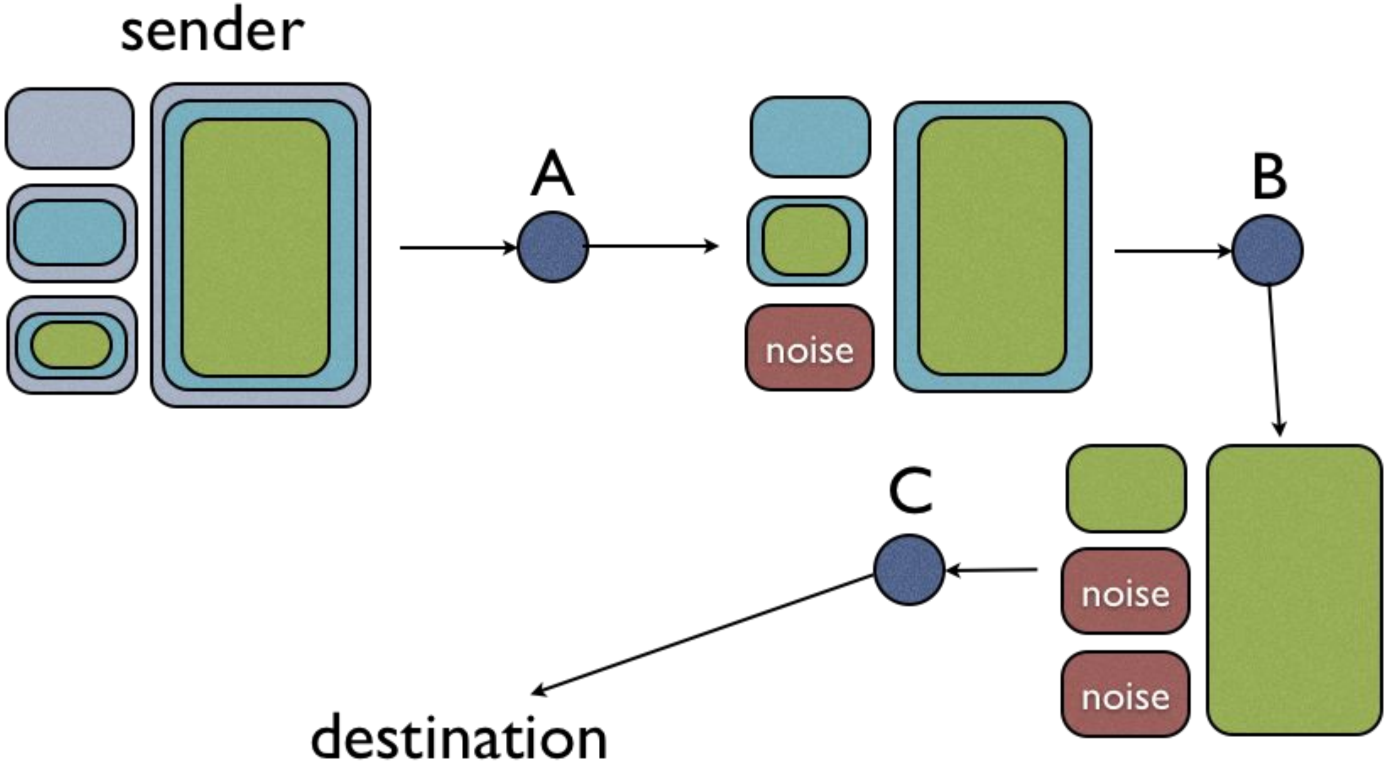


Not possible to relate whether P send msg1 or msg2 and similarly for Q (as long as there is one honest mix)

Decryption Mix-net



Routing via a Mix-net

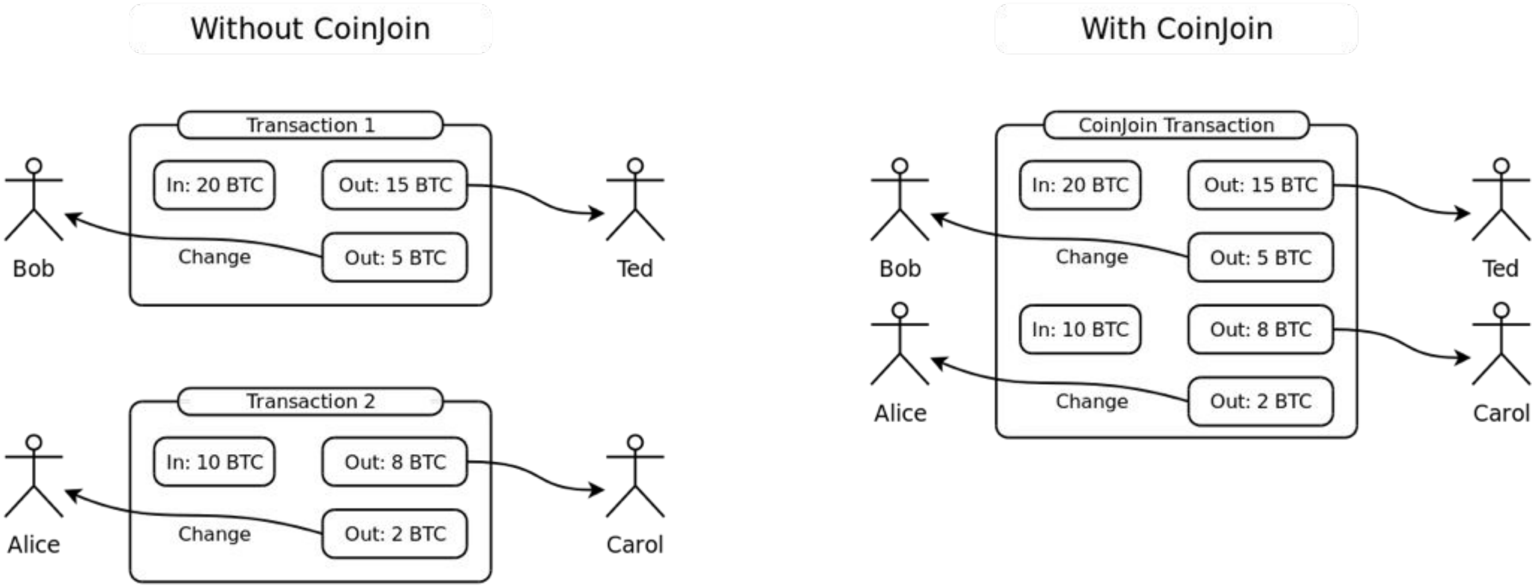


Mix-net for Coinjoin transactions

- 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 *a*1’,*a*2’, …, 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

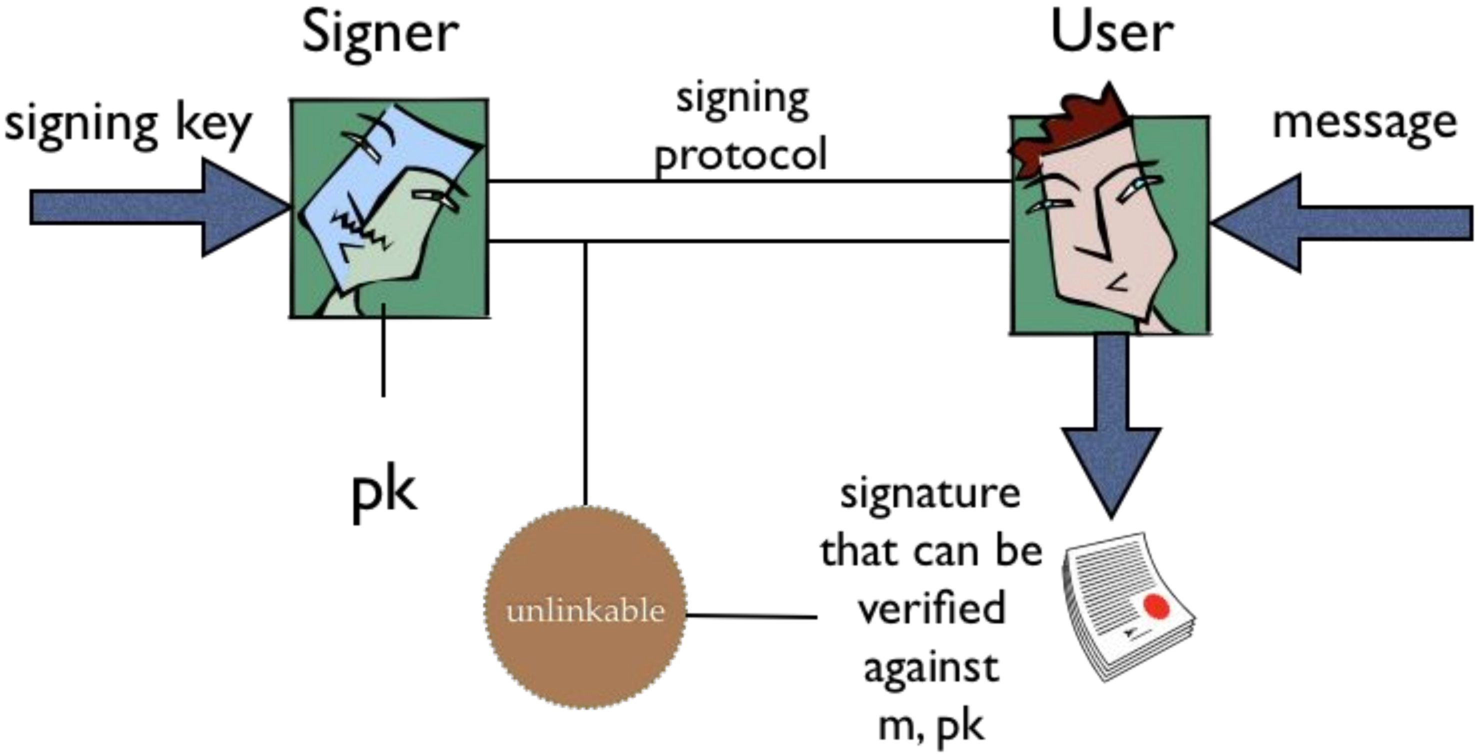
balances
are visible:



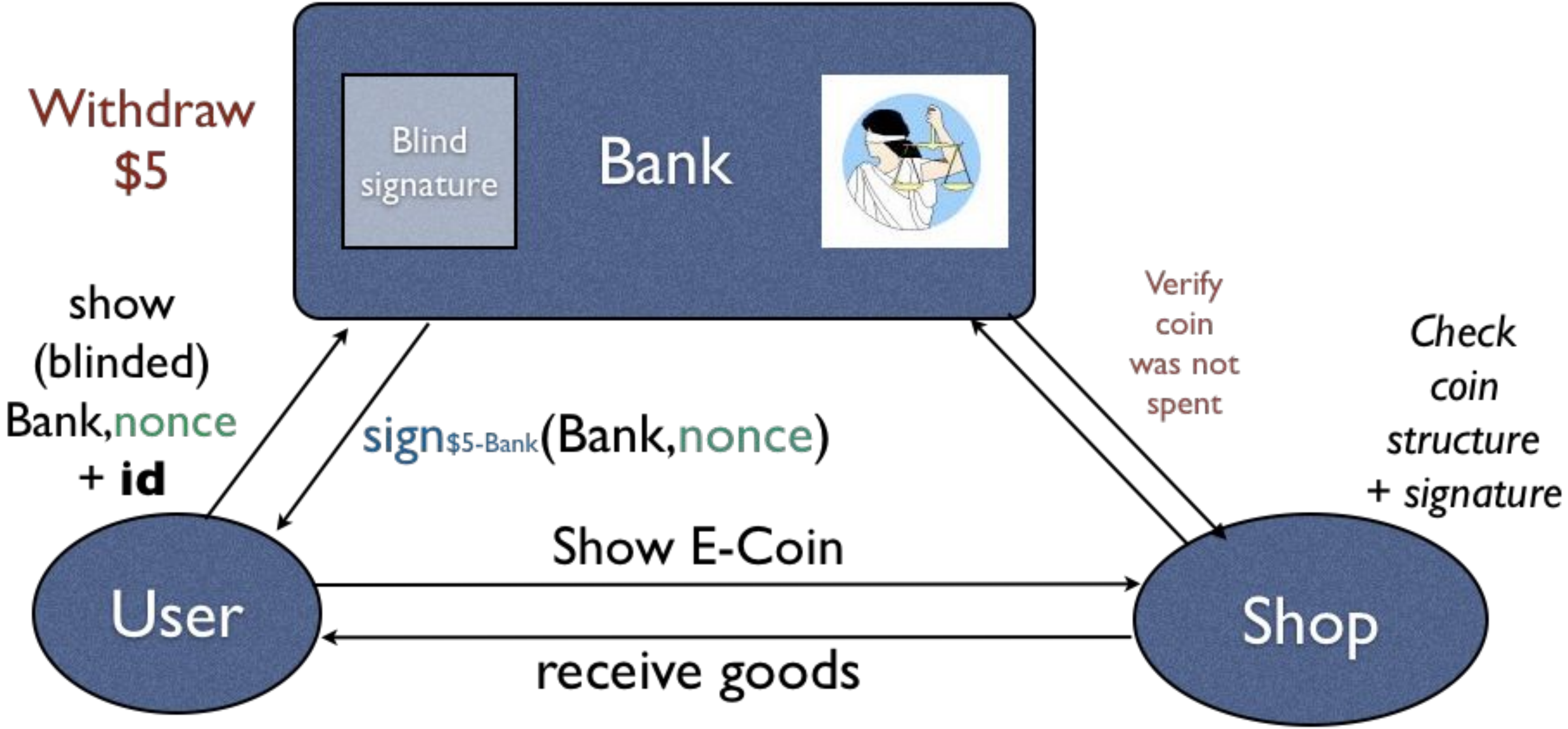
Coordination

- Coinjoin & similar techniques require coordination and message passing between the parties engaged in the transaction.
- Is it possible to improve that?
  a. Using an intermediate party.
  b. Using more advanced cryptographic techniques.

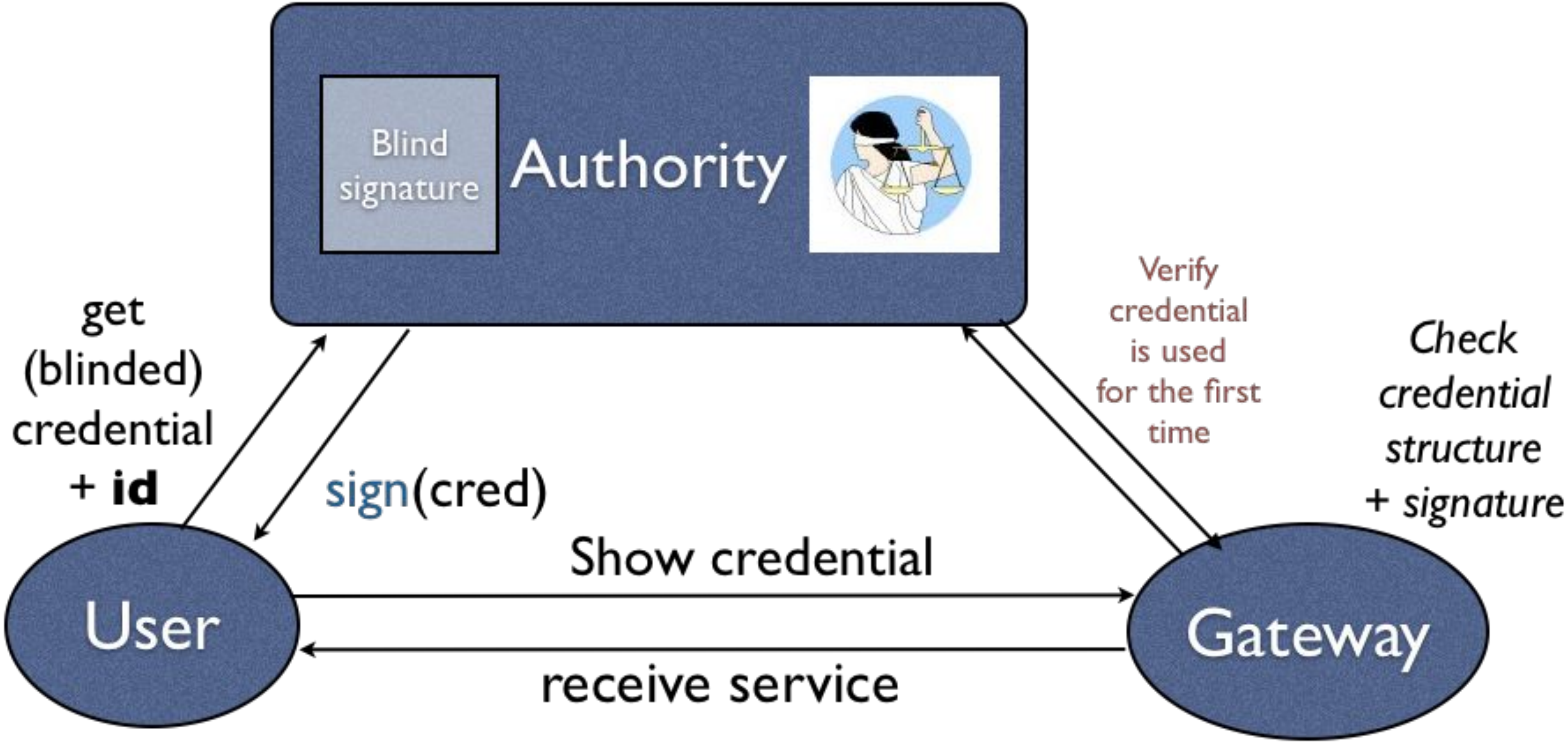
Blind-Signatures



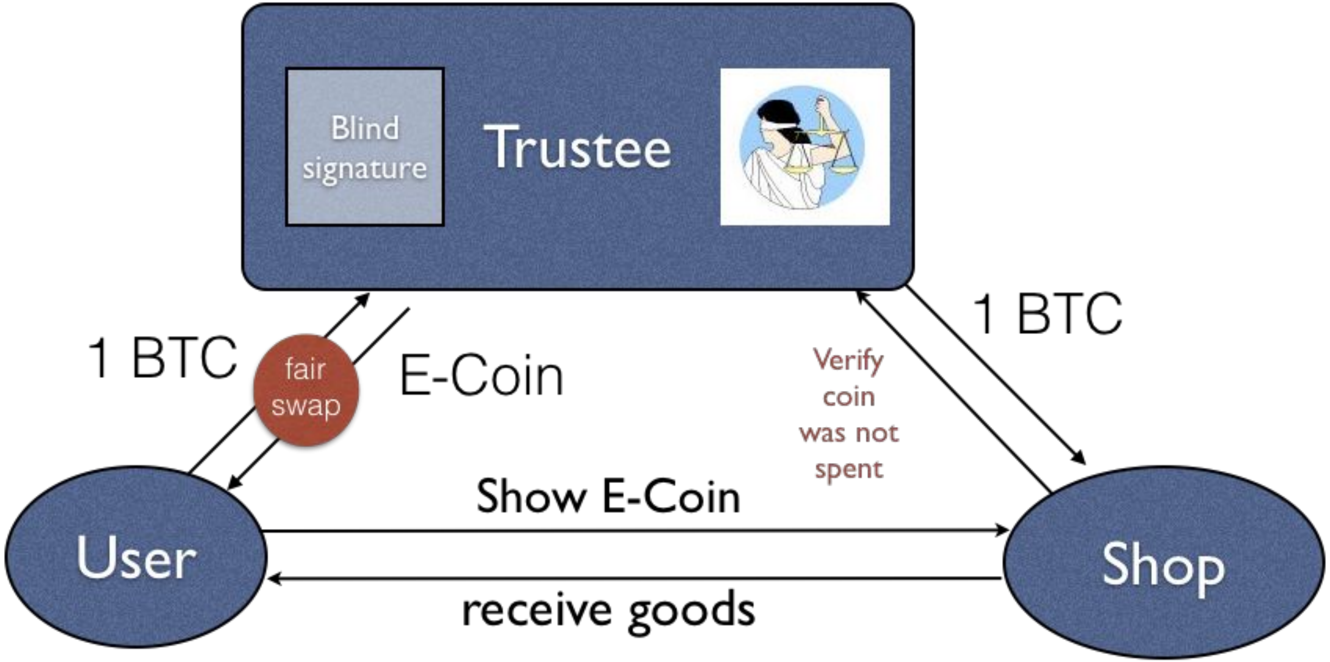
Chaum’s E-cash



Anonymous Credentials



Anonymizing Bitcoin Payments via E-cash



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

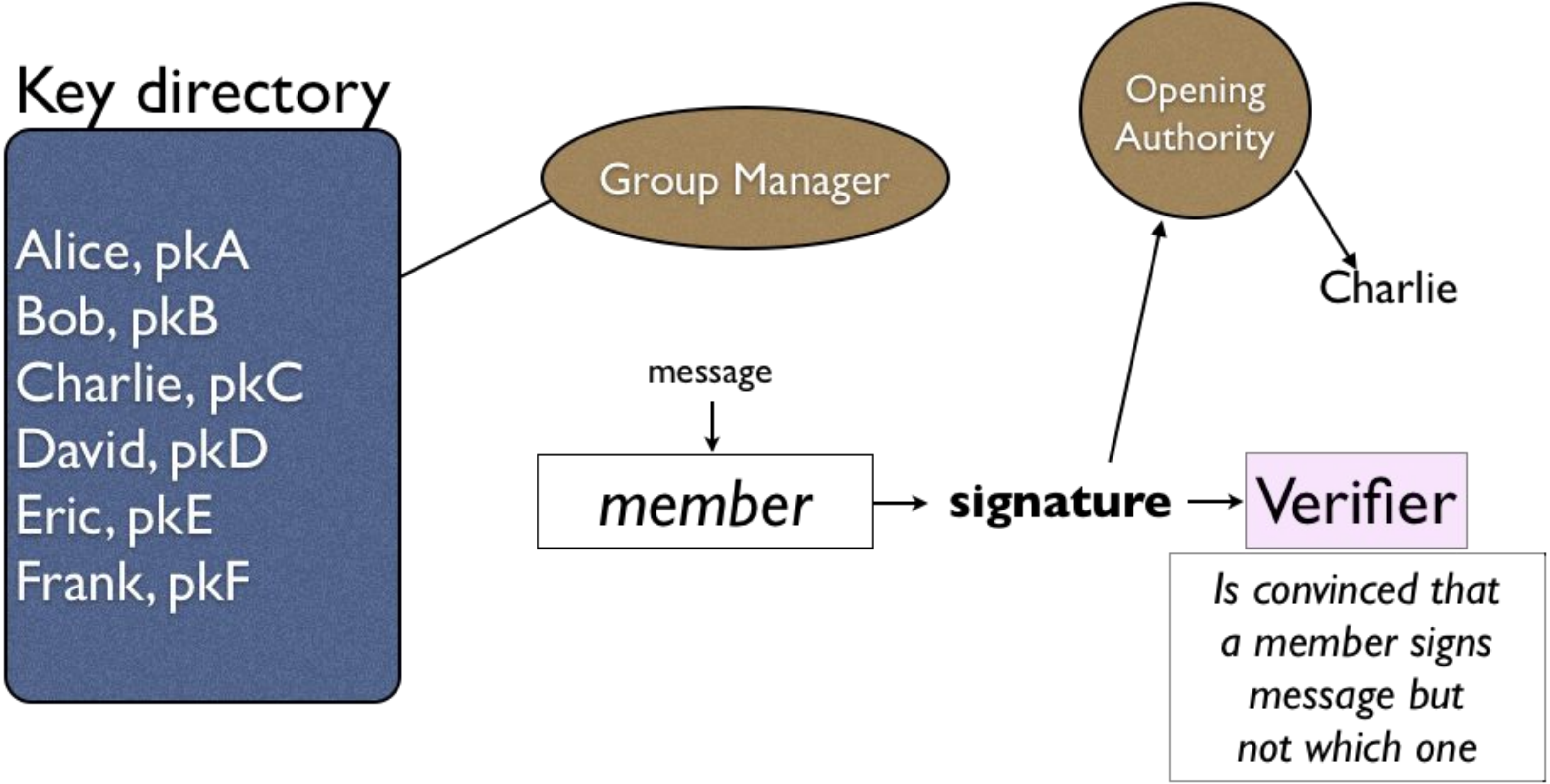
Fair Swaps

- 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

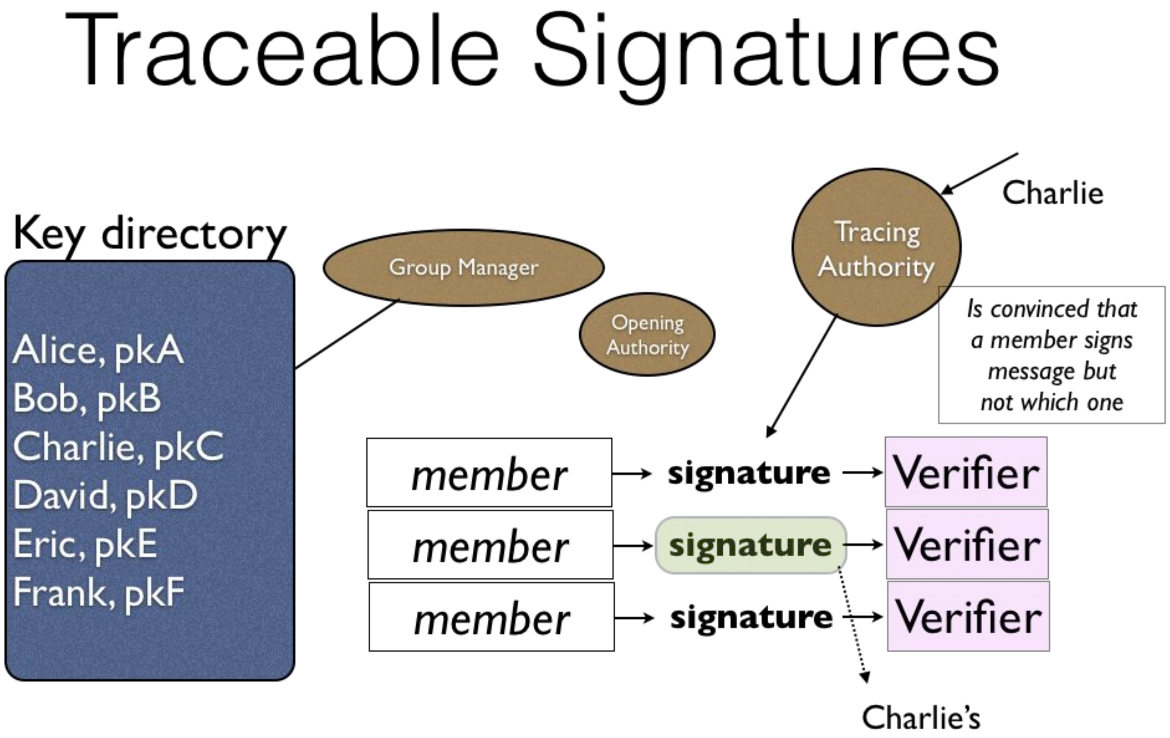
Anonymity and Digital Signatures

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

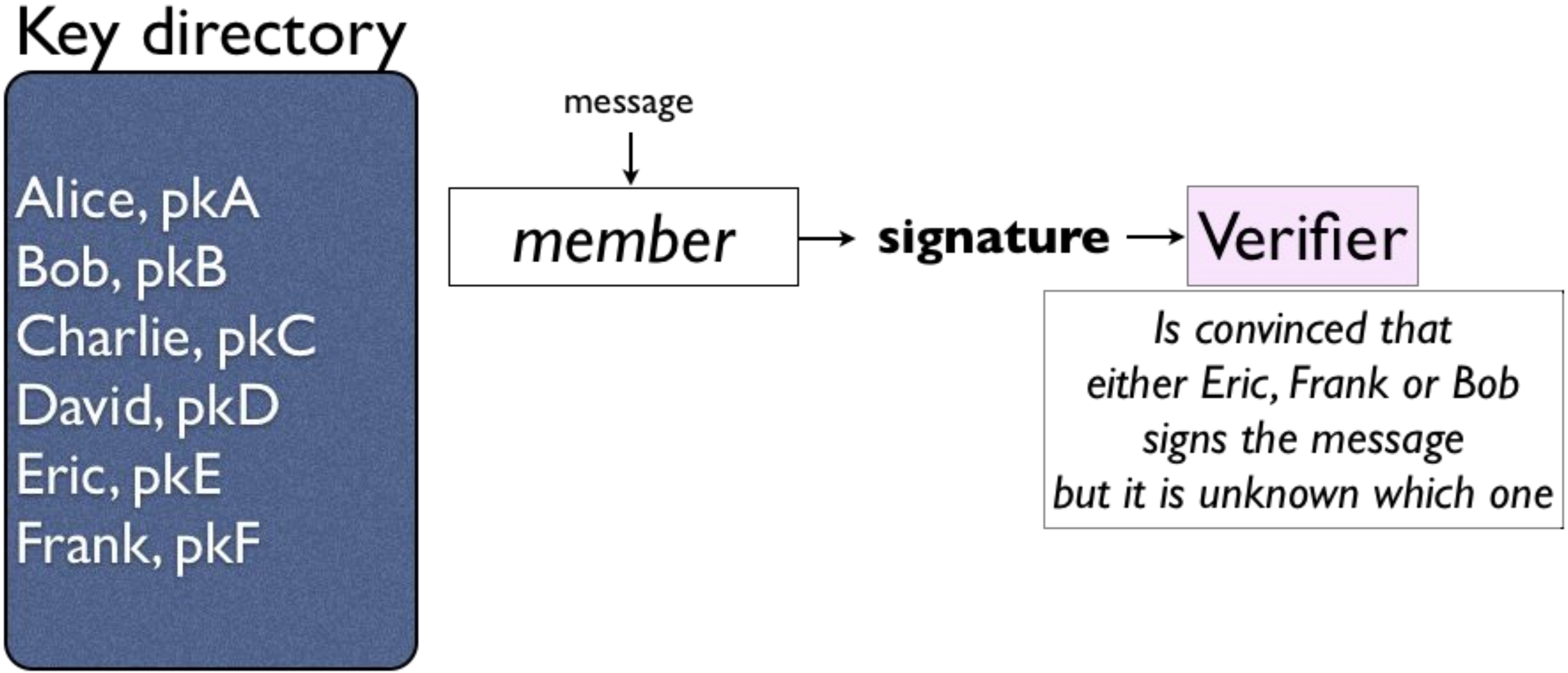
Group Signatures



Traceable Signatures



Ring Signatures



Monero/Cryptonote

- Uses *“stealth” addresses* and *linkable ring signatures* to provide better anonymity.
    a. For each payment an anonymity set is selected with accounts of the same monetary value.
    b. A ring signature is issued on behalf of that set, suitably restricted so that an account can only be used once (if twice it is *linkable*).
    c. 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

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

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)

$$\underline{\exists i : \psi_i} = \mathrm{Commit}(\rho, sn)$$

existential quantifier over all commitments in the blockchain

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 ρ).

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-SNARKs

- 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 ψ_1, ψ_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_{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)