CISPA
HELMHOLTZ CENTER FOR INFORMATION SECURITY

A Holistic Security Analysis of Monero Transactions


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DFG

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Monero and RingCT

Monero and RingCT

- Privacy-Focused Currency
- 2.5 Billion USD Market Cap

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- Transactions: RingCT

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  - Linkable Ring Signatures
  - Commitments
  - Range Proofs
  - Stealth Addresses

Monero and RingCT

- Privacy-Focused Currency
- 2.5 Billion USD Market Cap
- Transactions: RingCT

Is RingCT secure?

- Linkable Ring Signatures
- Commitments
- Range Proofs
- Stealth Addresses

Prior Work on RingCT

Prior Work on RingCT

Security for Building Blocks

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Security for Building Blocks

Composability?

Prior Work on RingCT

Security for Building Blocks

Security for New Schemes

Composability?

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Implications for RingCT?

Prior Work on RingCT

Security for Building Blocks

Security for New Schemes

Composability?

Implications for RingCT?

Is RingCT secure?

Our Work: Abstraction and Security Model

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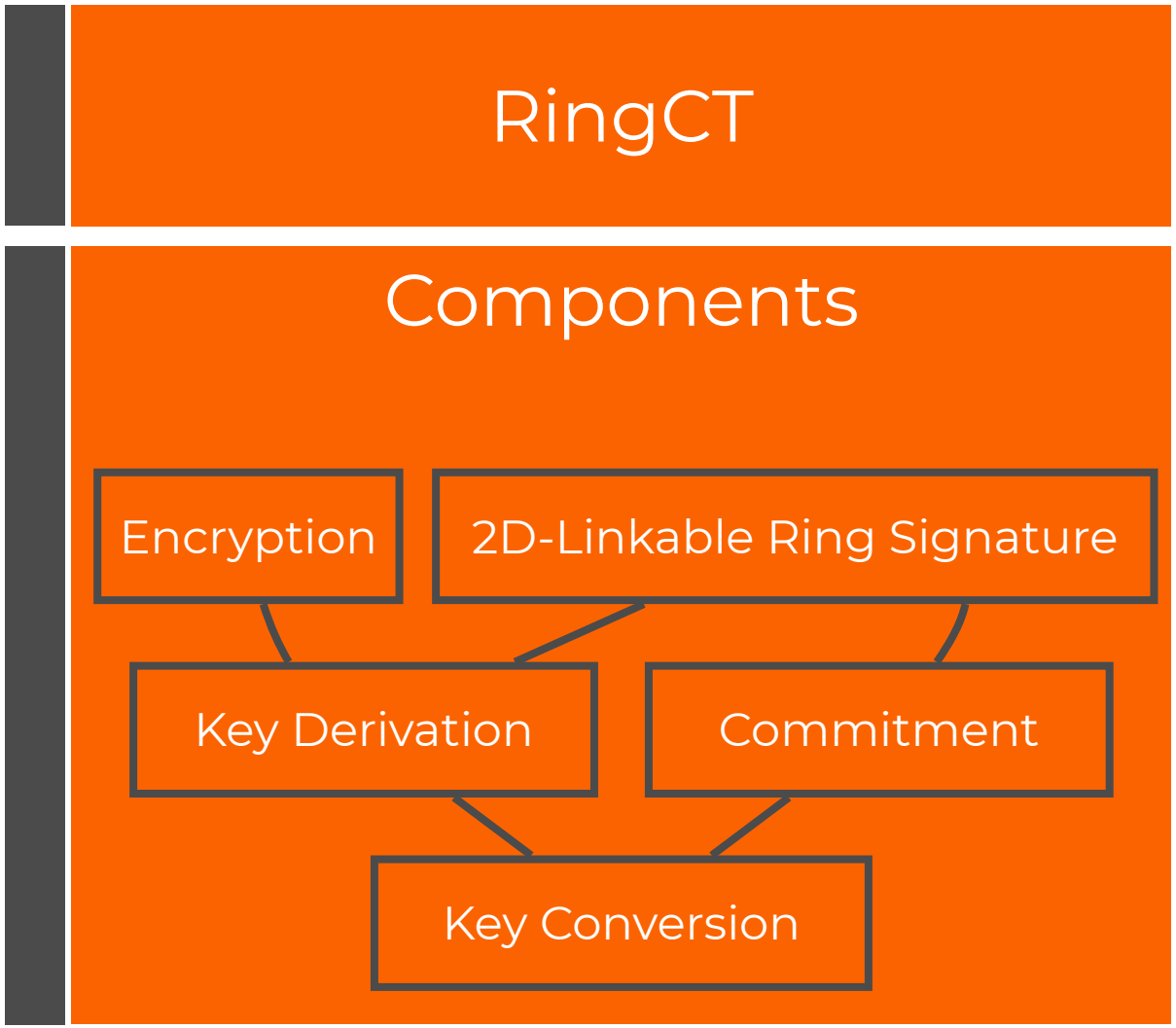


Our Work: Abstraction and Security Model

RingCT

Components

Encryption

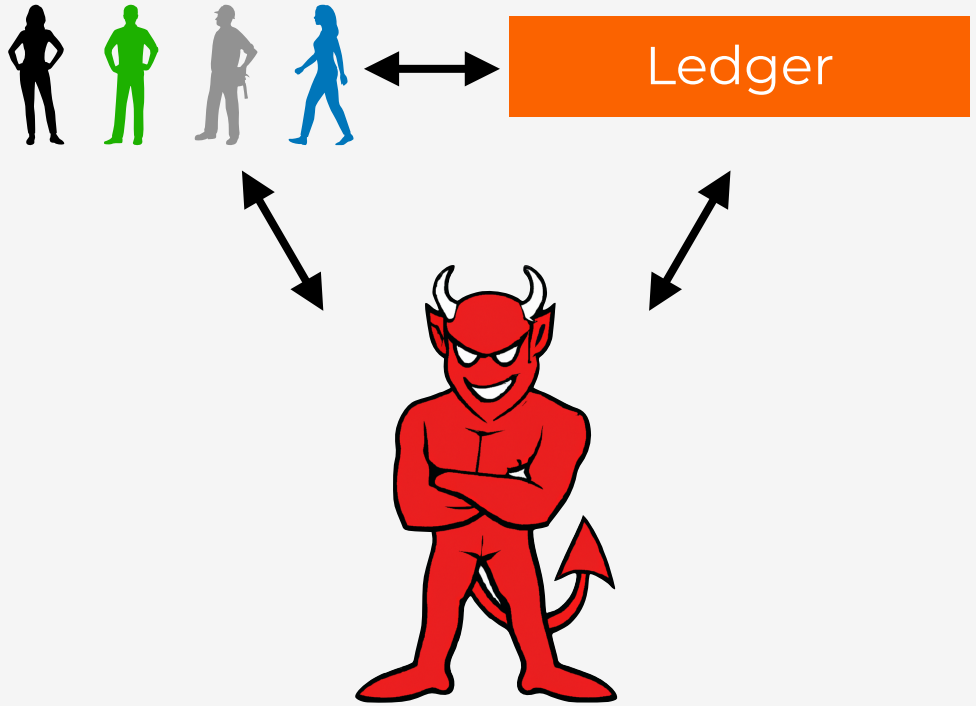
2D-Linkable Ring Signature

Key Derivation

Commitment

Key Conversion

Security Definition



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RingCT

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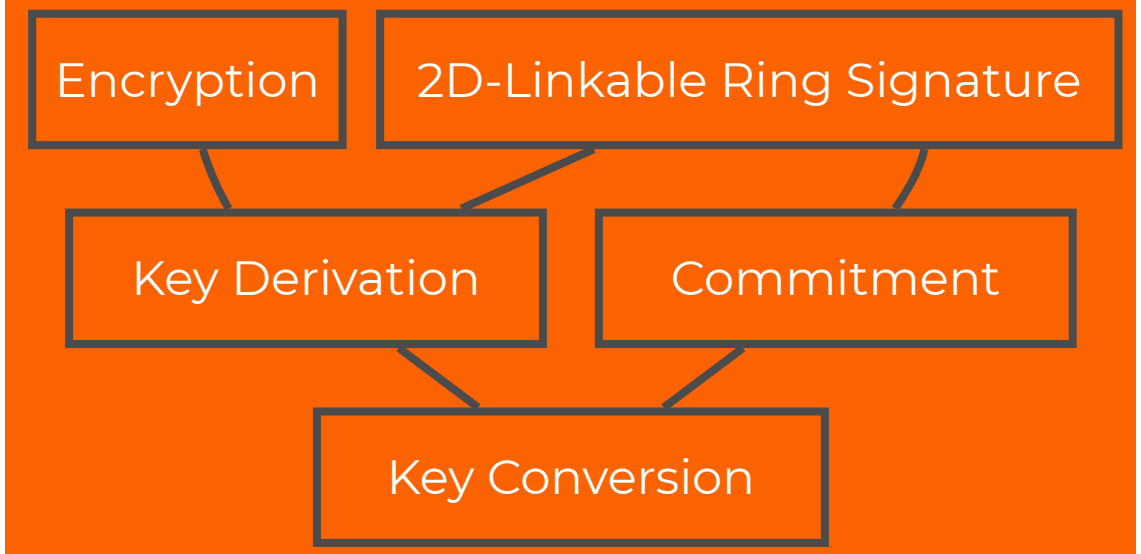

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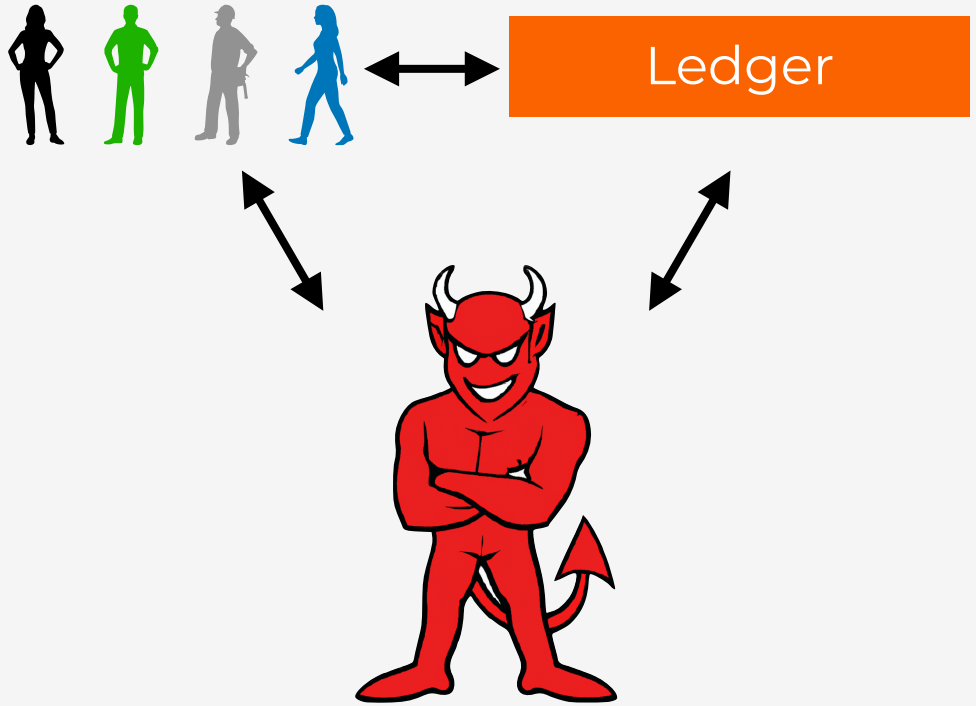
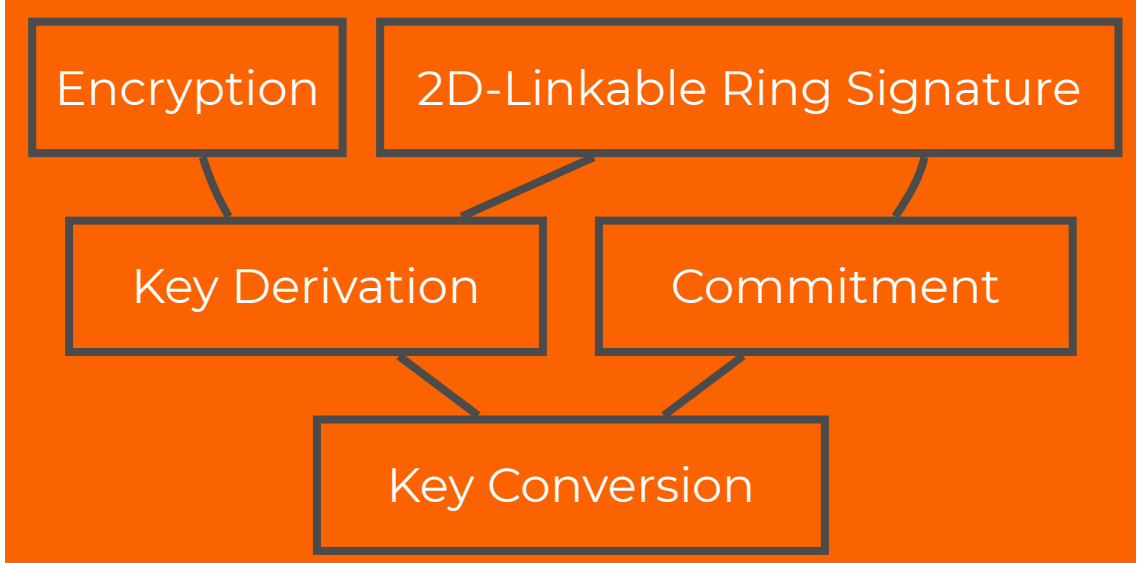


1. *Adversary can not steal coins.*

Our Work: Abstraction and Security Model

RingCT

Components



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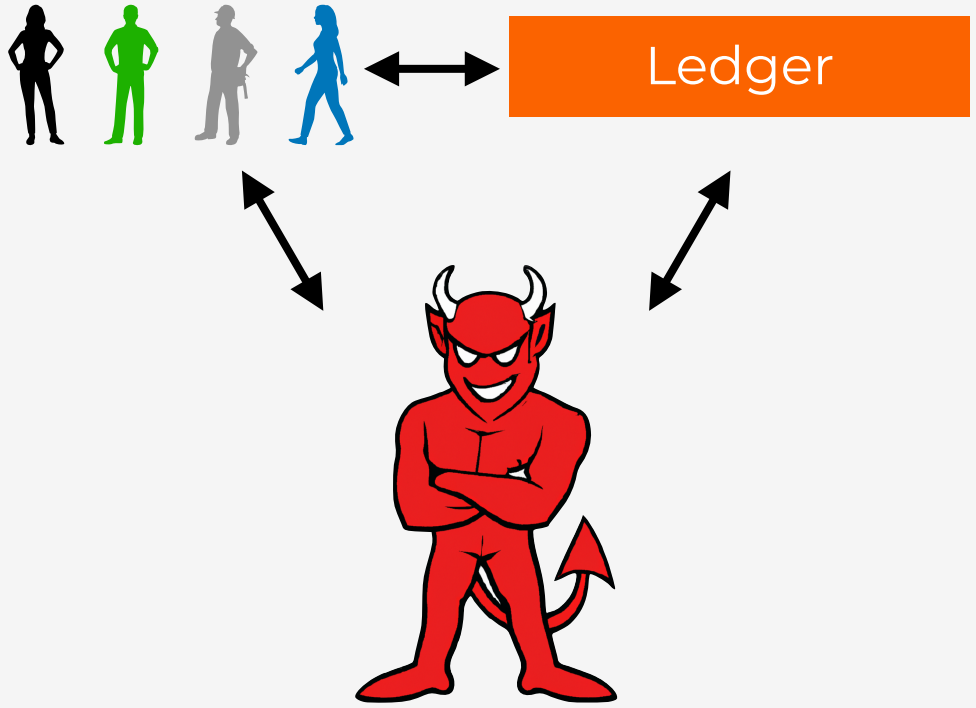

1. *Adversary can not steal coins.*
2. *Adversary can not create coins.*

Our Work: Security Analysis

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Security of RingCT

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Security of RingCT

Security of Components

Our Work: Security Analysis

Security of RingCT

Security of Components

2D-Linkable Ring Signature

Key Derivation

Knowledge Soundness

Knowledge Linkability

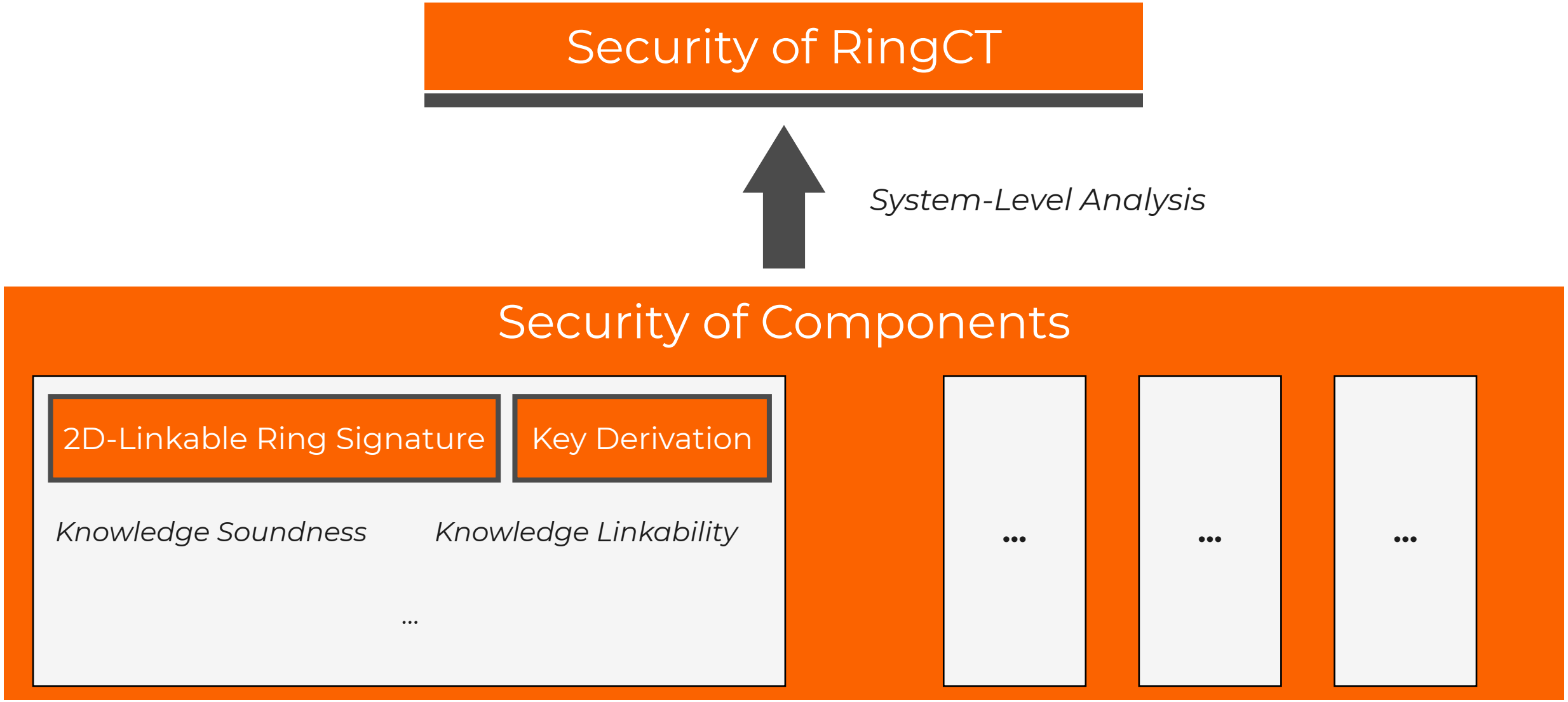
...

...

...

...

Our Work: Security Analysis



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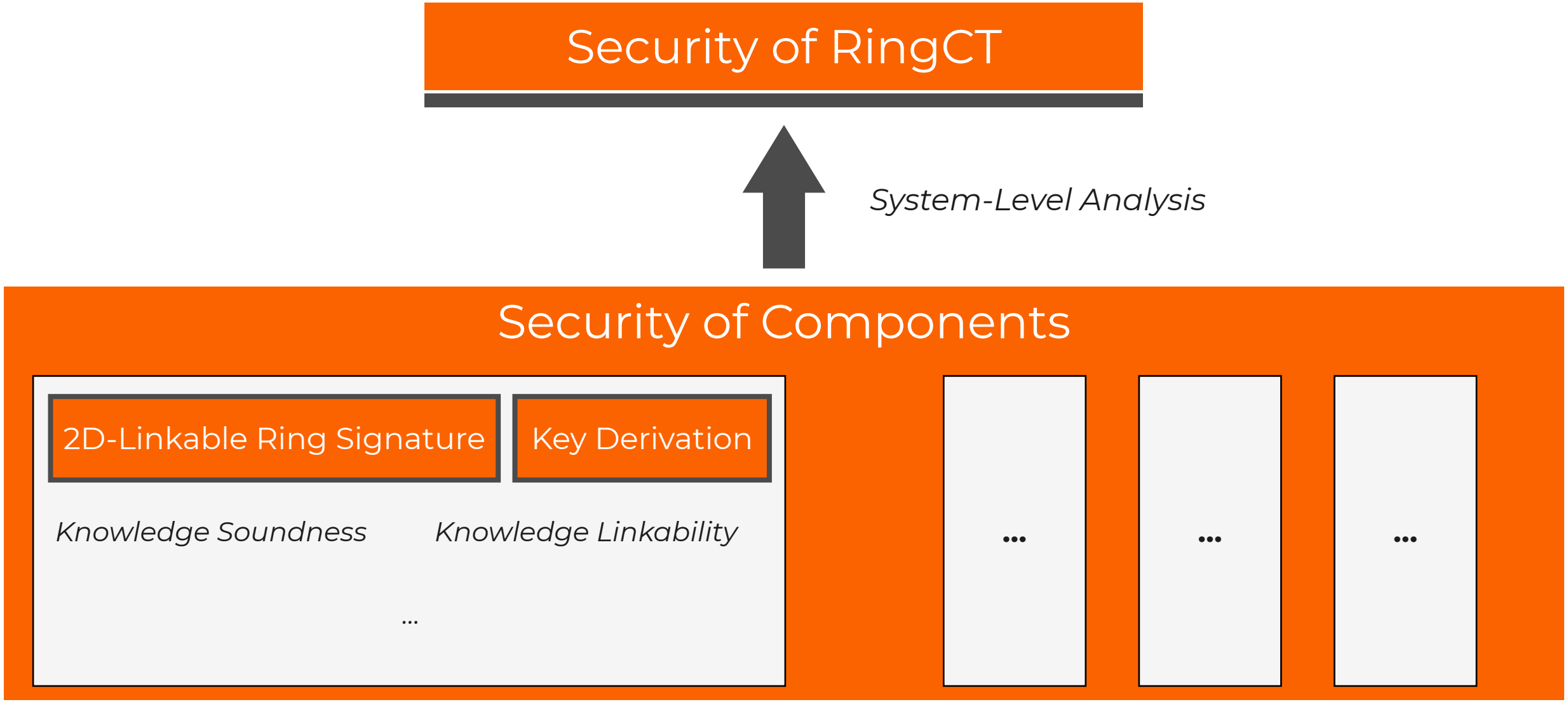

Outline

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Why is security unclear?

Stealth Addresses

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What do we prove?

Security Model

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Long Talk

YouTube

Details on RingCT

Proof Techniques

Outline

This Talk

- Why is security unclear?
- Stealth Addresses
- What do we prove?
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Long Talk

YouTube

- Details on RingCT
- Proof Techniques

Anatomy of Transactions

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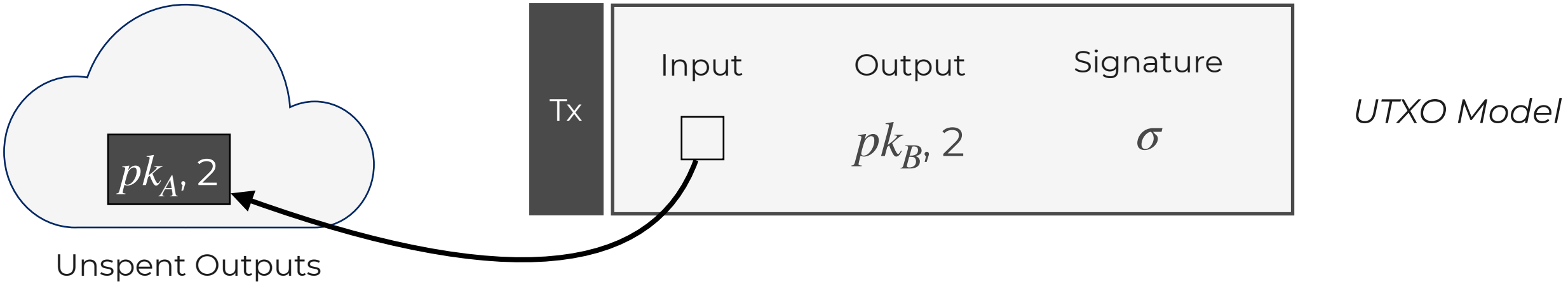

Main Ideas of RingCT

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Hiding Senders

Hiding Amounts

Hiding Receivers

Main Ideas of RingCT

Hiding Senders

Hiding Amounts

Hiding Receivers

Ring Signatures

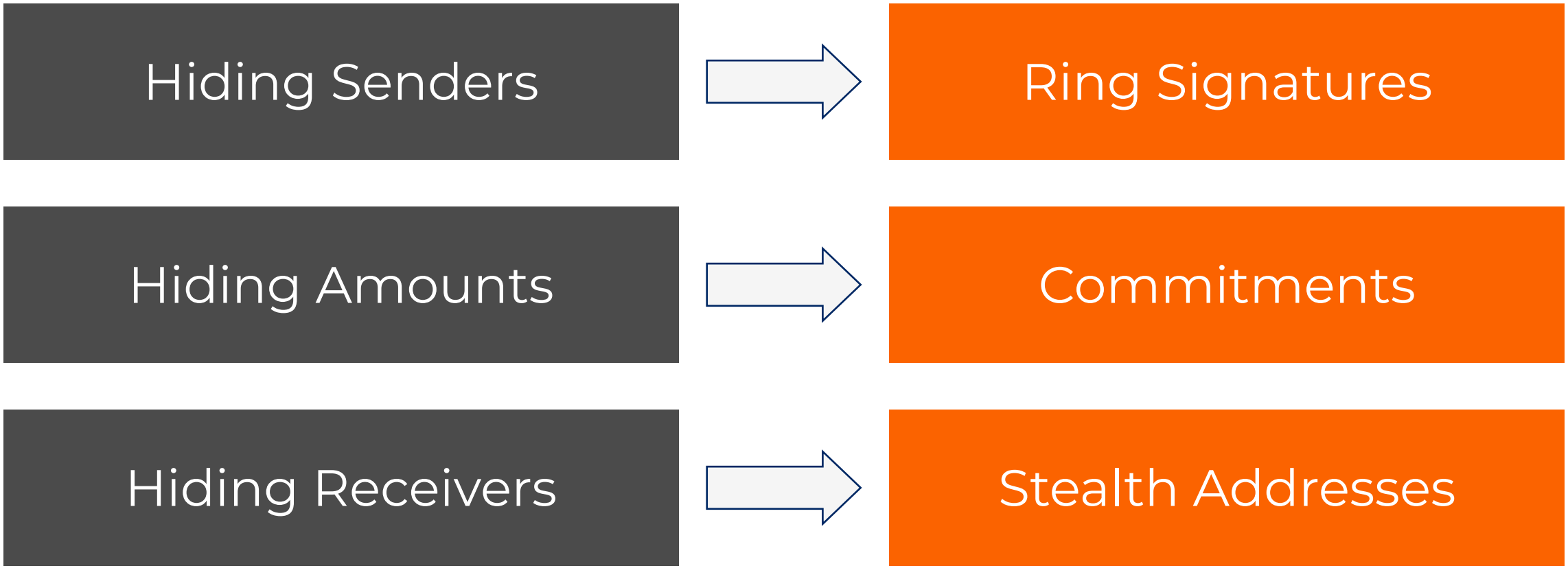
Main Ideas of RingCT

Hiding Senders → Ring Signatures

Hiding Amounts → Commitments

Hiding Receivers

Main Ideas of RingCT



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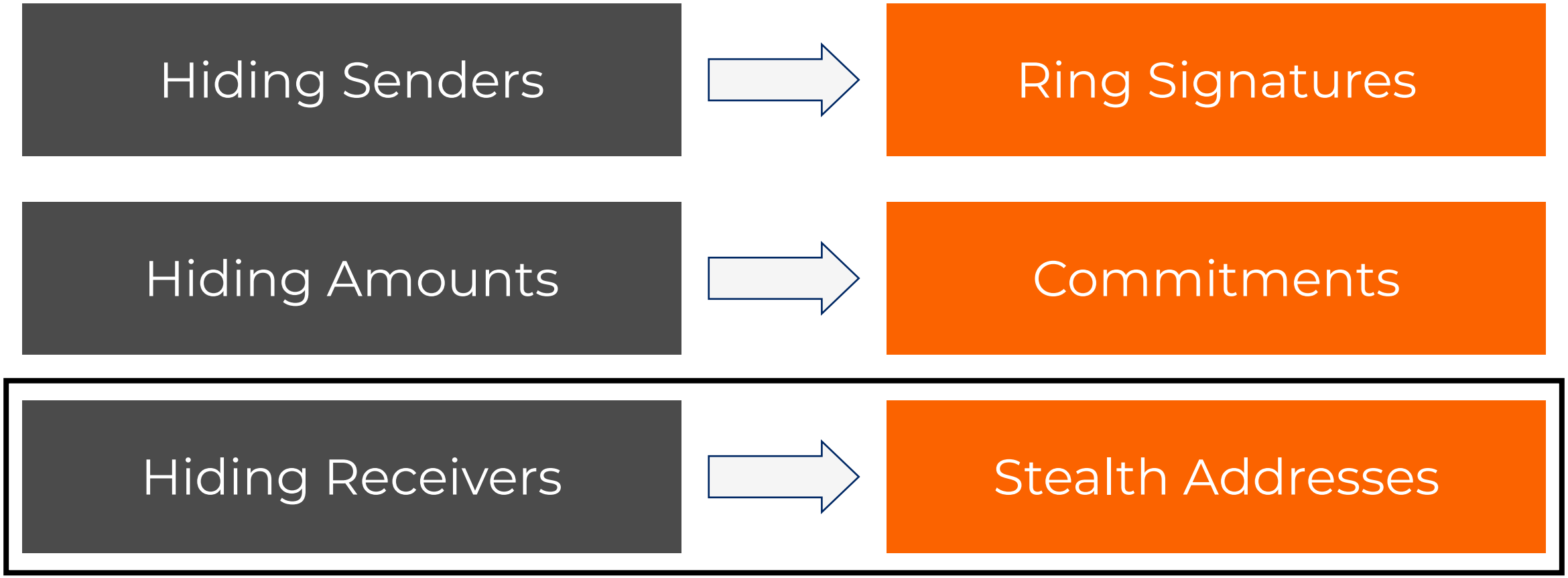

Hiding Receivers with Stealth Addresses

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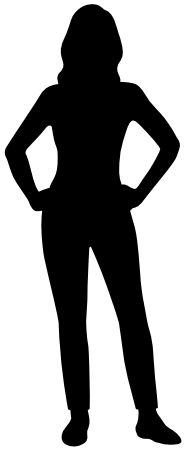

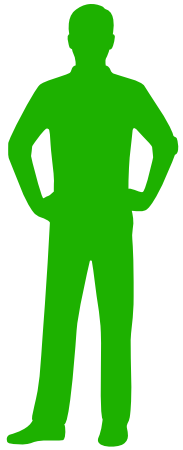

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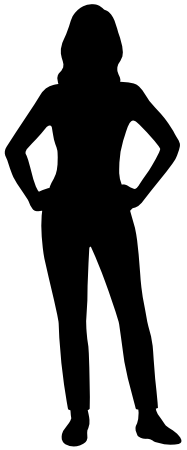

Tx	Inputs	Outputs	Signatures
	$pk_A, 1$		σ_1
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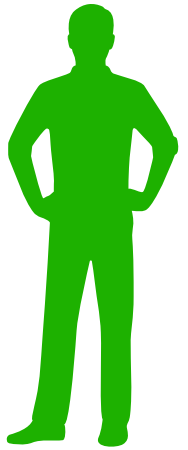

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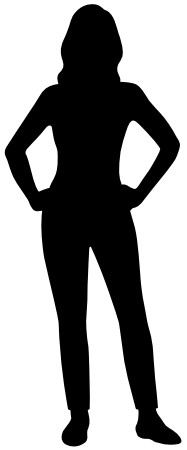

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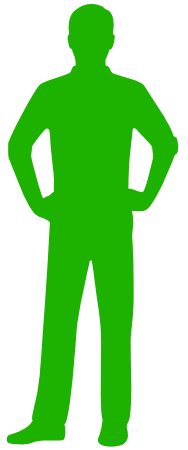
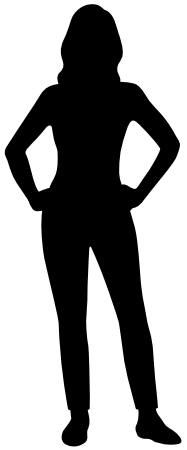


Goal #1: Bob can identify output

Hiding Receivers with Stealth Addresses



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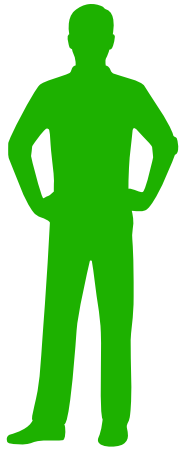
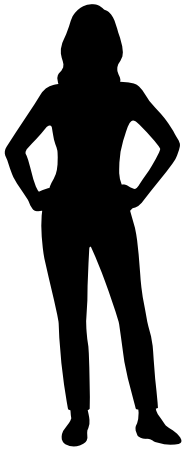


Goal #1: Bob can identify output

Goal #2: No one can link output to Bob

Hiding Receivers with Stealth Addresses



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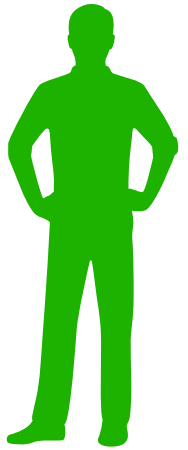

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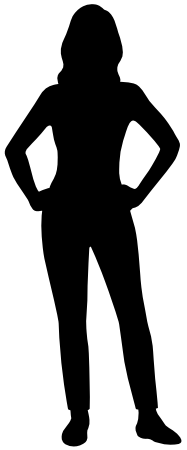
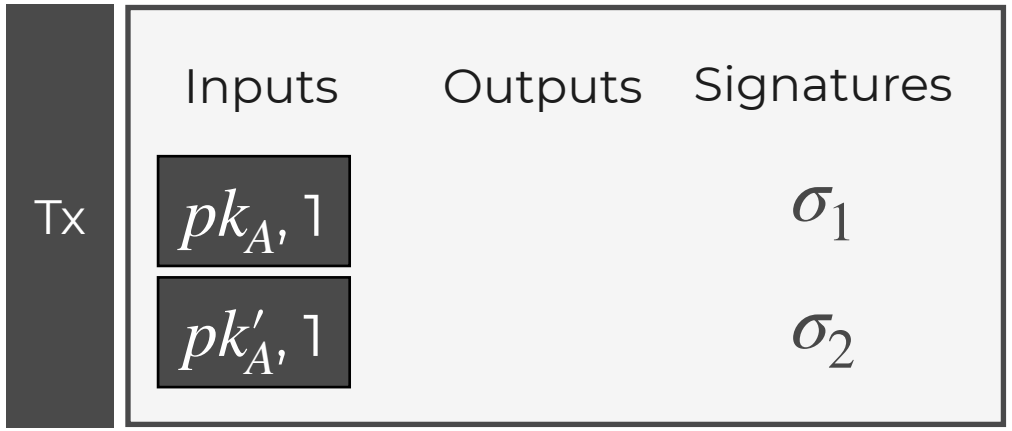
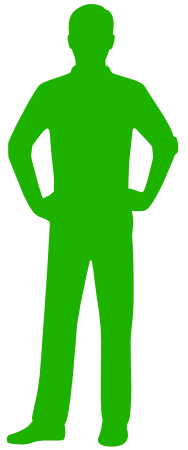
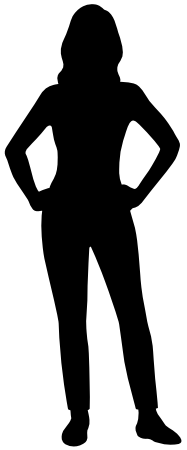






$k_v, k_s \leftarrow \mathbb{Z}_p$

Hiding Receivers with Stealth Addresses



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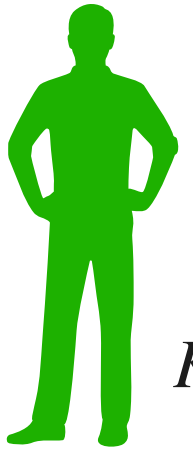
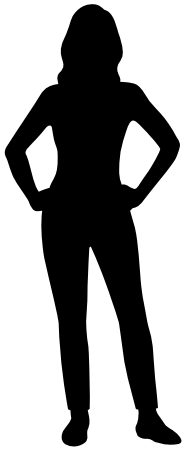


$$k_v, k_s \leftarrow \mathbb{Z}_p$$

$$K_v = g^{k_v},\ K_s = g^{k_s}$$

Hiding Receivers with Stealth Addresses



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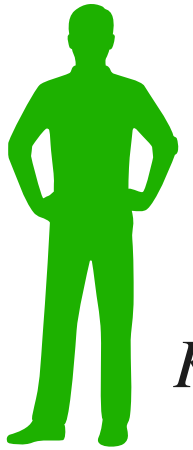

$$k_v, k_s \leftarrow \mathbb{Z}_p$$

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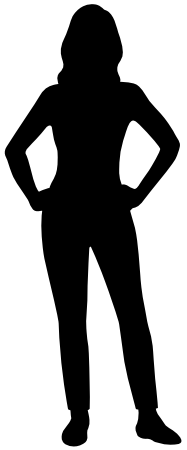
Public Long-Term Key

Hiding Receivers with Stealth Addresses



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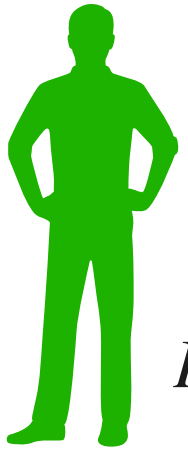

$k_v, k_s \leftarrow \mathbb{Z}_p$

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Public Long-Term Key

$r \leftarrow \mathbb{Z}_p$

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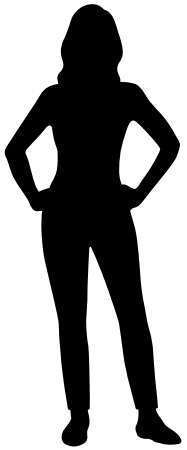

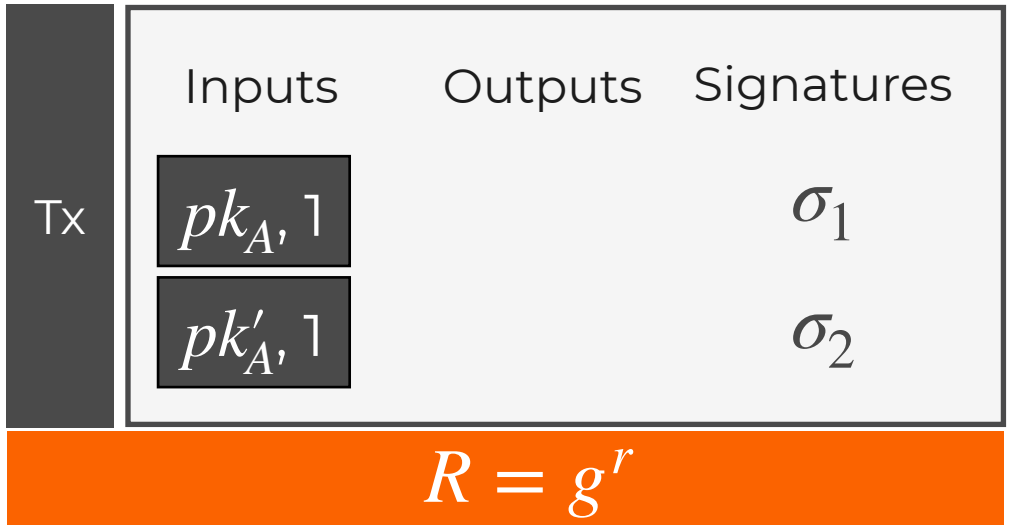

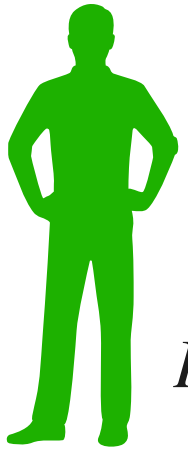

$r \leftarrow \mathbb{Z}_p$

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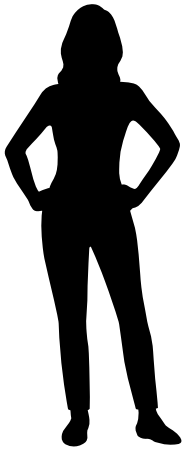

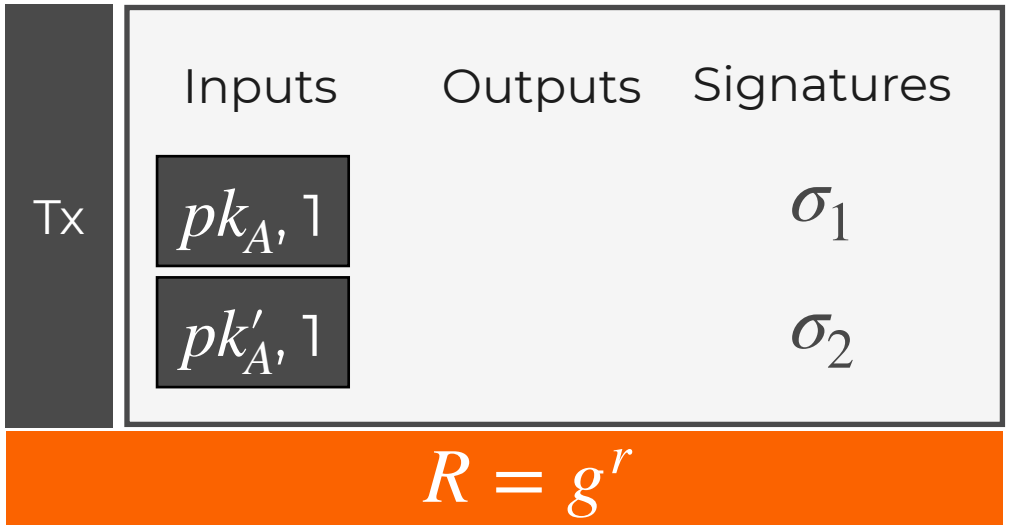

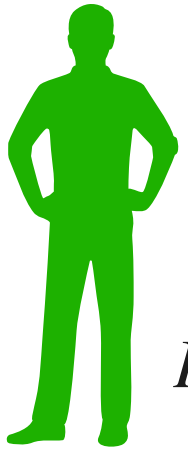

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Public Long-Term Key

$r \leftarrow \mathbb{Z}_p$

$ok := K_v^r$

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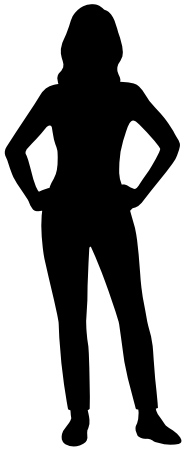

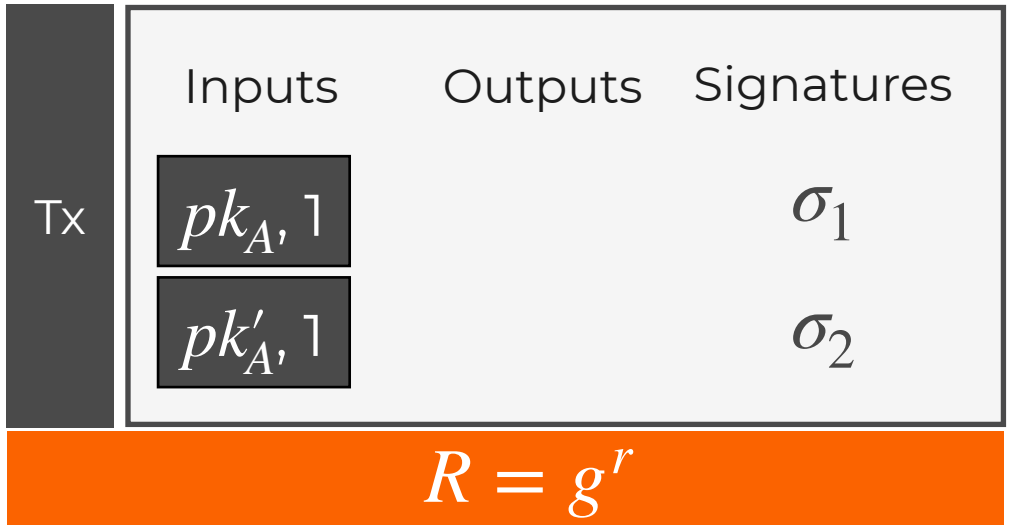

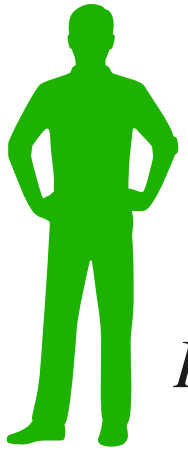

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Public Long-Term Key

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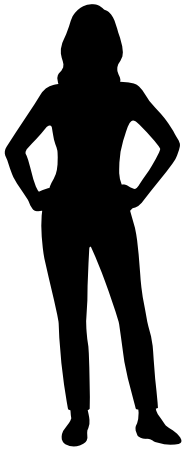
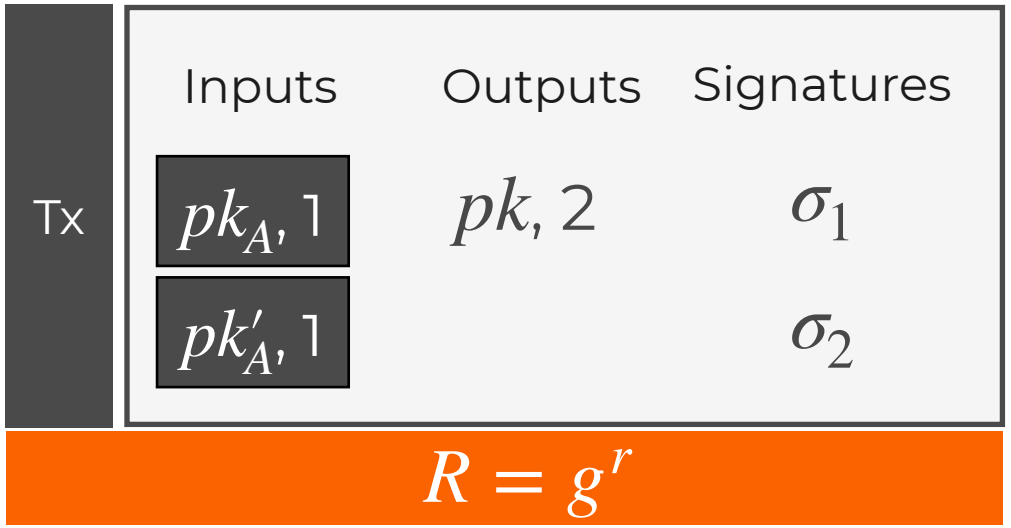
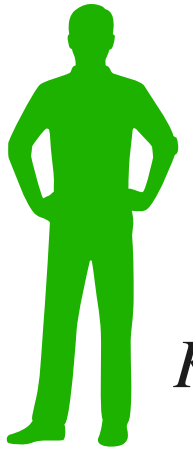
$pk := g^{H(ok)} \cdot K_s$

Hiding Receivers with Stealth Addresses







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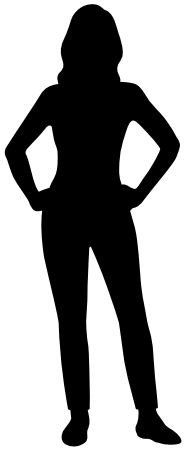

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	$pk_A, 1$	$pk, 2$	σ_1
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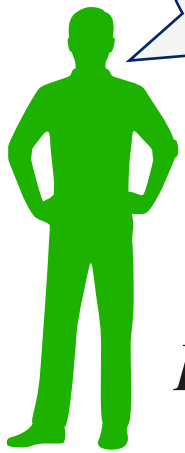
$R = g^r$



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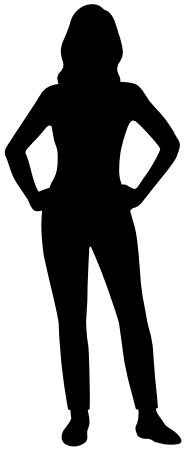

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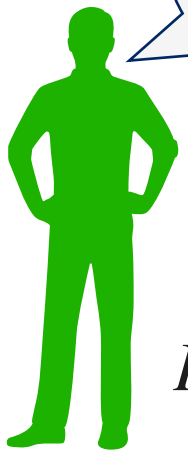

Is this output mine?

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Public Long-Term Key

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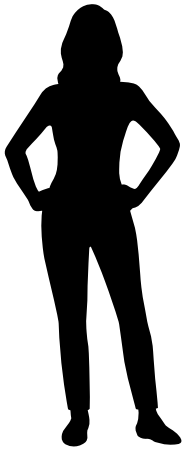
$ok := R^{k_v}$

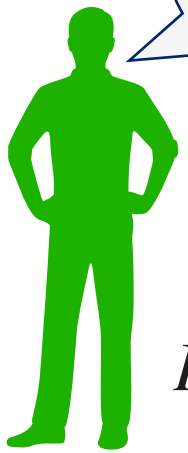
$pk = g^{H(ok)} \cdot K_s$??

Hiding Receivers with Stealth Addresses



Tx	Inputs	Outputs	Signatures
	$pk_A, 1$	$pk, 2$	σ_1
	$pk'_A, 1$		σ_2

$R = g^r$



Is this output mine?

$k_v, k_s \leftarrow \mathbb{Z}_p$

$K_v = g^{k_v}, K_s = g^{k_s}$

Public Long-Term Key

$r \leftarrow \mathbb{Z}_p$

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$ok := R^{k_v}$

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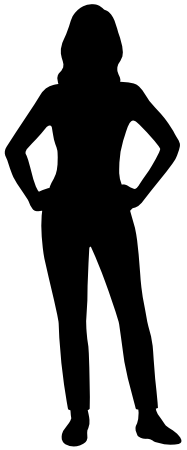
Hiding Receivers with Stealth Addresses



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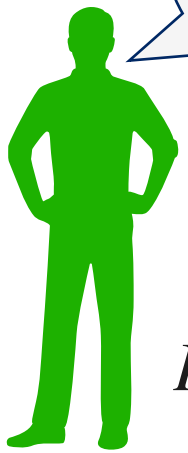

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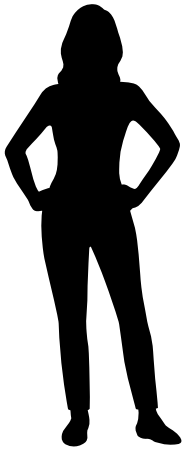

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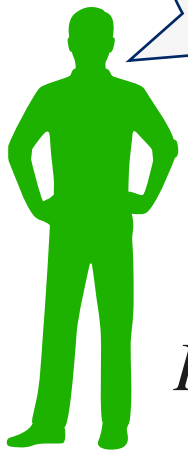

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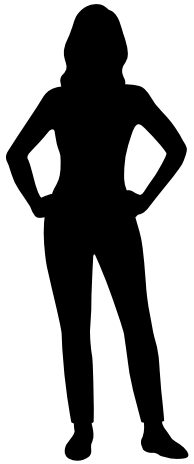
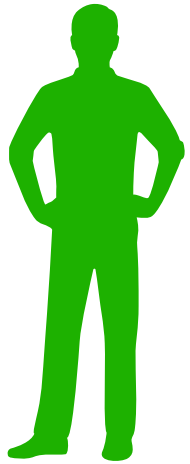
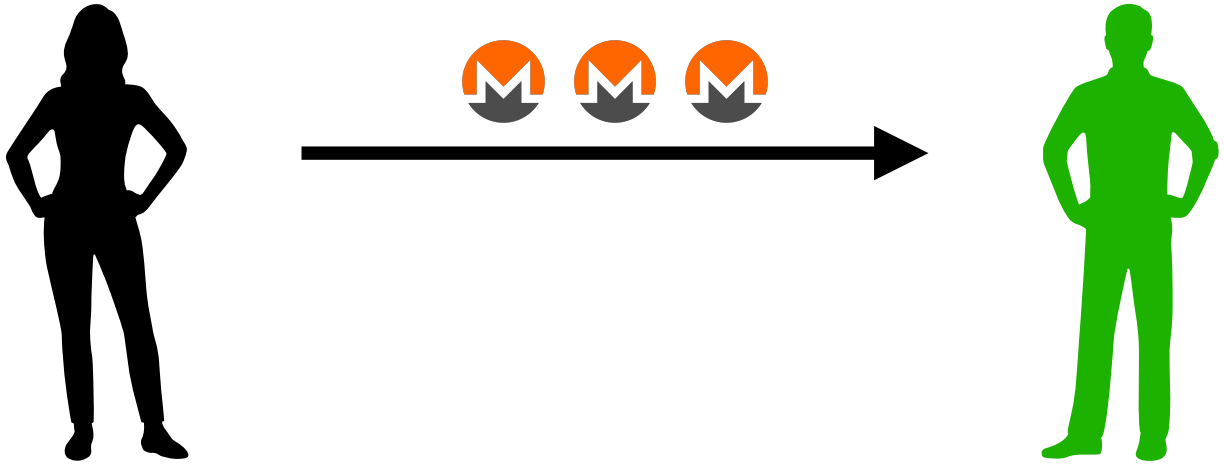
Hiding Receivers with Stealth Addresses

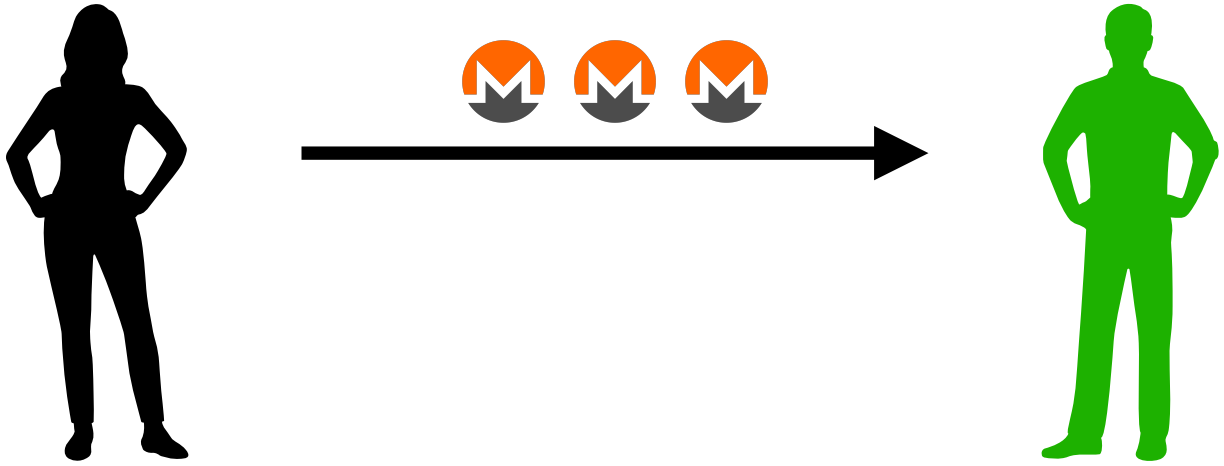




Hiding Receivers with Stealth Addresses

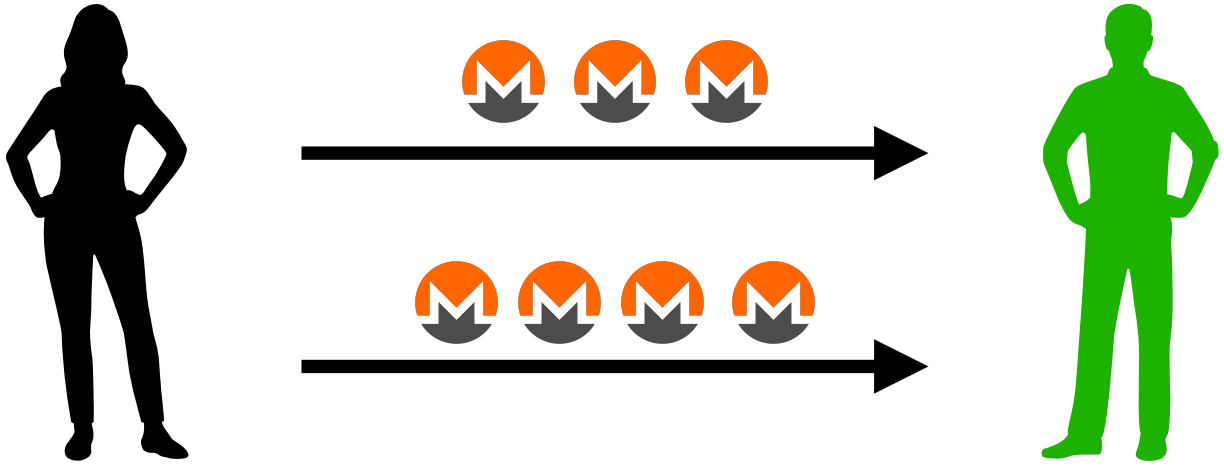


Hiding Receivers with Stealth Addresses



$$pk_1 = g^{H(ok_1)} \cdot K_s$$

Hiding Receivers with Stealth Addresses



$$pk_1 = g^{H(ok_1)} \cdot K_s$$

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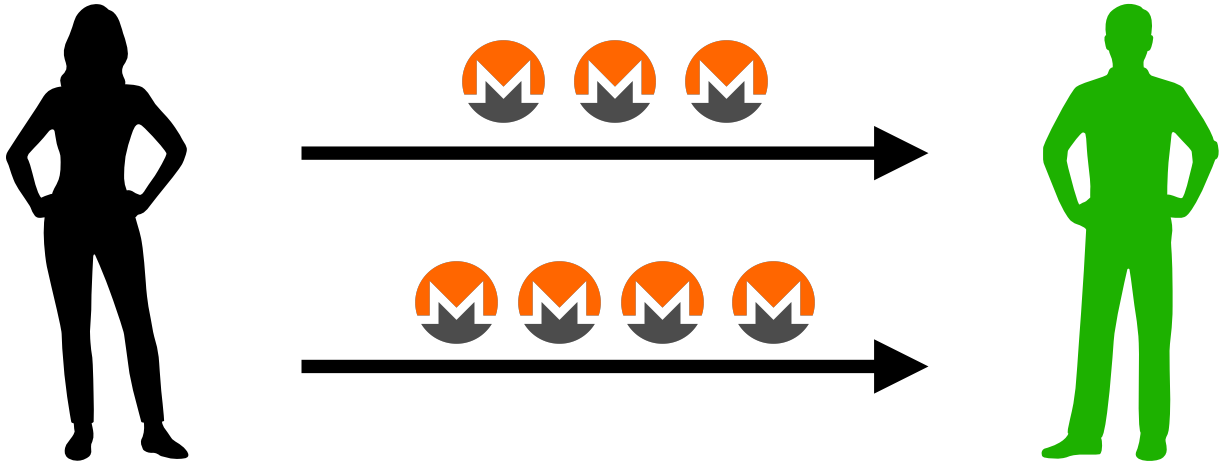
Hiding Receivers with Stealth Addresses

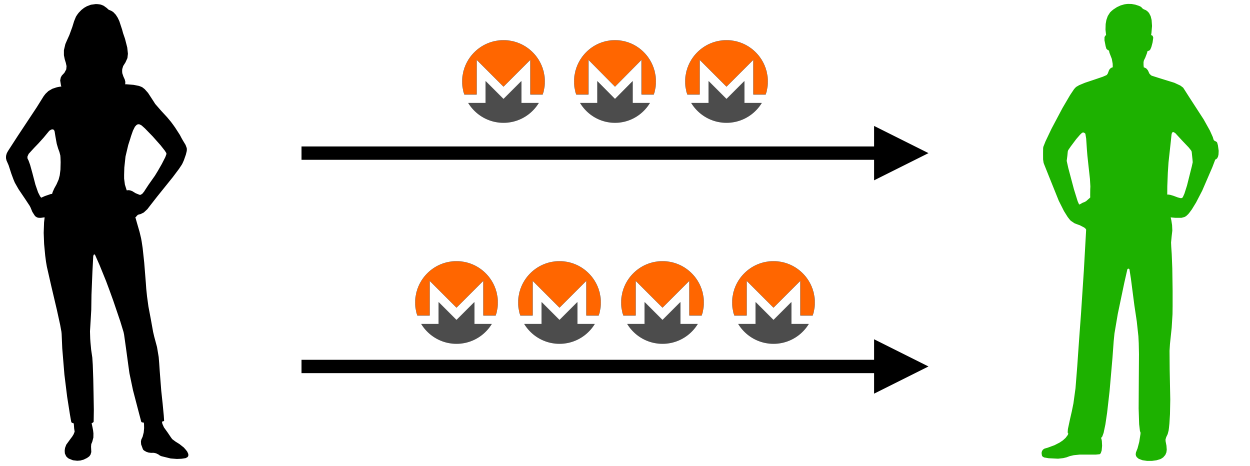


$$pk_1 = g^{H(ok_1)} \cdot K_s$$

$$pk_2 = g^{H(ok_2)} \cdot K_s$$

$$sk_1 - sk_2 = H(ok_1) - H(ok_2)$$

Hiding Receivers with Stealth Addresses



$$pk_1 = g^{H(ok_1)} \cdot K_s$$

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Related Key Attacks?

Outline

This Talk

Why is security unclear?

Stealth Addresses

What do we prove?

Security Model

Long Talk

YouTube

Details on RingCT

Proof Techniques

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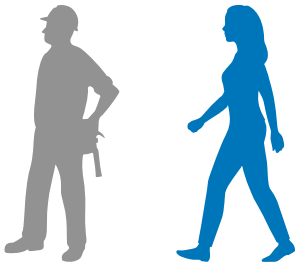
Proof Techniques

Security Model: Adversarial Capabilities

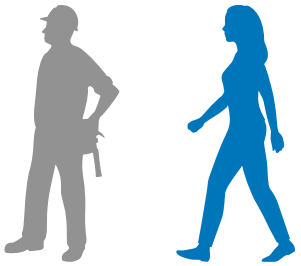
Ledger



Security Model: Adversarial Capabilities

Adversary can …

Ledger

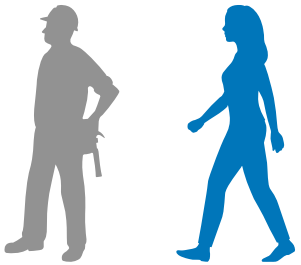


Security Model: Adversarial Capabilities

Adversary can …

- Create new honest users

Ledger



Security Model: Adversarial Capabilities

Adversary can …

- Create new honest users

K_s, k_v

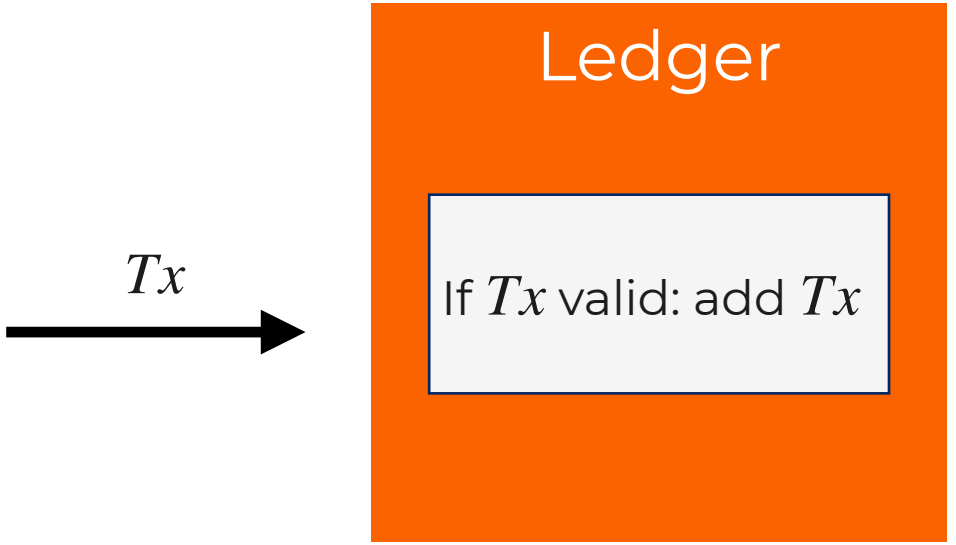
Ledger

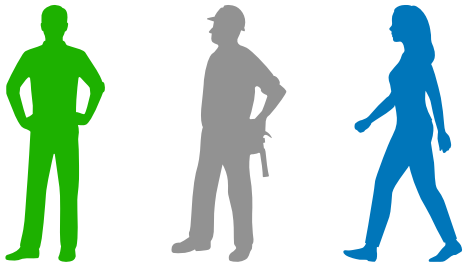
Security Model: Adversarial Capabilities

Adversary can …

- Create new honest users
- Submit txs

Tx



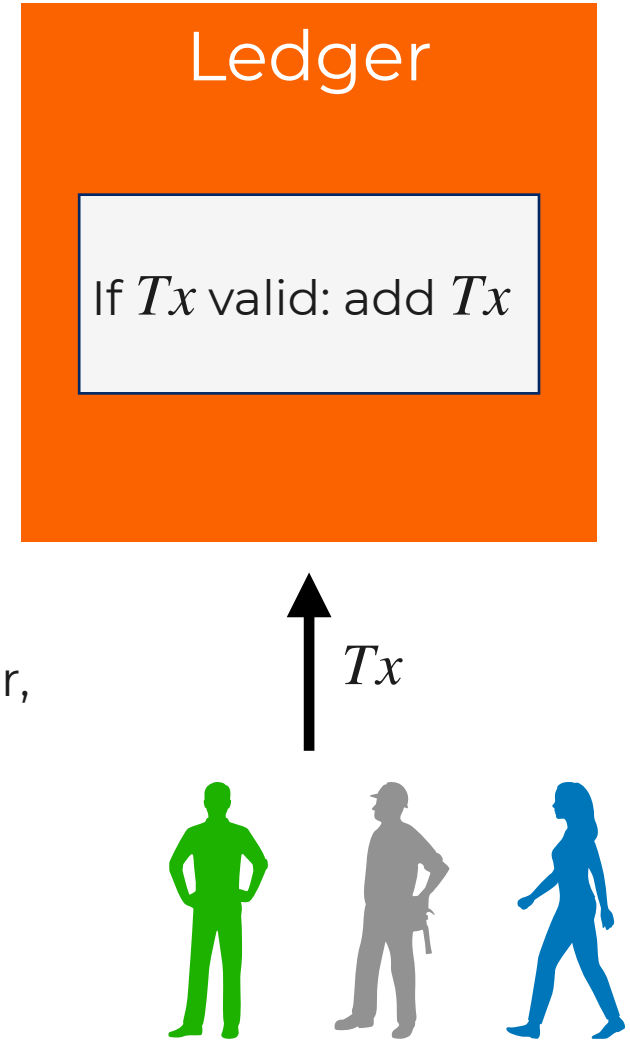


Security Model: Adversarial Capabilities

Adversary can …

- Create new honest users
- Submit txs
- Make users submit txs

Sender, Receiver, Amount



Security Model: Adversarial Capabilities

Adversary can …

- Create new honest users
- Submit txs
- Make users submit txs

Ledger

Security Model: Adversarial Capabilities

Adversary can …

- Create new honest users
- Submit txs
- Make users submit txs
- Corrupt users

k_s

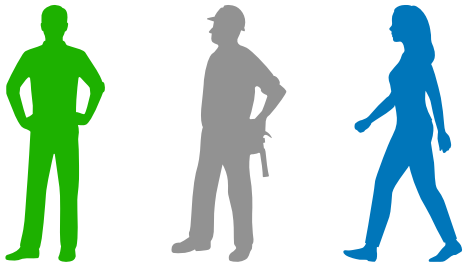
Ledger

Security Model: Adversarial Capabilities

Adversary can …

- Create new honest users
- Submit txs
- Make users submit txs
- Corrupt users
- Create new “source“ coins

Ledger



Security Model: Winning Conditions

Security Model: Winning Conditions

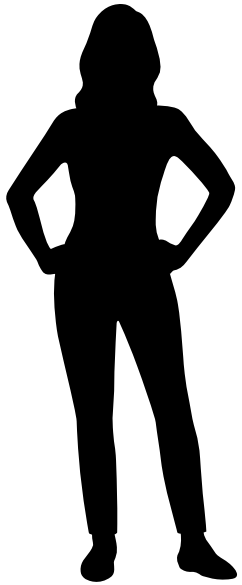
1. Winning Condition: Adversary steals coins

2. Winning Condition: Adversary creates coins

Security Model: Stealing

Security Model: Stealing

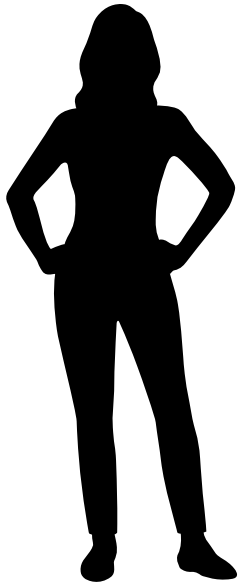
Ledger



Security Model: Stealing

Ledger

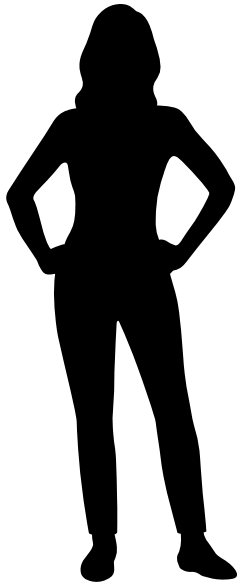
Send 10 coins to Bob



Security Model: Stealing

Ledger

Send 10 coins to Bob

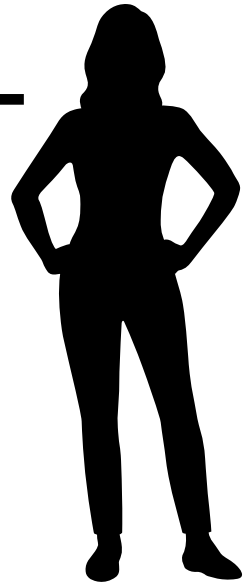


I have 10
unspent coins!

Security Model: Stealing

Ledger

Tx



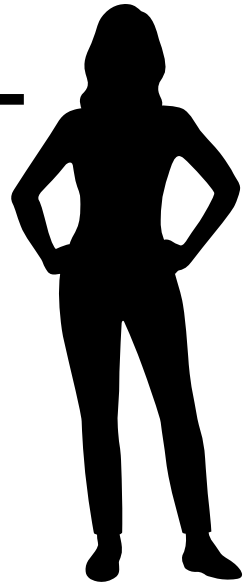
I have 10 unspent coins!

Send 10 coins to Bob

Security Model: Stealing

Ledger

Tx



I have 10 unspent coins!

Send 10 coins to Bob

1. Winning Condition: Tx is rejected $\Longrightarrow$ Adversary wins

Security Model: Creating Coins

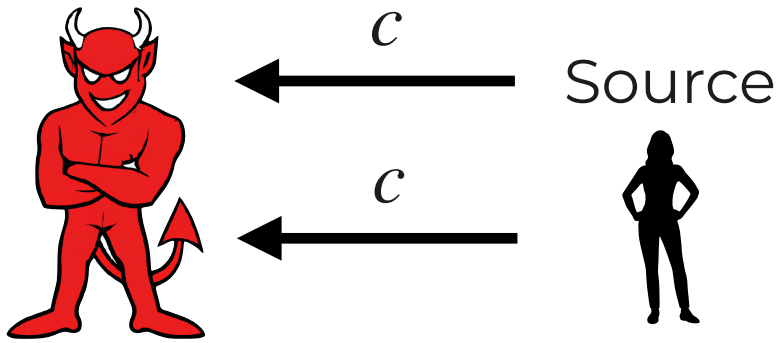
Security Model: Creating Coins

$\text{received} \in \mathbb{N}_0$

$\text{spent} \in \mathbb{N}_0$

Security Model: Creating Coins

received $\in \mathbb{N}_0$

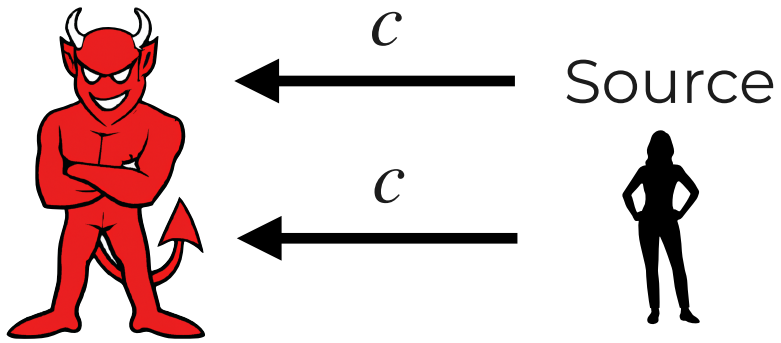


Adversary gets c coins
$\Longrightarrow$ received := received + c

spent $\in \mathbb{N}_0$

Security Model: Creating Coins

received $\in \mathbb{N}_0$



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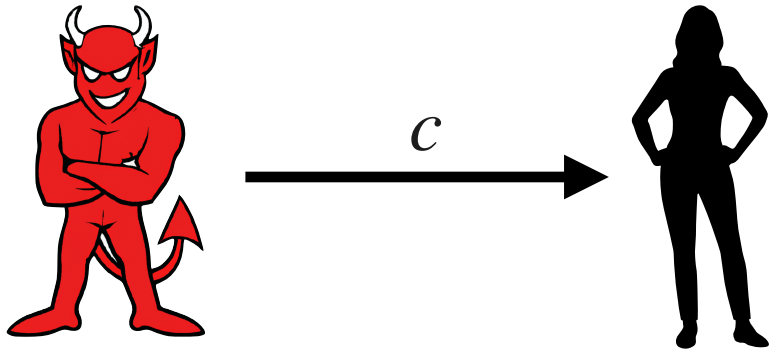
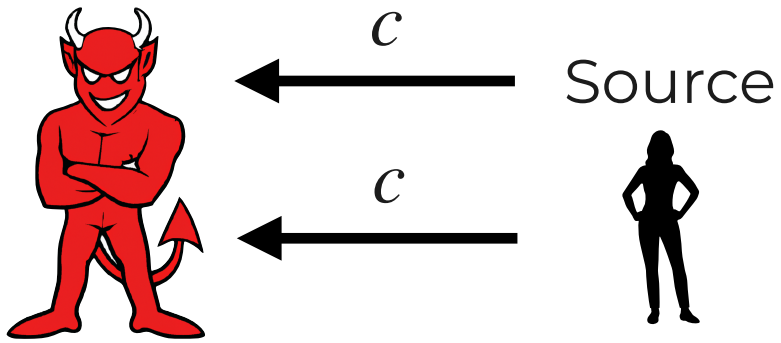


Adversary submits Tx and
honest user receives c coins
$\Longrightarrow$ spent := spent + c

Security Model: Creating Coins

received $\in \mathbb{N}_0$



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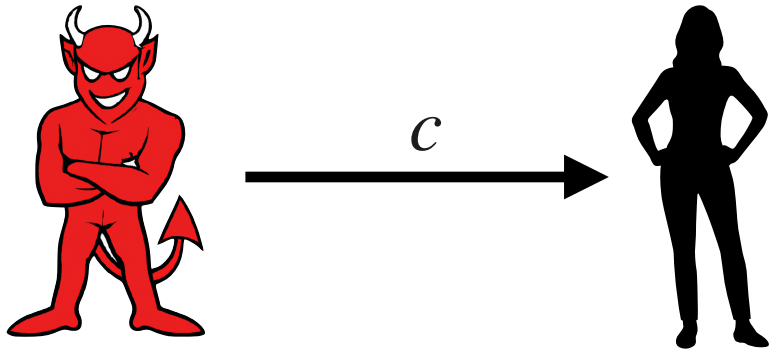

Adversary submits Tx and
honest user receives c coins
$\Longrightarrow$ spent := spent + c

2. Winning Condition: spent > received $\Longrightarrow$ Adversary wins

Summary

Summary

RingCT and Its Unclear Security

Summary

RingCT and Its Unclear Security

Our Security Model

Summary

- RingCT and Its Unclear Security
- Our Security Model
- Proof Techniques using Network Flow

CISPA
HELMHOLTZ CENTER FOR INFORMATION SECURITY

A Holistic Security Analysis of Monero Transactions



Paper

Long Talk