Statistical Zaps and New Oblivious Transfer Protocols

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Statistical Security in 2-party Protocols

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- **Everlasting security** Computational unbounded adversary can't break.

- **Hard to achieve**
  - Impossible for *both* parties to achieve for general functionalities

- **Focus of this work:** One-side Statistical Security
  - Interactive Proof Systems: Statistical Privacy for Prover
  - Oblivious Transfer: Statistical Privacy for Receiver

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Interactive Proof System

Prover

ω : witness

$x \in L$

Verifier

Interactive Proof System

Prover

$x \in L$

Verifier

ω : witness

Interactive Proof System

Prover

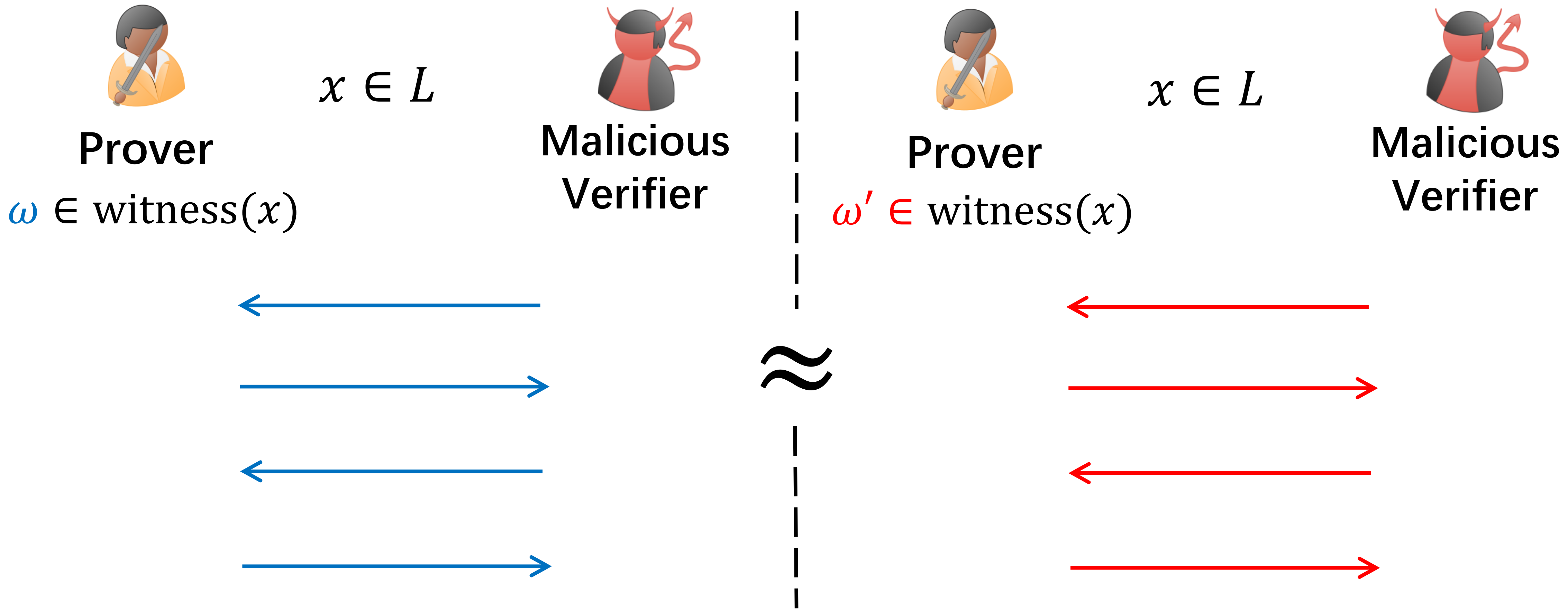
ω : witness

$x \in L$

Verifier

Accept/Reject

Witness Indistinguishability (WI)



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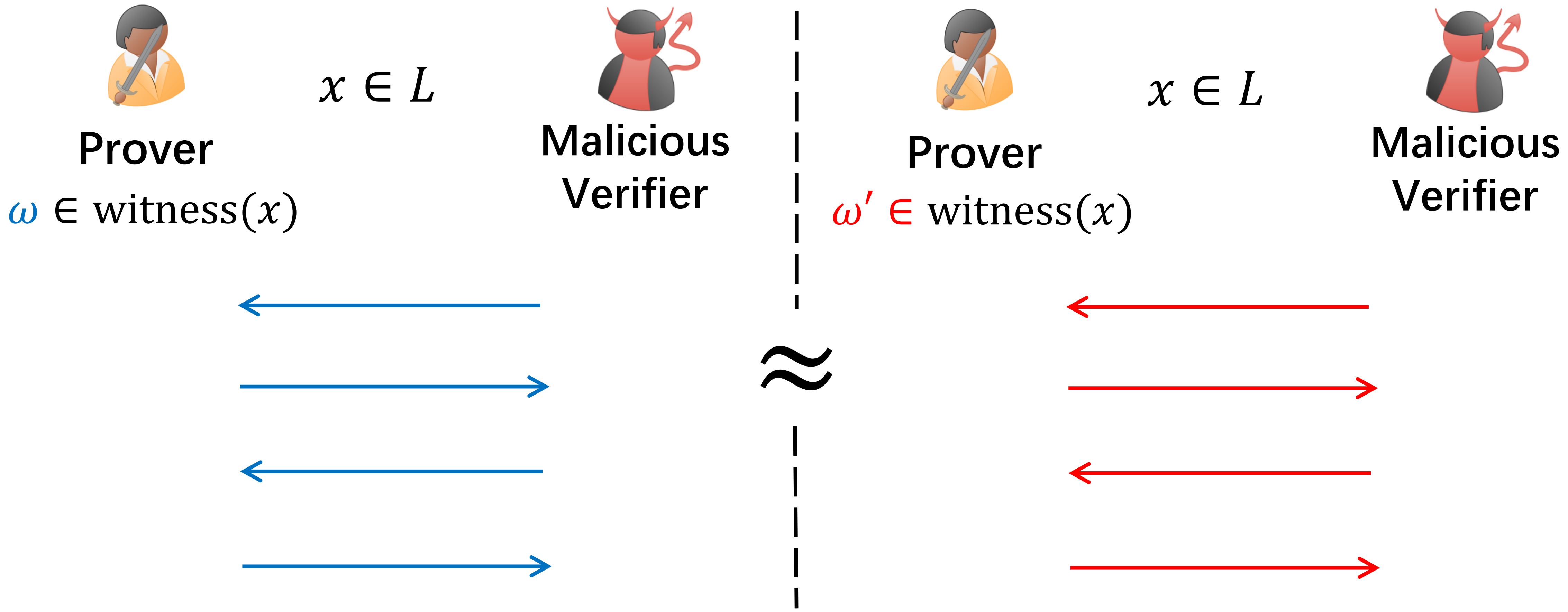

- Unlike zero-knowledge, WI can be achieved in 2-round

Zaps: 2-round Public-Coin WI [DN00]

Prover

$x \in L$

Verifier

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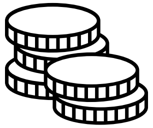
Prover

$x \in L$



Verifier

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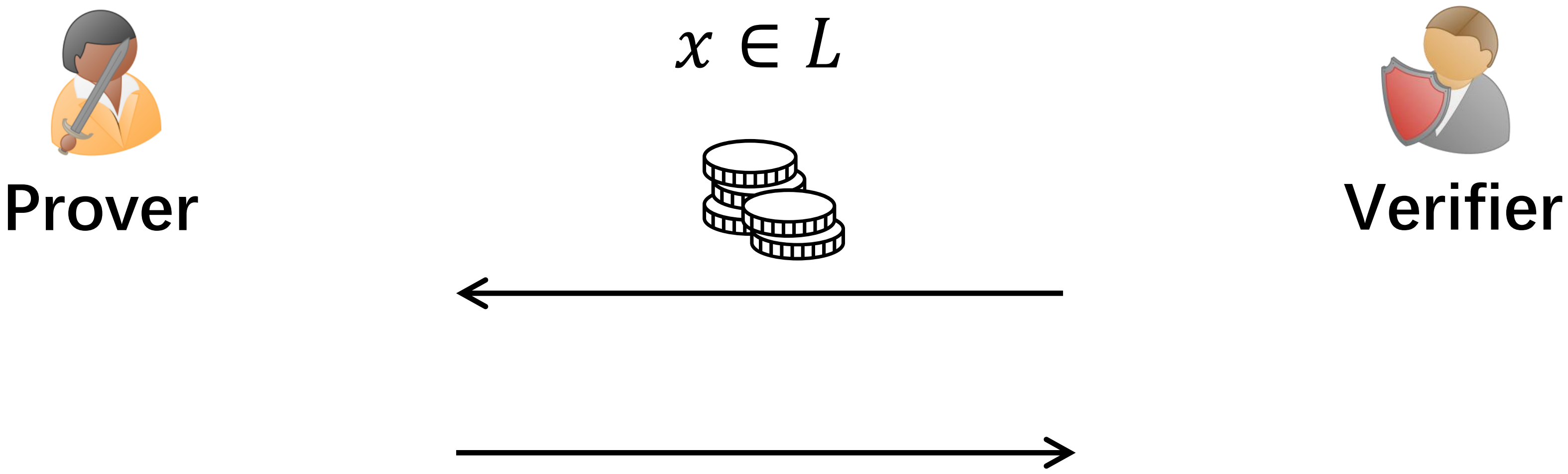

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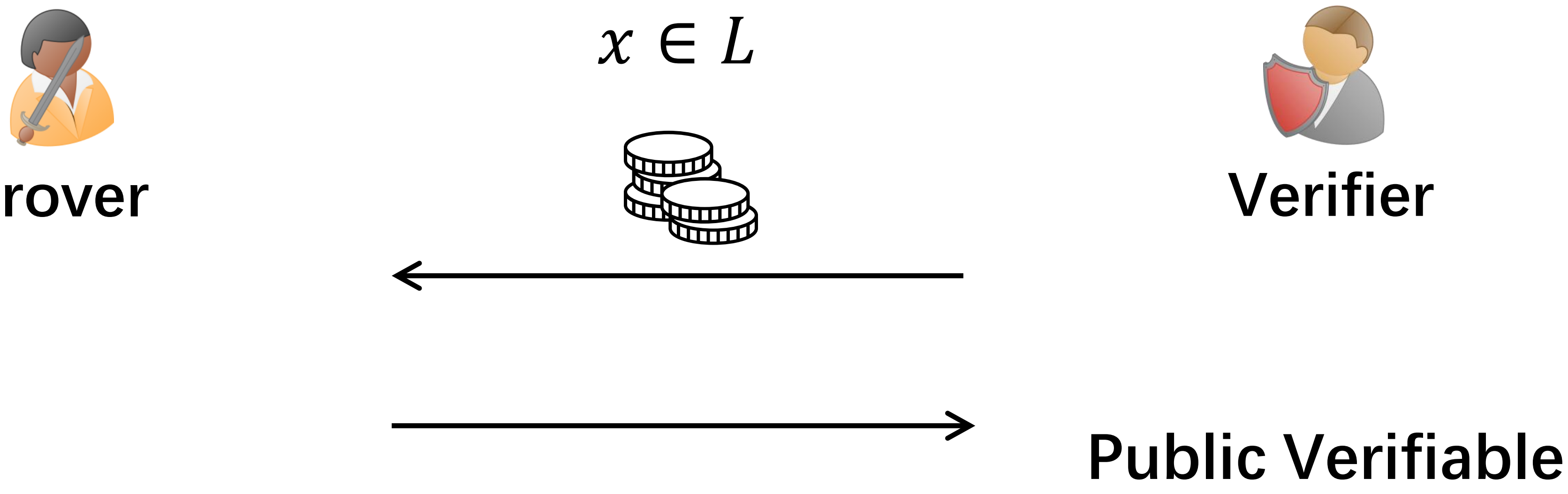

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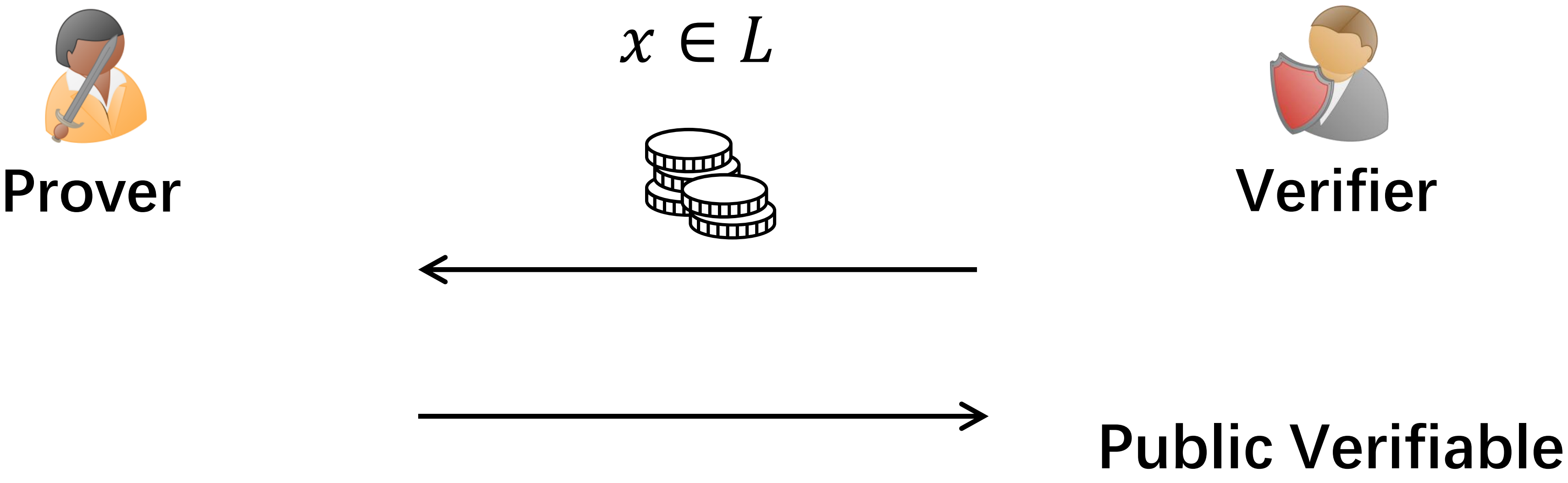

Public Coin: Verifier only uses public random coins

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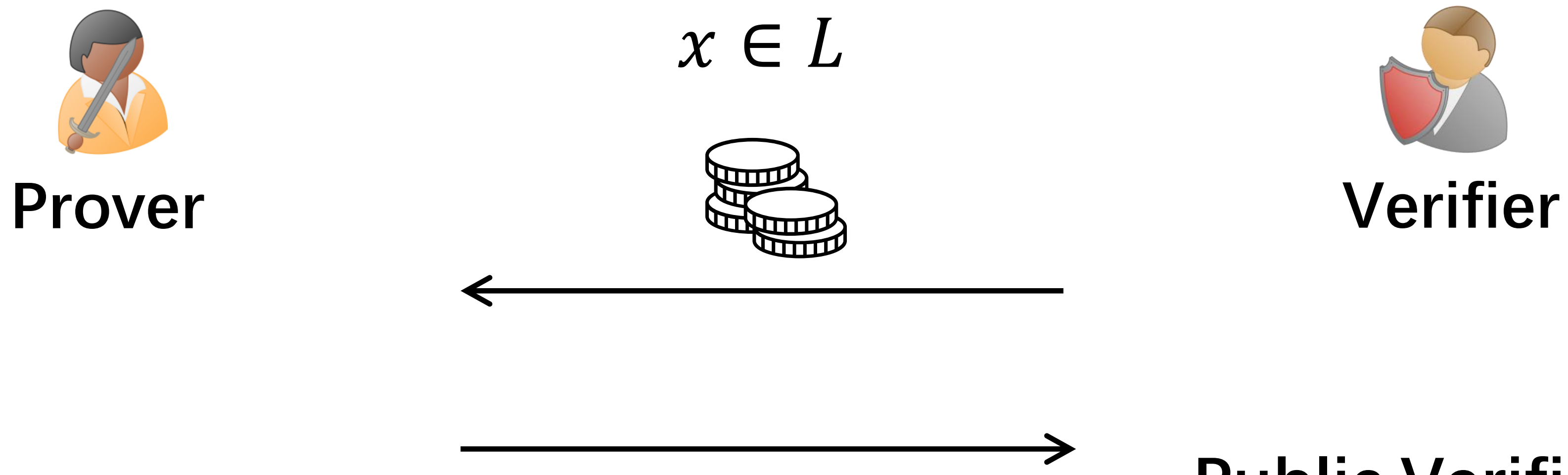

Public Verifiable

Public Coin: Verifier only uses public random coins

Many Applications:

- Round-efficient secure multiparty computation [HHPV18]
- Resettable-secure protocols [DGS09]

……

Previous Works

[DN00] Zaps and NIZK proofs in common random string model are equivalent.

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NIZKs

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→ **Zaps**

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→ **Zaps**

- [BP15] Zaps from Indistinguishability Obfuscation
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Question (1): Does there exist statistical Zaps?

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Result (1): Statistical Zaps from quasi-poly hard Learning with Errors

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[KKS18] achieves statistical *private-coin* WI.

Oblivious Transfer (OT)

Sender

m_0	m_1

Receiver

$\beta \in \{0,1\}$

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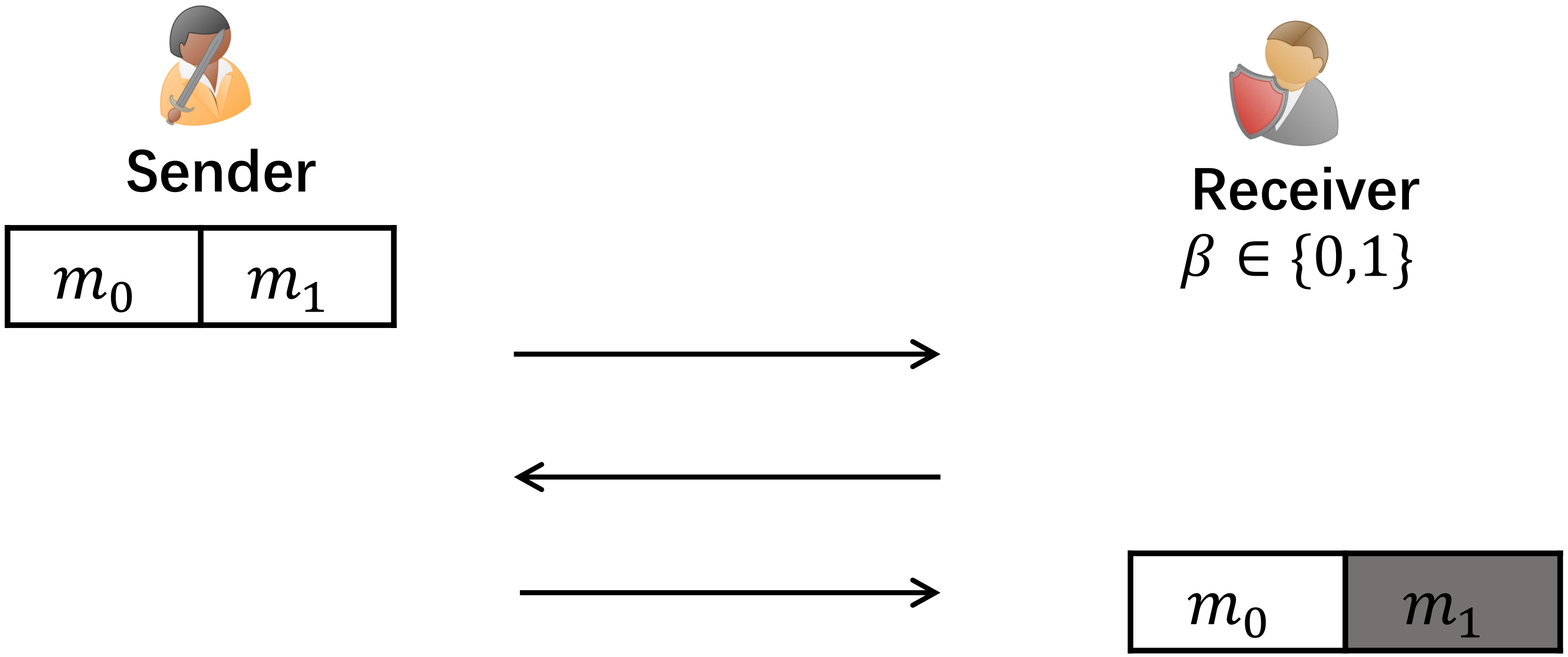

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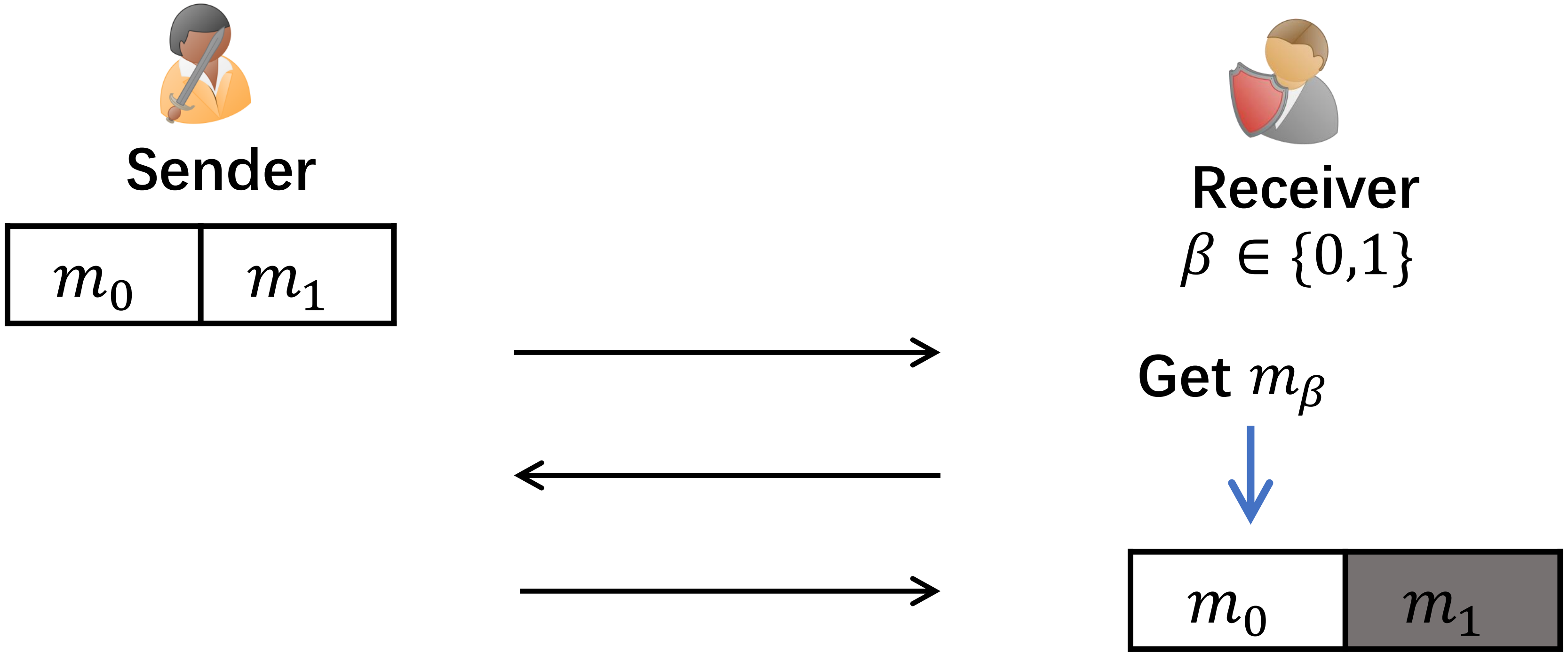

Oblivious Transfer (OT)

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Get m_β

Sender-Privacy:

$m_{1-\beta}$ is hidden

m_0	m_1

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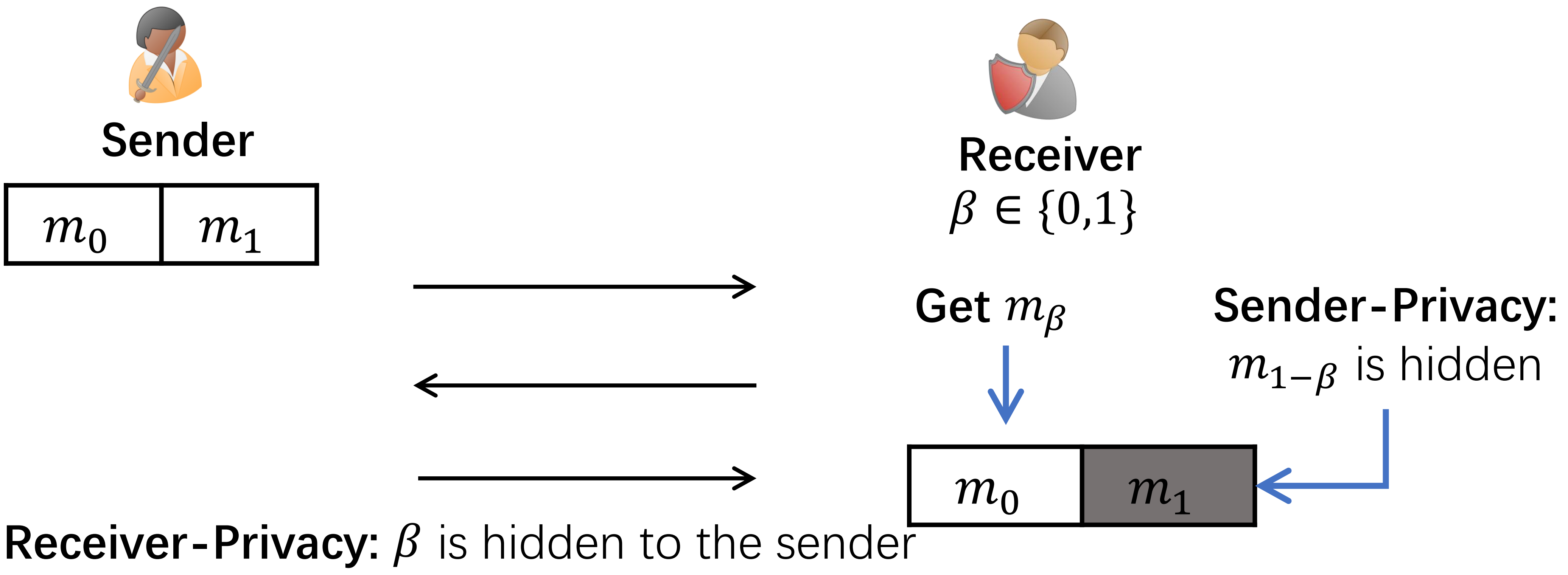

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Get m_β

Sender-Privacy:
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m_0	m_1

Receiver-Privacy: β is hidden to the sender

Many Applications:

- Secure multiparty computation [Yao86, GMW87]
- 2-round WI [JKKR17, BGI+17, KKS18]
- Non-malleable commitment [KS17]

Natural Question

2-round statistical sender-private OT in plain model

[NP01, AIR01, Kal05, HK12, BD18]

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Non-uniform Malicious Receiver

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$$\mathrm{ot}_1 \begin{cases} = \mathrm{OT}_1(\beta = 0; r_0) \\ = \mathrm{OT}_1(\beta = 1; r_1) \end{cases}$$

Non-uniform Malicious Receiver

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$\longleftarrow$

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$\longrightarrow$

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Non-uniform Malicious Receiver

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- [KKS18] 3-round protocol from *super-poly* hardness assumptions

Question (2): Based on *polynomial hardness* assumptions, does there exist 3-round statistical receiver-private OT in the plain model?

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Result (2): 3-round statistical receiver-private OT from poly-hardness

Construction (1): 2-round statistical sender-private OT

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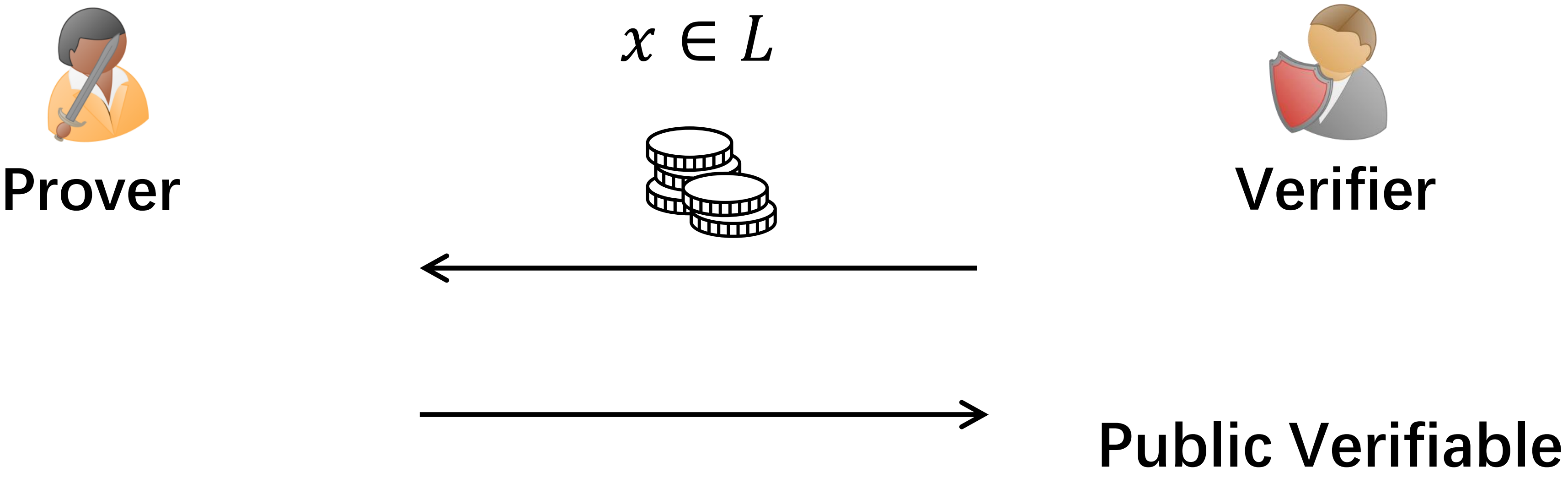
OT reversal

Construction (2): Computational Diffie-Hellman assumption

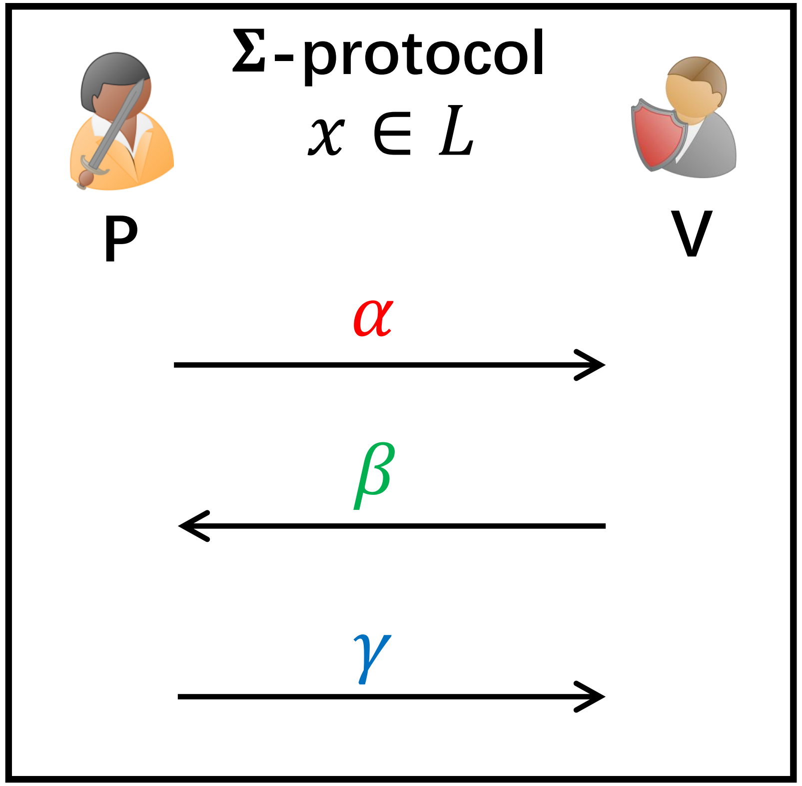
Technical Details
Part I: Statistical Zaps

Statistical Zaps



Starting Idea

- Compress a Σ-protocol via a **C**orrelation **I**ntractable **H**ash (CIH) $\{\mathrm{H}_k(\cdot)\}_k$ [CGH98, KRR17, CCRR18, HL18, CCH+19, PS19]



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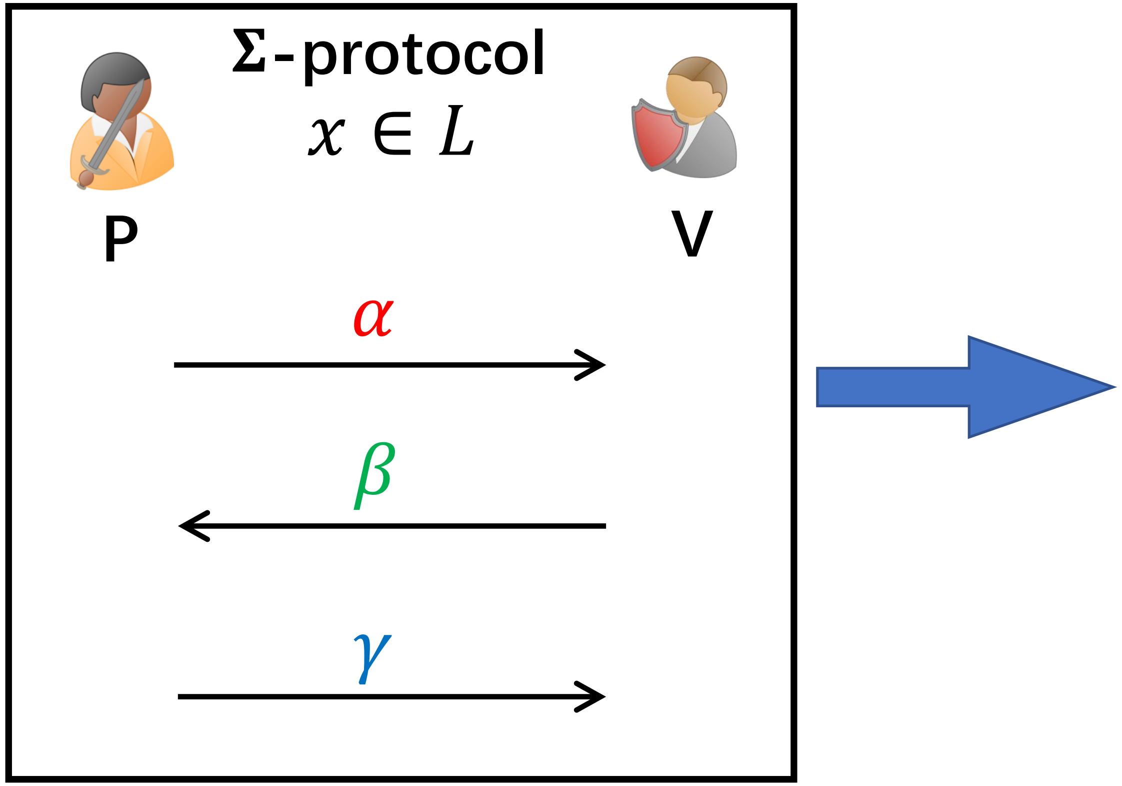

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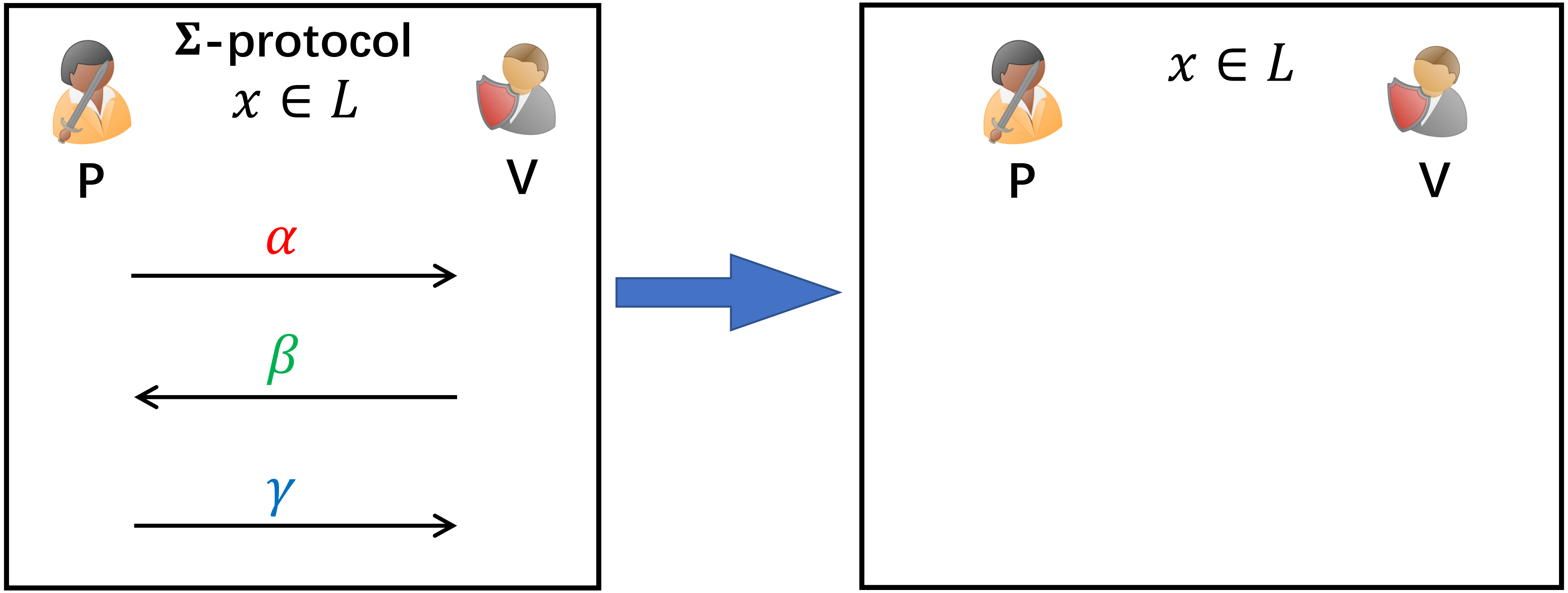

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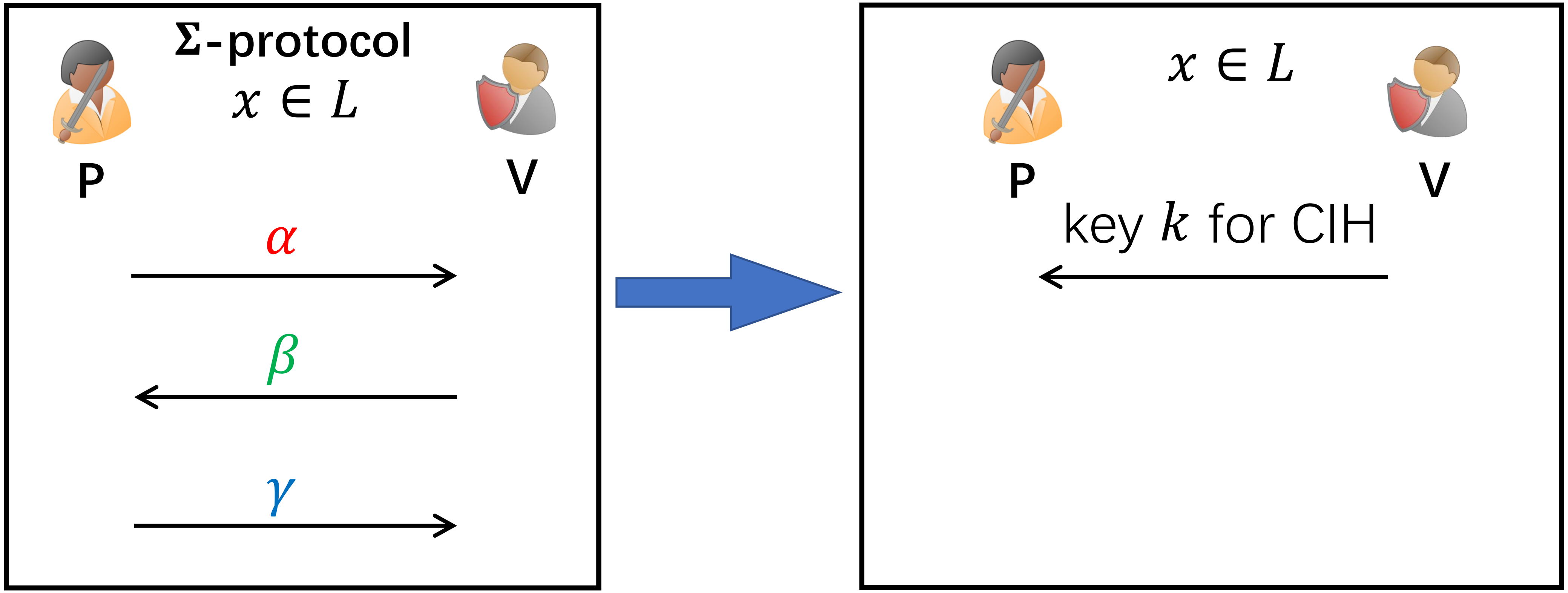

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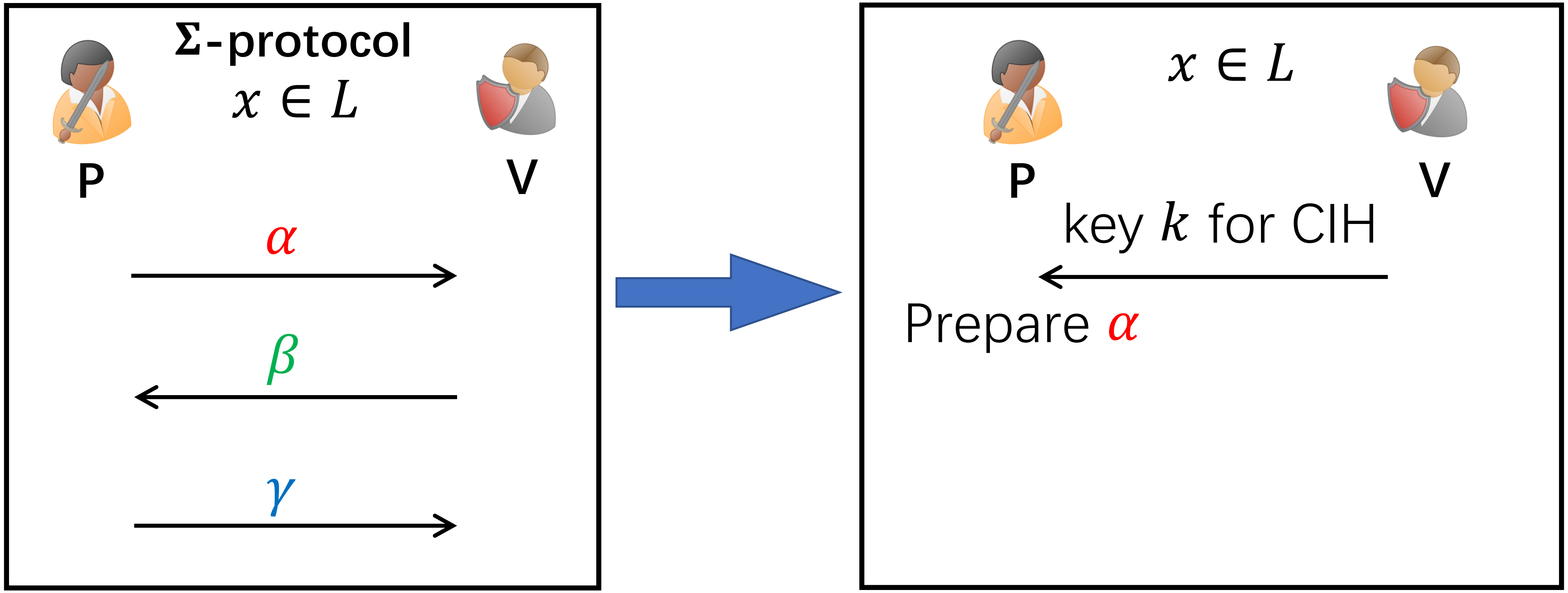

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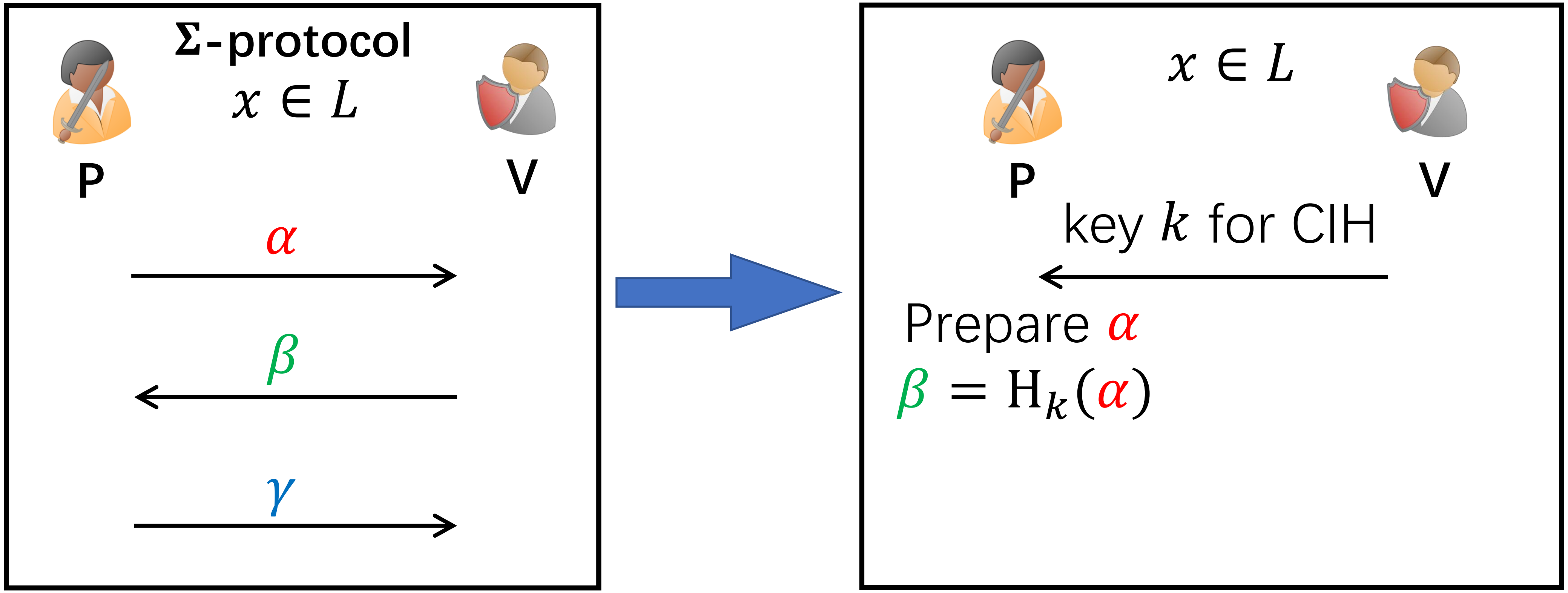

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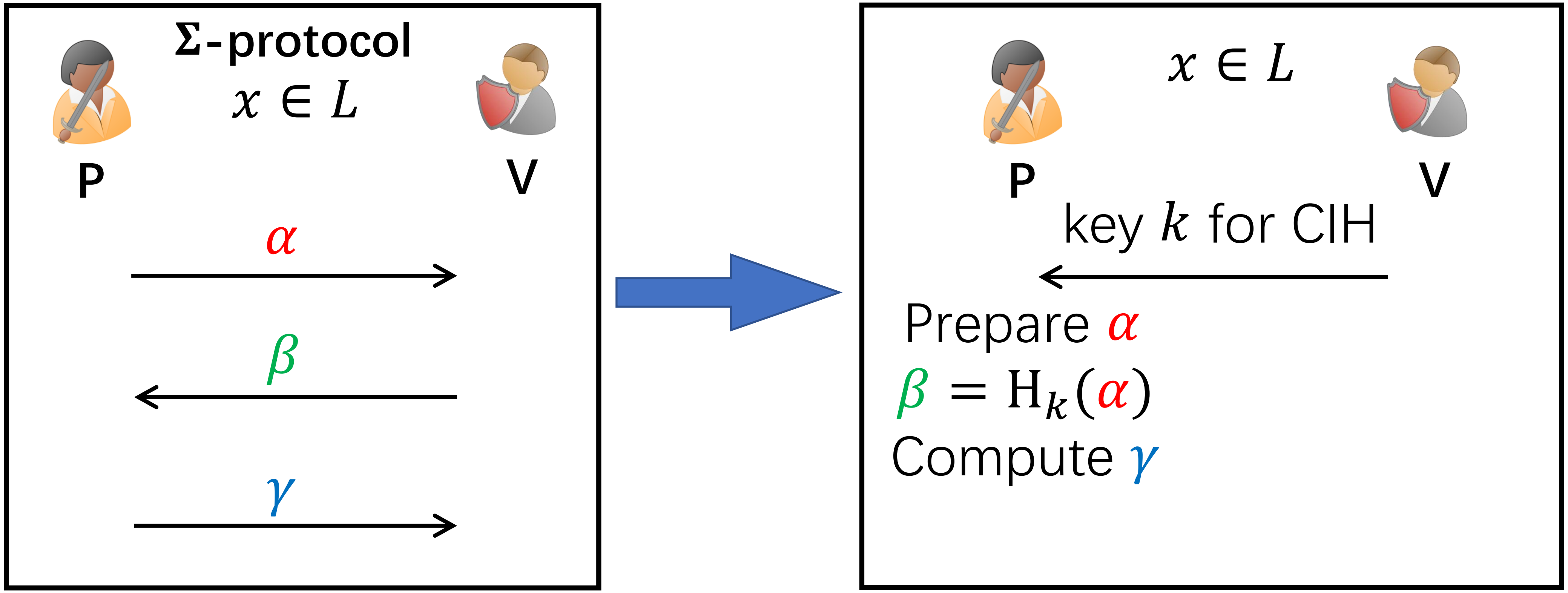

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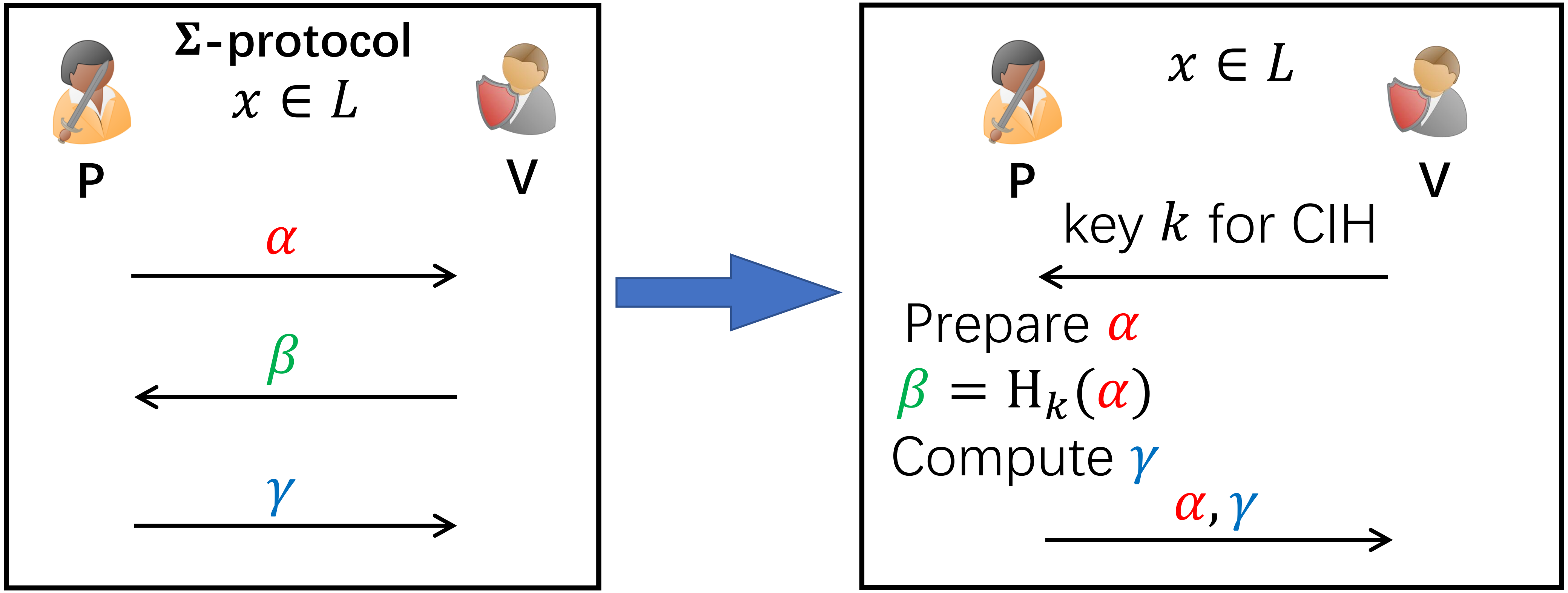
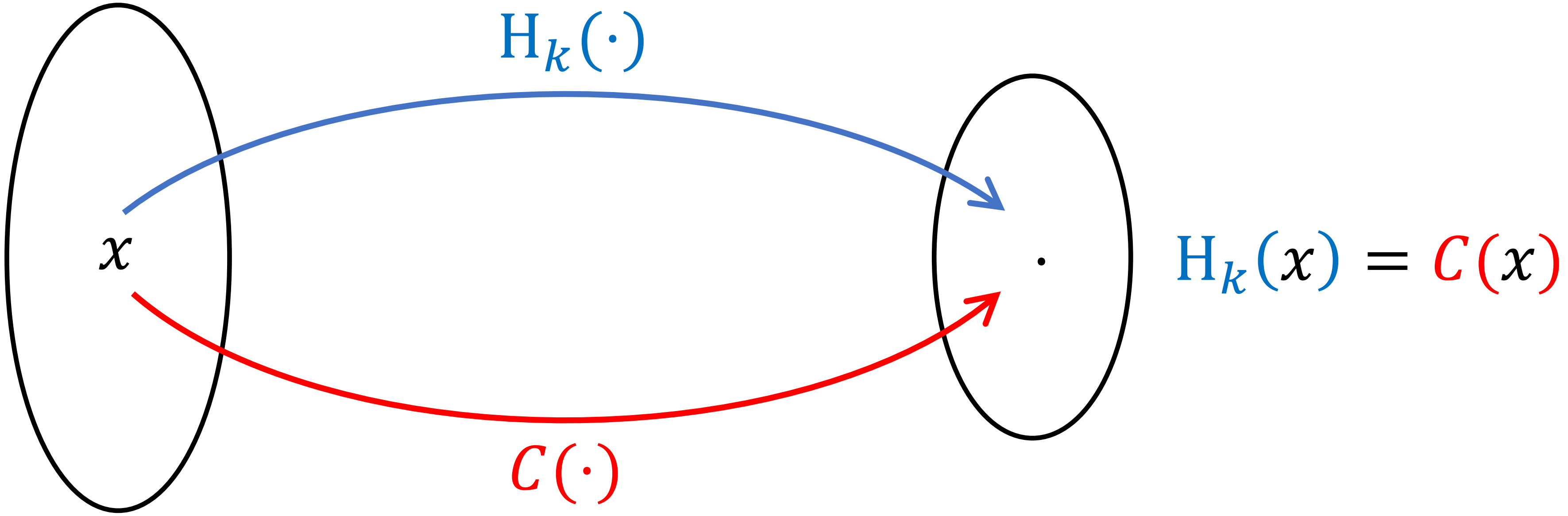


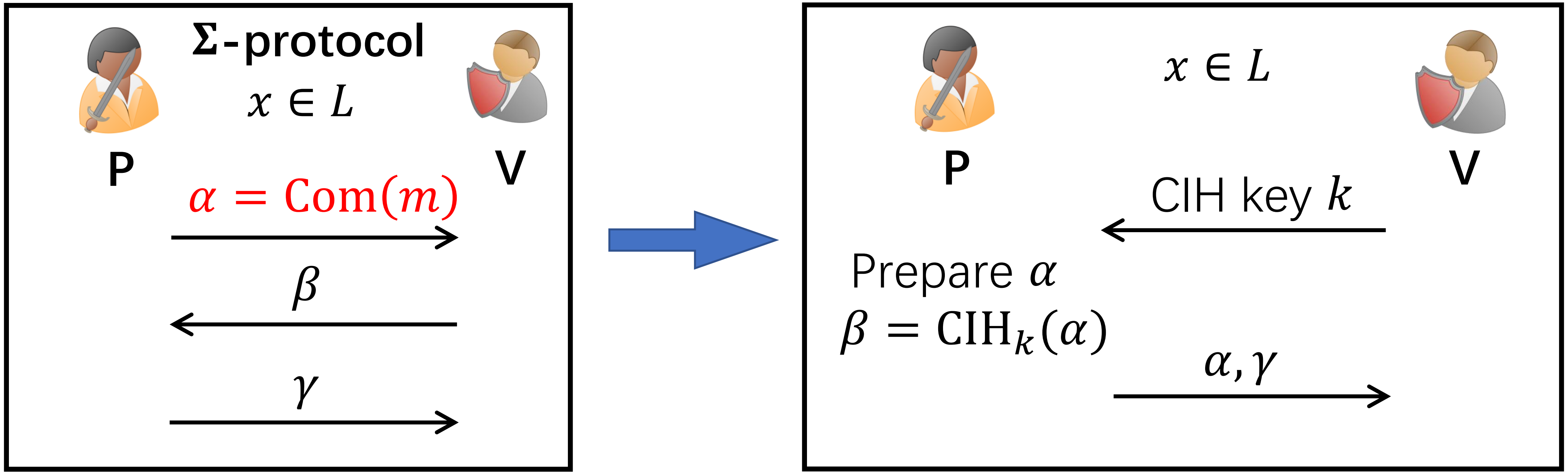
Correlation **I**ntractable **H**ash (CIH)

A CIH is a hash function $\{\mathrm{H}_k(\cdot)\}_k$:

$\forall$ C, let $k \leftarrow \{0,1\}^{\mathrm{poly}(\lambda)}$, it's hard to find an x, such that



Idea for Security



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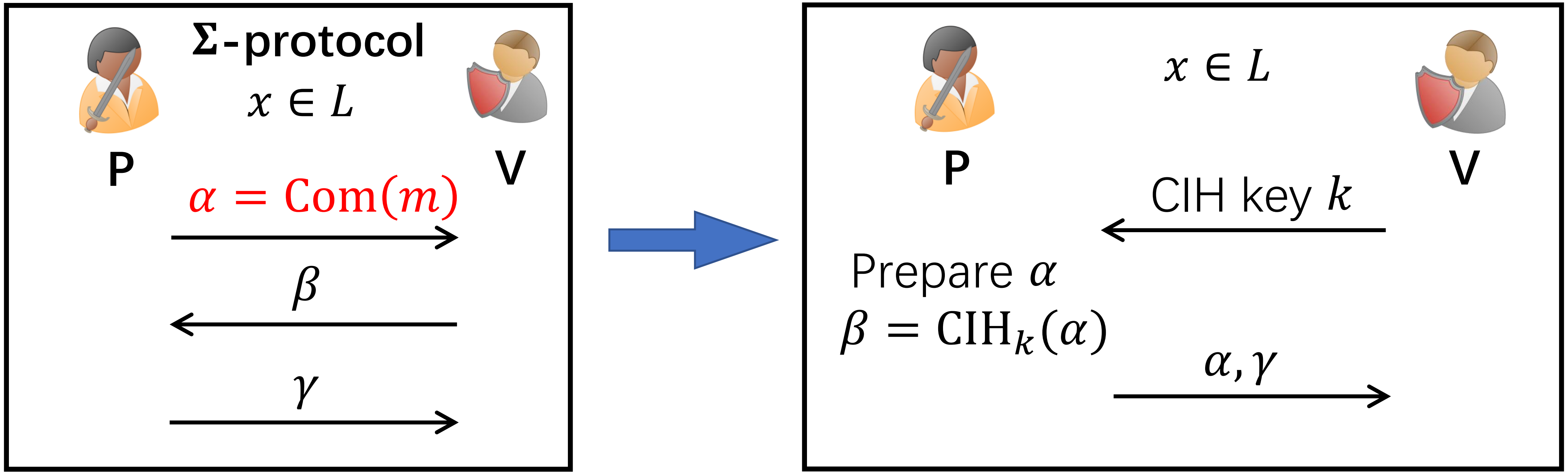

- **WI:** follows from *hiding property* of the commitment

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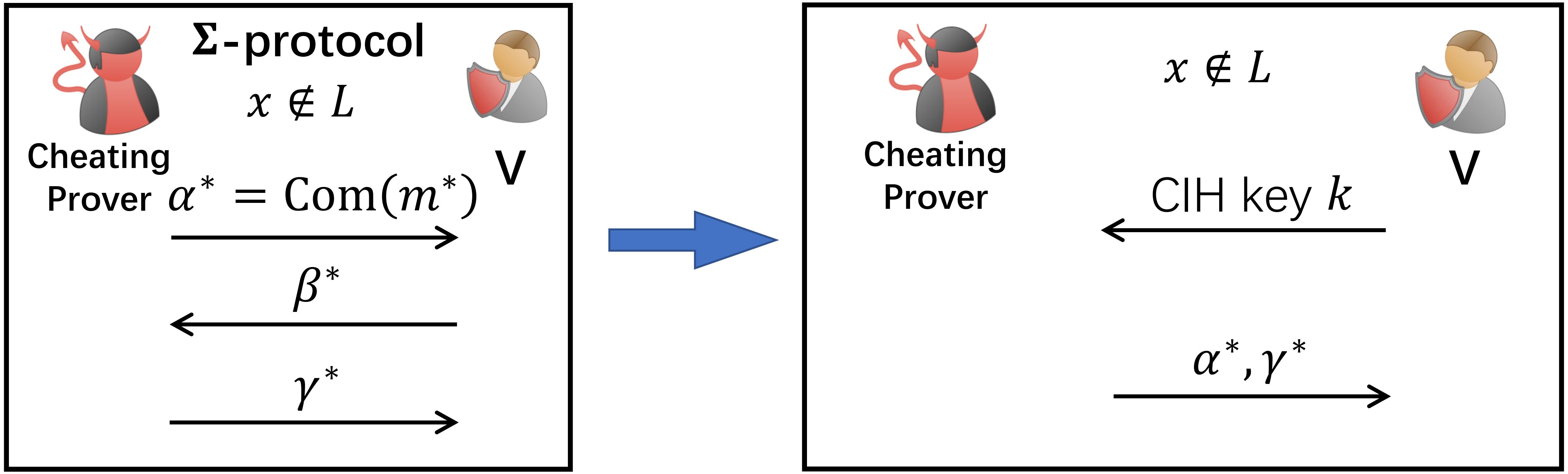

- **Soundness:** *Extract* m^* from α^* using a trapdoor

  Given m^*, the (only) accepting β^* is efficiently computable

  Verifier accepts ⇒ $\beta^* = \mathrm{CIH}_k(\alpha^*) = C(\alpha^*)$
- **Hiding & Extractable commitments** can be built in CRS model

  ⇒ Zaps in CRS model

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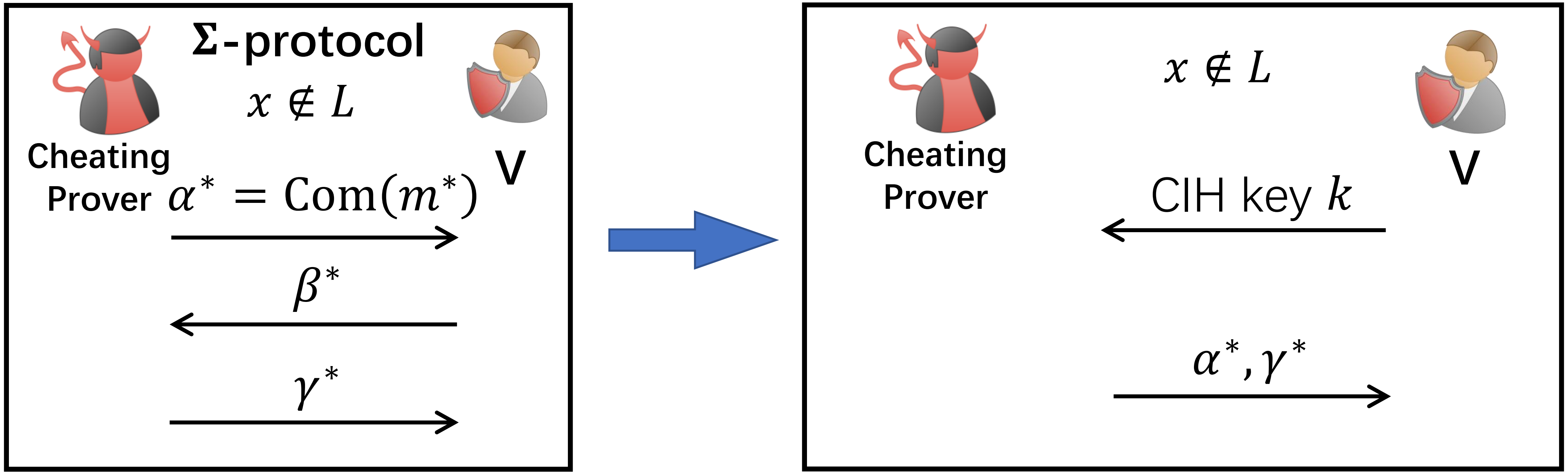

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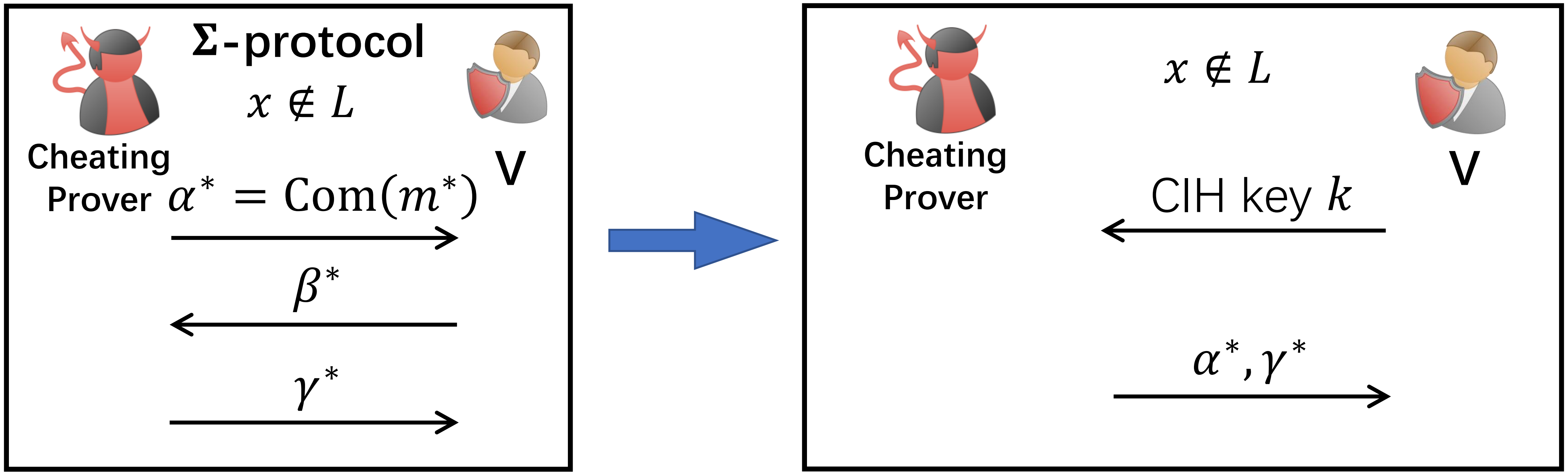

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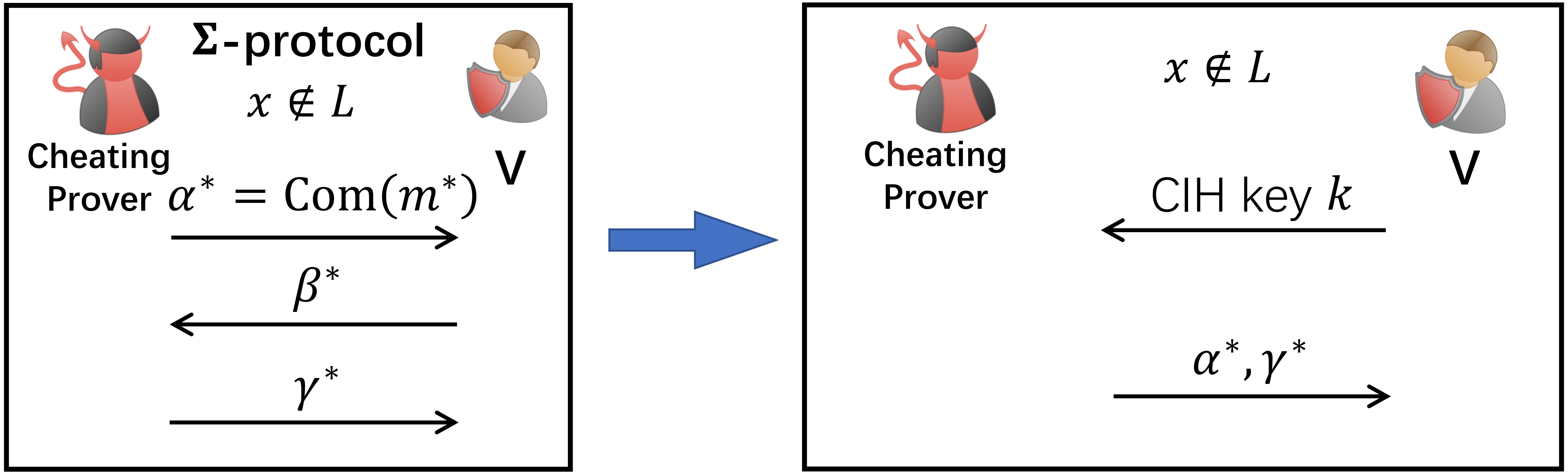

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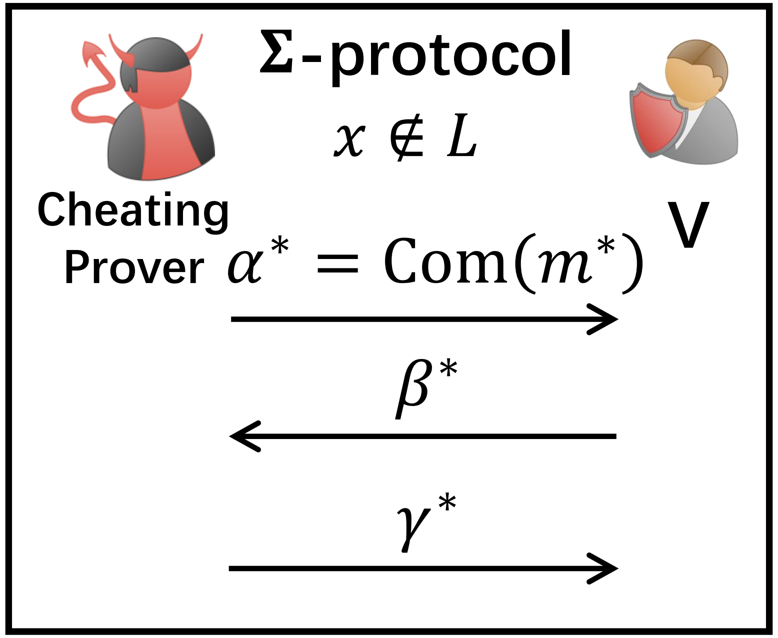

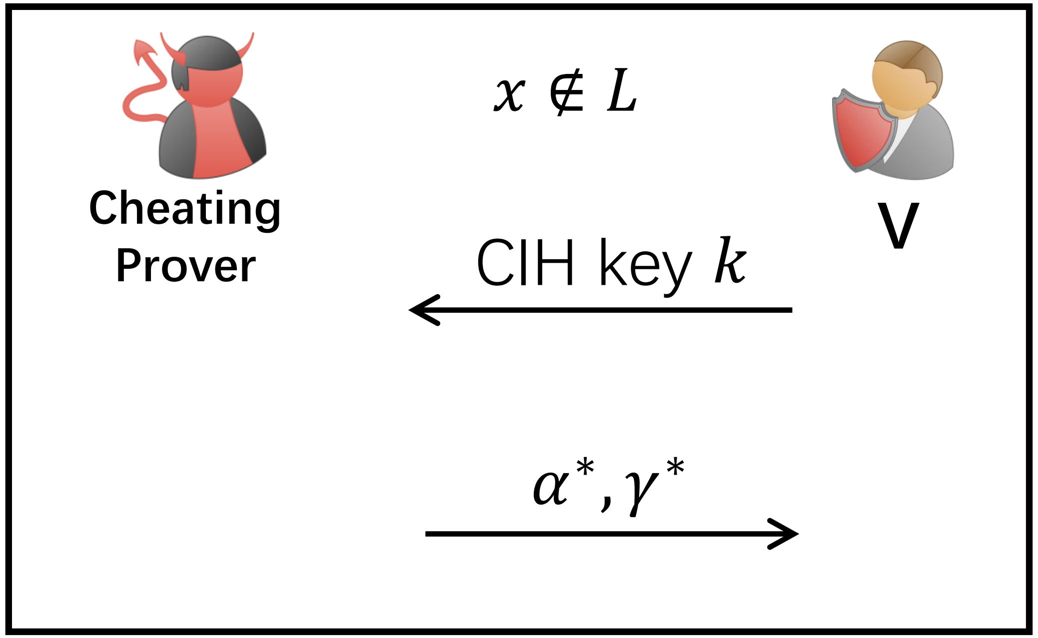

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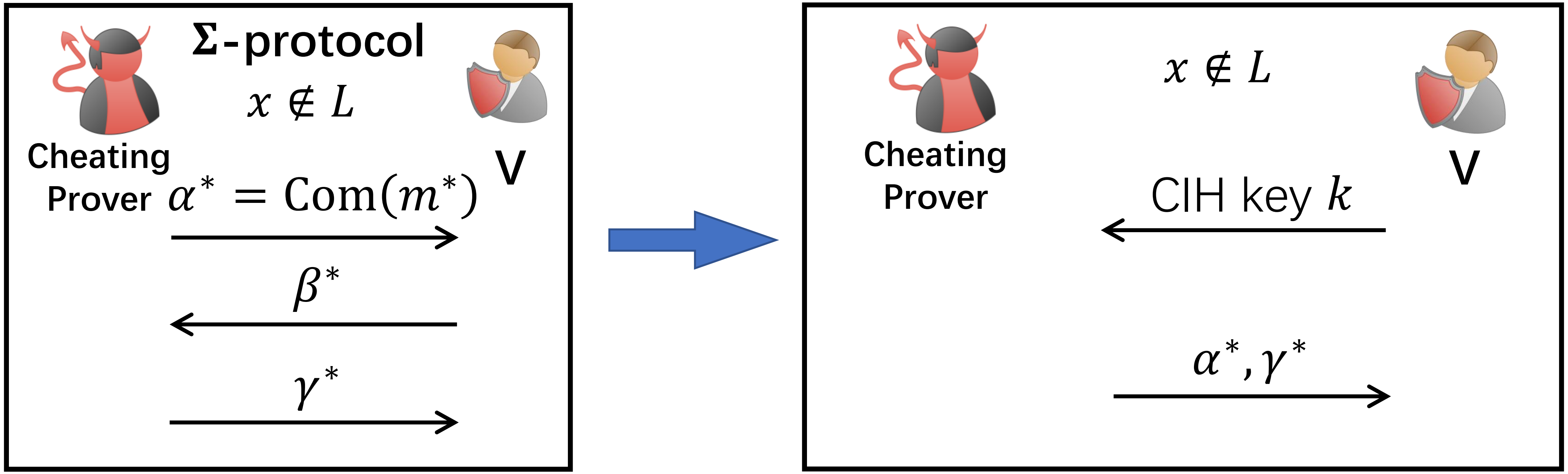

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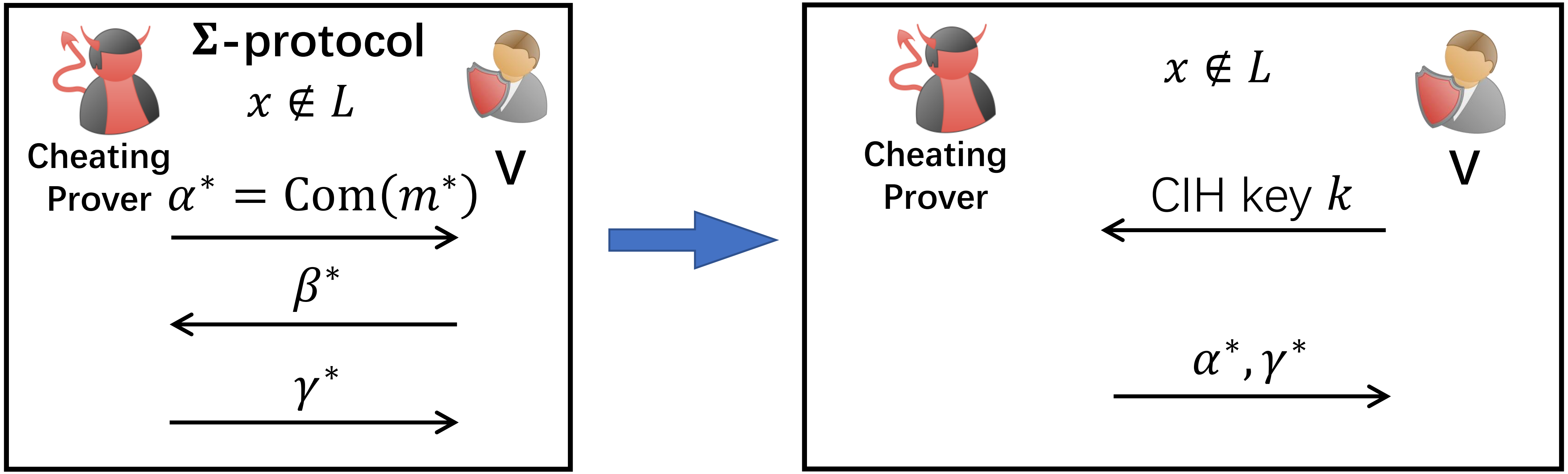

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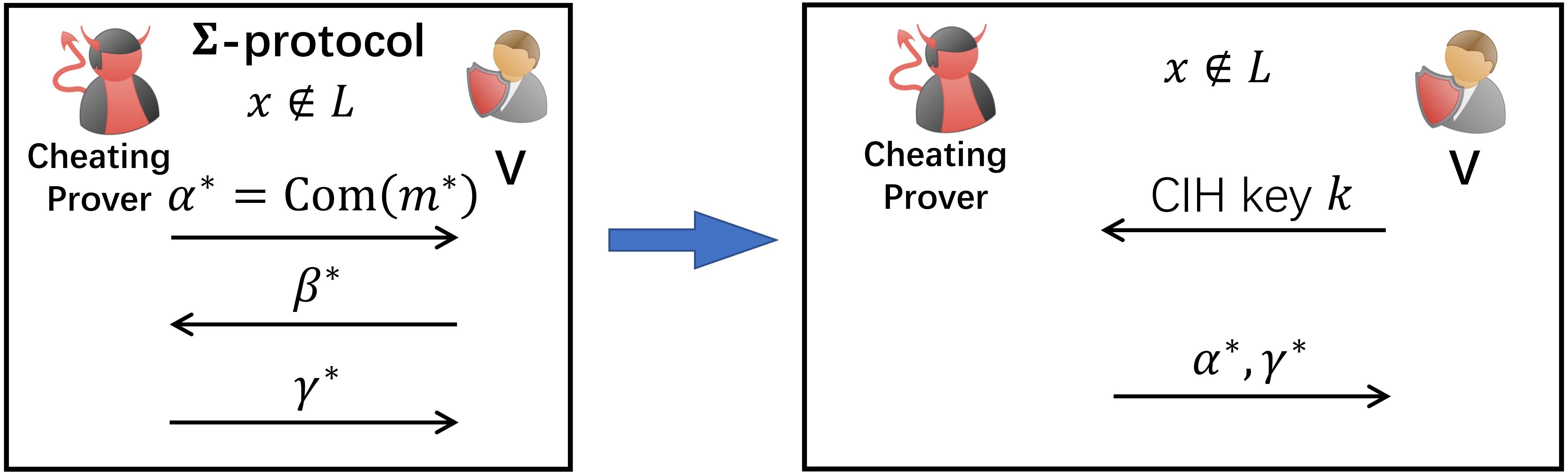

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Hiding & Extractability in Plain Model

- Use a 2-round statistical sender-private oblivious transfer

Hiding & Extractability in Plain Model

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P

V

Hiding & Extractability in Plain Model

- Use a 2-round statistical sender-private oblivious transfer

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Prepare m, $b' \leftarrow^{\$} \{0,1\}$

V

$b \leftarrow^{\$} \{0,1\}$

Hiding & Extractability in Plain Model

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<u>Sender</u>

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$b \leftarrow^{\$} \{0,1\}$

<u>Receiver</u>(b)

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Receiver(b)

$\leftarrow$

m	$\perp$

Put in b'-position

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$\longleftarrow$

m	$\perp$

$\longrightarrow$

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m	$\perp$

Put in b'-position

V

$b \leftarrow^{\$} \{0,1\}$

<u>Receiver</u>(b)

With $\Pr = 1/2$,

$b = b'$, extract m √

m	$\perp$

Hiding & Extractability in Plain Model

- Use a 2-round statistical sender-private oblivious transfer

P

Prepare m, $b' \xleftarrow{\$} \{0,1\}$

Sender

V

$b \xleftarrow{\$} \{0,1\}$

Receiver(b)

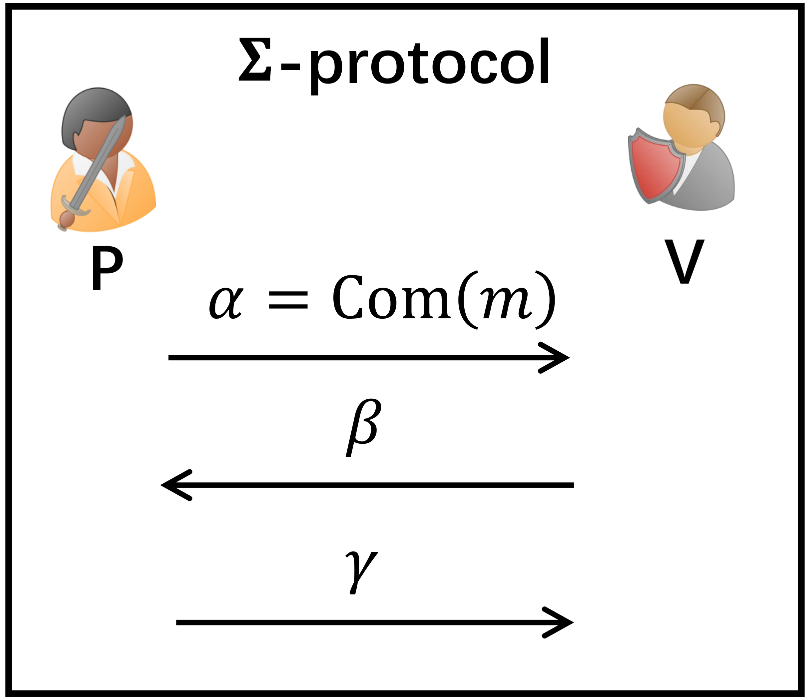
With $\Pr = 1/2$, $b \neq b'$, hide m √

m	$\perp$

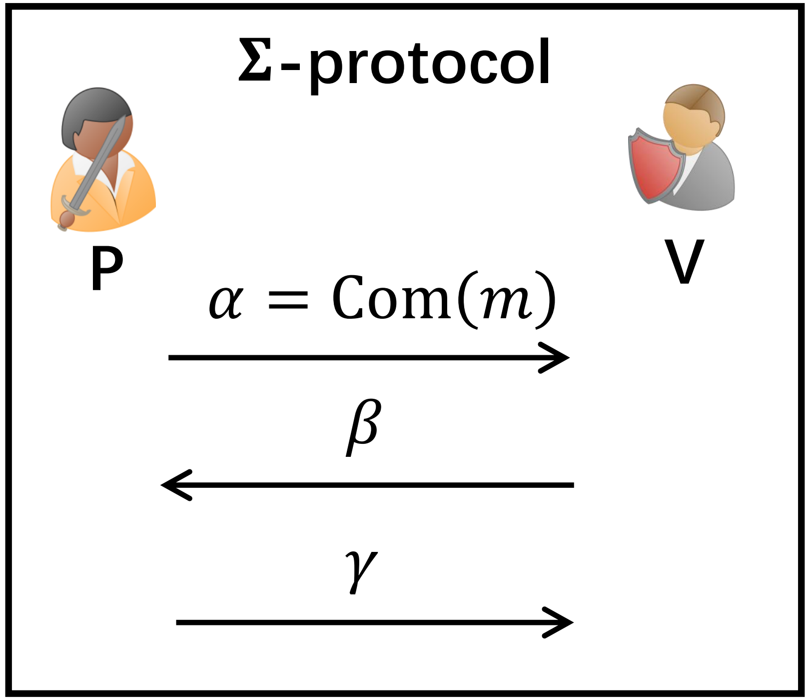
Put in b'-position

m	$\perp$

‘Weakly Secure’ Statistical Zaps



‘Weakly Secure’ Statistical Zaps



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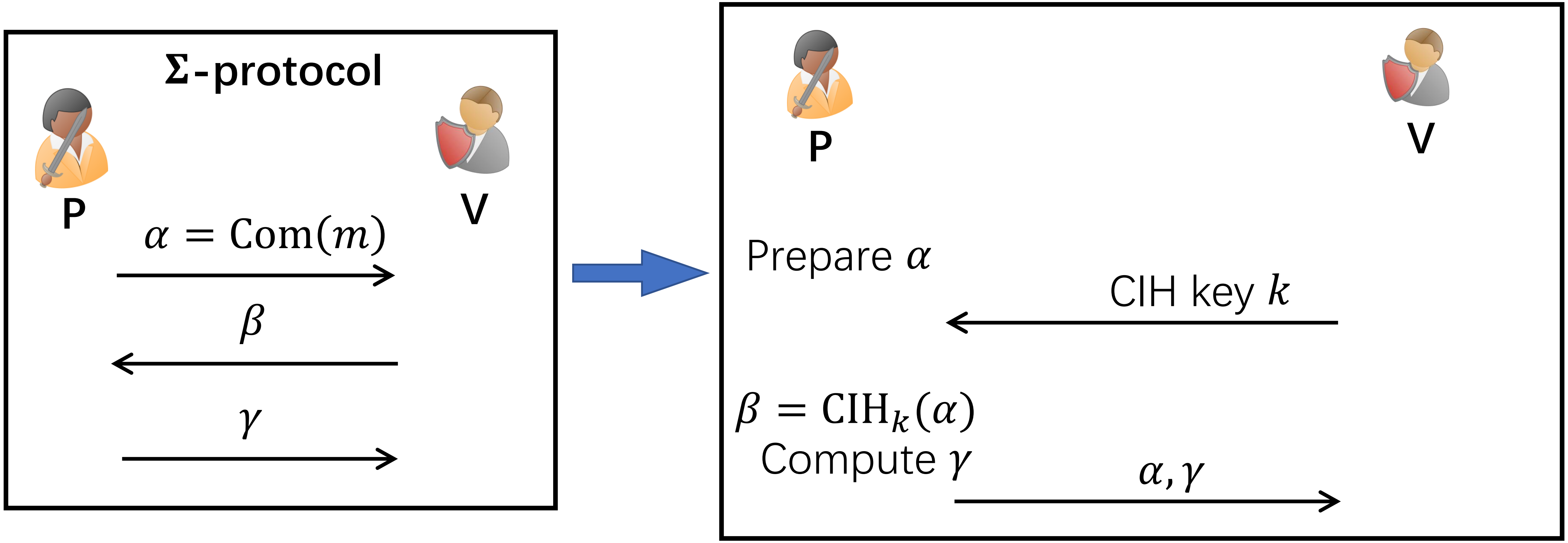

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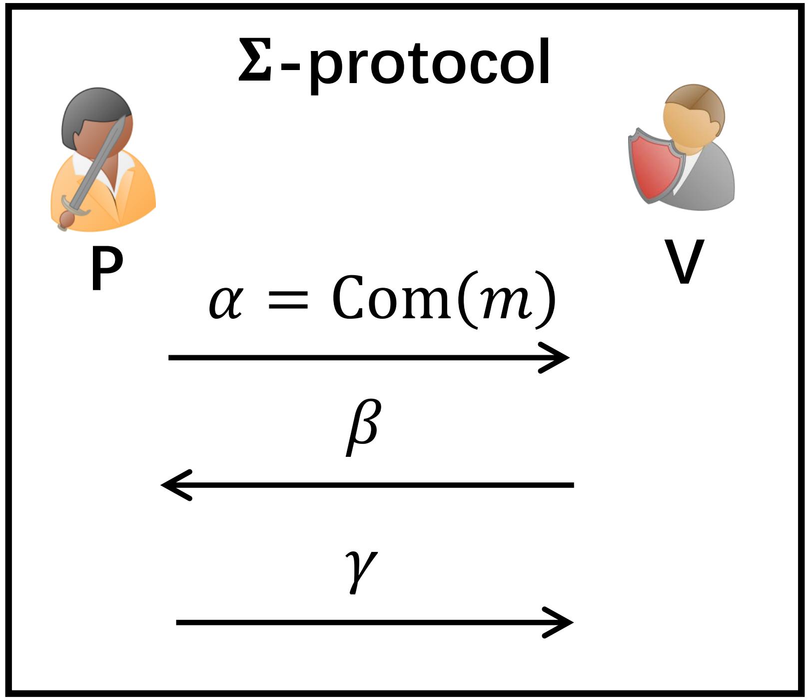

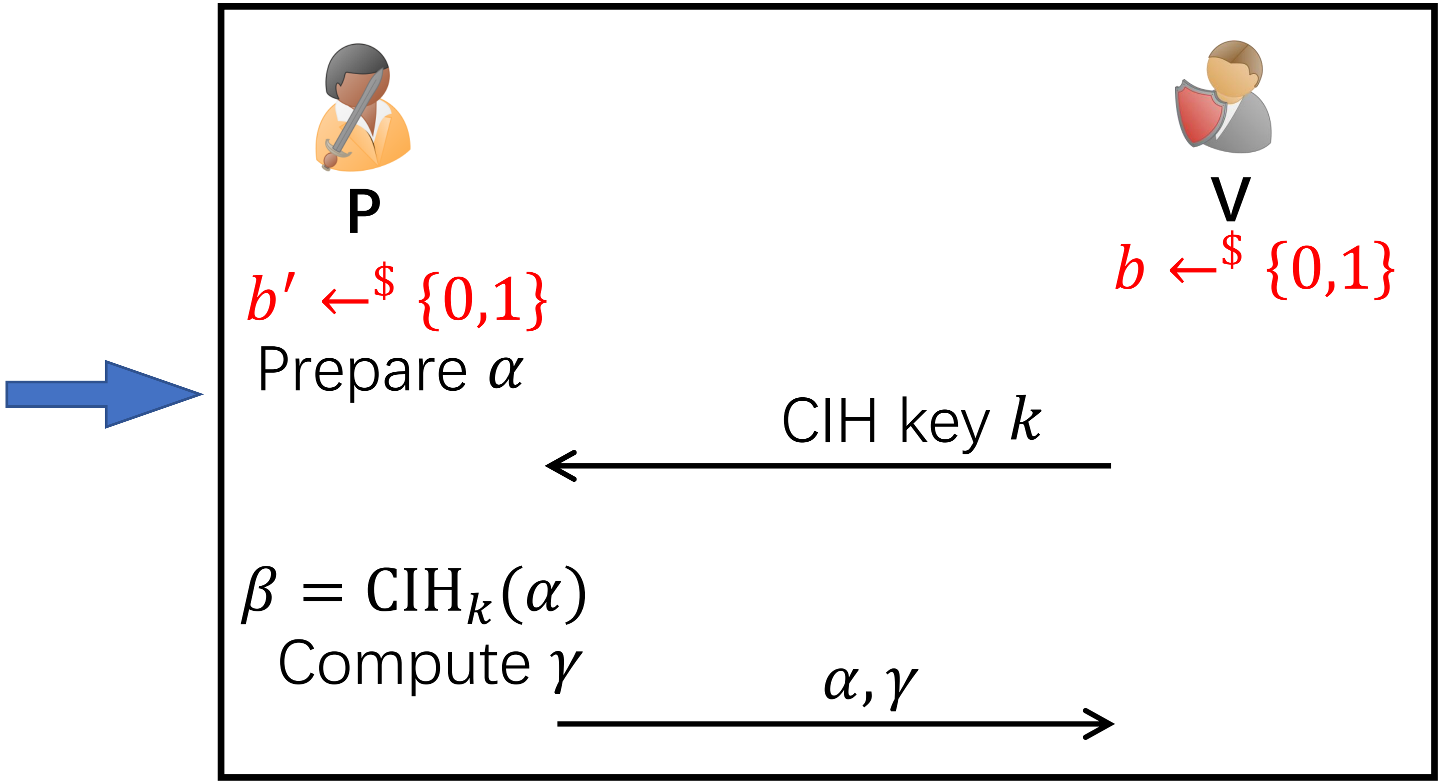

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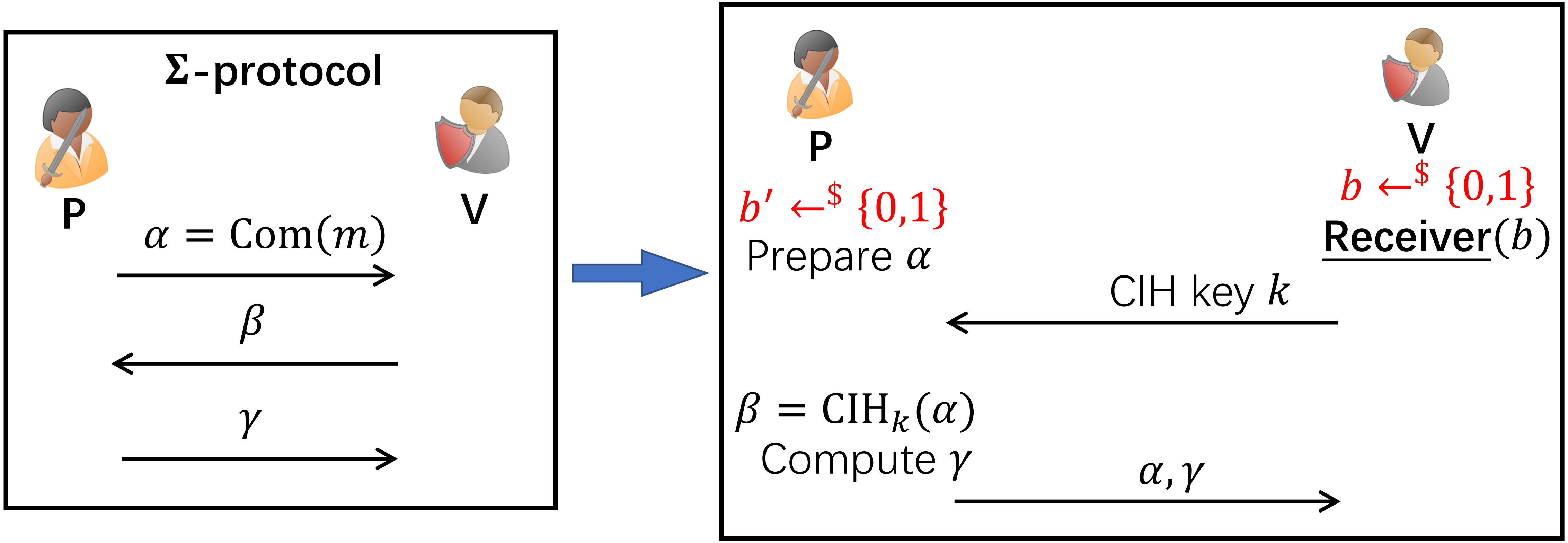

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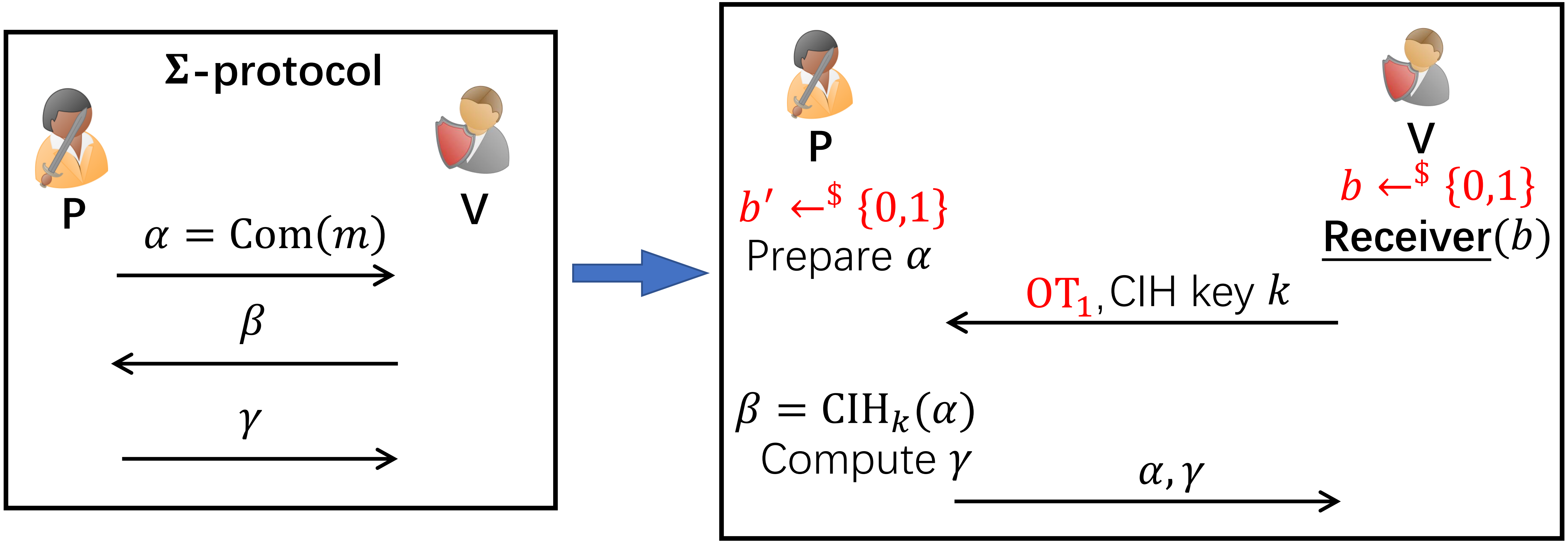

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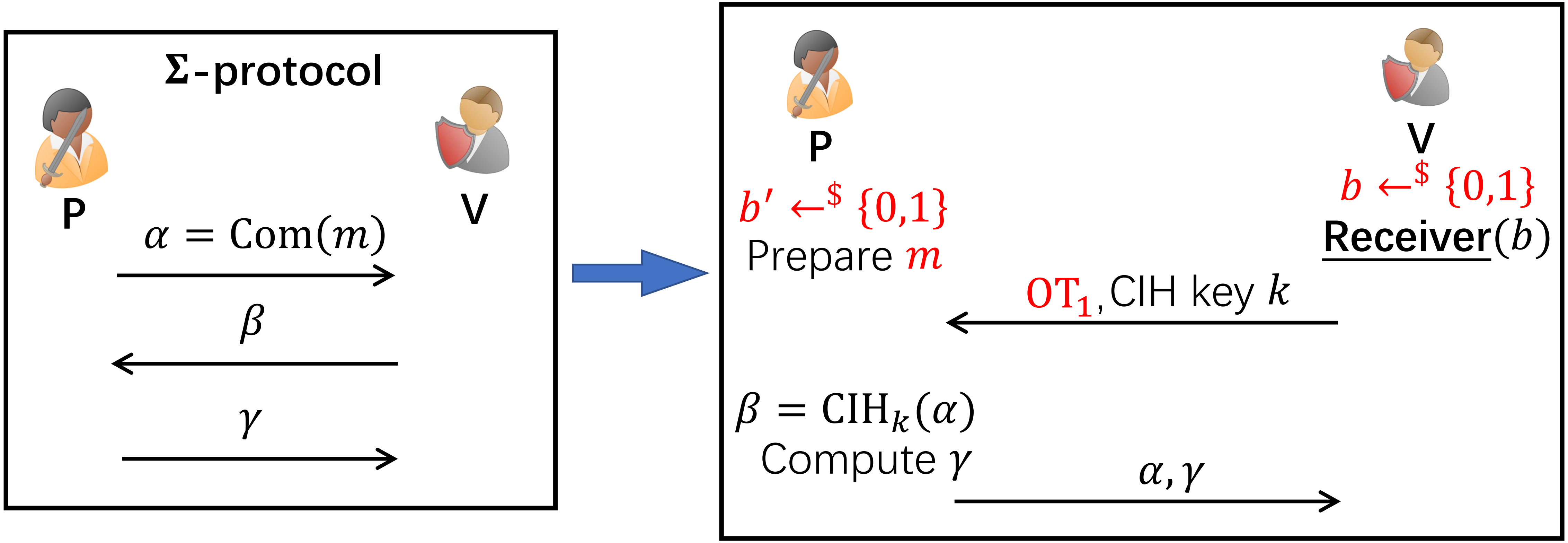

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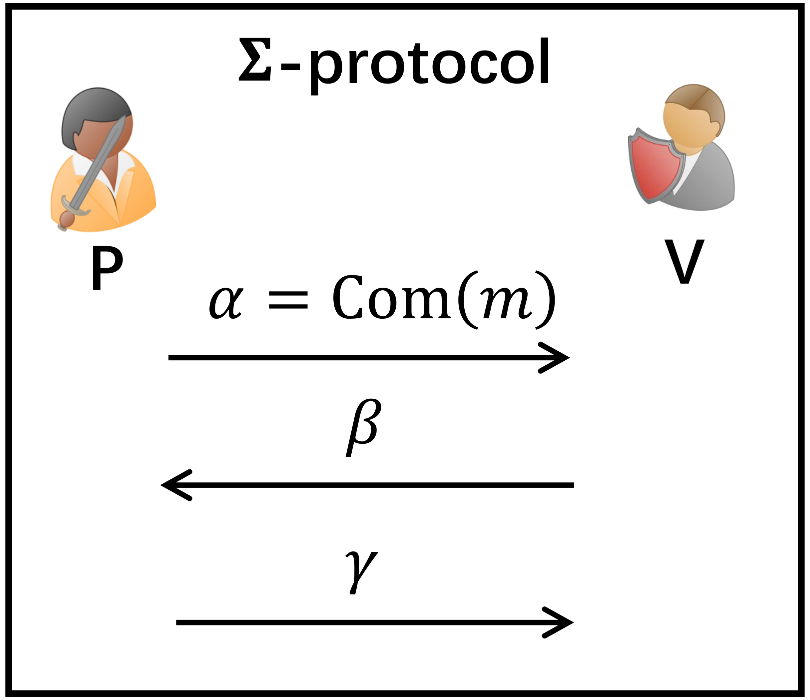

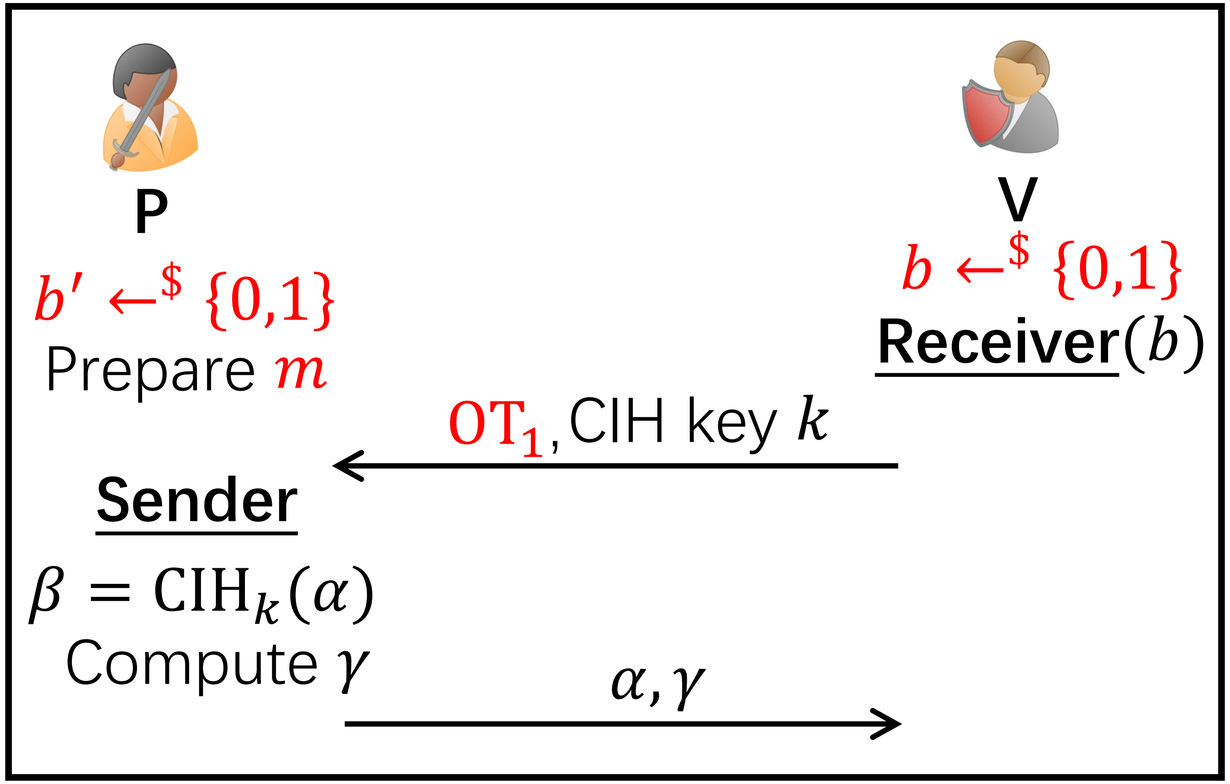

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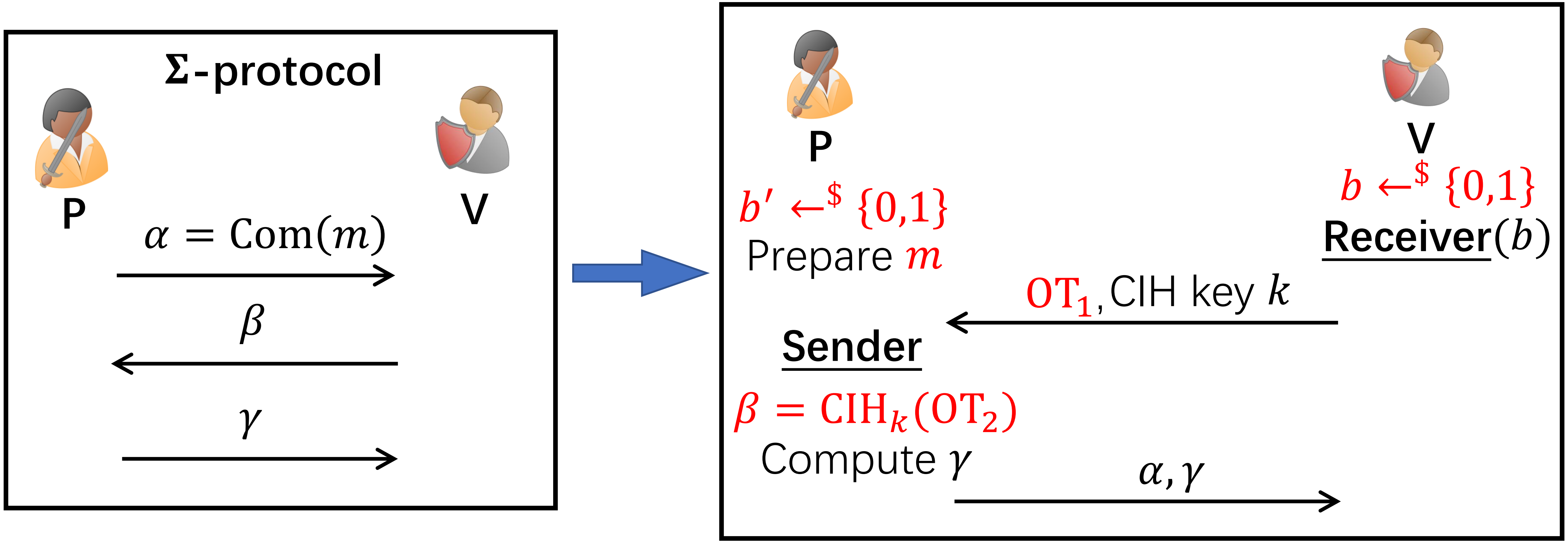

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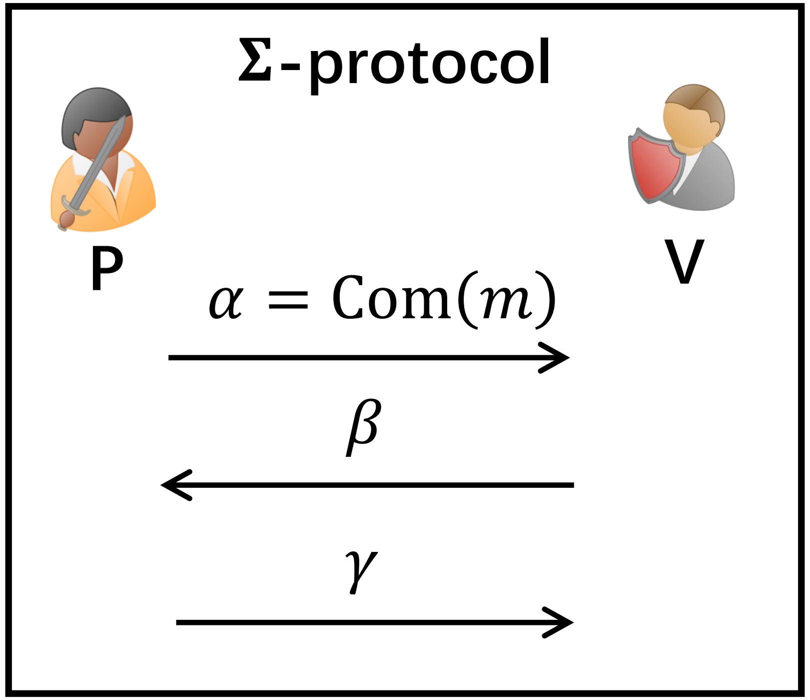

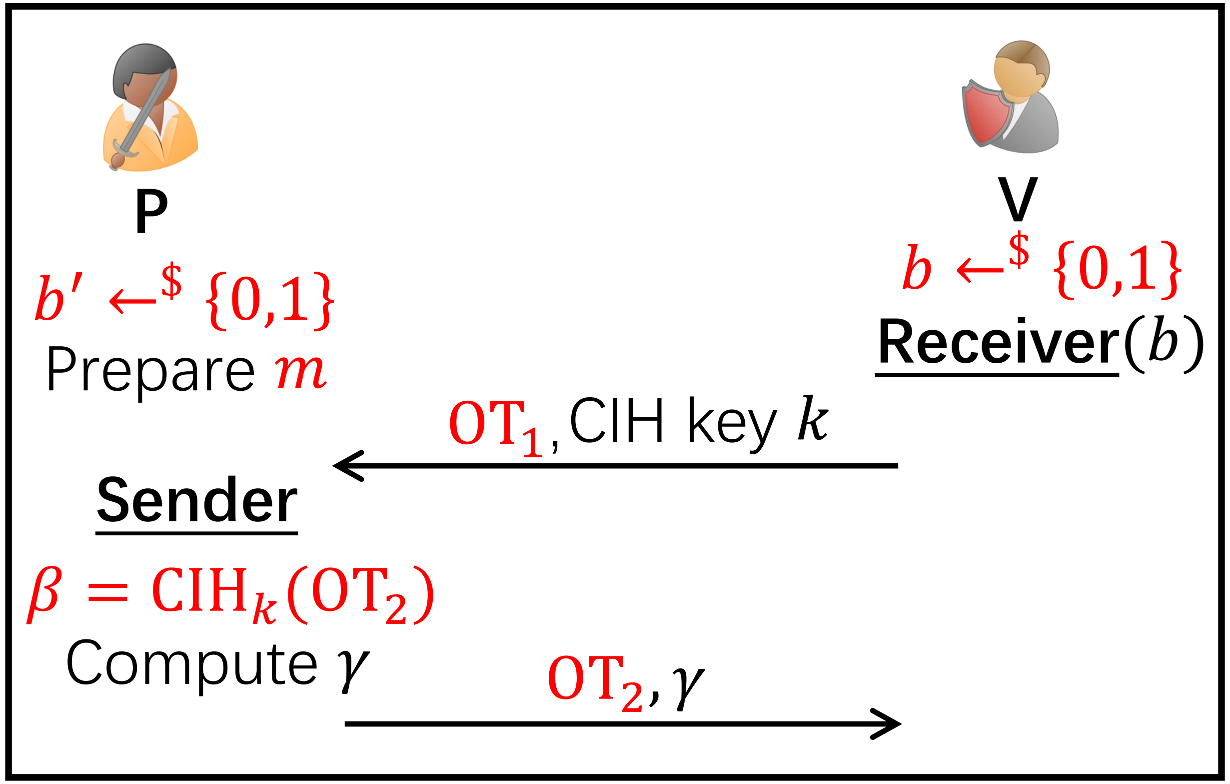

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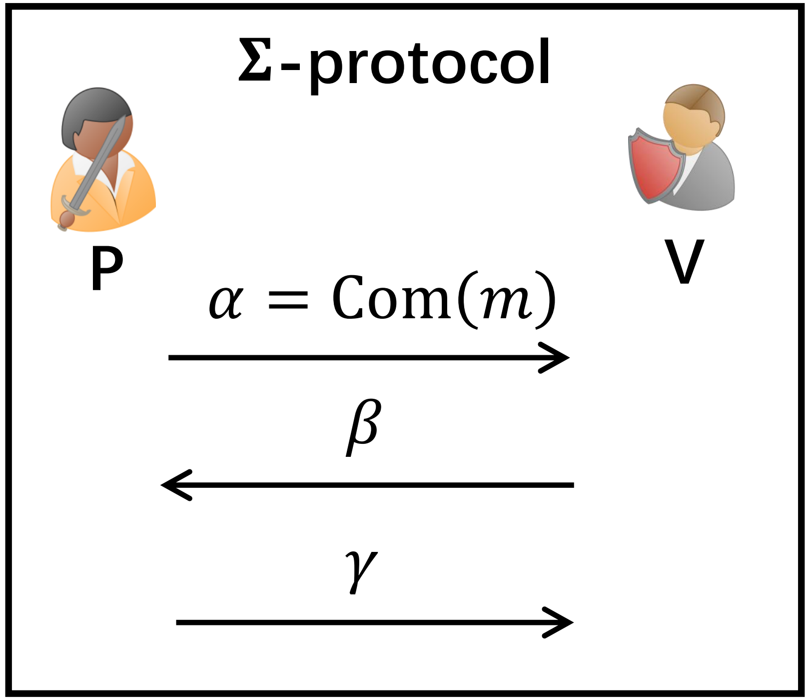
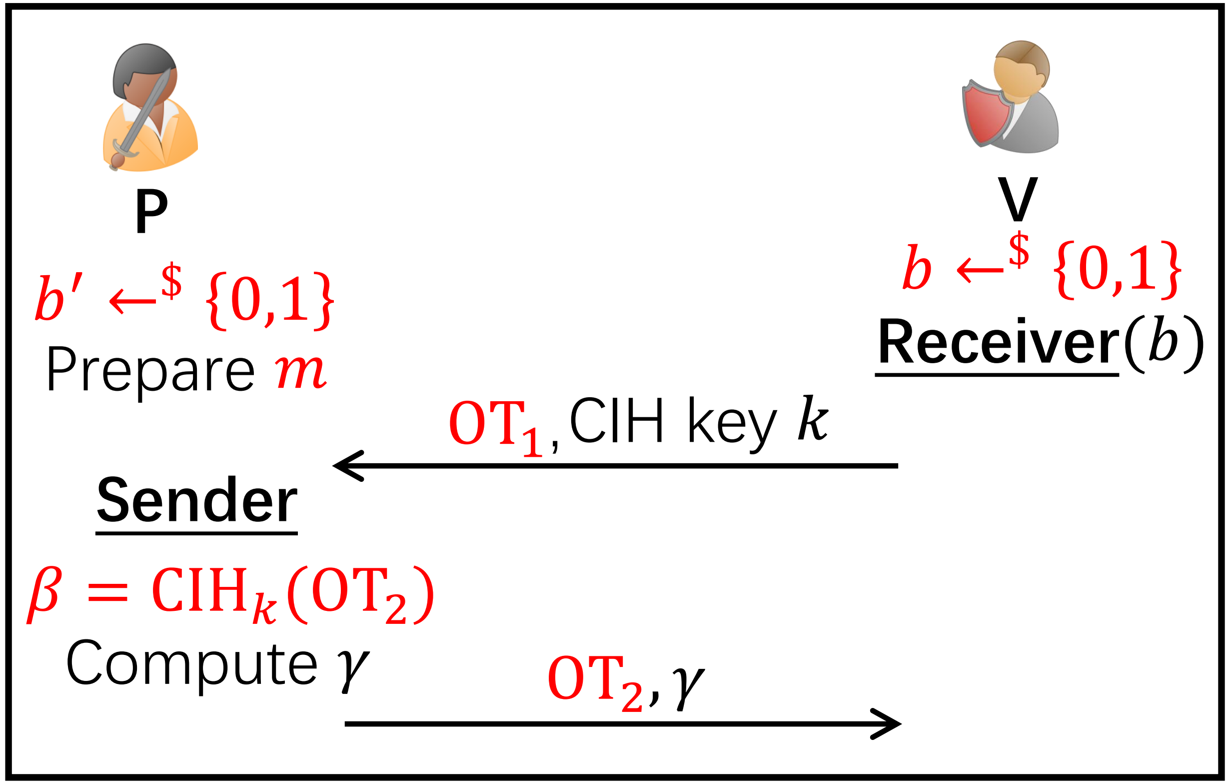
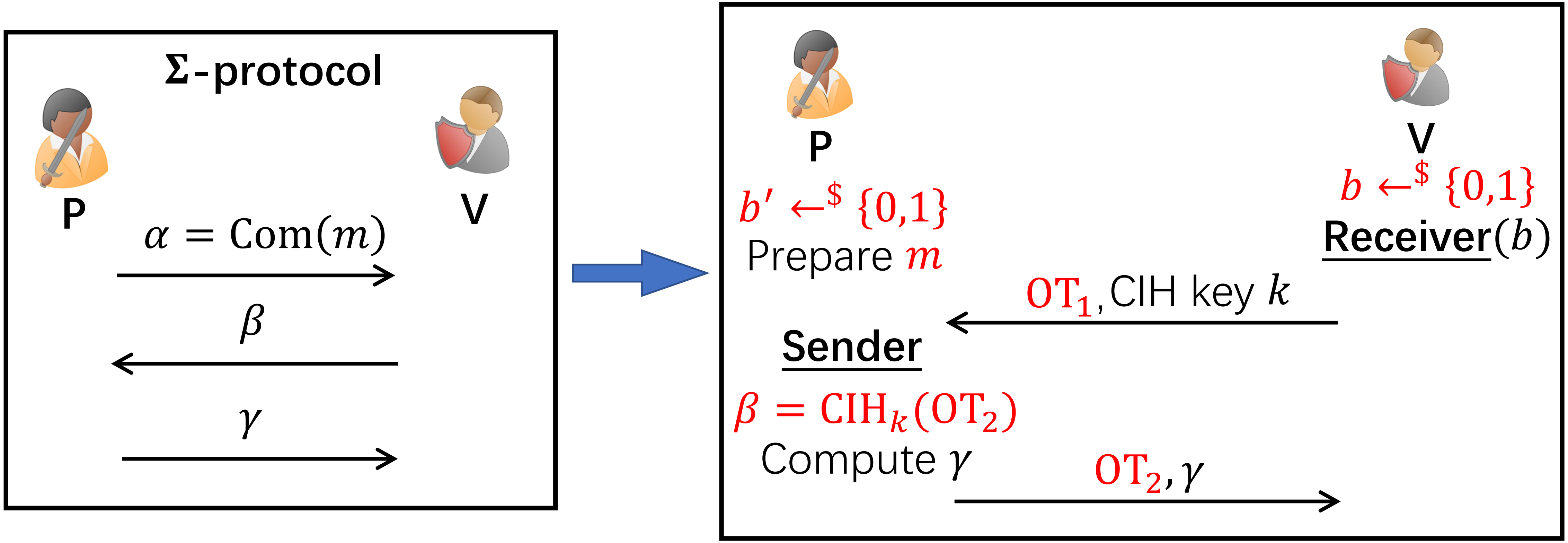




- Statistical WI with $\mathrm{err} \approx 1/2$ (when $b \neq b'$)
- Computational Soundness

‘Weakly Secure’ Statistical Zaps



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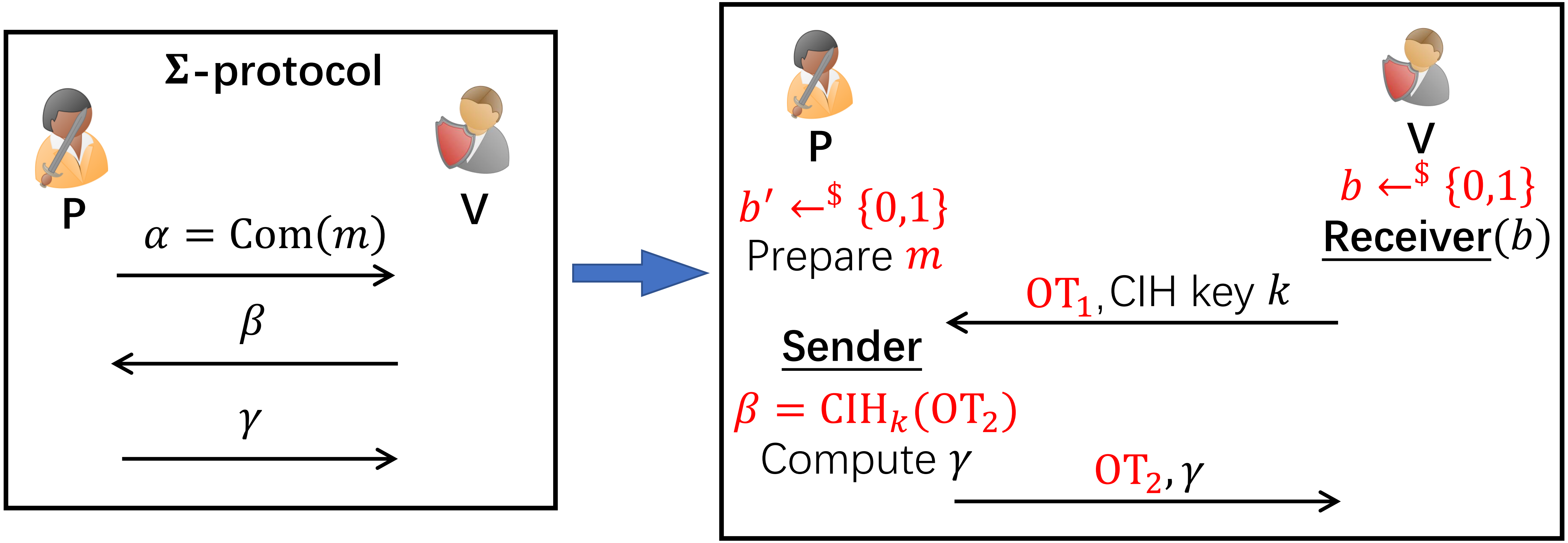

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- Computational Soundness

Amplify the Security

Sender

Receiver

Amplify the Security

Sender

$\boldsymbol{b}' \leftarrow \{0,1\}^l$

Receiver

$\boldsymbol{b} \leftarrow \{0,1\}^l$

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Amplify the Security

Sender

$\boldsymbol{b}' \leftarrow \{0,1\}^l$

2^l-positions

$\cdots$	$\perp$	m	$\perp$	$\cdots$

$\boldsymbol{b}'$-th position

Receiver

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Amplify the Security

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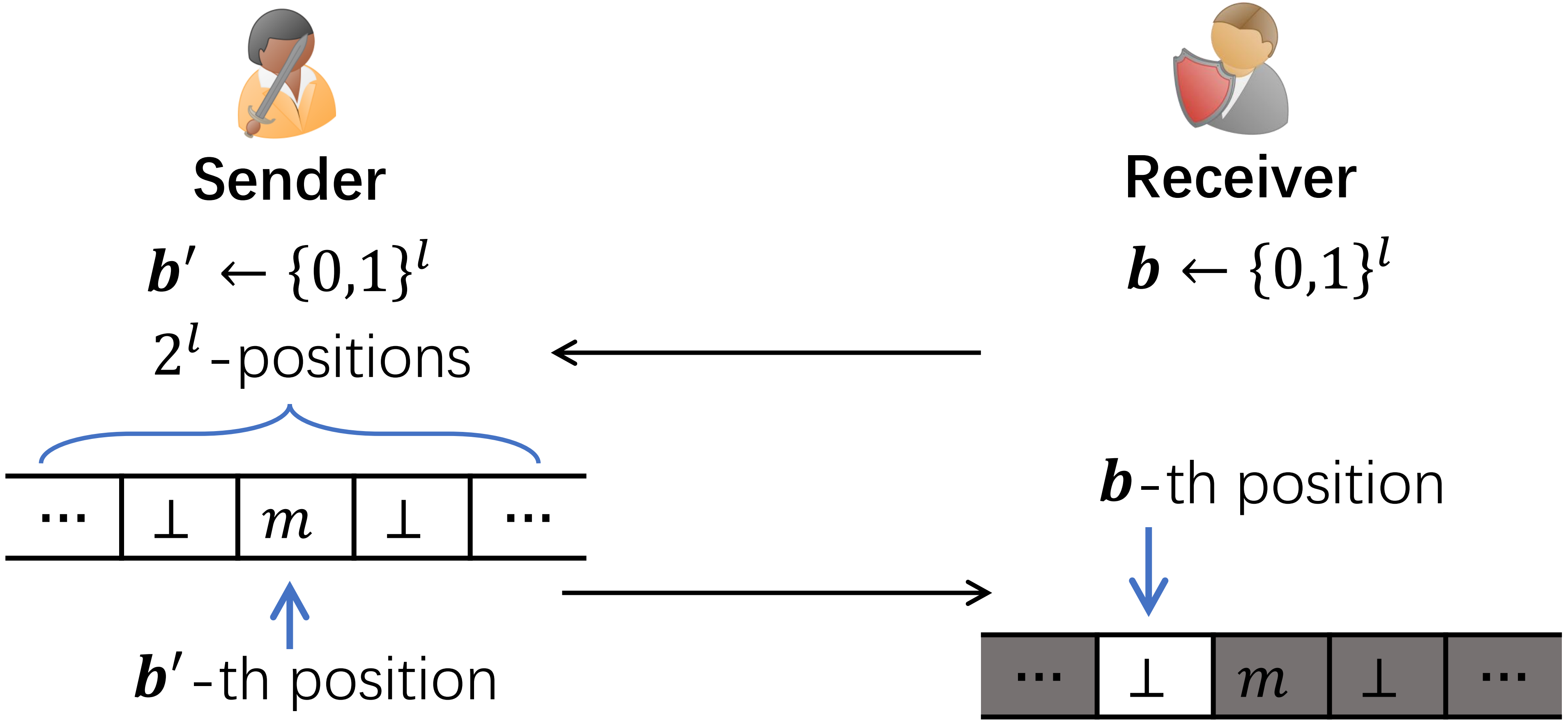

Amplify the Security

Sender

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2^l-positions

$\cdots$	$\perp$	m	$\perp$	$\cdots$

$\boldsymbol{b'}$-th position

Receiver

$\boldsymbol{b} \leftarrow \{0,1\}^l$

$\cdots$	$\perp$	m	$\perp$	$\cdots$

Amplify the Security

Sender

$\boldsymbol{b}' \leftarrow \{0,1\}^l$

2^l-positions

$\cdots$	$\perp$	m	$\perp$	$\cdots$

$\boldsymbol{b}'$-th position

Receiver

$\boldsymbol{b} \leftarrow \{0,1\}^l$

With $\Pr = 1 - 2^{-l}$,

$\boldsymbol{b} \neq \boldsymbol{b}'$, hide m √

$\cdots$	$\perp$	m	$\perp$	$\cdots$

Amplify the Security

Sender

$\boldsymbol{b}' \leftarrow \{0,1\}^l$

2^l-positions

⋯	$\perp$	m	$\perp$	⋯

$\boldsymbol{b}'$-th position

Receiver

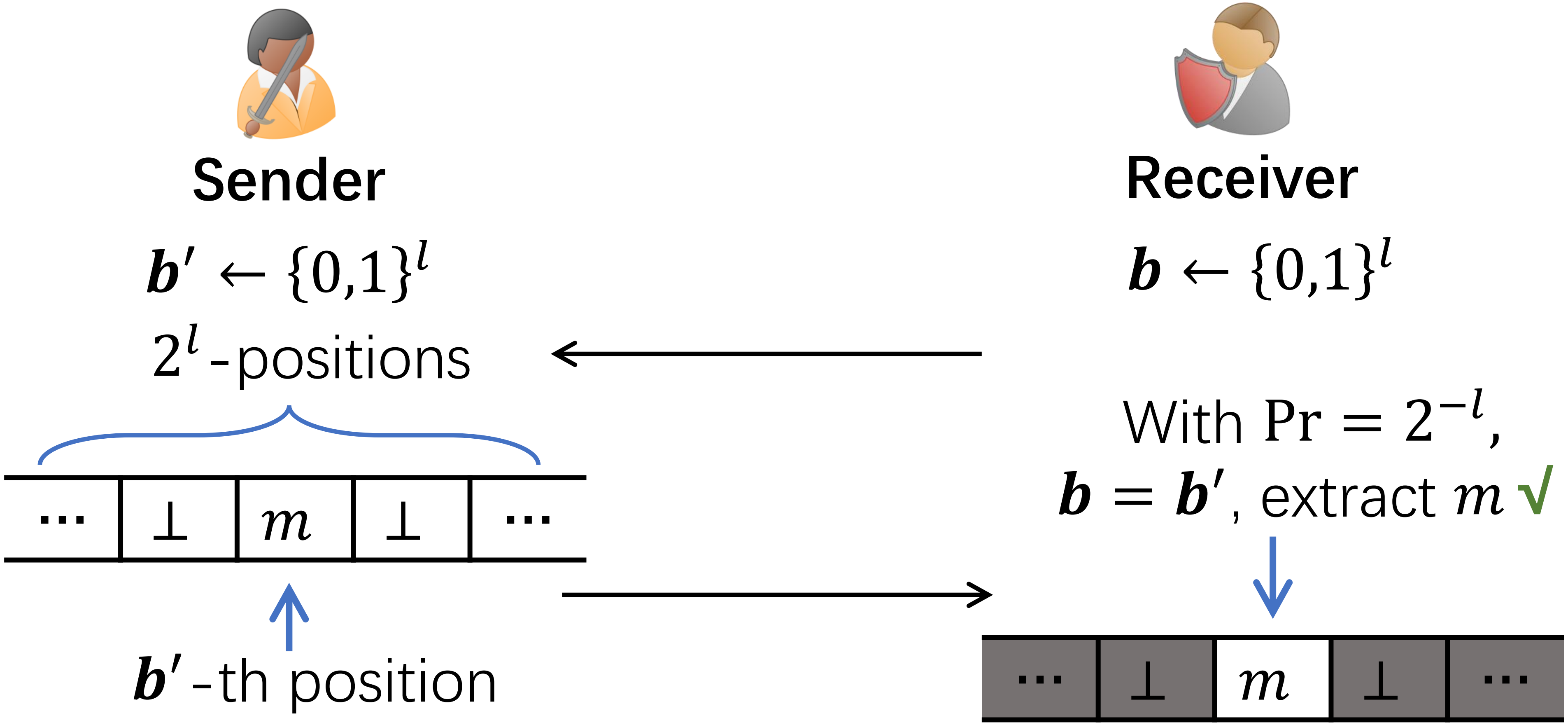
$\boldsymbol{b} \leftarrow \{0,1\}^l$

With $\Pr = 2^{-l}$,

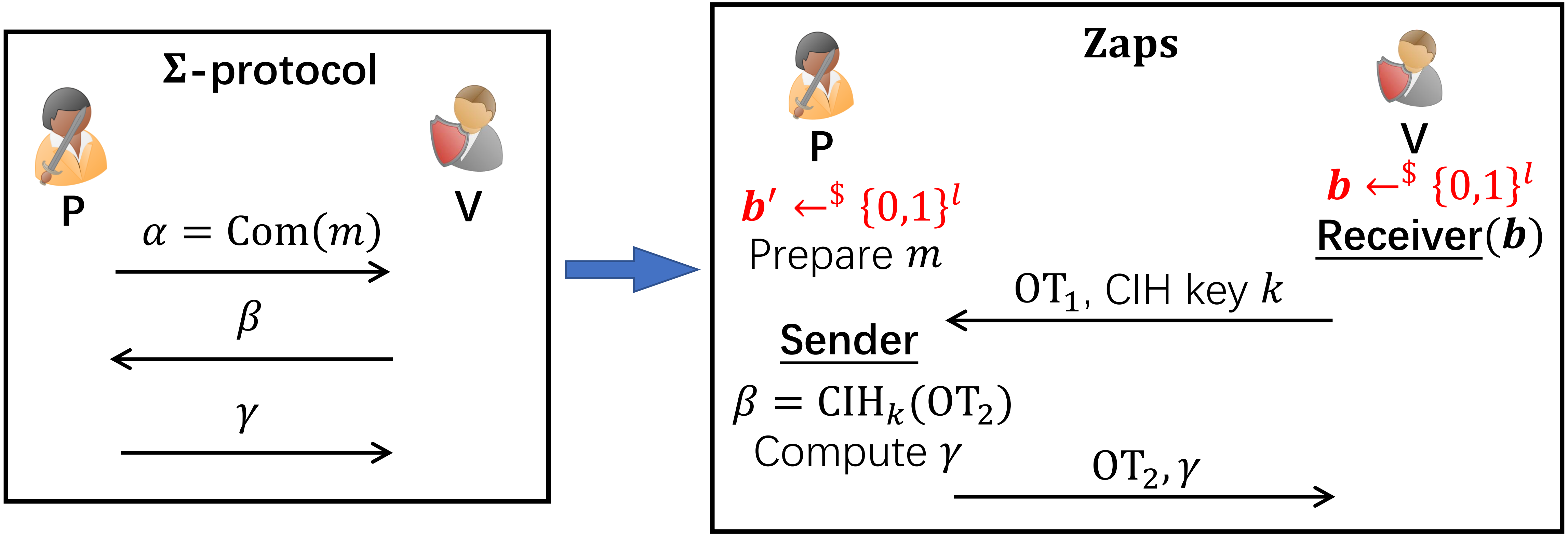
$\boldsymbol{b} = \boldsymbol{b}'$, extract m √

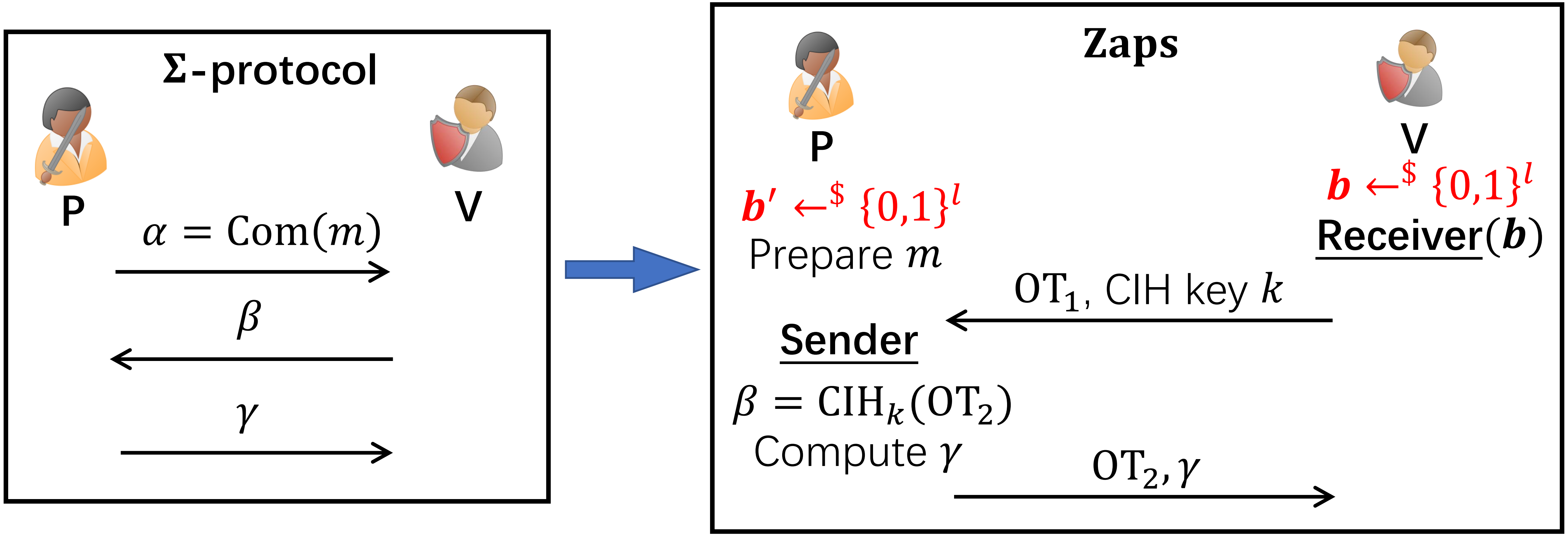
⋯	$\perp$	m	$\perp$	⋯

Amplify the Security

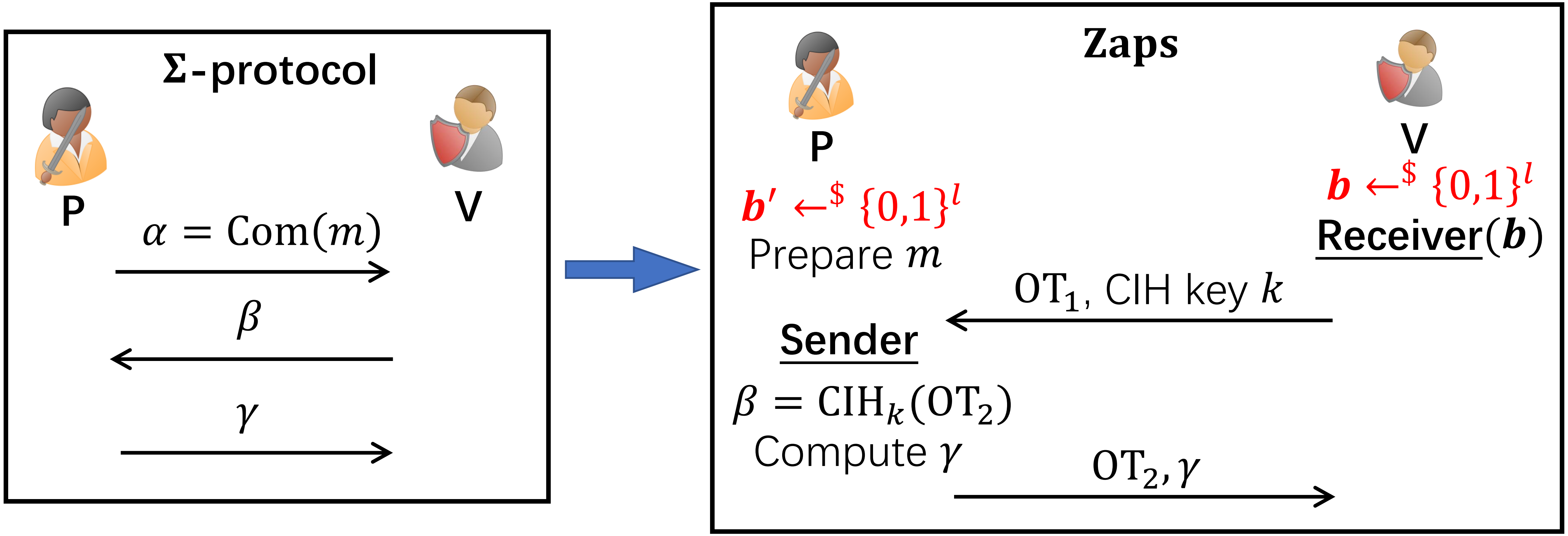


- Can be abstracted as a 2-round statistical hiding extractable commitment [KKS18]


Σ-protocol
P
V
$\alpha = \mathrm{Com}(m)$
β
γ
Zaps
P
V
$b' \leftarrow^{\$} \{0,1\}^l$
$b \leftarrow^{\$} \{0,1\}^l$
Prepare m
Receiver(b)
OT_1, CIH key k
Sender
$\beta = \mathrm{CIH}_k(\mathrm{OT}_2)$
Compute γ
OT_2, γ



- Statistical WI with $\mathrm{err} \approx 1/2^{l}$ (negligible)
- Computational Soundness via Complexity Leveraging
- Public Coin Property : OT_1 is pseudorandom



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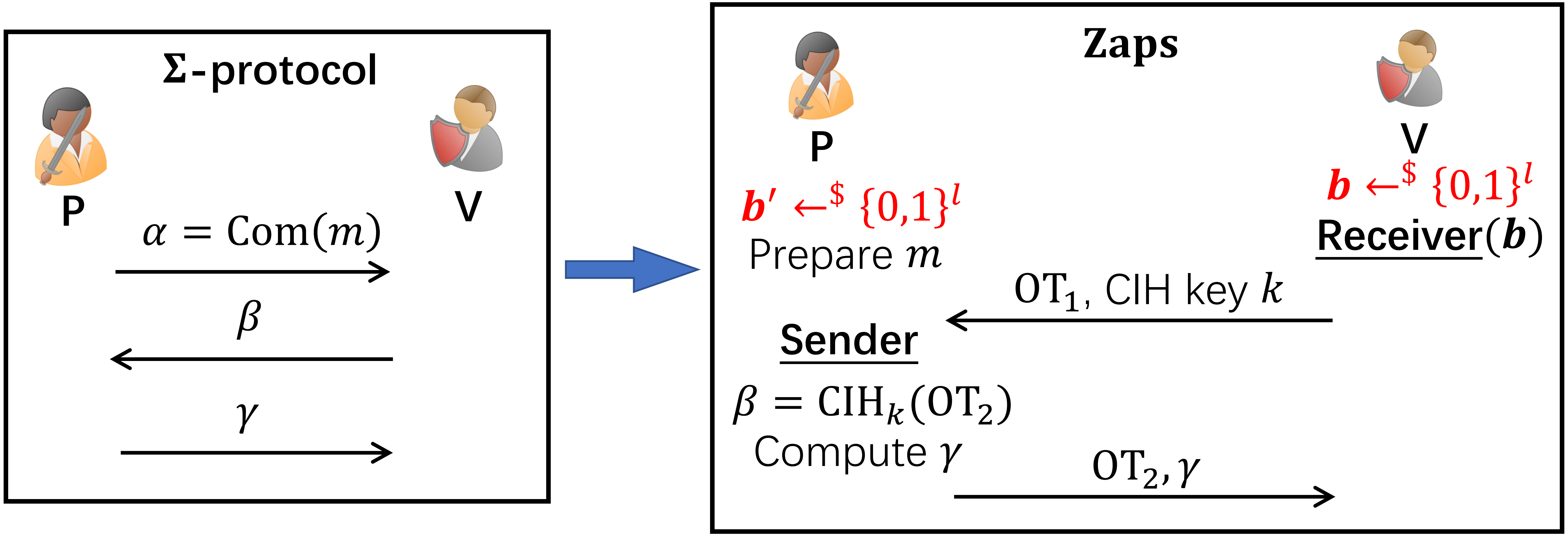

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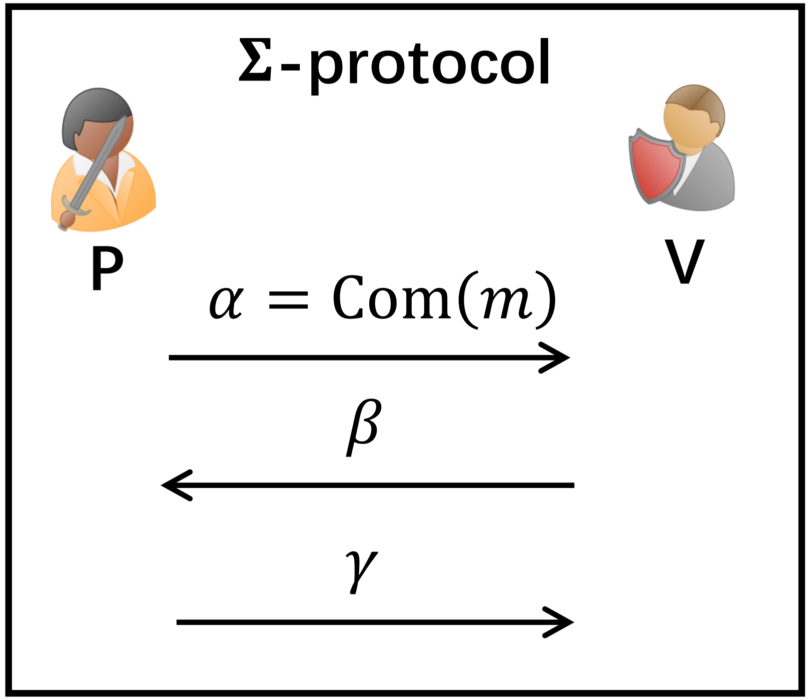

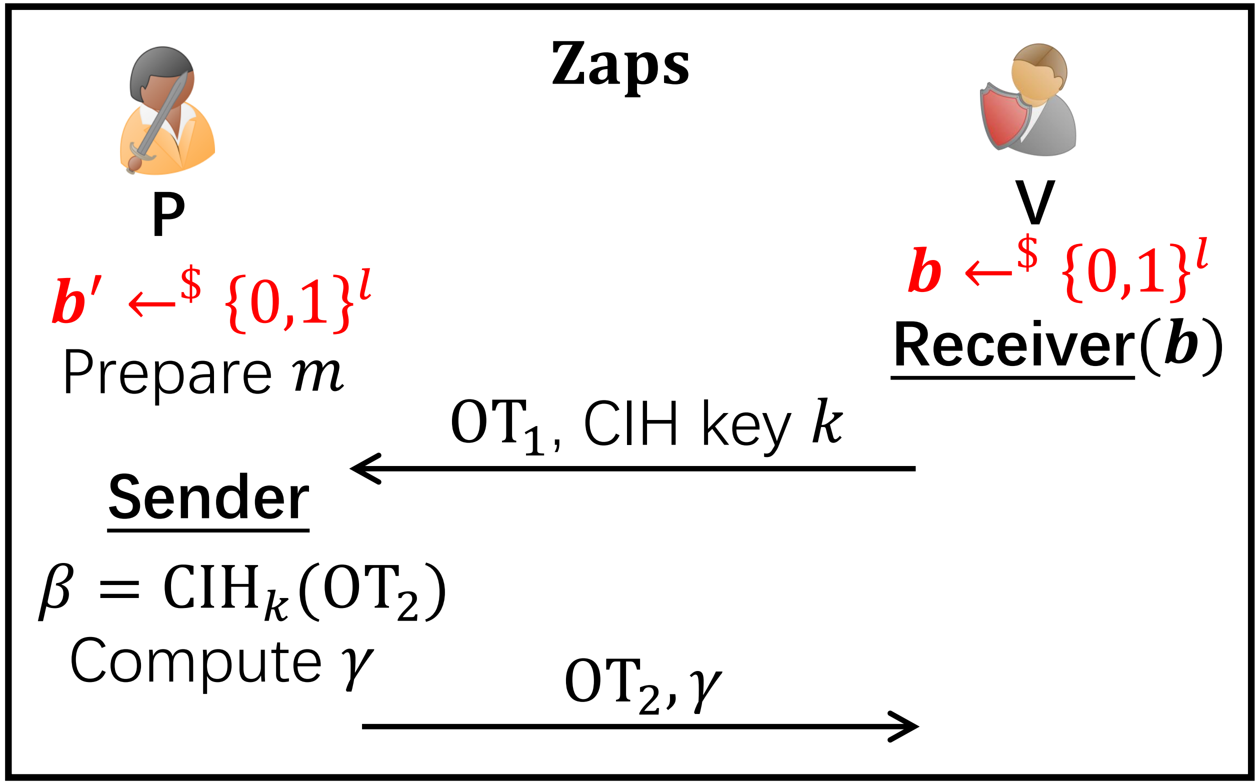

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Statistical Zaps

Technical Details
Part II: Oblivious Transfer (OT)

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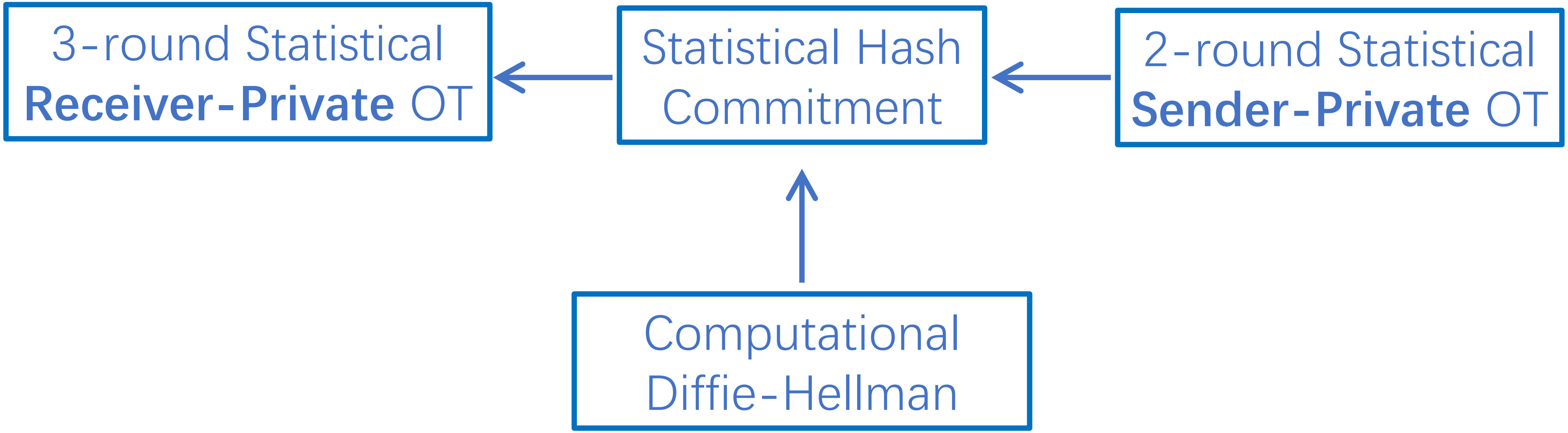
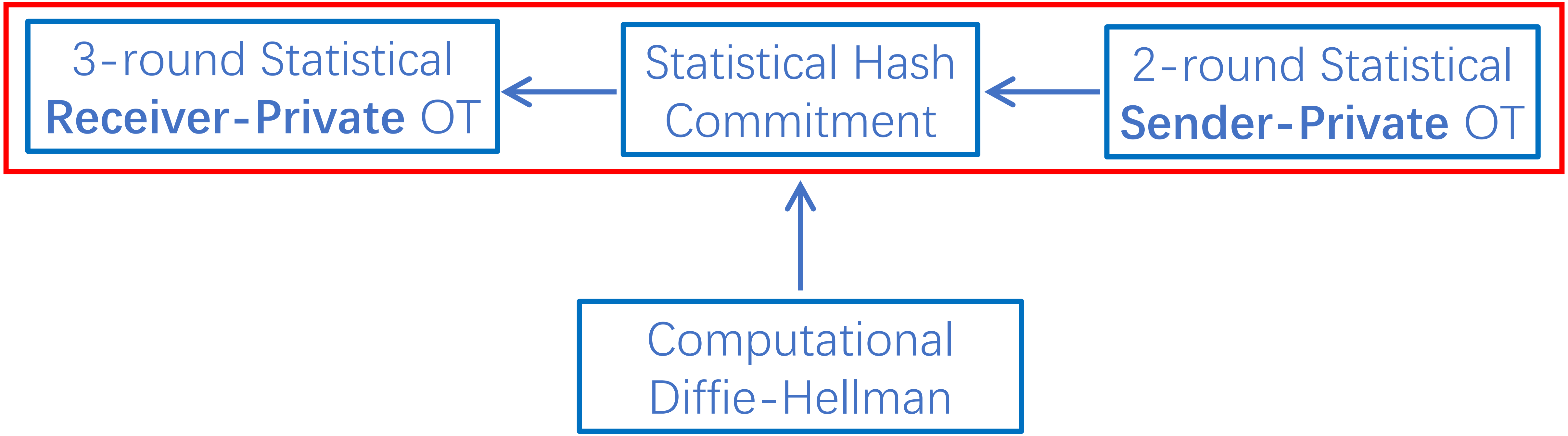


Technical Details
Part II: Oblivious Transfer (OT)



Statistical Receiver-Private OT

Sender

m_0	m_1

Receiver($\beta \in \{0,1\}$)

$\longrightarrow$

$\longleftarrow$

$\longrightarrow$

Get m_β

m_0	m_1

Statistical Receiver-Private OT

Sender

m_0	m_1

Receiver($\beta \in \{0,1\}$)

$\longrightarrow$

$\longleftarrow$

$\longrightarrow$

Get m_β

m_0	m_1

Statistical Receiver-Privacy: β is statistical hidden

Main Tool: Statistical Hash Commitments (SHC)

Main Tool: Statistical Hash Commitments (SHC)

Receiver

Committer$(\beta \in \{0,1\})$

Main Tool: Statistical Hash Commitments (SHC)

Receiver

Committing Phase:

Committer($\beta \in \{0,1\}$)

Main Tool: Statistical Hash Commitments (SHC)

Receiver

Committer$(\beta \in \{0,1\})$

Committing Phase:

Main Tool: Statistical Hash Commitments (SHC)

Receiver

Committer$(\beta \in \{0,1\})$

Committing Phase:

$\longrightarrow$

$\longleftarrow$

Opening Phase:

Main Tool: Statistical Hash Commitments (SHC)

Receiver **Committer**($\beta \in \{0,1\}$)

Committing Phase:

Opening Phase:

Hash value for $\beta = 0$:

Hash value for $\beta = 1$:

Main Tool: Statistical Hash Commitments (SHC)

Receiver

Committer$(\beta \in \{0,1\})$

Committing Phase:

Opening Phase:

Hash value for $\beta = 0$:

Hash value for $\beta = 1$:

β,

Main Tool: Statistical Hash Commitments (SHC)

Receiver

Committer($\beta \in \{0,1\}$)

Committing Phase:

$\longrightarrow$

$\longleftarrow$

Opening Phase:

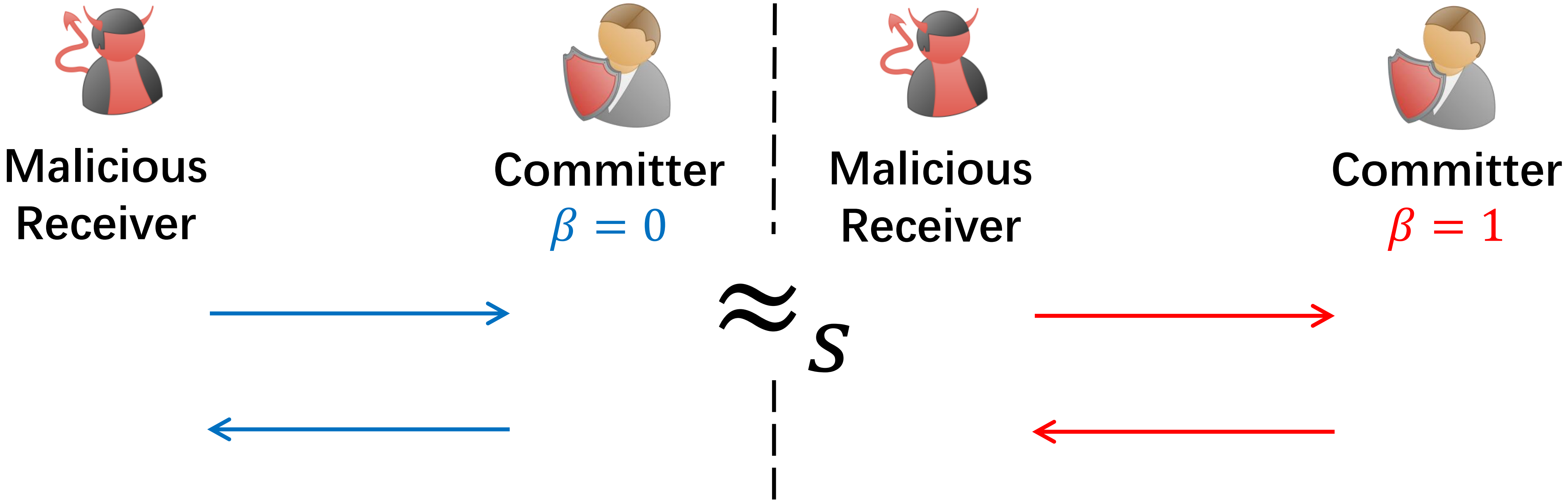
Hash value for $\beta = 0$:

Hash value for $\beta = 1$:

β,

Check $=?$

Statistical **H**ash **C**ommitments (SHC): Statistical Hiding Property



Statistical **H**ash **C**ommitments (SHC): Computational Binding

Receiver

Malicious Committer

Committing Phase:

Hash value for $\beta = 0$:

Hash value for $\beta = 1$:

Statistical **H**ash **C**ommitments (SHC): Computational Binding

Receiver

Malicious Committer

Committing Phase:

Hash value for $\beta = 0$:

Hash value for $\beta = 1$:

Computational Binding:

it's hard for committer to find both

3-round Statistical Receiver-Private OT from SHC

3-round Statistical Receiver-Private OT from SHC

Sender(m_0, m_1)

Receiver$(b \in \{0,1\})$

3-round Statistical Receiver-Private OT from SHC

Sender(m_0, m_1)

Committing Phase

Receiver$(b \in \{0,1\})$

Hash values for opening:

b

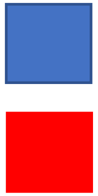
3-round Statistical Receiver-Private OT from SHC

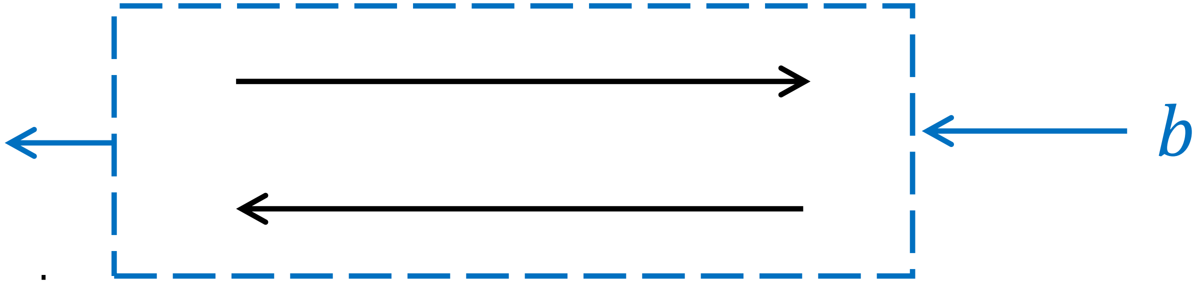
Sender(m_0, m_1)

Committing Phase

Receiver$(b \in \{0,1\})$

Hash values for opening:





$hc(\cdot)$: Goldreich-Levin hardcore predicate

3-round Statistical Receiver-Private OT from SHC

Sender(m_0, m_1)

Committing Phase

Receiver$(b \in \{0,1\})$

b

Hash values for opening:

$hc(\cdot)$: Goldreich-Levin hardcore predicate

$hc(\ ) \oplus m_0$

$hc(\ ) \oplus m_1$

3-round Statistical Receiver-Private OT from SHC

Sender(m_0, m_1) **Committing Phase** **Receiver**$(b \in \{0,1\})$

Hash values for opening: $\boxed{}$ $\boxed{}$

b

$hc(\cdot)$: Goldreich-Levin hardcore predicate

$hc(\boxed{}) \oplus m_0$

$hc(\boxed{}) \oplus m_1$

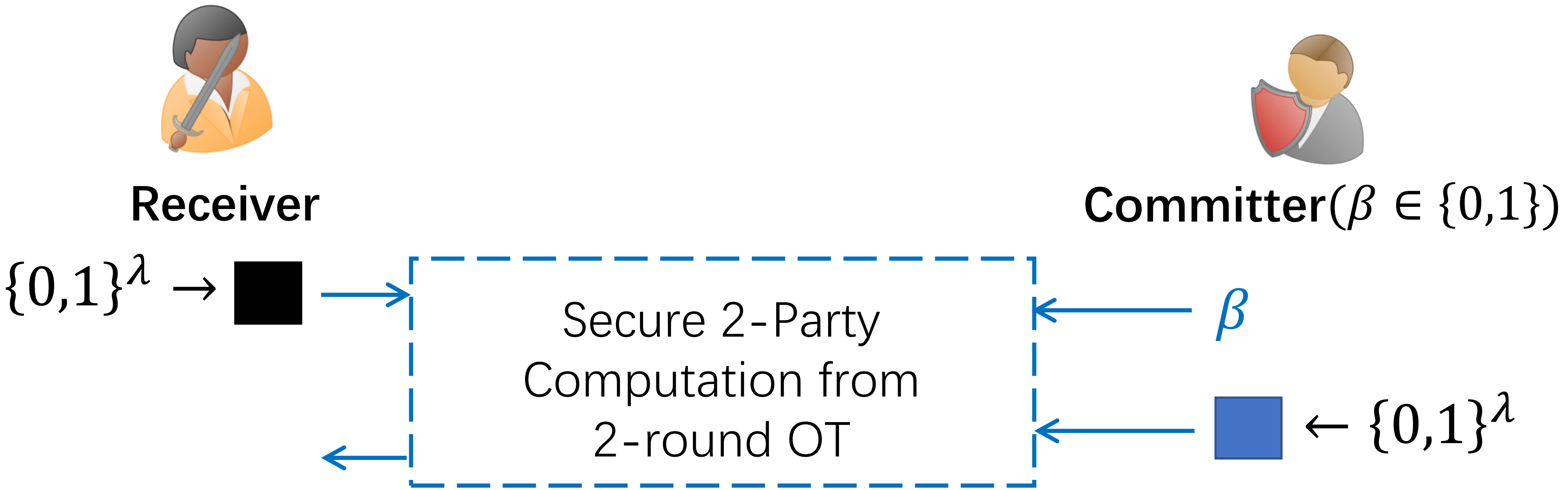
- Statistical Hiding ⇒ Statistical Receiver-Private
- Computational Binding ⇒ Computational Sender-Private

Statistical Hash Commitment from 2-round OT

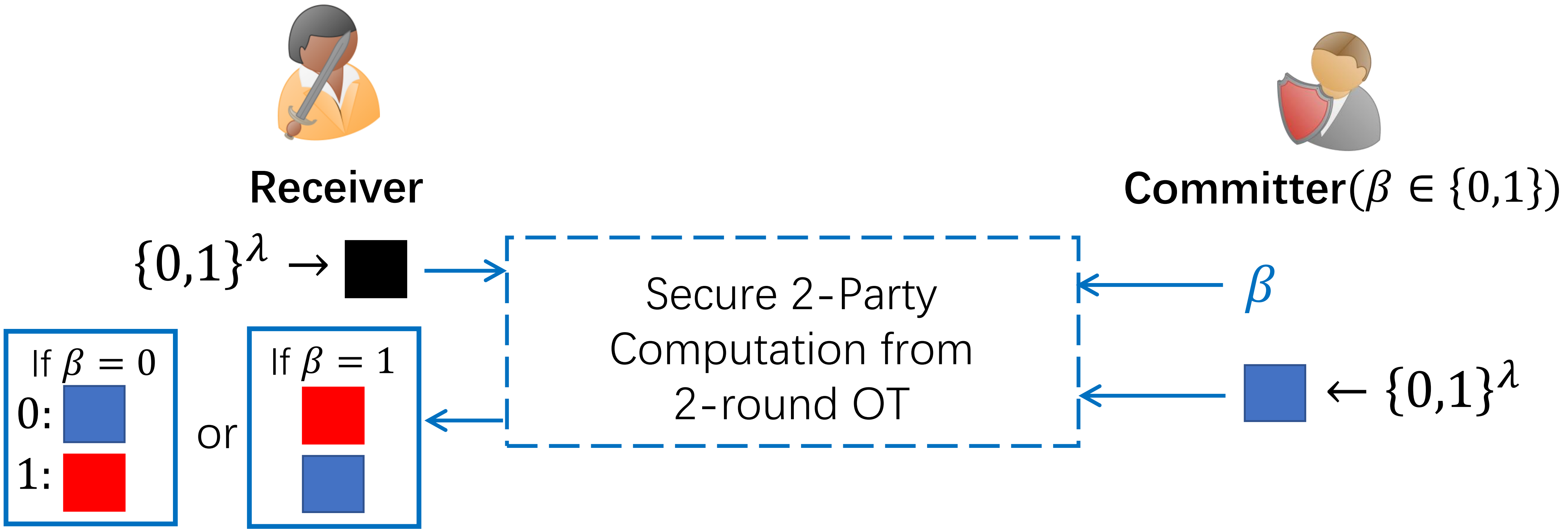
Receiver

Committer$(\beta \in \{0,1\})$

Statistical Hash Commitment from 2-round OT



Statistical Hash Commitment from 2-round OT



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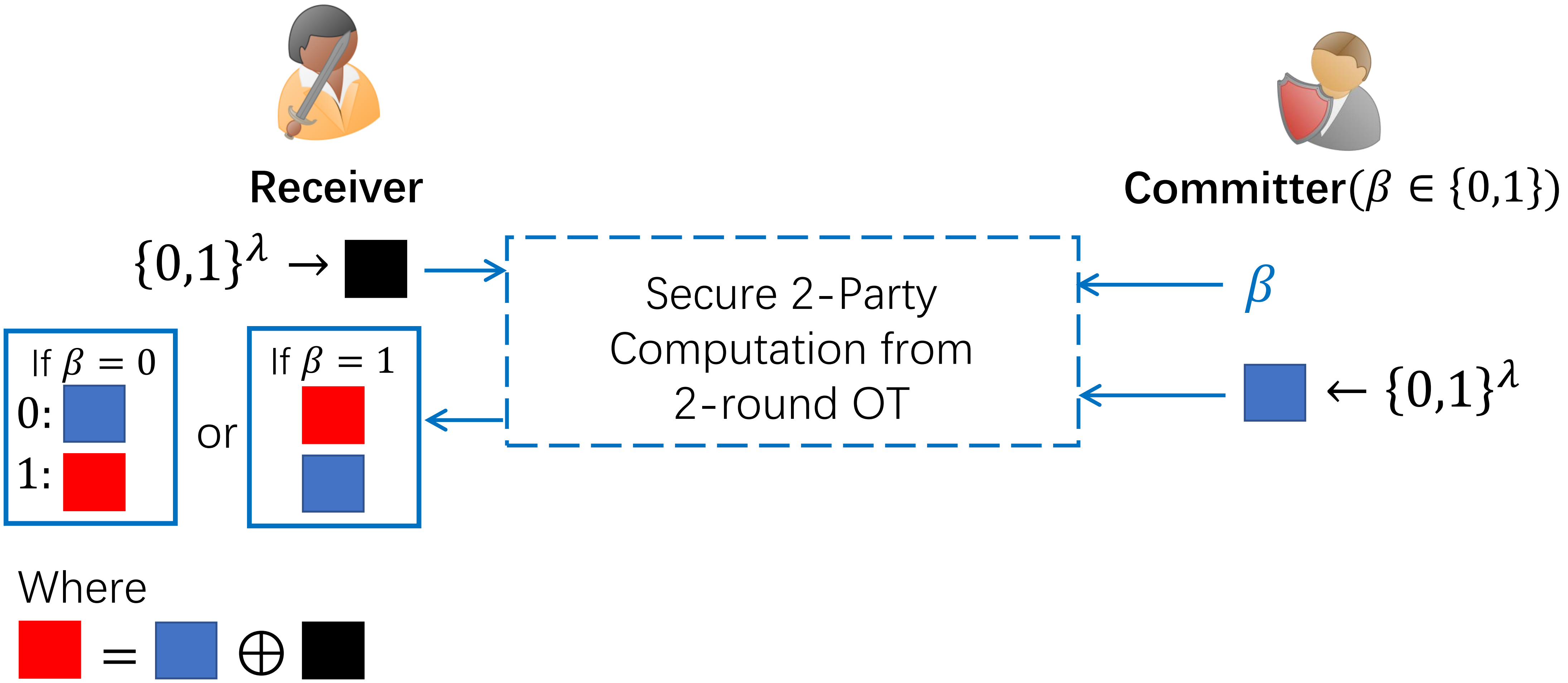

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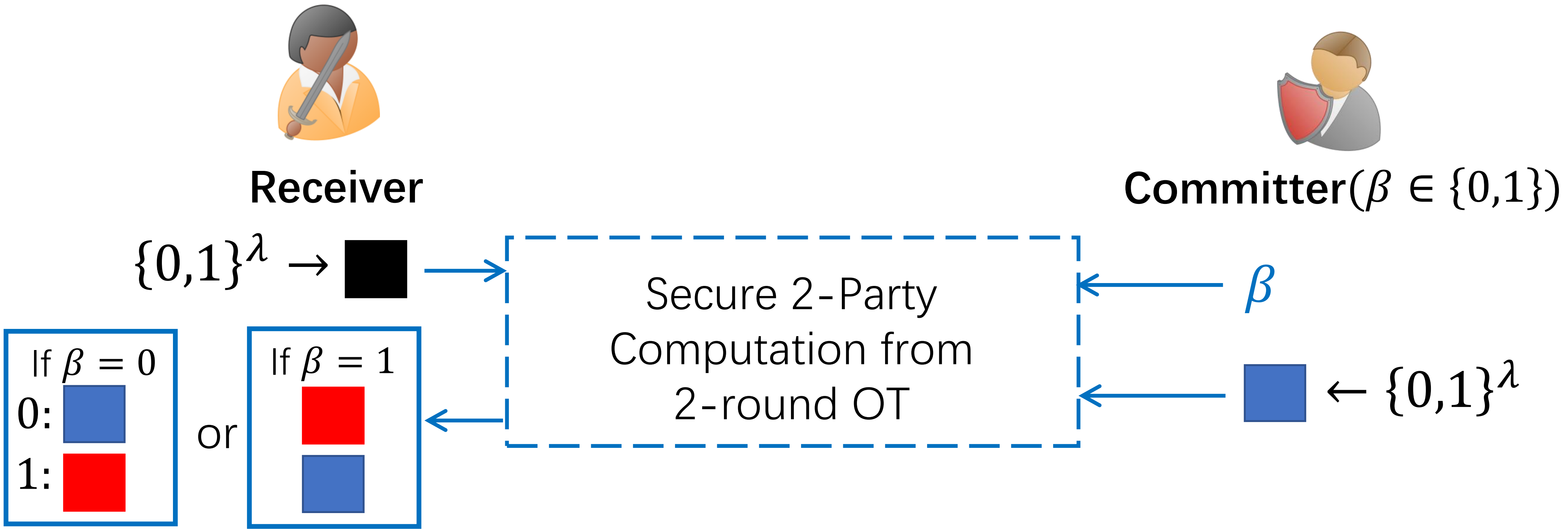

Where

- Statistical Sender-Privacy of OT ⇒ Statistical Hiding
- Computational Hiding of ■ ⇒ Computational Binding

Summary of Results

- Statistical Zaps from quasi-poly hardness Learning with Errors
- 3-round statistical receiver-private oblivious transfer from poly hardness
  - 2-round statistical sender-private oblivious transfer
  - Computational Diffie-Hellman Assumption

Full version : [ia.cr/2020/235](ia.cr/2020/235)

Thank you!