Non-Interactive Batch Arguments for NP from Standard Assumptions

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Non-Interactive Batch Arguments for NP

CRS

$C, x_1, \cdots, x_k$

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$\text{SAT} = \{(C, x) \mid \exists w \ s.t. \ C(x, w) = 1\}$

$\forall i \in [k], (C, x_i) \in \text{SAT}$

Non-Interactive Batch Arguments for NP

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Π is publicly verifiable

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CRS

$C, x_1, \cdots, x_k$

Π

$\longrightarrow$

$C, x_1, \cdots, x_k$

Π is publicly verifiable

No PPT  can produce accepting Π if

$\exists i^* \in [k], (C, x_{i^*}) \cancel{\in} \mathrm{SAT}$

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$C, x_1, \cdots, x_k$

$w_1, \ldots, w_k$

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$C, x_1, \cdots, x_k$

$\ll |w| \cdot k$

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$C, x_1, \cdots, x_k$

$\ll |w| \cdot k$

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Verifier running time:
$k \cdot |x| + |\Pi|$

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Prior Works

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Interactive batch proofs

[Reingold-Rothblum-Rothblum’16, Reingold-Rothblum-Rothblum’18, Rothblum-Rothblum’20]

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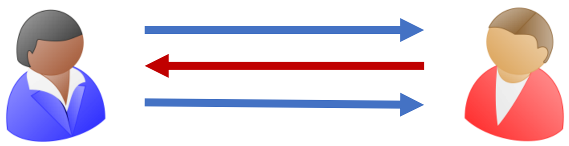

Secure against unbounded cheating prover.

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Interactive batch proofs for UP

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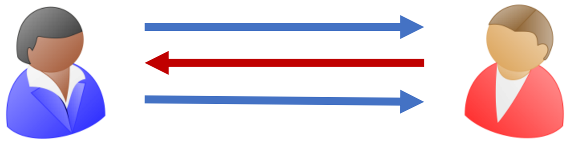

UP – each statement has a unique witness.

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Succinct Non-interactive Arguments (SNARGs) for NP

[Micali'94, Damgård-Faust-Hazay'12, Bitansky-Canetti-Chiesa-Tromer'13, Bitanksy-Canetti-Chiesa-Goldwasser-Lin-Rubinstein-Tromer'16]

SNARGs

$|\Pi| \ll |w|$

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SNARGs for NP from Non-falsifiable assumptions/ Random oracle model

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Designated Verifier non-interactive batch arguments for NP

[Brakerski-Holmgren-Kalai'17, Brakerski-Kalai'20]

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Non-interactive batch arguments for NP from new non-standard assumption

[Kalai-Paneth-Yang'19]

Falsifiable assumption on groups with bilinear maps.

Do there exists non-interactive batch arguments for NP based on standard assumptions?

Our Result

Theorem

Assuming QR + (LWE/sub-exp DDH) there exists a non-interactive batch argument for NP where

$$|\Pi| = \tilde{O}(|C| + \sqrt{k|C|})$$

QR – Quadratic residuosity, LWE – Learning with Error, DDH – Decisional Diffie-Hellman

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Key Insights

Fiat-Shamir (FS) Methodology

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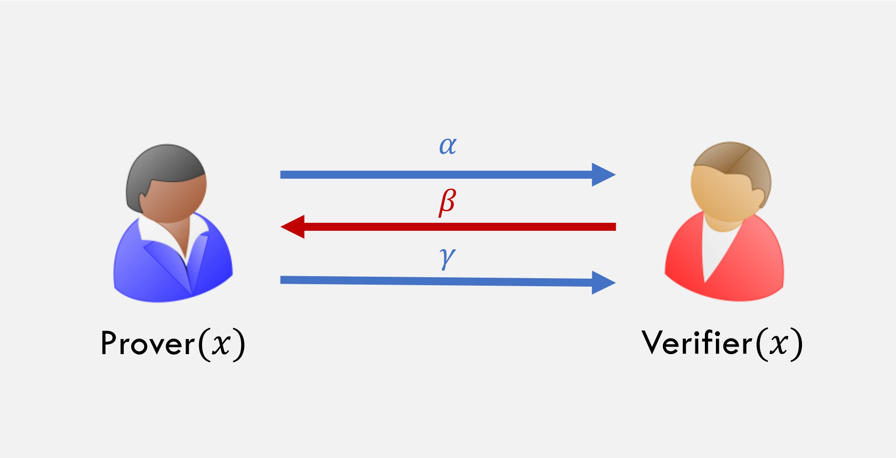
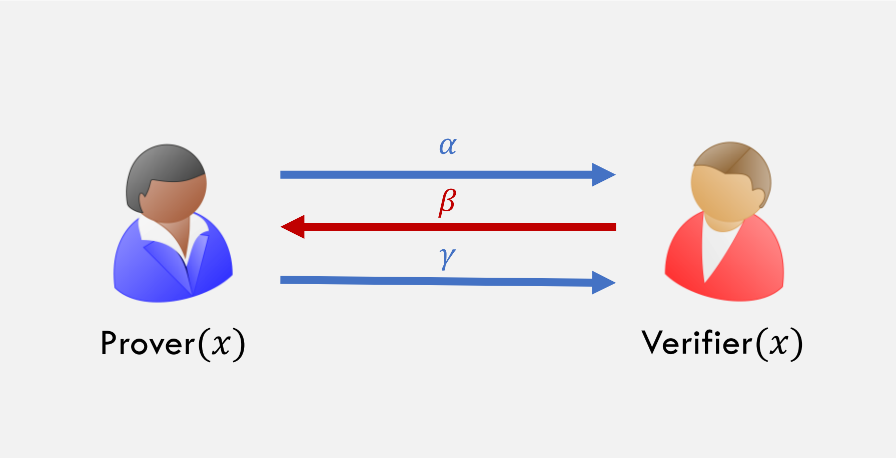


β is a random string

Fiat-Shamir (FS) Methodology



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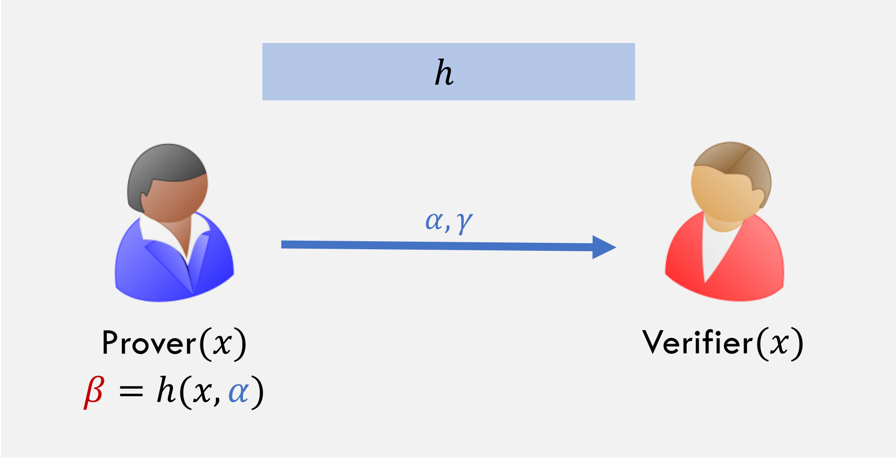
[Fiat-Shamir'86]



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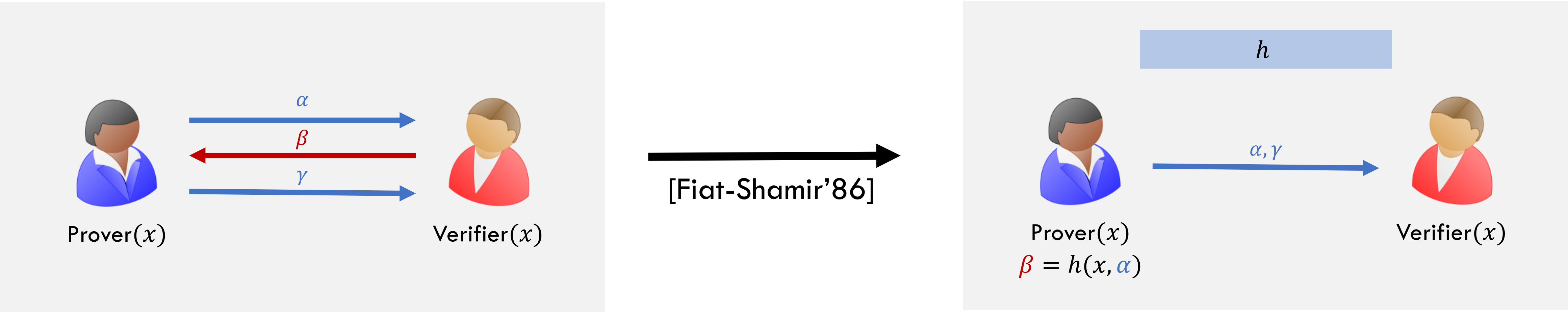

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FS methodology is secure for certain protocols under a variety of assumptions (via correlation intractable hash functions)

[Kalai-Rothblum-Rothblum'17, Canetti-Chen-Reyzin-Rothblum'18, Holmgren-Lombardi'18, Canetti-Chen-Holmgren-Lombardi-Rothblum-Rothblum-Wichs'19, Peikert-Sheihian'19, Brakerski-Koppula-Mour'20, Couteau-Katsumata-Ursu'20, Jain-Jin'21, Jawale-Kalai-Khurana-Zhang'21, Holmgren-Lombardi-Rothblum'21]

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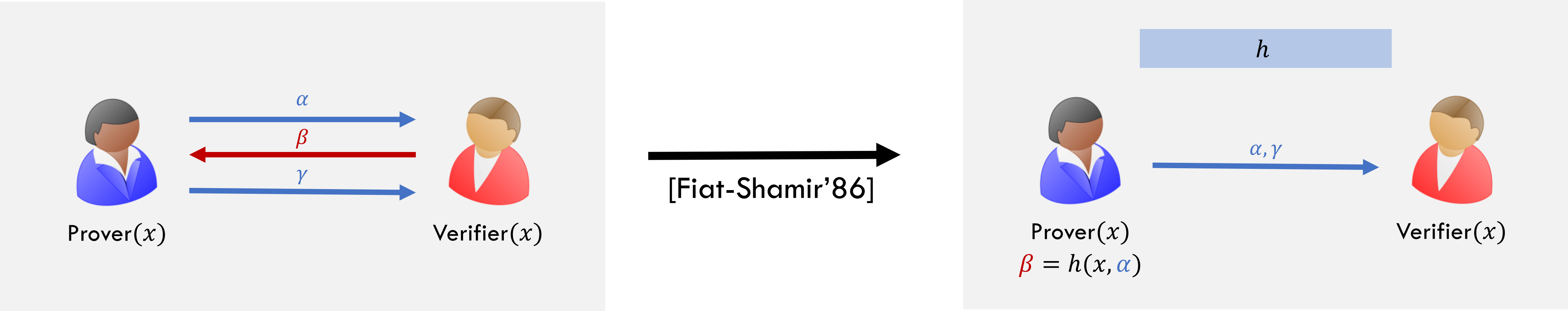

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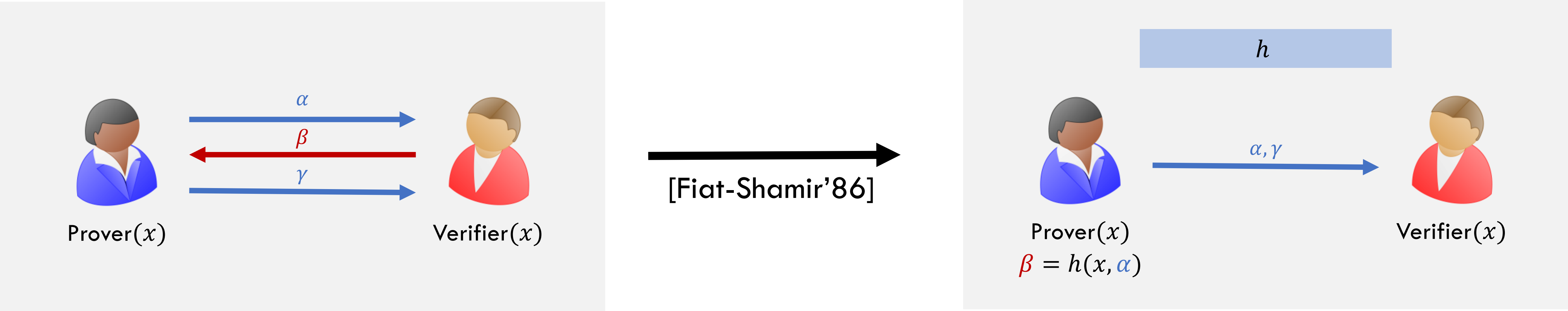

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Proven secure if starting with statistically secure interactive protocols (interactive proofs).

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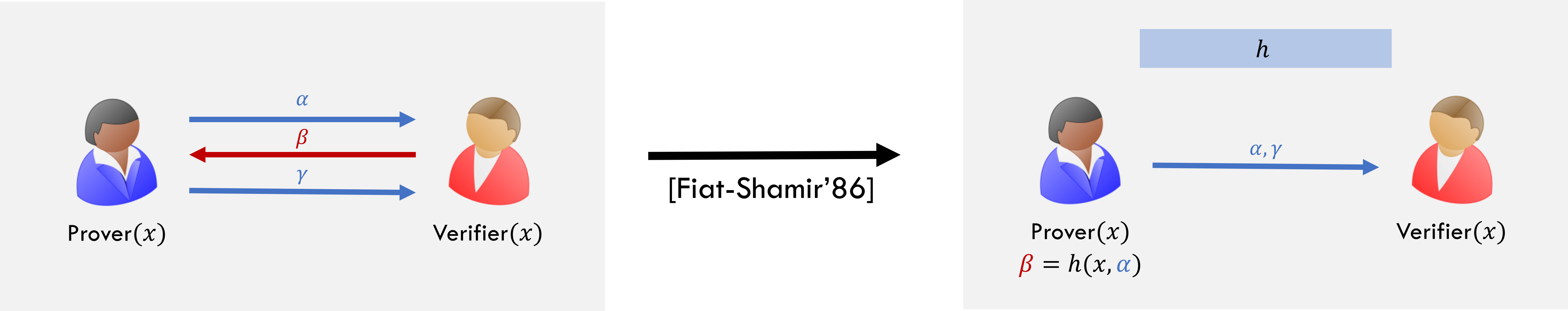

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No known interactive proofs for batch NP.

Dual-Mode Interactive Batch Arguments

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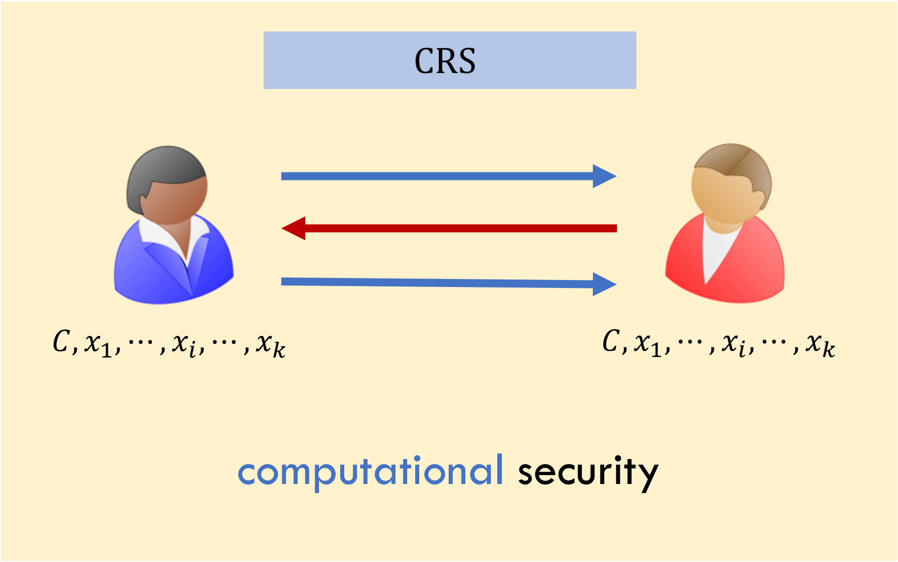

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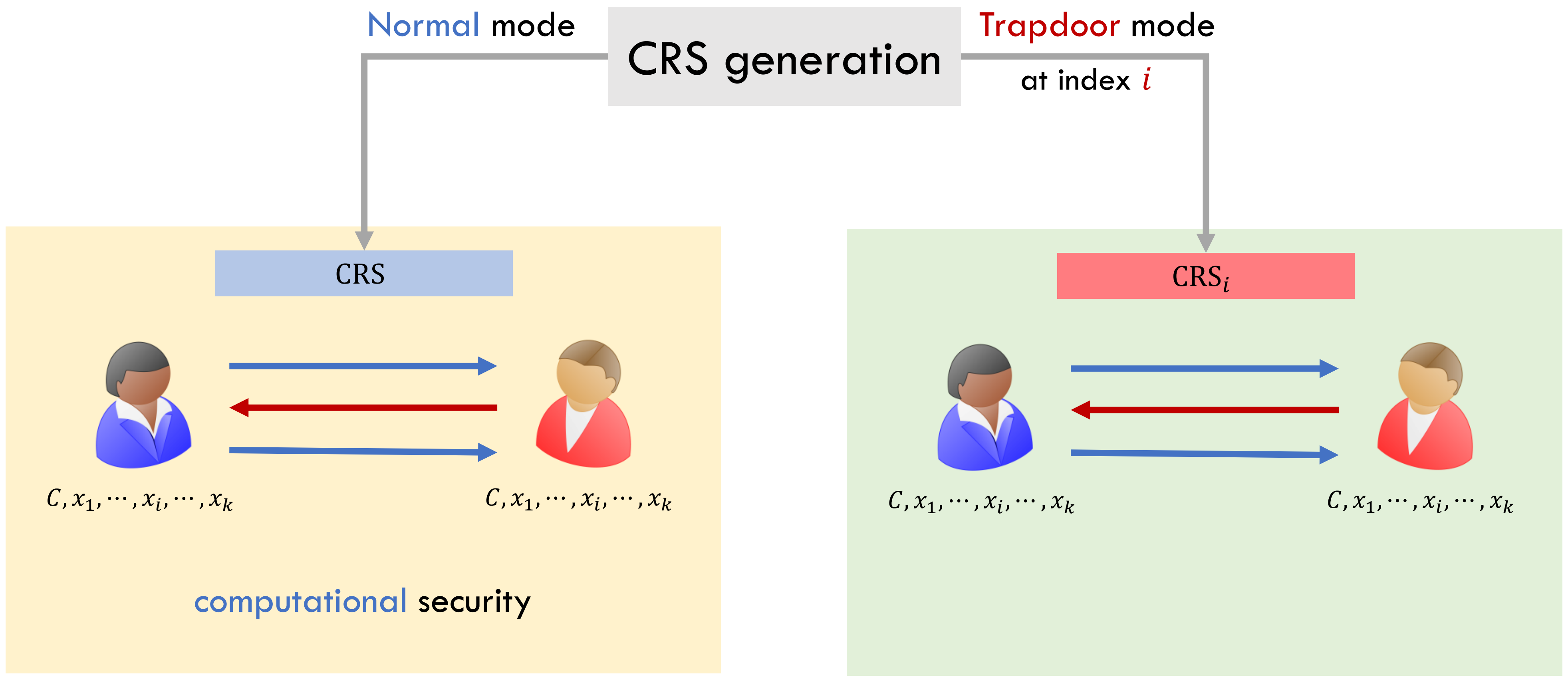

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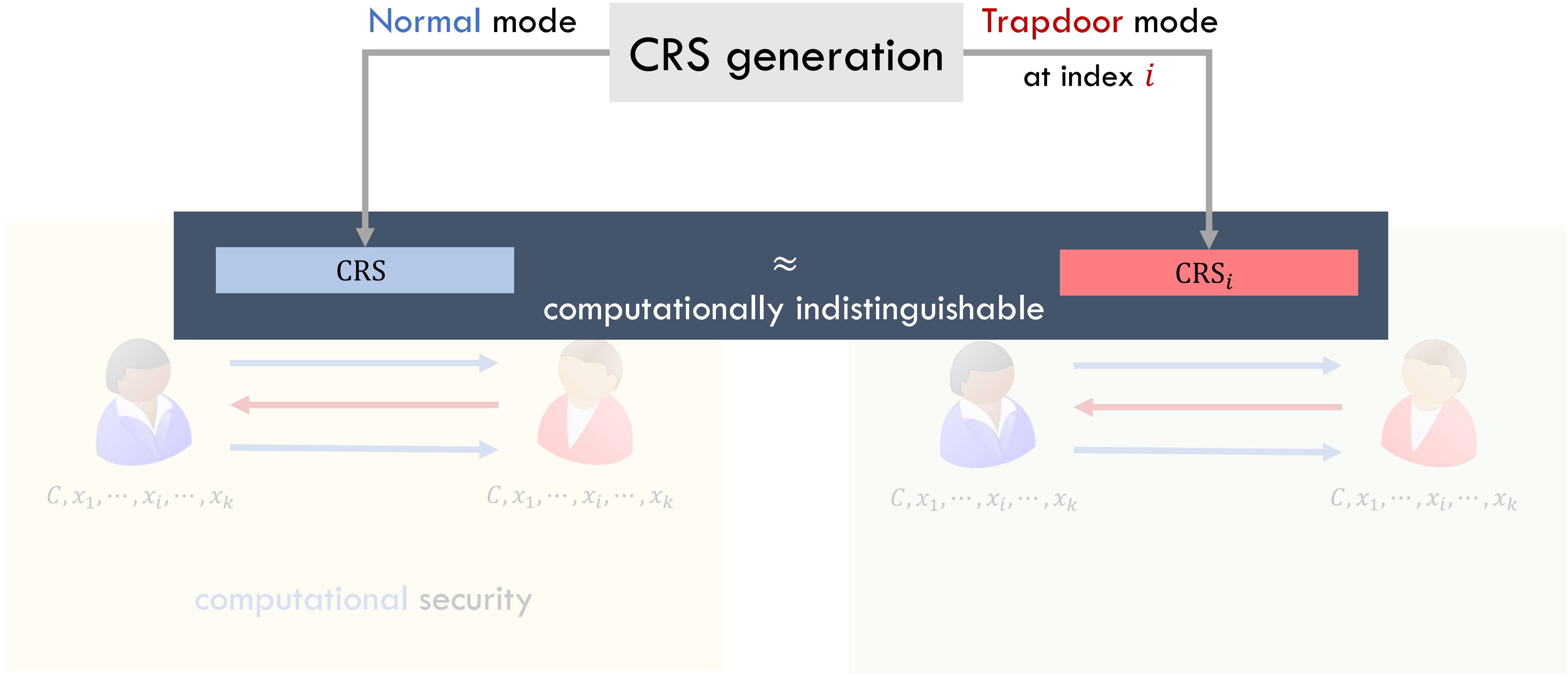

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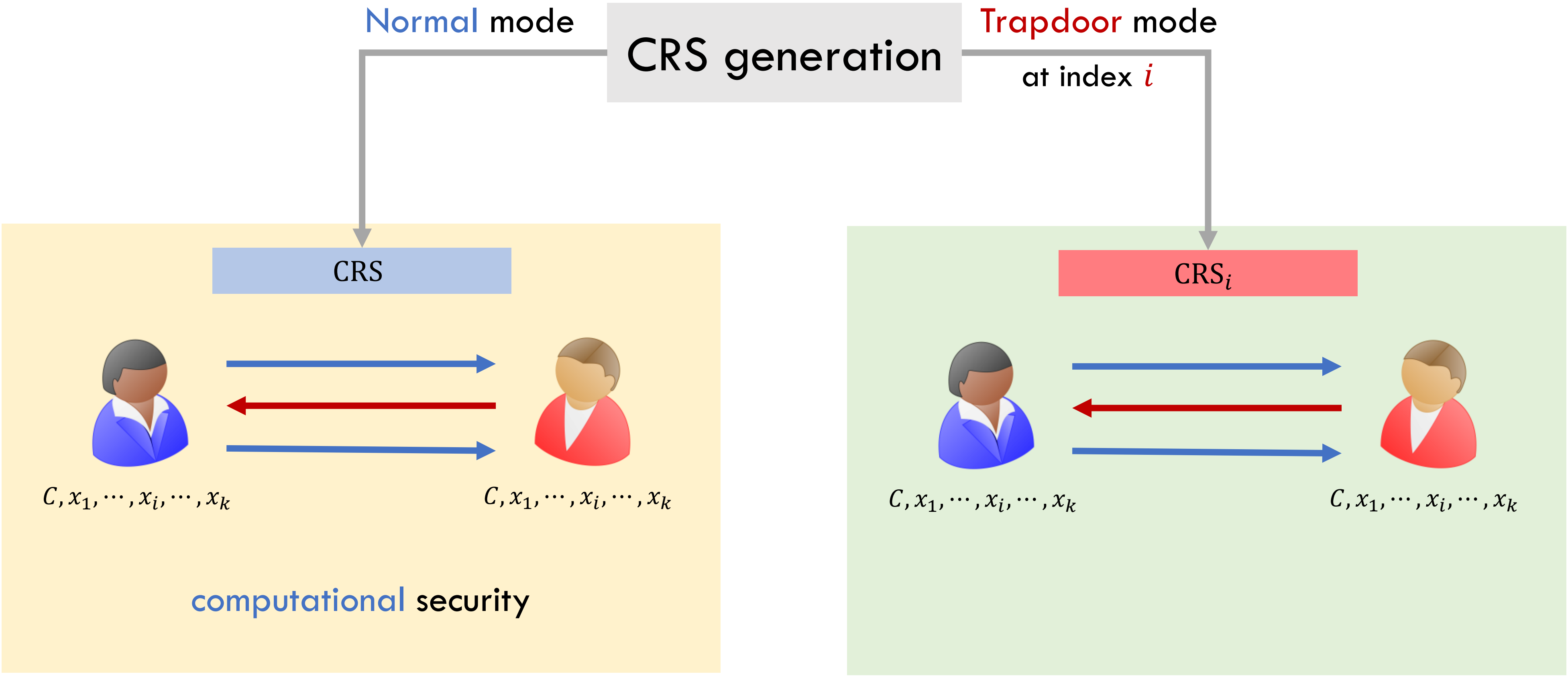

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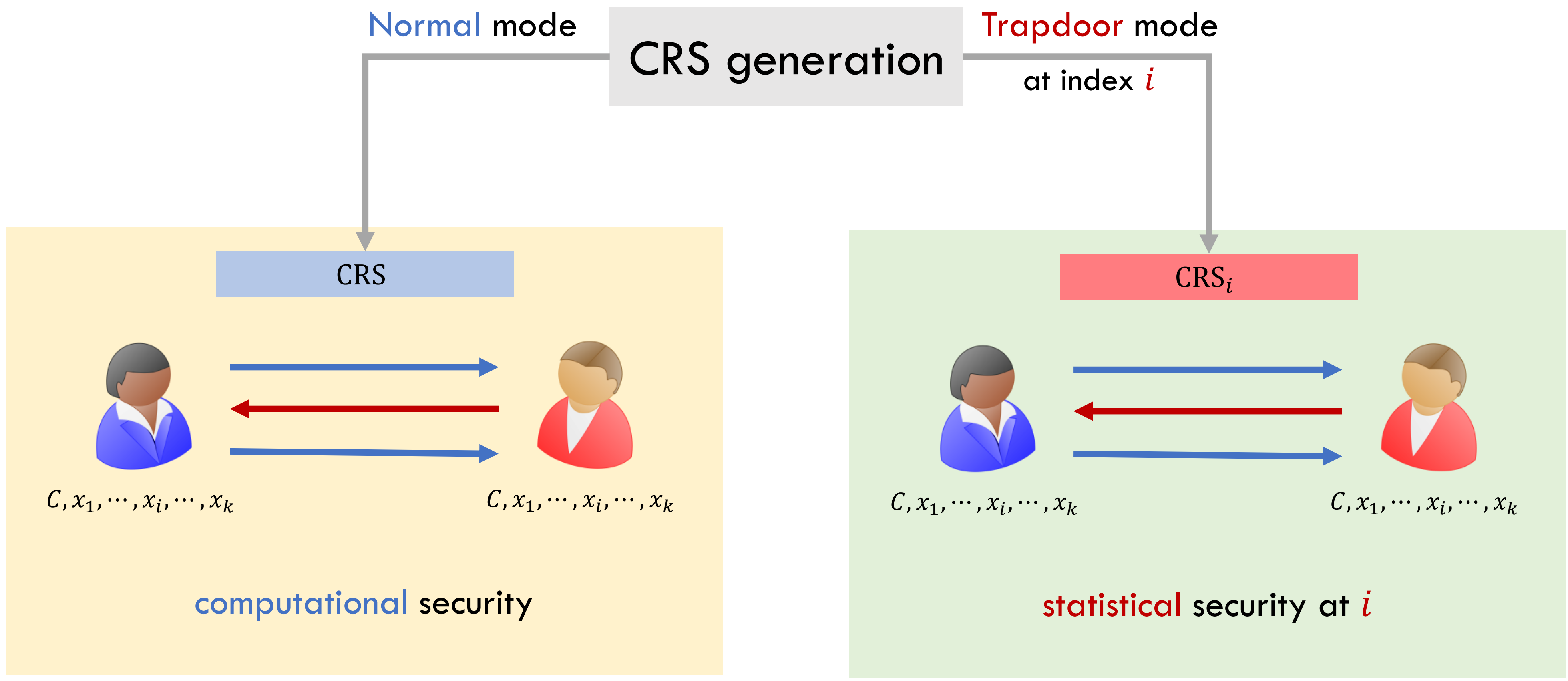

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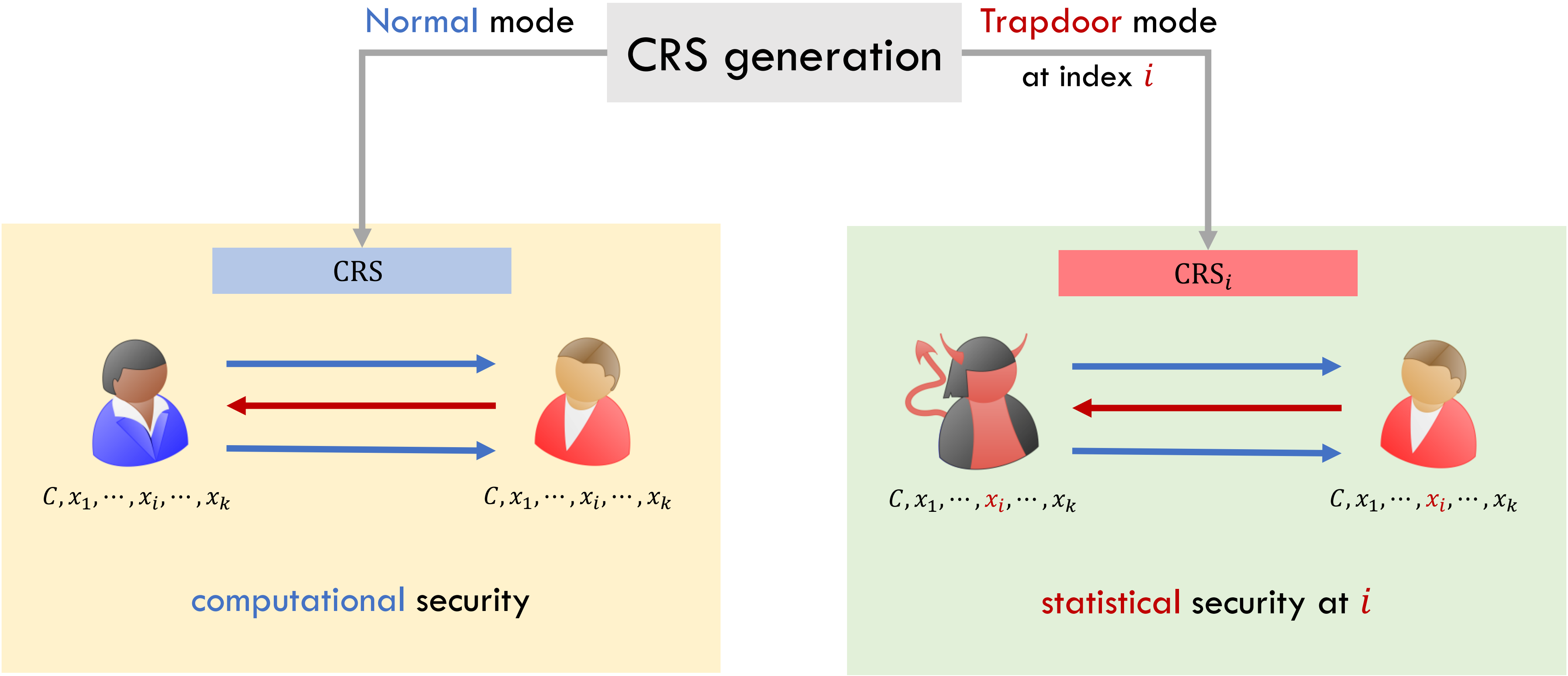
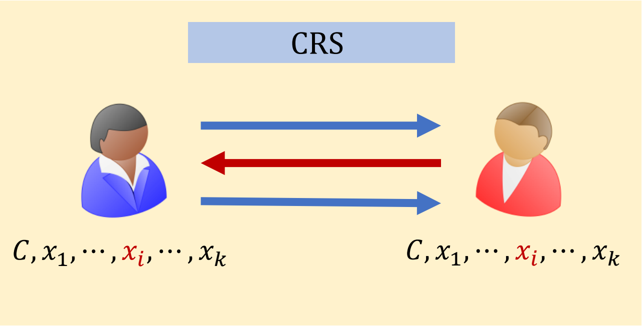


Even unbounded cannot make accept if $(C, x_i) \notin \mathrm{SAT}$

Security Intuition



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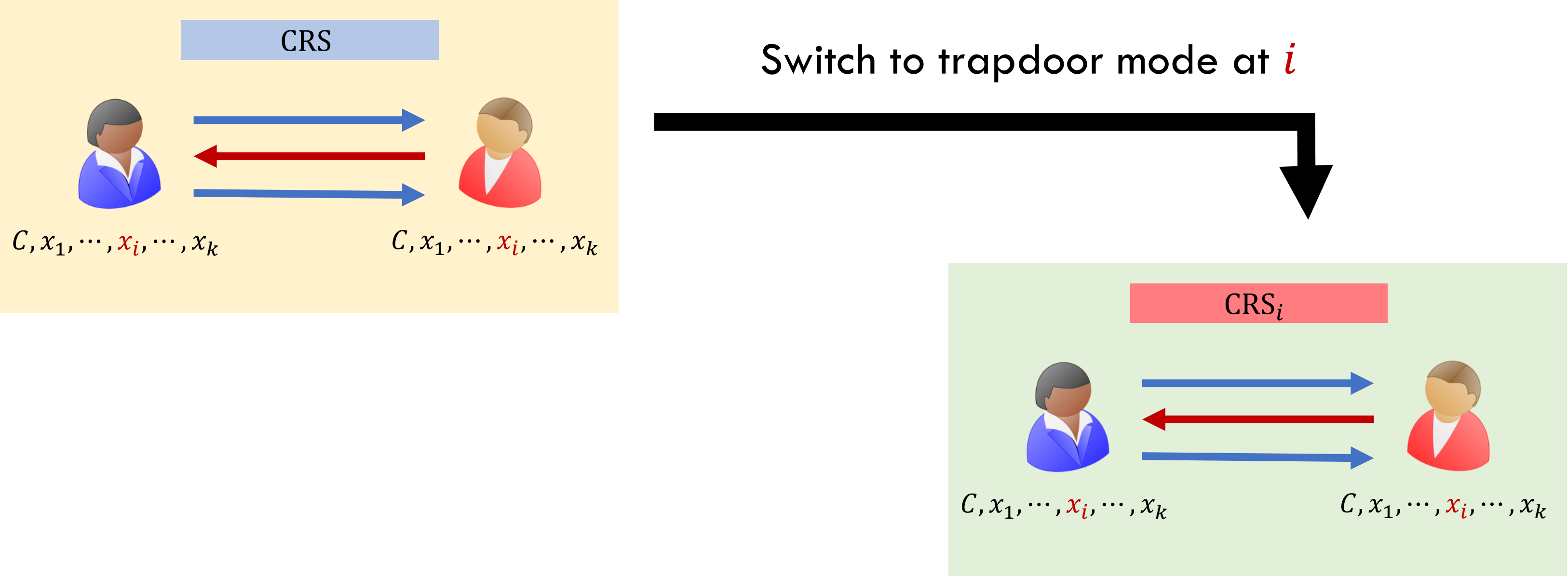

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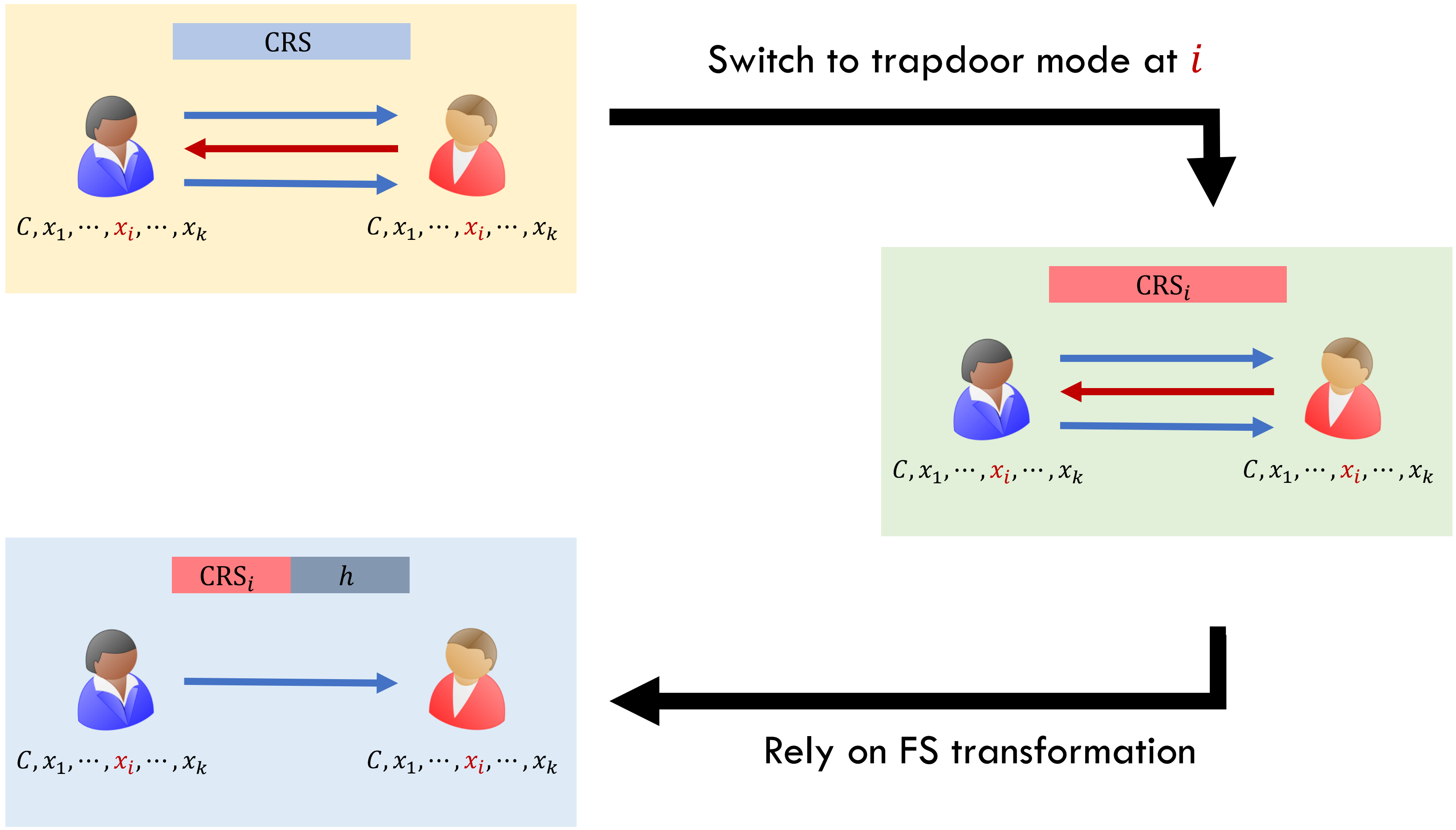
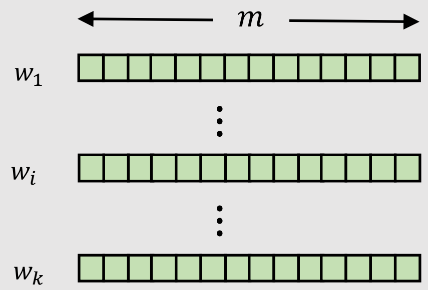


Dual Mode Batch Argument

Protocol Template



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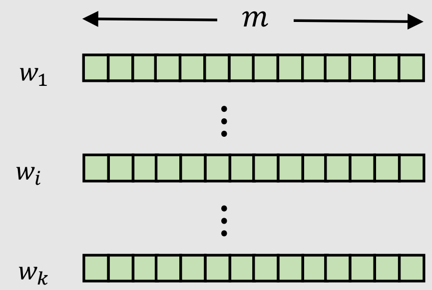

commitment key K

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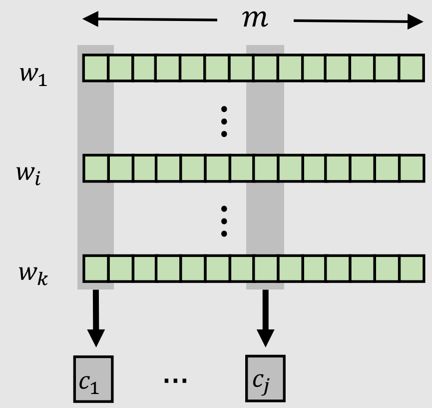

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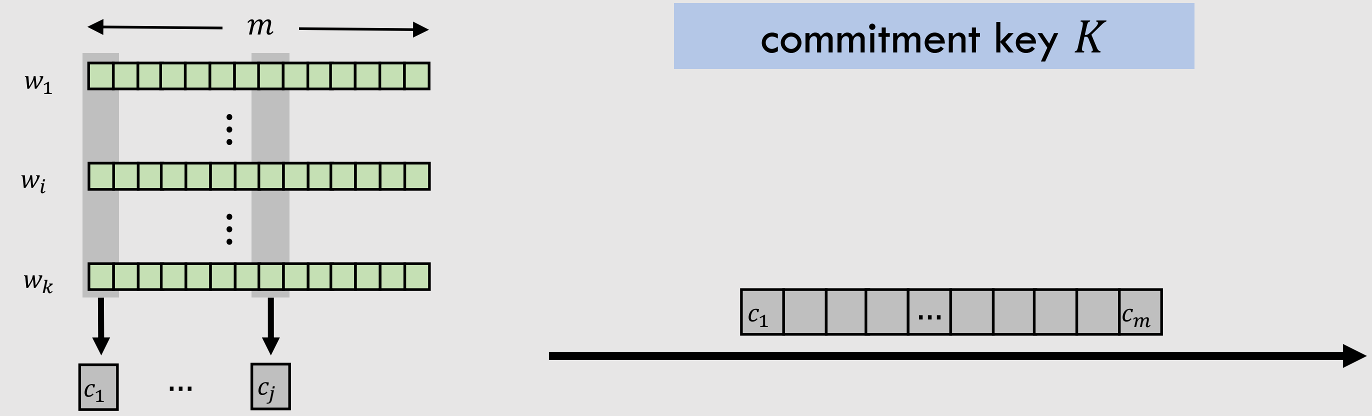

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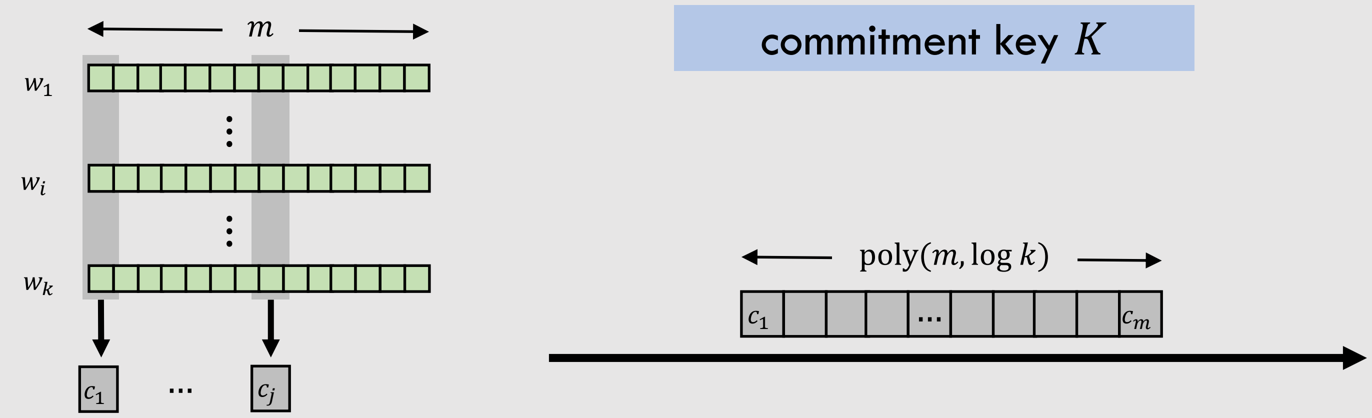

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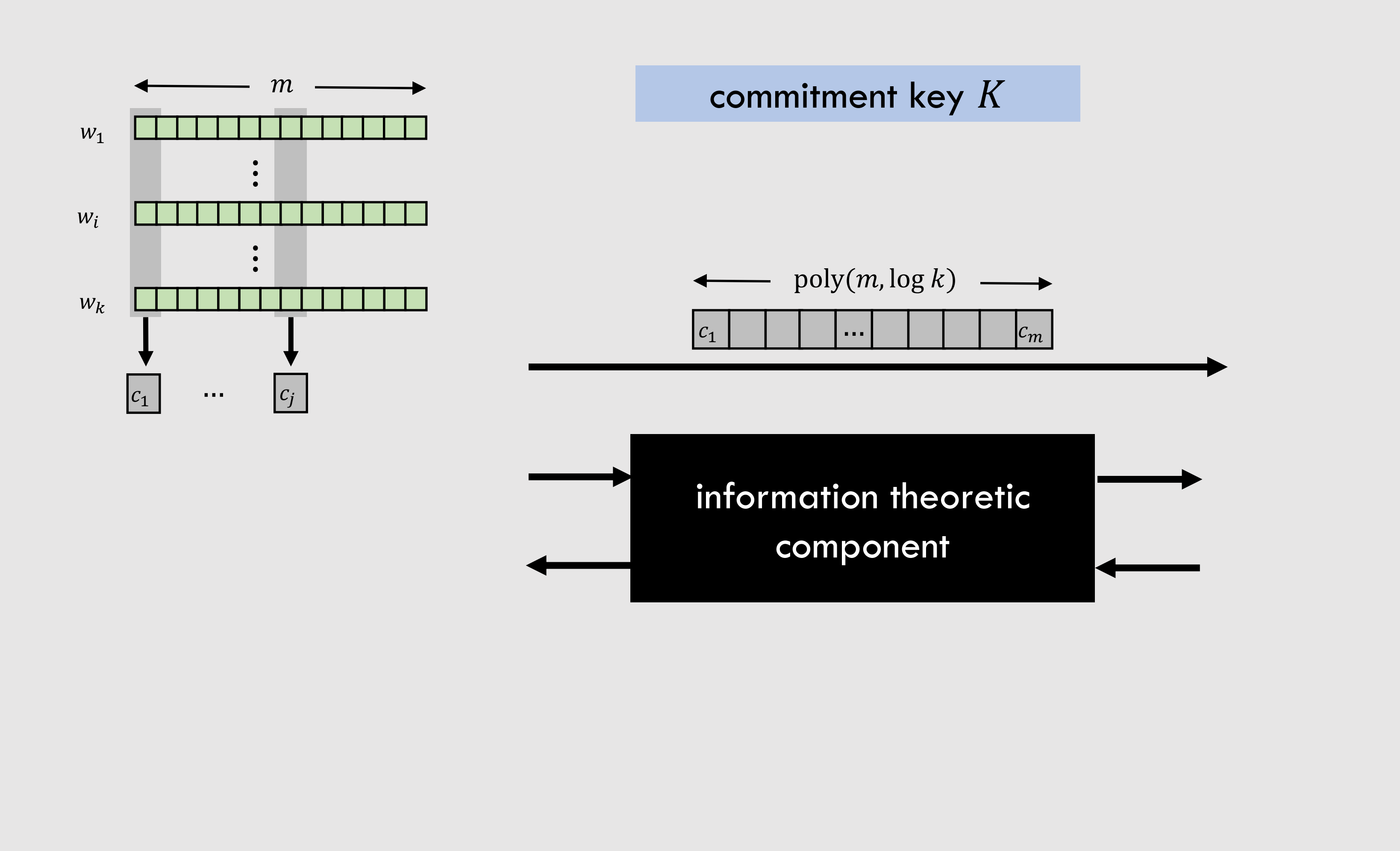

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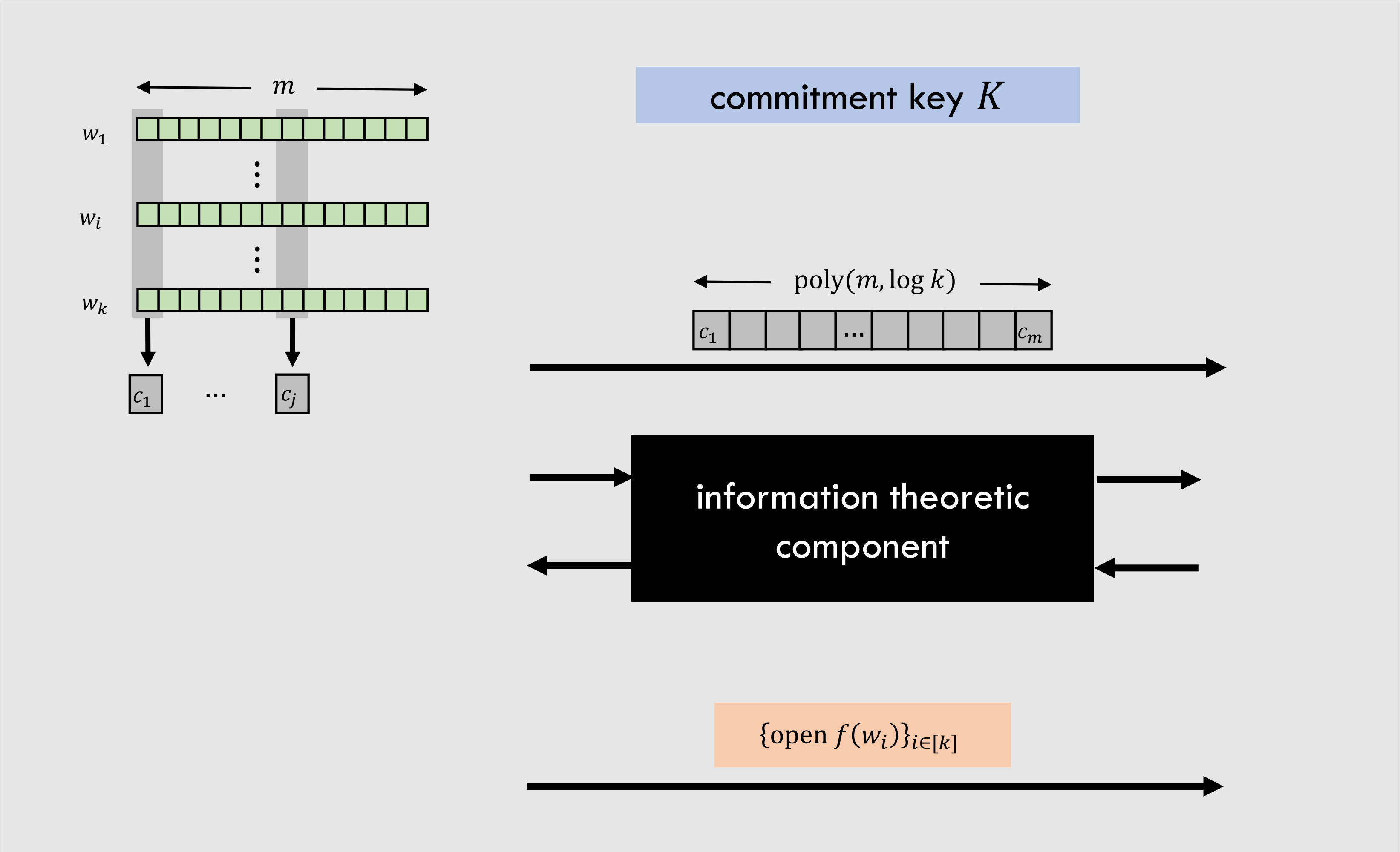

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f determined by the information theoretic component.

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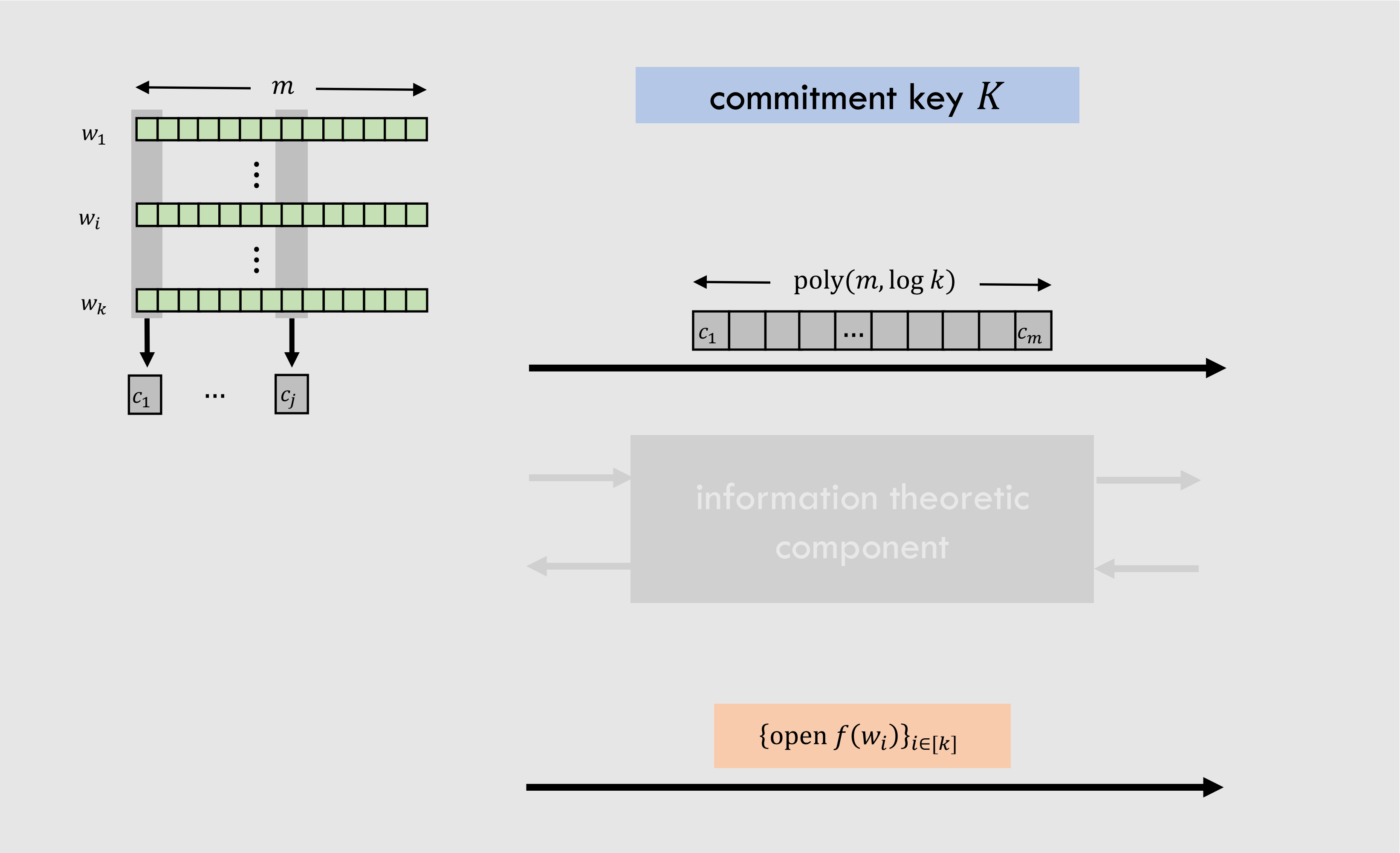

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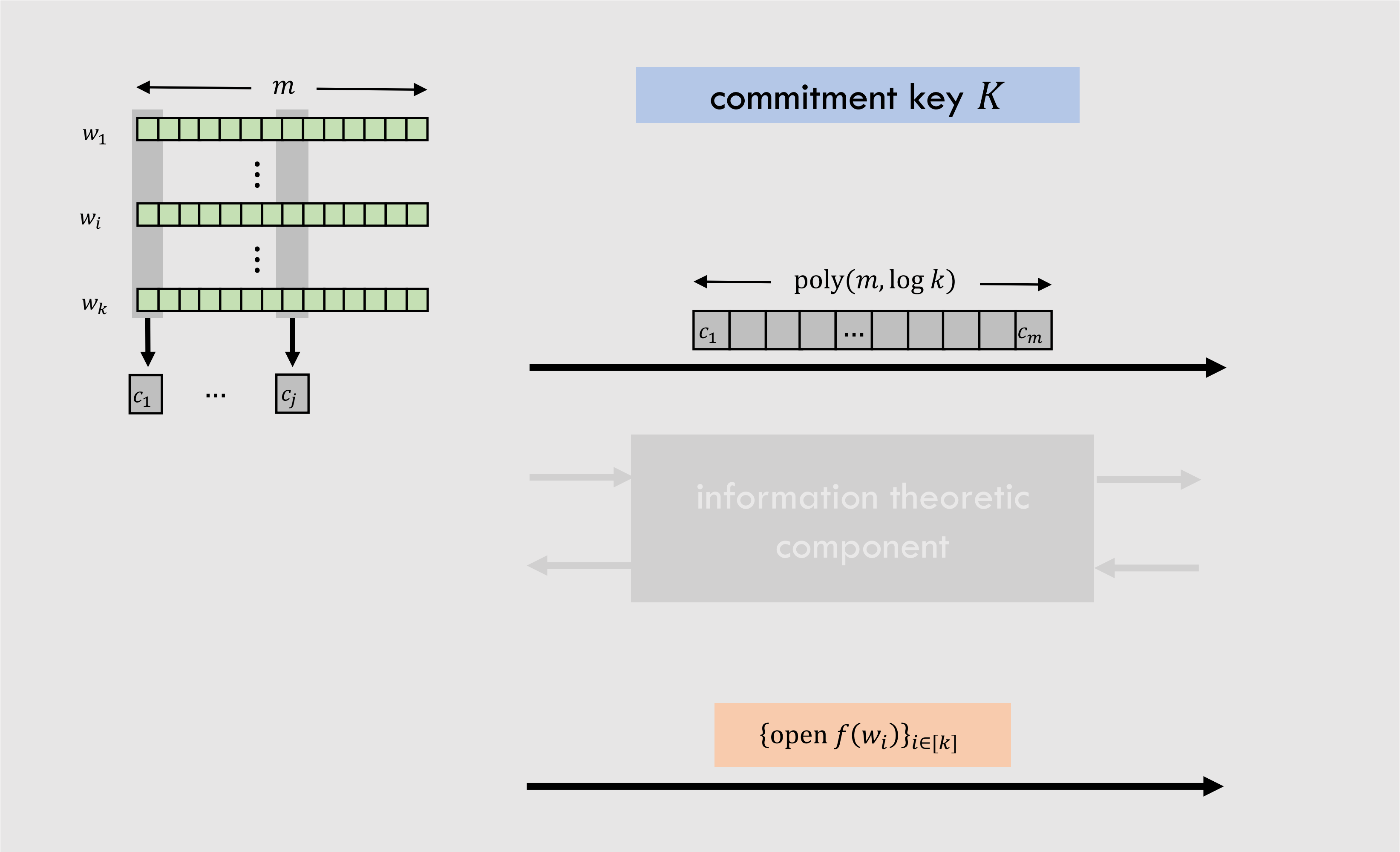

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Somewhere Statistically Binding (SSB) Commitment Scheme

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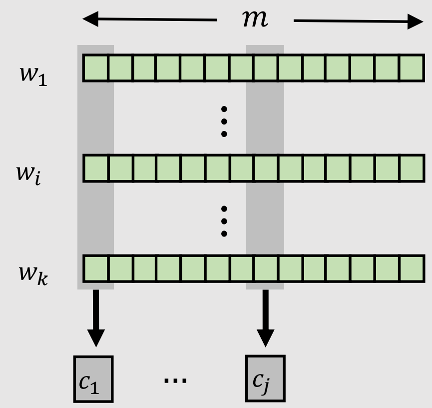

Trapdoor mode

commitment key K_i^*

$\text{poly}(m, \log k)$

c_1 … c_m

information theoretic component

$\{\text{open } f(w_i)\}_{i \in [k]}$

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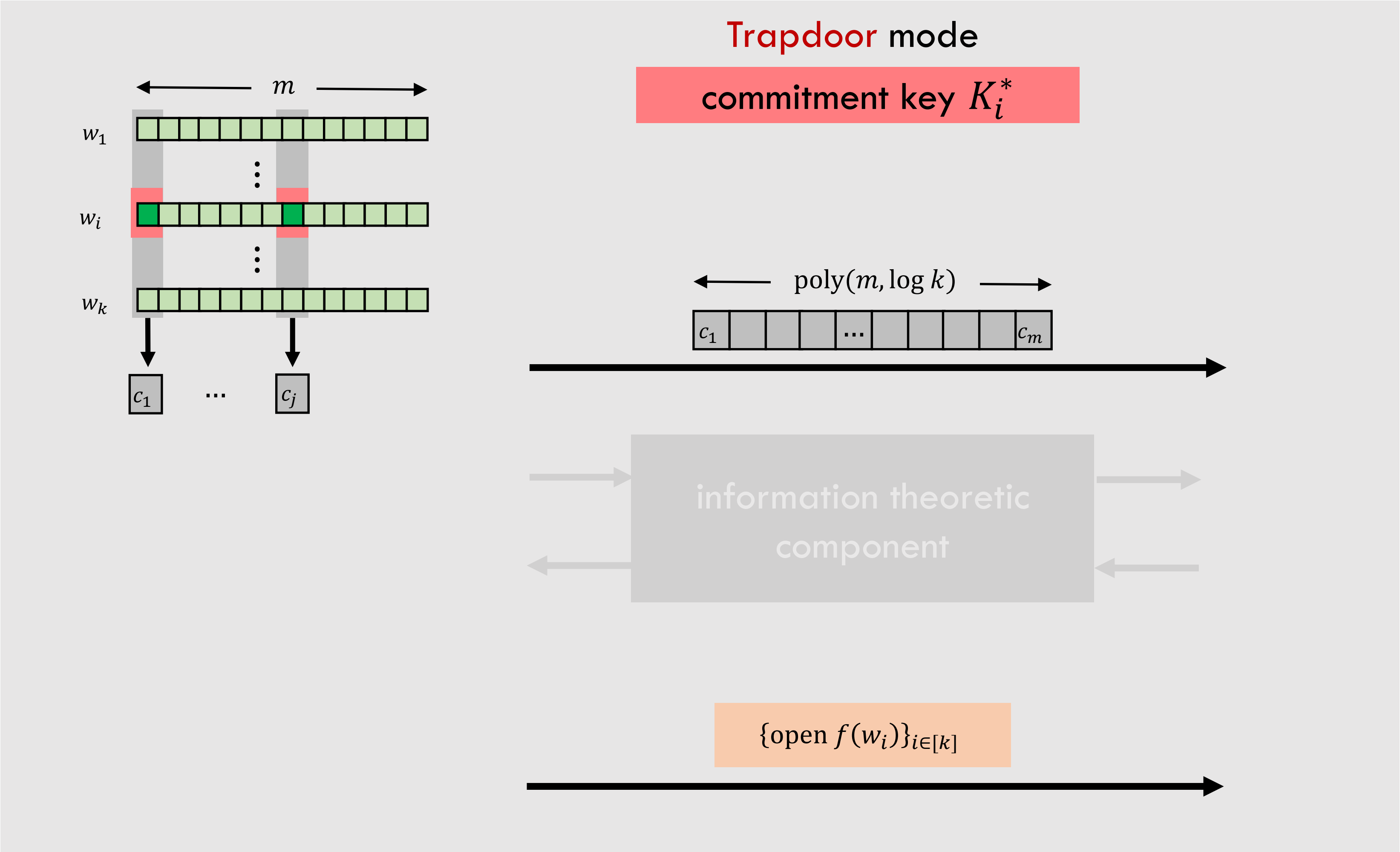

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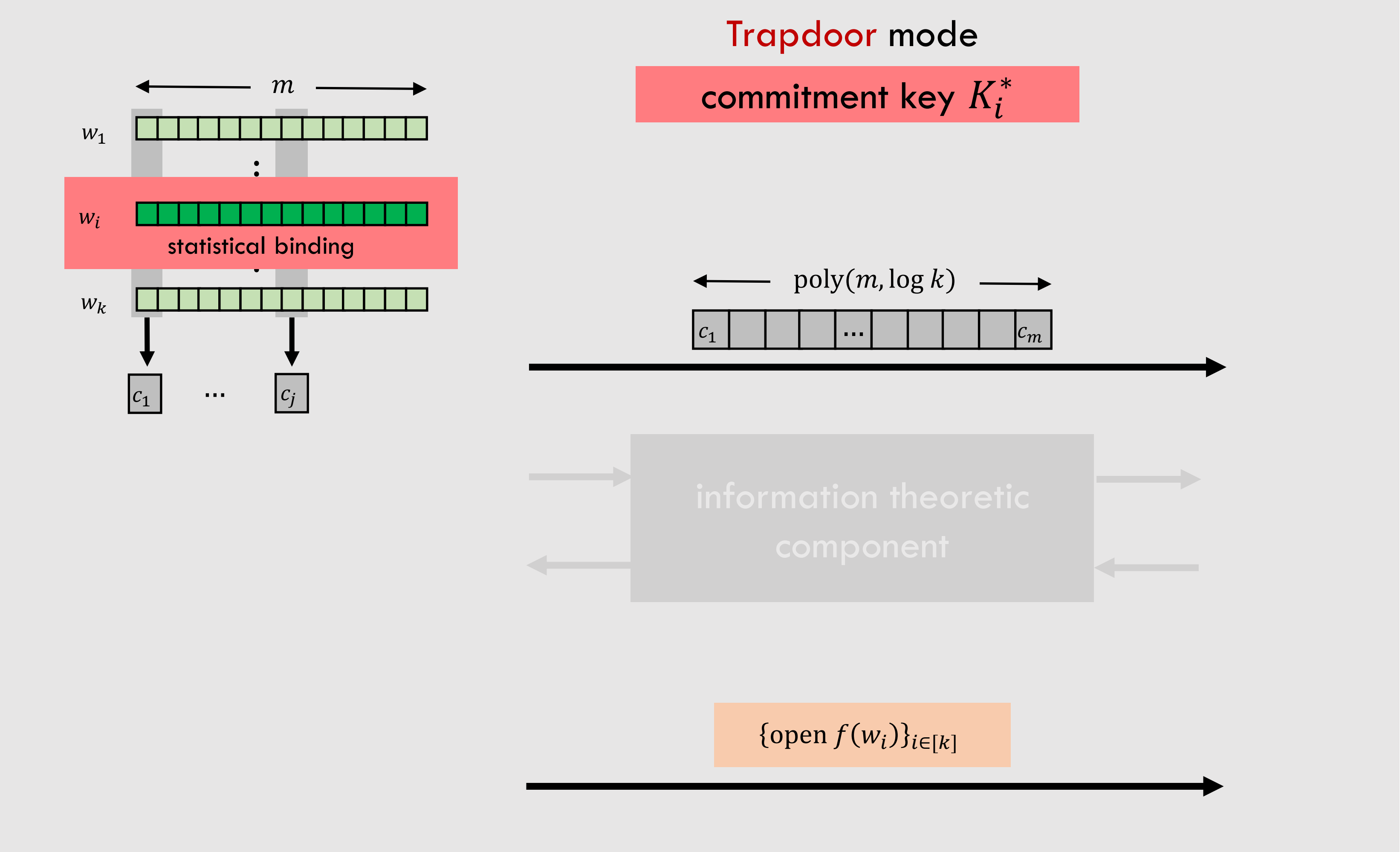

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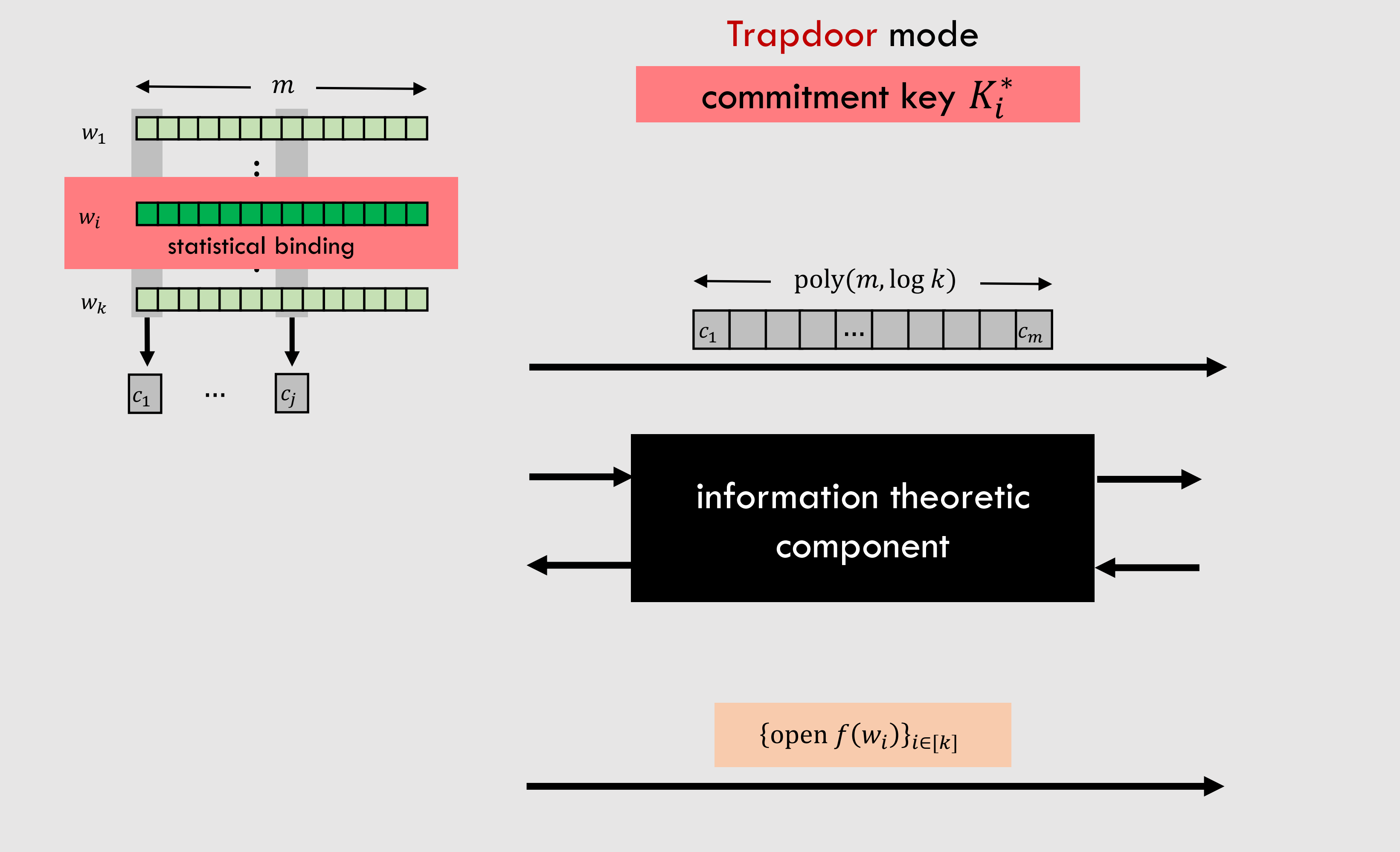

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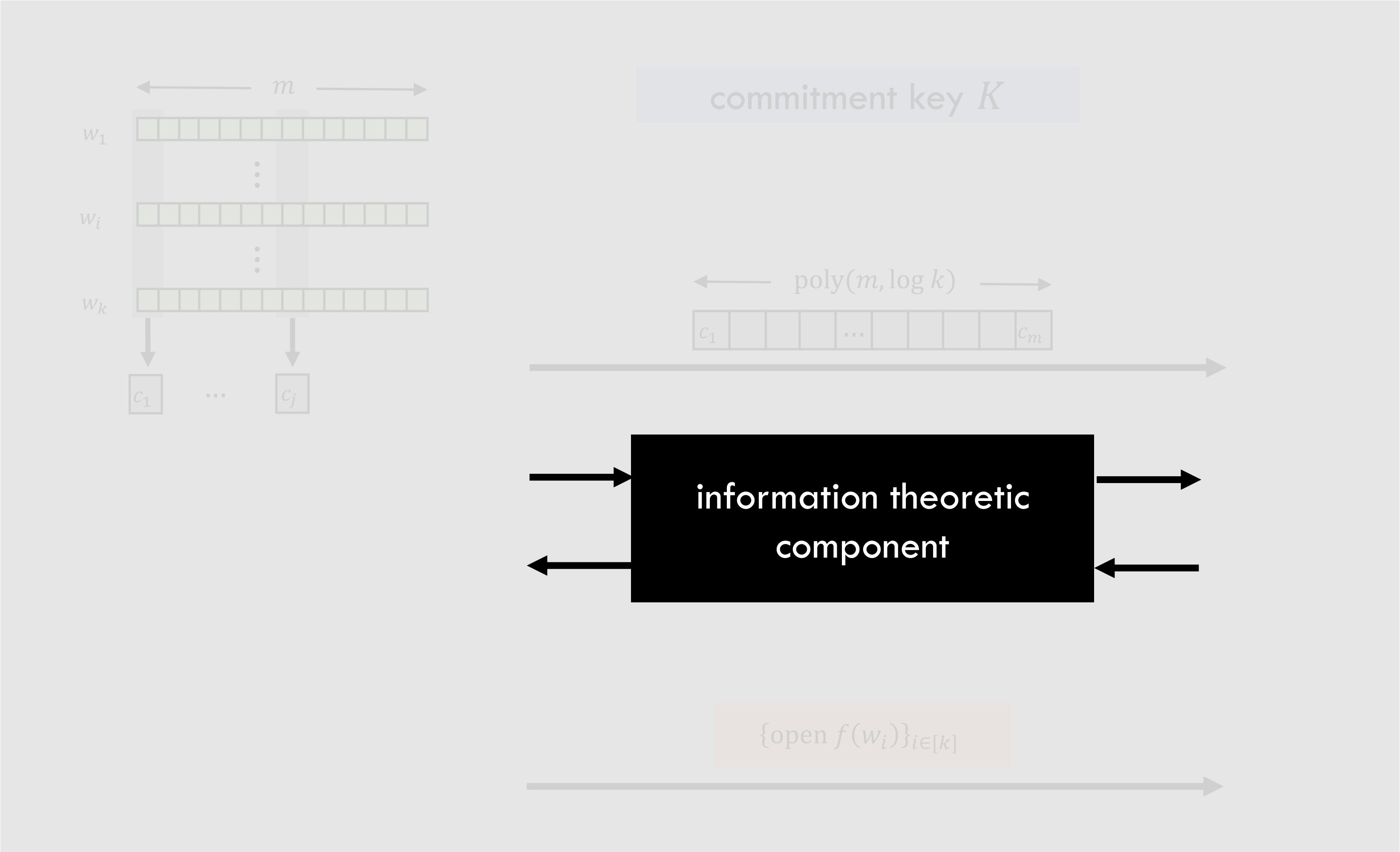

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Based on LWE/sub-exp DDH

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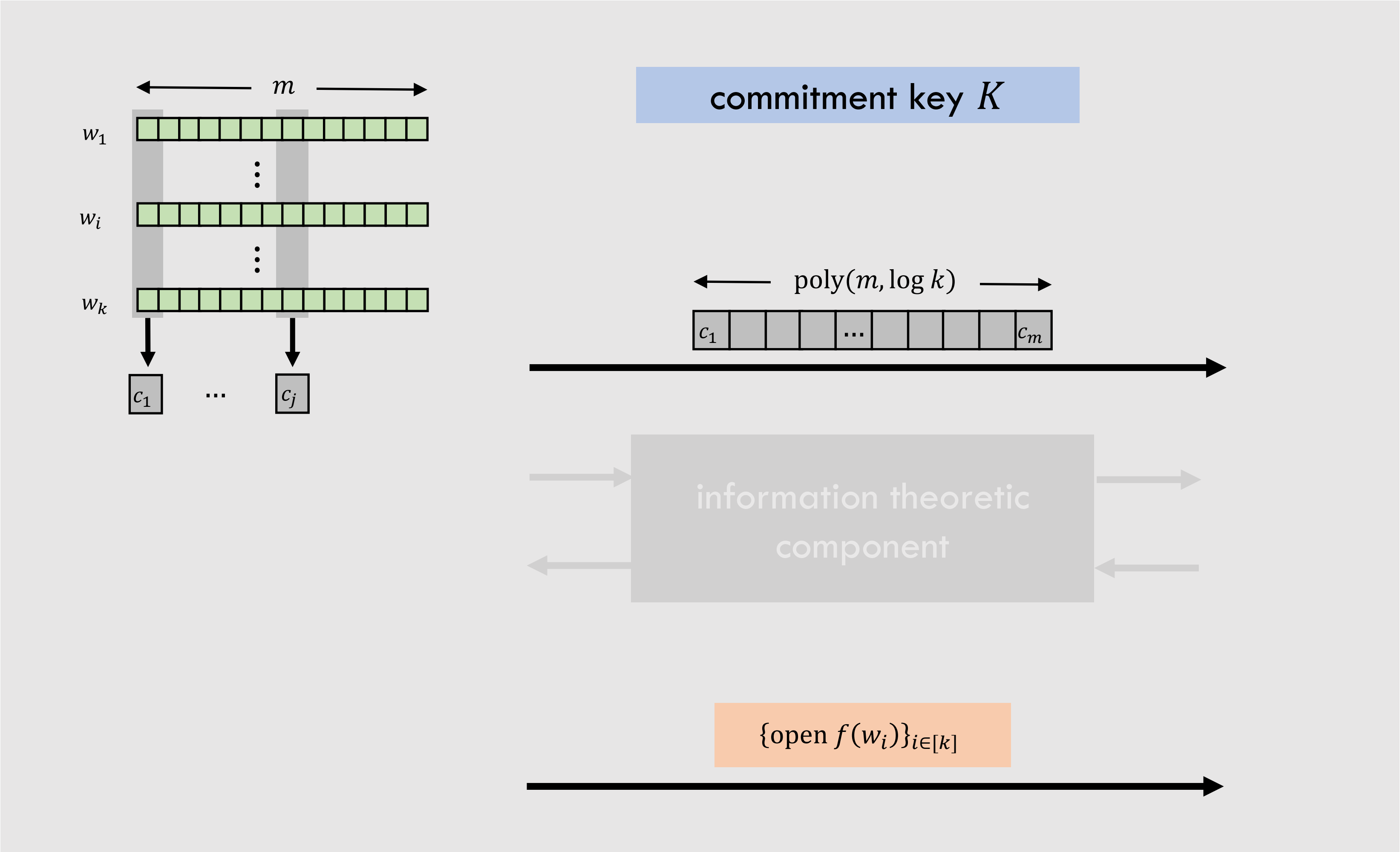

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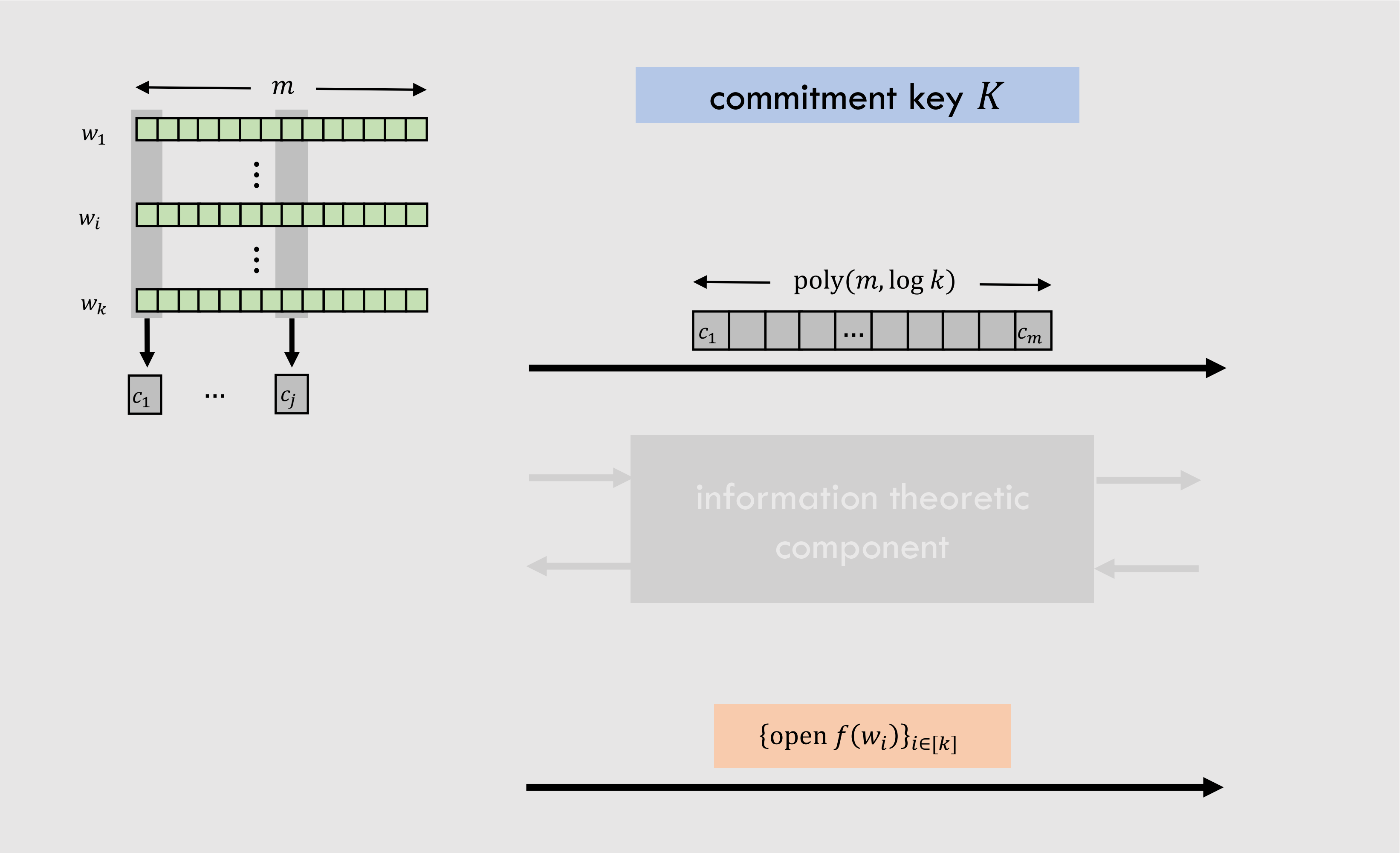

$\text{SAT} = \{(C, x) \mid \exists w \text{ s.t. } C(x, w) = 1\}$

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We construct SSB with appropriate opening to f (with additional properties) based on QR

Needs to be Fiat-Shamir friendly.

Based on LWE/sub-exp DDH

(Some) Technical Details

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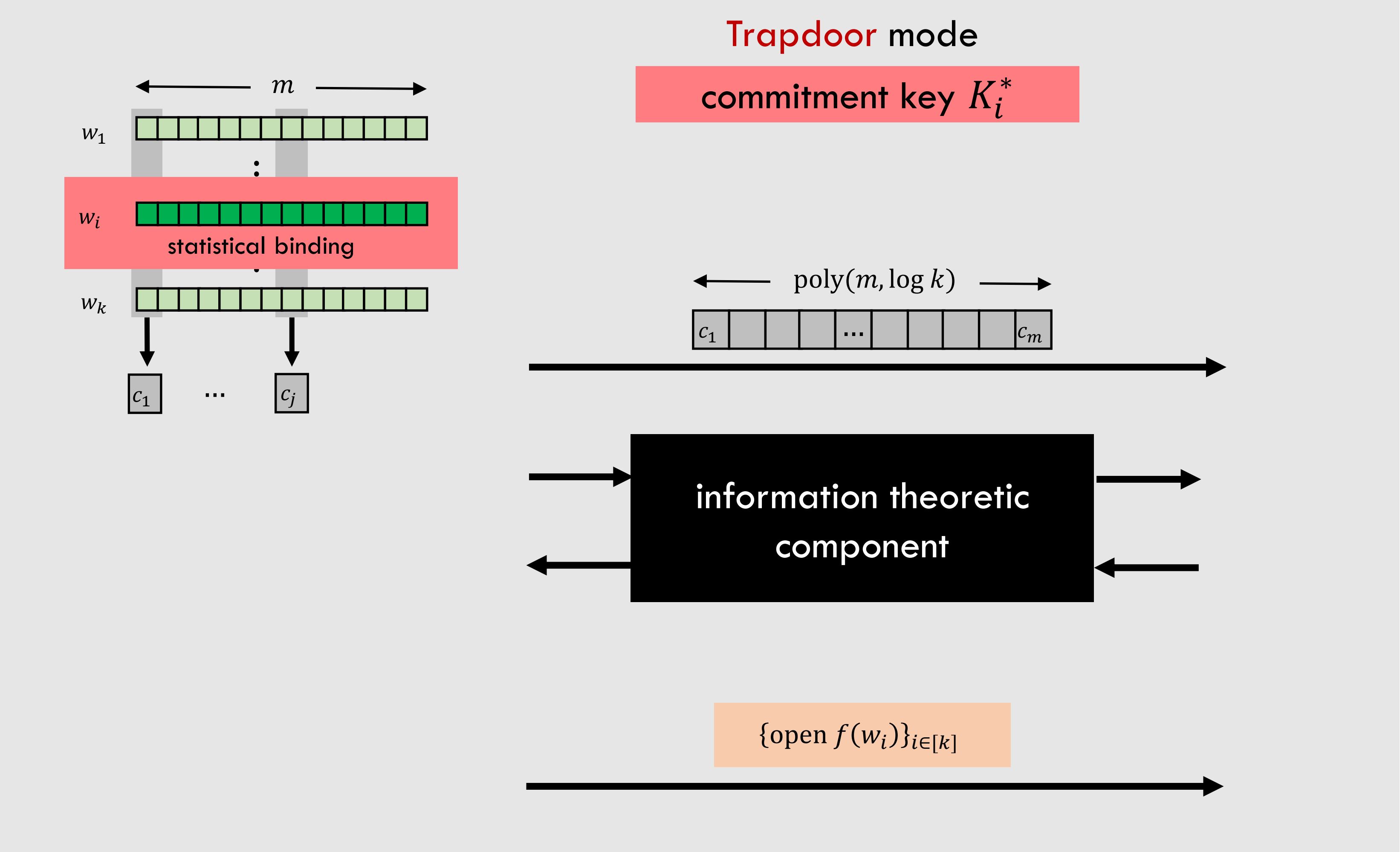

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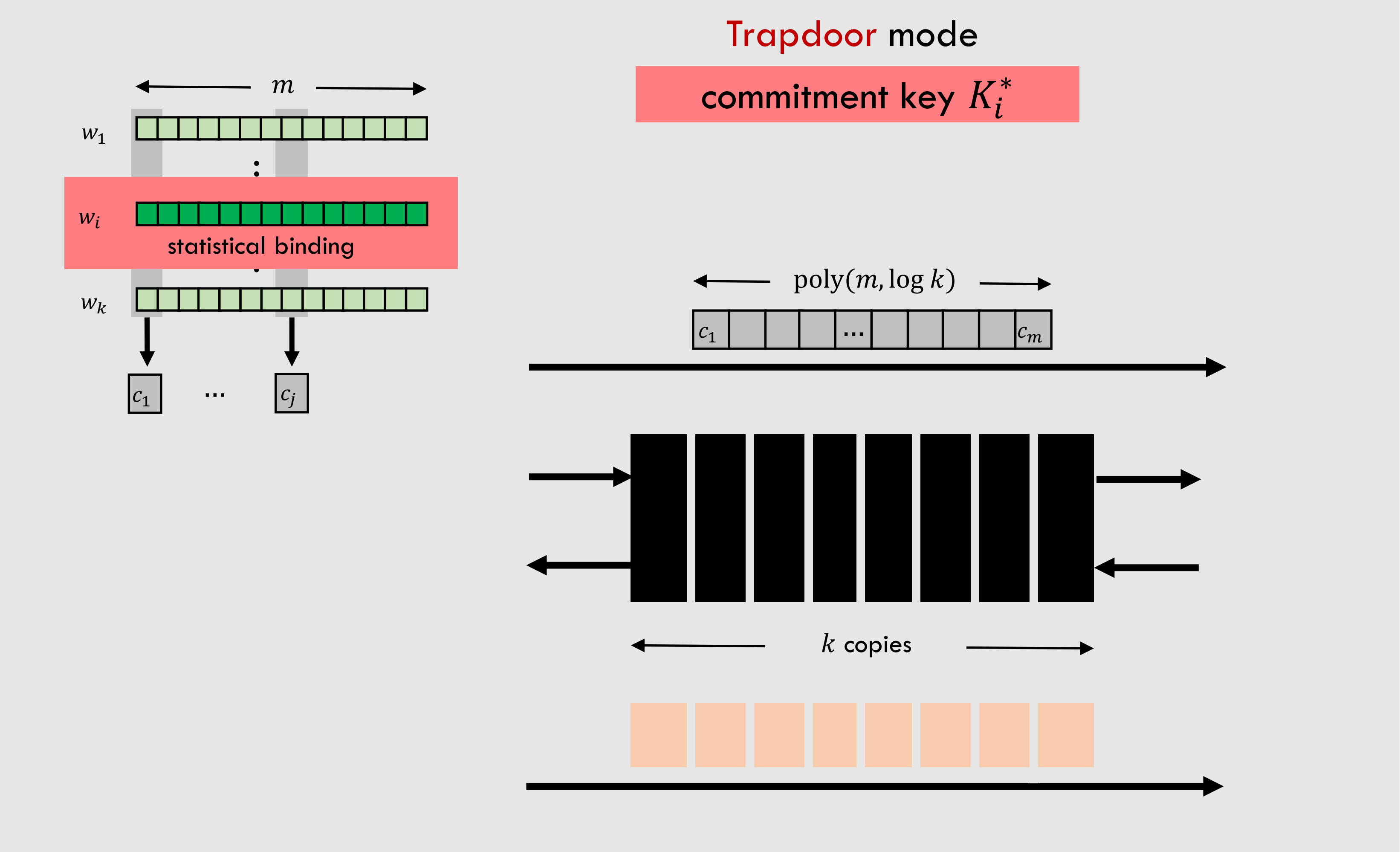

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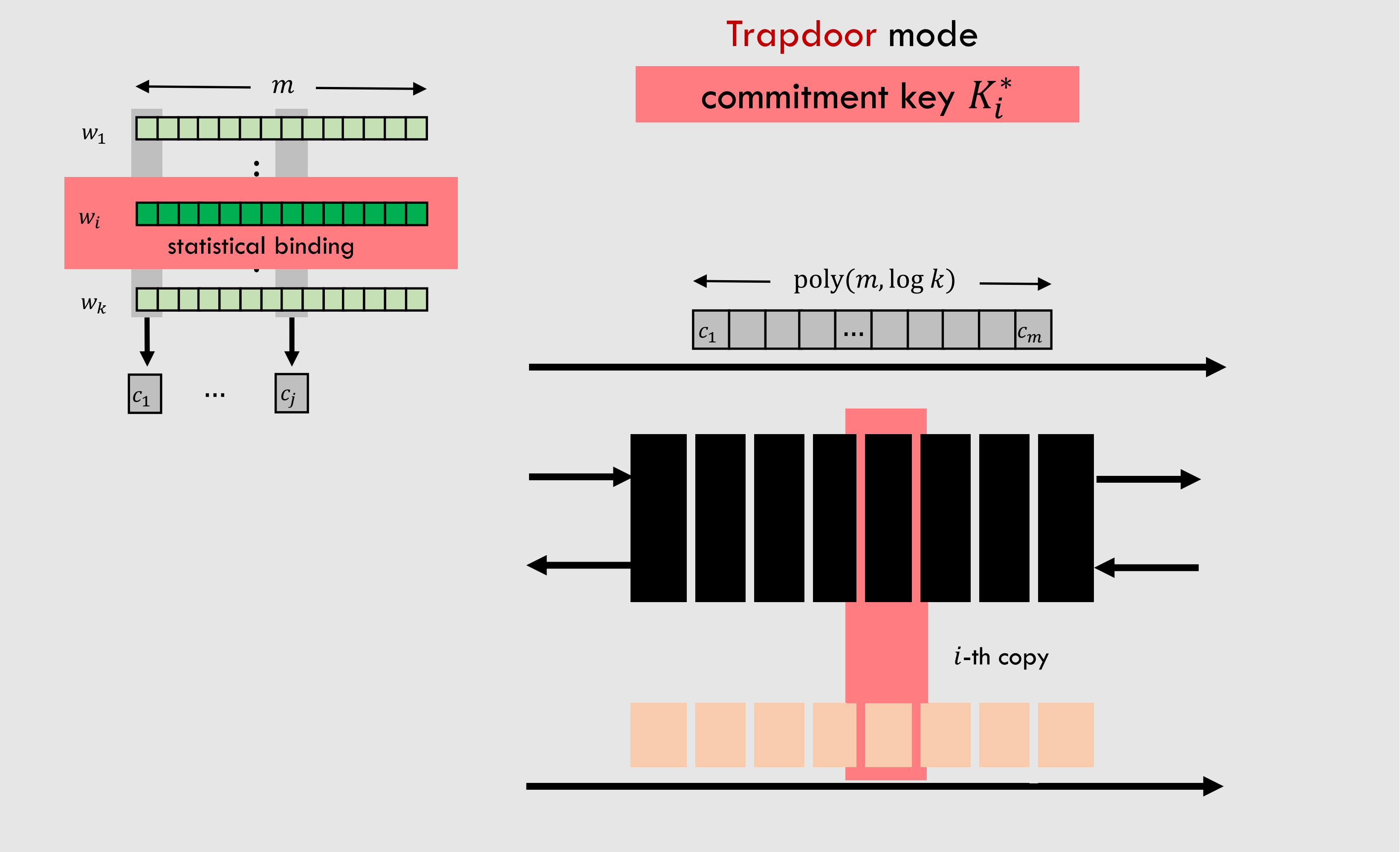

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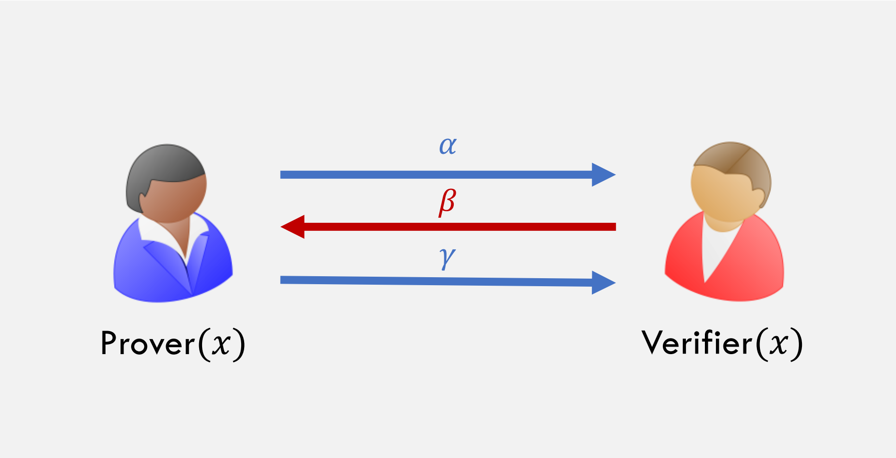
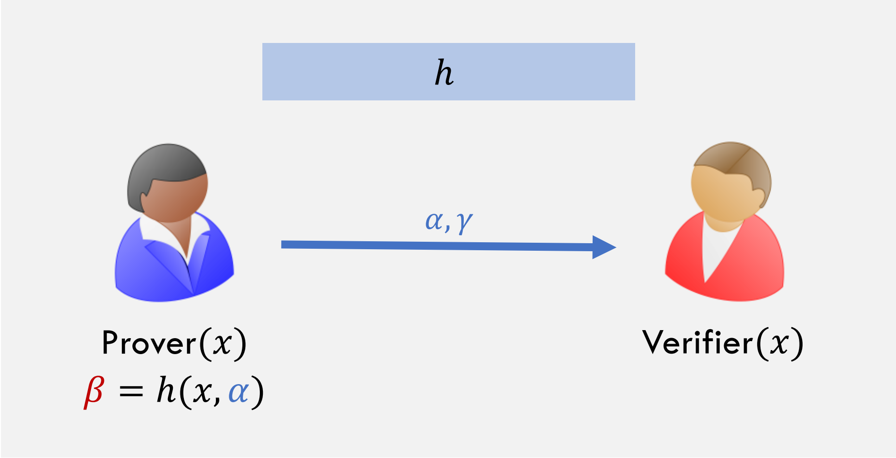
Fiat-Shamir (FS) Methodology



β is a random string

[Fiat-Shamir'86]



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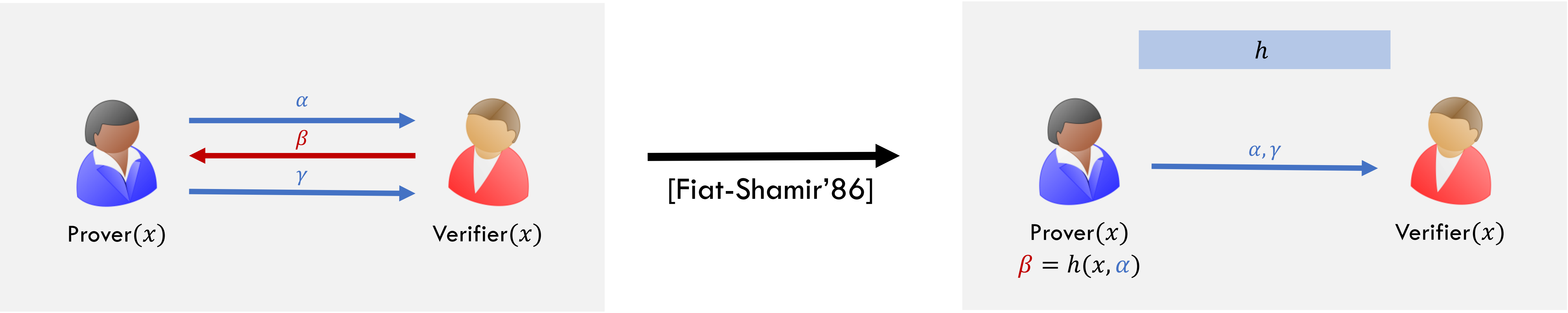

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$\forall\, x \notin \mathcal{L}$

$\mathrm{BAD}_{x,\alpha} = \{\beta \mid \exists \gamma$ s.t. Verifier accepts $(\alpha, \beta, \gamma)\}$

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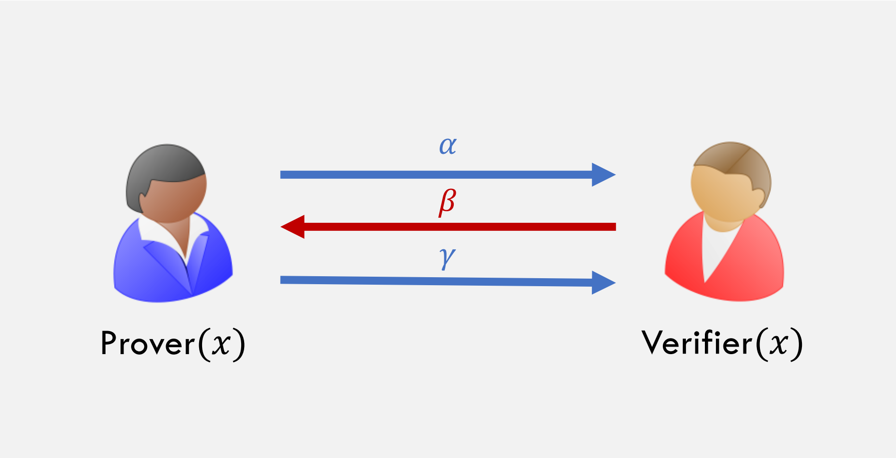

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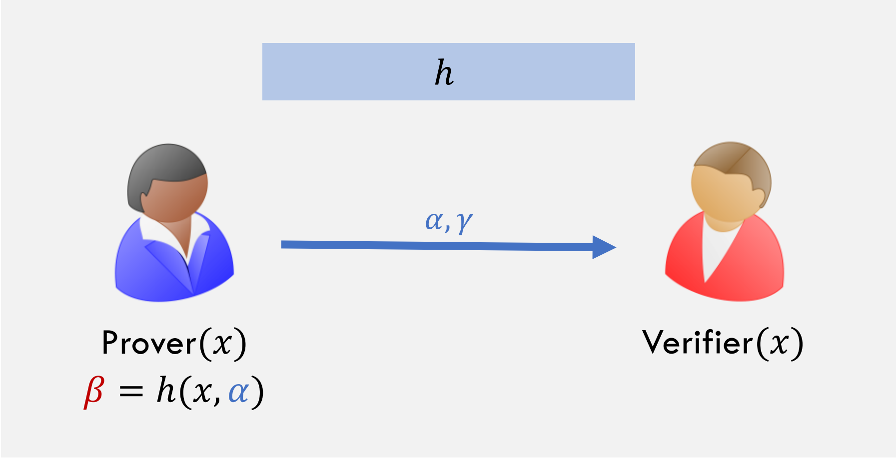

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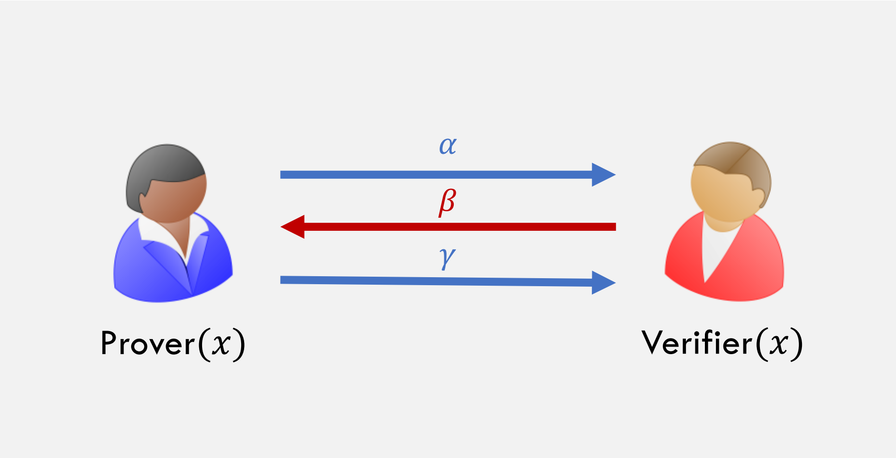

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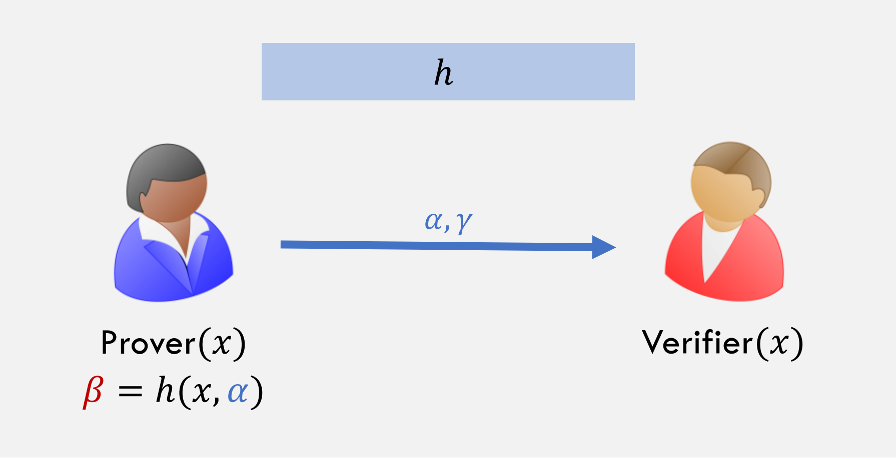

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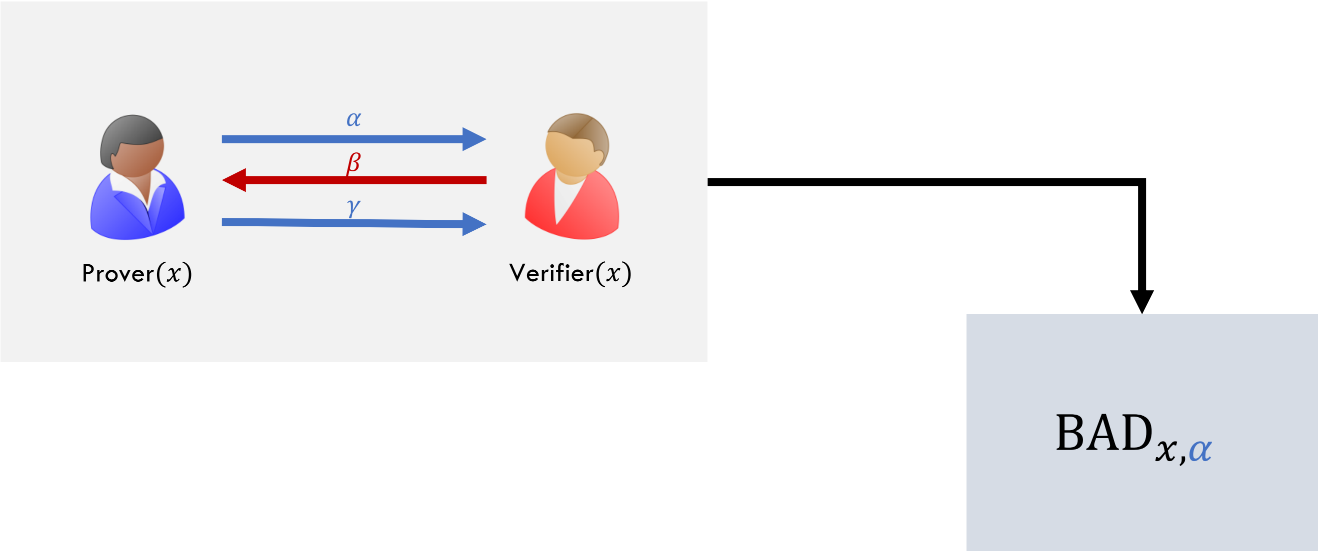
h is correlation intractable (CI) for $\mathrm{BAD}_{x,\alpha}$

Instantiating the FS Transform



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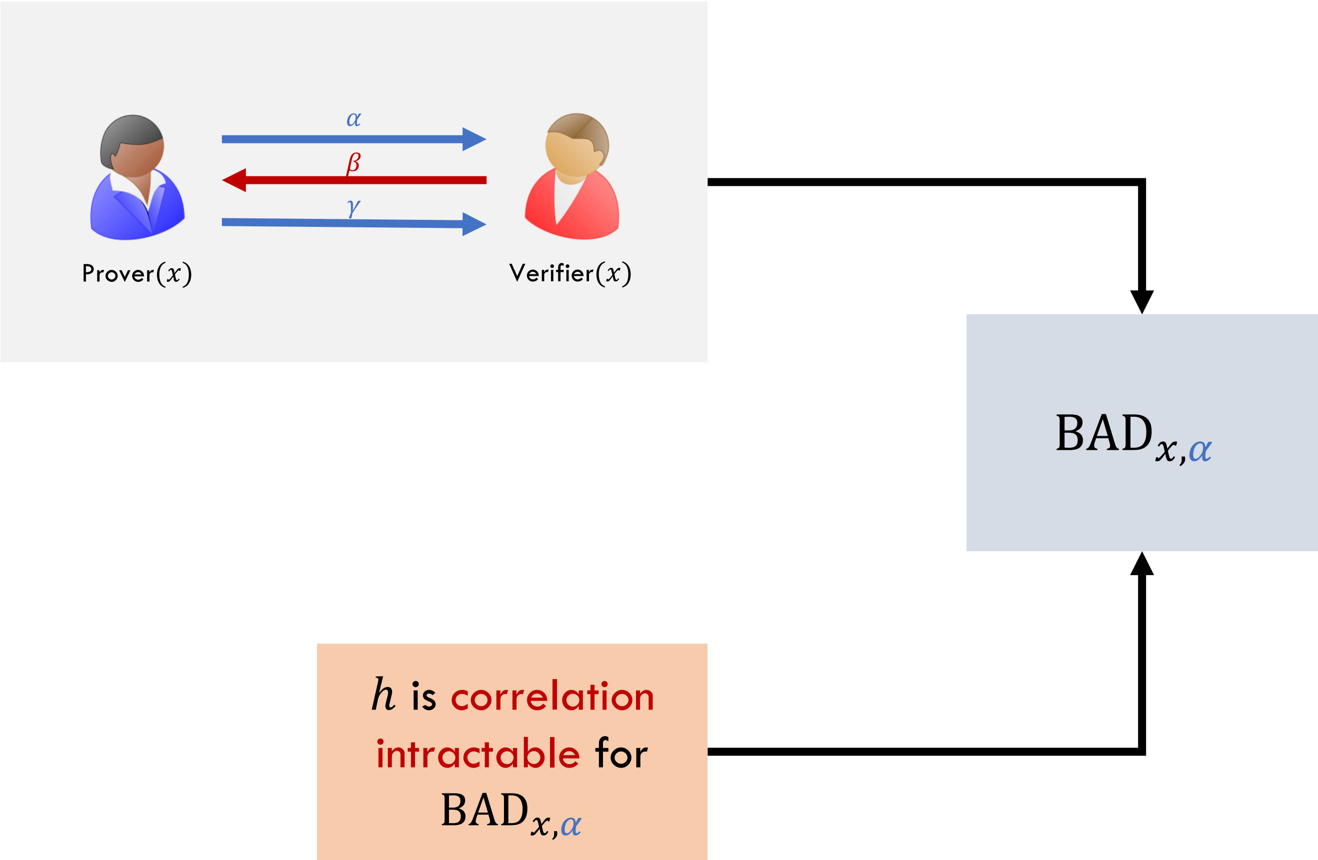

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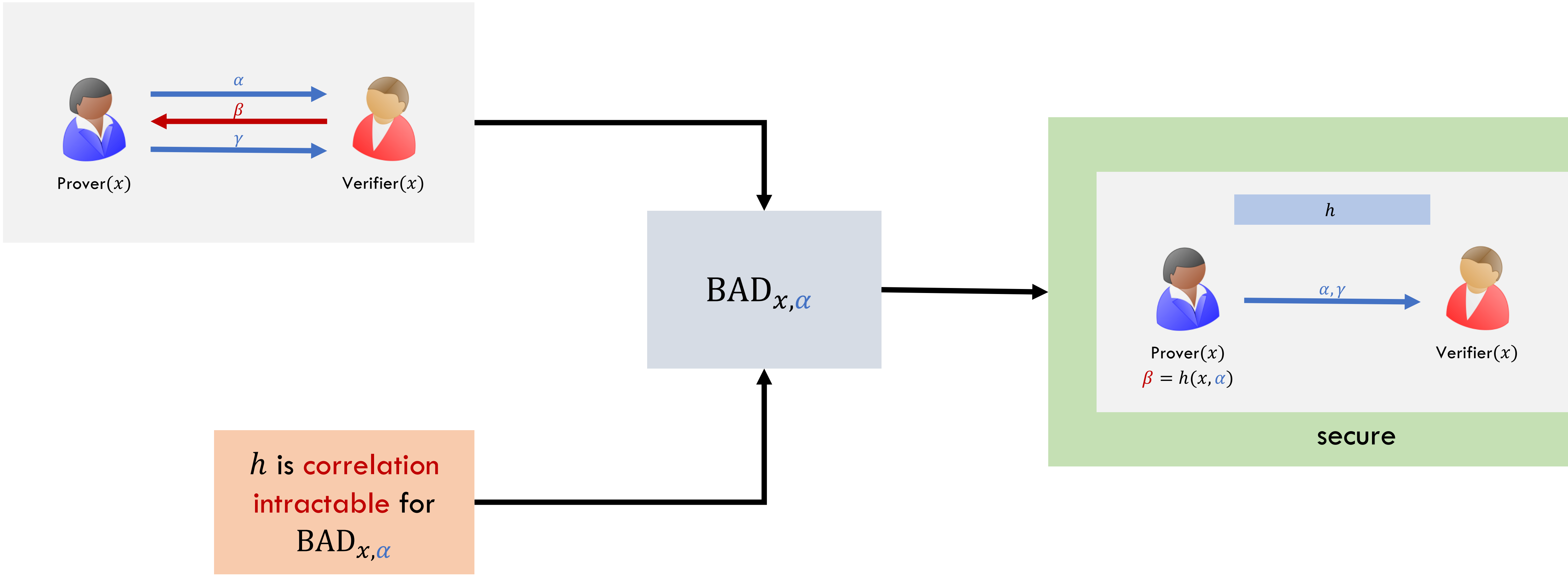
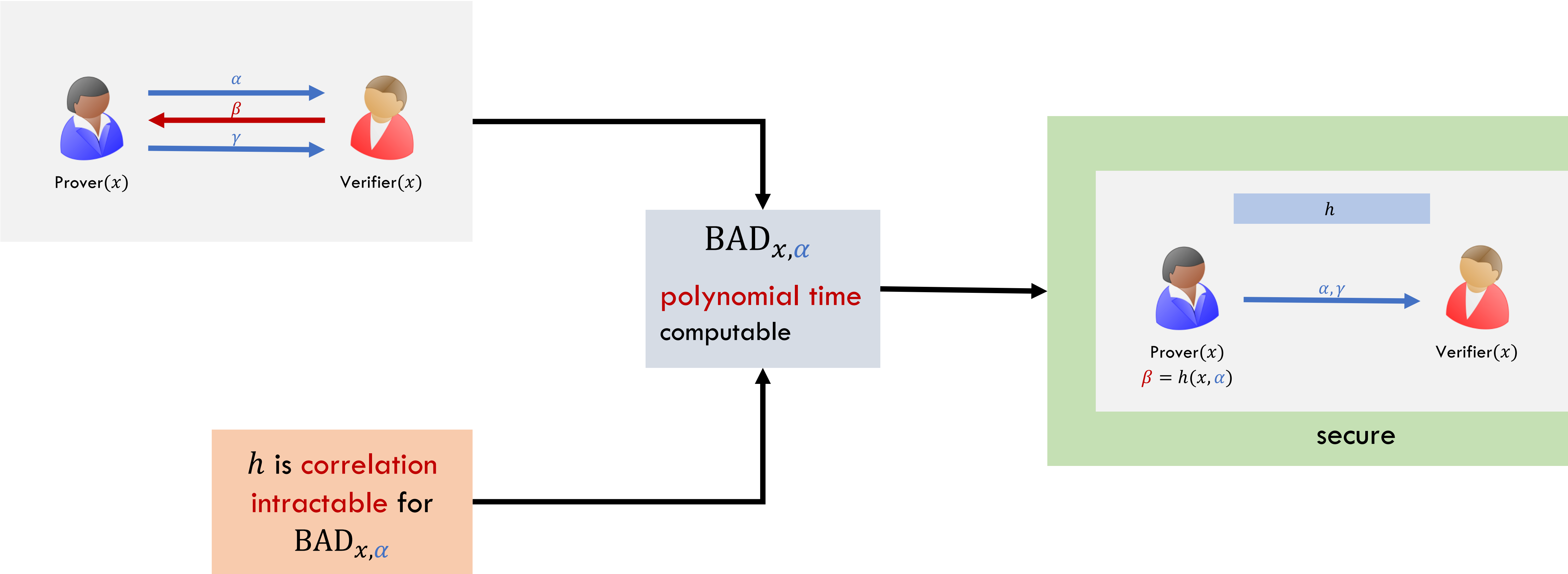


Instantiating the FS Transform



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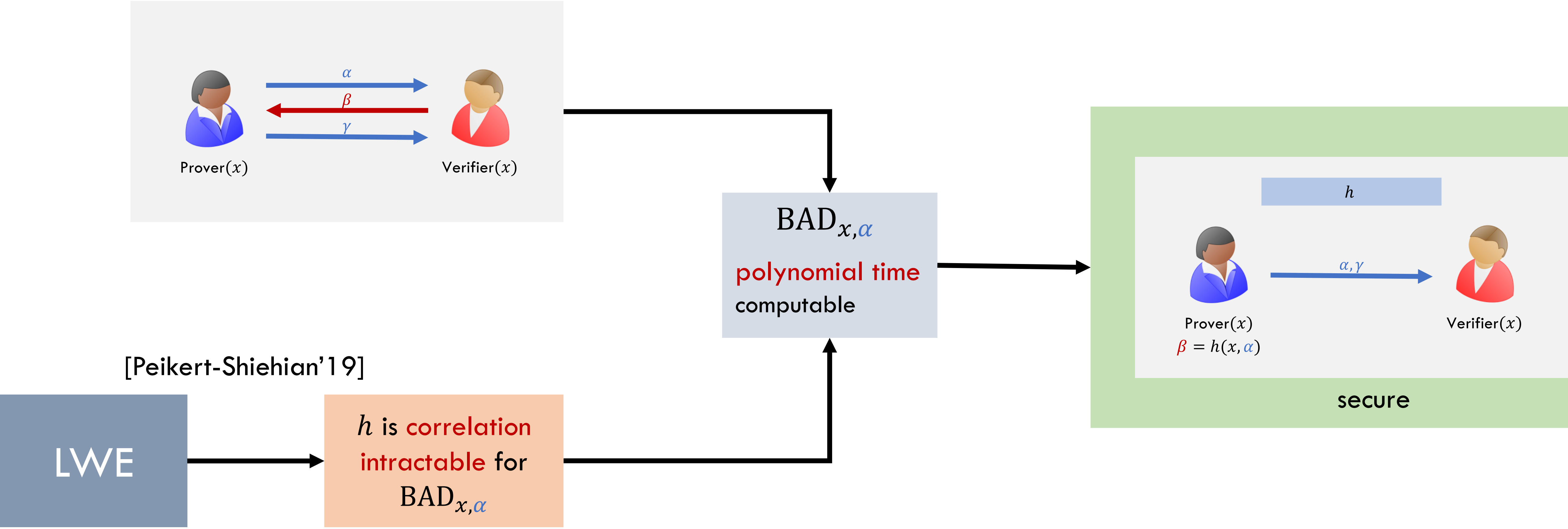

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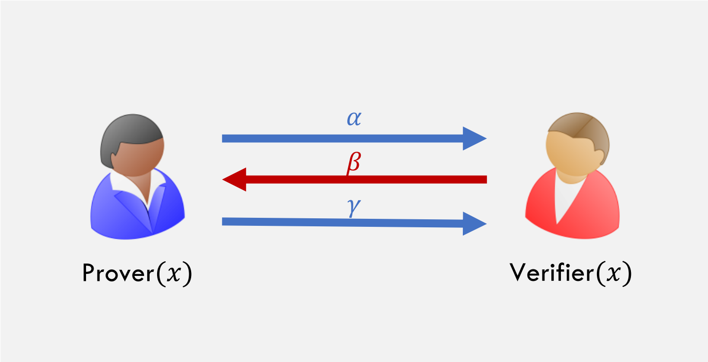
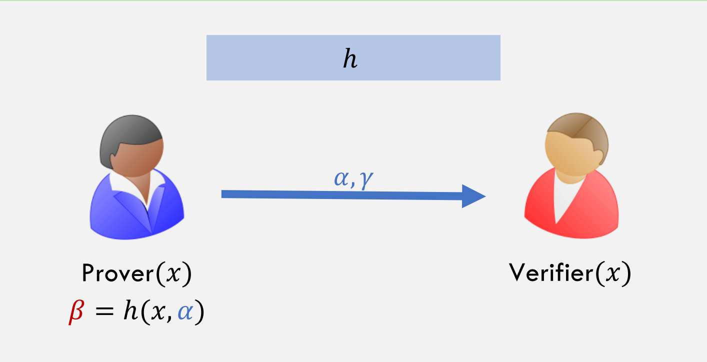


$\mathrm{BAD}_{x,\alpha}$

computable in TC^0

h is correlation intractable for $\mathrm{BAD}_{x,\alpha}$



secure

TC^0 - Constant depth polynomial-size threshold circuits

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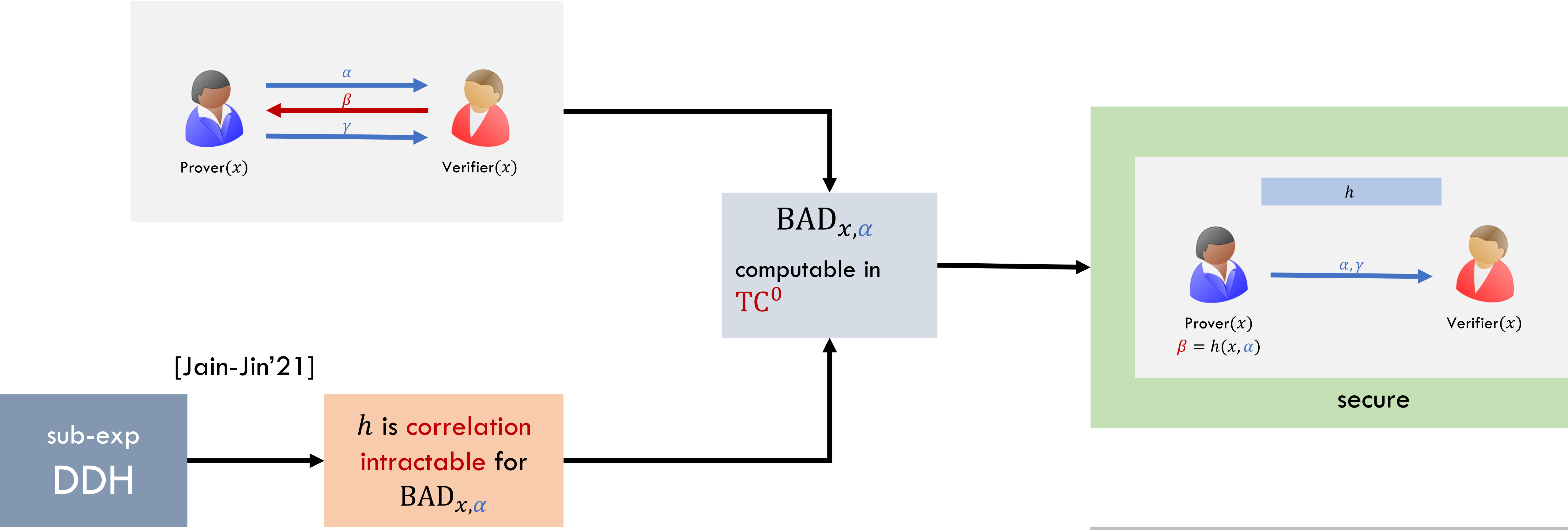

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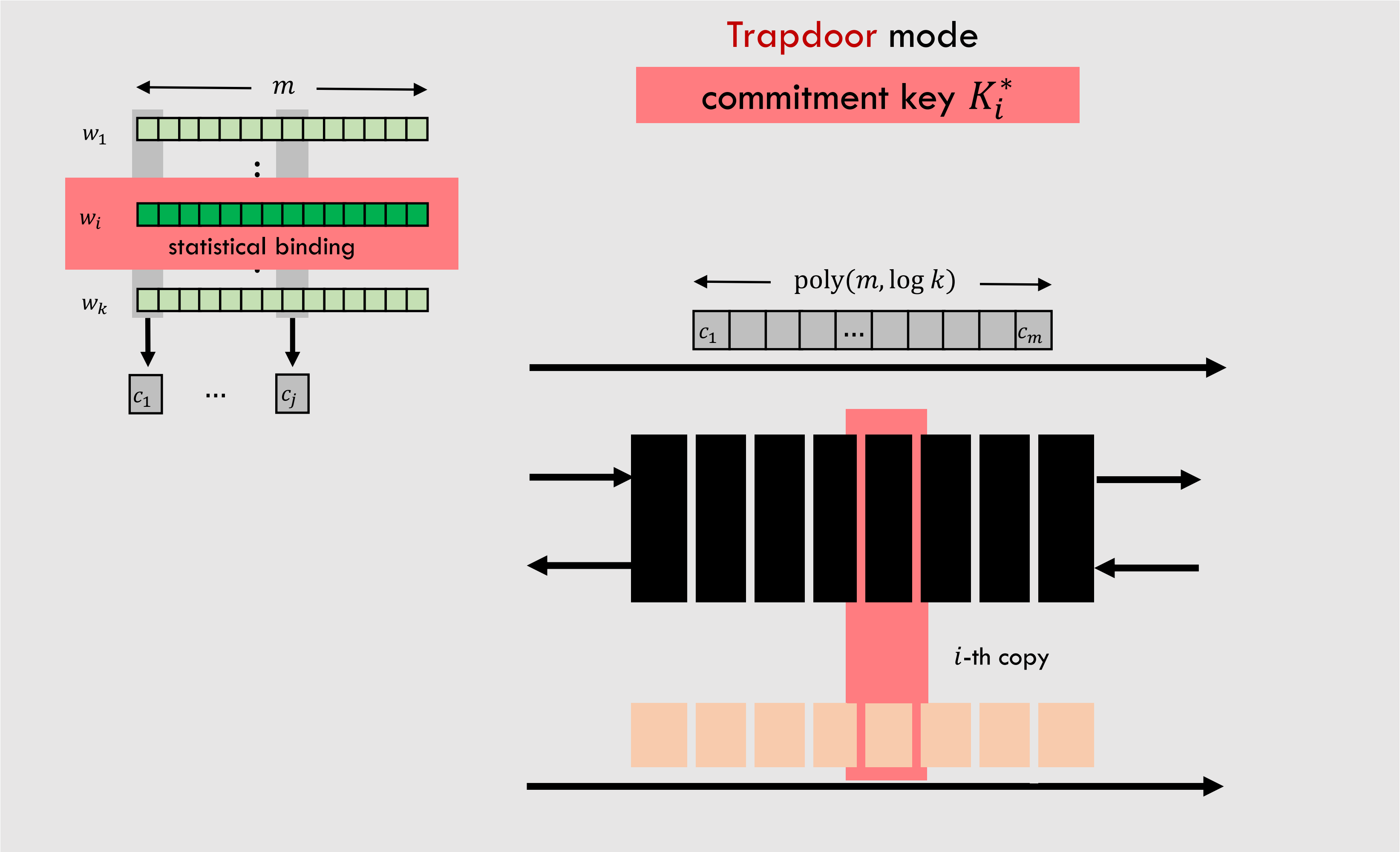

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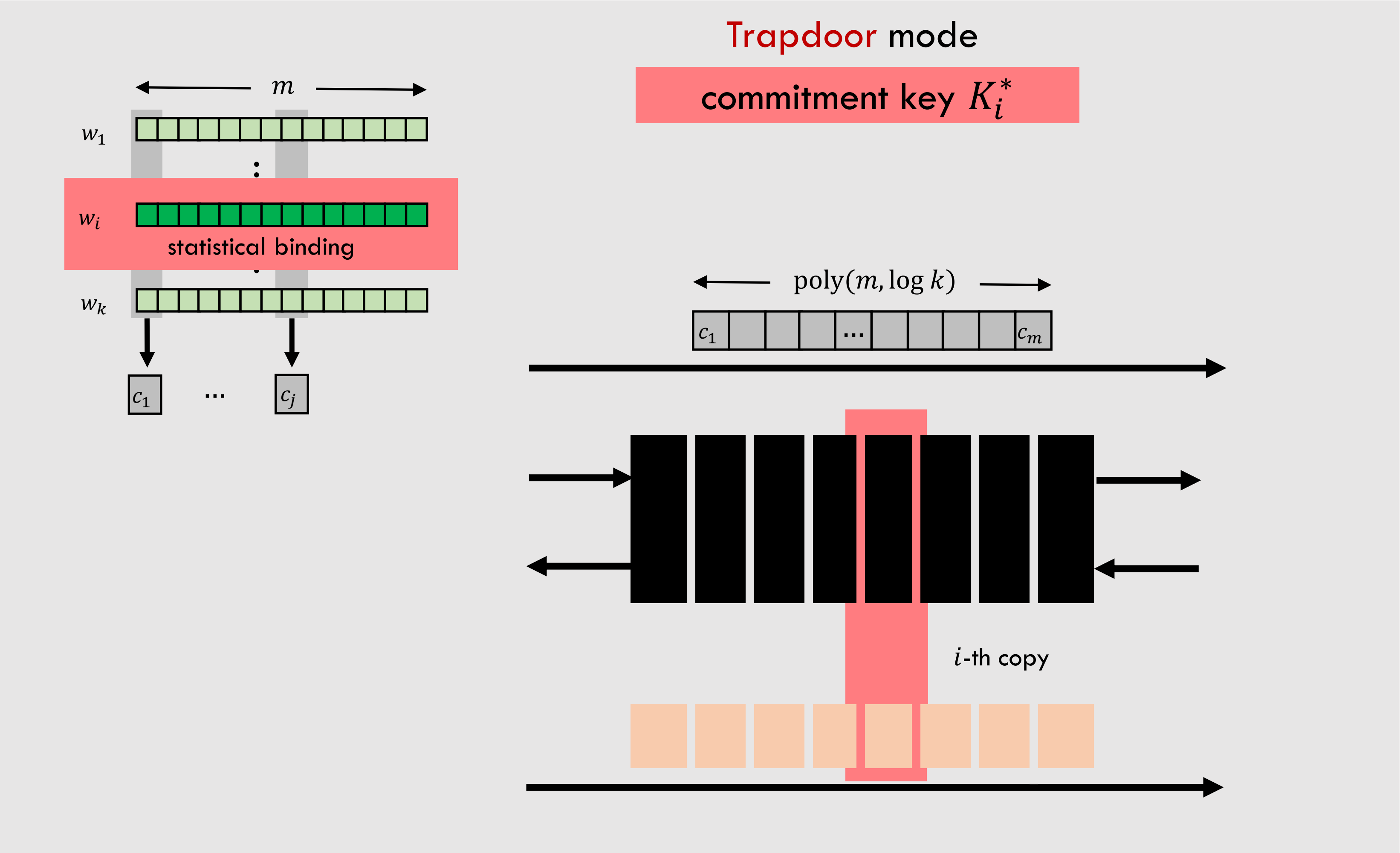

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Building Block: Spartan [Setty'20]

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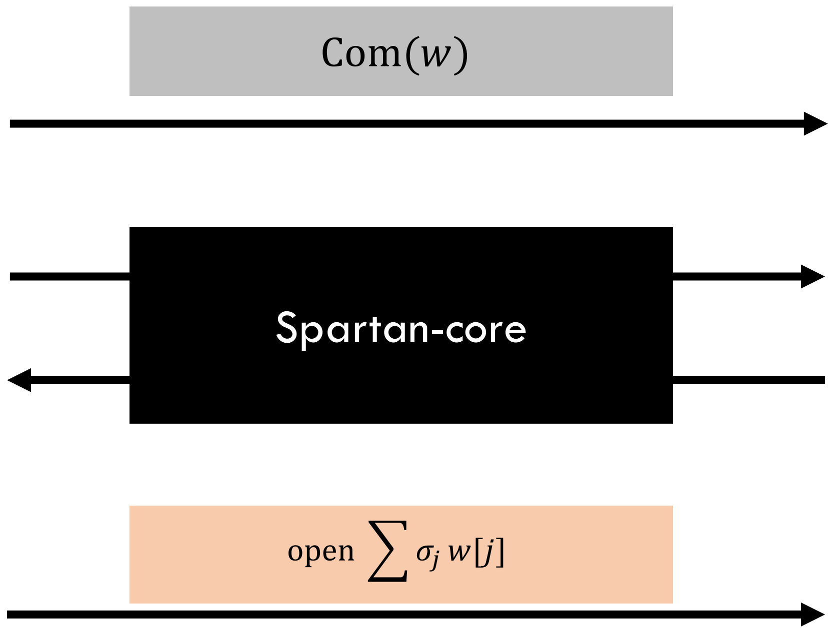

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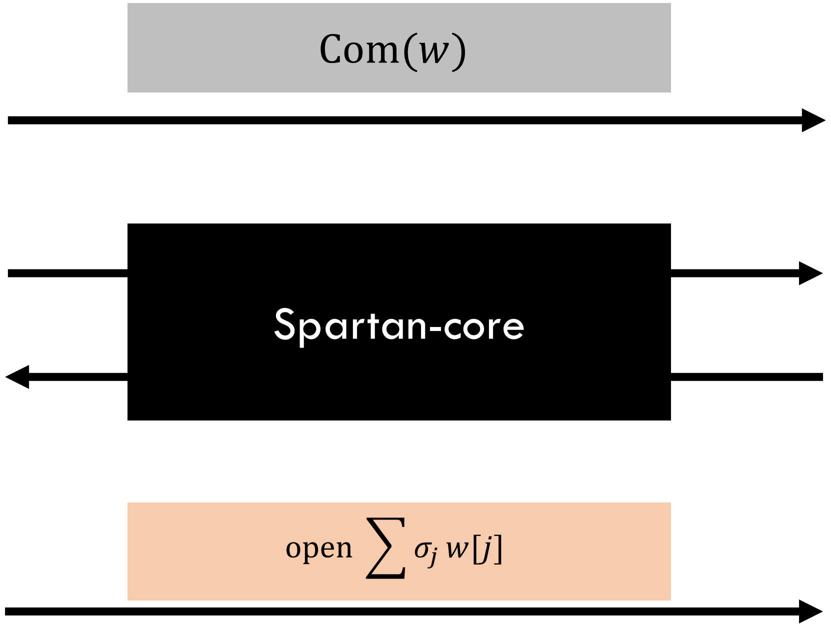

Spartan-core primarily consists of the Sumcheck protocol.

Building Block: Spartan [Setty'20]

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$\mathrm{Com}(w)$

$\vdots$

polynomial $g(x)$

$\beta \leftarrow \mathbb{F}$

$\vdots$

open $\sum \sigma_j \, w[j]$

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the "true" polynomial an honest prover would have sent

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⋮

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Show that appropriate field $\mathbb{F}$, BAD can be computed in TC^0.

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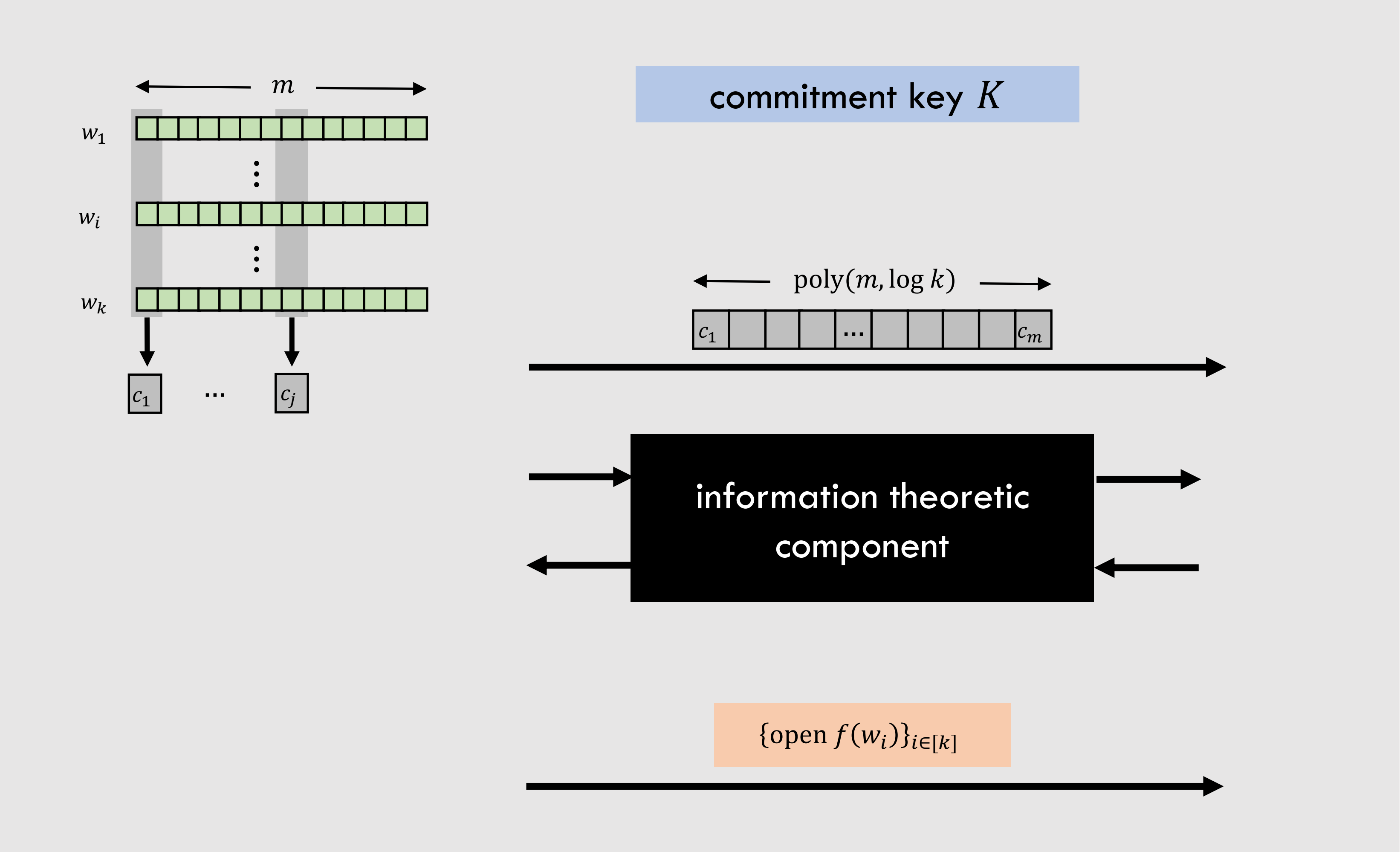

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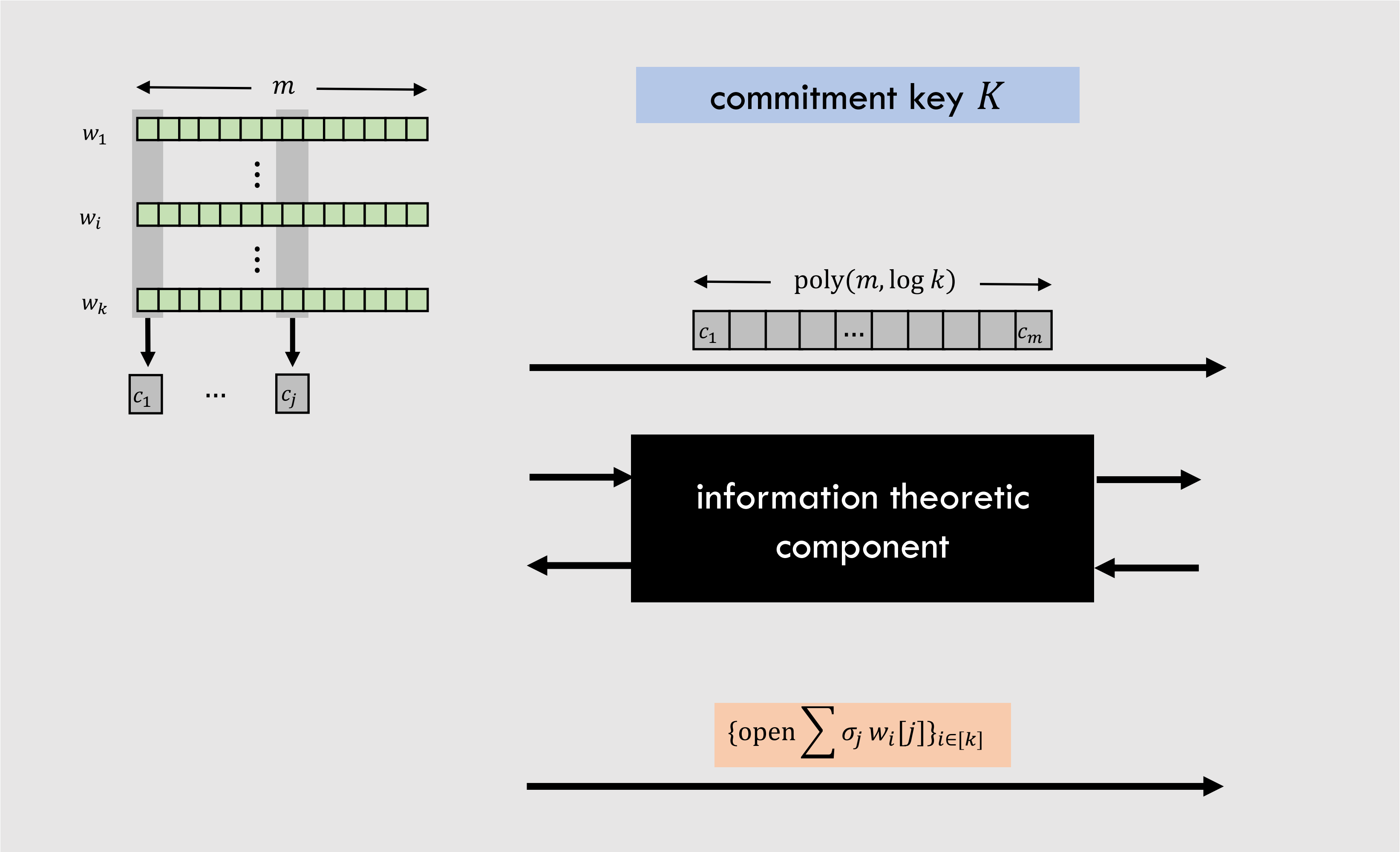

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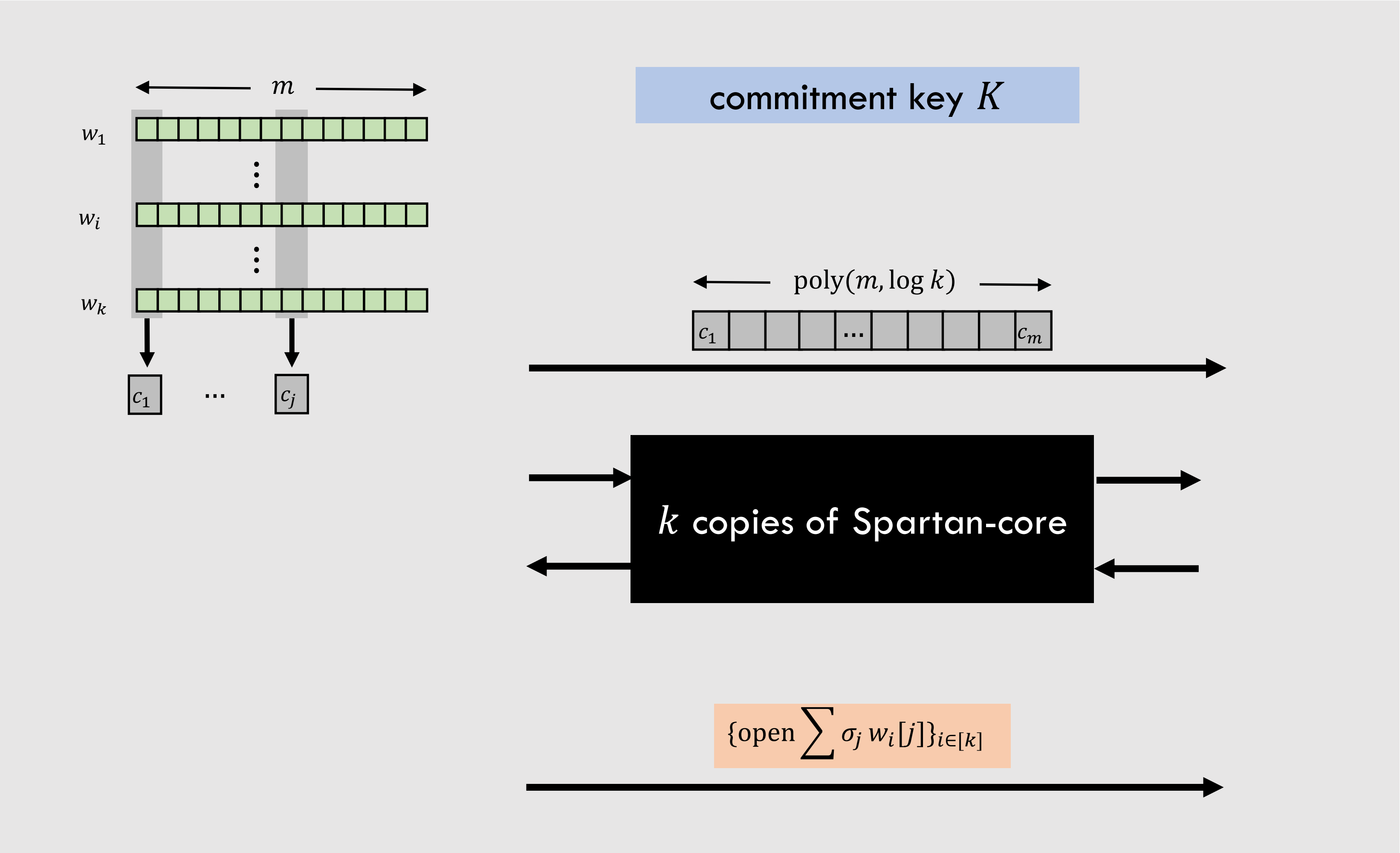

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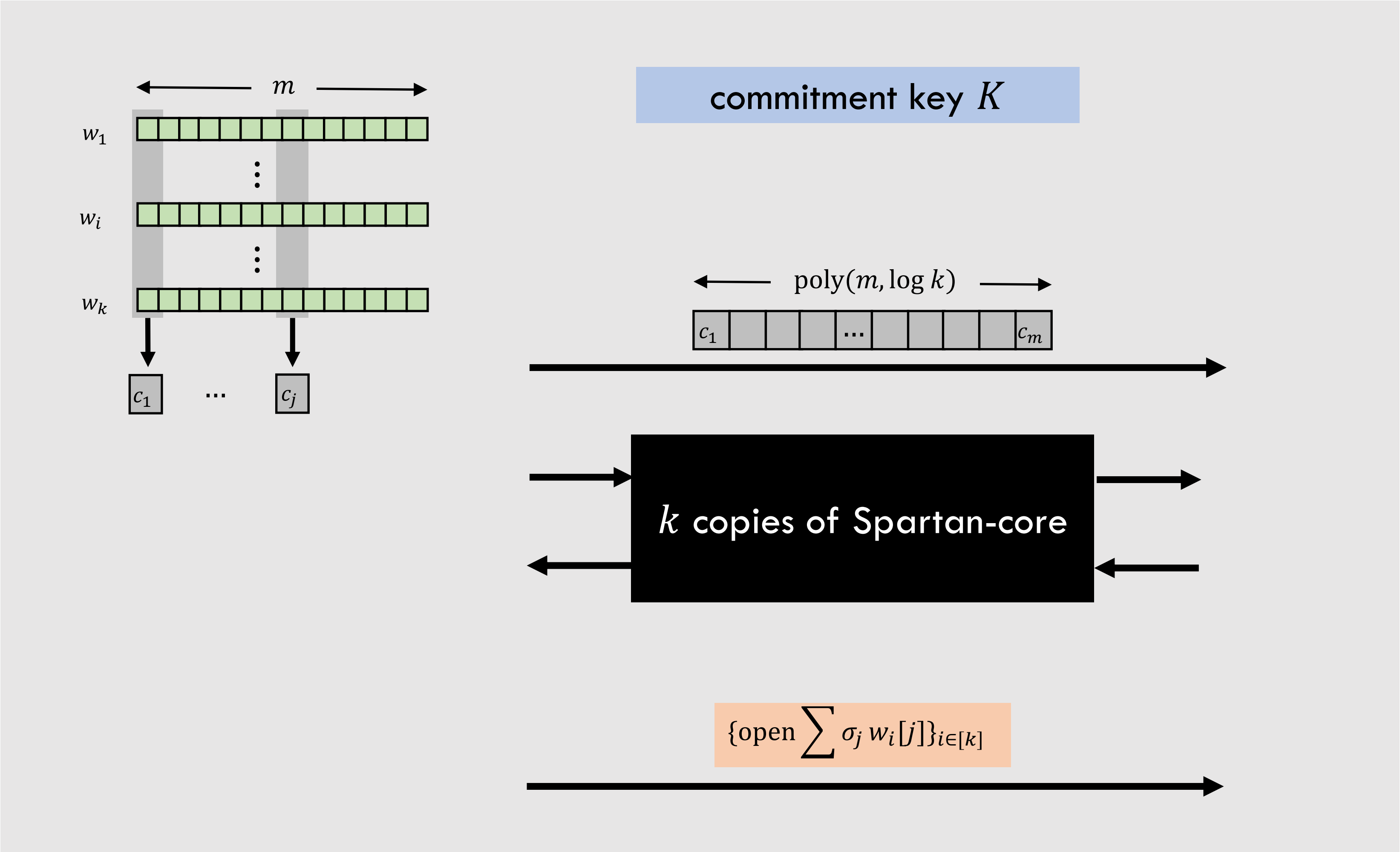

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Concluding Remarks

Theorem

Assuming QR + (LWE/sub-exp DDH) there exists a non-interactive batch argument for NP where

$$|\Pi| = \tilde{O}(|C| + \sqrt{k|C|})$$

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Follow up work [C-Jain-Jin'21b] (ia.cr/2021/808)

- Batch arguments for NP with improved parameters
- Application of batch arguments to construct delegation scheme for $\mathcal{P}$

Thank you. Questions?

Arka Rai Choudhuri

achoud@cs.jhu.edu

ia.cr/2021/807