A Composable View of Verifiable Homomorphic Encryption in Multi-Party Settings

Ganyuan Cao

March 31, 2025

Motivation

- On-the-Fly MPC [LTV12]

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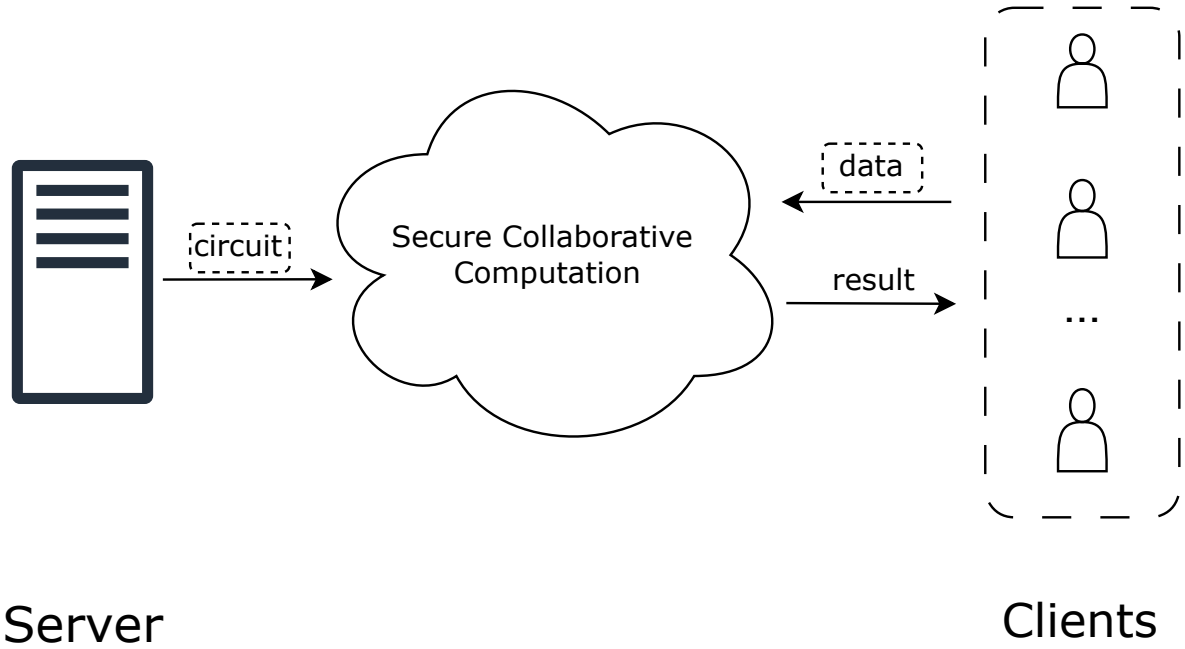

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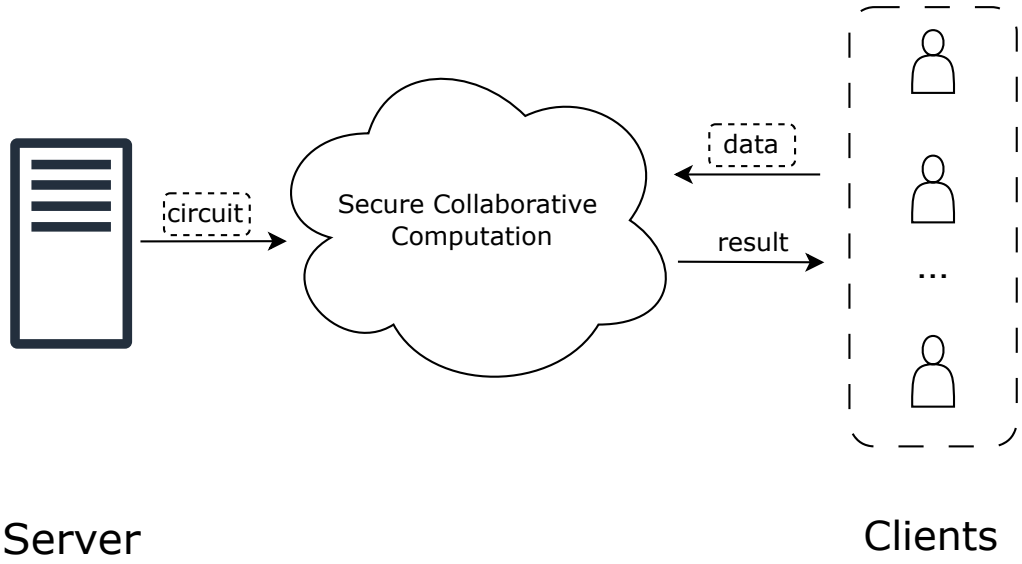

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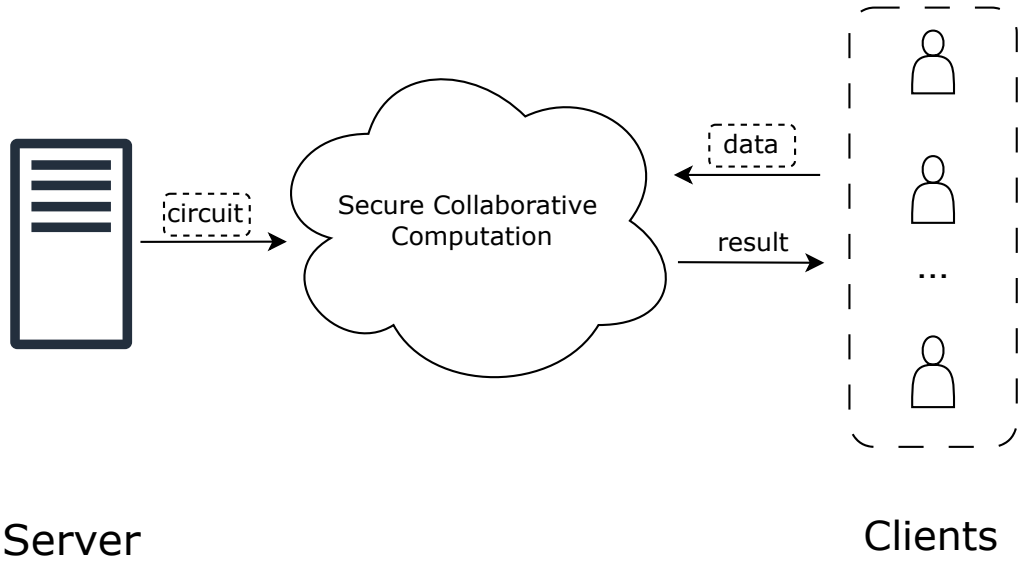


- Dynamically joining parties.
- Computation outsourced to untrusted but powerful server.

Motivation

– Homomorphic Encryption (HE) is a good candidate...

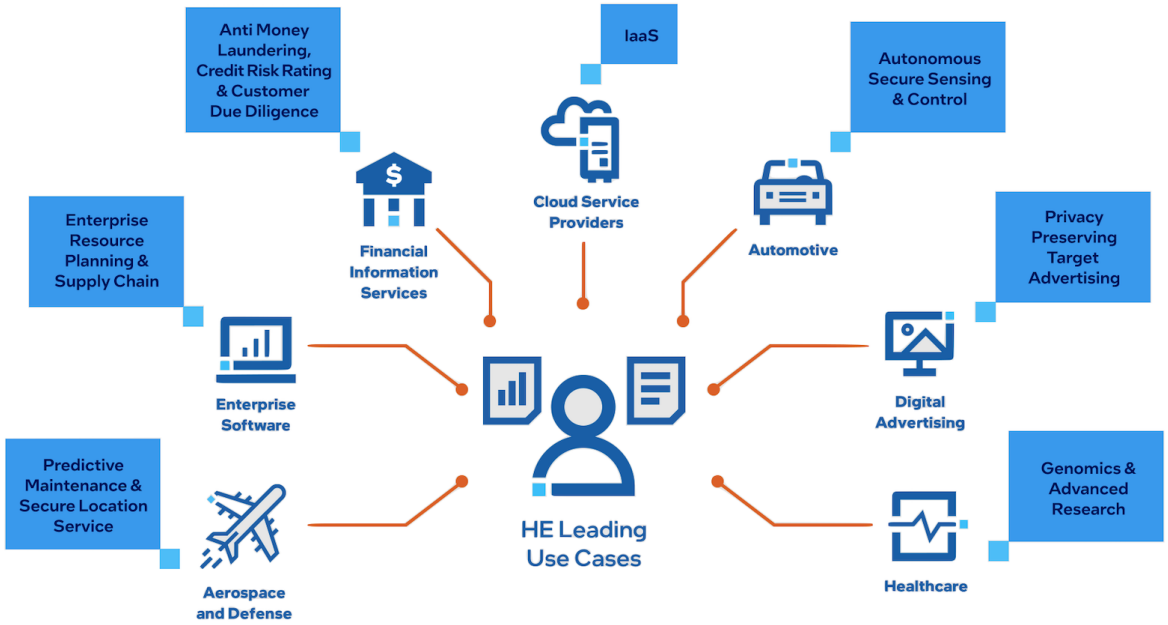
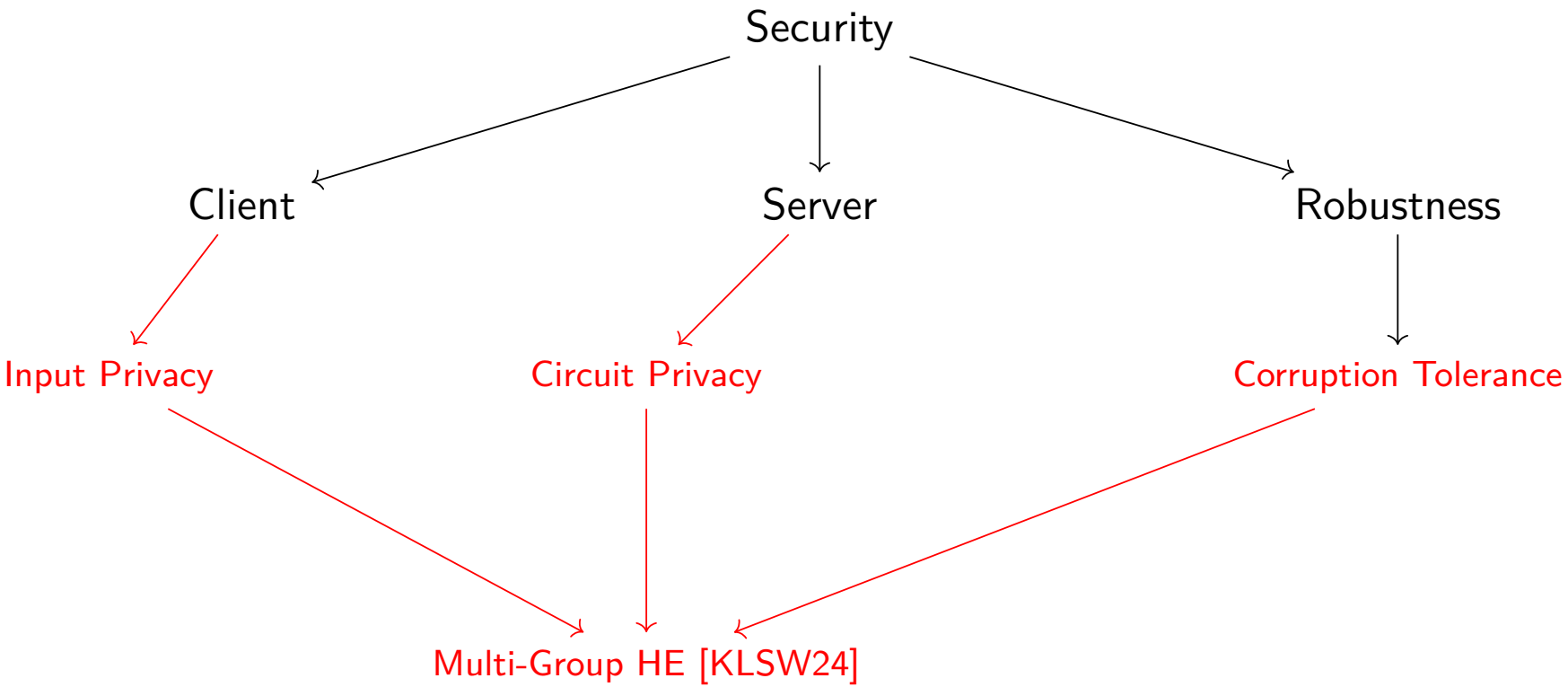


Figure: Use cases of HE [Int].

Goal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Server
Robustness
Input Privacy
Circuit Privacy
Corruption Tolerance
Multi-Group HE [KLSW24]

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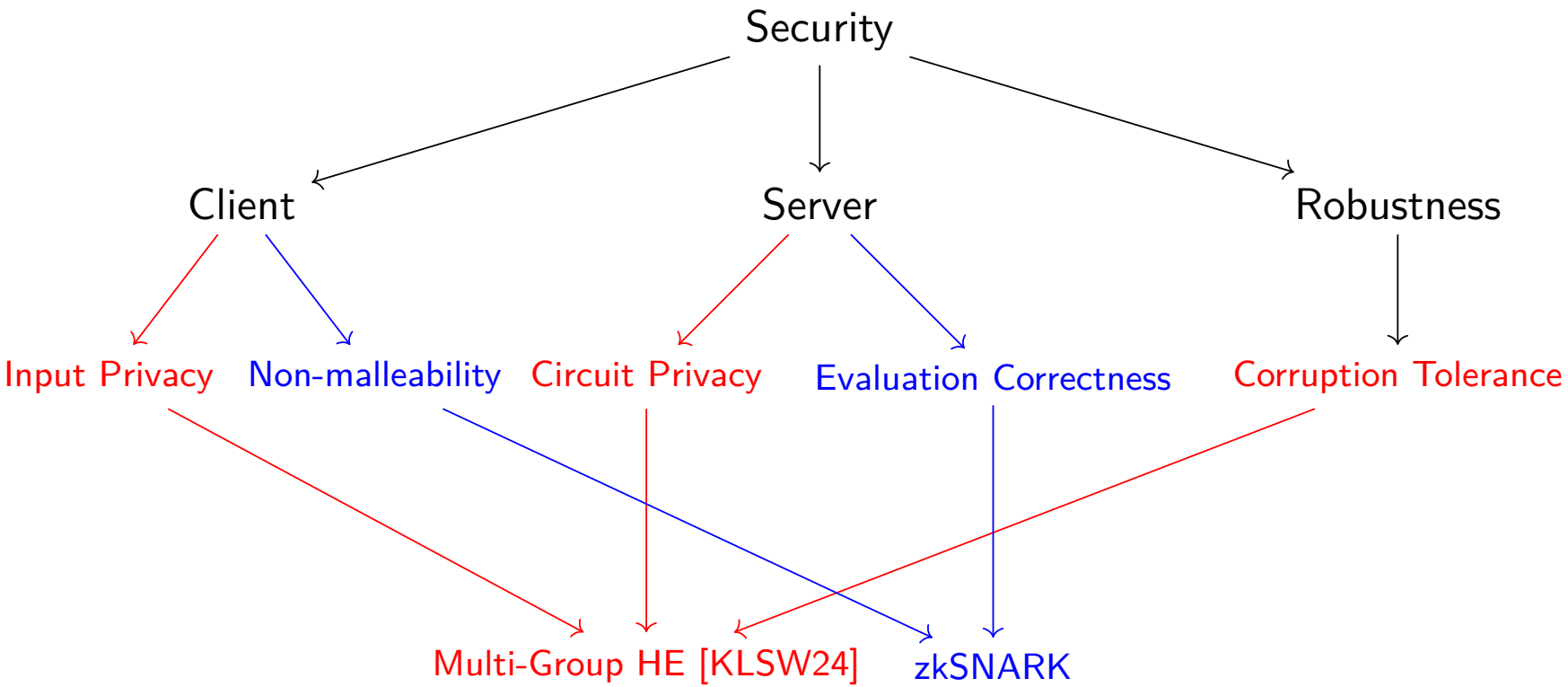
Security
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Server
Robustness
Input Privacy
Non-malleability
Circuit Privacy
Evaluation Correctness
Corruption Tolerance
Multi-Group HE [KLSW24]
zkSNARK

Contribution

- Formalism

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EPFL

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  - New game-based notions for (Multi-Key, Threshold, Multi-Group) HE in multi-party setting.

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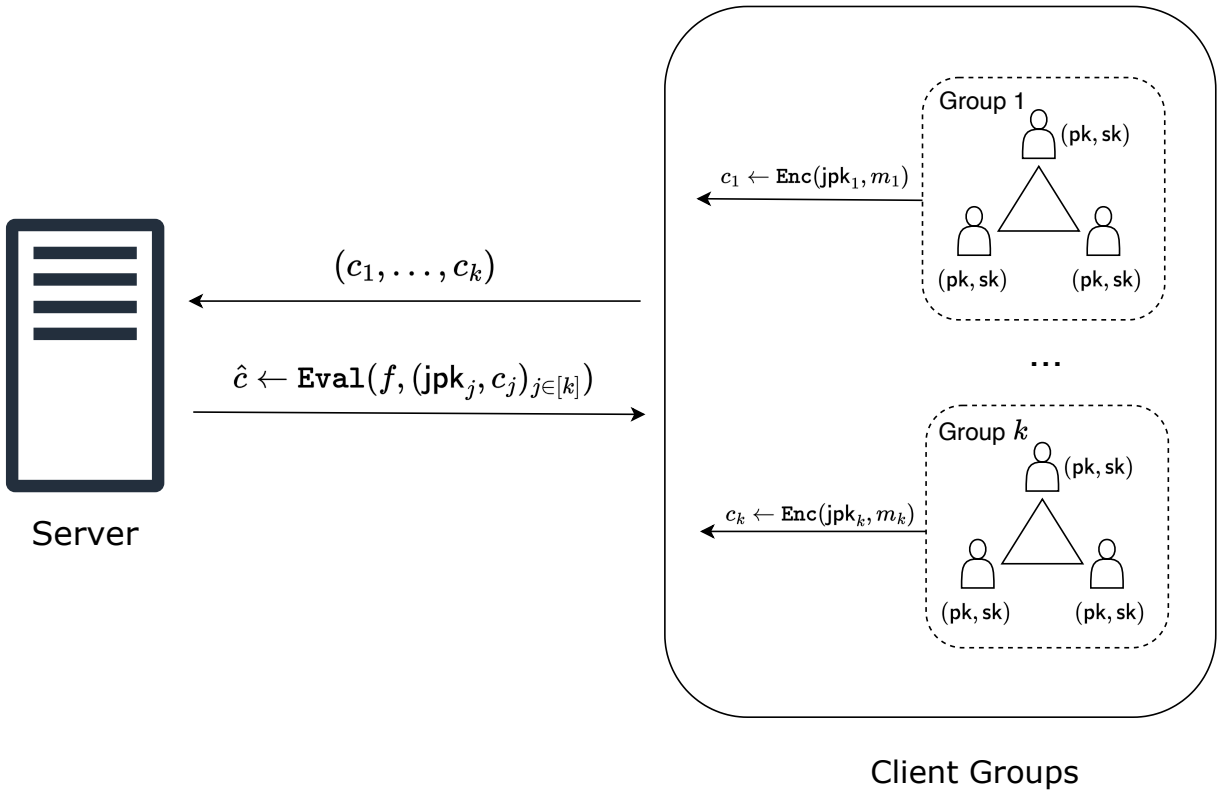
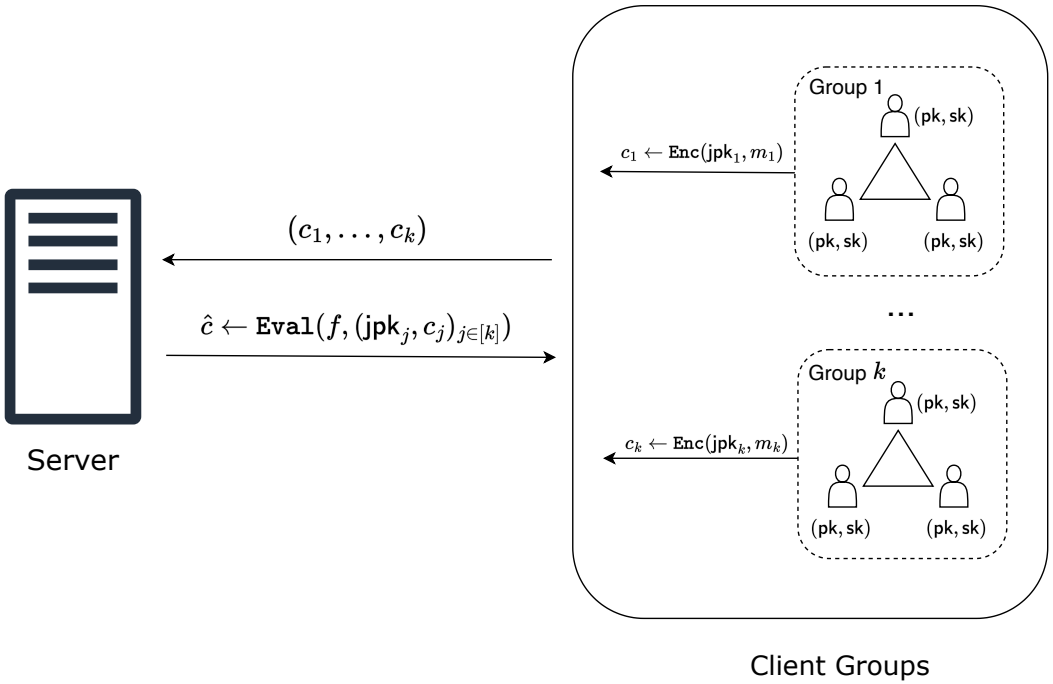
  - New game-based notions for (Multi-Key, Threshold, Multi-Group) HE in multi-party setting.
  - UC functionality for HE in multi-party setting.
- Construction
  - UC-secure MPC via verifiable multi-group HE.

Multi-Group HE (MGHE) [KLSW24]



Multi-Group HE (MGHE)



- Hybrid approach between Threshold HE and Multi-Key HE

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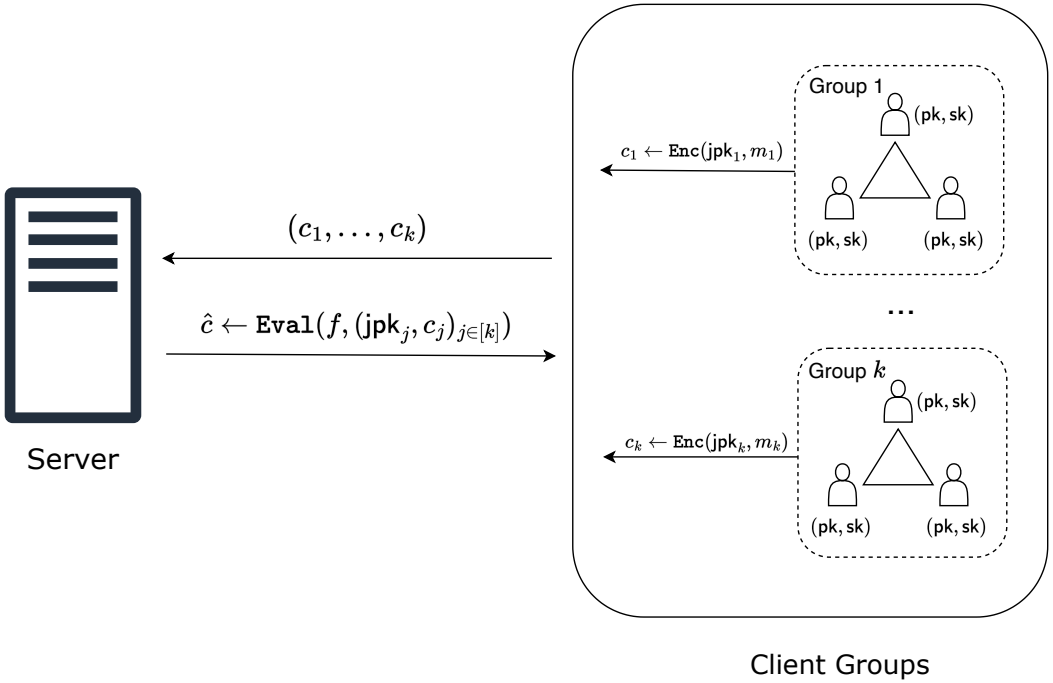

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  - Fewer public keys $\Rightarrow$ better scalability

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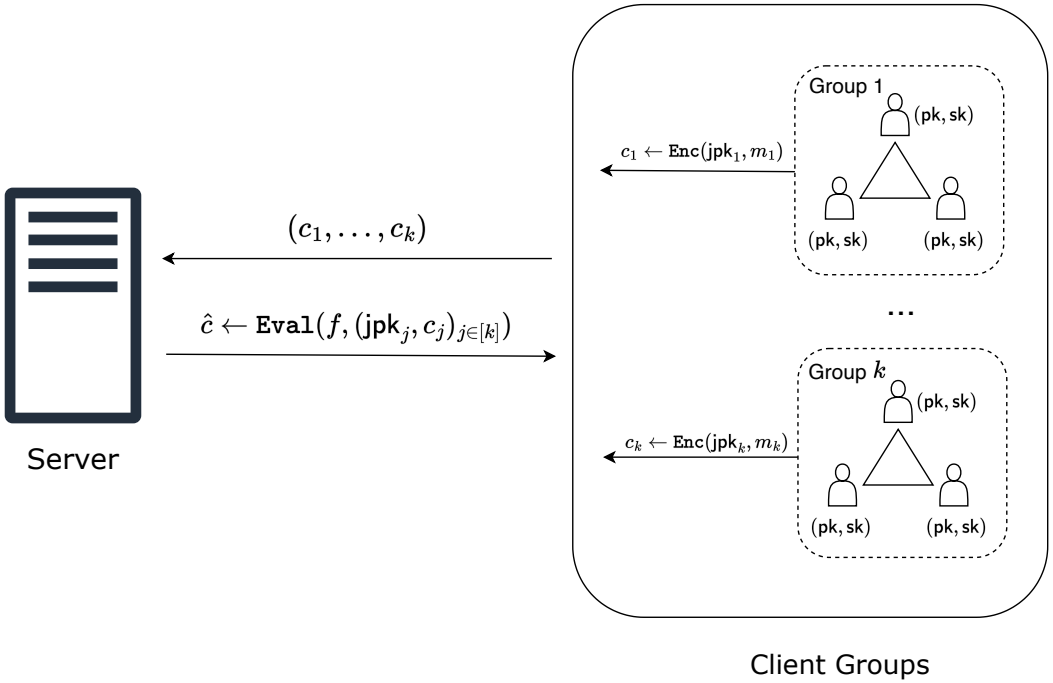
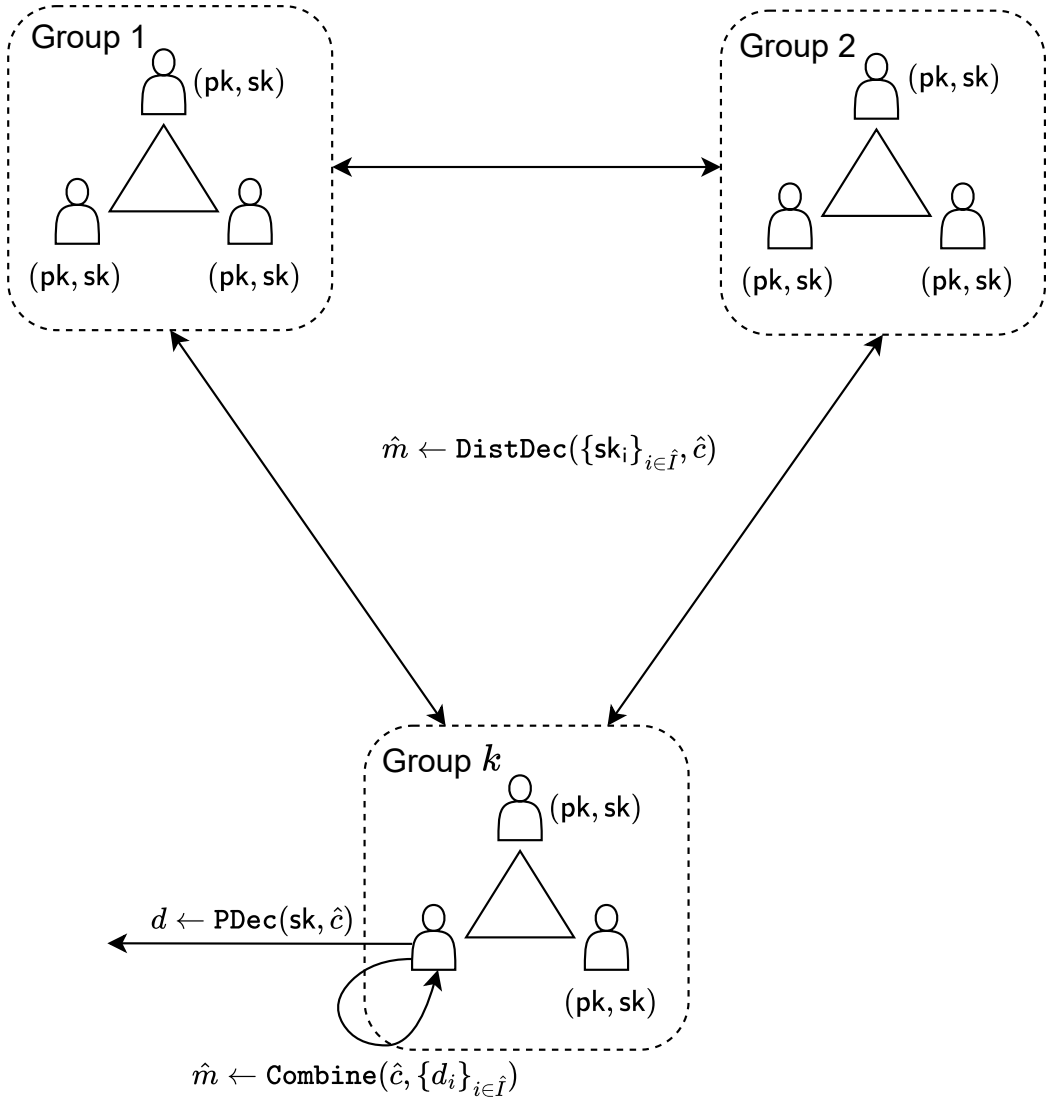


- Hybrid approach between Threshold HE and Multi-Key HE
  - Fewer public keys ⇒ better scalability
  - Allow for dynamically joining parties ⇒ better flexibility

Multi-Group HE



Confidentiality with Multi-Group HE

EPFL

$$\mathcal{G}_{\mathsf{KRK}} \xrightarrow{\Pi_{\mathsf{MGHE}}} \mathcal{F}_{\mathsf{MGHE}}$$

if MGHE satisfies

$$\begin{aligned} & \text{IND-CPA}^{\text{pD}} \\ \wedge\ & \{\text{IND}, \text{SIM}\}\text{-CIRC} \\ \wedge\ & \text{SIM-PDEC} \\ \wedge\ & \text{Decryption Consistency (DC)} \end{aligned}$$

Client Side: IND-CPA^{pD} Security

IND-CPA

For PKE

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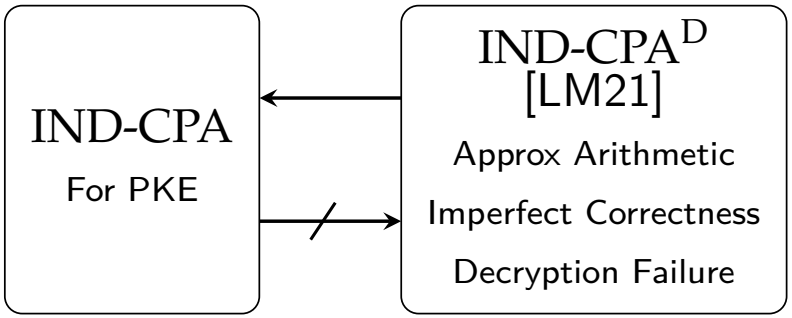

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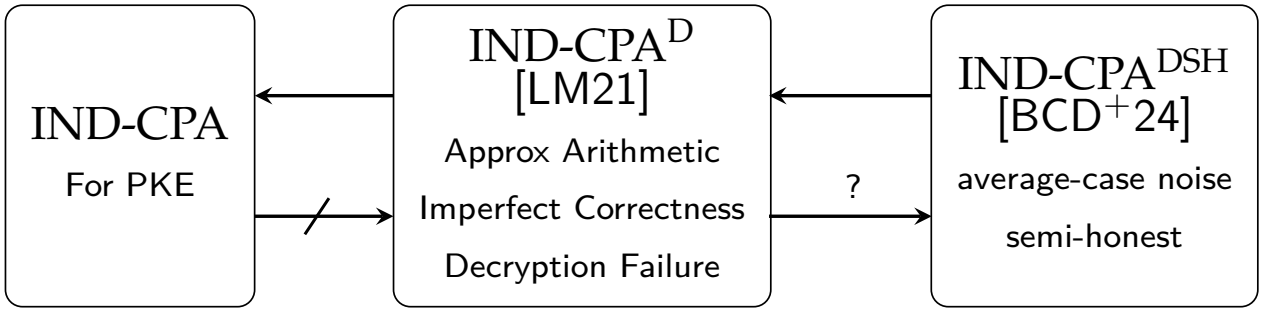

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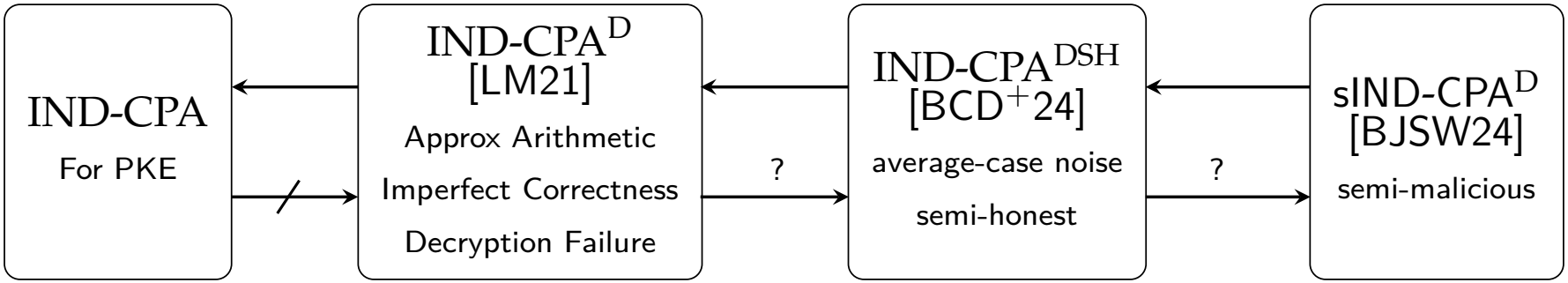

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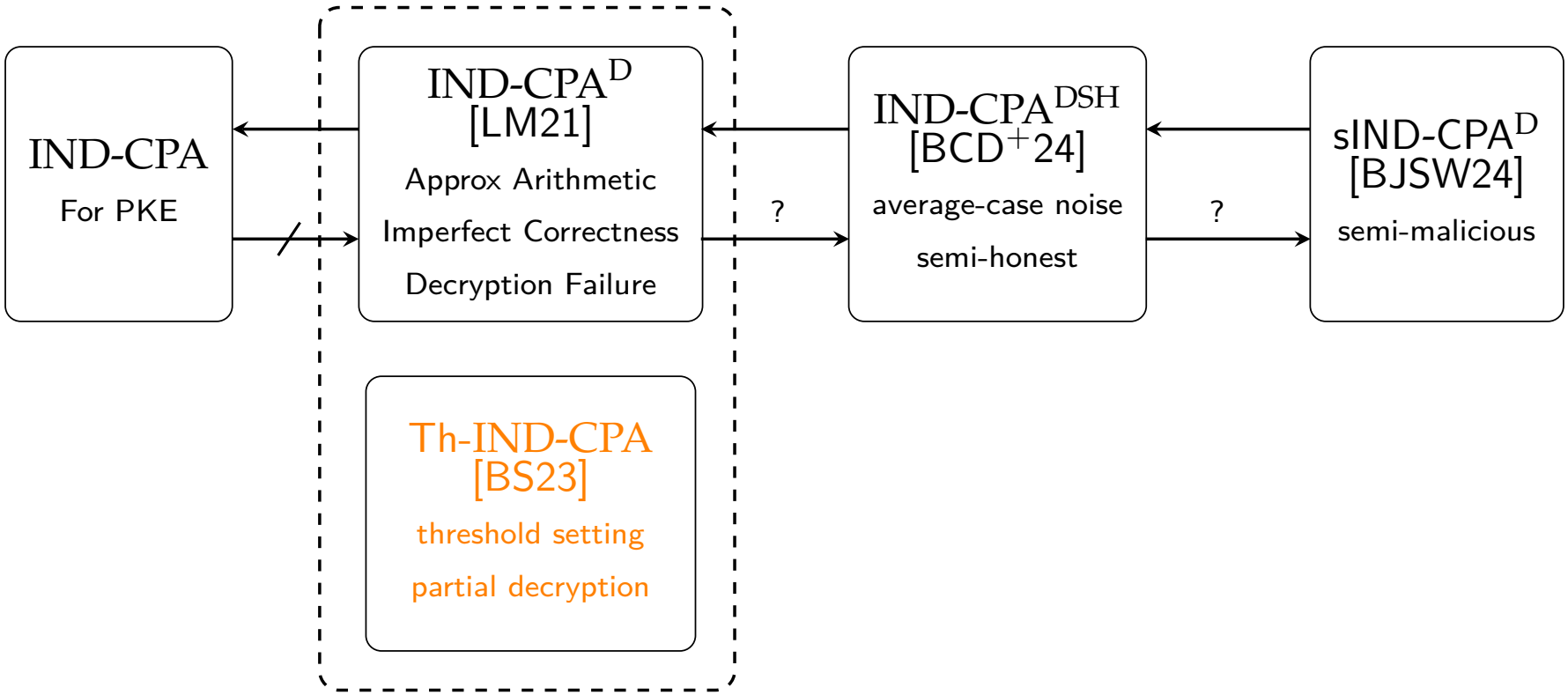

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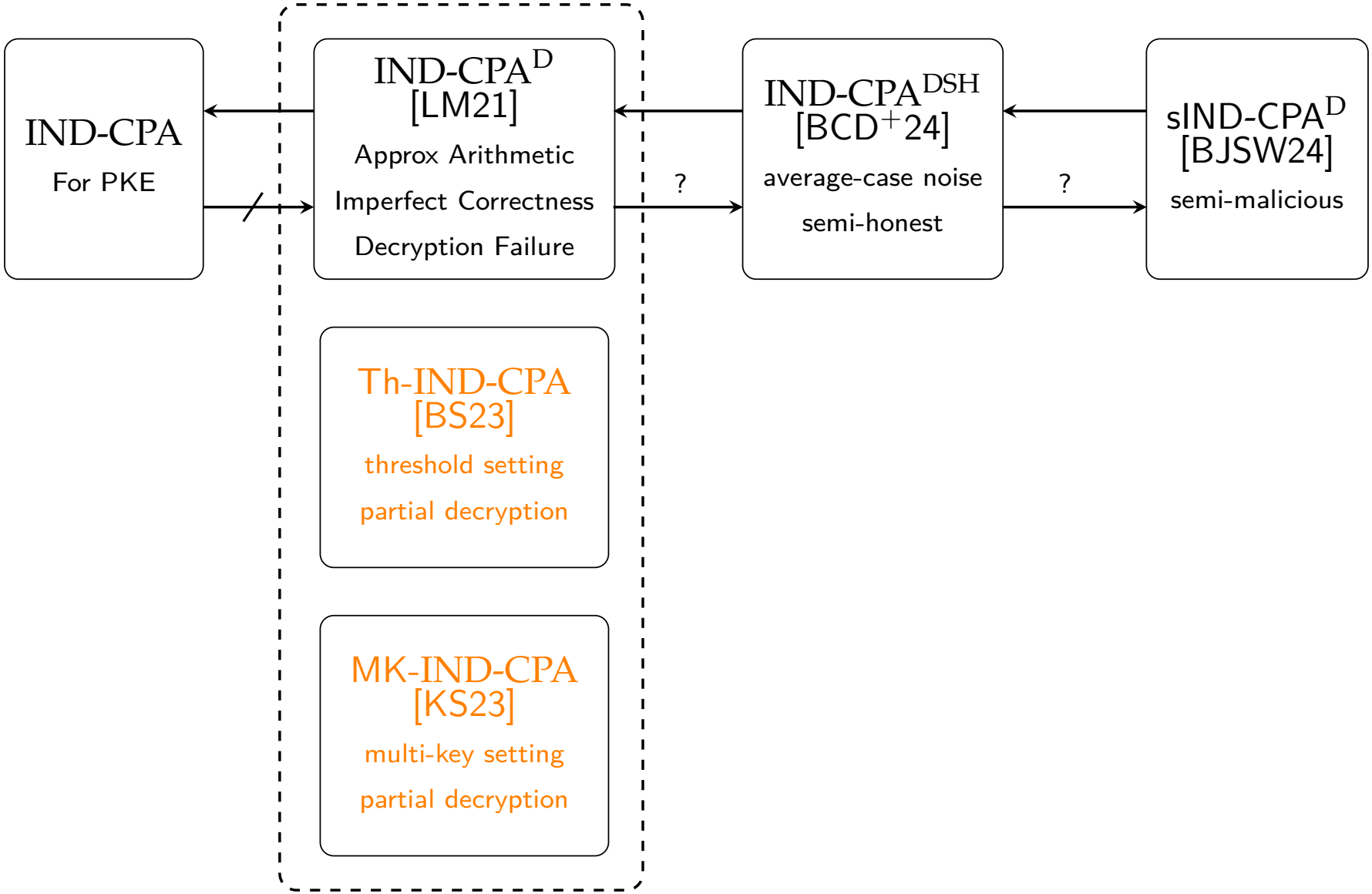

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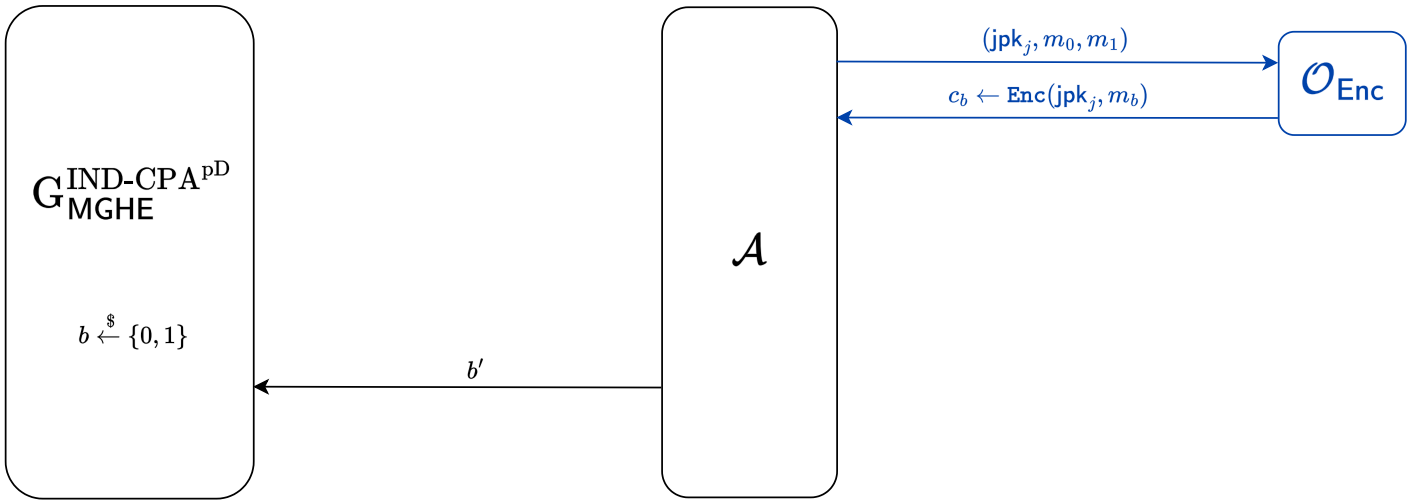

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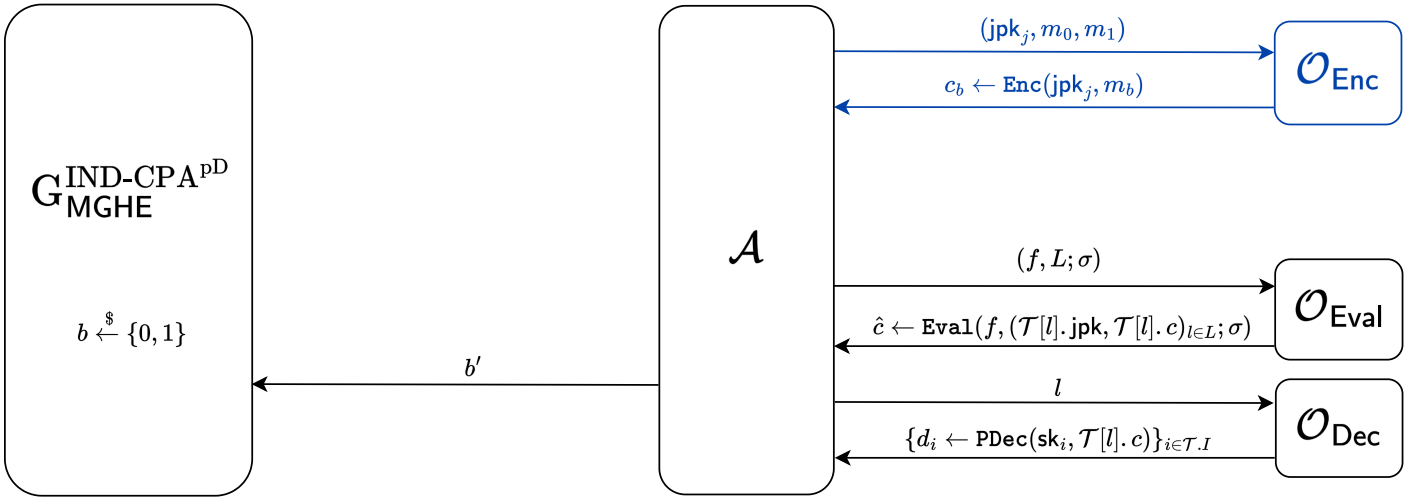

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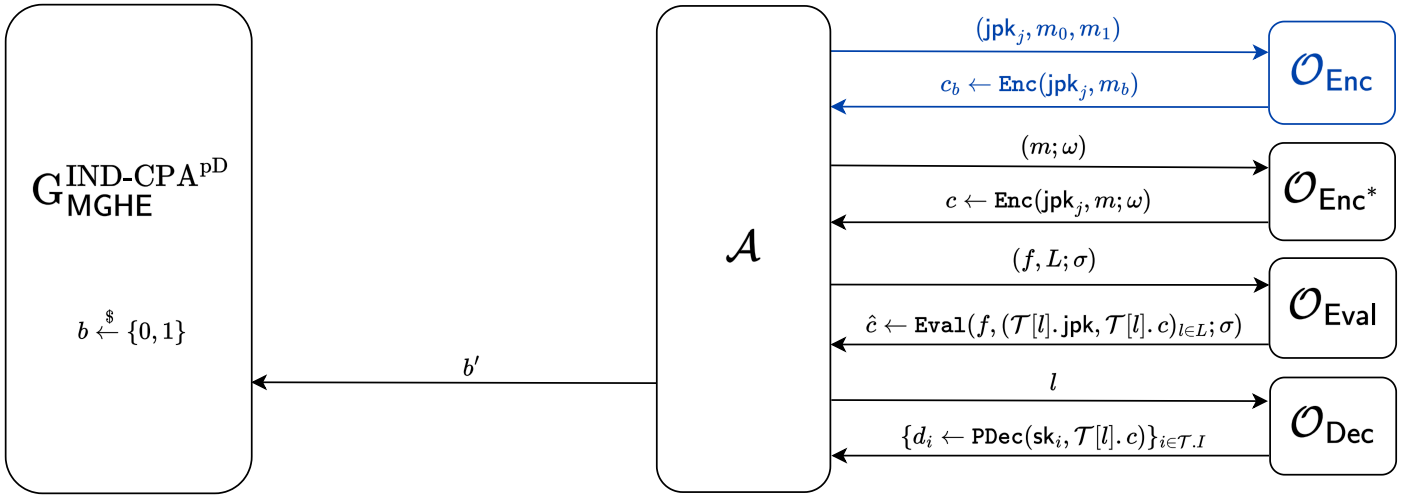

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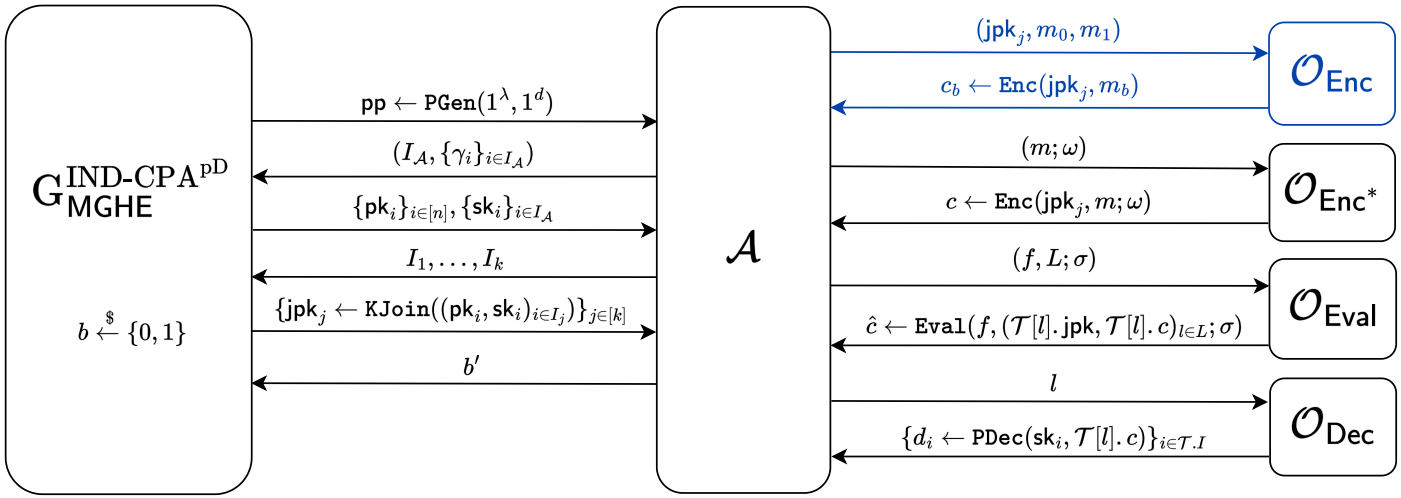

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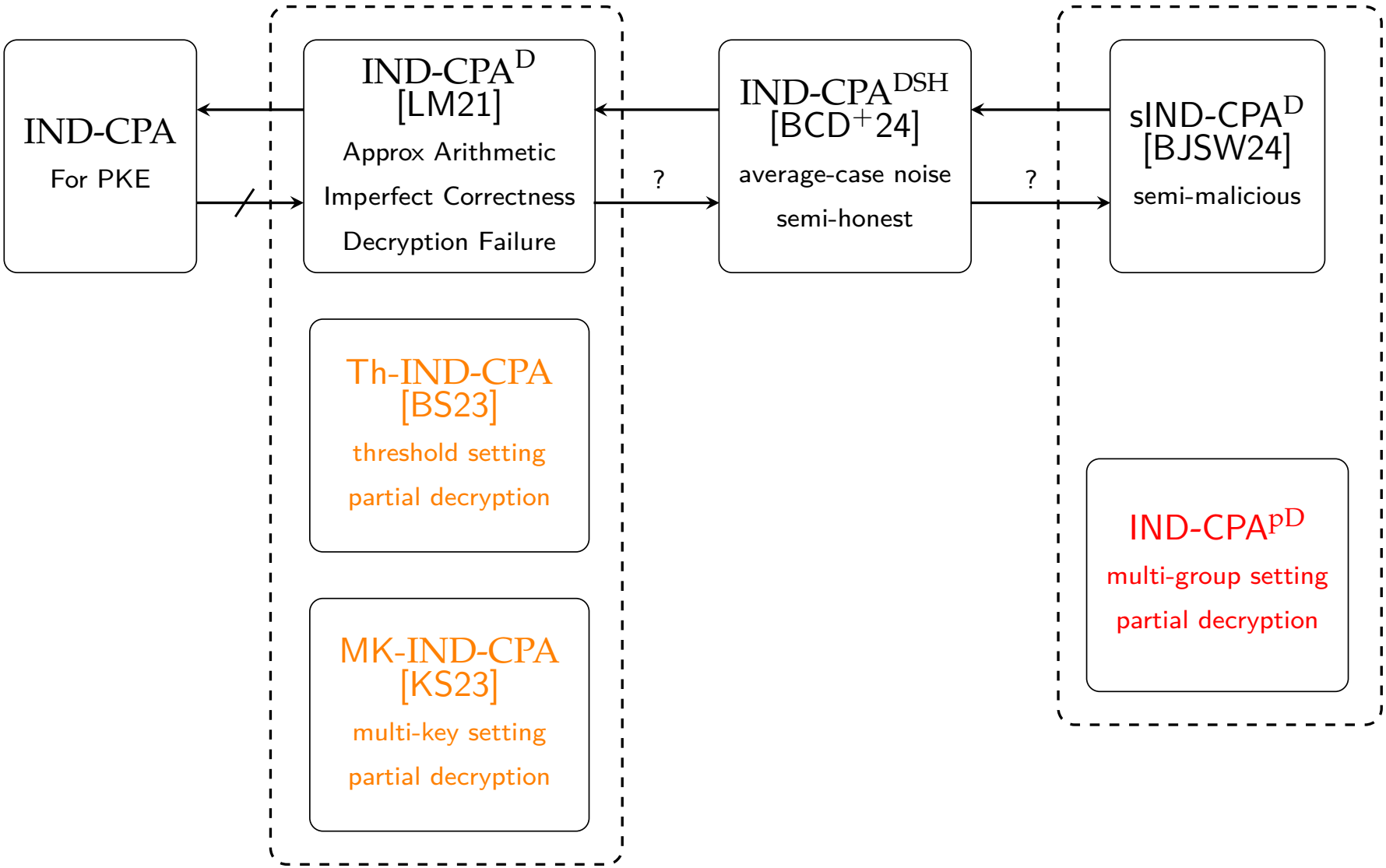

Server Side: Circuit Privacy

EPFL

– Usually formalized using *Simulation* [IP07, Gen09, BdPMW16].

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$$\mathtt{Sim}_{circ}((\mathsf{jpk}_1,\ldots,\mathsf{jpk}_\ell), f(m_1,\ldots,m_\ell))$$
$$\overset{s}{\approx}$$
$$\hat{c} \leftarrow \mathsf{MGHE}.\mathtt{Eval}(f,(\mathsf{jpk}_j,c_j)_{j\in[\ell]})$$

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– Stronger security with *statistical indistinguishability*.

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$$\hat{m} = f(m_1, \ldots, m_\ell)$$

$$\hat{m} + \varepsilon \leftarrow \mathsf{MGHE.Dec}(\hat{c})$$

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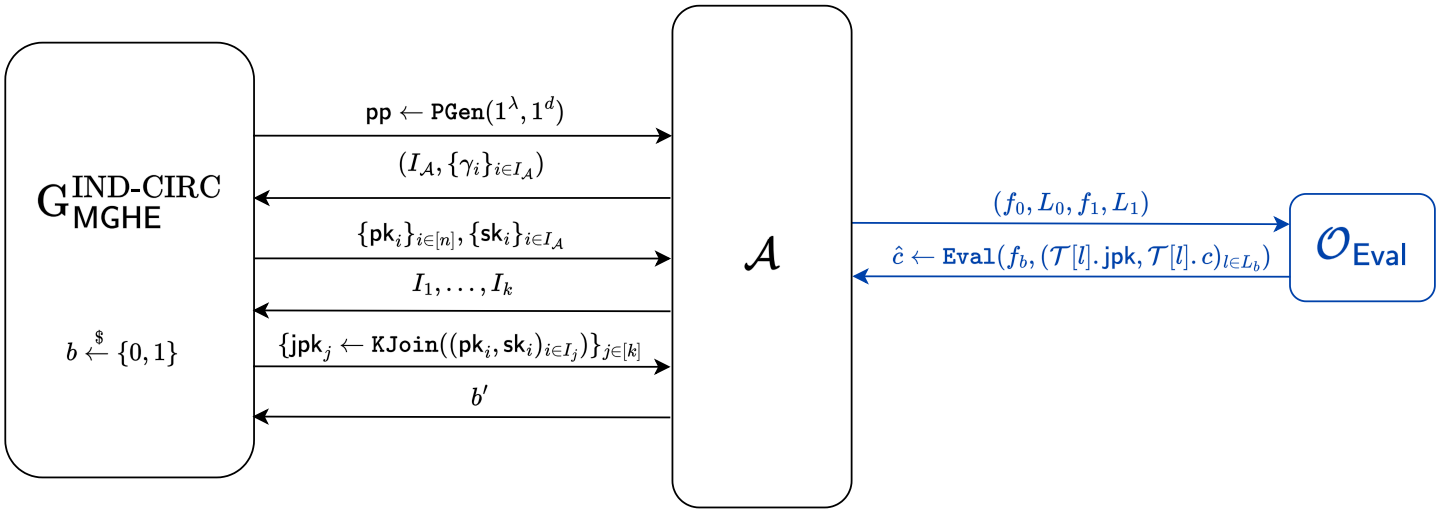

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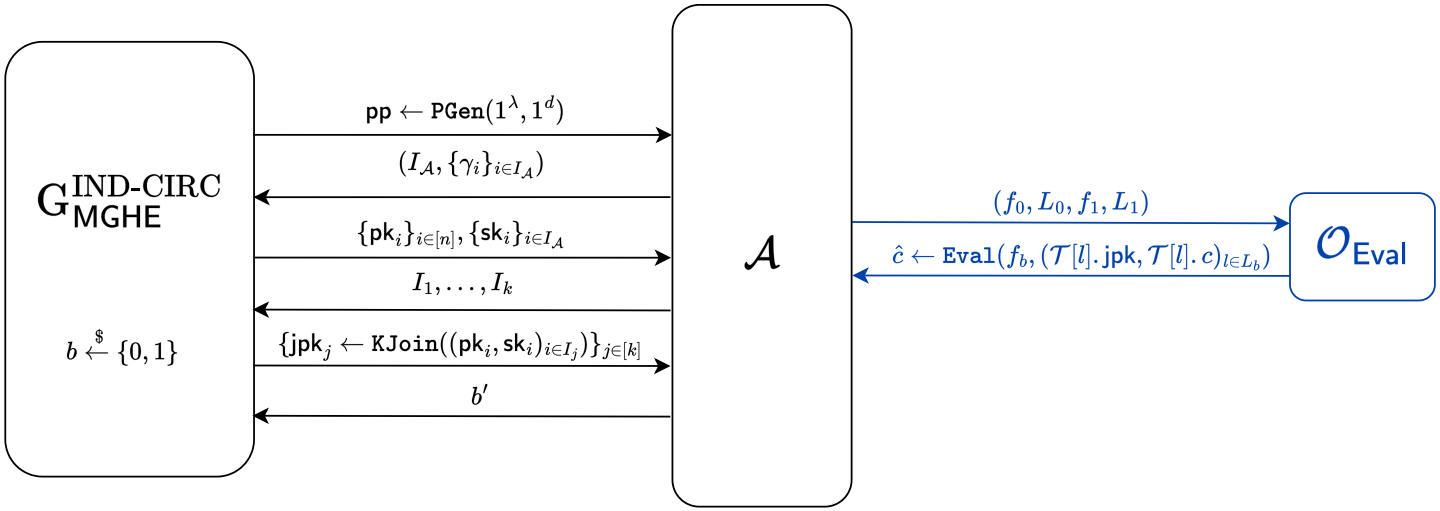

– Challenge with (f_0, L_0, f_1, L_1) instead s.t.

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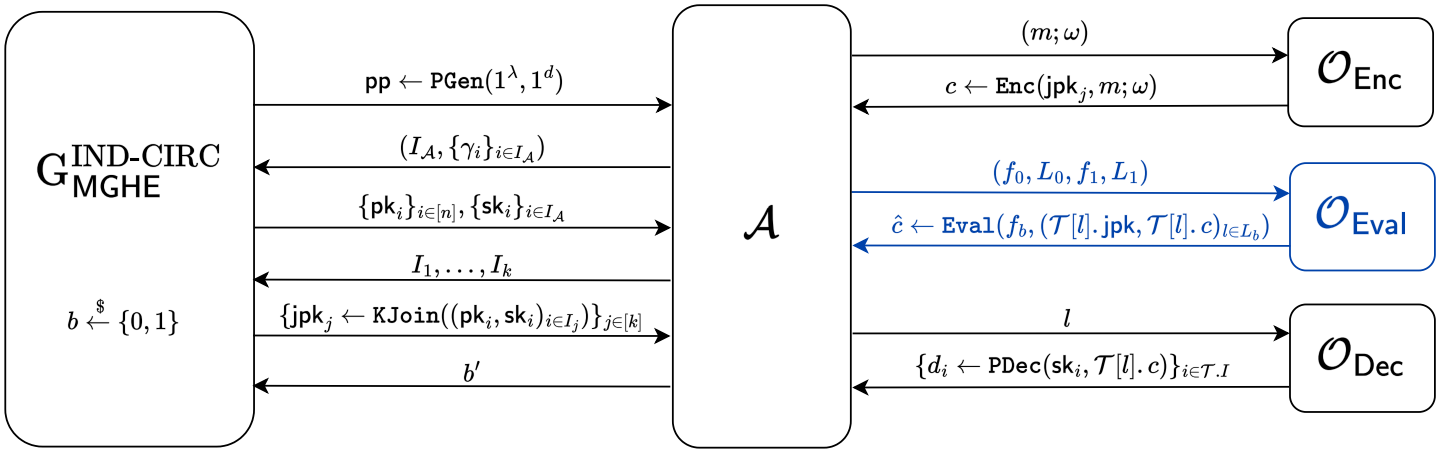

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$$\overset{s}{\approx}$$
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– Security of secret key sk_j of honest client i.e., $j \notin I_{\mathcal{A}}$

Threshold Security: Decryption Consistency

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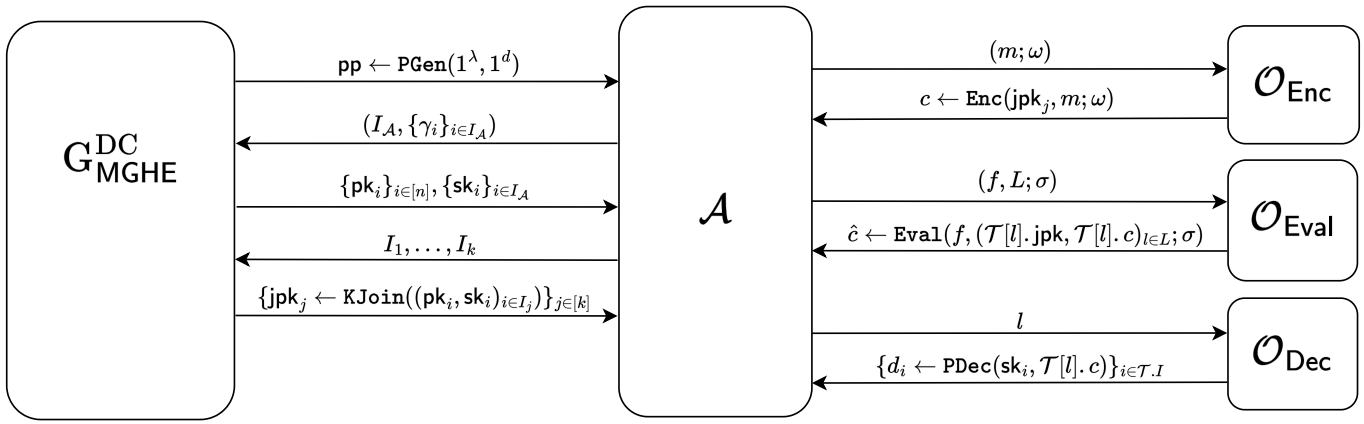

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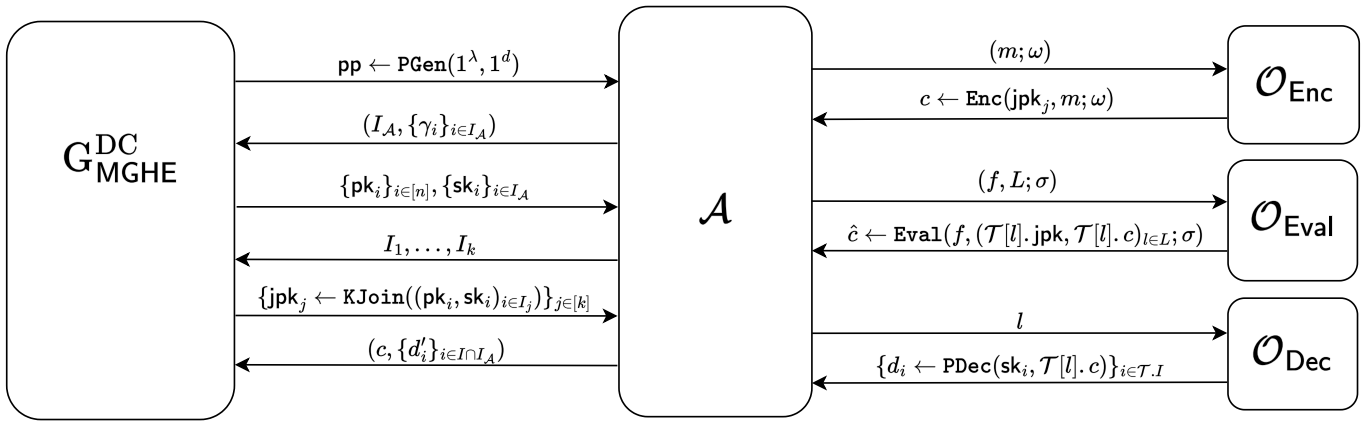

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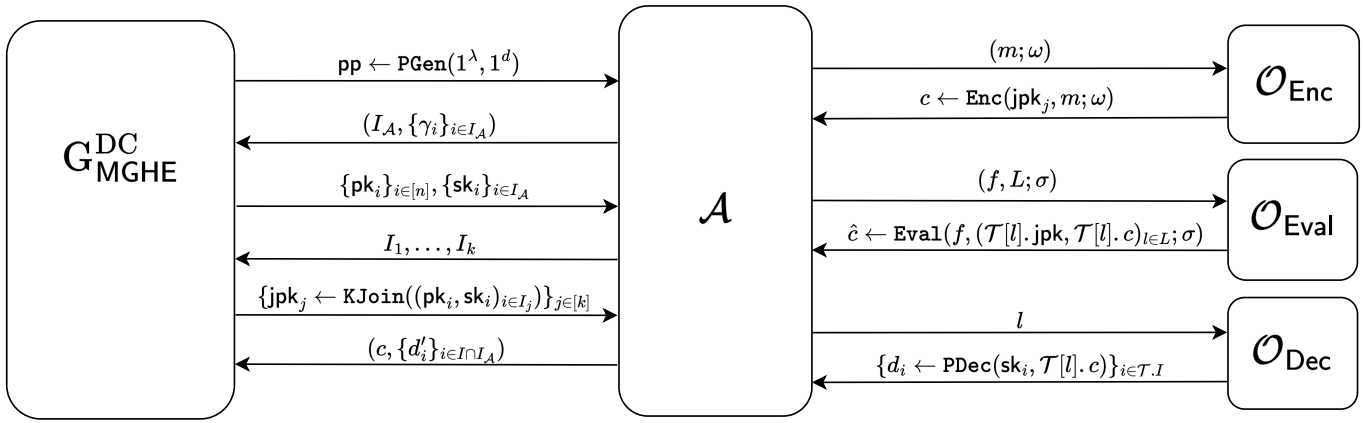


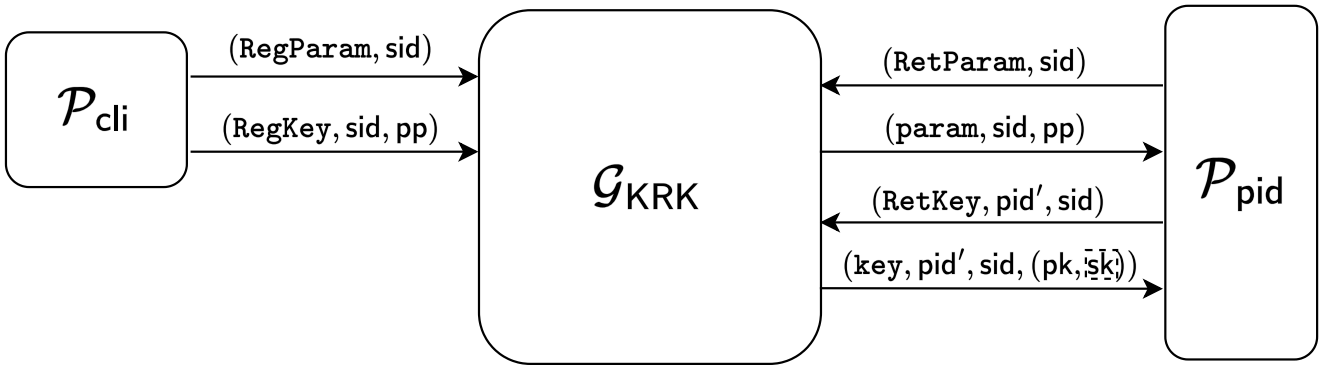
- $\mathcal{A}$ wins if

$$m \neq \mathtt{Combine}(c, \{d_i\}_{i \in I \setminus I_{\mathcal{A}}} \cup \{d'_i\}_{i \in I \cap I_{\mathcal{A}}})$$

UC: Global Key Registry $\mathcal{G}_{\mathsf{KRK}}$

EPFL

– Global subroutine for key management taken from [BCNP04].



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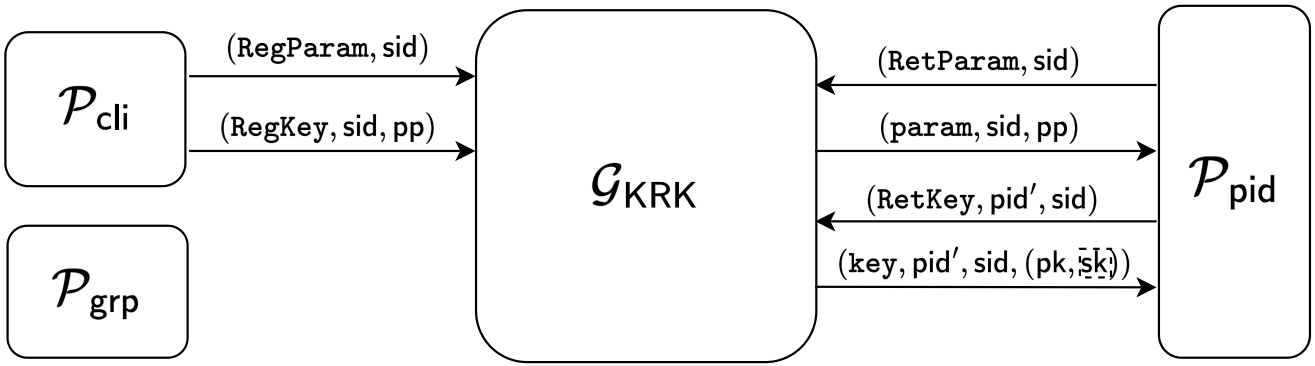

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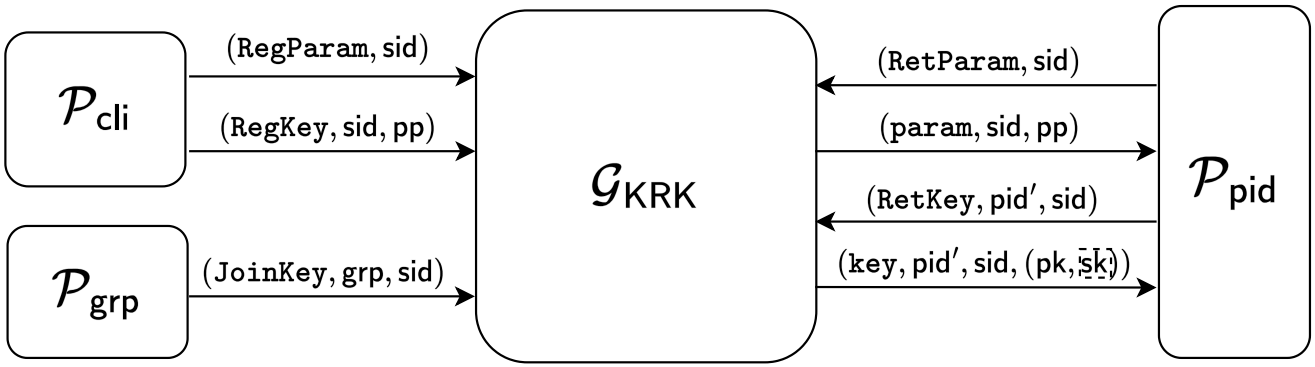
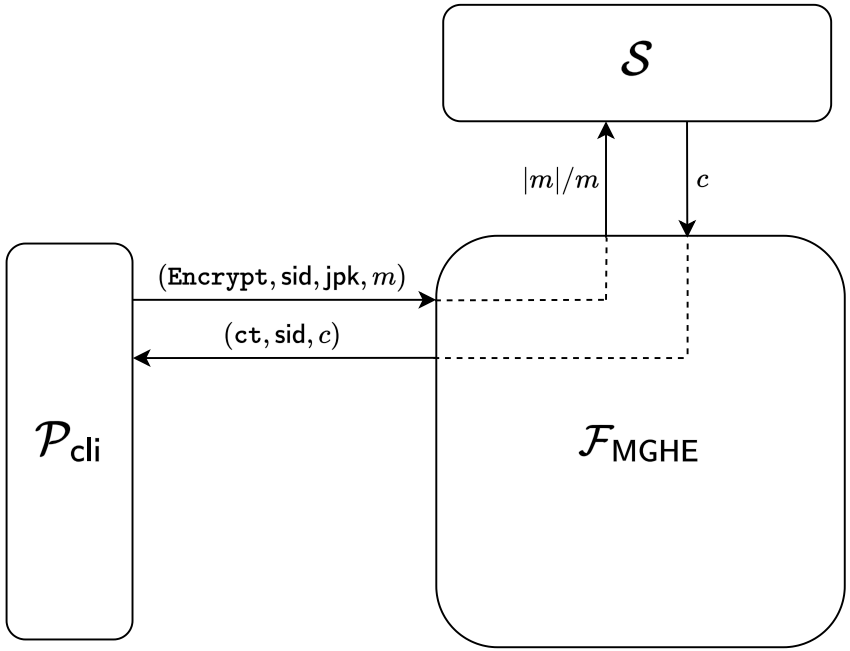
- Key aggregation for groups (equivalent to $\mathcal{F}_{\mathsf{MPC}}$).



UC: Ideal Functionality $\mathcal{F}_{\mathsf{MGHE}}$



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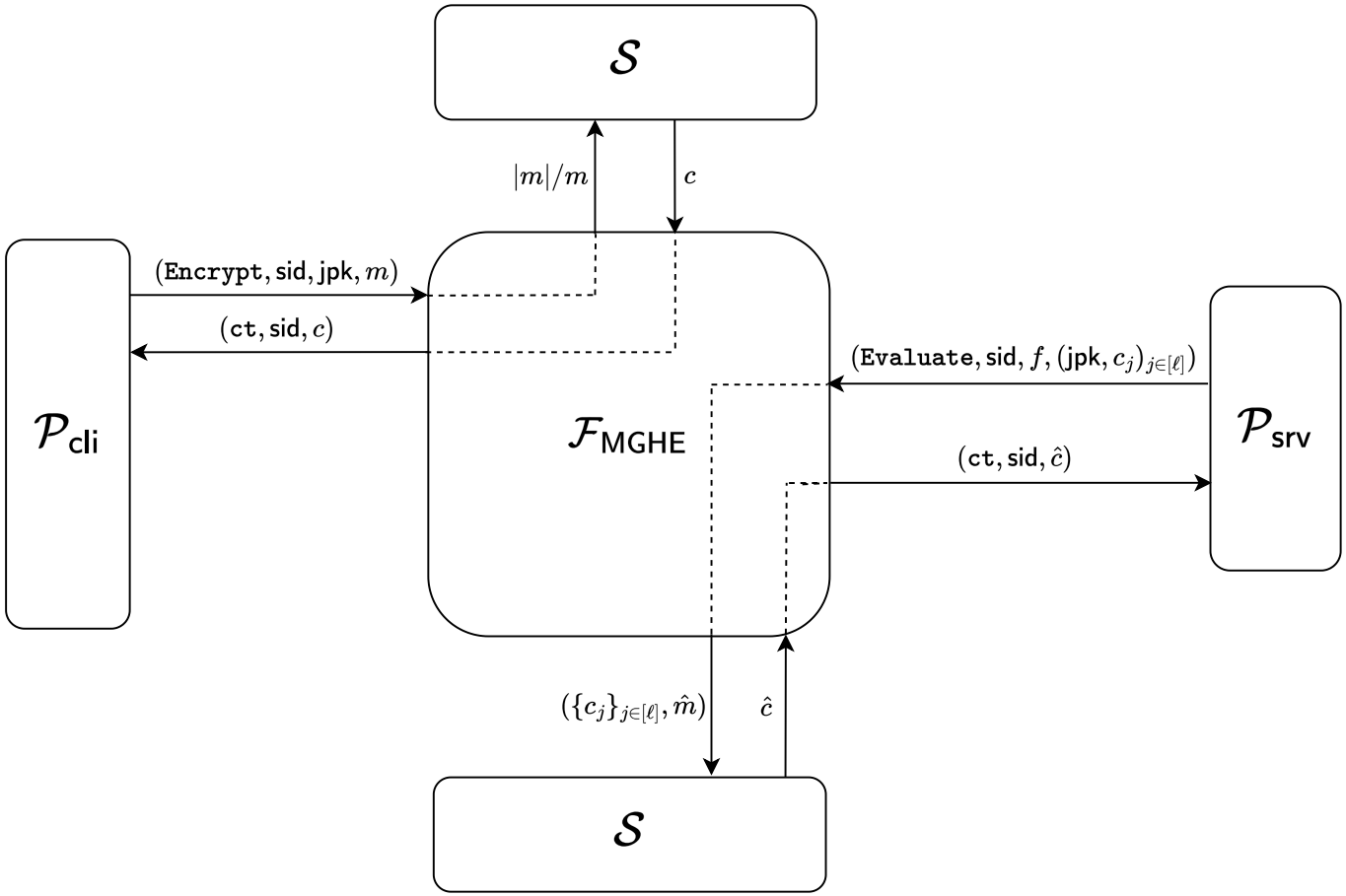

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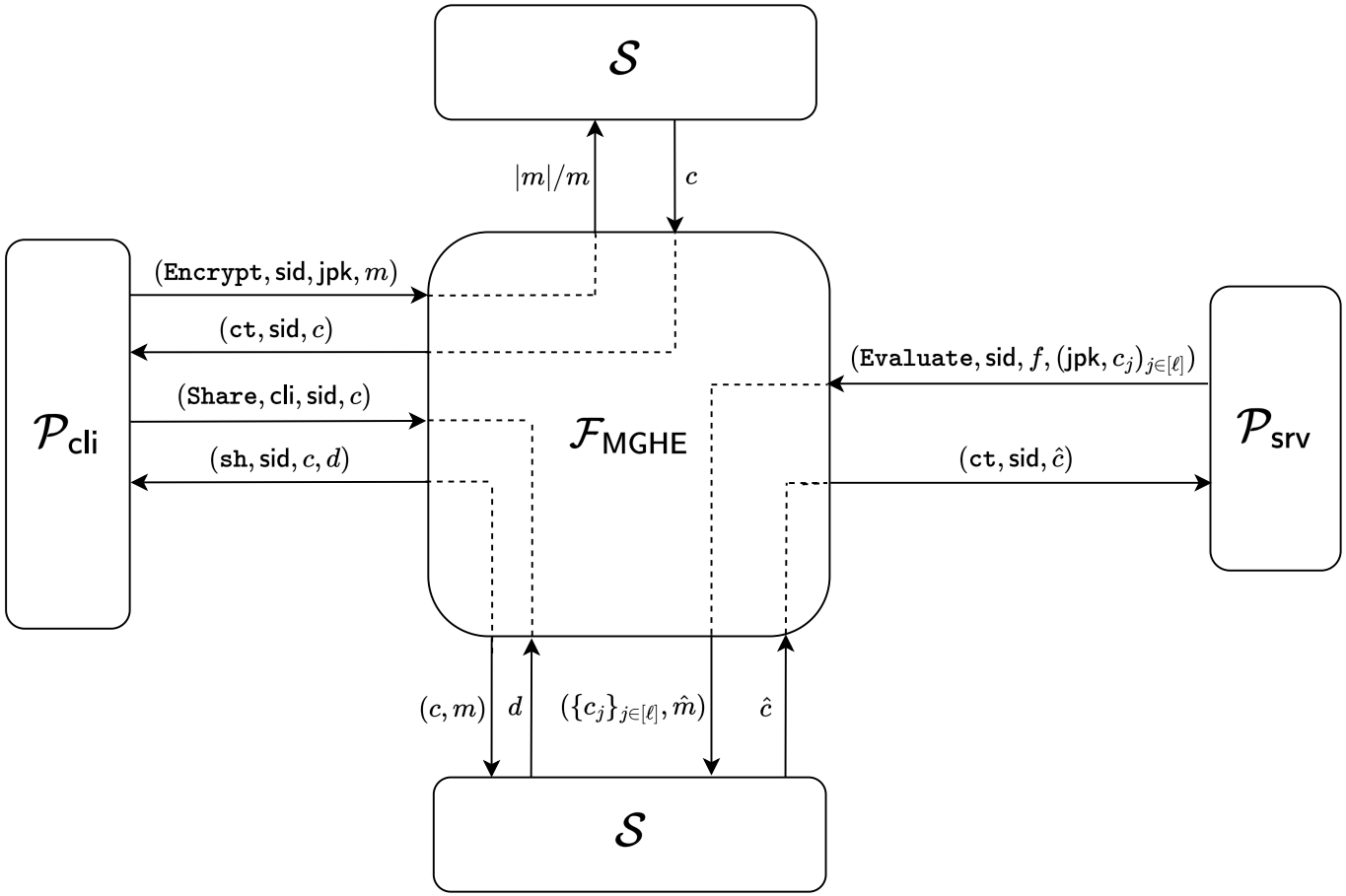

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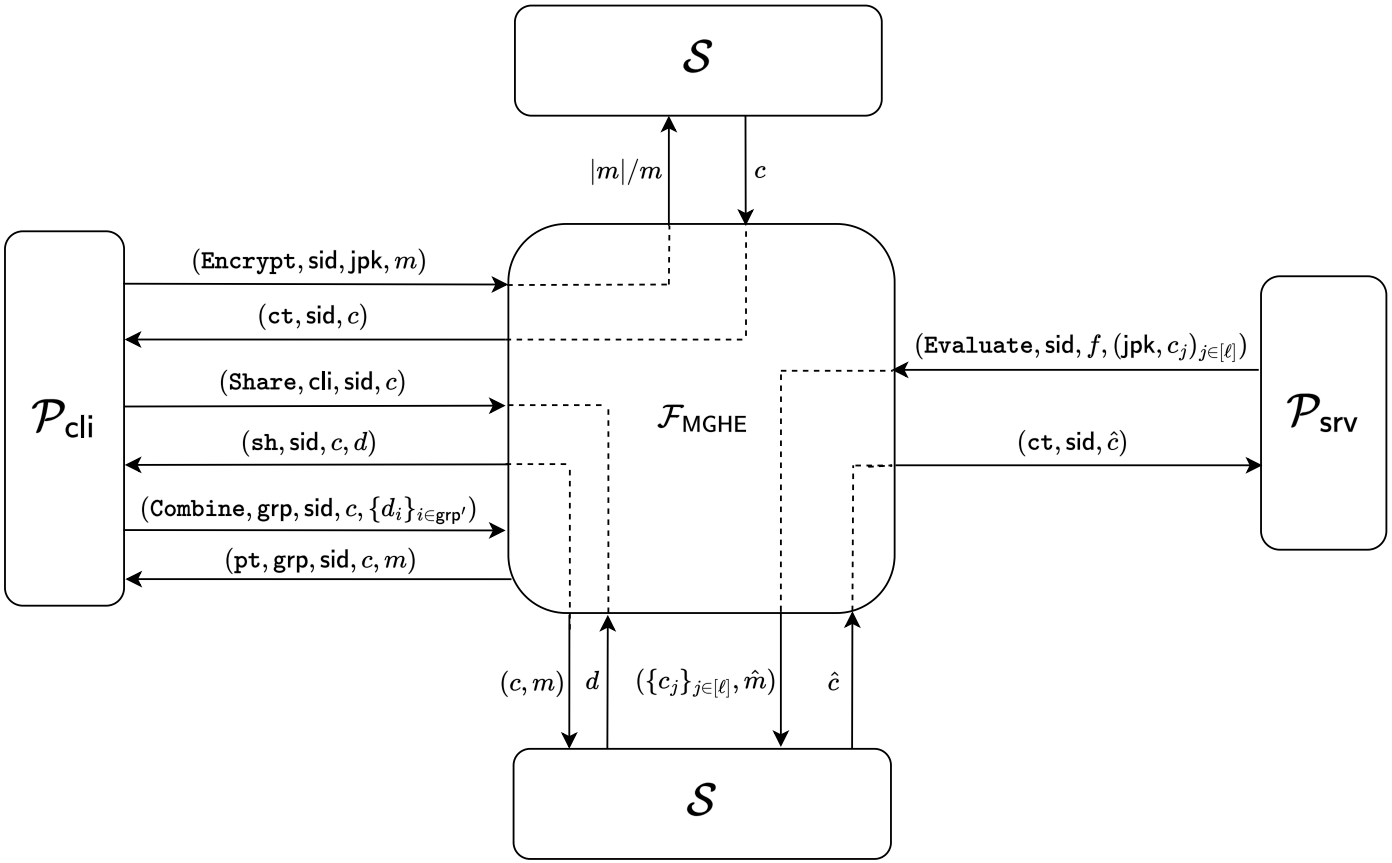


Realization of $\mathcal{F}_{\text{MGHE}}$

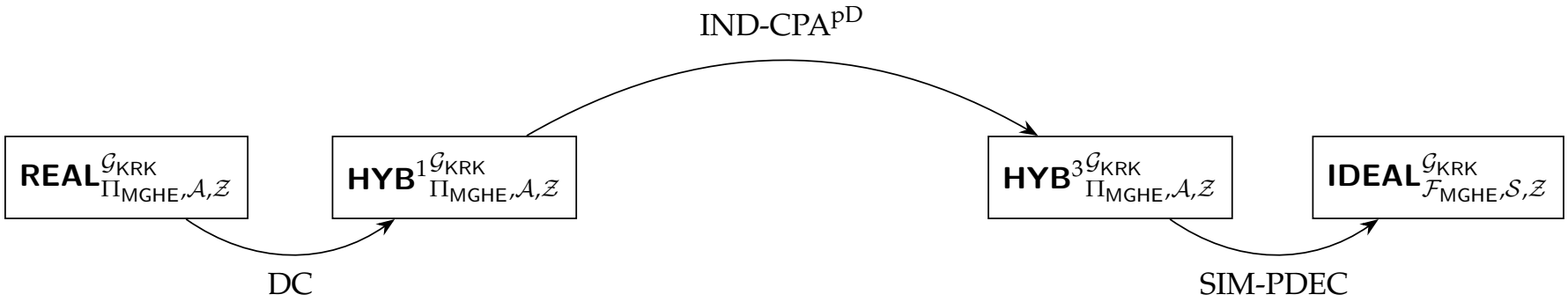
EPFL

Theorem 1

Π_{MGHE} *UC-realizes* $\mathcal{F}_{\text{MGHE}}$ *against a semi-malicious adversary in presence of* $\mathcal{G}_{\text{KRK}}$ *if* MGHE *satisfies decryption consistency* (DC), *is* IND-CPA$^{\text{pD}}$, IND-CIRC (SIM-CIRC), *and* SIM-PDEC *secure under the static corruption of clients in a group up to the threshold and possibly the server.*

Realization of $\mathcal{F}_{\text{MGHE}}$

Both server and clients are corrupted.



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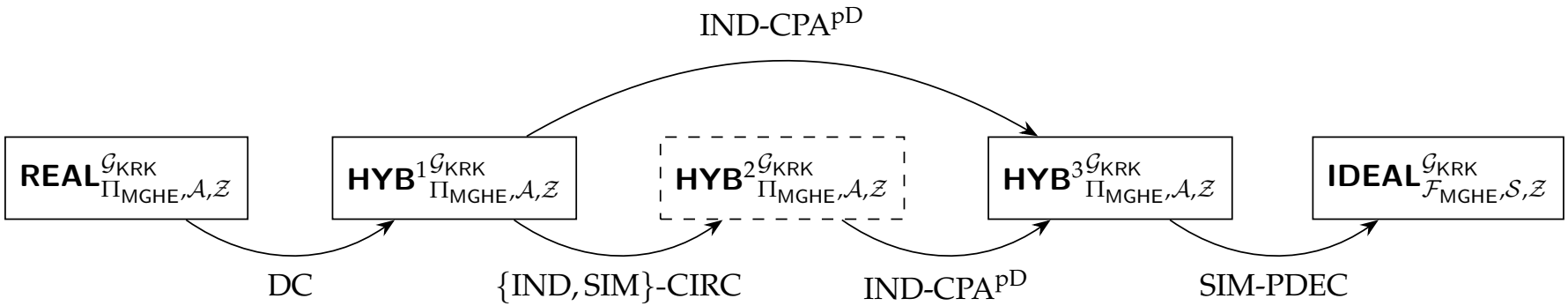

MPC with MGHE

EPFL

- Three-phase protocol

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EPFL

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  - Data Uploading $\Rightarrow$ MGHE.$\mathtt{Enc}(\cdot)$

MPC with MGHE

EPFL

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  - Circuit Evaluation $\Rightarrow$ MGHE.$\texttt{Eval}(\cdot)$

MPC with MGHE

EPFL

- Three-phase protocol
  - Data Uploading $\Rightarrow$ MGHE.$\texttt{Enc}(\cdot)$
  - Circuit Evaluation $\Rightarrow$ MGHE.$\texttt{Eval}(\cdot)$
  - Result Retrieval $\Rightarrow$ MGHE.$\texttt{PDec}(\cdot)$ then MGHE.$\texttt{Combine}(\cdot)$

Integrity via Verifiability

MGHE $\Rightarrow$ MPC against *semi-malicious* adversary

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MGHE $\Rightarrow$ MPC against *semi-malicious* adversary

MGHE + zkSNARK $\Rightarrow$ MPC against *(full) malicious* adversary

zkSNARK in the ROM

EPFL

- UC-secure zkSNARK

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EPFL

– UC-secure zkSNARK

zkSNARK		[CF24]	[BFKT24]	[GKO+23]
NIZK	[Gro06]	[LR22]		[LR22]
	CRS	ROM	ROM-AGM	CRS-ROM

zkSNARK in the ROM

EPFL

– UC-secure zkSNARK

	CRS	ROM	ROM-AGM	CRS-ROM
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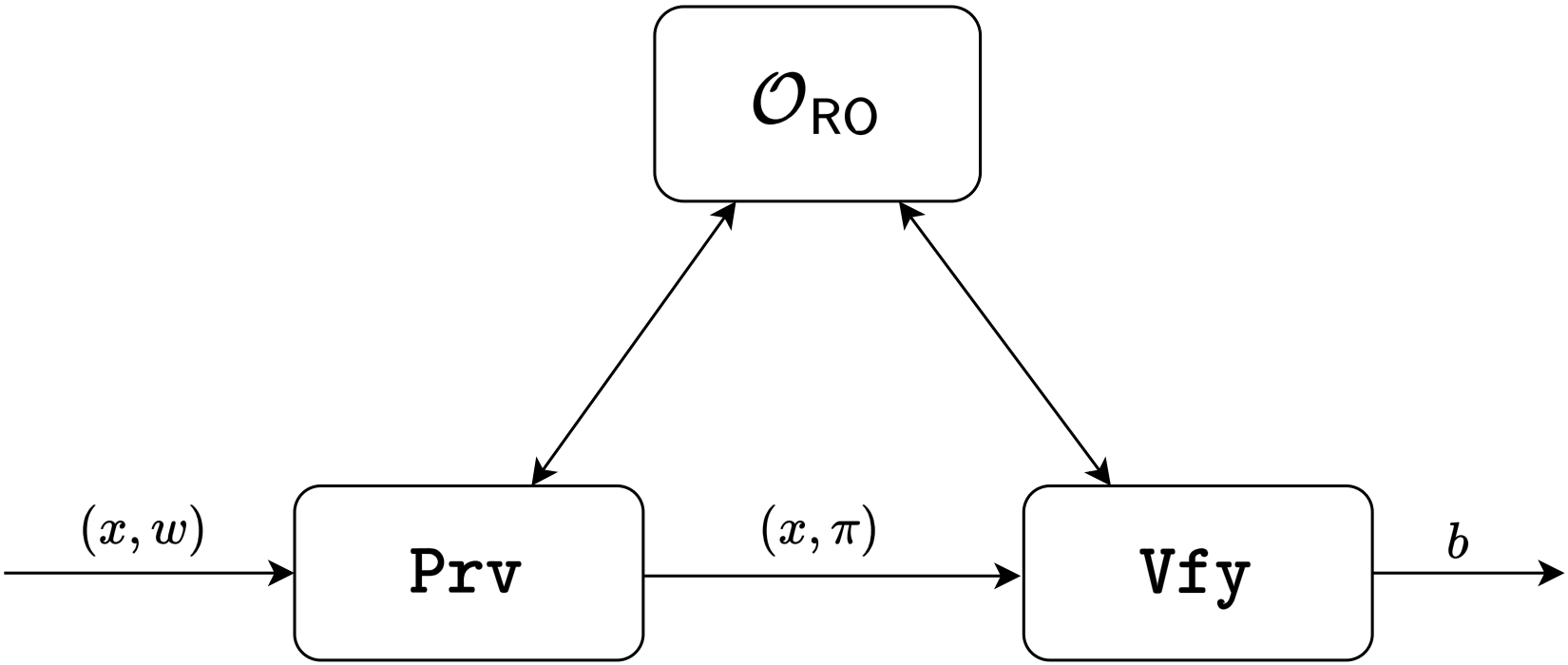

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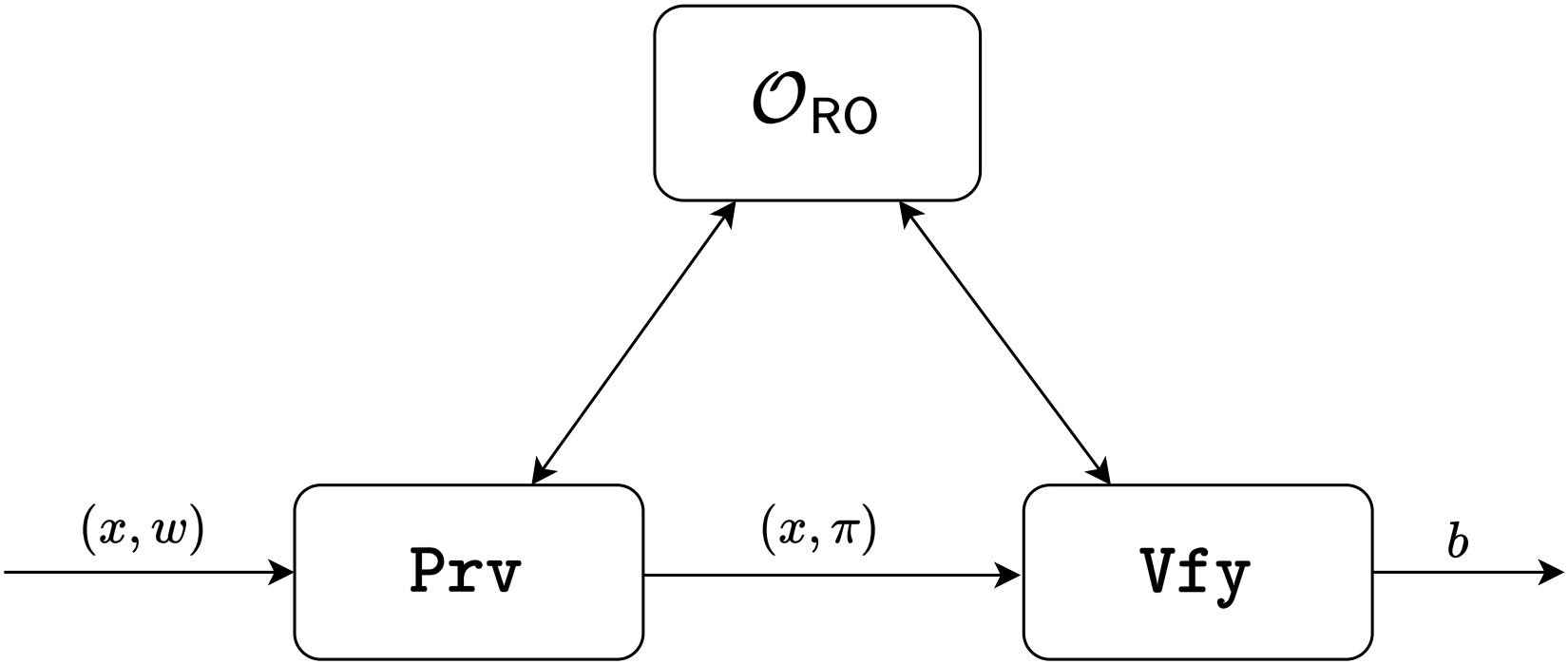


Succinctness: $|\pi| \ll |w|$

Properties of zkSNARK

EPFL

Completeness: Valid arguments must be accepted.

$$\forall (x,w) \in R,\ \Pr\left[\mathtt{Vfy}^{\mathcal{O}_{\mathsf{RO}}}(x,\pi) = 1 \;\middle|\; \begin{array}{l} \mathcal{O}_{\mathsf{RO}} \leftarrow \mathcal{U}(\lambda) \\ \pi \leftarrow \mathtt{Prv}^{\mathcal{O}_{\mathsf{RO}}}(x,w) \end{array}\right] = 1.$$

Properties of zkSNARK

EPFL

Zero-Knowledge: Arguments do not disclose information about witness.

$$\left\{ \mathsf{out} \;\middle|\; \begin{array}{l} \mathcal{O}_{\mathsf{RO}} \leftarrow \mathcal{U}(\lambda) \\ (x, w, \mathsf{aux}) \leftarrow \mathcal{A}^{\mathcal{O}_{\mathsf{RO}}} \\ \pi \leftarrow \mathtt{Prv}^{\mathcal{O}_{\mathsf{RO}}}(x, w) \\ \mathsf{out} \leftarrow \mathcal{A}^{\mathcal{O}_{\mathsf{RO}}}(\mathsf{aux}, \pi) \end{array} \right\} \approx \left\{ \mathsf{out} \;\middle|\; \begin{array}{l} \mathcal{O}_{\mathsf{RO}} \leftarrow \mathcal{U}(\lambda) \\ (x, w, \mathsf{aux}) \leftarrow \mathcal{A}^{\mathcal{O}_{\mathsf{RO}}} \\ (\pi, \mathsf{pg}) \leftarrow \mathtt{Sim}^{\mathcal{O}_{\mathsf{RO}}}(x) \\ \mathsf{out} \leftarrow \mathcal{A}^{\mathcal{O}_{\mathsf{RO}}[\mathsf{pg}]}(\mathsf{aux}, \pi) \end{array} \right\}$$

Properties of zkSNARK

EPFL

Simulation Soundness: Non-malleability of arguments.

$$\Pr\left[\begin{array}{l} |x| \leq n \\ \wedge\, x \notin \mathcal{L}(R) \\ \wedge\, \mathtt{Vfy}^{\mathcal{O}_{\mathsf{RO}}}(x,\pi) = 1 \end{array} \middle| \begin{array}{l} \mathcal{O}_{\mathsf{RO}} \leftarrow \mathcal{U}(\lambda) \\ (x,\pi) \leftarrow \mathcal{A}^{\mathcal{O}_{\mathsf{RO}}}(\mathtt{Sim}) \end{array}\right] \leq \mathsf{negl}.$$

MPC with MGHE + zkSNARK

MGHE + zkSNARK $\Rightarrow$ MPC against *(full) malicious* adversary

Phase 1: Data Uploading

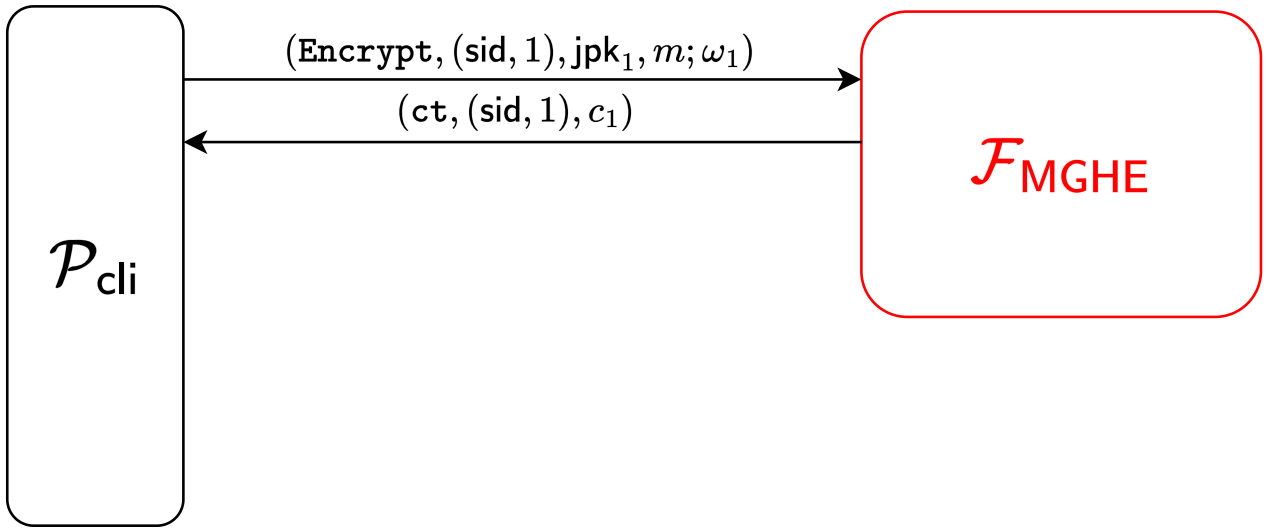
EPFL

- Naor-Yung Double Encryption Paradigm.

Phase 1: Data Uploading

EPFL

– Naor-Yung Double Encryption Paradigm.



Phase 1: Data Uploading

EPFL

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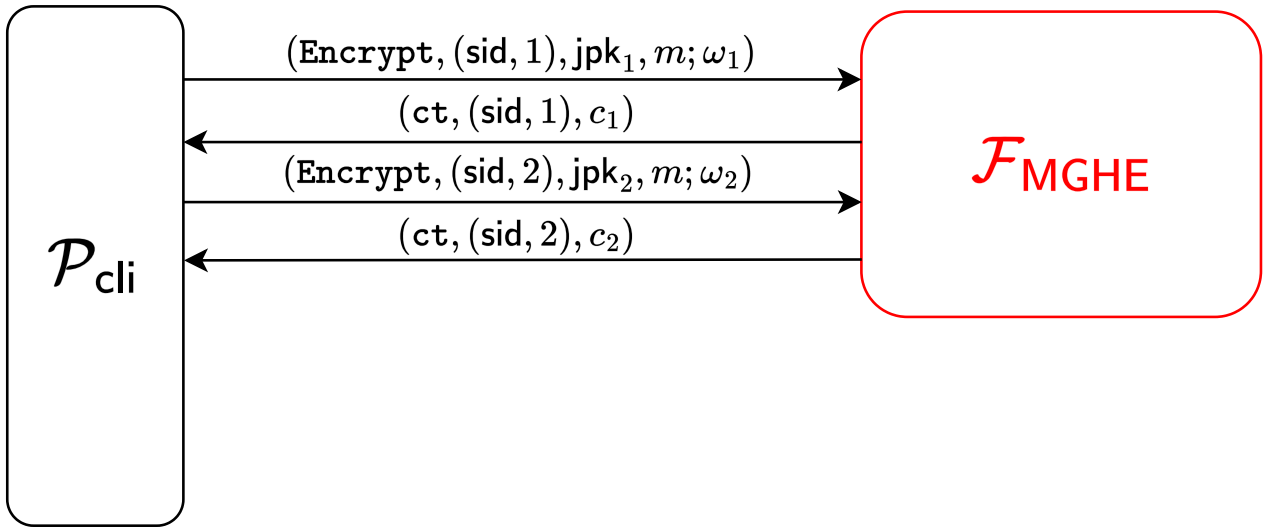

Phase 1: Data Uploading

EPFL

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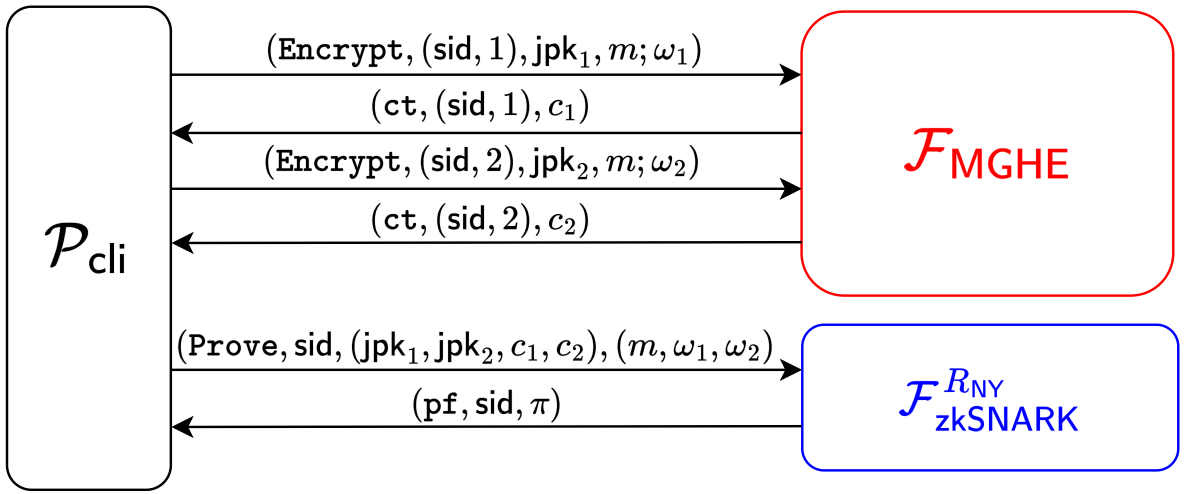
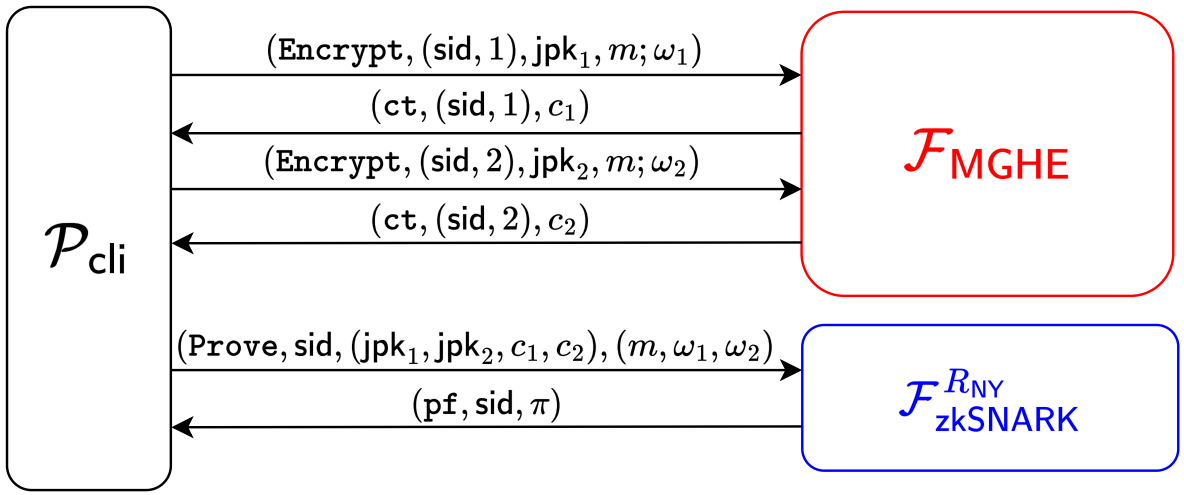


– Naor-Yung Double Encryption Paradigm.



$$R_{\mathsf{NY}} = \left\{ \left(\begin{pmatrix} \mathsf{jpk}_1, c_1, \\ \mathsf{jpk}_2, c_2 \end{pmatrix}, (m, \omega_1, \omega_2) \right) \;\middle|\; \begin{array}{l} c_1 = \mathsf{MGHE.Enc}(\mathsf{jpk}_1, m; \omega_1) \\ \wedge \\ c_2 = \mathsf{MGHE.Enc}(\mathsf{jpk}_2, m; \omega_2) \end{array} \right\}$$

Phase 1: Data Uploading

EPFL

- CCA1-secure HE as in [LMSV12, BSW12, CRRV17].

Phase 1: Data Uploading

EPFL

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  - Tampering with c_1 or $c_2 \Rightarrow$ Verification fails.

Phase 1: Data Uploading

EPFL

- CCA1-secure HE as in [LMSV12, BSW12, CRRV17].
  - Tampering c_1 or $c_2 \Rightarrow$ Verification fails.
  - Must know m to generate valid ciphertext tuple.

Phase 1: Data Uploading

Naor-Yung + Simulation Soundness

Phase 1: Data Uploading

Naor-Yung + Simulation Soundness

or

One-Pass + Simulation Extractability

Phase 1: Data Uploading

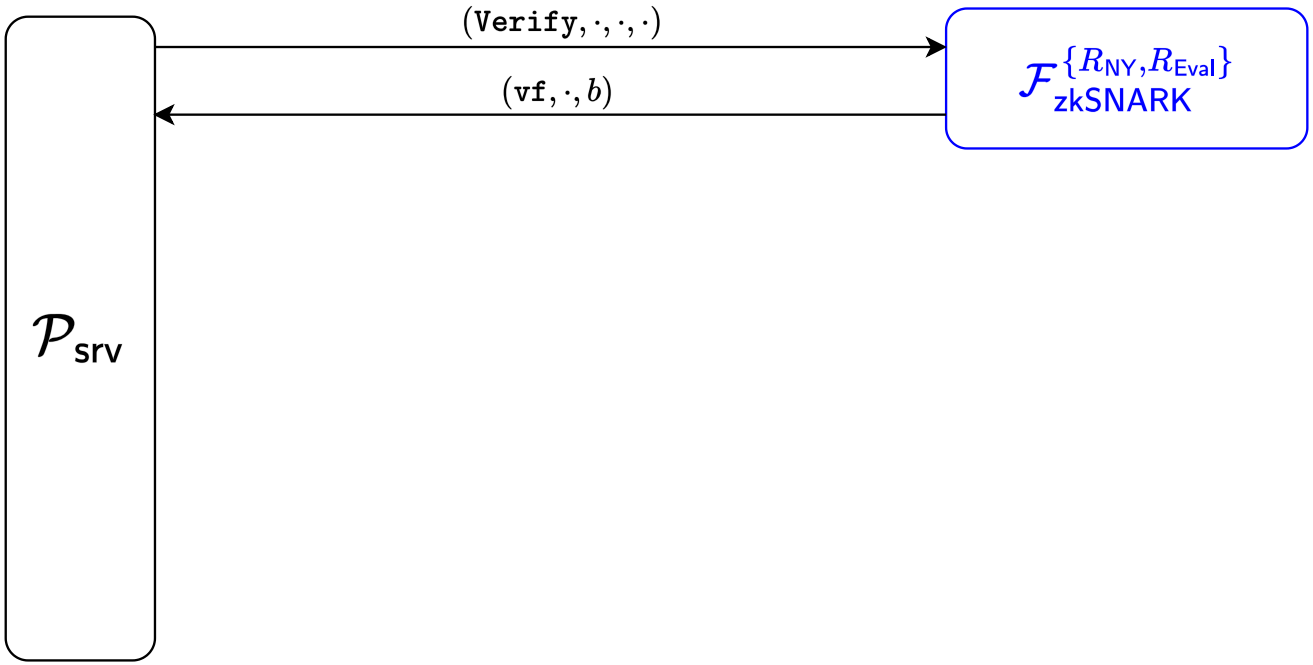
Naor-Yung + Simulation Soundness

or

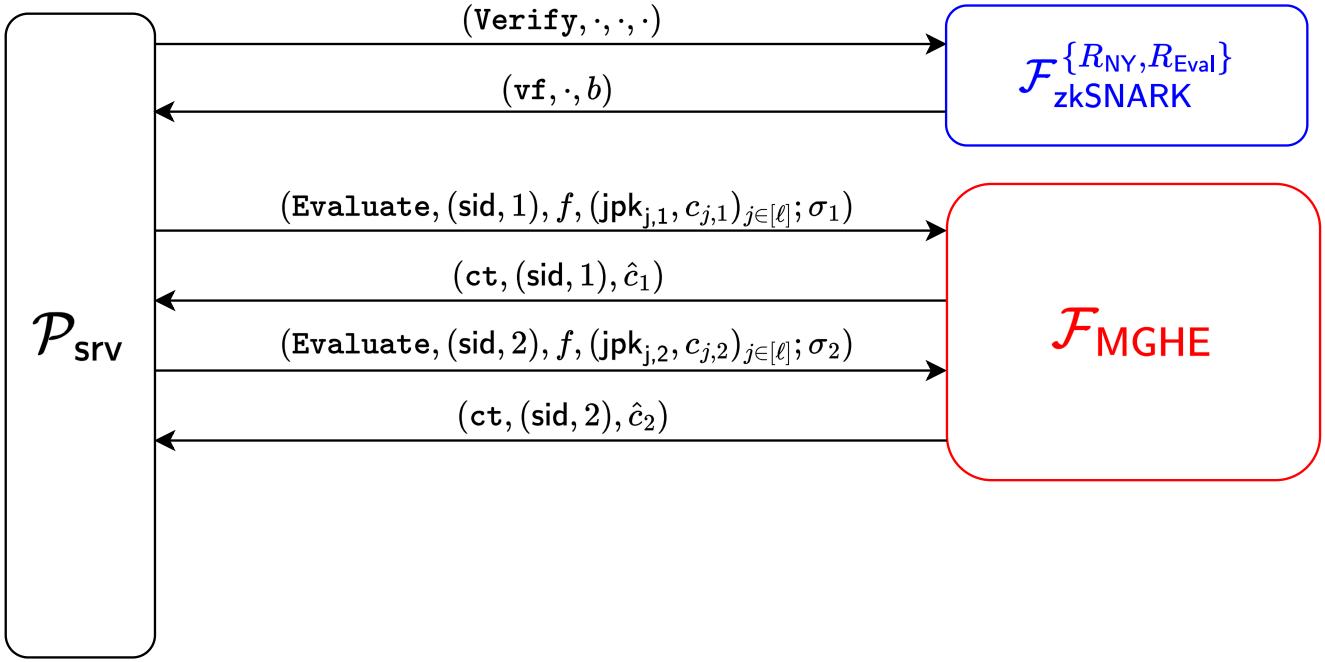
One-Pass + Simulation Extractability

$$R_{\mathsf{NY}} = \{(\mathsf{jpk}, c), (m, \omega)) \quad c = \mathsf{MGHE.Enc}(\mathsf{jpk}, m; \omega)\}$$

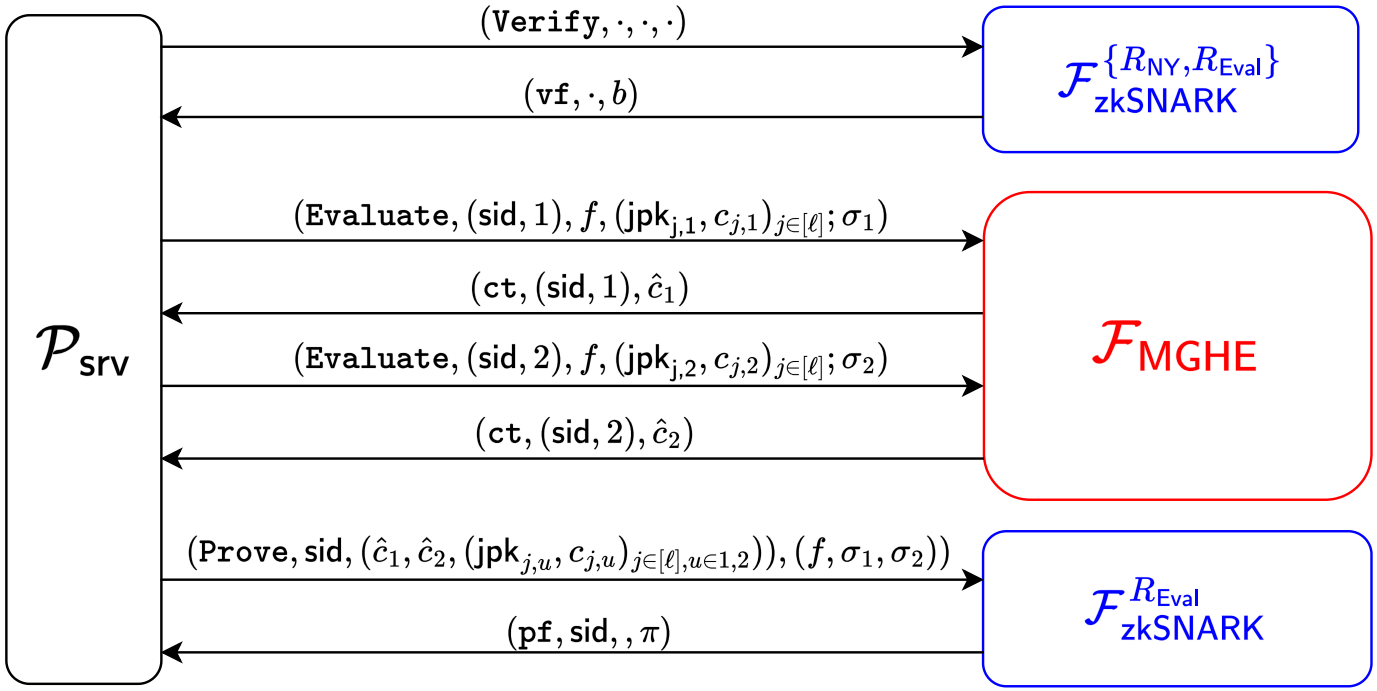
Phase 2: Circuit Evaluation



Phase 2: Circuit Evaluation



Phase 2: Circuit Evaluation

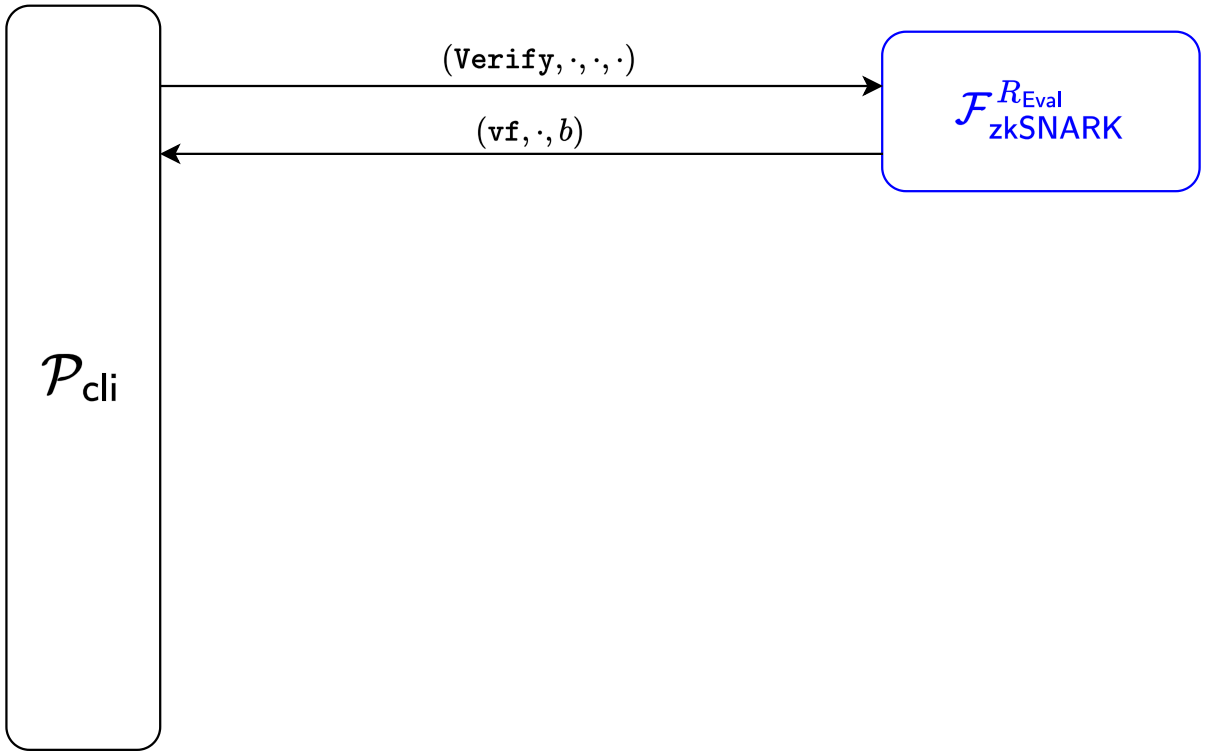


Phase 2: Circuit Evaluation

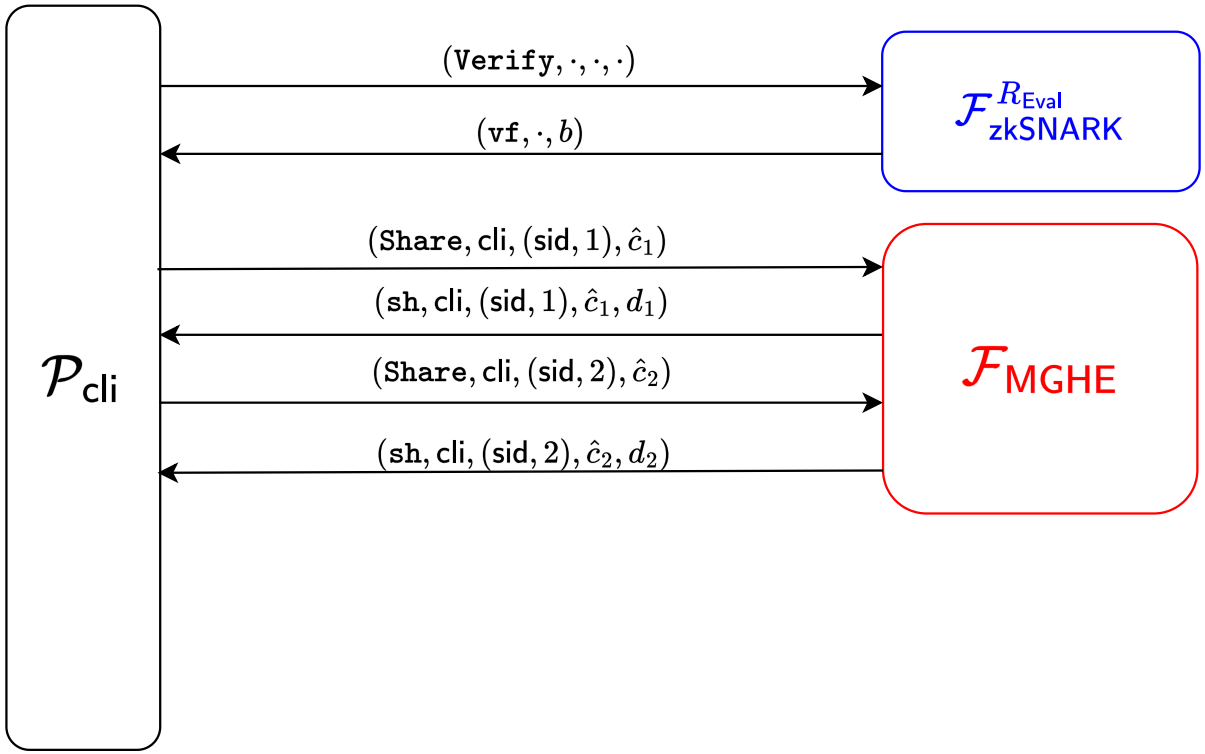
EPFL

$$R_{\mathsf{Eval}} = \left\{ \left(\begin{pmatrix} \hat{c}_1, (\mathsf{jpk}_{j,1}, c_{j,1})_{j\in[\ell]}, \\ \hat{c}_2, (\mathsf{jpk}_{j,2}, c_{j,2})_{j\in[\ell]} \end{pmatrix}, (f, \sigma_1, \sigma_2) \right) \;\middle|\; \begin{array}{l} \hat{c}_1 = \mathsf{MGHE.Eval}(f, (\mathsf{jpk}_{j,1}, c_{j,1})_{j\in[\ell]}; \sigma_1) \\ \wedge \\ \hat{c}_2 = \mathsf{MGHE.Eval}(f, (\mathsf{jpk}_{j,2}, c_{j,2})_{j\in[\ell]}; \sigma_2) \end{array} \right\}.$$

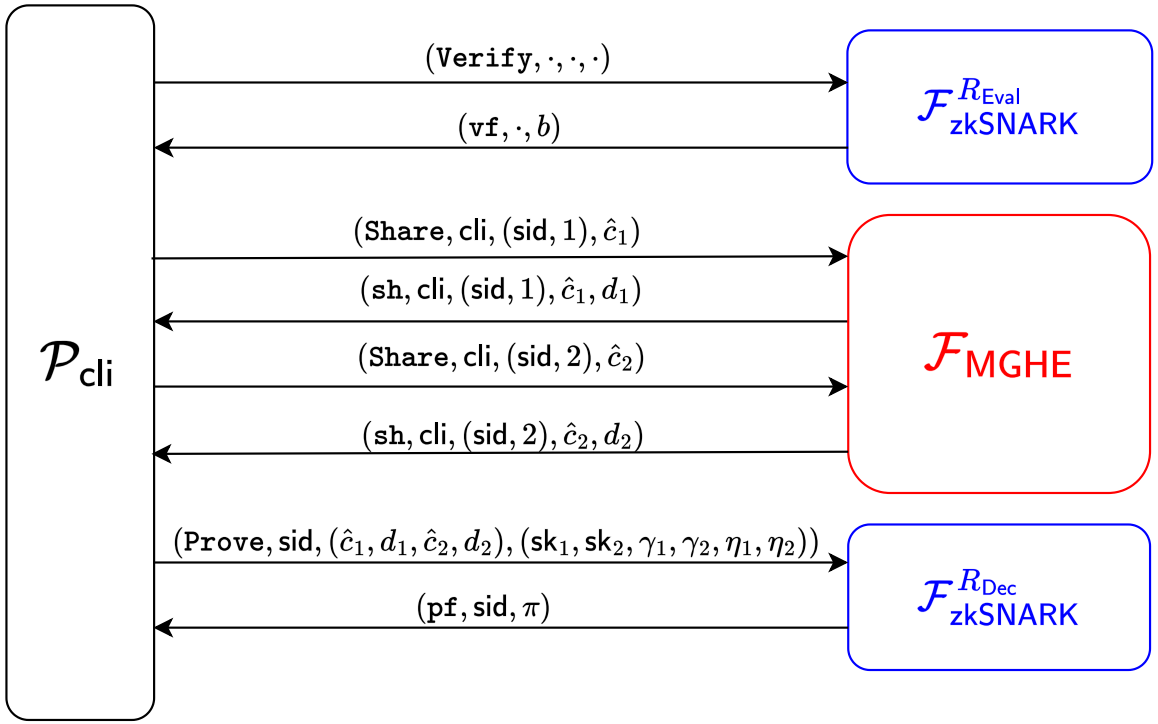
Phase 3: Result Retrieval - Partial Decryption



Phase 3: Result Retrieval - Partial Decryption

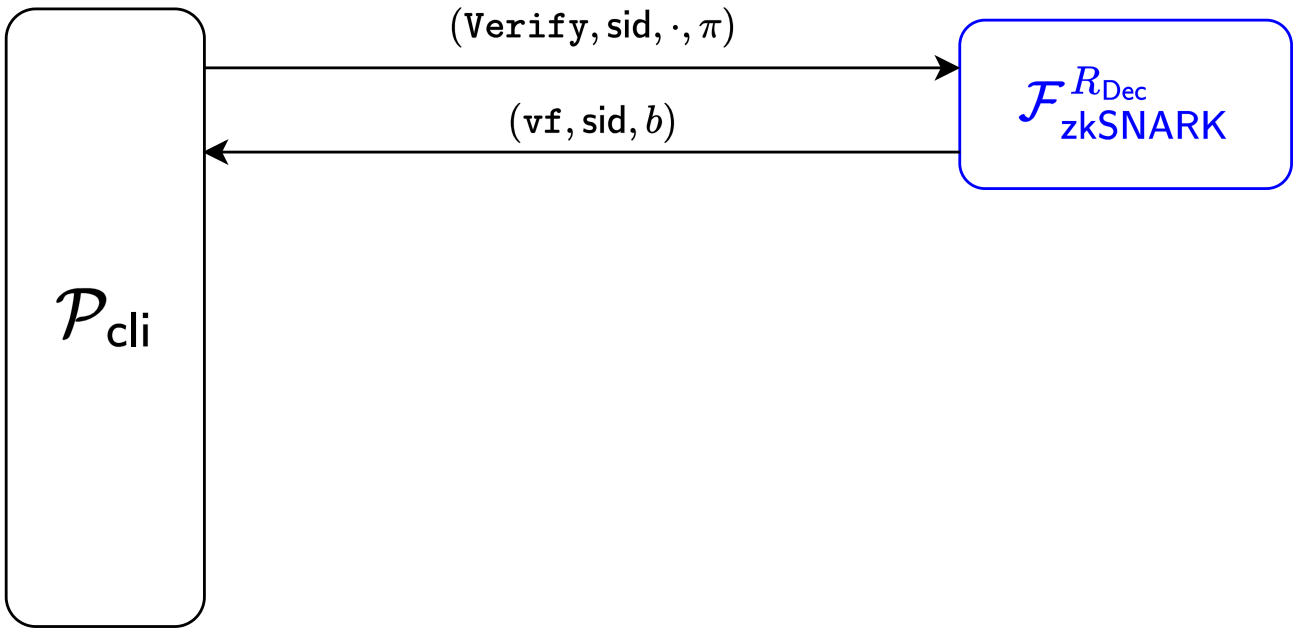


Phase 3: Result Retrieval - Partial Decryption

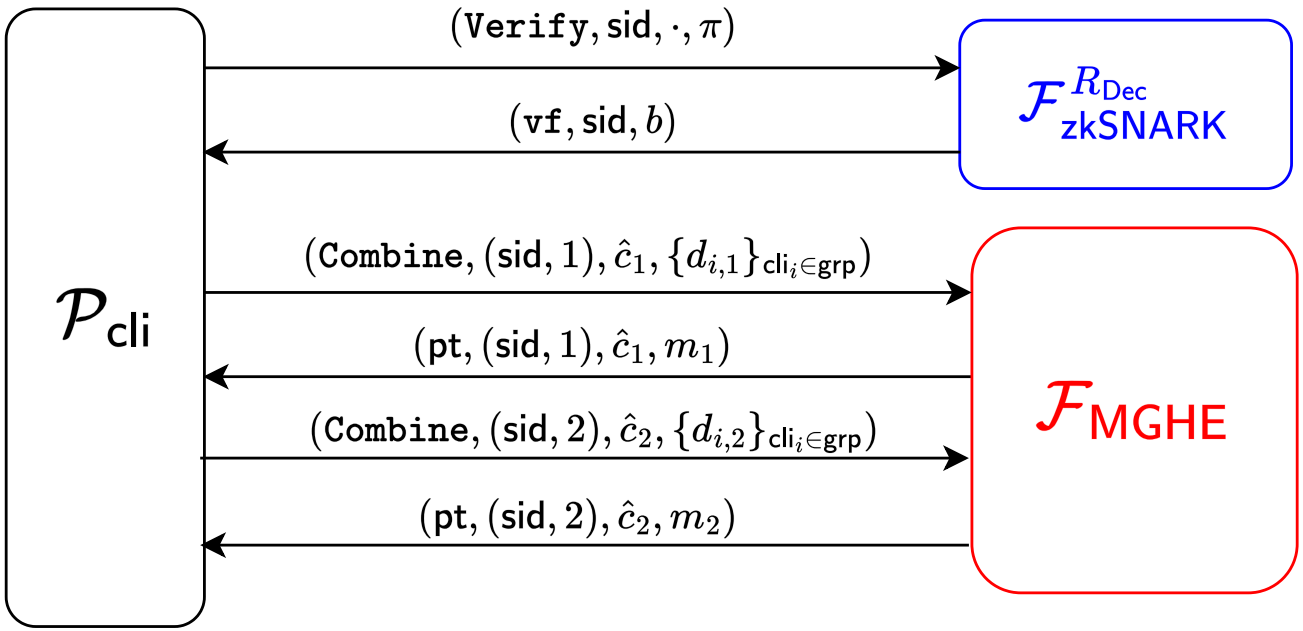


$$R_{\mathsf{Dec}} = \left\{ \begin{pmatrix} \mathsf{pp}_1, \mathsf{pk}_1, c_1, d_1, \\ \mathsf{pp}_2, \mathsf{pk}_2, c_2, d_2 \end{pmatrix}, \begin{pmatrix} \mathsf{sk}_1, \gamma_1, \eta_1 \\ \mathsf{sk}_2, \gamma_2, \eta_2 \end{pmatrix} \middle| \begin{array}{l} \forall u \in \{1,2\} : \\ \quad d_u = \mathsf{MGHE.PDec}(\mathsf{sk}_u, c_u; \eta_u) \\ \quad \wedge\, \mathsf{pk}_u = \mathsf{PKGen}(\mathsf{pp}_u, \mathsf{sk}_u; \gamma_u) \end{array} \right\}.$$

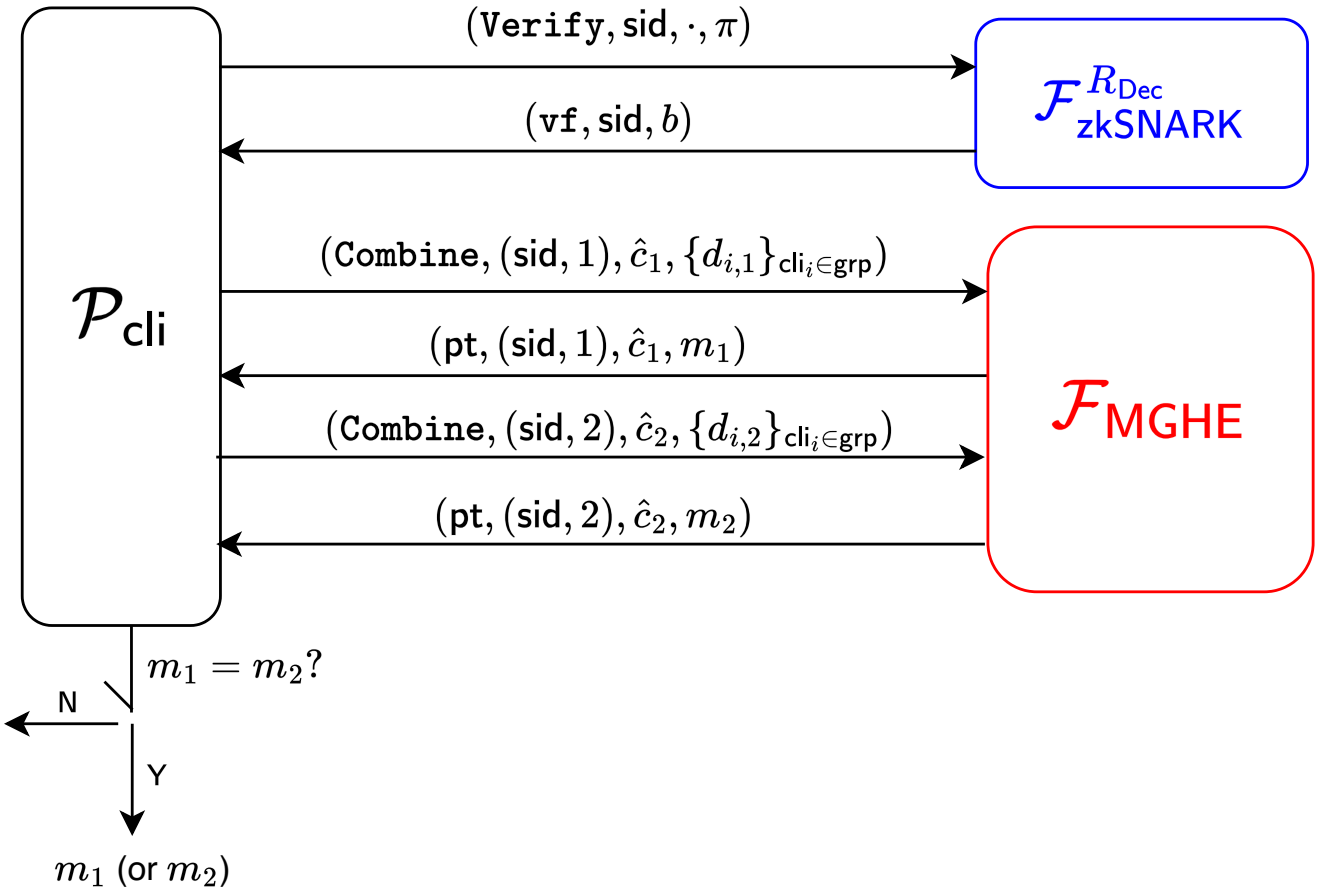
Phase 3: Result Retrieval - Reconstruction



Phase 3: Result Retrieval - Reconstruction



Phase 3: Result Retrieval - Reconstruction



Realization of On-the-Fly MPC

EPFL

Theorem 2

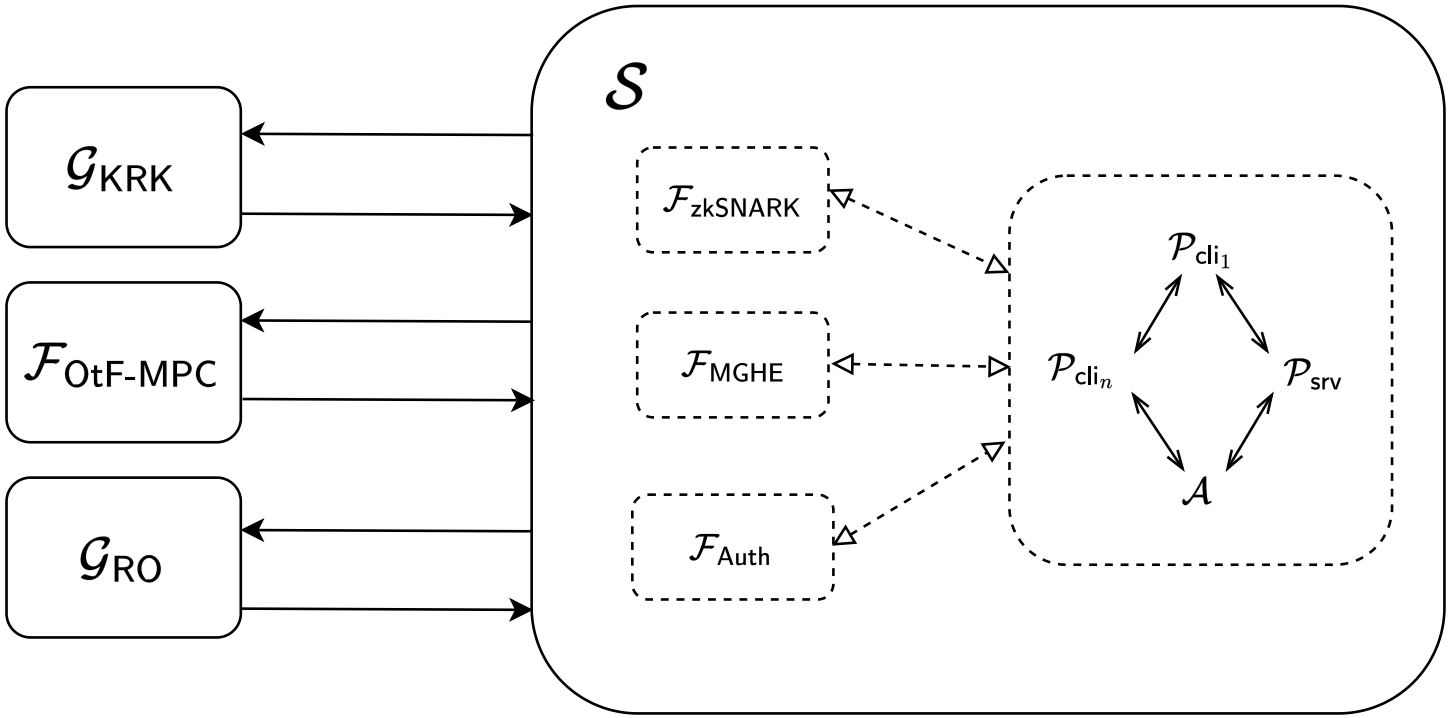
$\Pi_{\text{OtF-MPC}}$ *UC-realizes* $\mathcal{F}_{\text{OtF-MPC}}$ *in* $[\mathcal{F}_{\text{MGHE}}, \mathcal{F}_{\text{zkSNARK}}, \mathcal{F}_{\text{Aut}}]$*-hybrid model in presence of* $\mathcal{G}_{\text{KRK}}$ *and* $\mathcal{G}_{\text{RO}}$.

Realization of On-the-Fly MPC

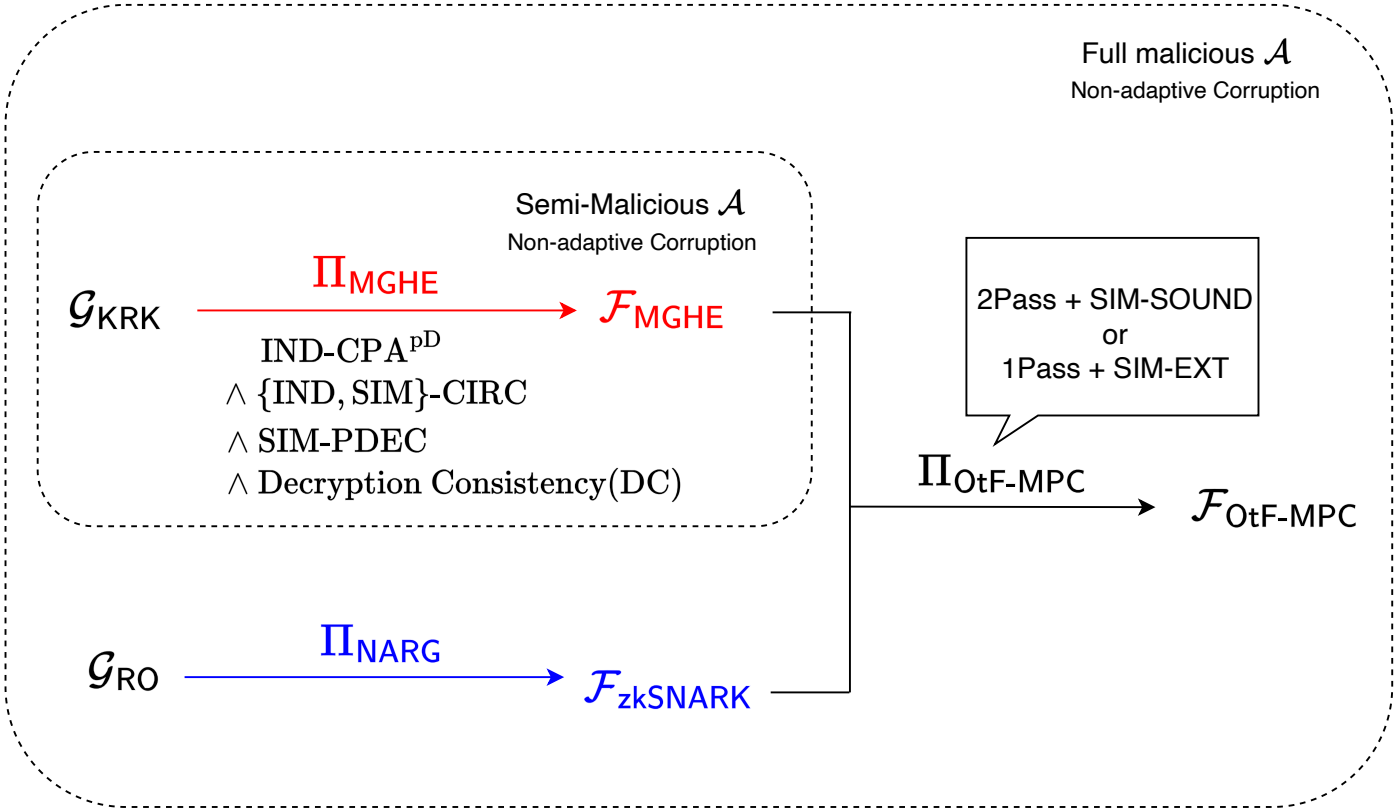
EPFL

Theorem 2

$\Pi_{\text{OtF-MPC}}$ UC-realizes $\mathcal{F}_{\text{OtF-MPC}}$ in $[\mathcal{F}_{\text{MGHE}}, \mathcal{F}_{\text{zkSNARK}}, \mathcal{F}_{\text{Aut}}]$-hybrid model in presence of $\mathcal{G}_{\text{KRK}}$ and $\mathcal{G}_{\text{RO}}$.

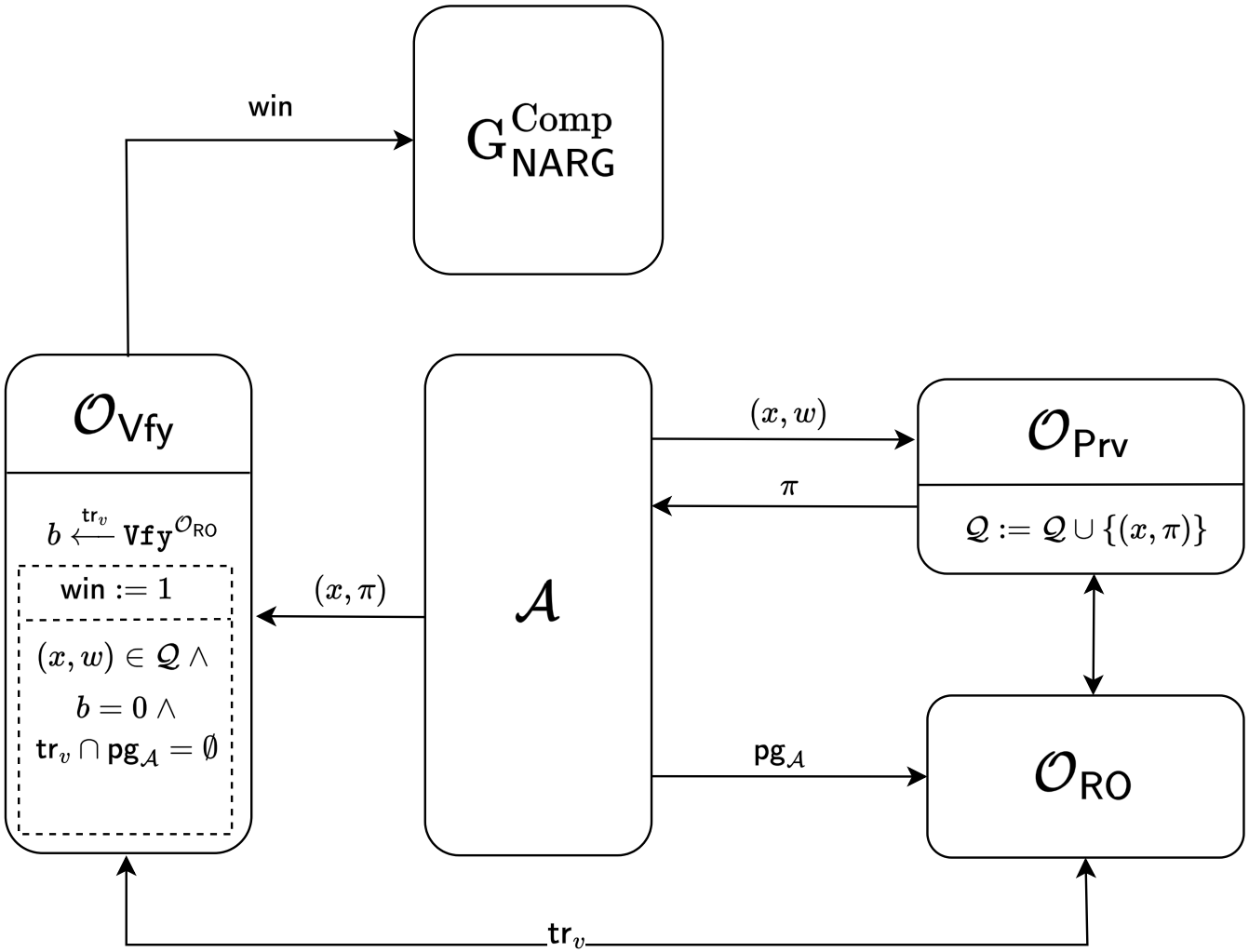


Conclusion


Full malicious $\mathcal{A}$
Non-adaptive Corruption
Semi-Malicious $\mathcal{A}$
Non-adaptive Corruption
$\mathcal{G}_{\mathsf{KRK}}$
Π_{MGHE}
$\mathcal{F}_{\mathsf{MGHE}}$
$\mathrm{IND\text{-}CPA}^{\mathrm{pD}}$
$\wedge$ {IND, SIM}-CIRC
$\wedge$ SIM-PDEC
$\wedge$ Decryption Consistency(DC)
2Pass + SIM-SOUND
or
1Pass + SIM-EXT
$\Pi_{\mathsf{OtF\text{-}MPC}}$
$\mathcal{F}_{\mathsf{OtF\text{-}MPC}}$
$\mathcal{G}_{\mathsf{RO}}$
Π_{NARG}
$\mathcal{F}_{\mathsf{zkSNARK}}$

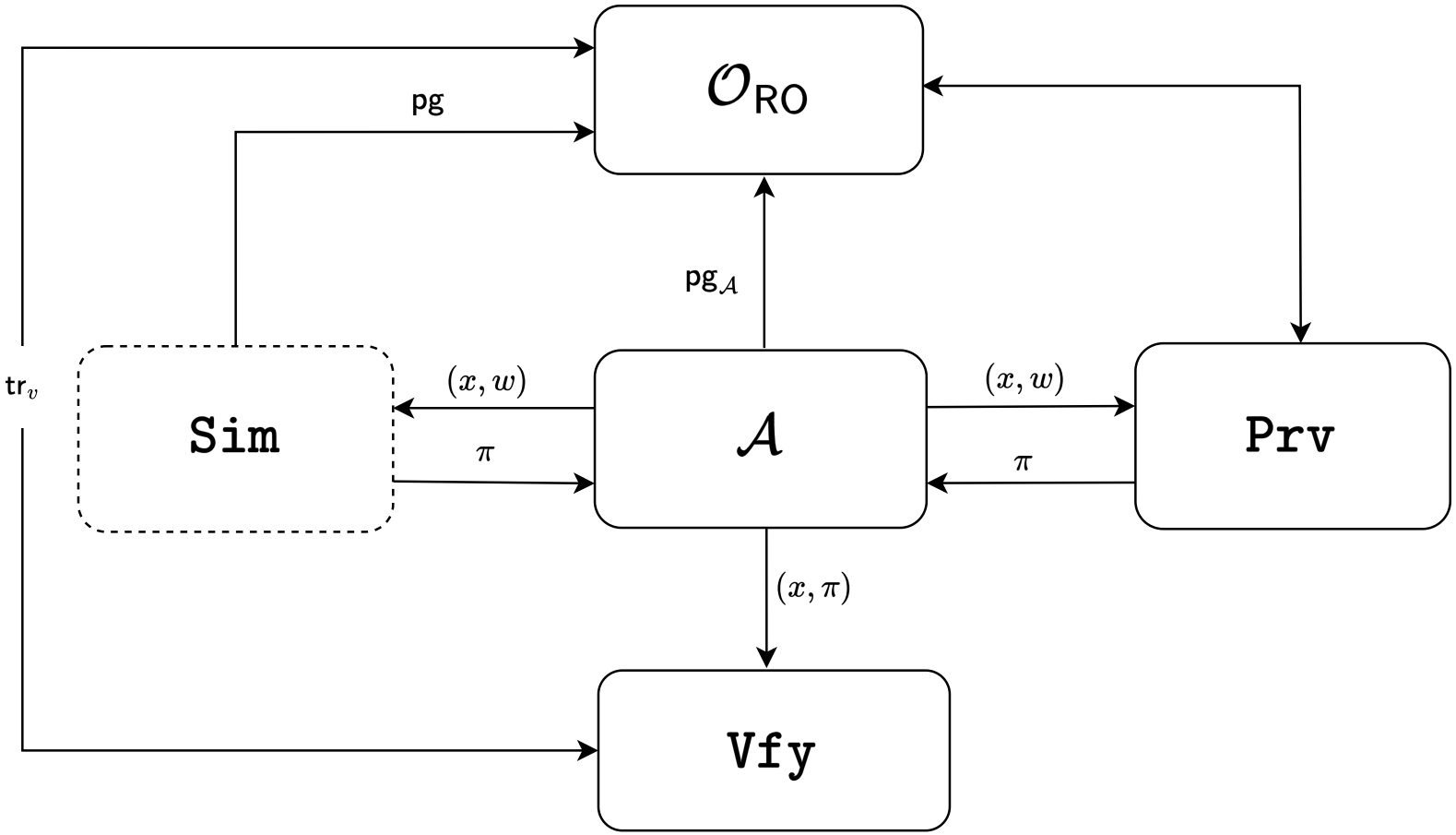
Appendix: Completeness

– Valid arguments must be accepted.



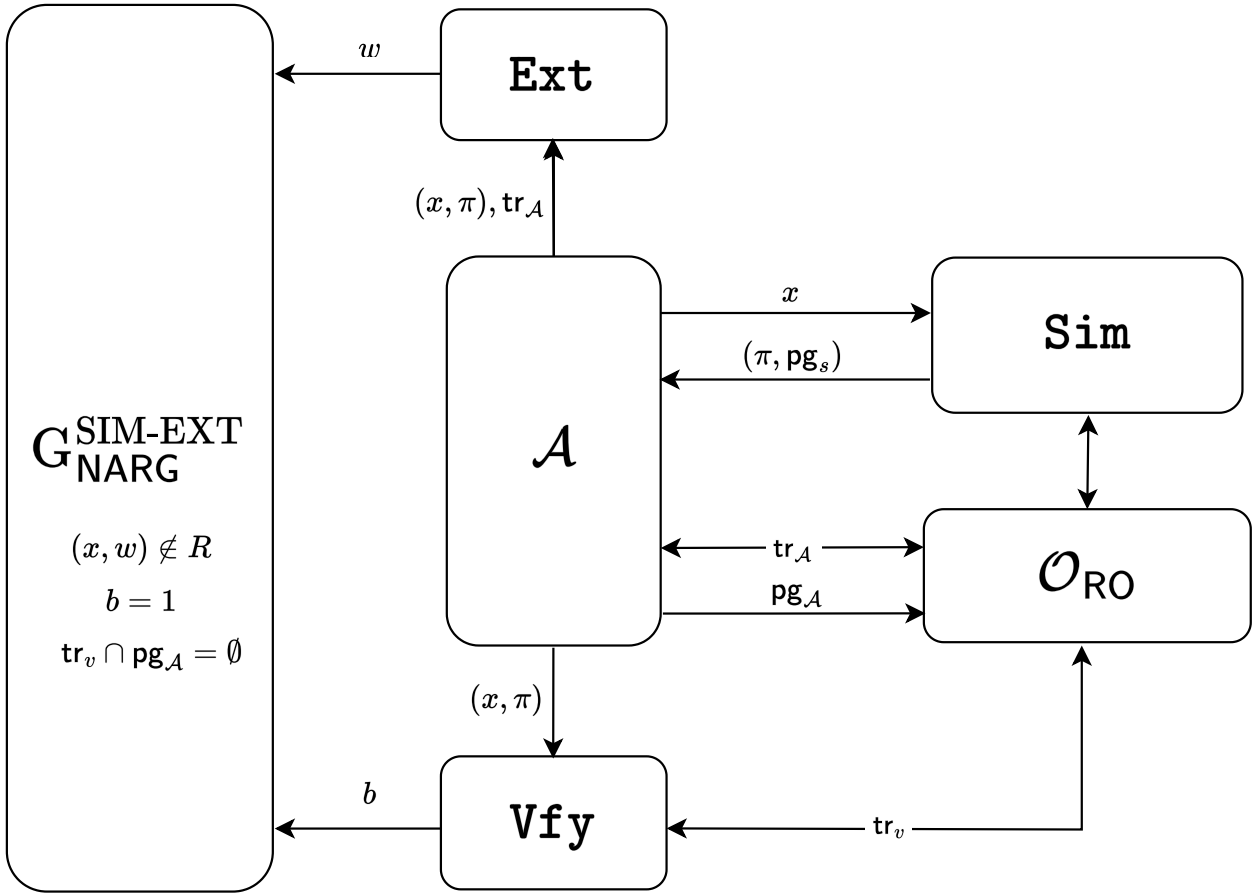
Appendix: Zero-Knowledge

– Arguments does not disclose information about witness.



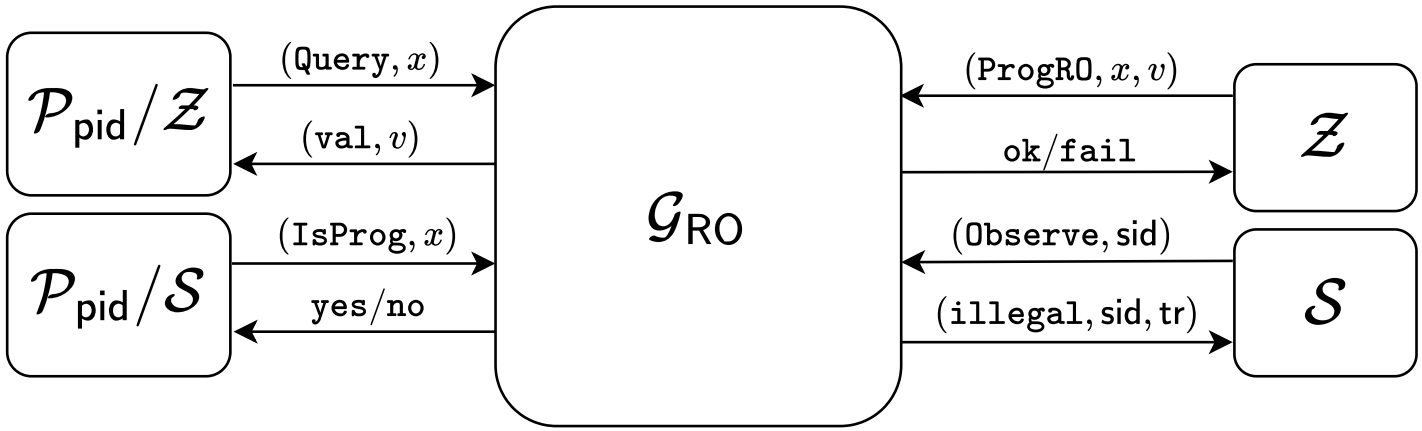
Appendix: *s*SIM-EXT

- Stronger version for *Knowledge Soundness*.
- *Non-malleability* for UC-security.

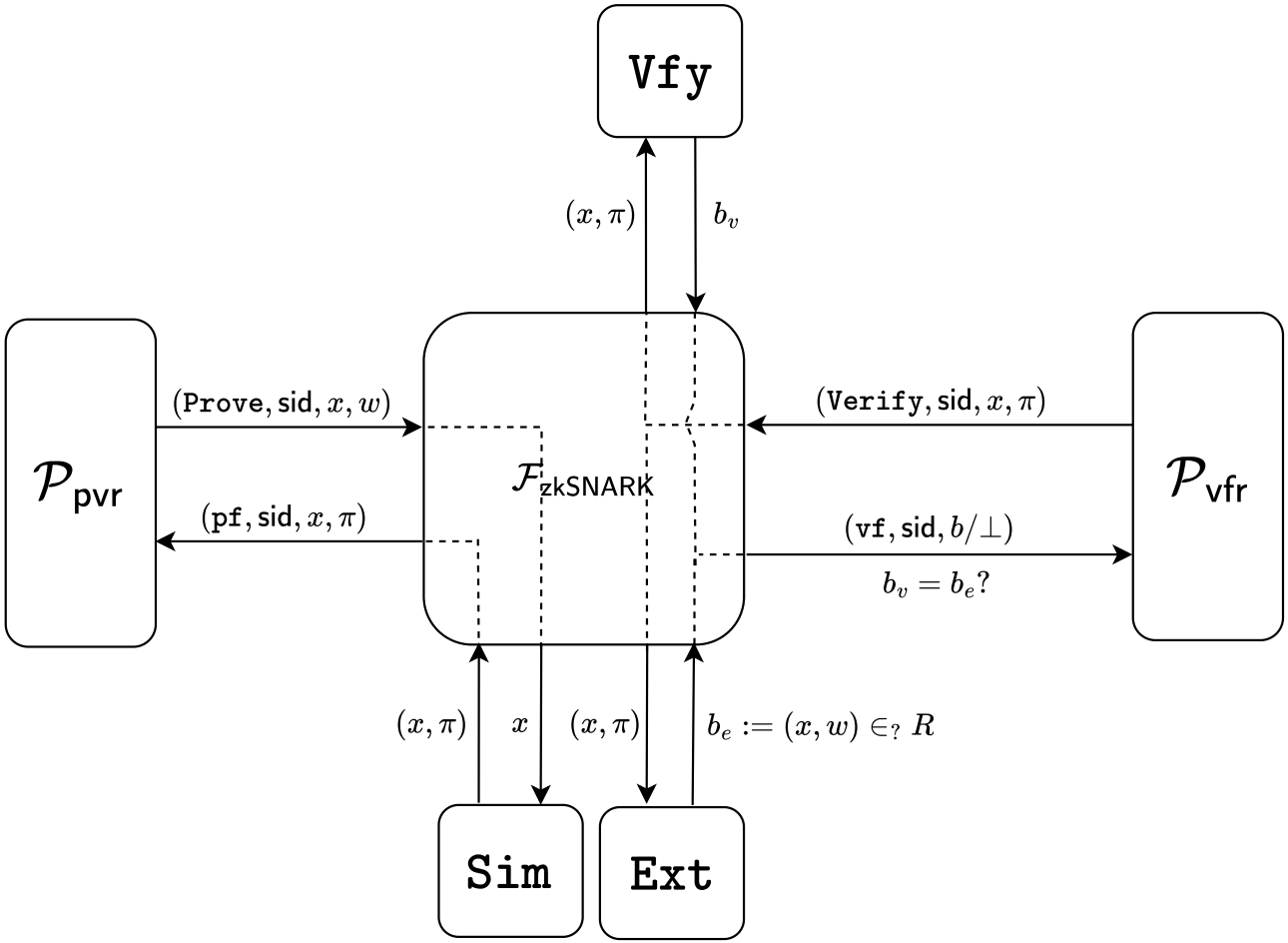


Appendix: Global Random Oracle $\mathcal{G}_{\mathsf{RO}}$

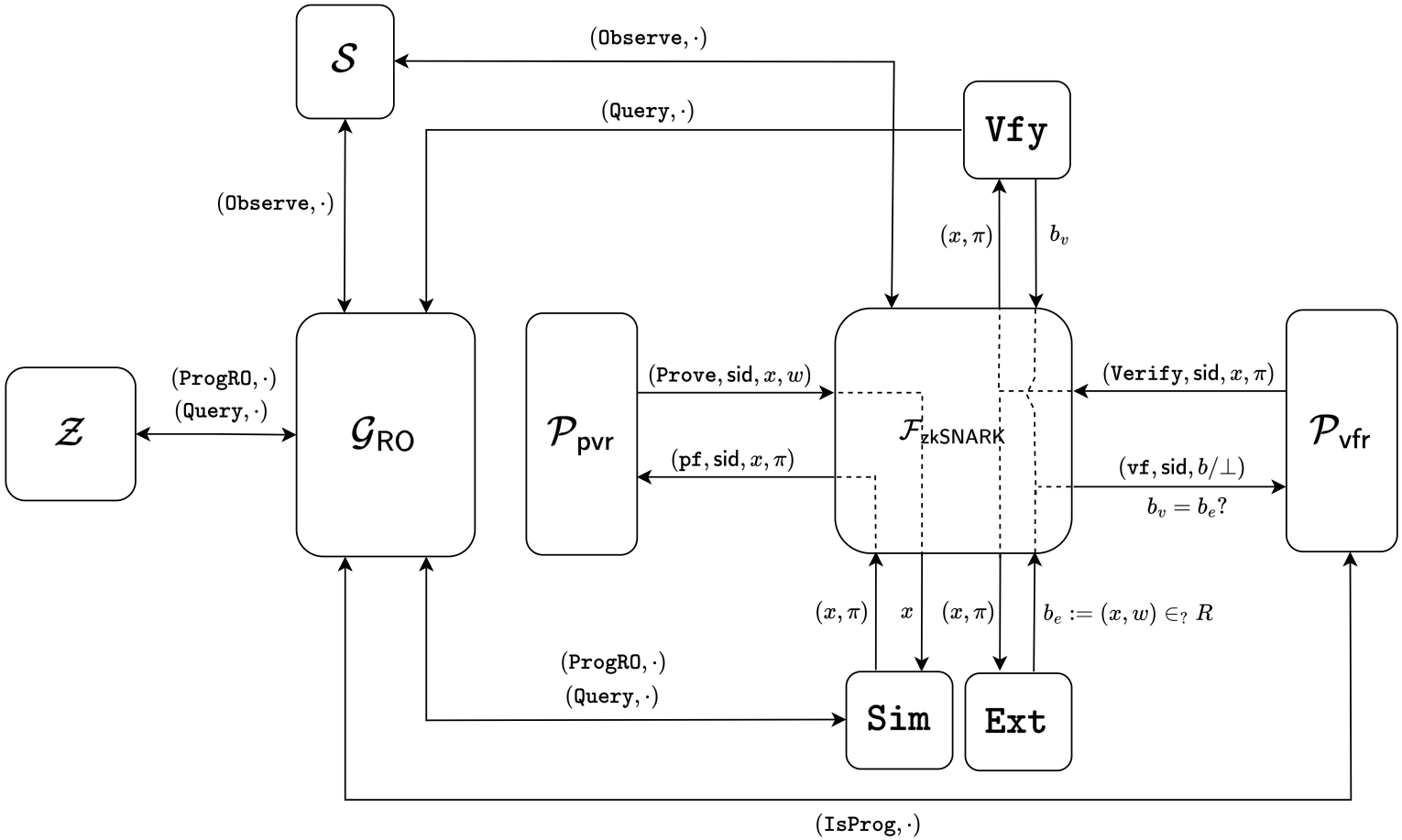
– Global random oracle with restricted *programming* and *observability* [CDG+18].



Appendix: Functionality $\mathcal{F}_{\mathsf{zkSNARK}}$ [CF24]



Appendix: $\mathcal{F}_{\mathsf{zkSNARK}} + \mathcal{G}_{\mathsf{RO}}$

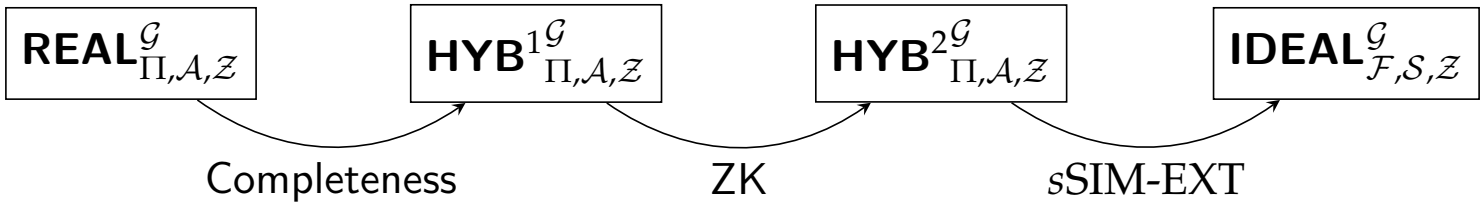


Appendix: Realization of $\mathcal{F}_{\mathsf{zkSNARK}}$

EPFL

Theorem 3[CF24]

Π_{NARG} *UC-realizes* $\mathcal{F}_{\mathsf{zkSNARK}}$ *in presence of* $\mathcal{G}_{\mathsf{RO}}$ *if and only if* NARG *satisfies completeness,* sSIM-EXT, *and zero-knowledge.*




Flavio Bergamaschi, Anamaria Costache, Dana Dachman-Soled, Hunter Kippen, Lucas LaBuff, and Rui Tang.
Revisiting the security of approximate FHE with noise-flooding countermeasures.
Cryptology ePrint Archive, Report 2024/424, 2024.
URL: https://eprint.iacr.org/2024/424.


Boaz Barak, Ran Canetti, Jesper Buus Nielsen, and Rafael Pass.
Universally composable protocols with relaxed set-up assumptions.
pages 186–195, 2004.
doi:10.1109/FOCS.2004.71.


Florian Bourse, Rafaël del Pino, Michele Minelli, and Hoeteck Wee.
FHE circuit privacy almost for free.
pages 62–89, 2016.
doi:10.1007/978-3-662-53008-5_3.


Jan Bobolz, Pooya Farshim, Markulf Kohlweiss, and Akira Takahashi.

The brave new world of global generic groups and UC-secure zero-overhead SNARKs.
pages 90–124, 2024.
doi:10.1007/978-3-031-78011-0_4.


Olivier Bernard, Marc Joye, Nigel P. Smart, and Michael Walter.
Drifting towards better error probabilities in fully homomorphic encryption schemes.
Cryptology ePrint Archive, Paper 2024/1718, 2024.
URL: https://eprint.iacr.org/2024/1718.


Katharina Boudgoust and Peter Scholl.
Simple threshold (fully homomorphic) encryption from LWE with polynomial modulus.
pages 371–404, 2023.
doi:10.1007/978-981-99-8721-4_12.


Dan Boneh, Gil Segev, and Brent Waters.
Targeted malleability: homomorphic encryption for restricted computations.

pages 350–366, 2012.
doi:10.1145/2090236.2090264.


Jan Camenisch, Manu Drijvers, Tommaso Gagliardoni, Anja Lehmann, and Gregory Neven.
The wonderful world of global random oracles.
pages 280–312, 2018.
doi:10.1007/978-3-319-78381-9_11.


Alessandro Chiesa and Giacomo Fenzi.
zkSNARKs in the ROM with unconditional UC-security.
pages 67–89, 2024.
doi:10.1007/978-3-031-78011-0_3.


Jung Hee Cheon, Andrey Kim, Miran Kim, and Yong Soo Song.
Homomorphic encryption for arithmetic of approximate numbers.
pages 409–437, 2017.
doi:10.1007/978-3-319-70694-8_15.


Ran Canetti, Srinivasan Raghuraman, Silas Richelson, and Vinod Vaikuntanathan.
Chosen-ciphertext secure fully homomorphic encryption.
pages 213–240, 2017.
doi:10.1007/978-3-662-54388-7_8.


Craig Gentry.
A fully homomorphic encryption scheme.
PhD thesis, Stanford University, 2009.
crypto.stanford.edu/craig.


Chaya Ganesh, Yashvanth Kondi, Claudio Orlandi, Mahak Pancholi, Akira Takahashi, and Daniel Tschudi.
Witness-succinct universally-composable SNARKs.
pages 315–346, 2023.
doi:10.1007/978-3-031-30617-4_11.


Jens Groth.

Simulation-sound NIZK proofs for a practical language and constant size group signatures.
pages 444–459, 2006.
doi:10.1007/11935230_29.

Intel.
Intel® homomorphic encryption toolkit.
https://www.intel.com/content/www/us/en/developer/tools/homomorphic-encryption/overview.html.

Yuval Ishai and Anat Paskin.
Evaluating branching programs on encrypted data.
pages 575–594, 2007.
doi:10.1007/978-3-540-70936-7_31.

Hyesun Kwak, Dongwon Lee, Yongsoo Song, and Sameer Wagh.
A general framework of homomorphic encryption for multiple parties with non-interactive key-aggregation.
pages 403–430, 2024.
doi:10.1007/978-3-031-54773-7_16.


Kamil Kluczniak and Giacomo Santato.
On circuit private, multikey and threshold approximate homomorphic encryption.
Cryptology ePrint Archive, Report 2023/301, 2023.
URL: https://eprint.iacr.org/2023/301.


Baiyu Li and Daniele Micciancio.
On the security of homomorphic encryption on approximate numbers.
pages 648–677, 2021.
doi:10.1007/978-3-030-77870-5_23.


Jake Loftus, Alexander May, Nigel P. Smart, and Frederik Vercauteren.
On CCA-secure somewhat homomorphic encryption.
pages 55–72, 2012.
doi:10.1007/978-3-642-28496-0_4.


Anna Lysyanskaya and Leah Namisa Rosenbloom.
Universally composable Σ-protocols in the global random-oracle model.
pages 203–233, 2022.

doi:10.1007/978-3-031-22318-1_8.

Adriana López-Alt, Eran Tromer, and Vinod Vaikuntanathan.
On-the-fly multiparty computation on the cloud via multikey fully homomorphic encryption.
pages 1219–1234, 2012.
doi:10.1145/2213977.2214086.