Privacy and Integrity Preserving Computations with CRISP

S. Chatel, A. Pyrgelis, J.R. Troncoso-Pastoriza, J-P. Hubaux
Laboratory for Data Security, EPFL

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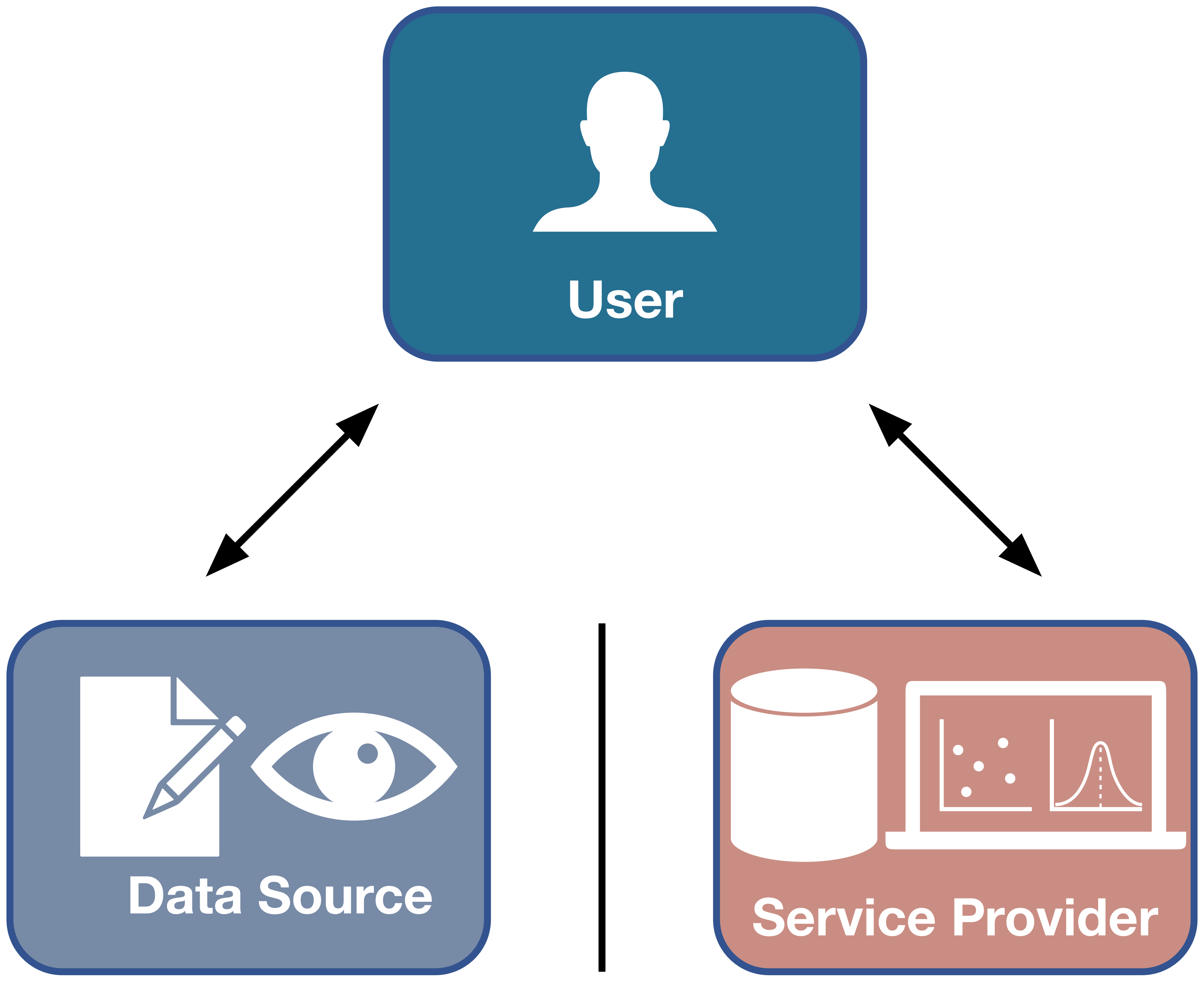
Data Analysis Cycle

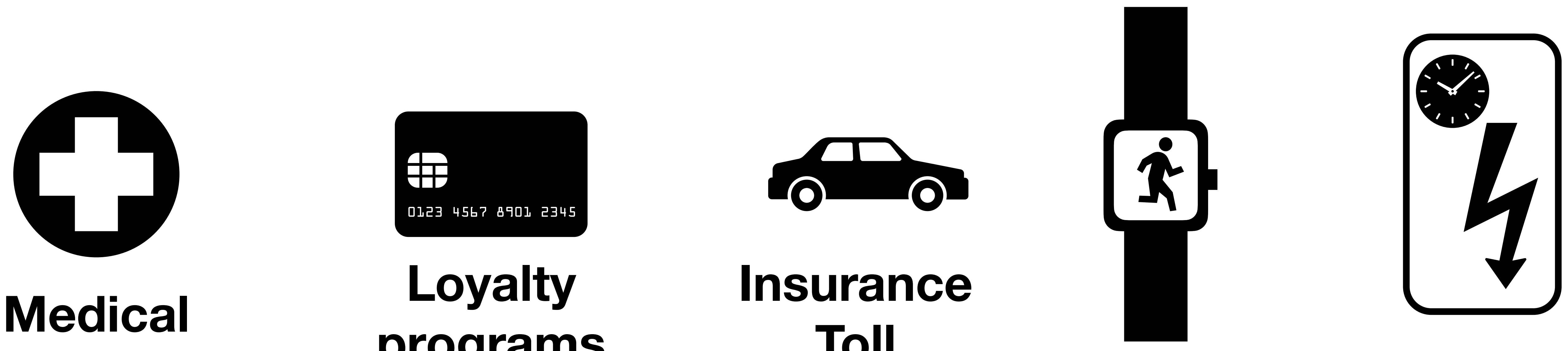
Data source creates data about a user

The **user** wishes to obtain a service from a provider

A **provider** is interested in gaining some information



This data flow models several real-life use case:



Medical and Health Programs

Loyalty programs

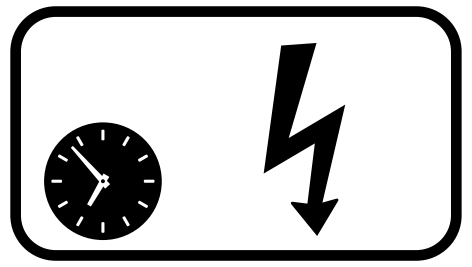
Insurance Toll

Activity Tracking

Smart Metering

Motivation

Real-world data flows are vulnerable to attacks on privacy and authenticity e.g.:



Smart Metering

Load balancing, forecast, energy savings

Inference on user's behavior

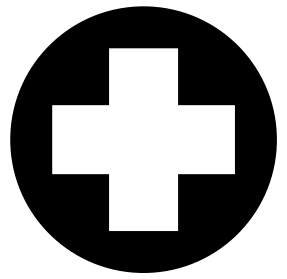
Protection required to avoid disruption

Personal Tracking

Location-based activity tracking

Privacy breach about user's behaviour or even national security interests

Protection required for insurance fraud

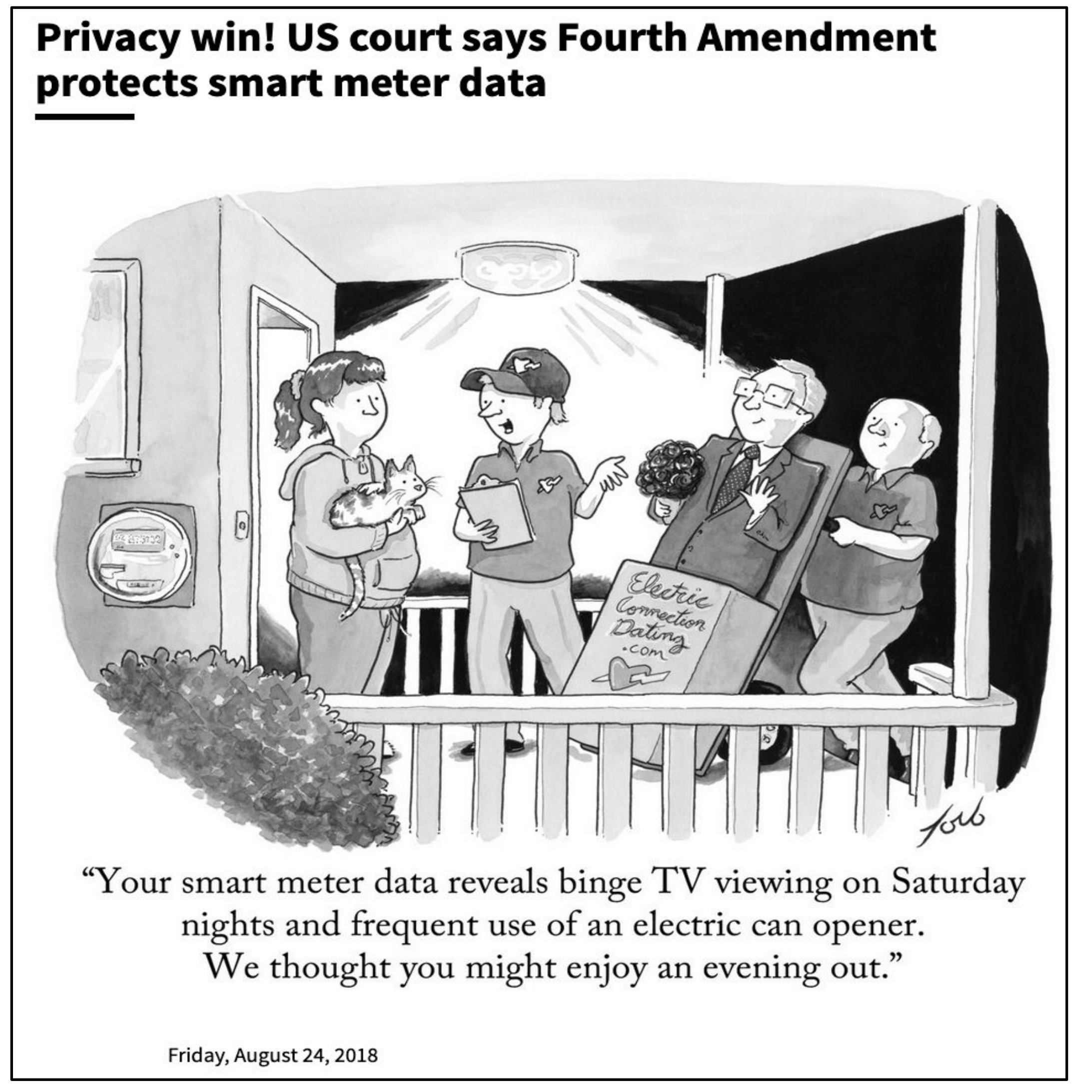


Medical Monitoring

Genomic Data Analysis

Privacy breach for user and relatives

Protection required to avoid misdiagnosis



Naperville Smart Meter Awareness v. City of Naperville, No. 16-3766 (7th Cir. 2018)

Hubaux et al., Genomic Data Privacy and Security: Where We Stand and Where We Are Heading IEEE Security & Privacy 2017

Objectives of CRISP

We design and implement CRISP, a solution to compute securely on authenticated data at an acceptable cost in utility, without compromising privacy

Privacy

Prevent the service provider from gaining more information than required

Integrity

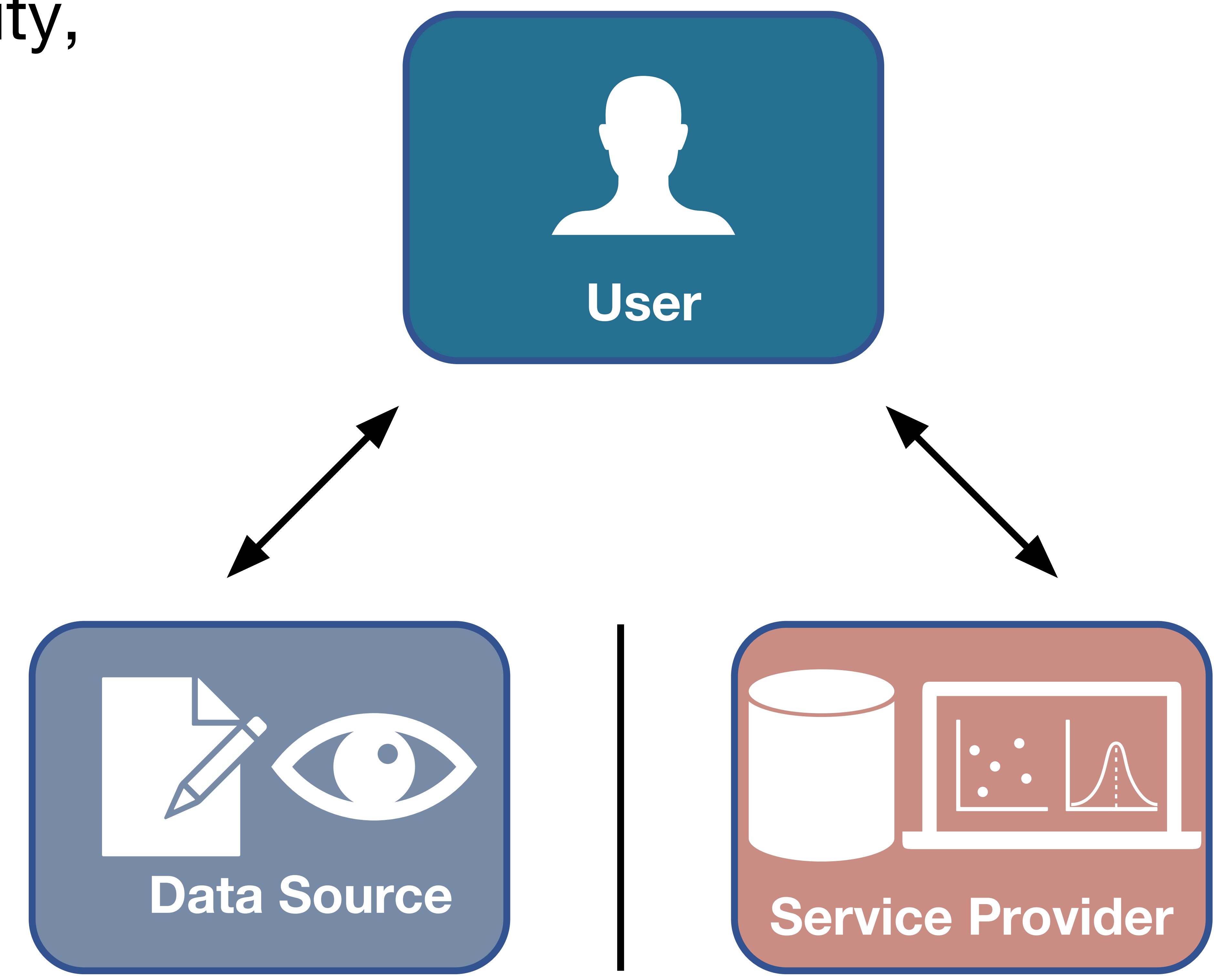
Prevent the user from cheating the service provider

Utility

Ensure good quality of service for both user and service provider

Deployability

Ensure smooth deployment with existing software and hardware infrastructure



CRISP Overview

Utility

Flexible Computations

Fully Homomorphic Encryption [a]

Enable polynomial computations on the encrypted data without decryption

Privacy

Input Data Confidentiality

Commitments and Blindings [c]

Reveal only the result of the computation and prevent cheating

Security

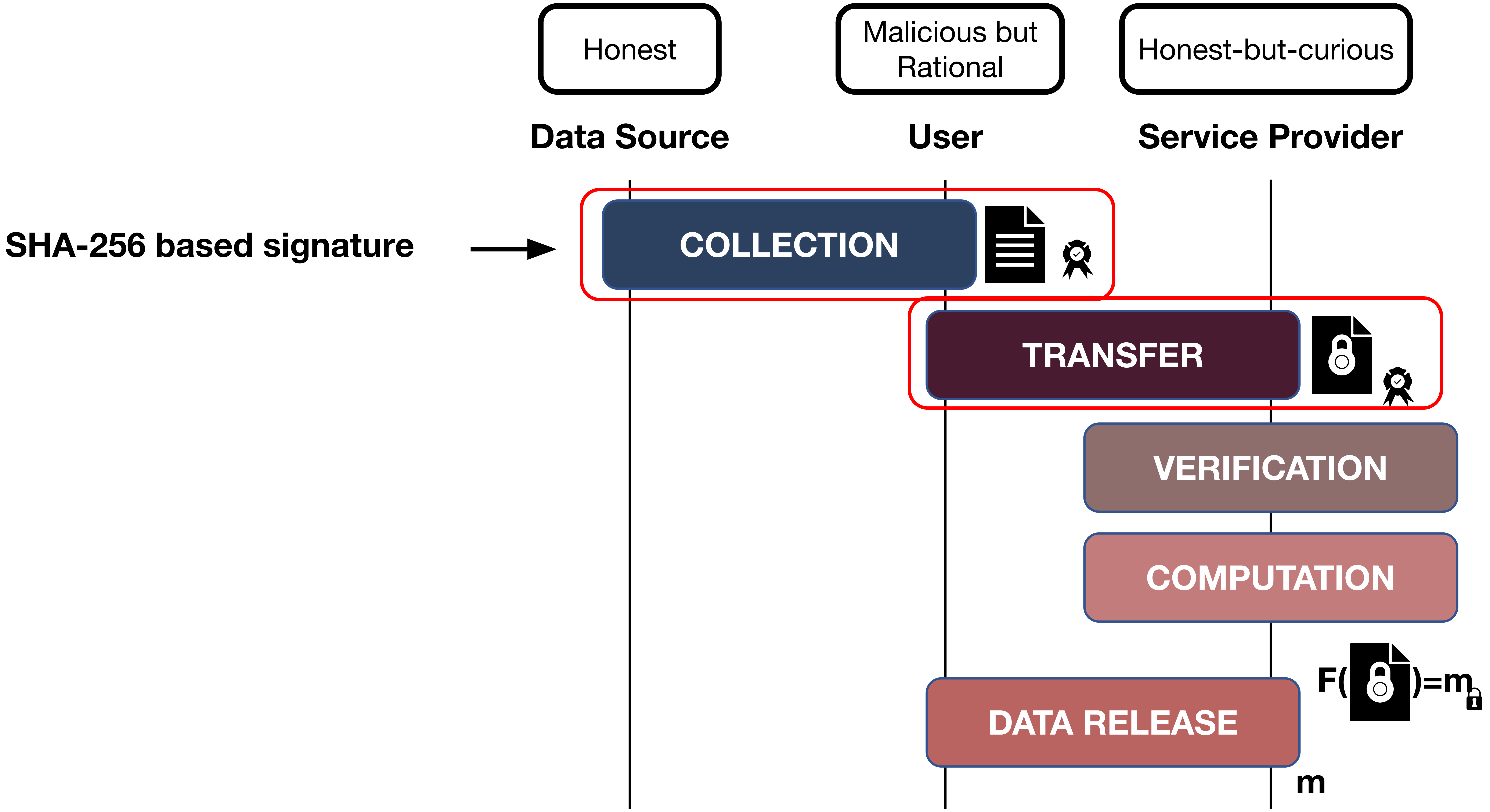
Data Authenticity

Zero-Knowledge Circuit Evaluation [b]

Evaluate a tailored circuit checking the encryption and hash of the data

(a) Cheon et al., “Homomorphic Encryption for Arithmetic of Approximate Numbers”, ASIACRYPT 2017
(b1) Giacomelli et al., “ZKBoo: Faster Zero-Knowledge for Boolean Circuits”, USENIX Security 2016
(b2) Chase et al., “Post-Quantum Zero-Knowledge and Signatures from Symmetric-Key Primitives”, CCS 2017
(c) Baum et al., “More Efficient Commitments from Structured Lattice Assumptions”, ePrint 2016

CRISP Model



Honest
Malicious but Rational
Honest-but-curious
Data Source
User
Service Provider
SHA-256 based signature
COLLECTION
TRANSFER
VERIFICATION
COMPUTATION
F( )=m
DATA RELEASE
m

Transfer Phase

The user generates a proof guaranteeing

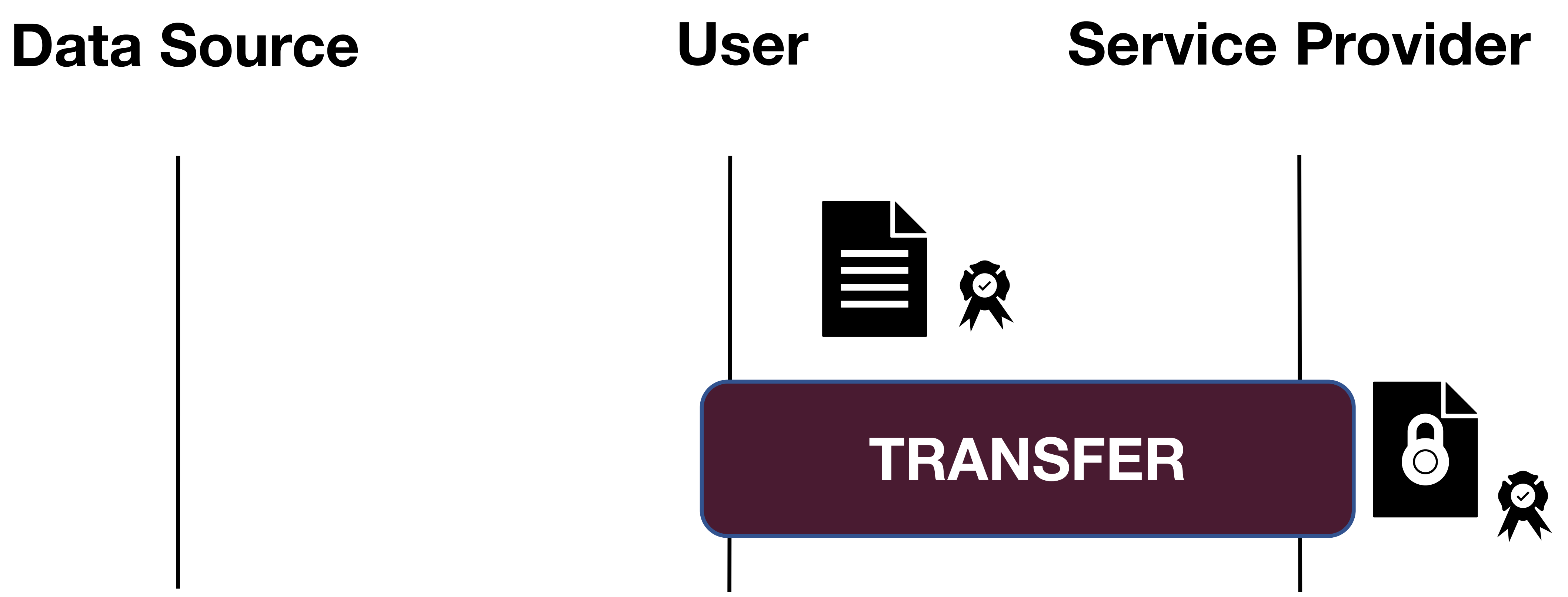
- Correct encryption
- Integrity of the data

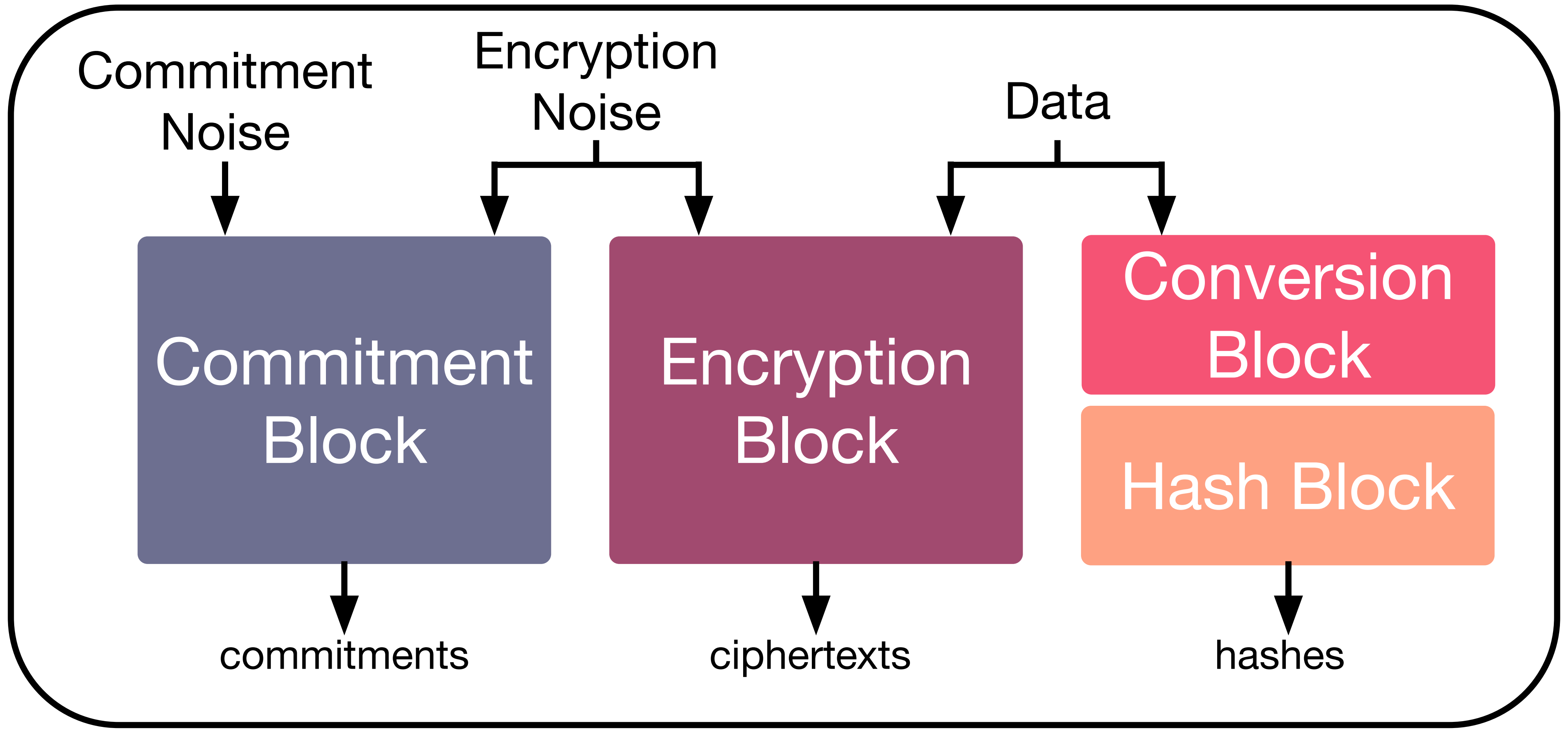
We designed a custom circuit to check simultaneously

- The hash of the data
- The norm of the encryption noises
- The encryption of the data

CRISP relies on a Zero-Knowledge Circuit Evaluation and Lattice-Based Commitments

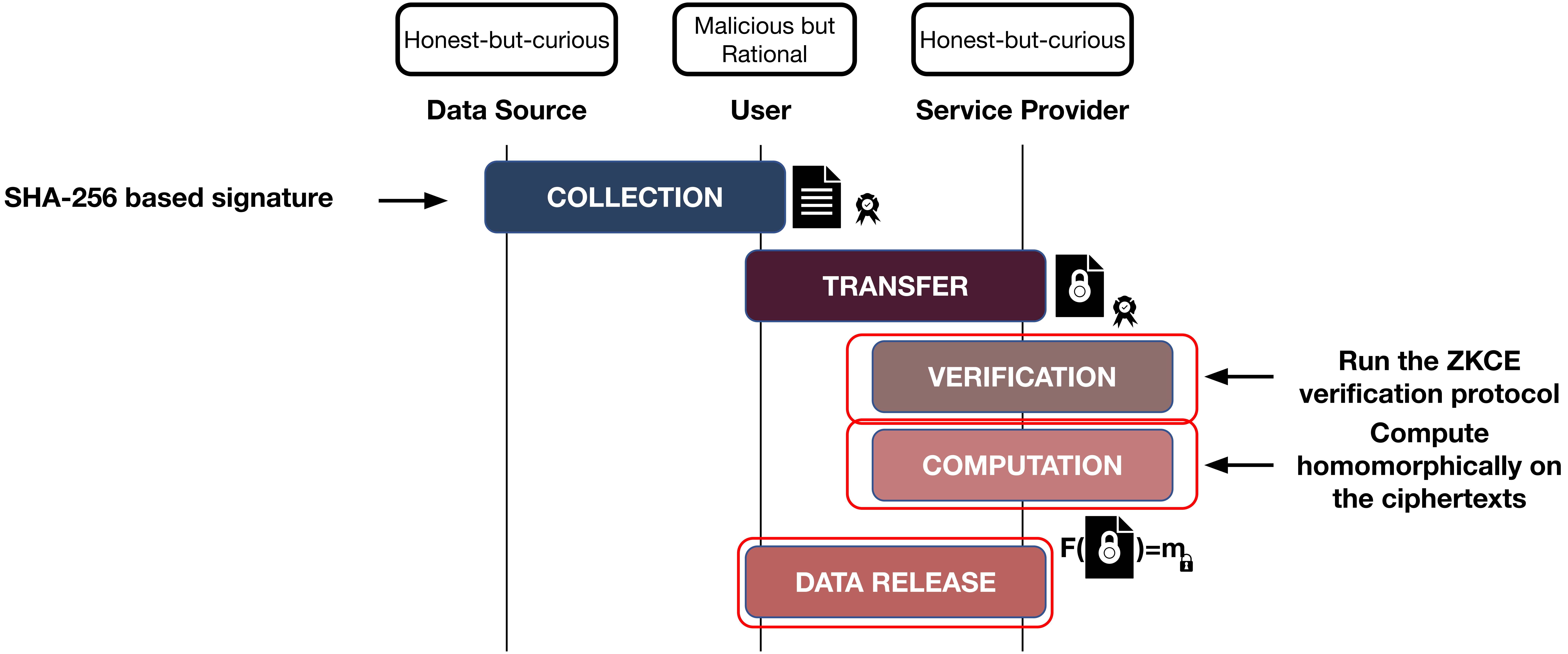
Eventually, the user sends the message M={ciphertexts, commitments, proof, hashes, signatures}





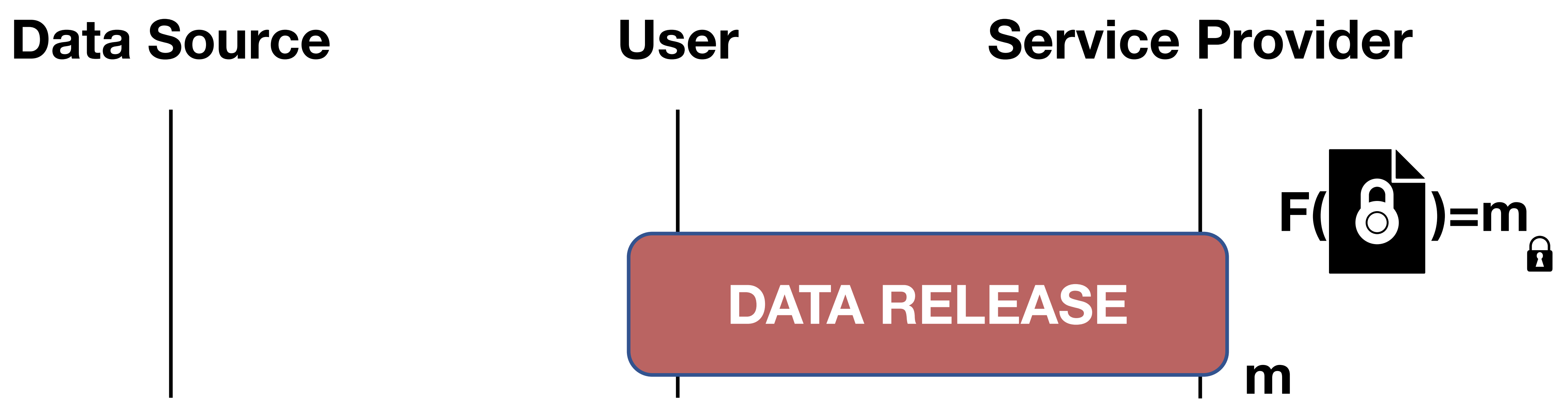
Tailored circuit used in the Zero-Knowledge Circuit Evaluation

Verification and Computation Phase

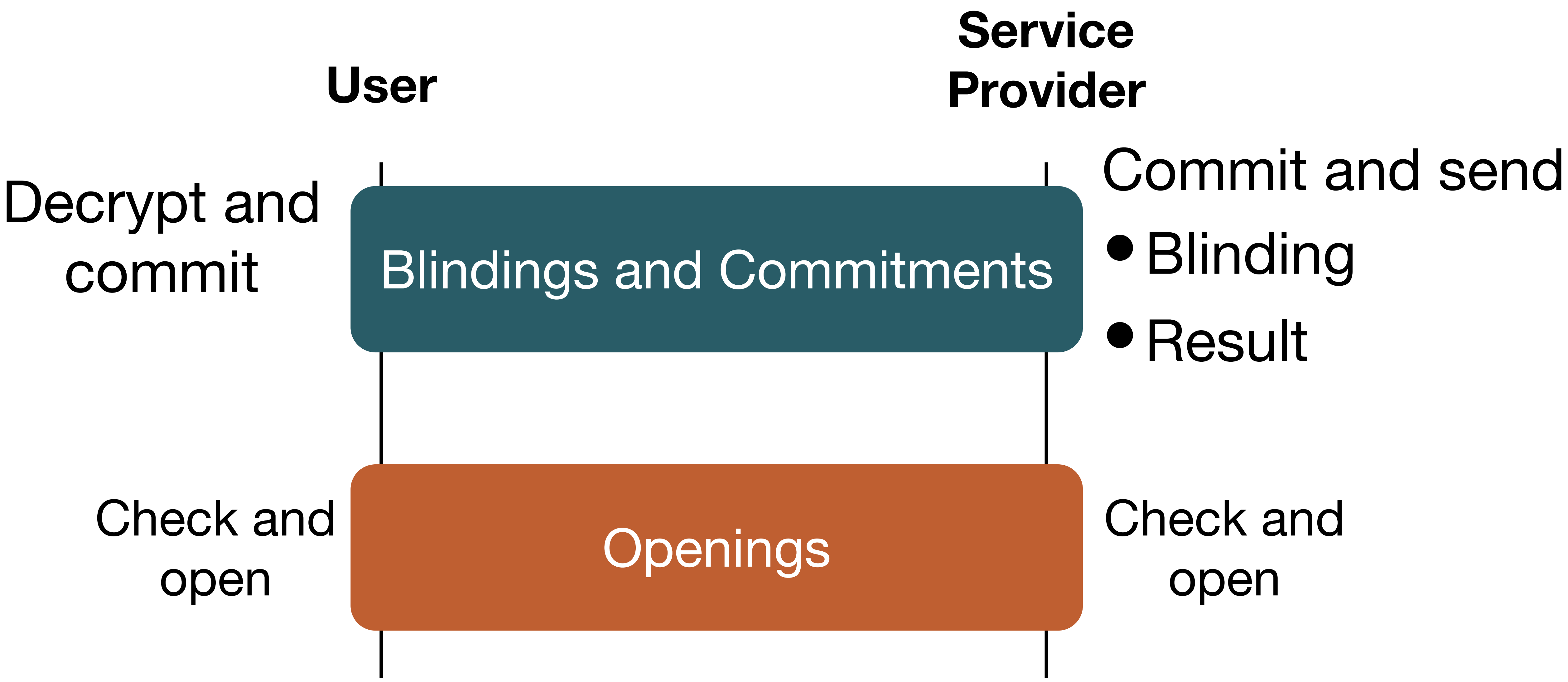


Release Phase

The **user** and **service provider** engage in an interactive protocol to reveal only the result of the computation in a tamper-proof manner



Two-round protocol the security of which relies on the security of the underlying commitment scheme



Evaluation: Overhead

We evaluated the communication and computation overhead.
Overall, we achieve:

- One-shot generation and offloading of the proof for multiple computations
- Packing of numerous data points into one ciphertext
- Support for several subsequent operations at no additional proof cost

Use Case	t_{PROVE} (s)	t_{VERIFY} (s)	Proof Size (MB)
Smart Metering	200 ± 10	82 ± 5	650
Disease Susceptibility based on Genomic Data	26 ± 4	13 ± 2	54
Location-Based Activity-Tracking	470 ± 40	210 ± 10	1,603

Acceptable overhead, considering:

- Possibility to offload the proof to a public billboard
- Several optimisations can reduce the overhead

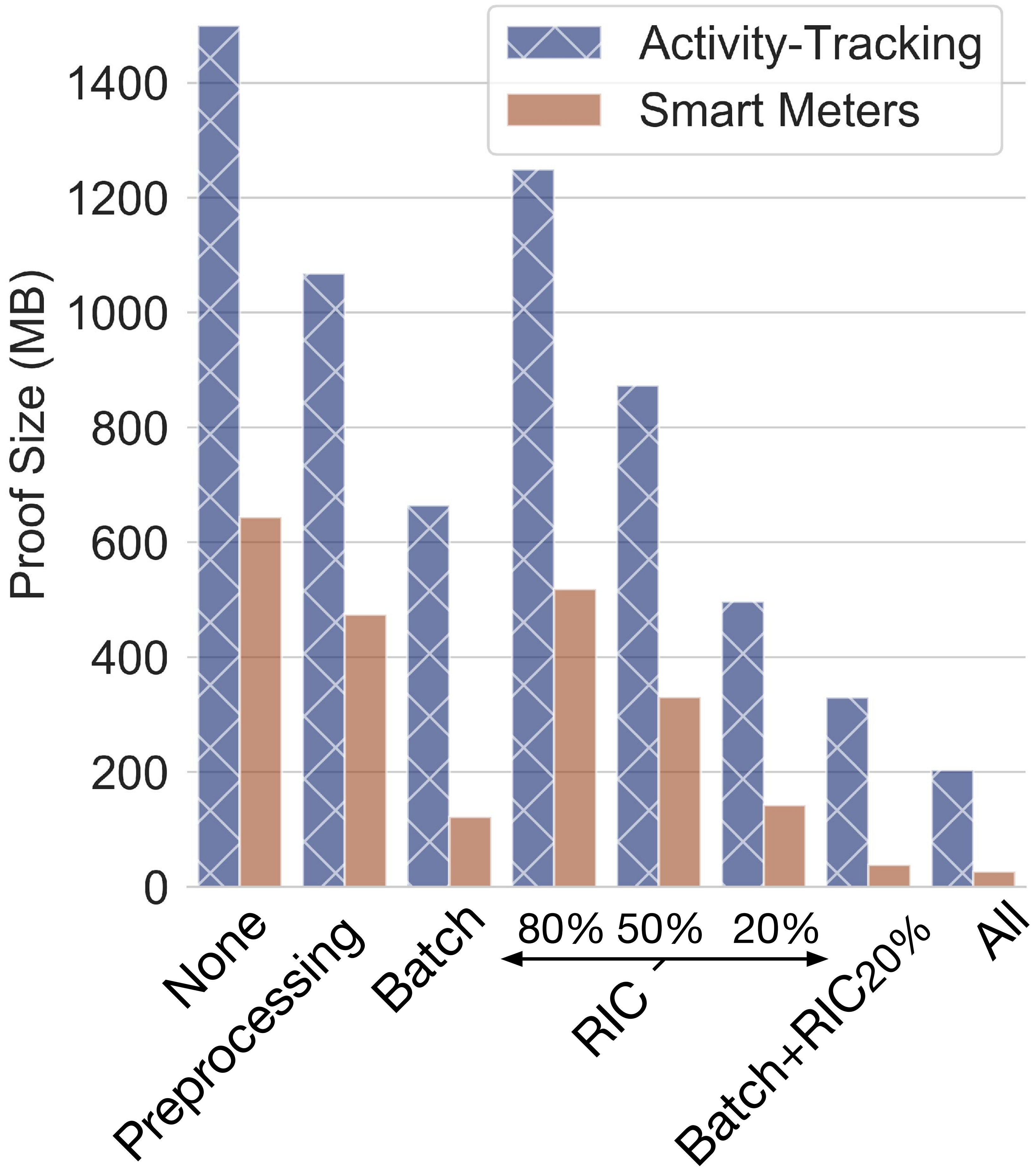
Optimizations

Several optimizations are possible to reduce the proof size:

- **Zero-Knowledge Circuit Evaluator Preprocessing**[(d)]
  Rely on an offline phase to reduce the number of required online interactions

- **Batching**
  Use the signature to its full extent to pack as many data points as possible (data source modification required)

- **Random Integrity Checks (RIC)**
  The verifier picks at random a subset of data points which authenticity is checked



(d) Katz et al. "Improved non-interactive zero knowledge with applications to post-quantum signatures." CCS 2019

Conclusion on CRISP

Reconciles **security**, **privacy**, and **utility** using zero-knowledge proofs and homomorphic encryption:

- Ensures **computations on authenticated data**
- Preserves privacy of the data
- Does not affect accuracy more than the FHE scheme
- **One-time communication** overhead for the prover

Future work

- Malicious Service Provider
- Further reduce the proof size relying on alternative zero-knowledge proofs or increasing the number of parties

Thank you

sylvain.chatel@epfl.ch

https://github.com/ldsec/CRISP