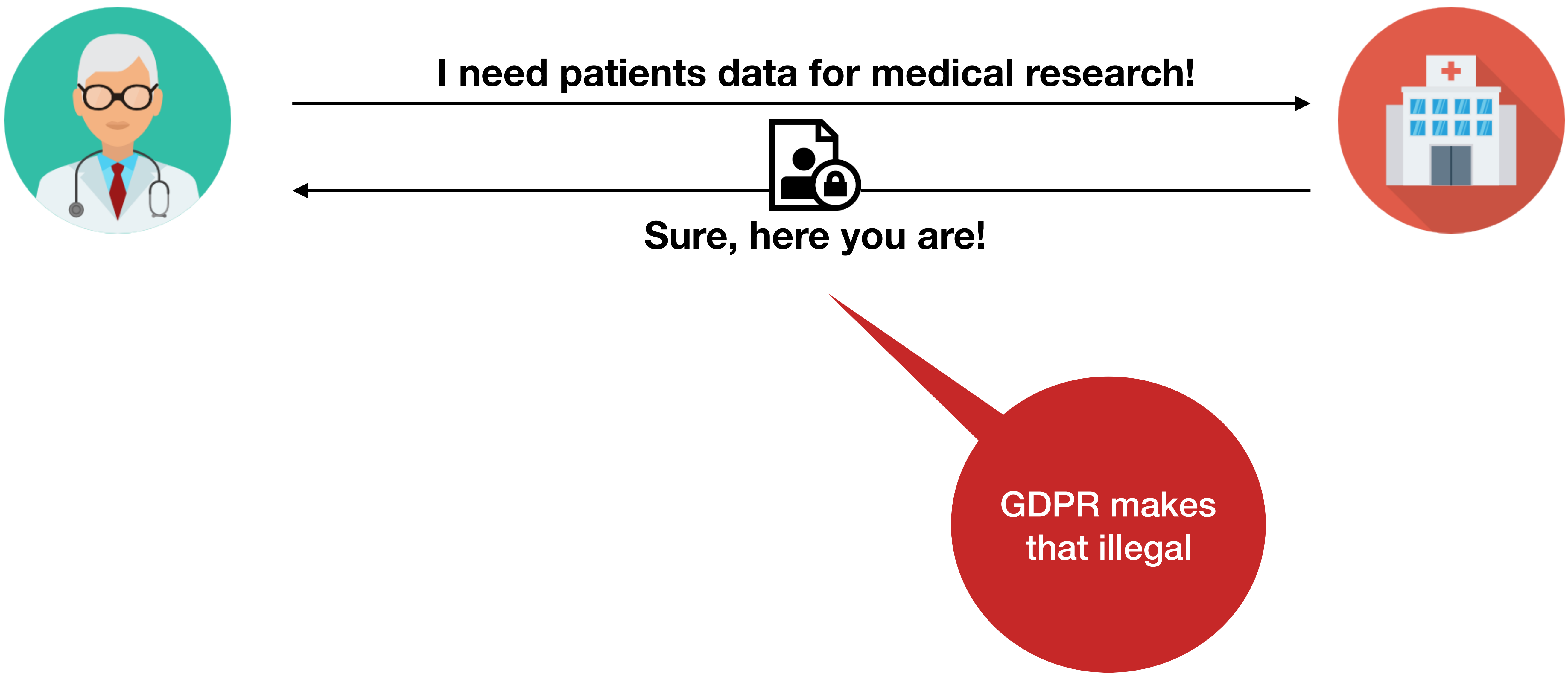
Accountable and privacy preserving data processing via distributed ledgers

National and Kapodistrian University of Athens
Theoretical Computer Science

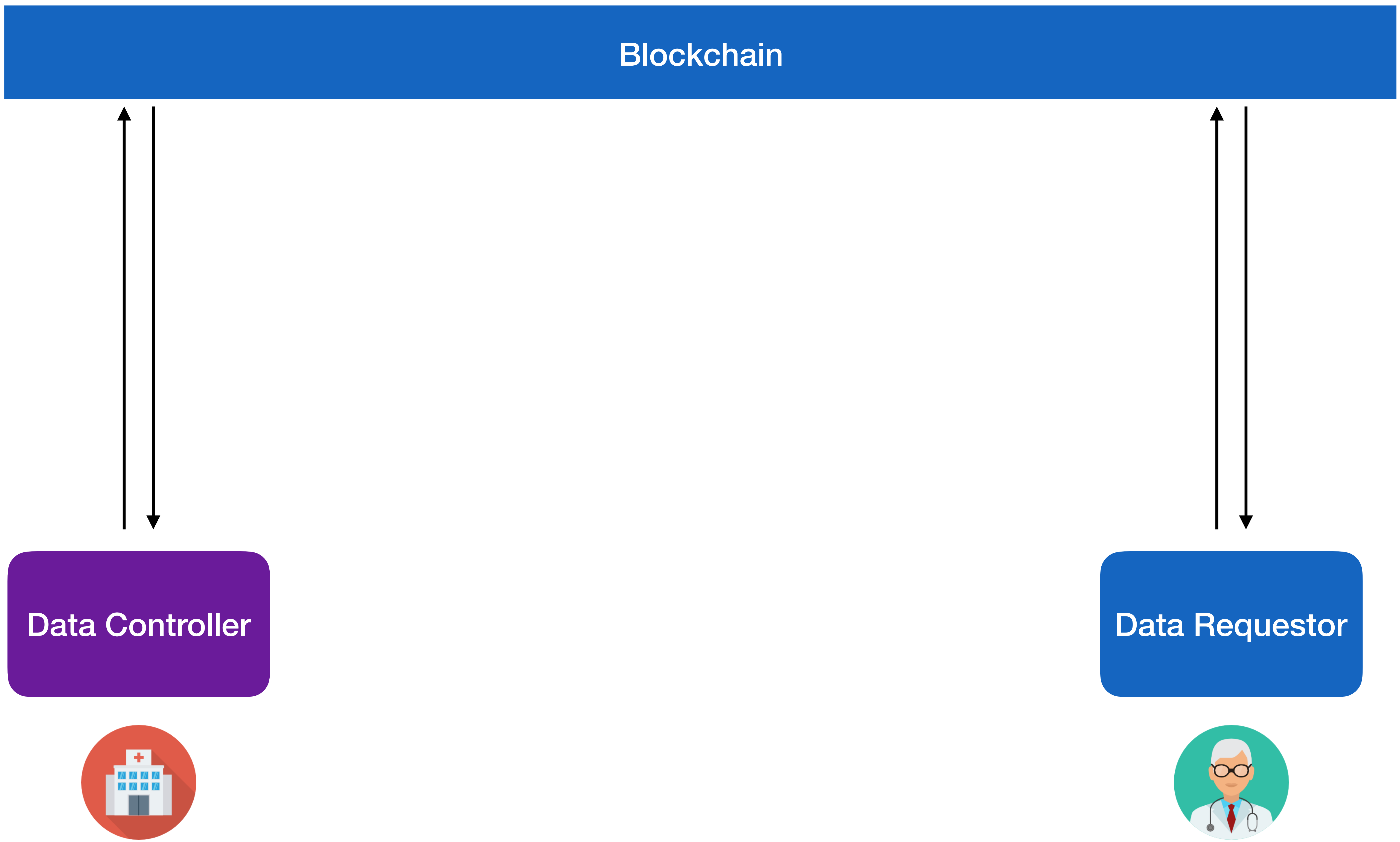
Christos Nasikas

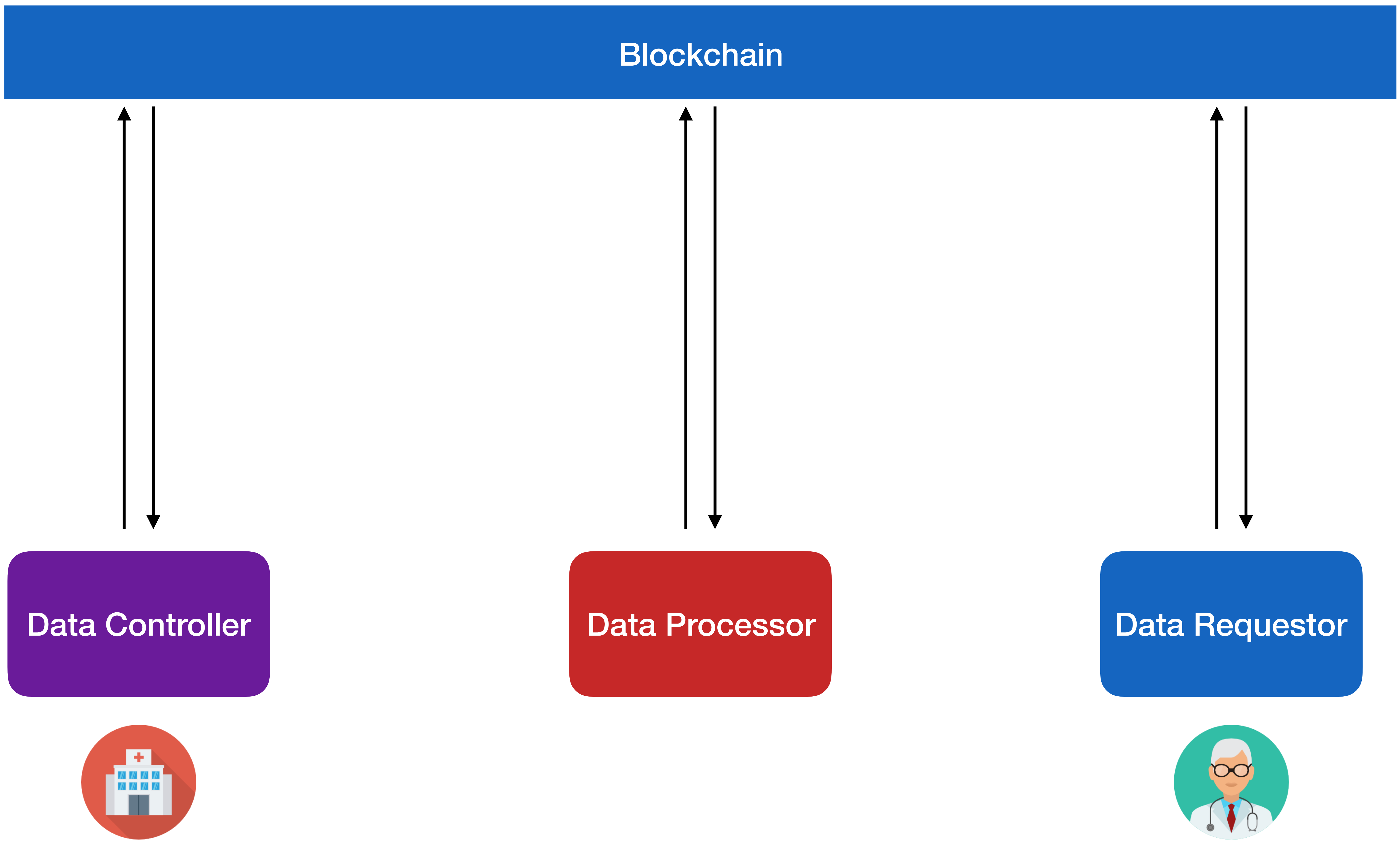
Outline

- Introduction
- Architecture
- Future work
- Related work


I need patients data for medical research!
Sure, here you are!
GDPR makes that illegal

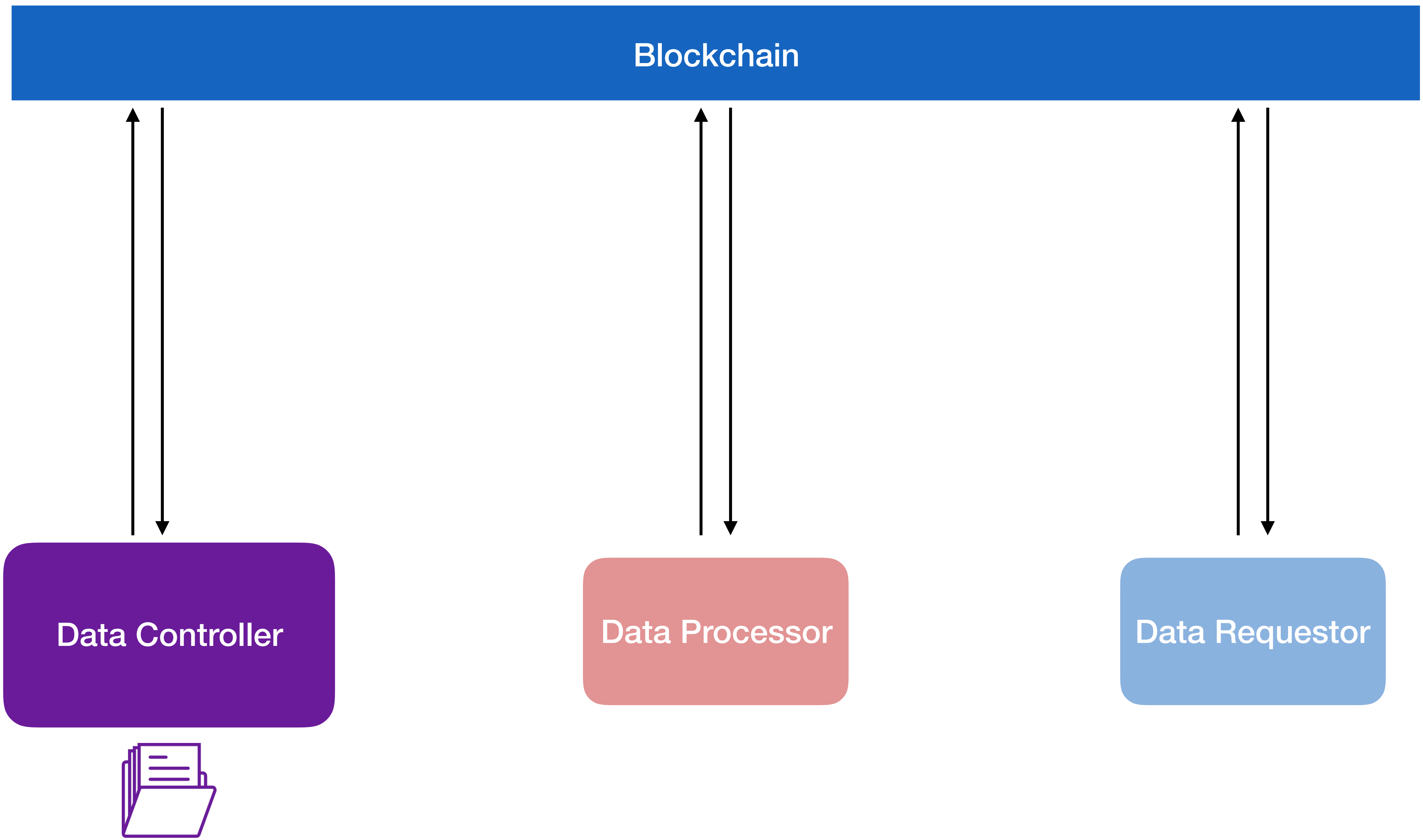
How can we help Dr. House help the patients ?


Blockchain
Data Controller
Data Requestor

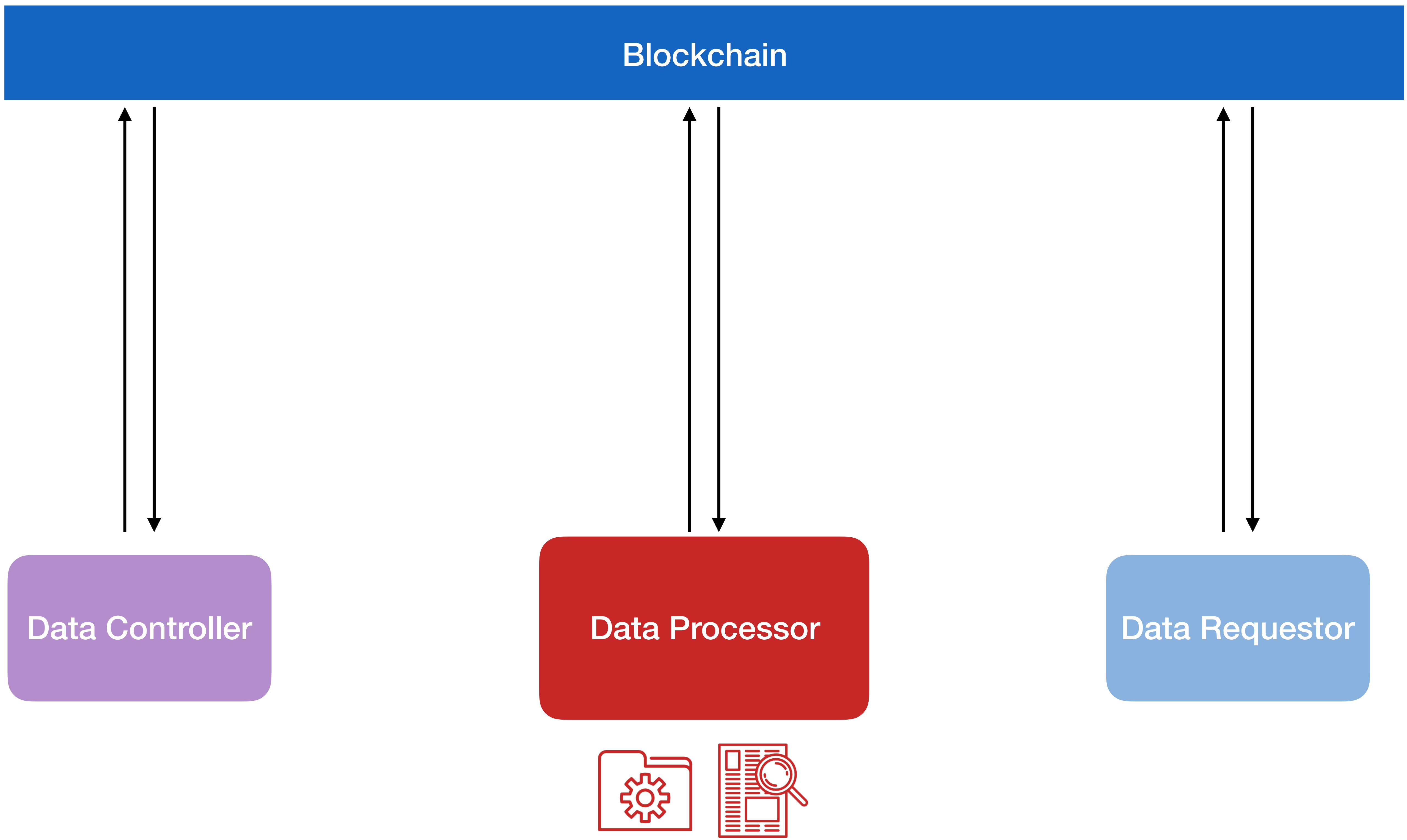

Blockchain
Data Controller
Data Processor
Data Requestor

Architecture

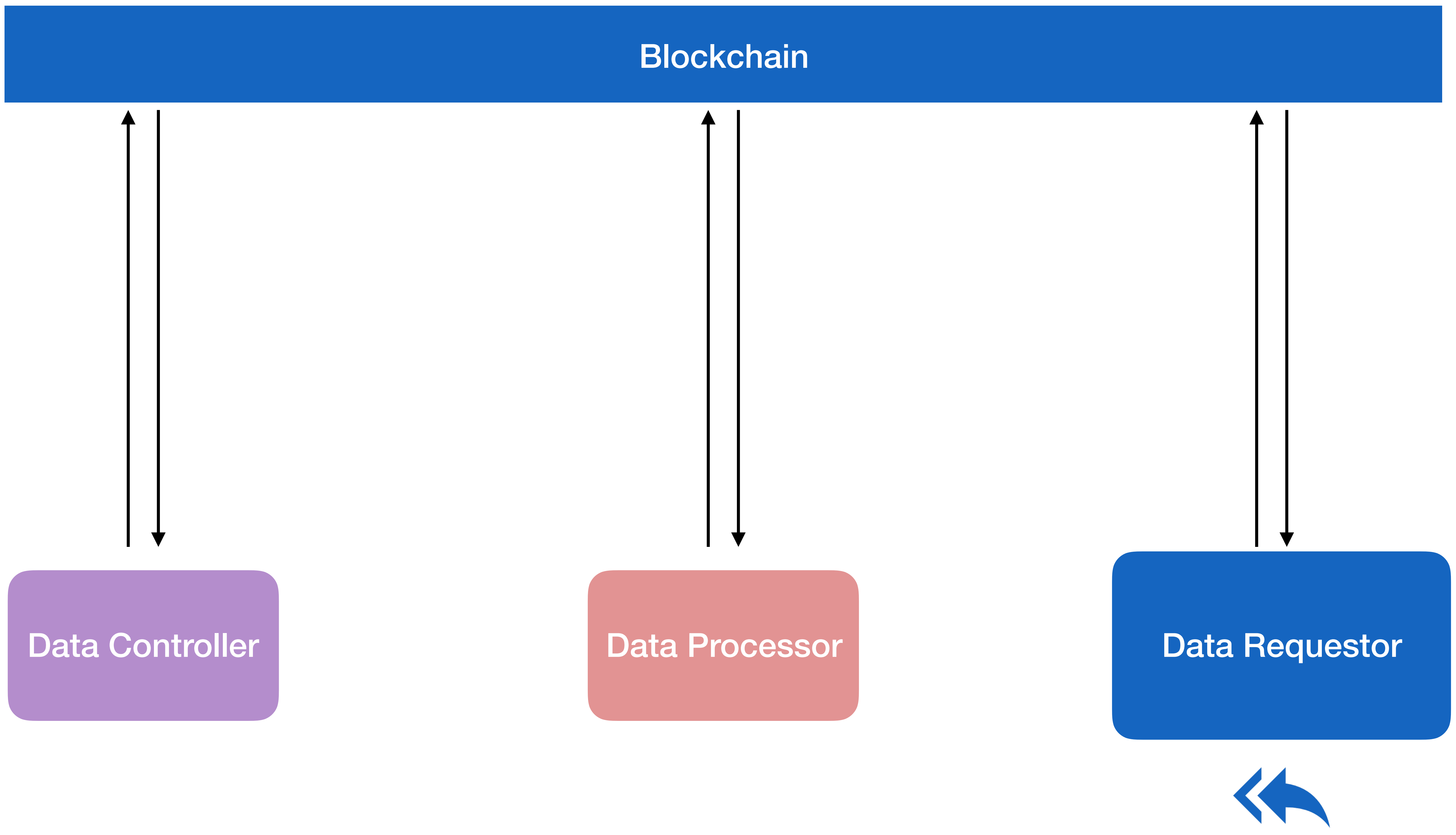
Participants



Participants



Participants



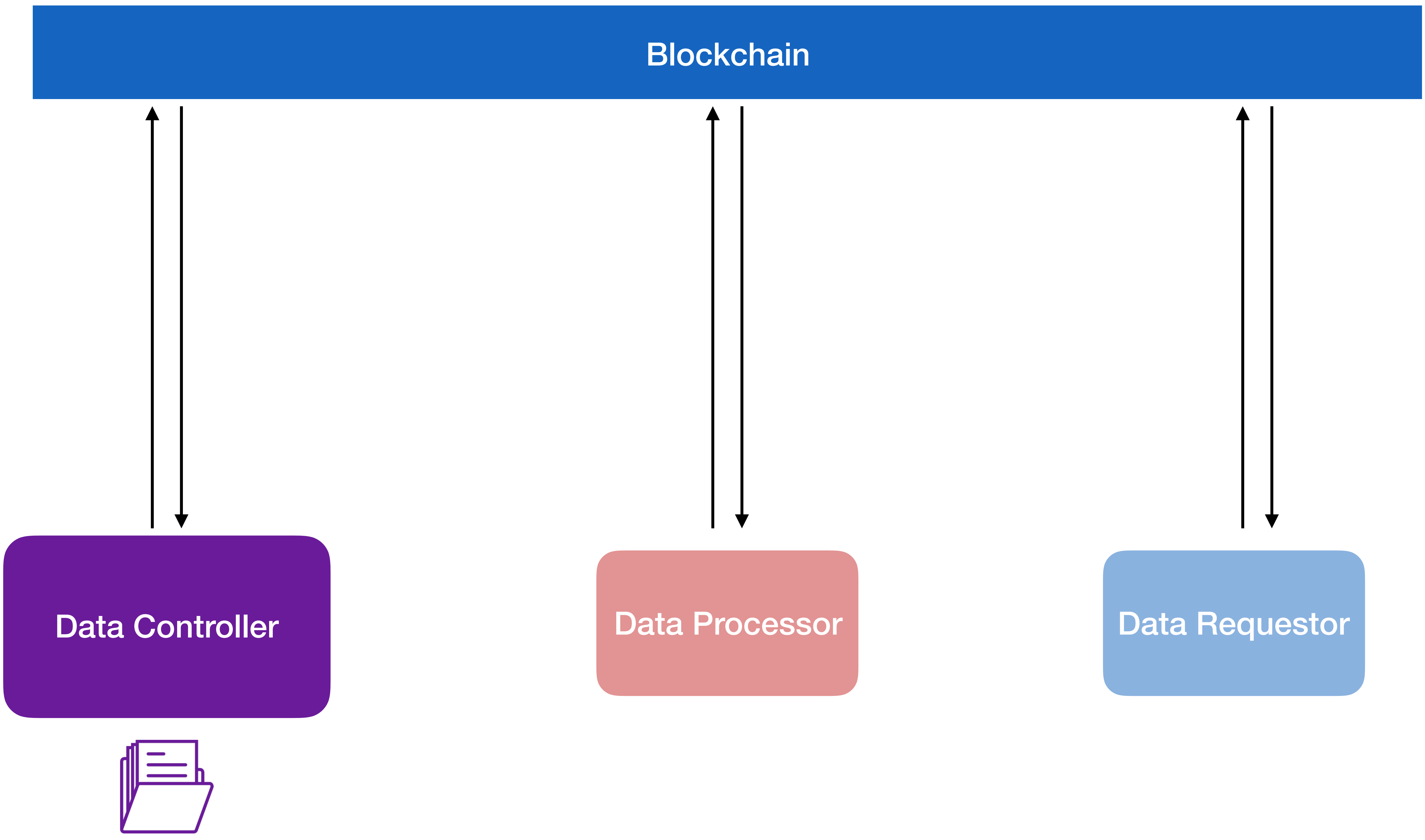
Blockchain advantages

- Immutability
- Accountability
- Auditability
- Non-repudation
- Public bulletin board
- Secure decentralized time-stamping

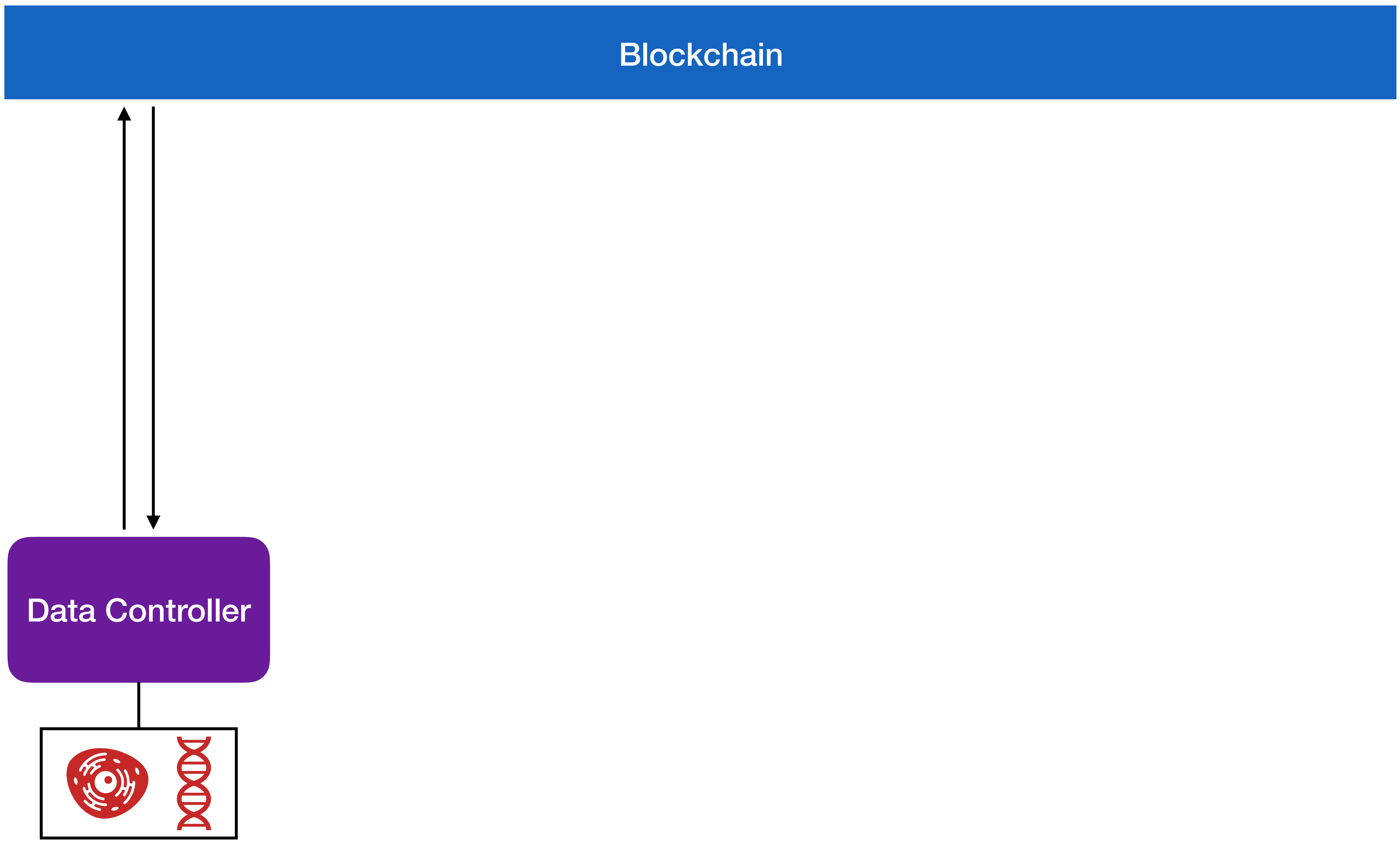
Algorithms

- Sum
- Average
- Count
- Maximum / Minimum
- Median

Data registration

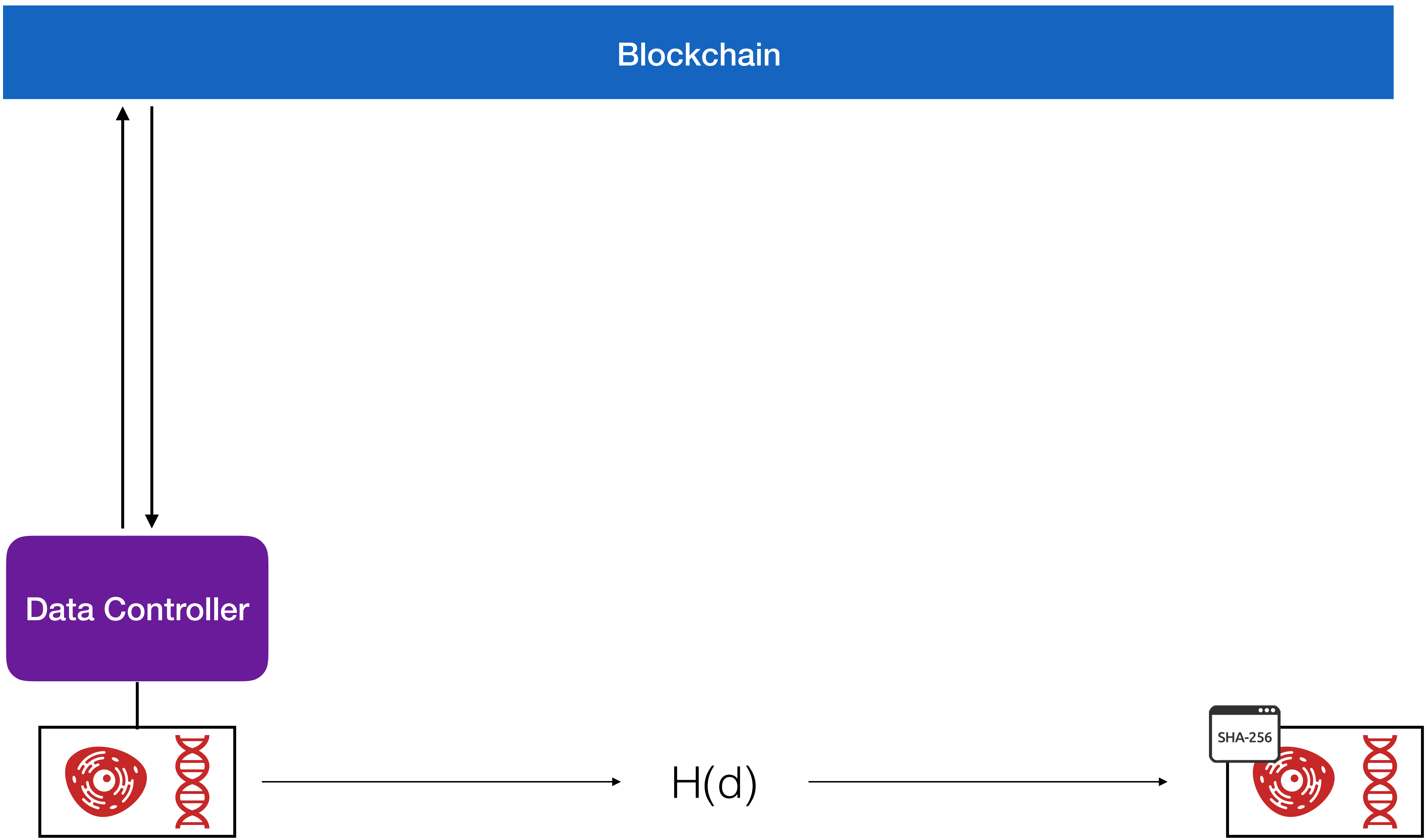


Dataset Registration



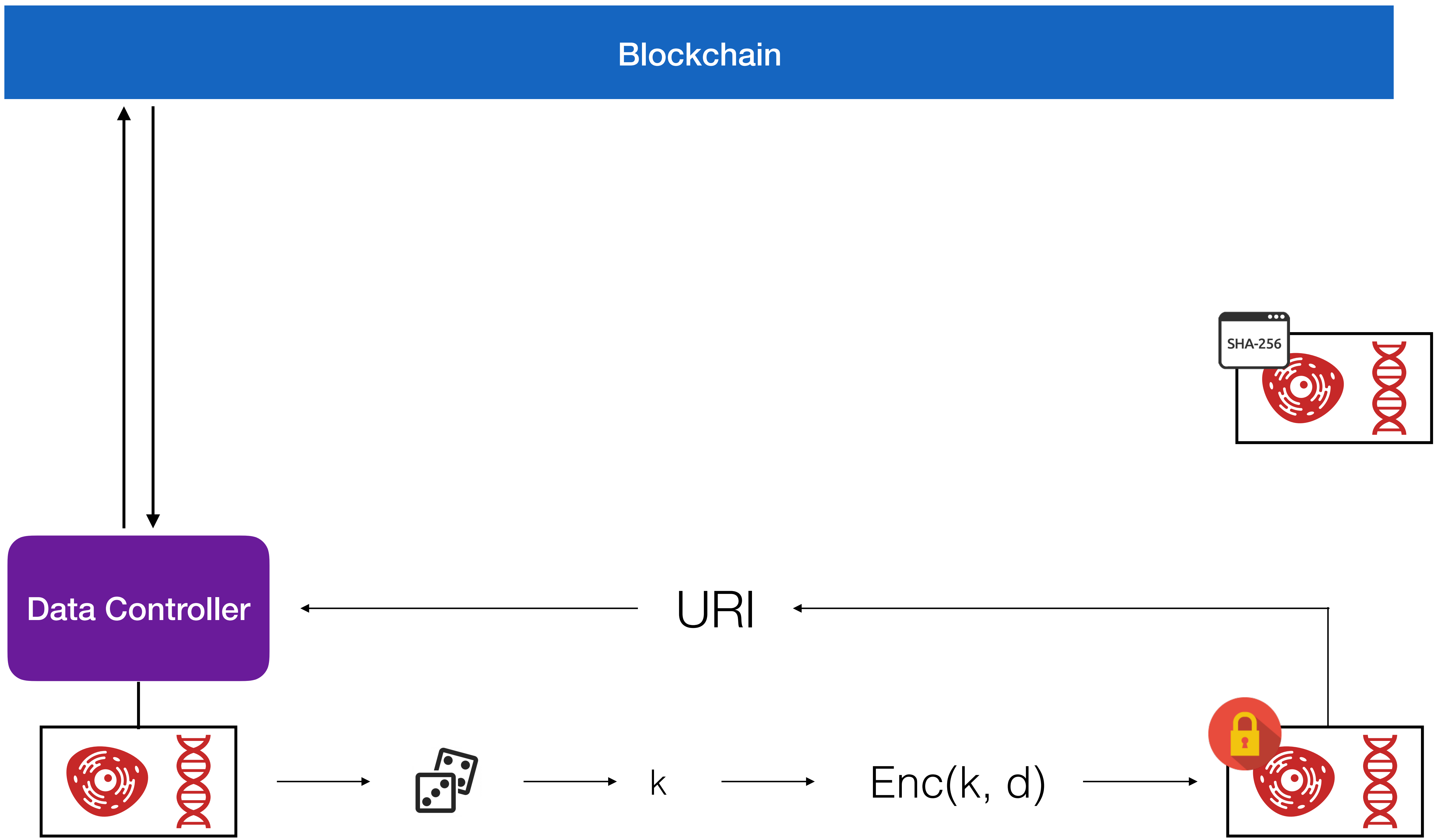
Dataset Registration

Step 1:
Hash dataset



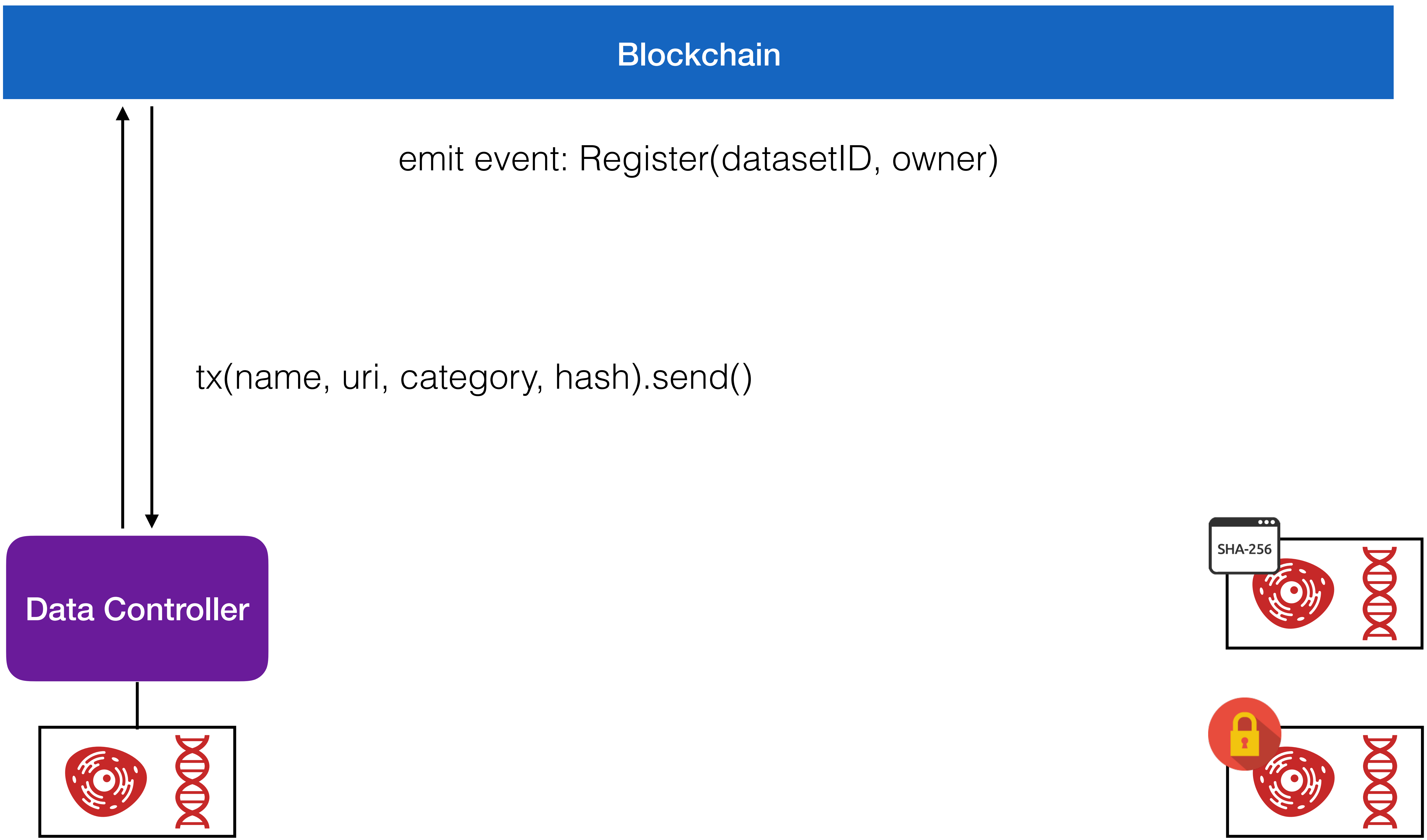
Dataset Registration

Step 2:
Encrypt dataset

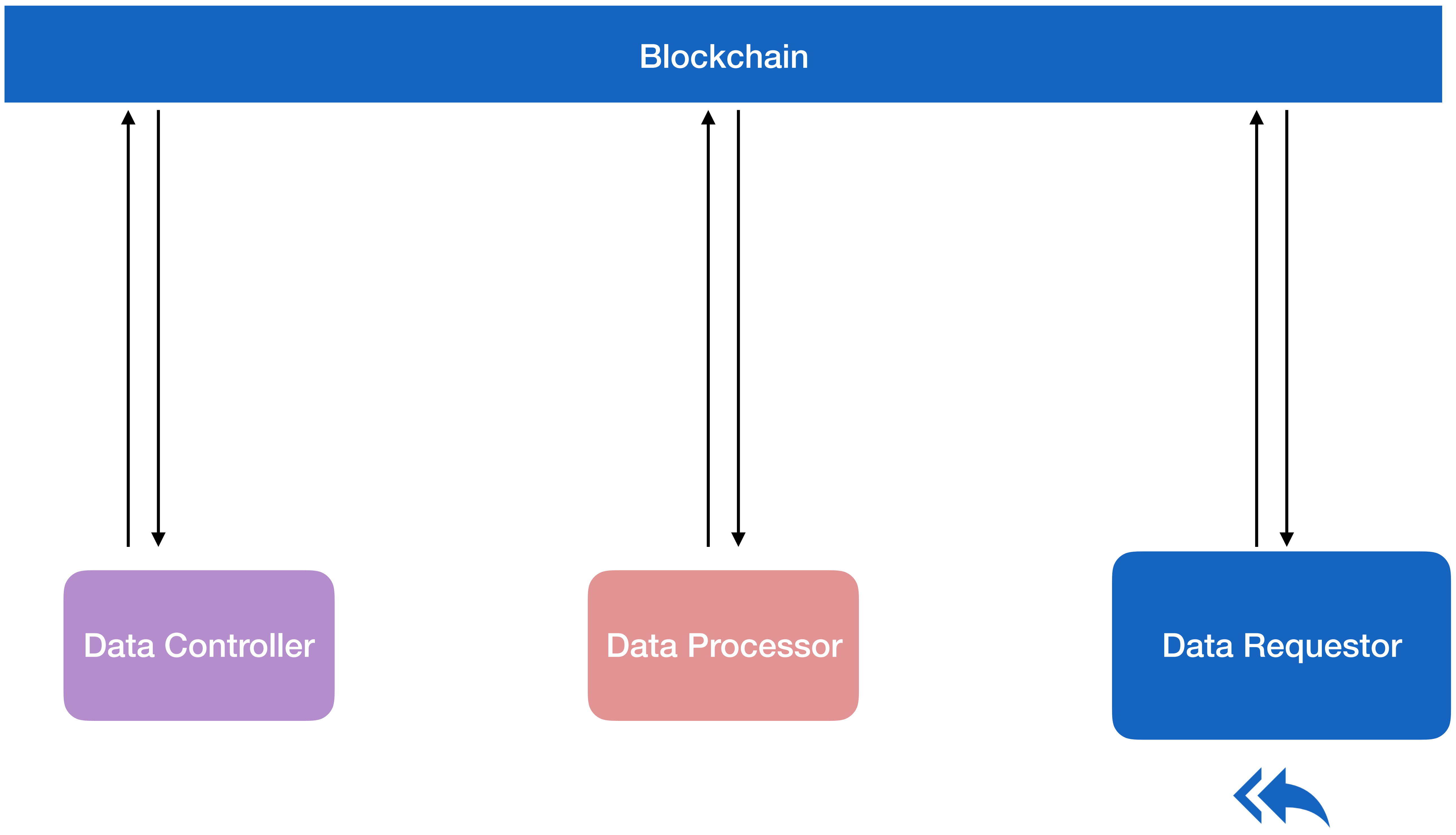


Dataset Registration

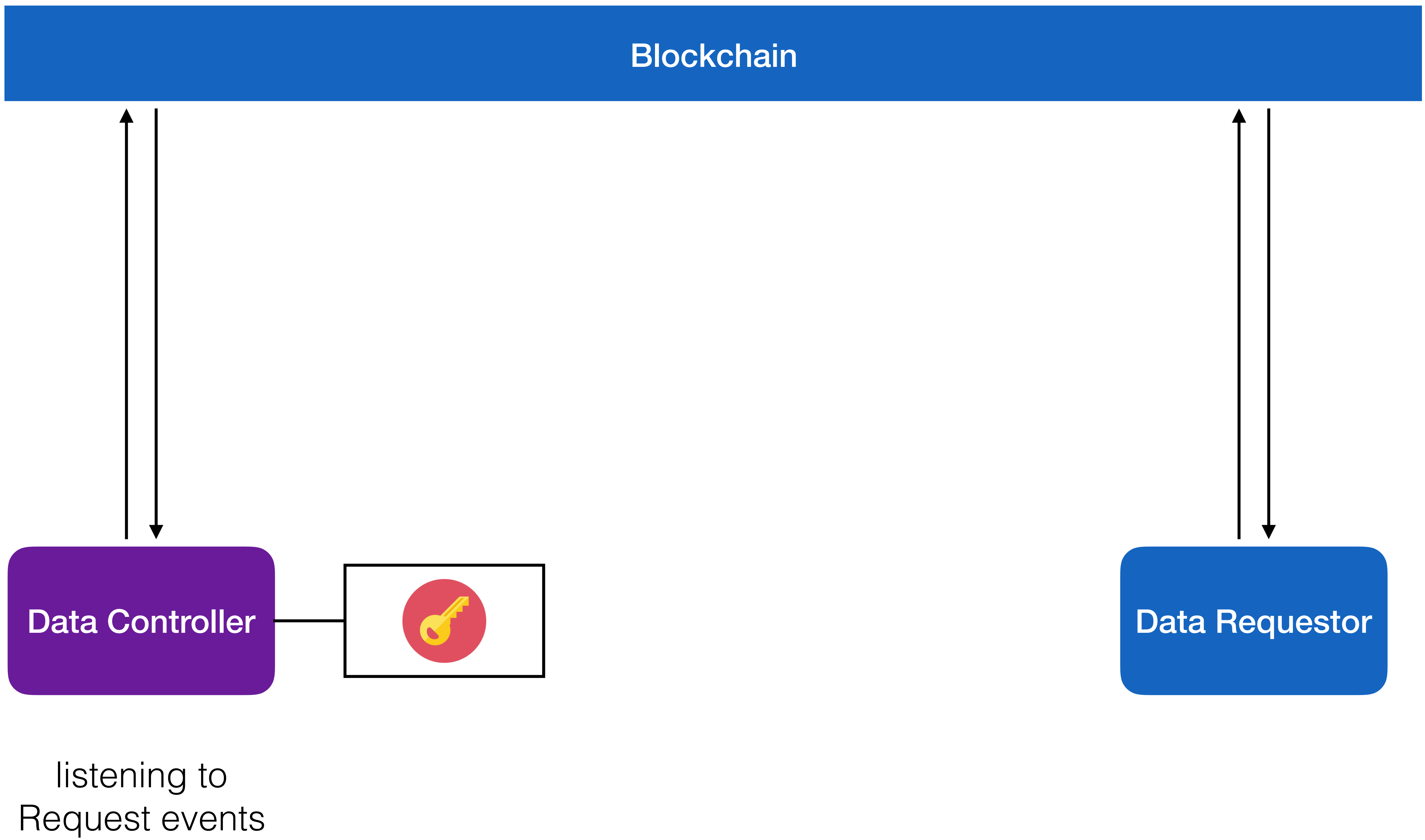
Step 3:
Register dataset



Request for processing

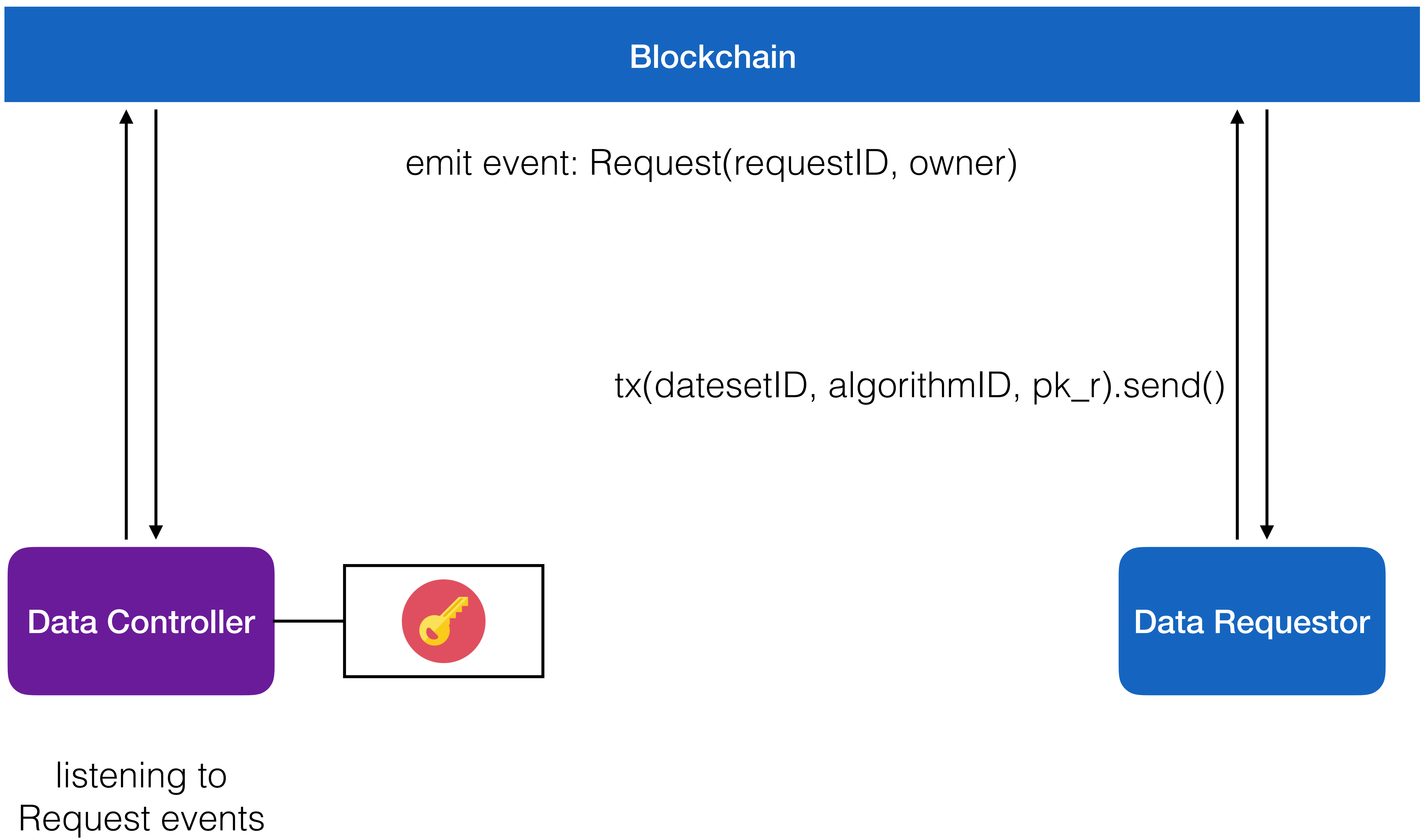


Request for processing



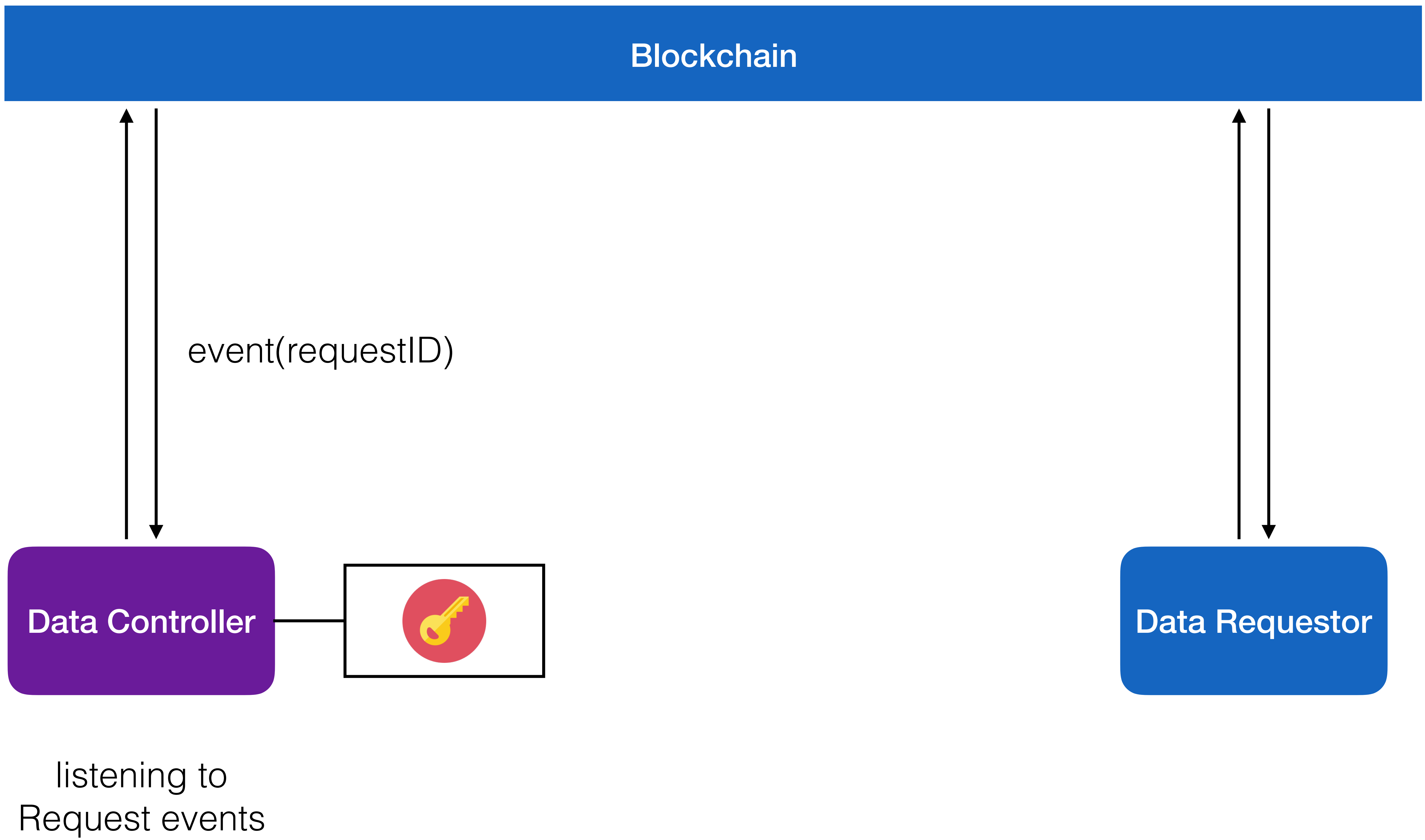
Request for processing

Step 1:
Request for dataset processing



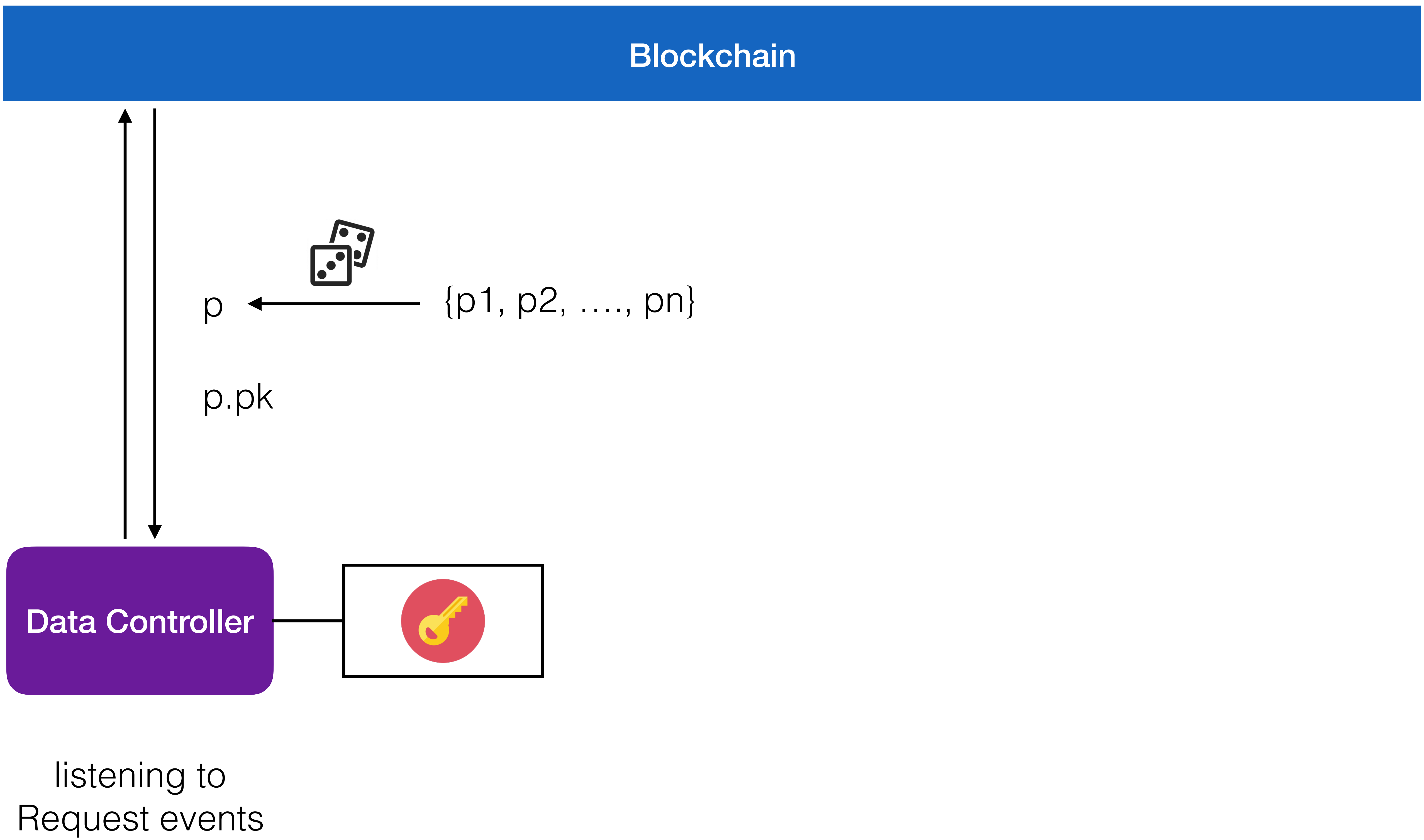
Request for processing

Step 1:
Request for dataset processing



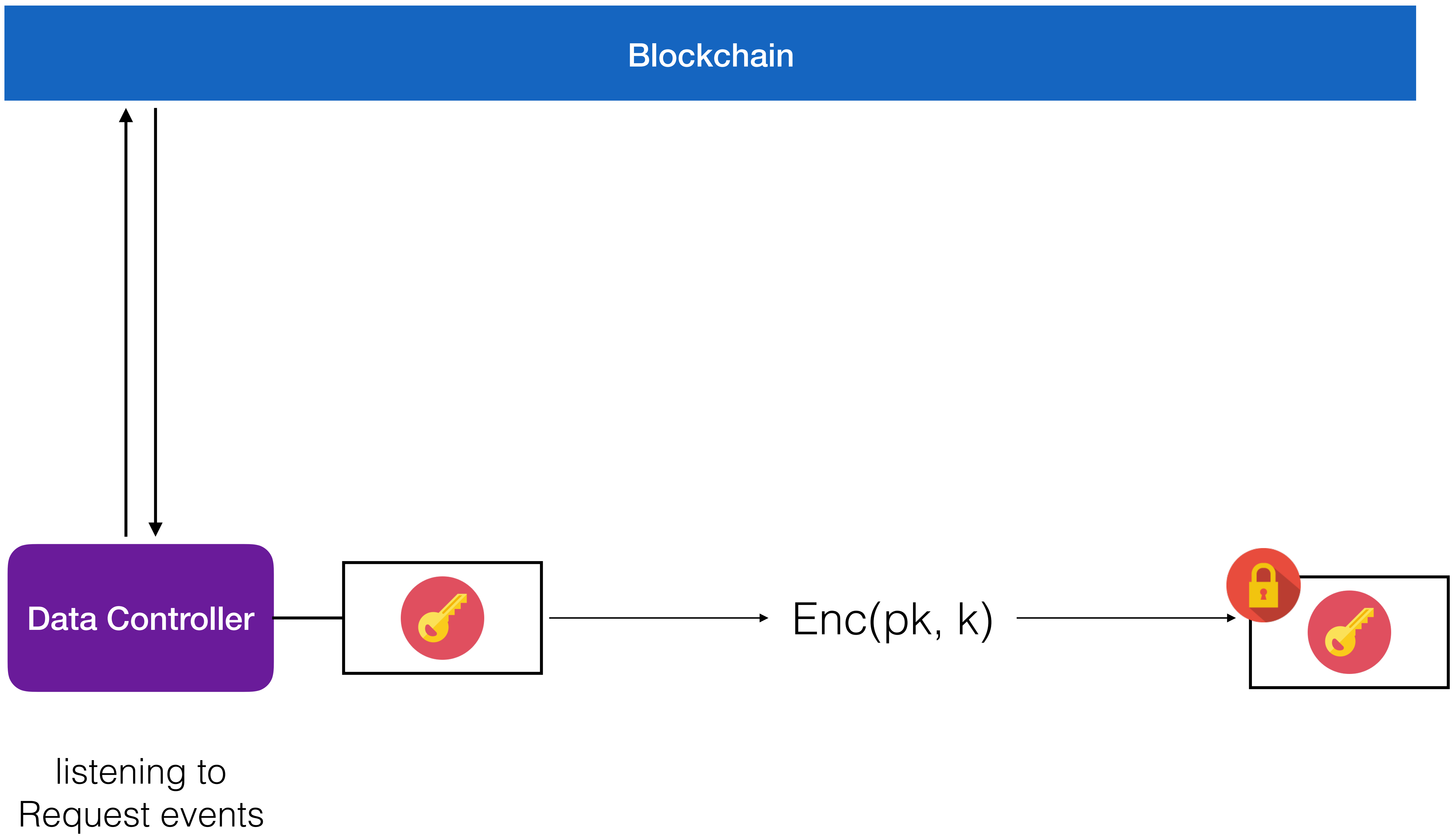
Request for processing

Step 2:
Get processor's public key



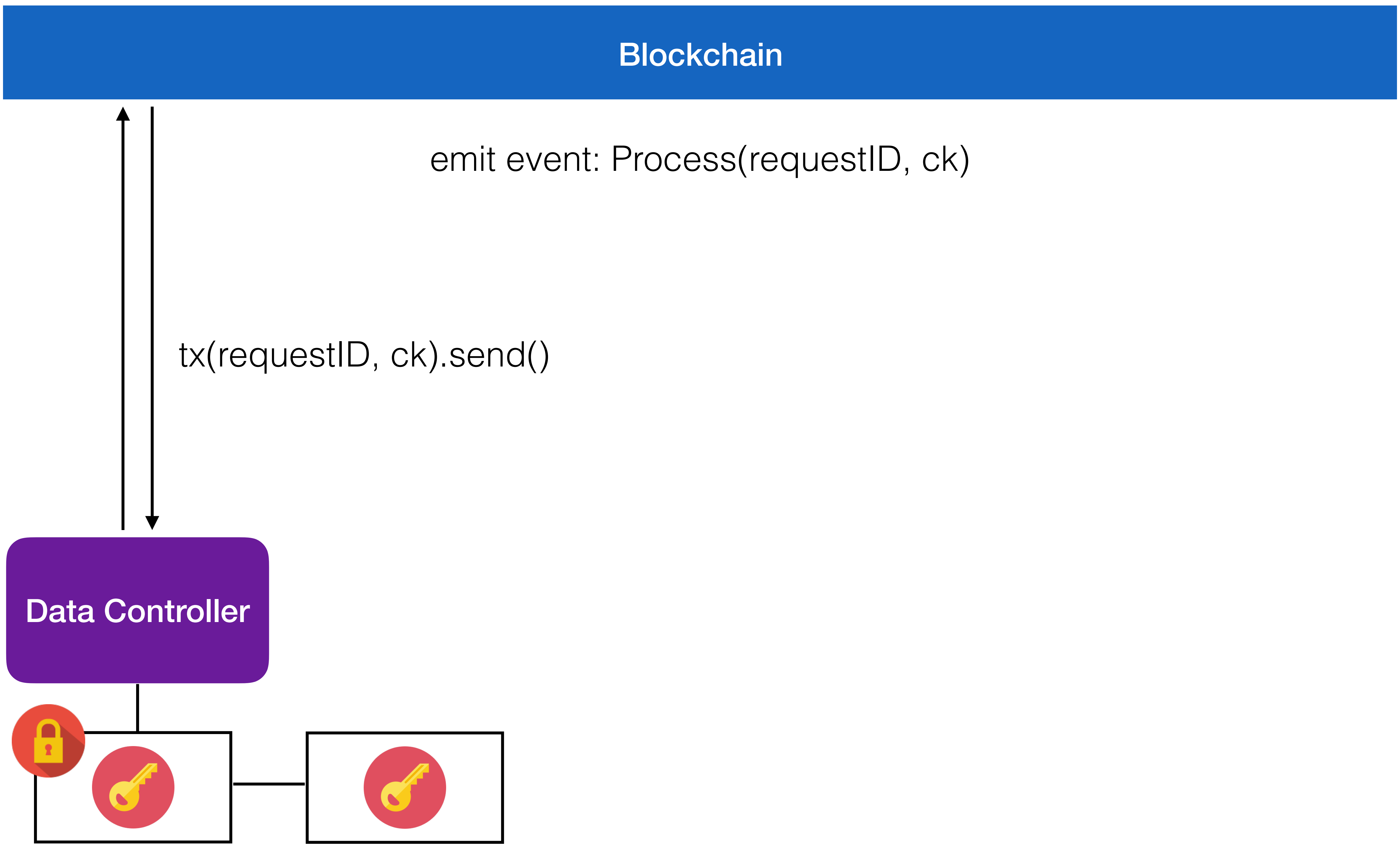
Request for processing

Step 3:
Encrypt symmetric key

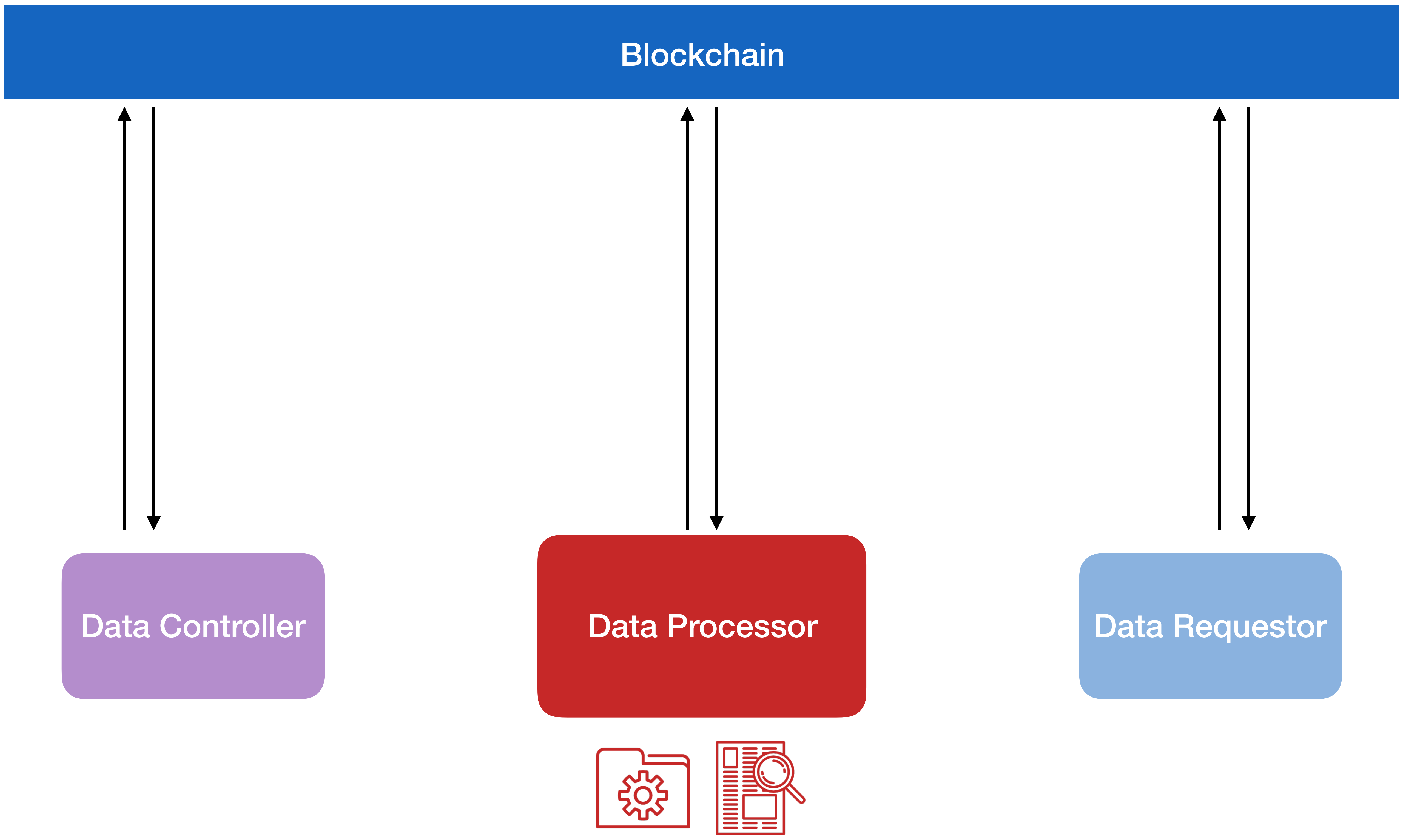


Request for processing

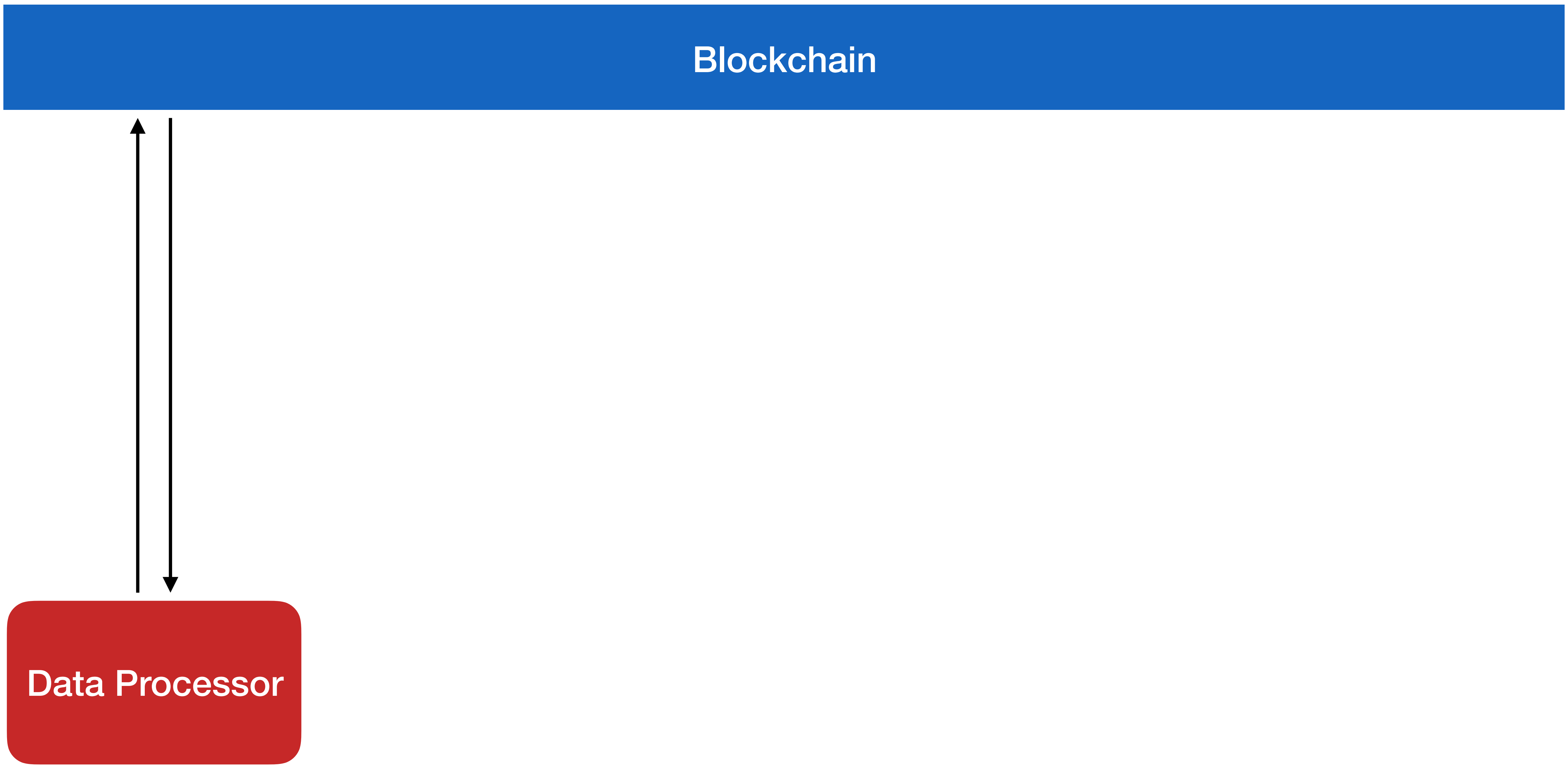
Step 4:
Send symmetric key to processor



Processing


Blockchain
Data Controller
Data Processor
Data Requestor

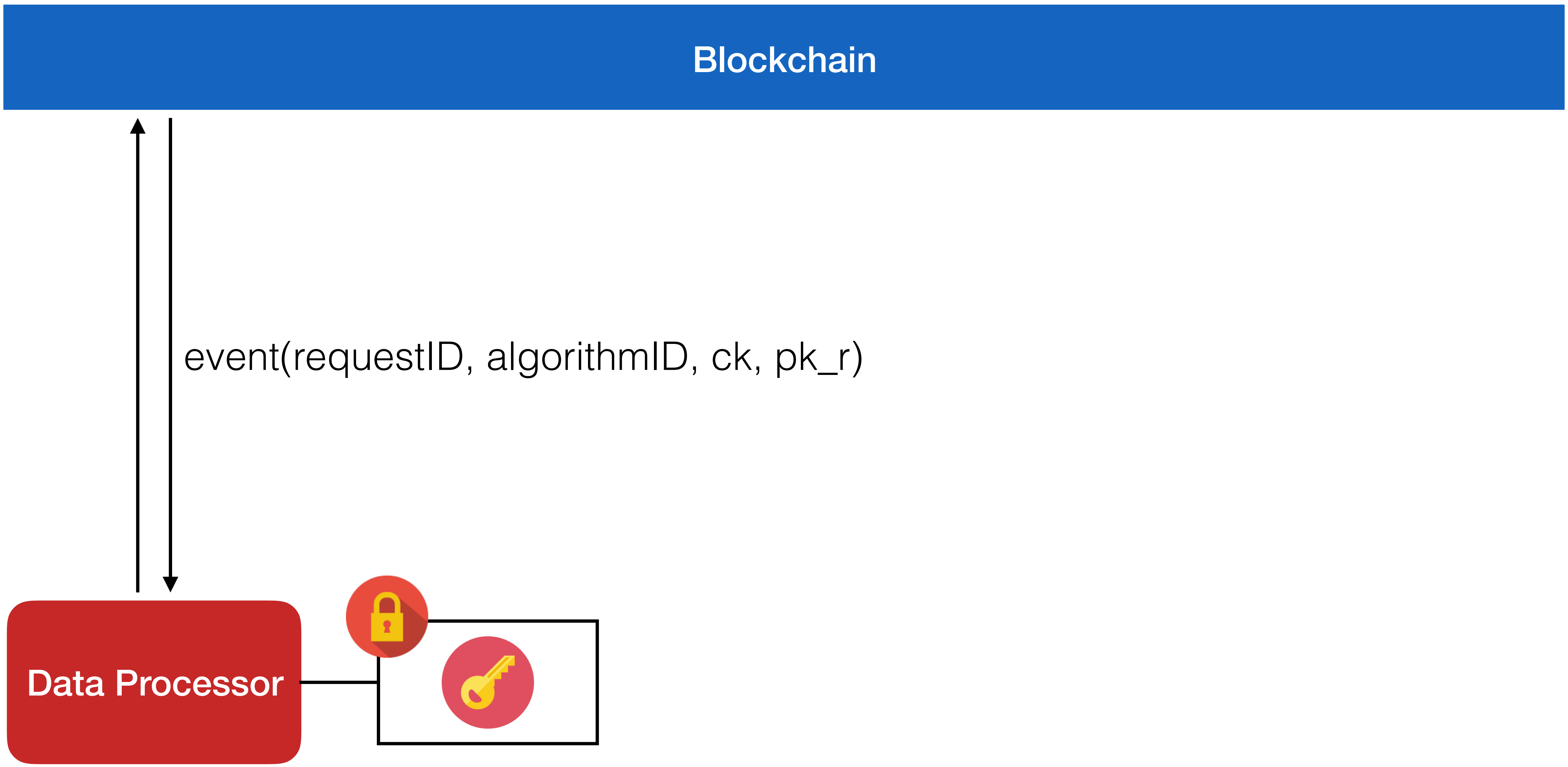
Processing



listening to
Process events

Processing

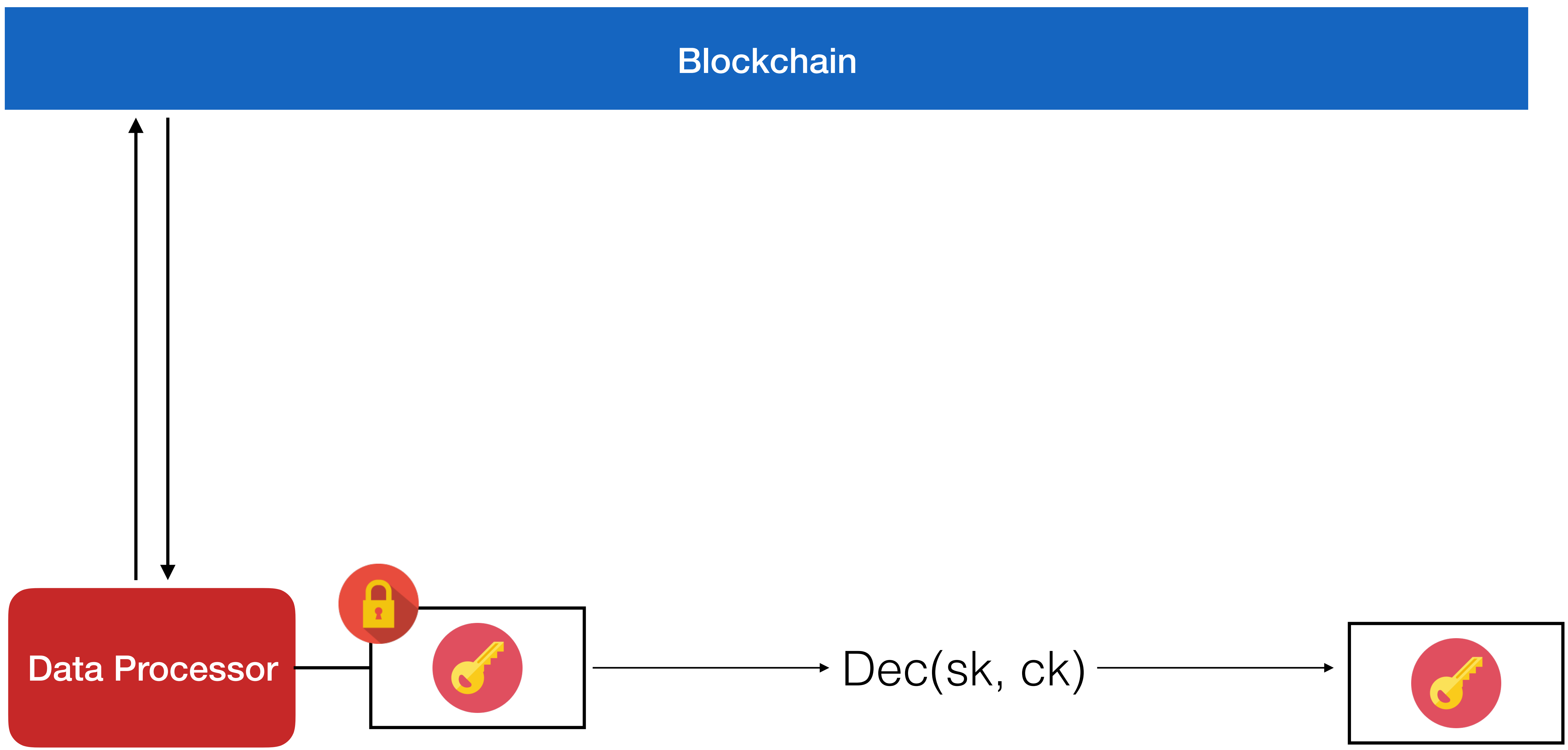
Step 1:
Catch process event



listening to
Process events

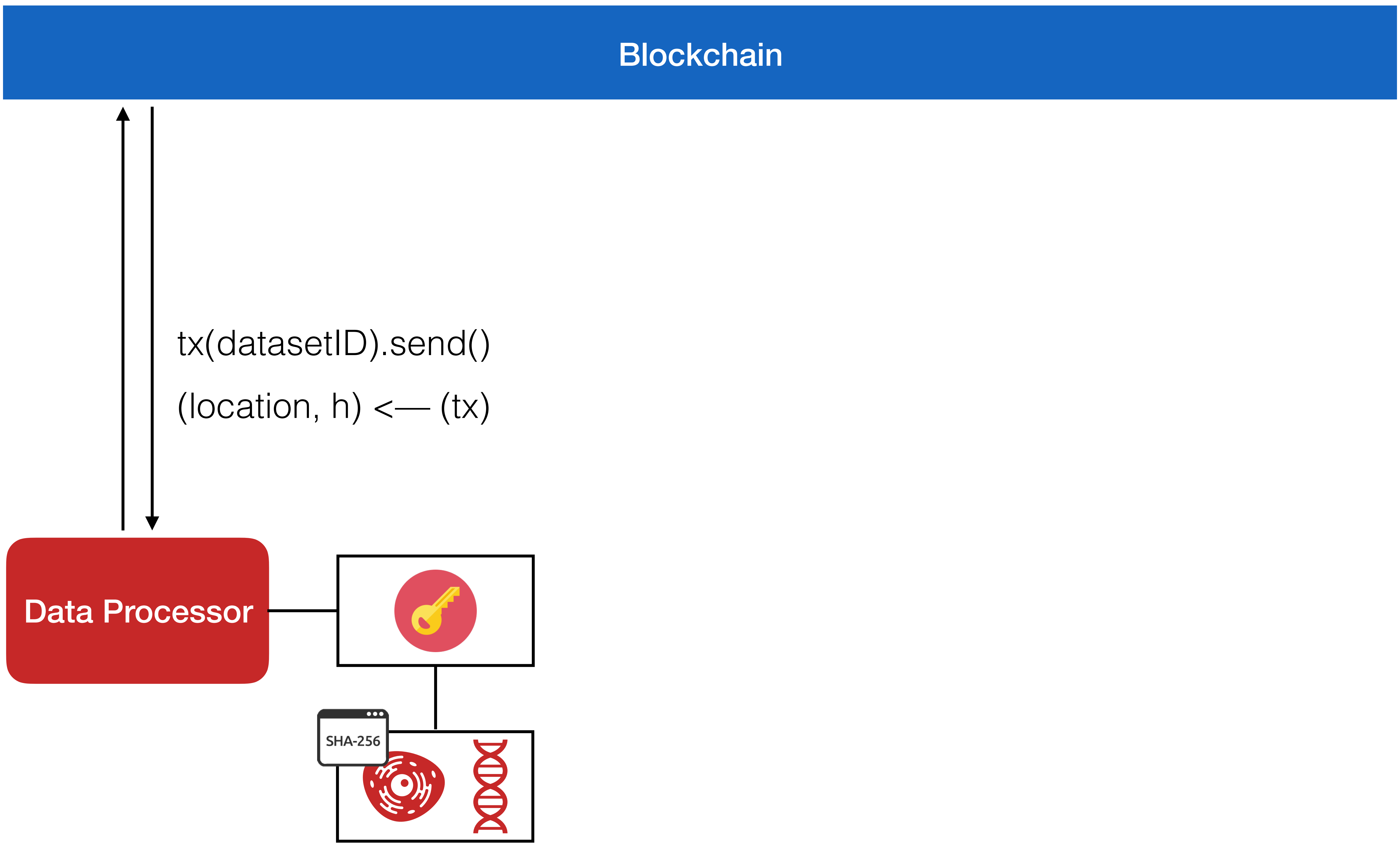
Processing

Step 2:
Decrypt key



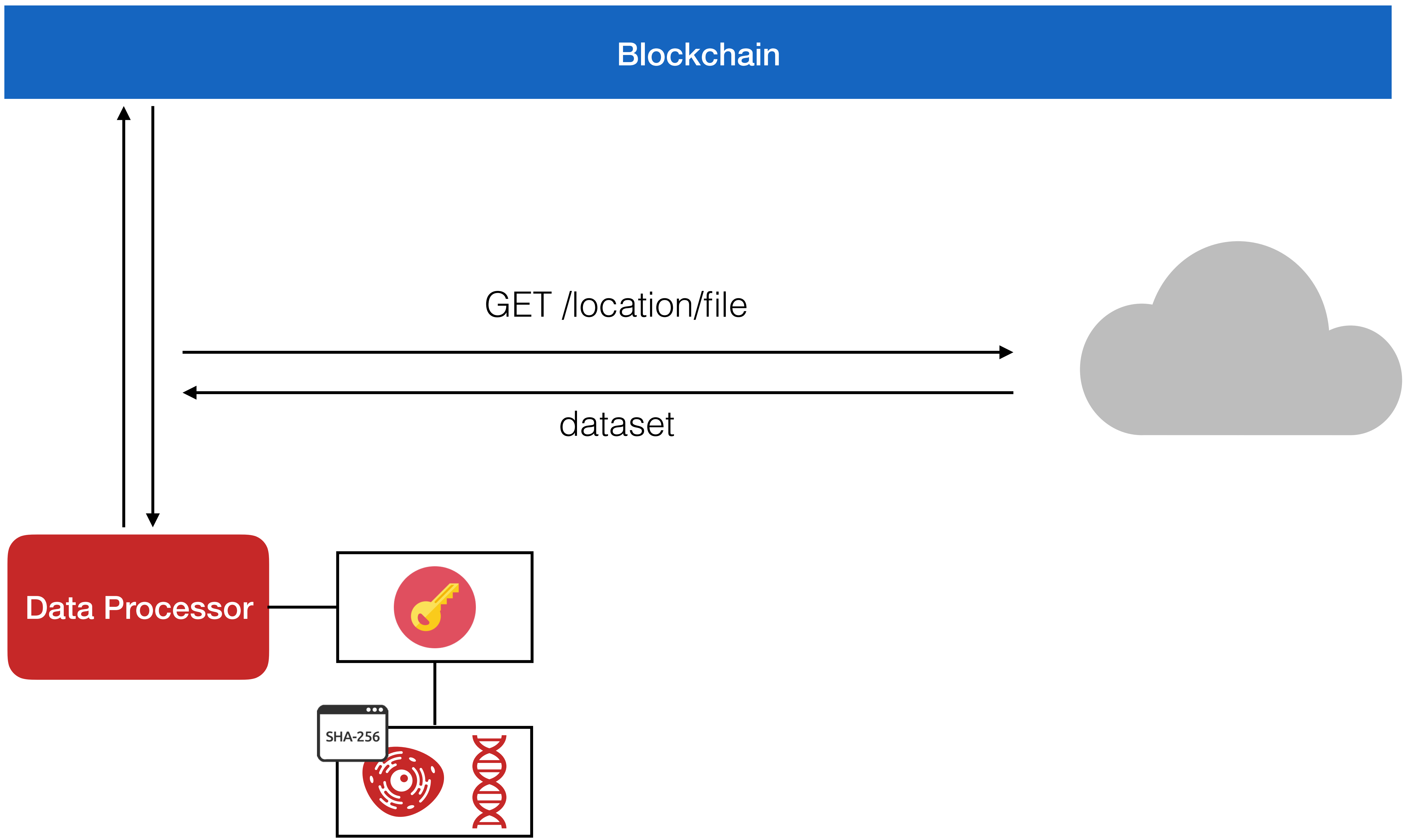
Processing

Step 4:
Get dataset info



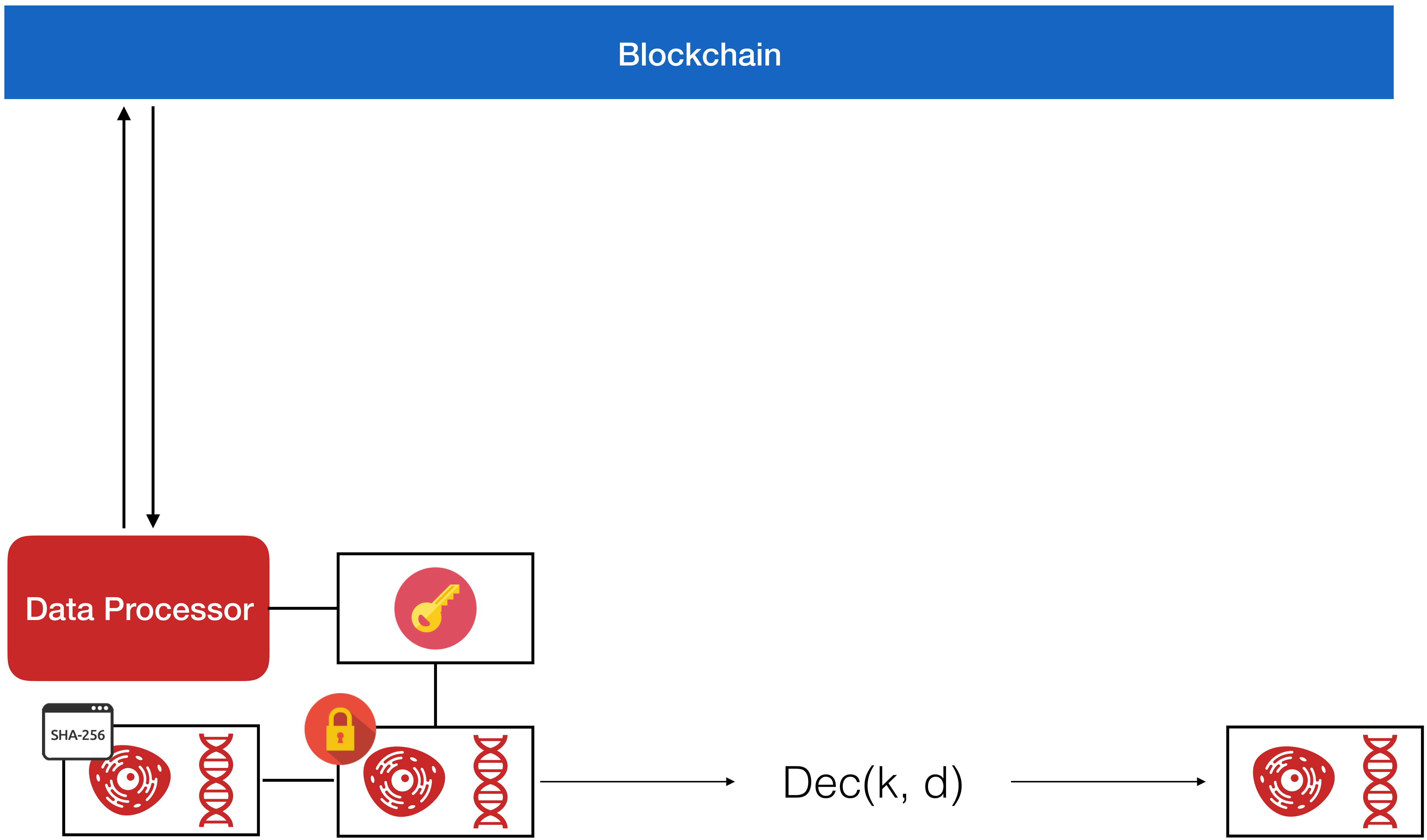
Processing

Step 5:
Get dataset



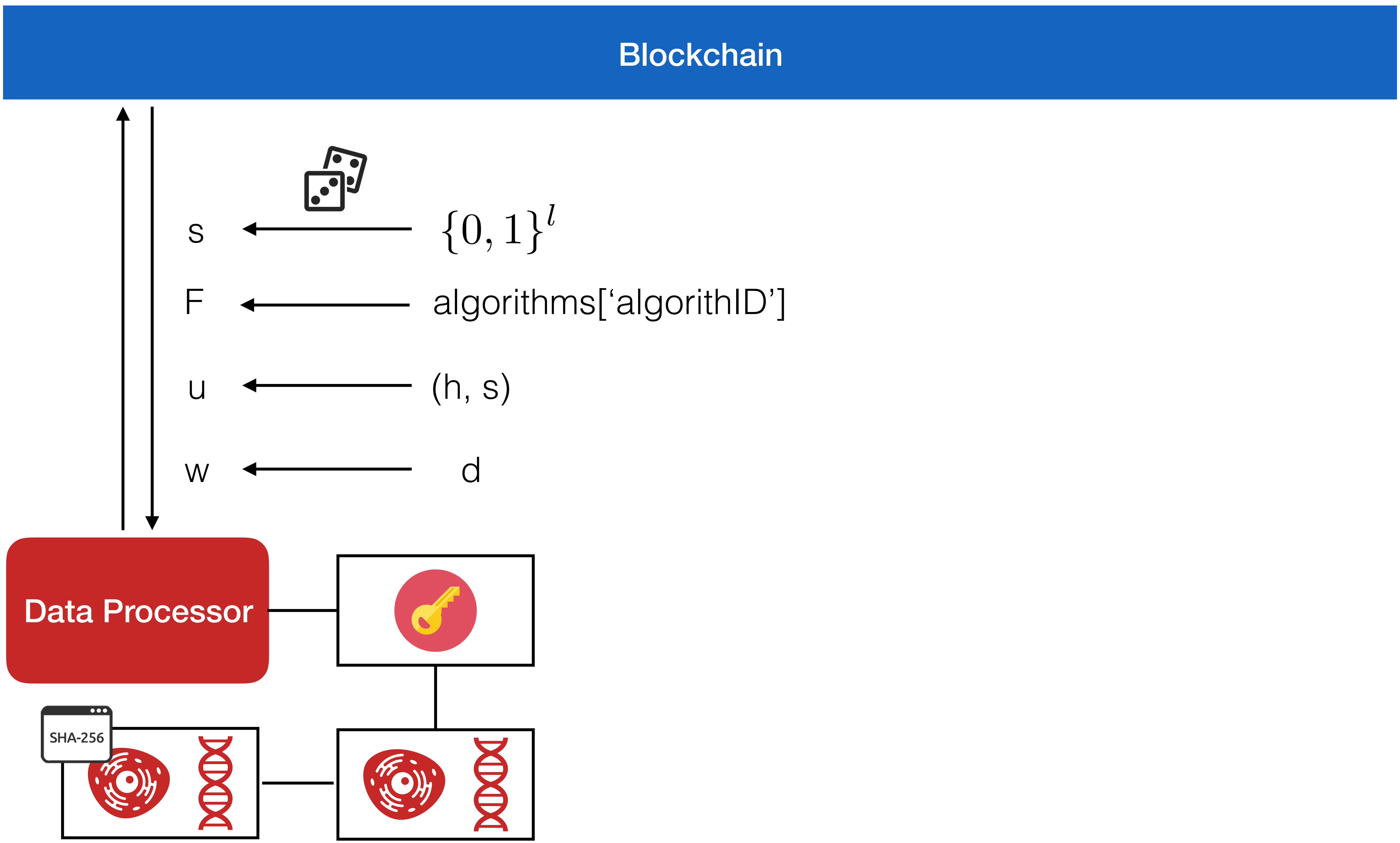
Processing

Step 6:
Decrypt dataset



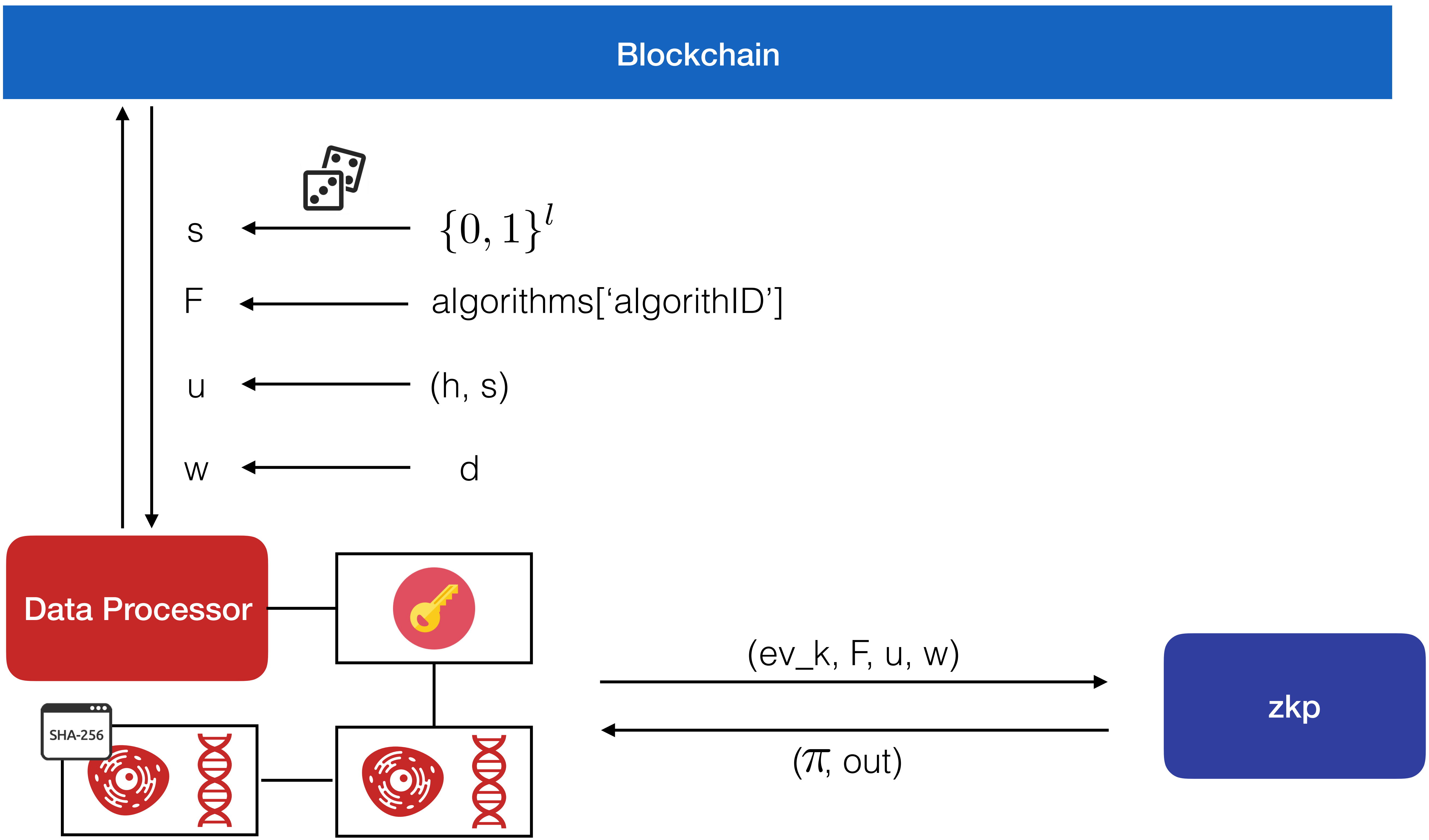
Processing

Step 6:
Proof



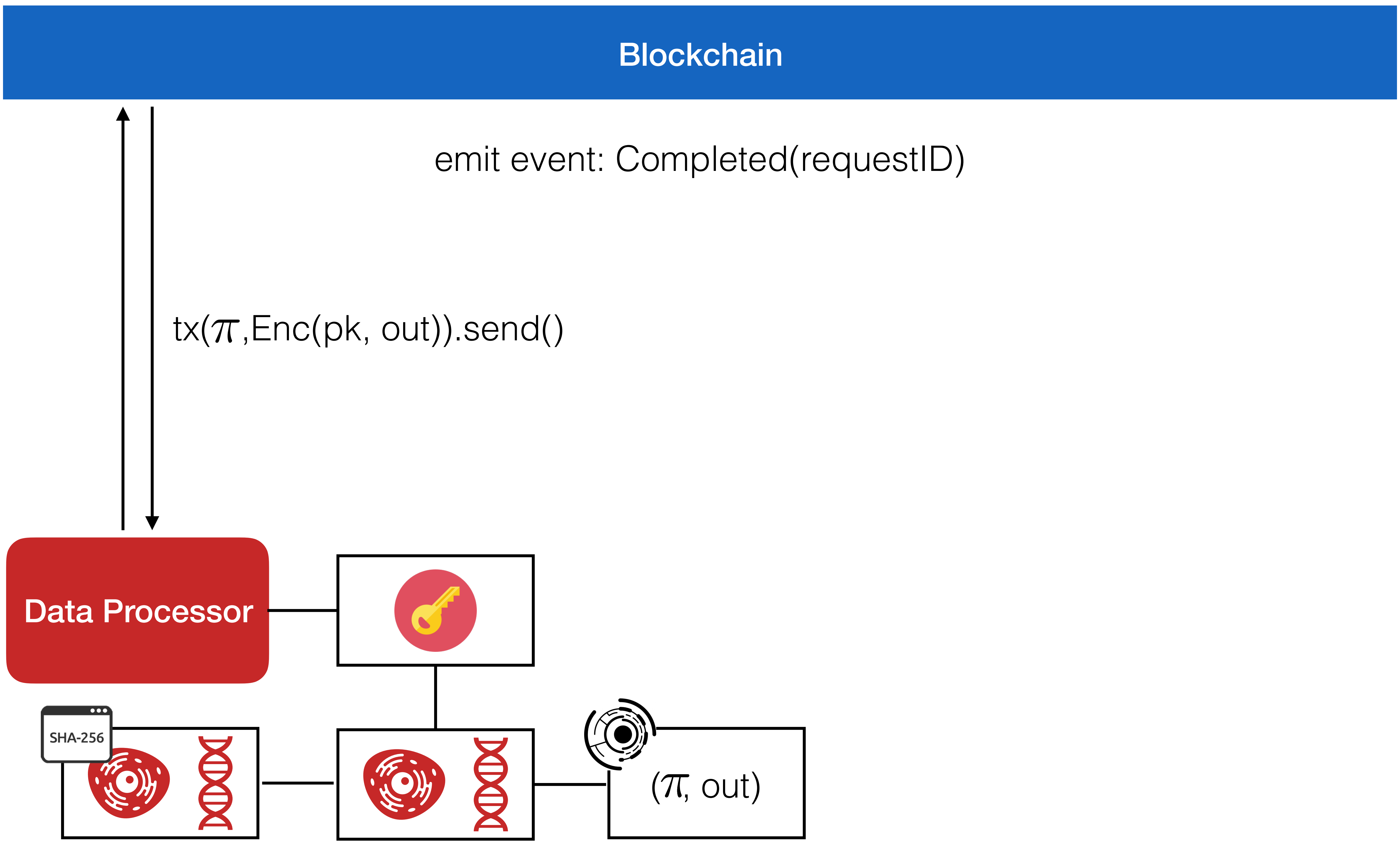
Processing

Step 6:
Proof

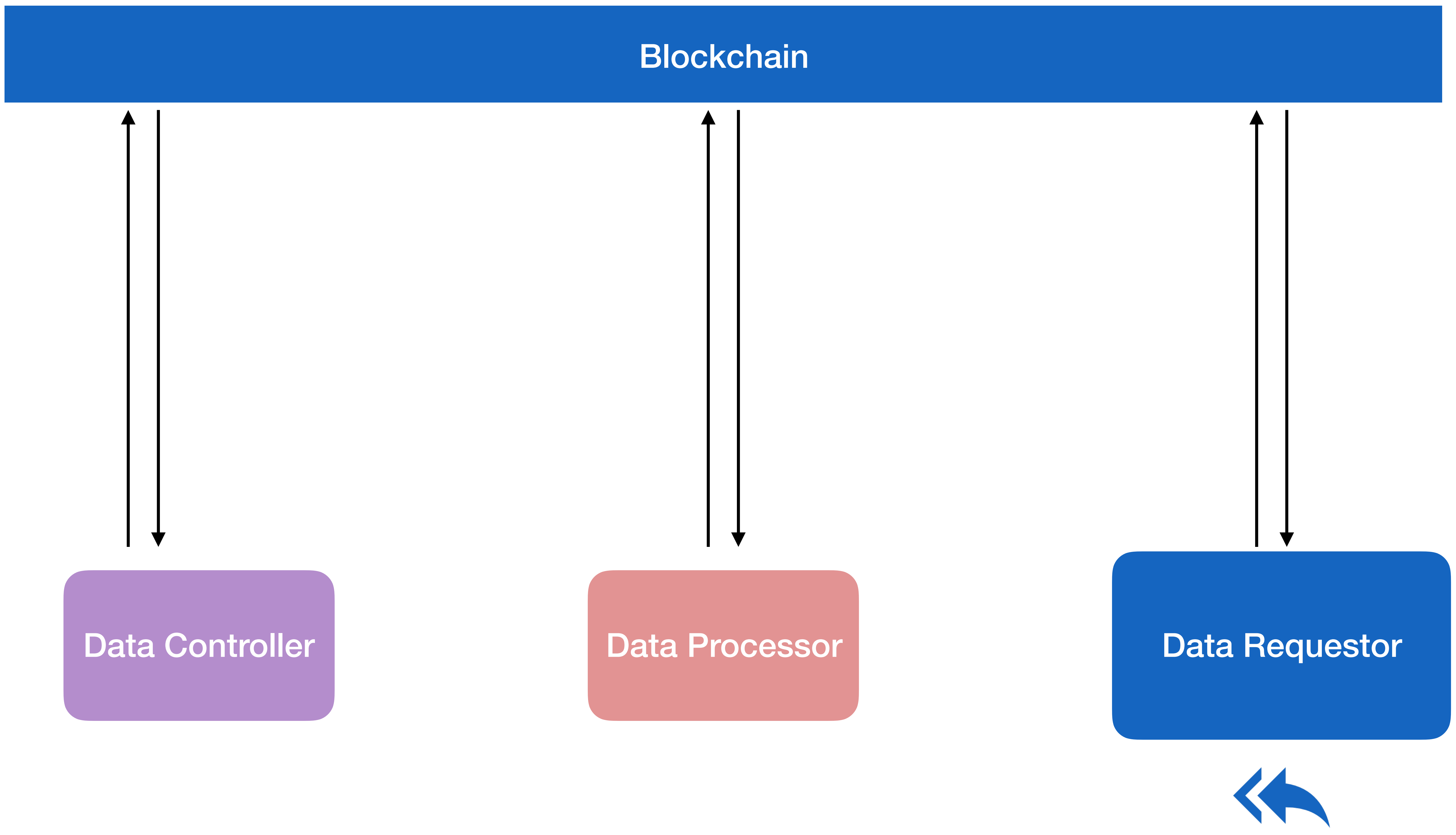


Processing

Step 6:
Send proof

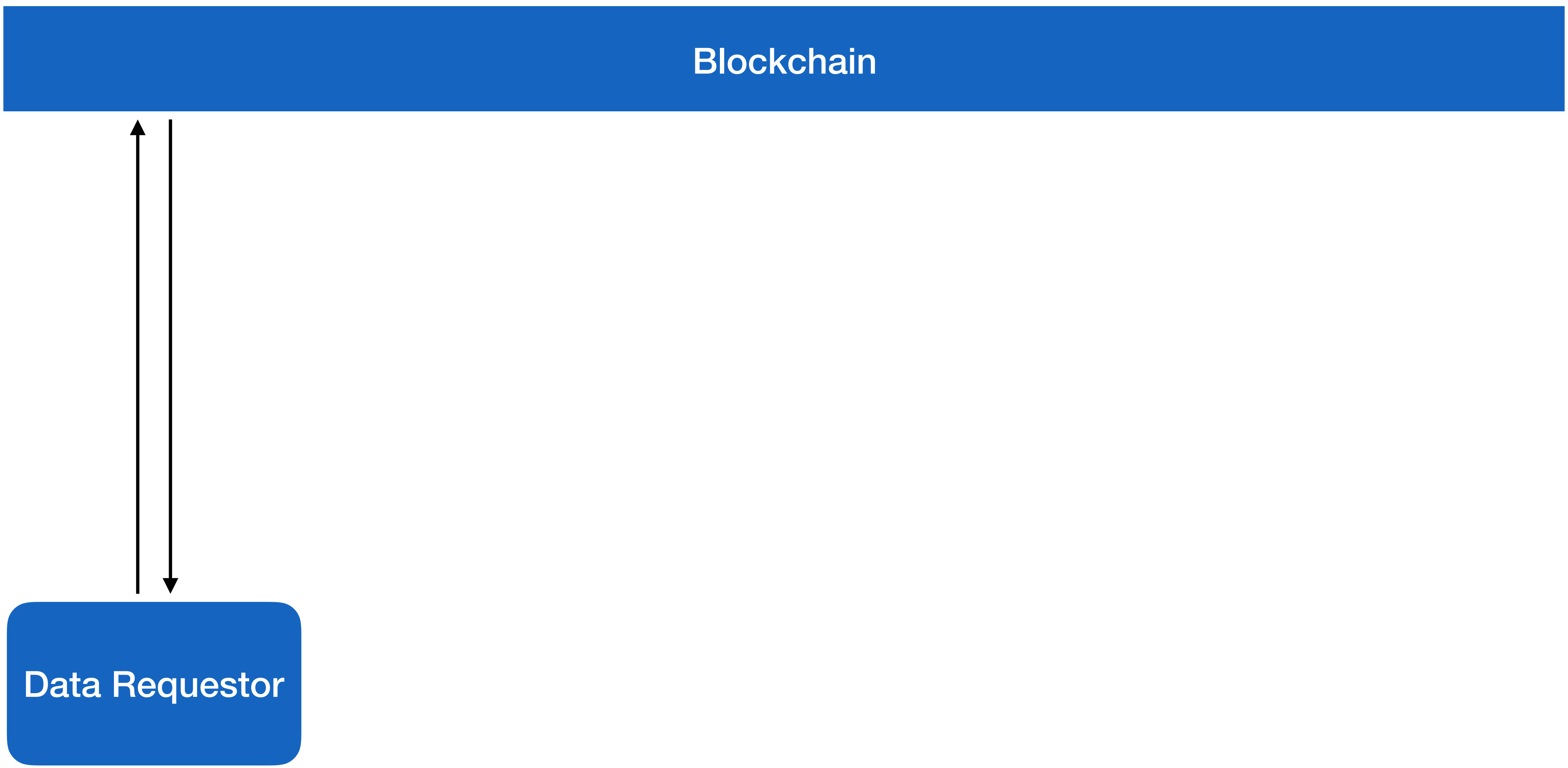


Verification



Verification

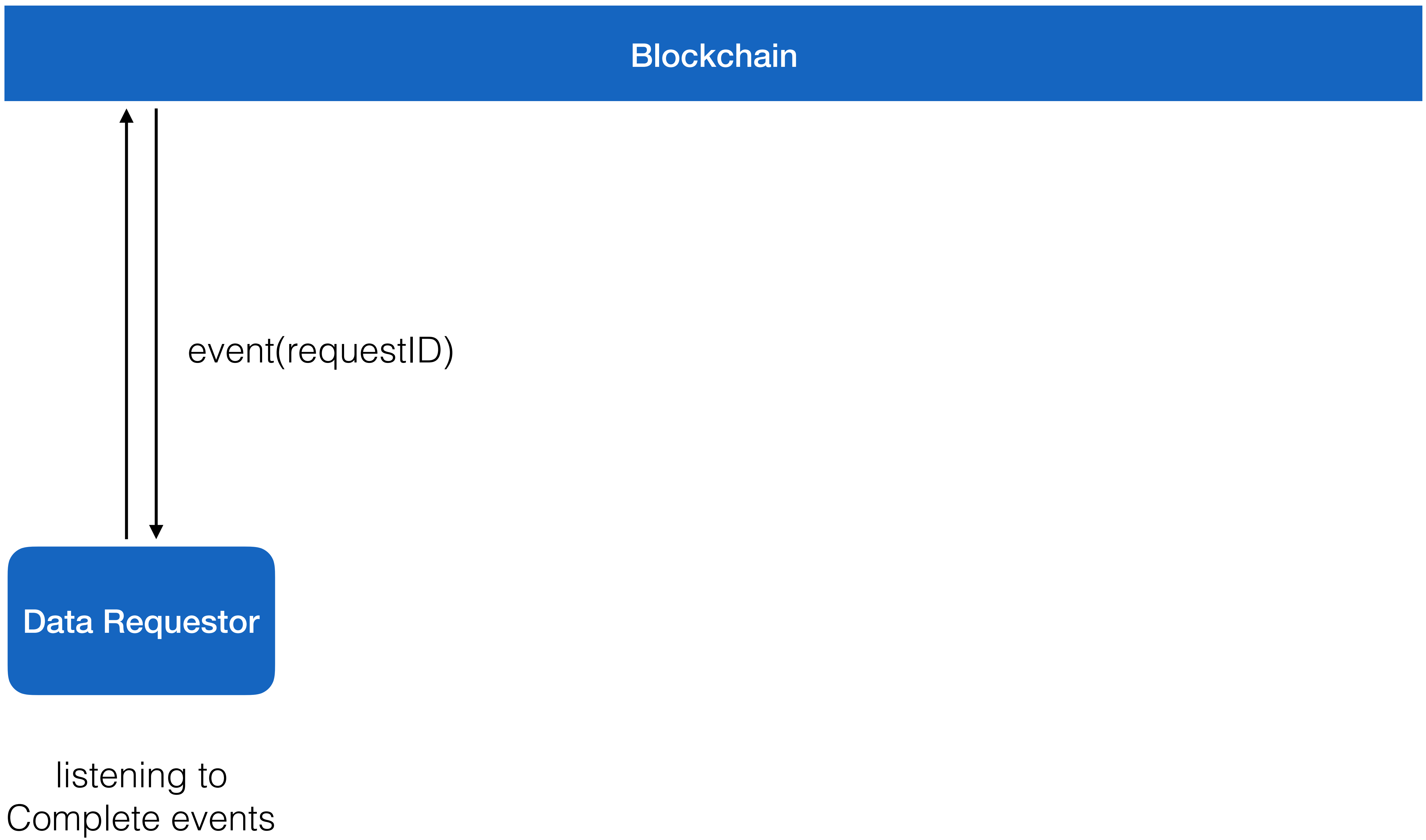
Step 1:
Get proof



listening to
Complete events

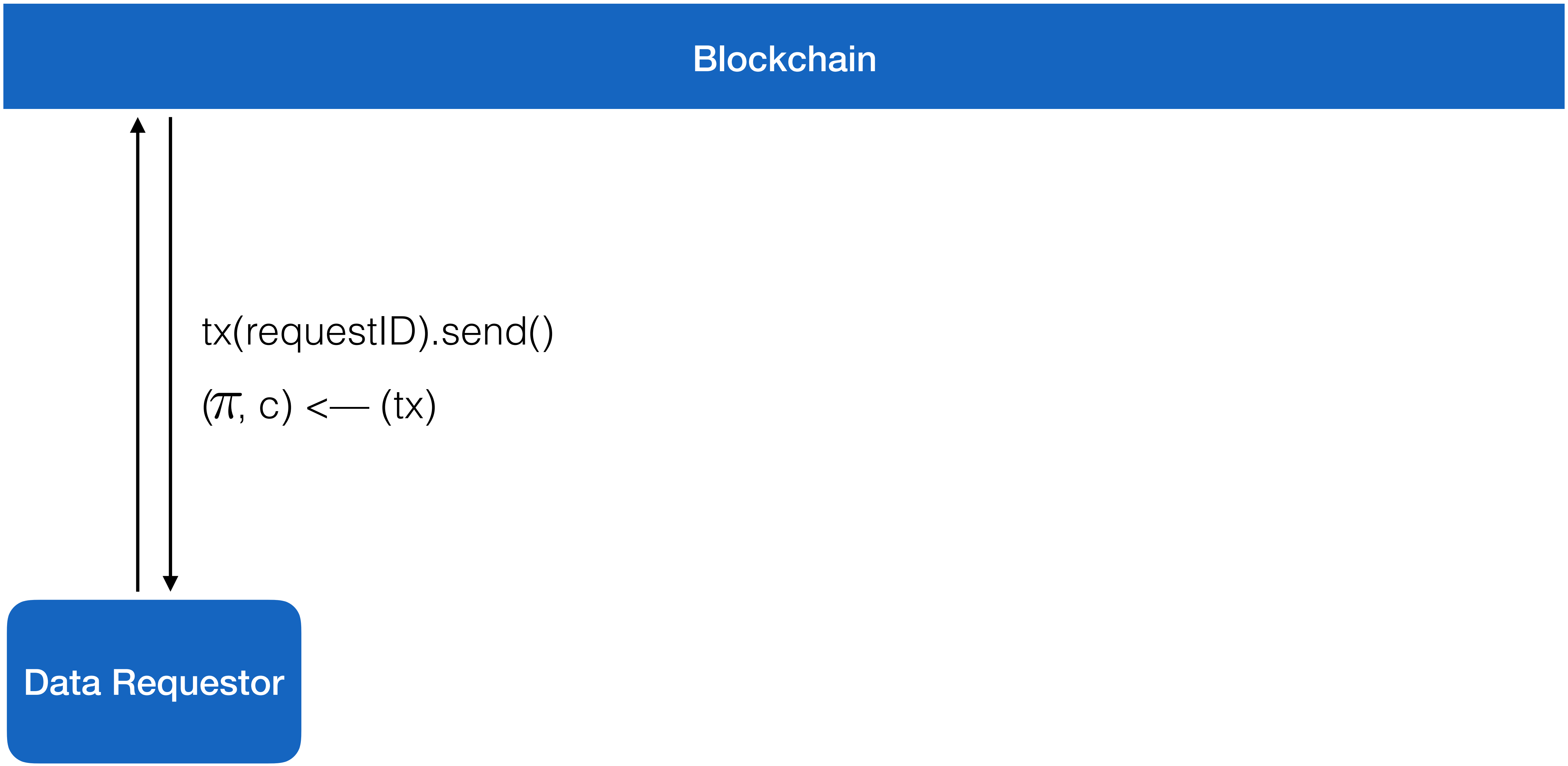
Verification

Step 1:
Get proof



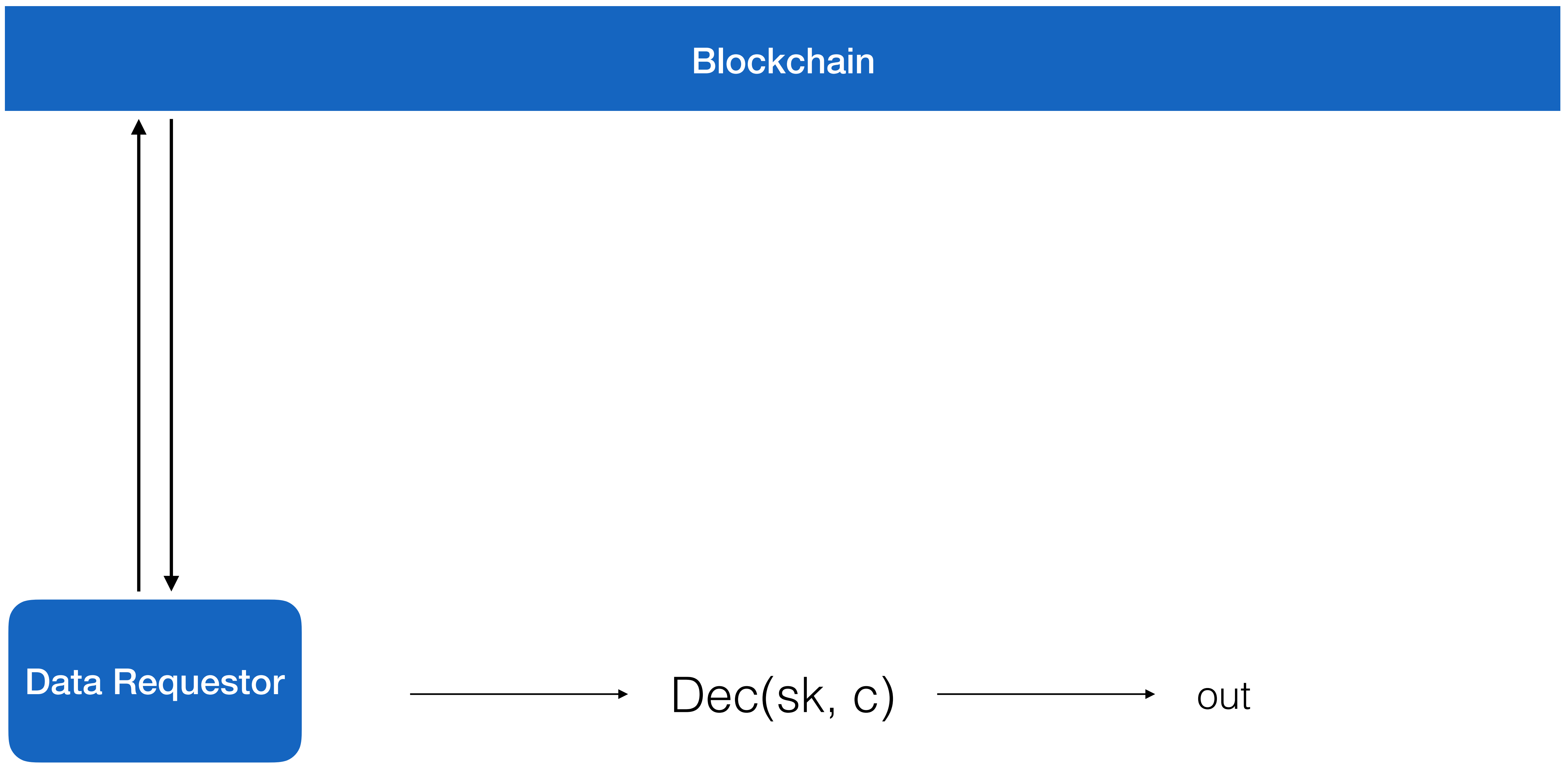
Verification

Step 1:
Get proof



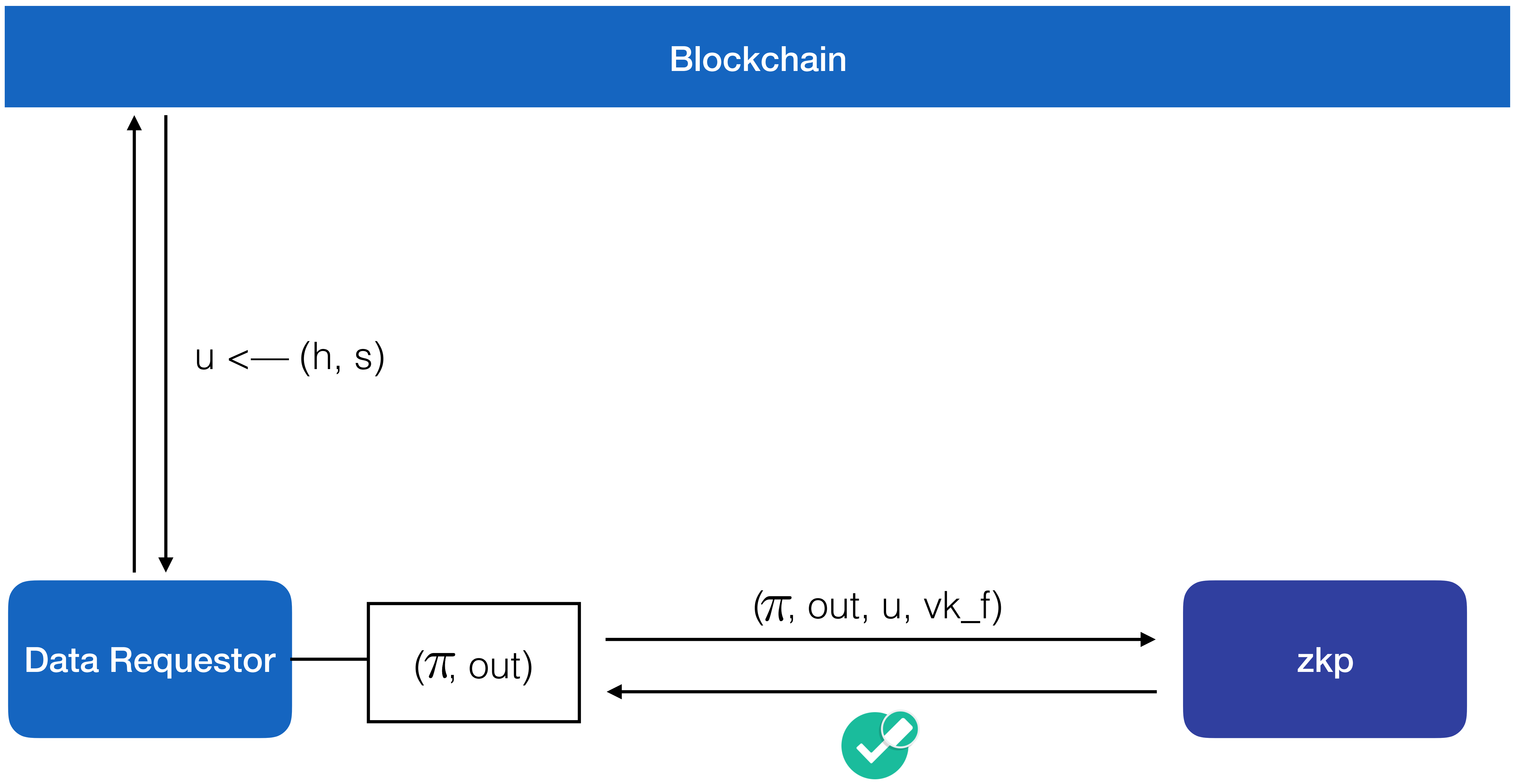
Verification

Step 2:
Decrypt results



Verification

Step 3:
Verify proof



zkSNARKs [PHGR13]

Let **F** an outsource function, a public input **u,** a private input **w** and **y = F(u, w)**

A zero knowledge verifiable computation scheme consist of a set of three polynomial algorithms:

$$(ek_f, vk_f) \leftarrow \mathcal{G}(F, 1^\lambda)$$

$$(y, \pi) \leftarrow \mathsf{Compute}(ek_f,\ u)$$

$$\{0, 1\} \leftarrow \mathsf{Verify}(vk_f, u, y, \pi)$$

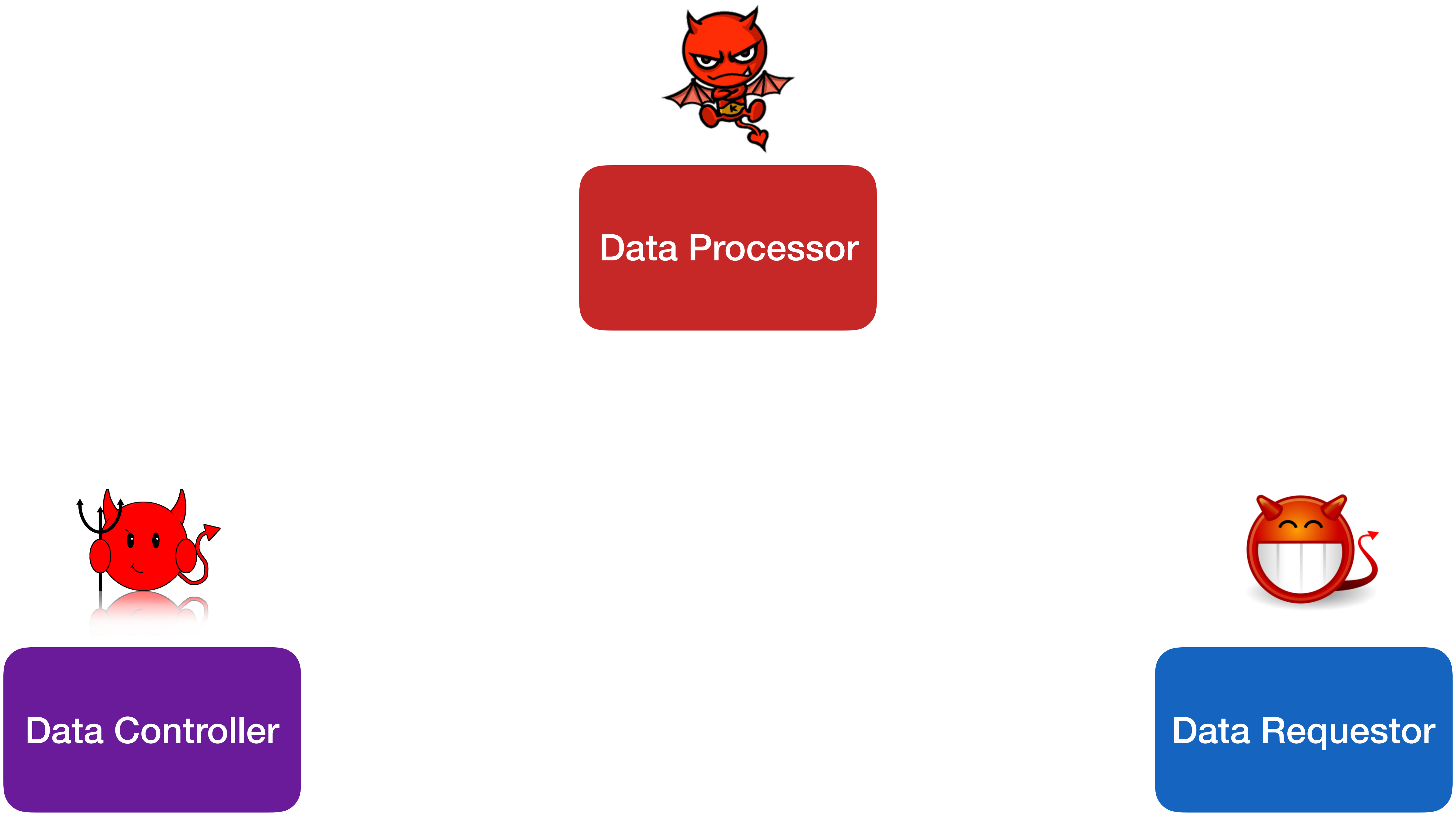
Security assumptions

- Public key infrastructure (PKI)
    - Authenticates and verifies the data processor and the data controller
    - Perform the trusted setup for each algorithm

Assumptions

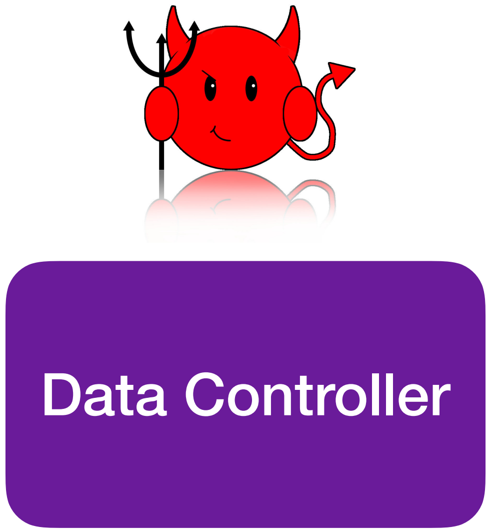
- Data controller:
  - Integrity
  - Confidentiality
- Data processor:
  - Confidentiality

Threat model



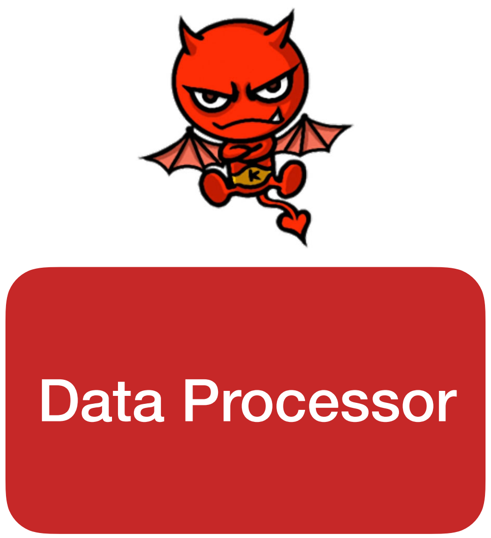
Threat model

- Fabricated dataset to manipulate results
- Collusion with data processor



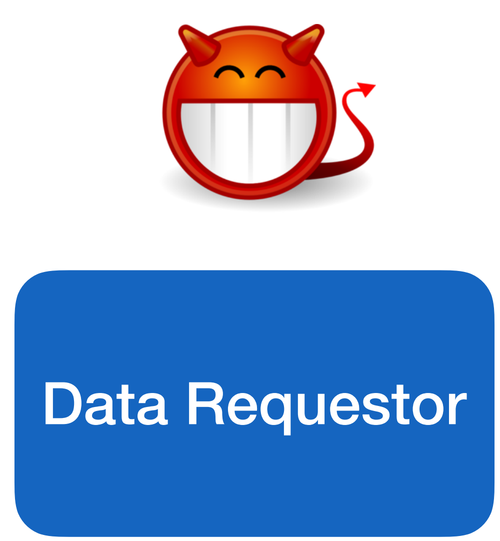
Threat model

- Fake computation
- Process different dataset
- Use different algorithm
- Fake results
- Expose dataset



Threat model

- DDoS attacks



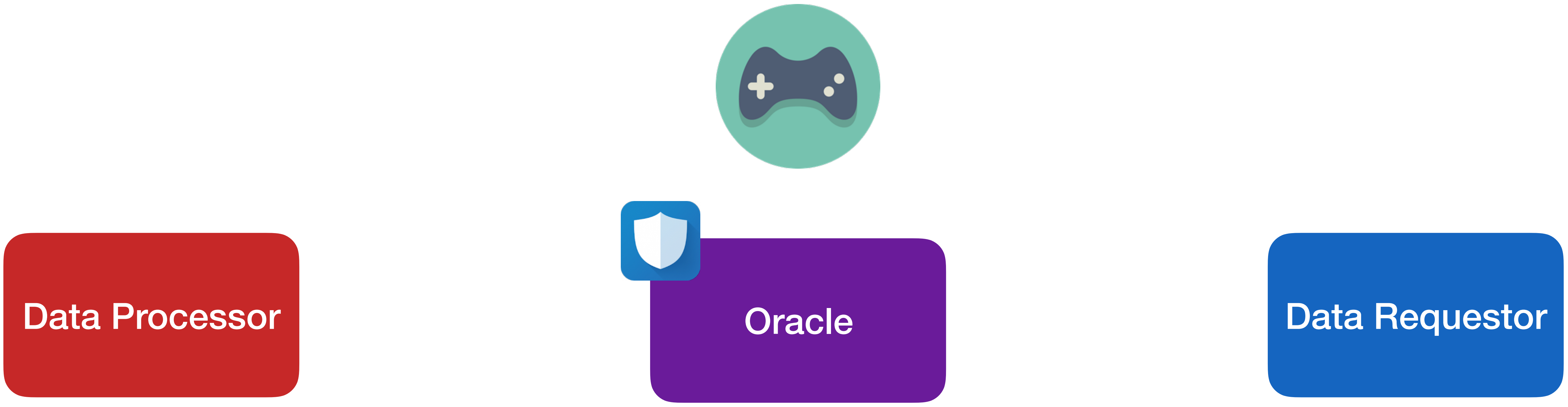
Proof

“I did the **correct** computation on the **requested** dataset and algorithm”

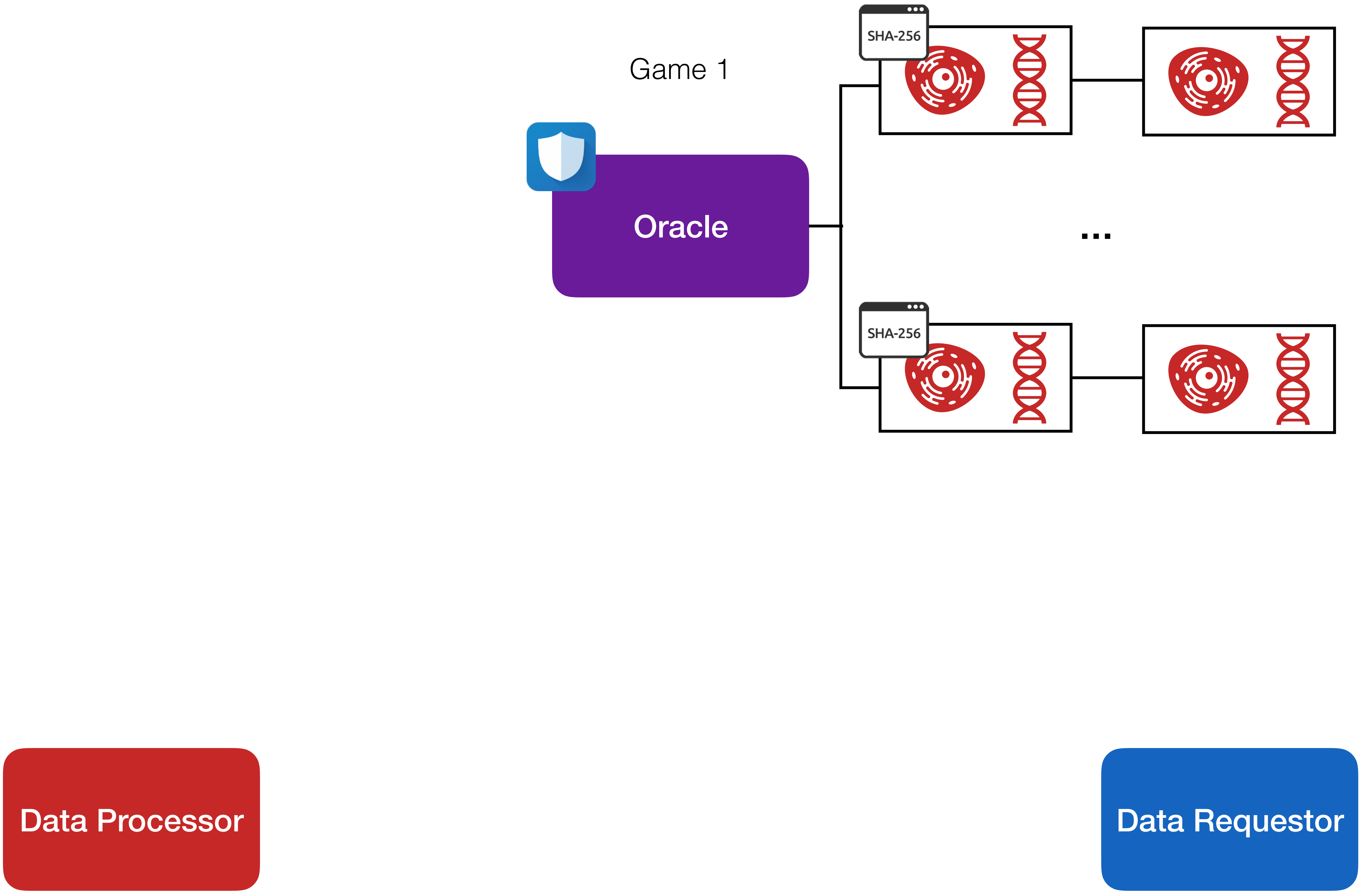
Proof

Trusted Oracle:

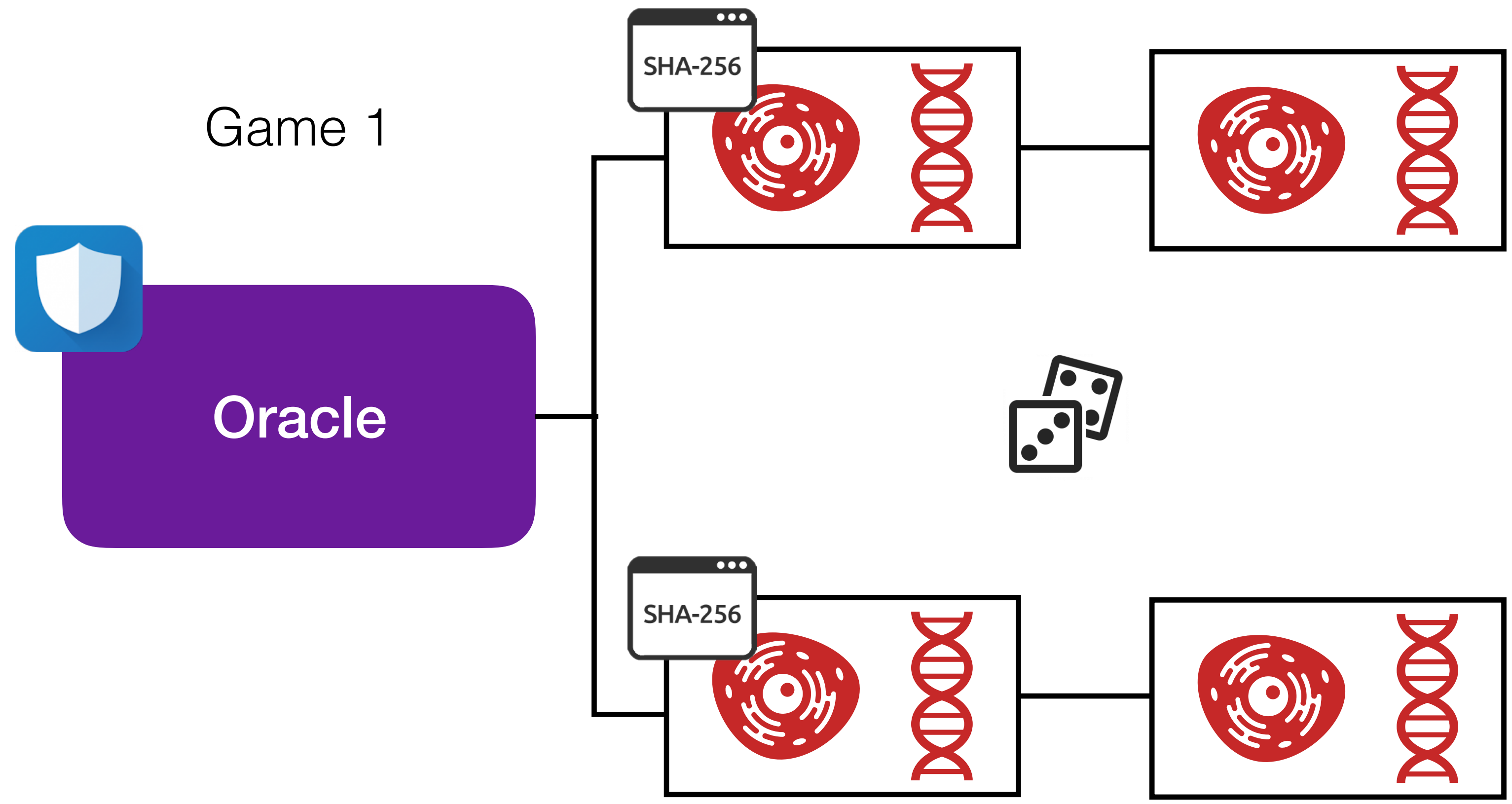
- Hold a list of random datasets with corresponding digests
- The only owner of the datasets and digests
- Cannot lie about the content of the dataset neither of the digest
- No collusion with other participants



Proof



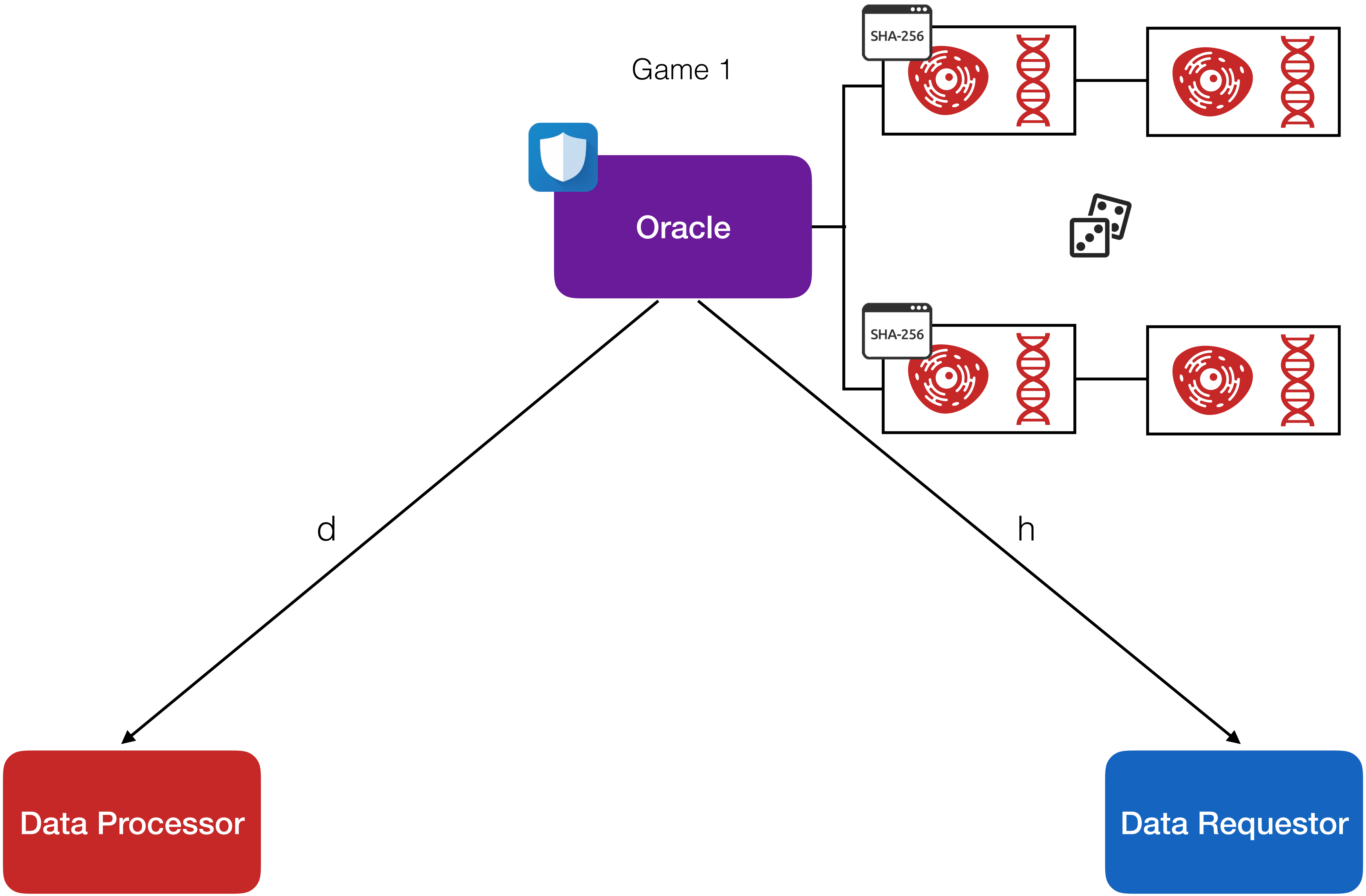
Proof



Data Processor

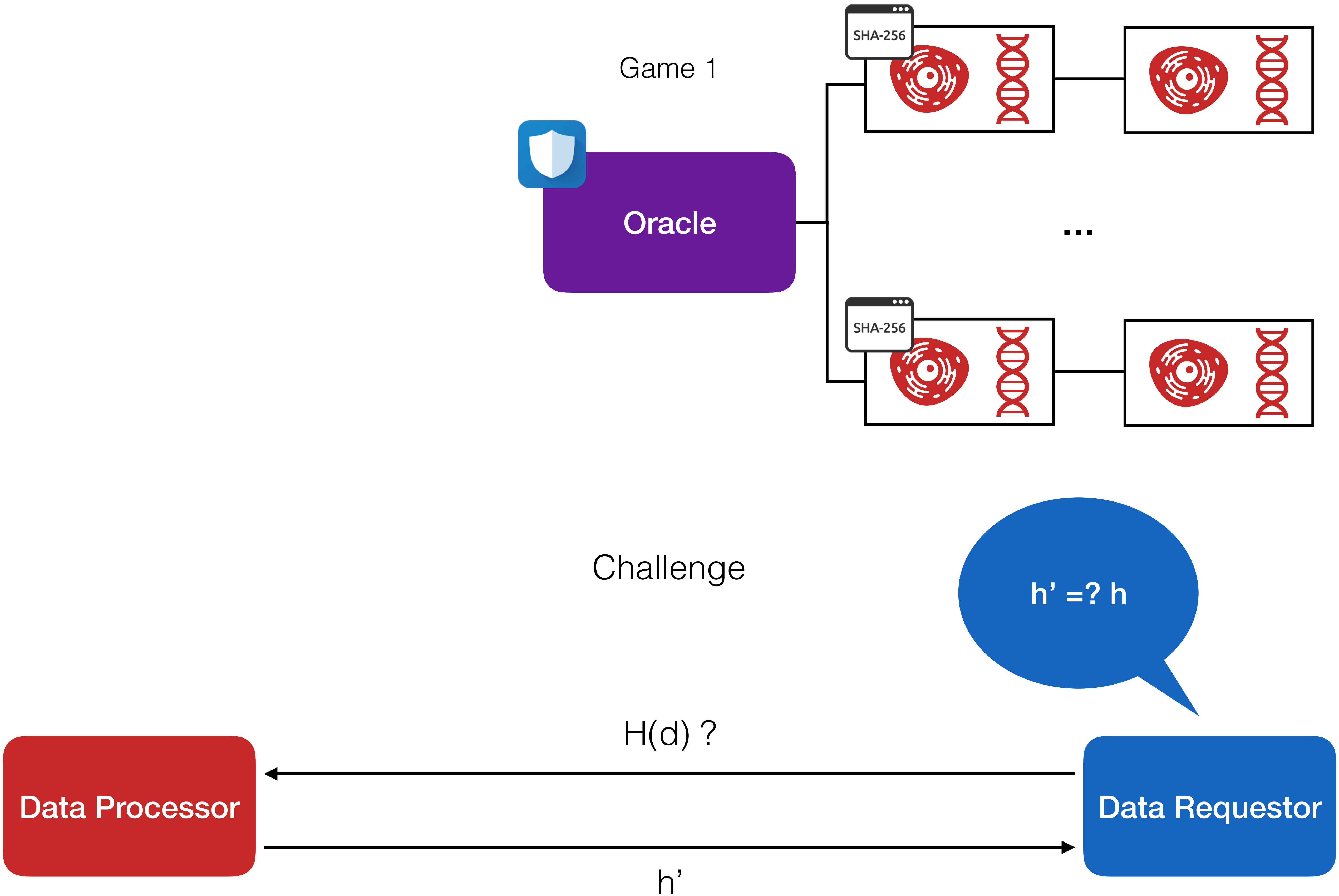
Data Requestor

Proof

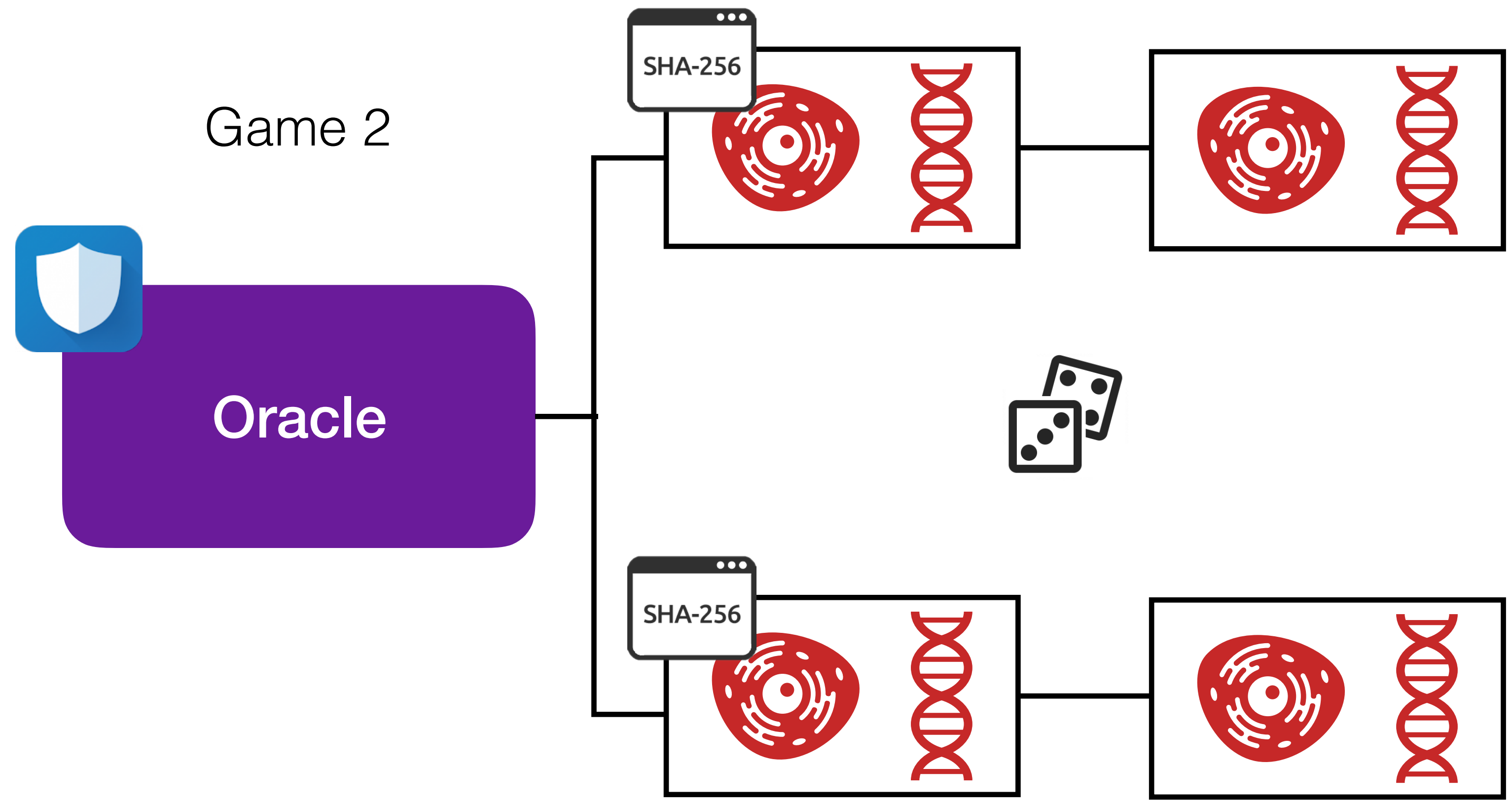


Game 1
SHA-256
SHA-256
Oracle
d
h
Data Processor
Data Requestor

Proof


Game 1
SHA-256
SHA-256
Oracle
...
Challenge
h' =? h
H(d) ?
Data Processor
Data Requestor
h'

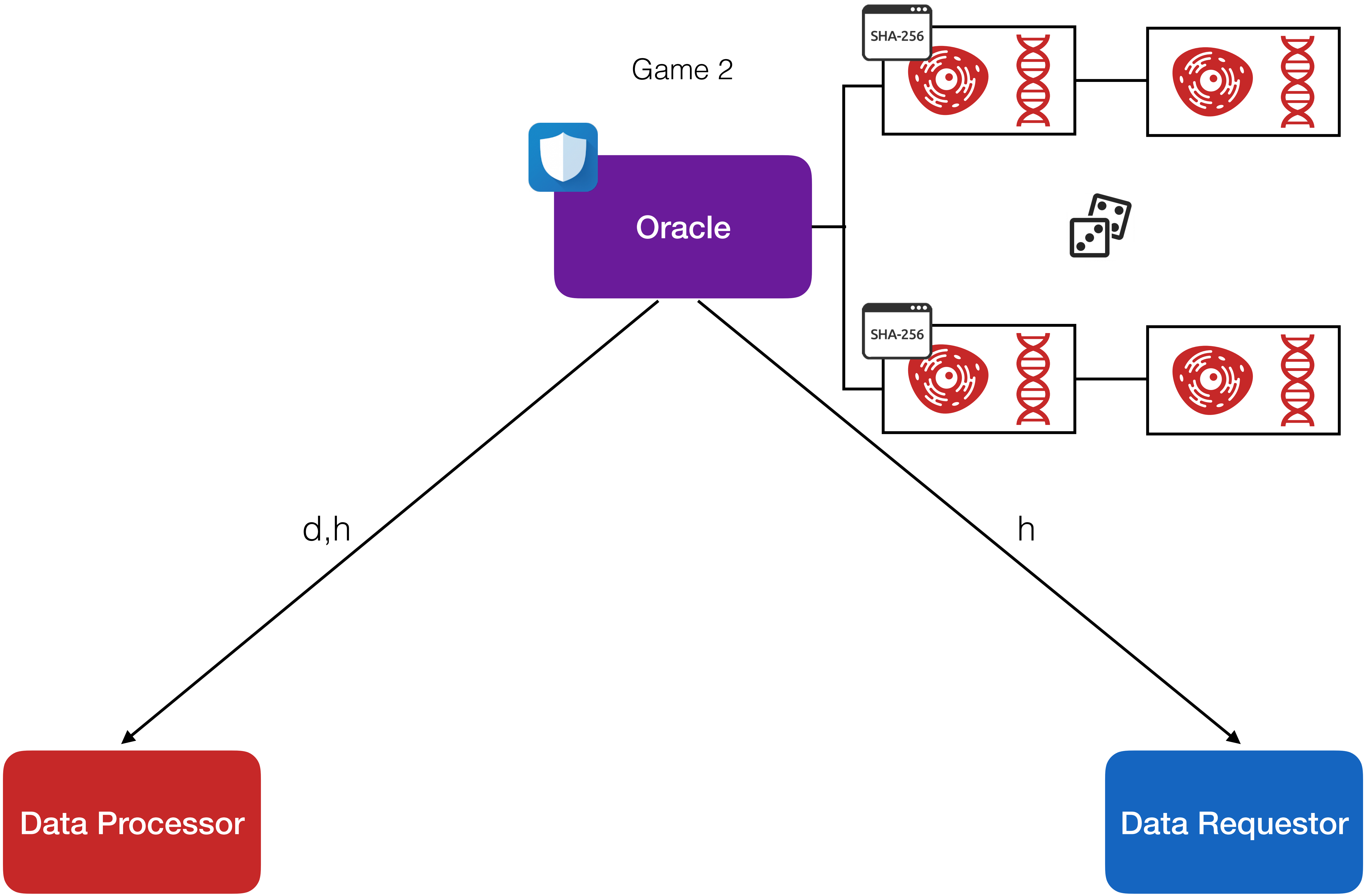
Proof



Data Processor

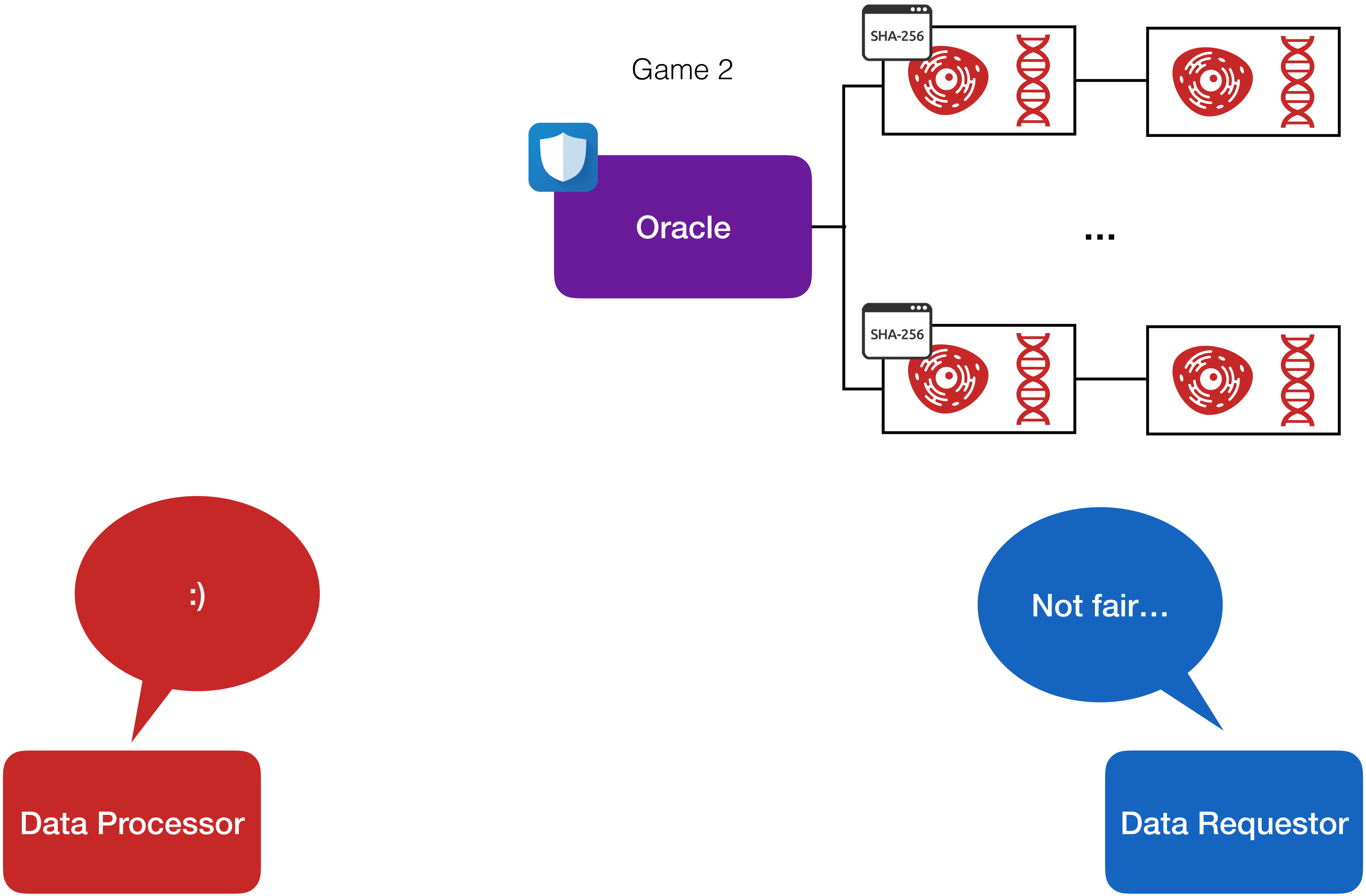
Data Requestor

Proof

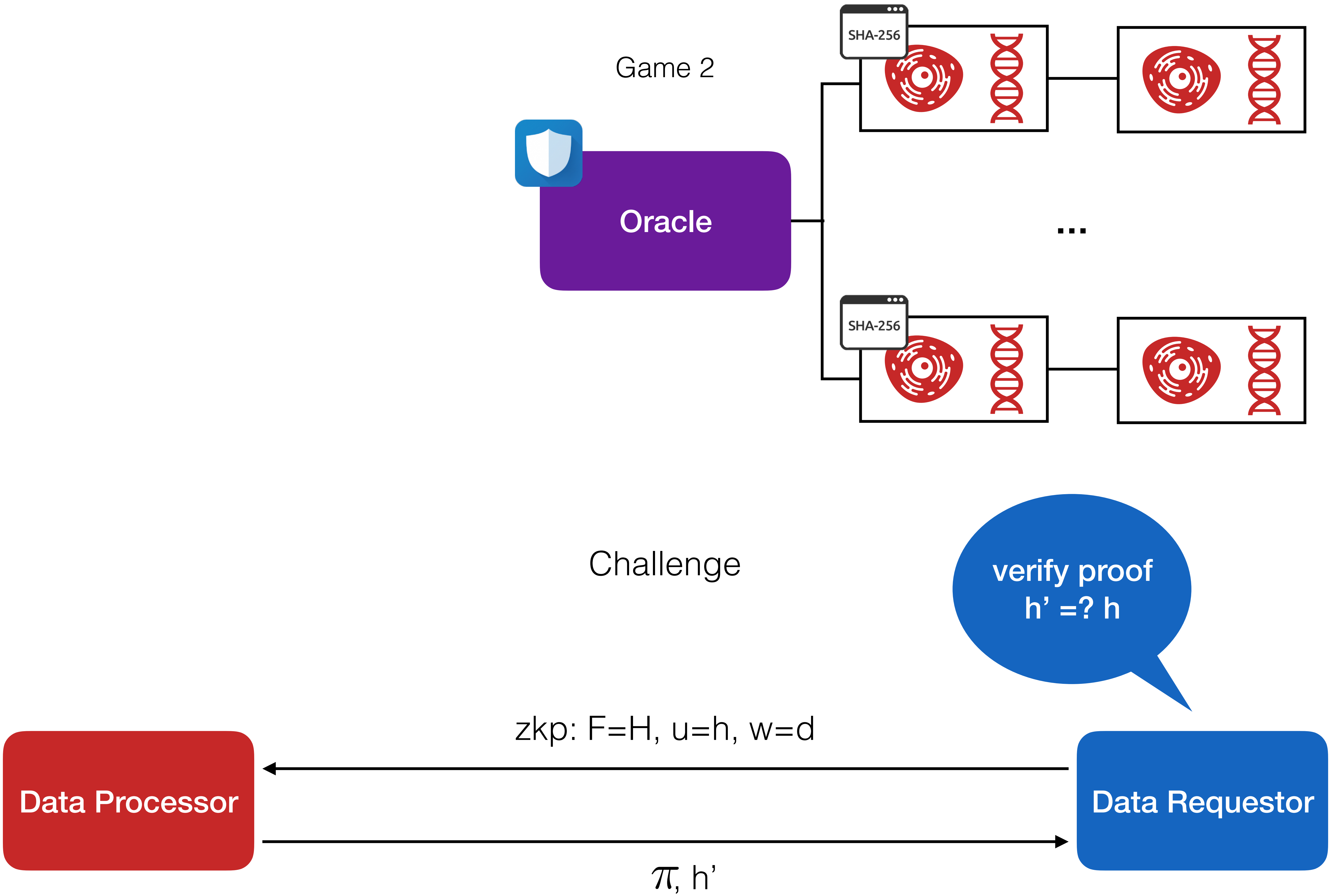


Game 2
Oracle
SHA-256
SHA-256
d,h
h
Data Processor
Data Requestor

Proof


Game 2
SHA-256
SHA-256
Oracle
...
:)
Data Processor
Not fair...
Data Requestor

Proof



Game 2
SHA-256
Oracle
SHA-256
...
Challenge
verify proof
h' =? h
zkp: F=H, u=h, w=d
Data Processor
Data Requestor
π, h'

Proof

- Ideally the controller could be the trusted oracle
- No security proof
- No indistinguishability assumption

Proof

“I know a dataset **d** such as **H(d) = h**
and I correctly compute **F(d) = y**”

Proof

- The proof is public in the blockchain
- The results of the computation are encrypted with requestor's public key and in the blockchain
- But…

Data Processor

Data Requestor

Proof

- The verification algorithm, verification key and the proof are public
- An adversary can brute-force and guess correctly the output

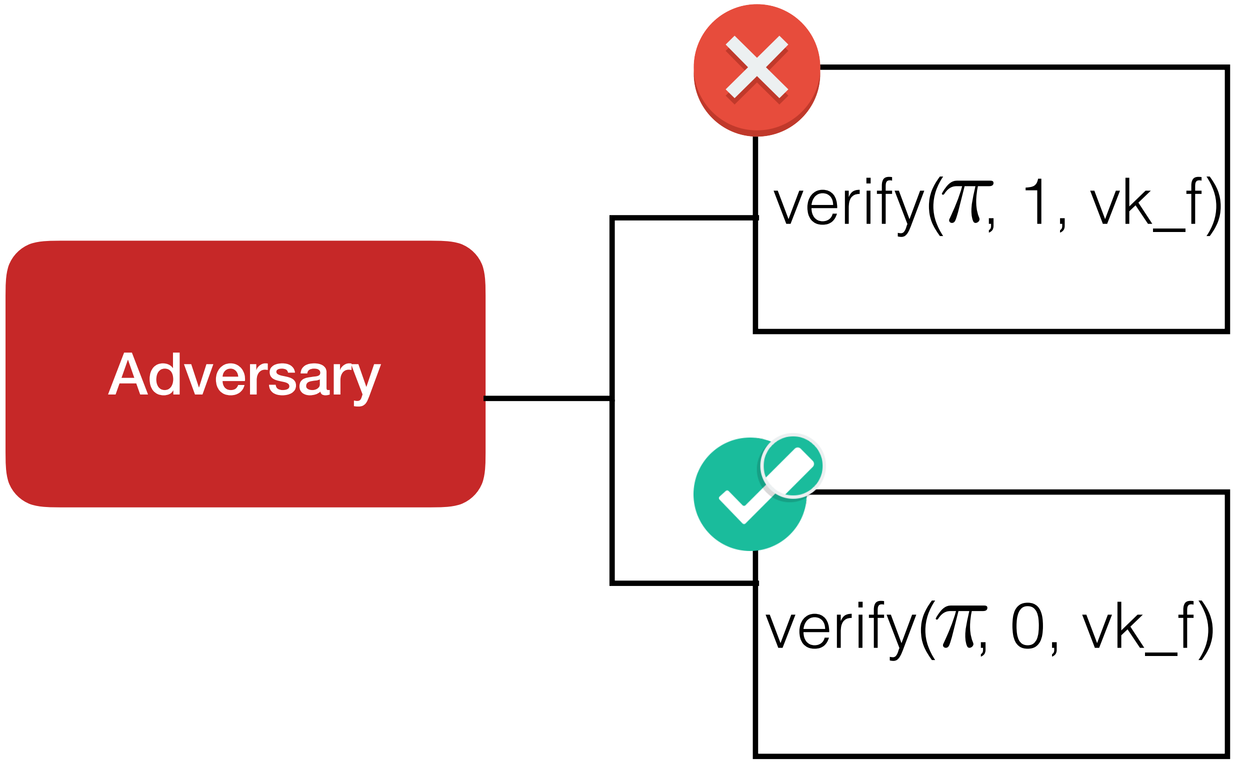
Adversary

Data Requestor

Proof

Parity check

$$F : \{0,1\}^n \to \{0,1\}$$

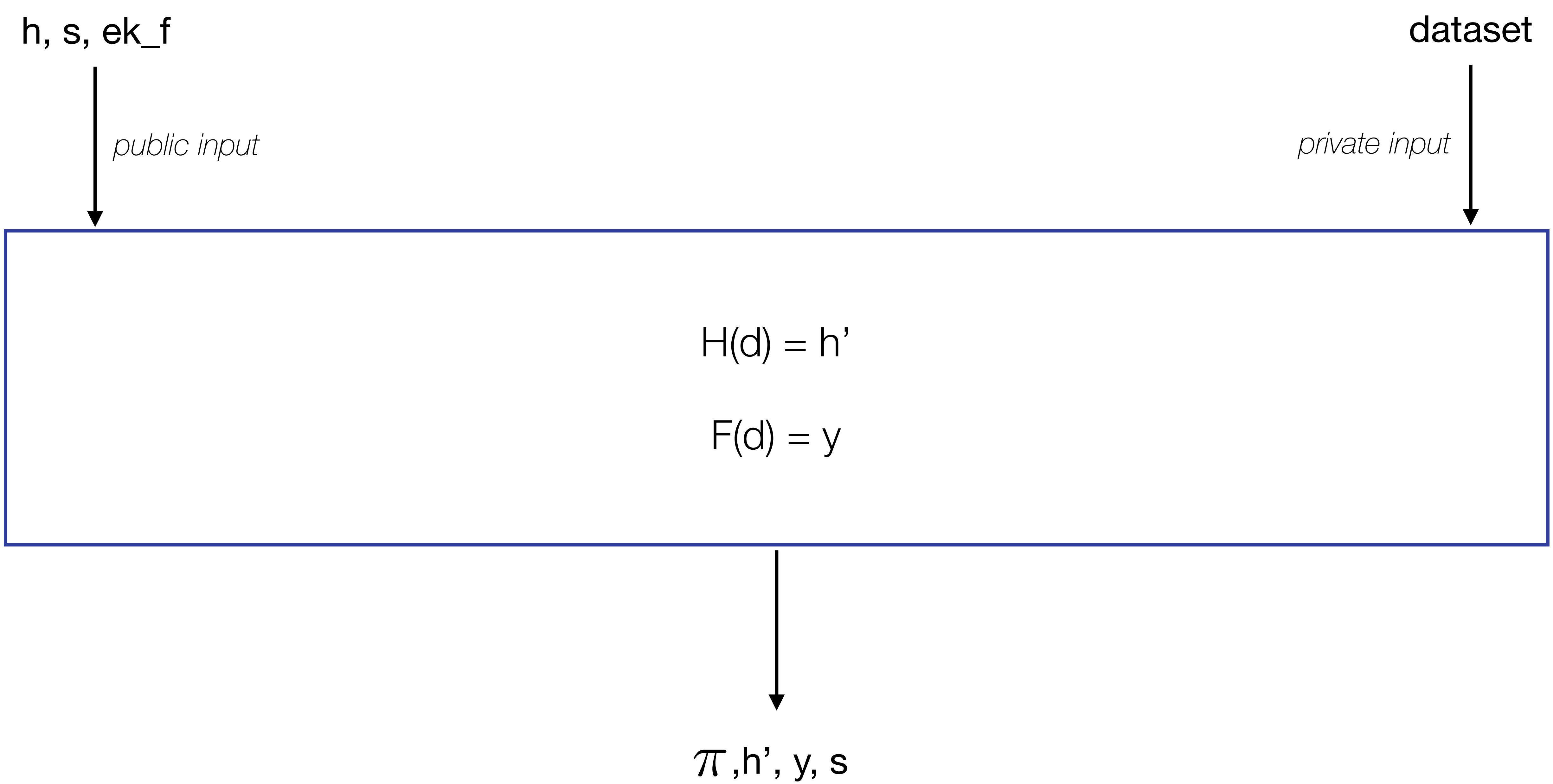


Proof

Solution

- Salt: $s \xleftarrow{\texttt{r}} \{0, 1\}^l$
- Generated by the processor for each proof
- Public in the zkSNARK setting

Proof



Evaluation

Implementation

- Ethereum
- Smart contracts
- RESTful API
- DApp
- CLI
- Blockchain, Storage, Crypto libraries
- Controller, Processor, Requestor nodes
- ZKP ecosystem

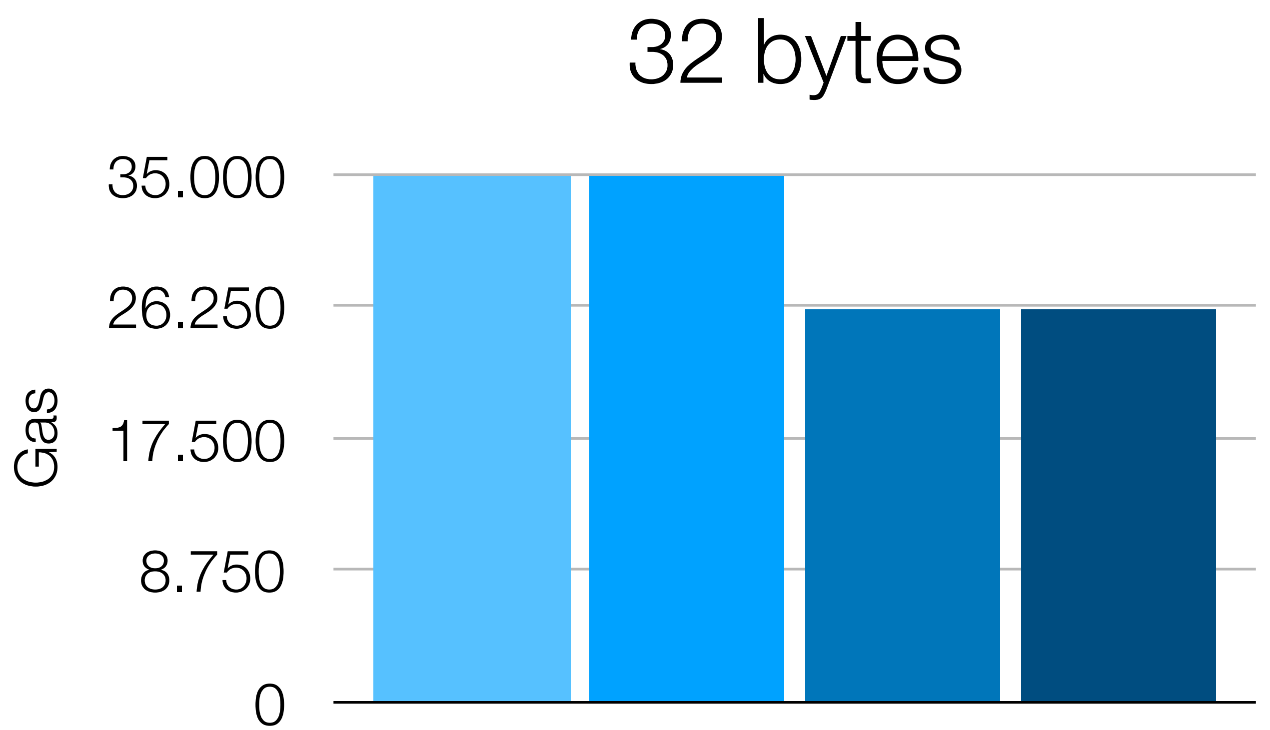
Evaluation

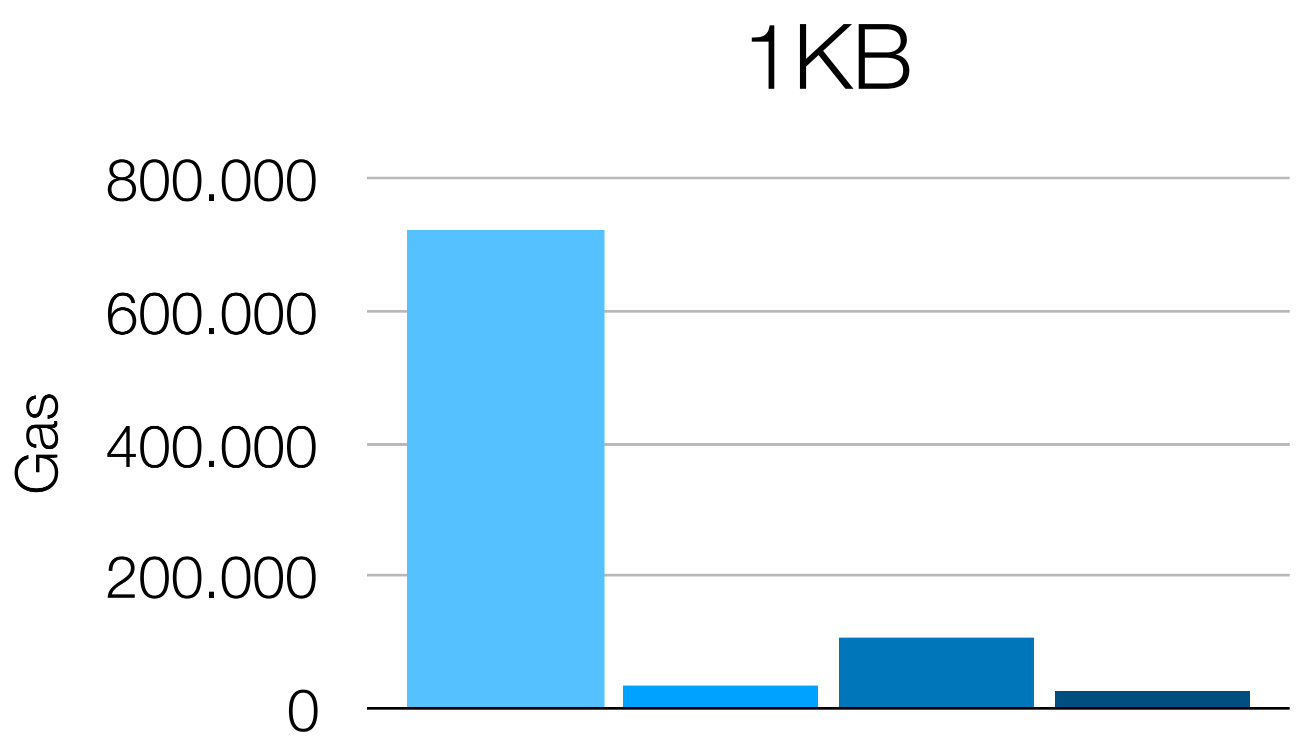
How much it cost to store data ?

Size	Gas	Cost
32 bytes	20.000	$0,037
1KB	724.664	$1.357
1MB	697.325.562	$1,305.393
10MB	~7.000.000.000	~$13,104
100MB	~70.000.000.000	~$131,040
1GB	~700.000.000.000	~$13,104,000

ETH Price: $942.99 (Feb 18, 2018) - Gas Price: 2 Gwei

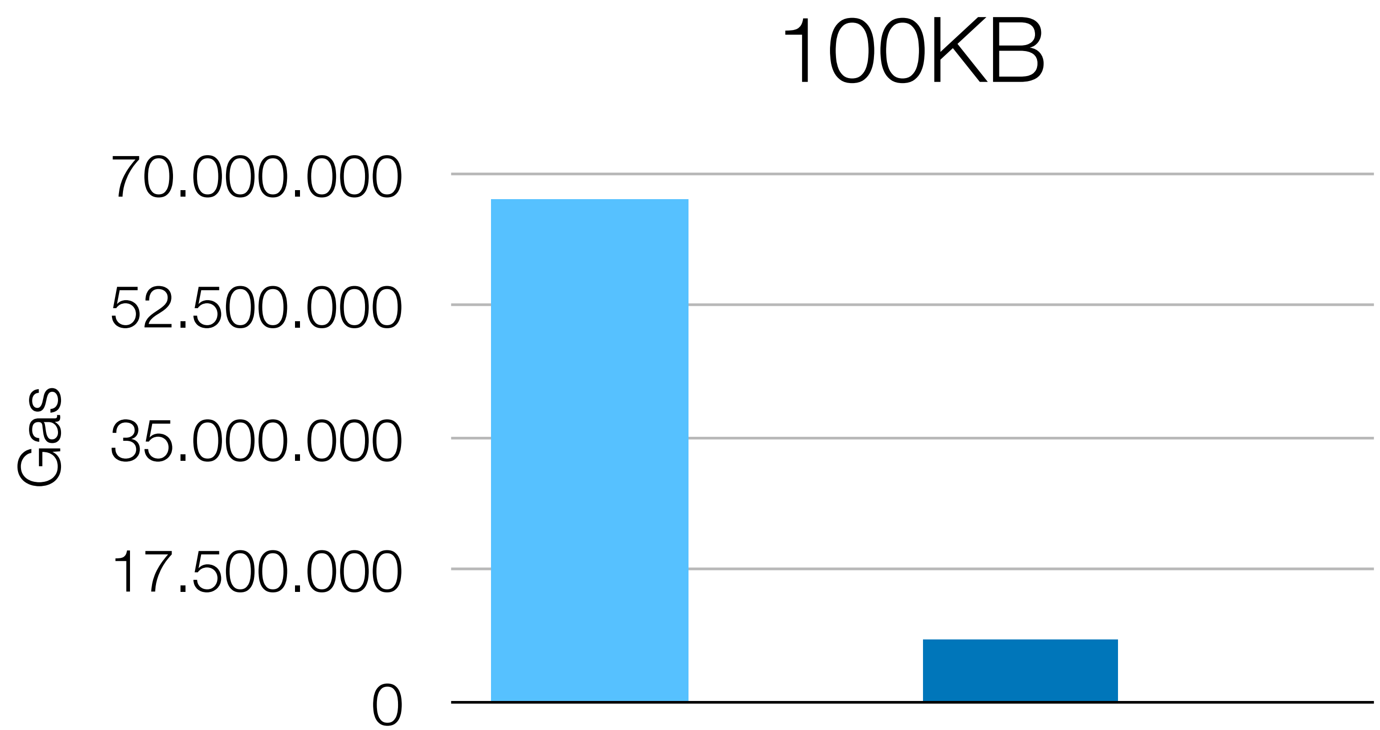
Evaluation: Storage costs

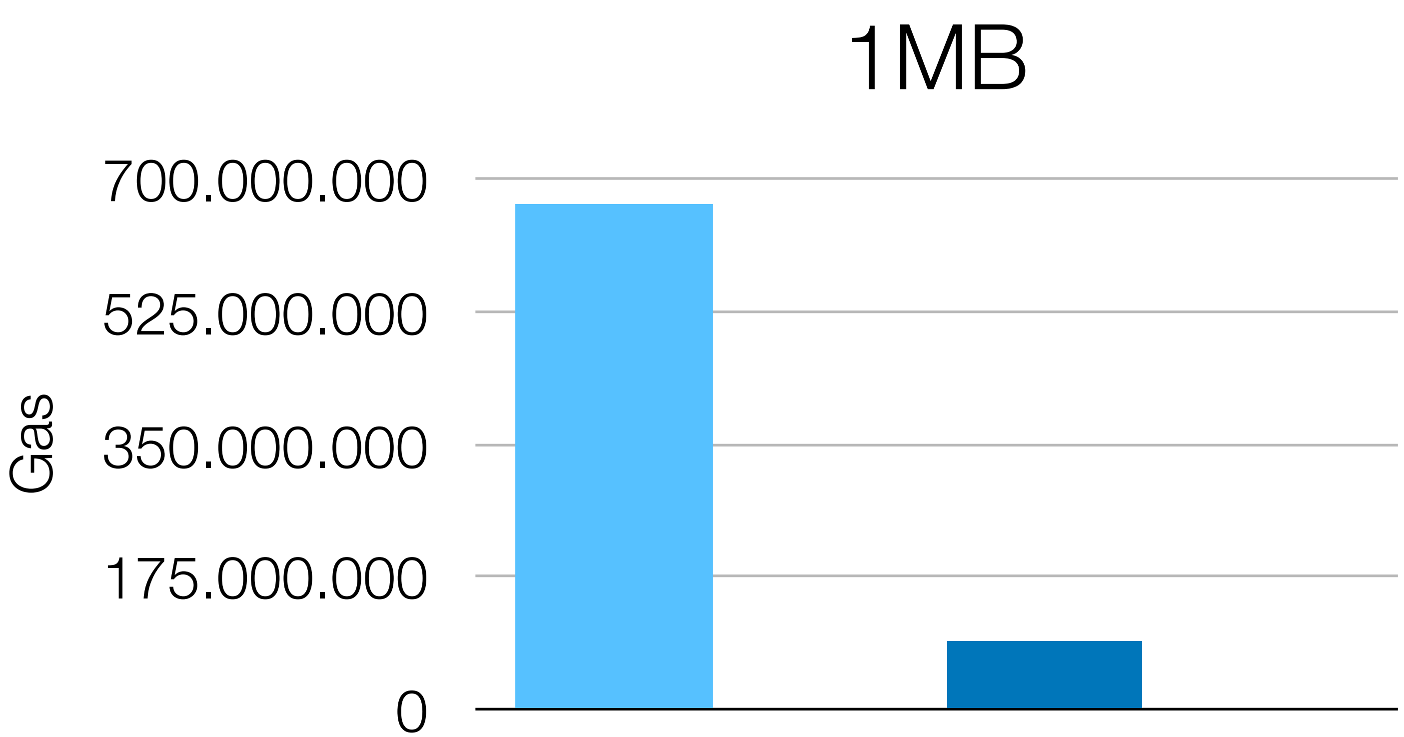




ETH Price: $942.99 (Feb 18, 2018) - Gas Price: 2 Gwei

Evaluation: Storage costs





ETH Price: $942.99 (Feb 18, 2018) - Gas Price: 2 Gwei

Evaluation: Storage costs

How much it cost to use the system ?

Type	Gas	Cost
App deployment	3.004.253	$5.66
Register	233.487	$0.44
Request	89.206	$0.15
Process	83.274	$0.15
Register entity	25.279	$0.04
Proof	100.248	$0.18

ETH Price: $942.99 (Feb 18, 2018) - Gas Price: 2 Gwei

Evaluation: ZKP

	Setup (s)	**Compute (s)**	**Verify (ms)**	**Eval key (MB)**	**Ver key (KB)**	**Proof (B)**
Sum	10	8	27	0,144	100	304
Count	15	9	37	0,036	100	304
Min / Max	29	14	49	17	100	304
Median	1700	780	12	64	100	304
Mean	16	8	10	0,82	100	304

1000 values

Future Work

- MPC
- Fees
- Reputation System
- Privacy Preserving Algorithms
- New Ideas ?

Related Work

- Enigma
- MedRec
- AD-SNARKs
- Zokrates

Questions ?