Trident: Efficient 4PC Framework for Privacy Preserving Machine Learning

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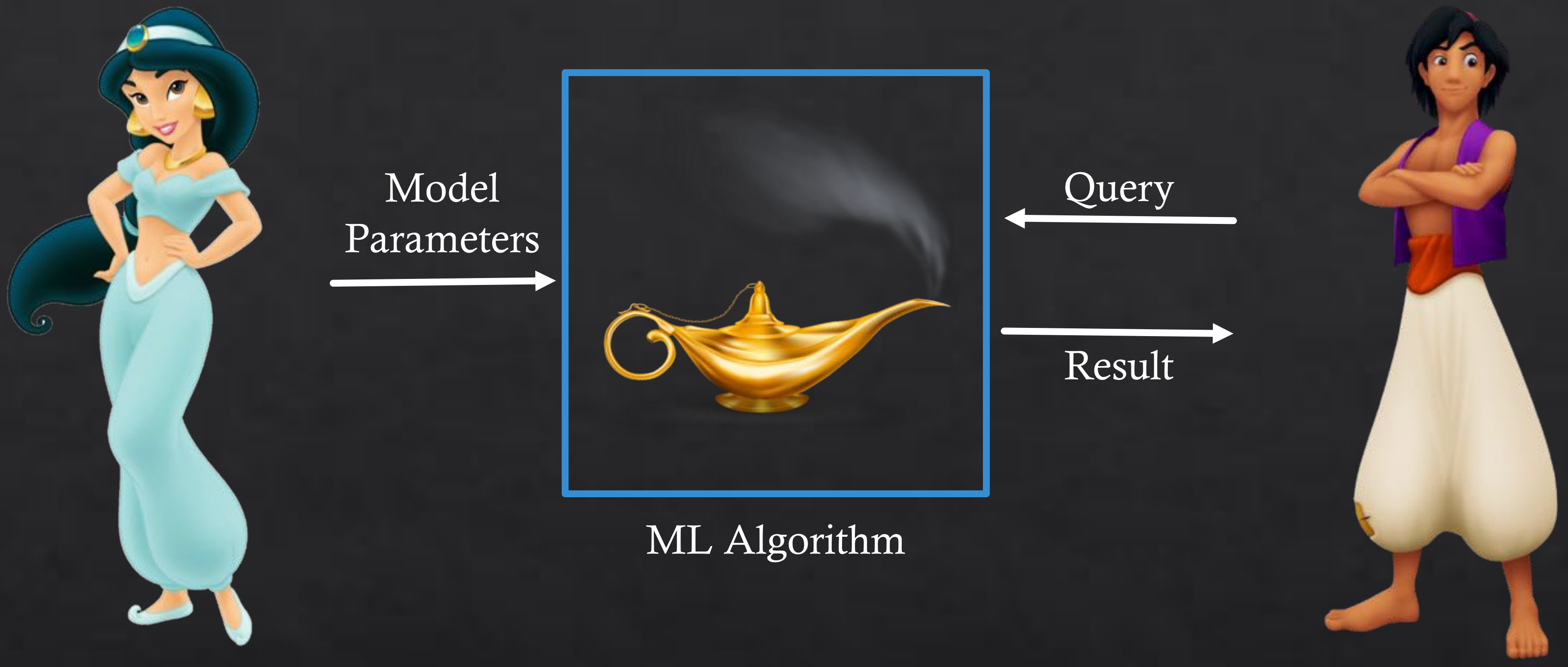
Outline

- ❑ Privacy Preserving Machine Learning (PPML)
- ❑ Secure Multi-party Computation (MPC)
- ❑ Overview of Trident Protocol
- ❑ Benchmarking Results

Machine Learning (ML) Prediction – An Abstraction



Model Parameters

Query

Result

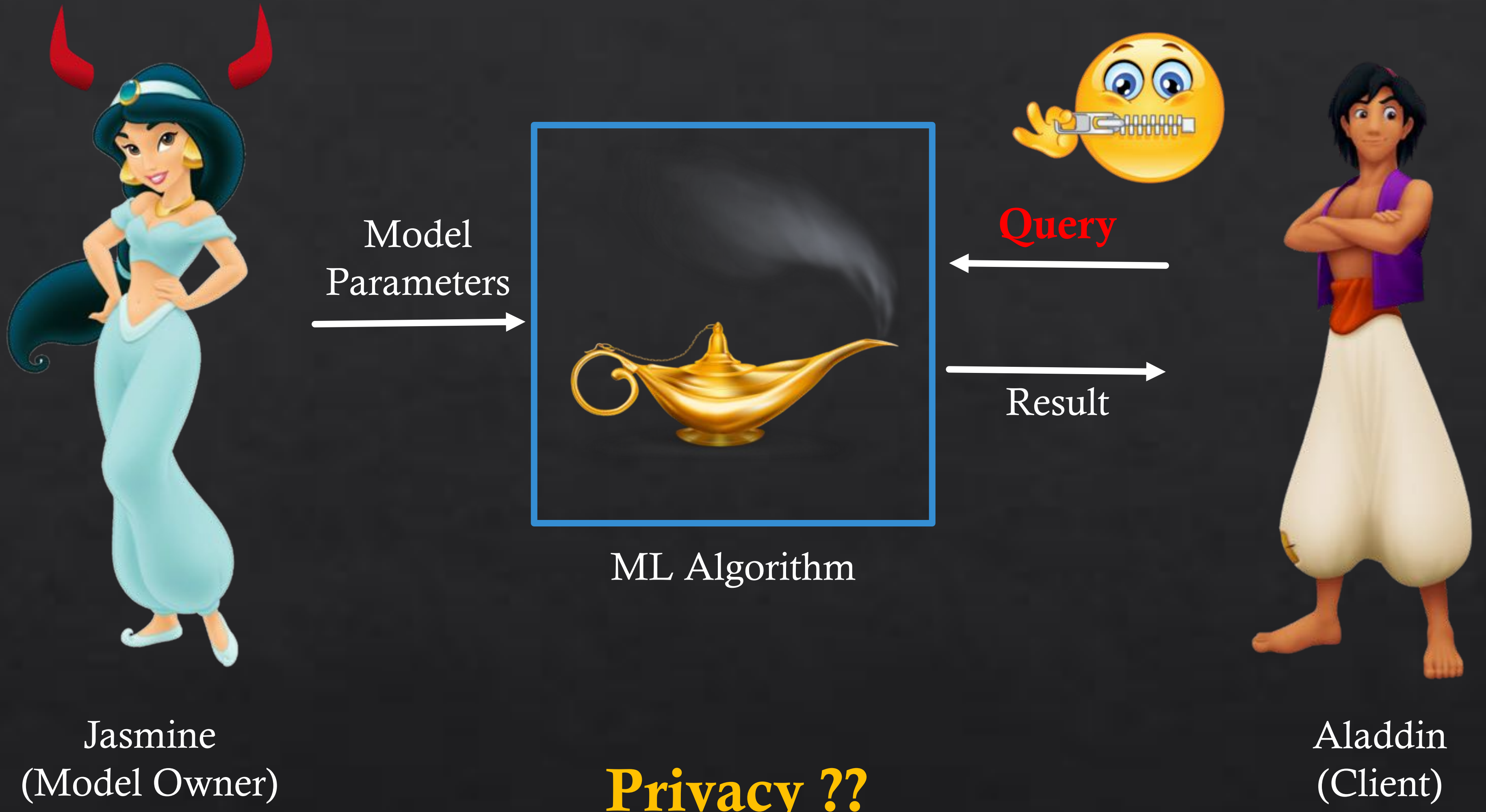
ML Algorithm

Jasmine
(Model Owner)

Aladdin
(Client)

Privacy ??

Machine Learning (ML) Prediction – An Abstraction



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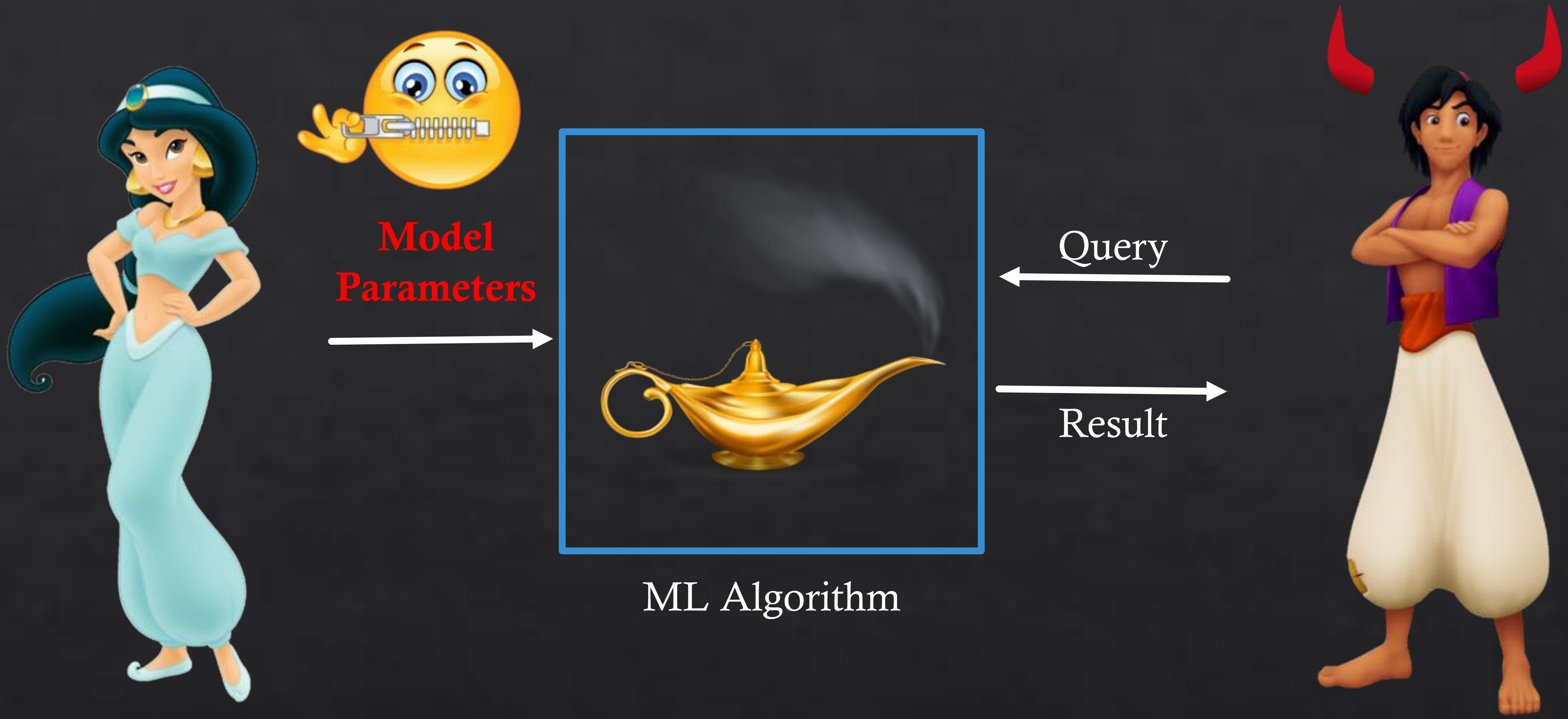

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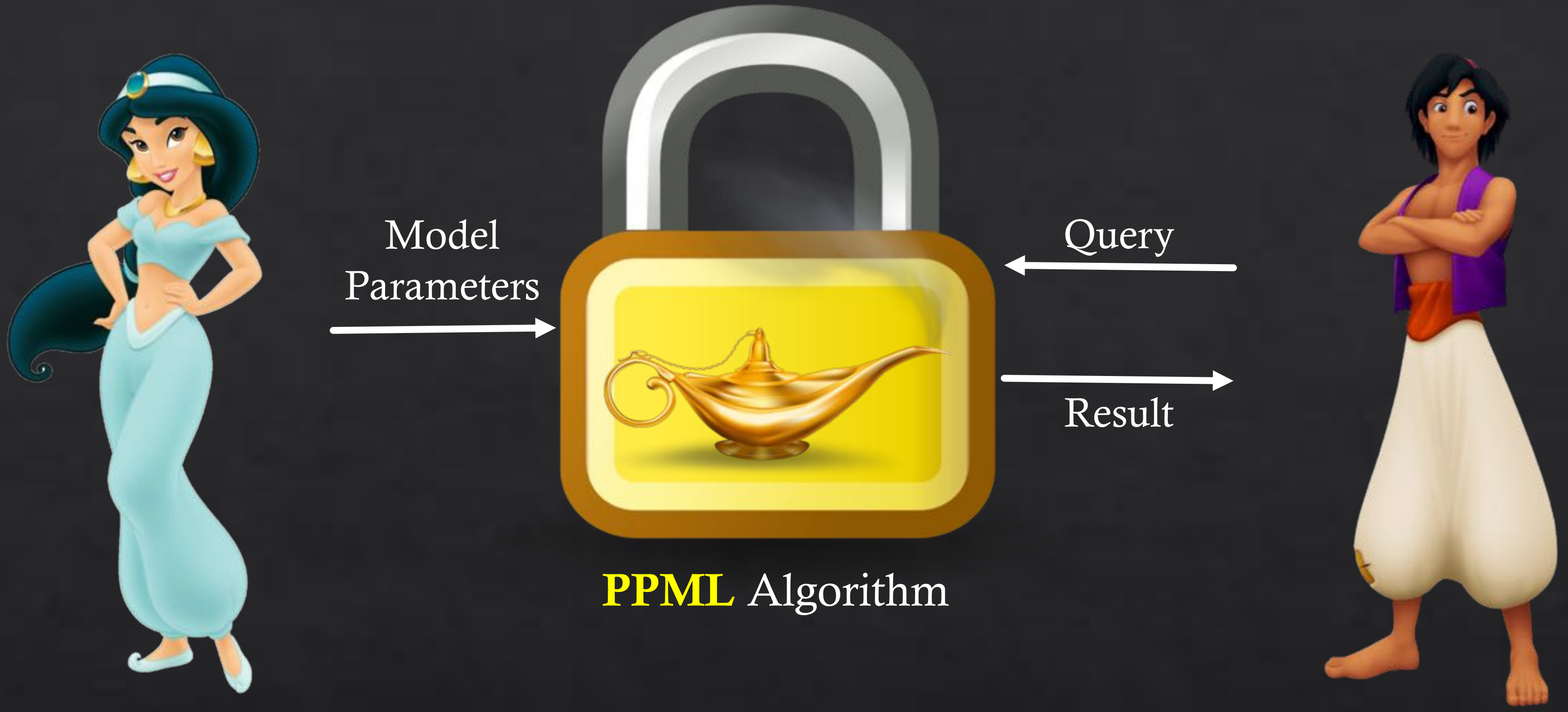
Privacy Preserving Machine Learning (PPML)



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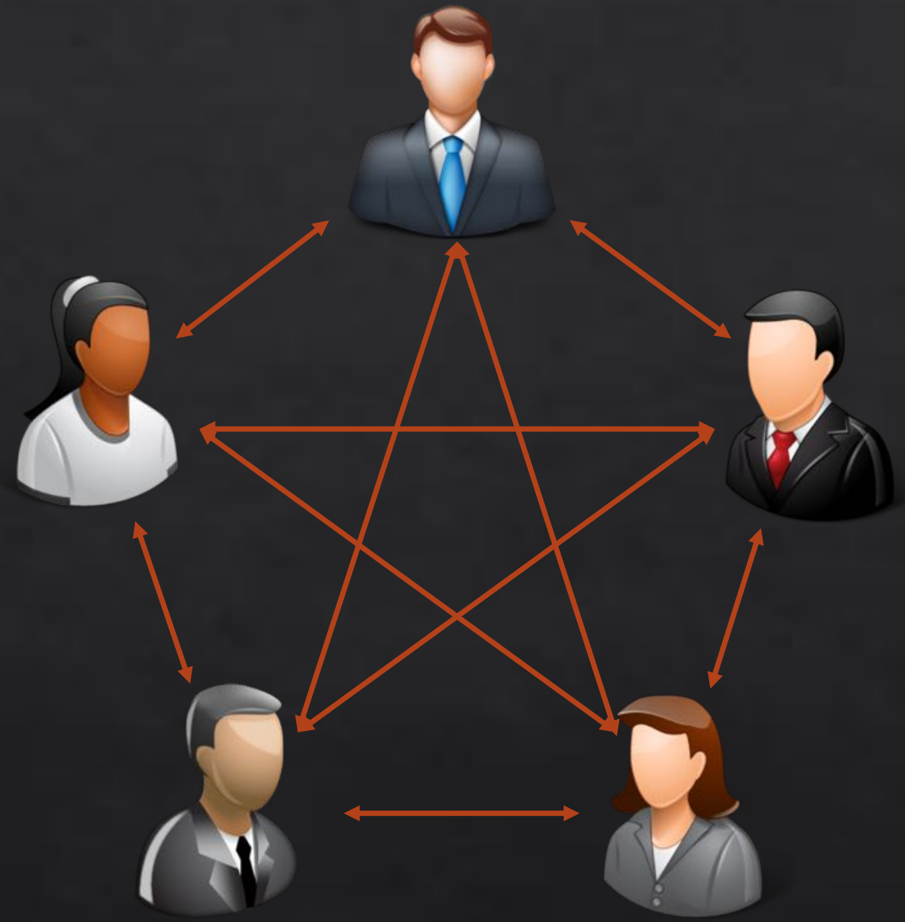
MPC meets ML

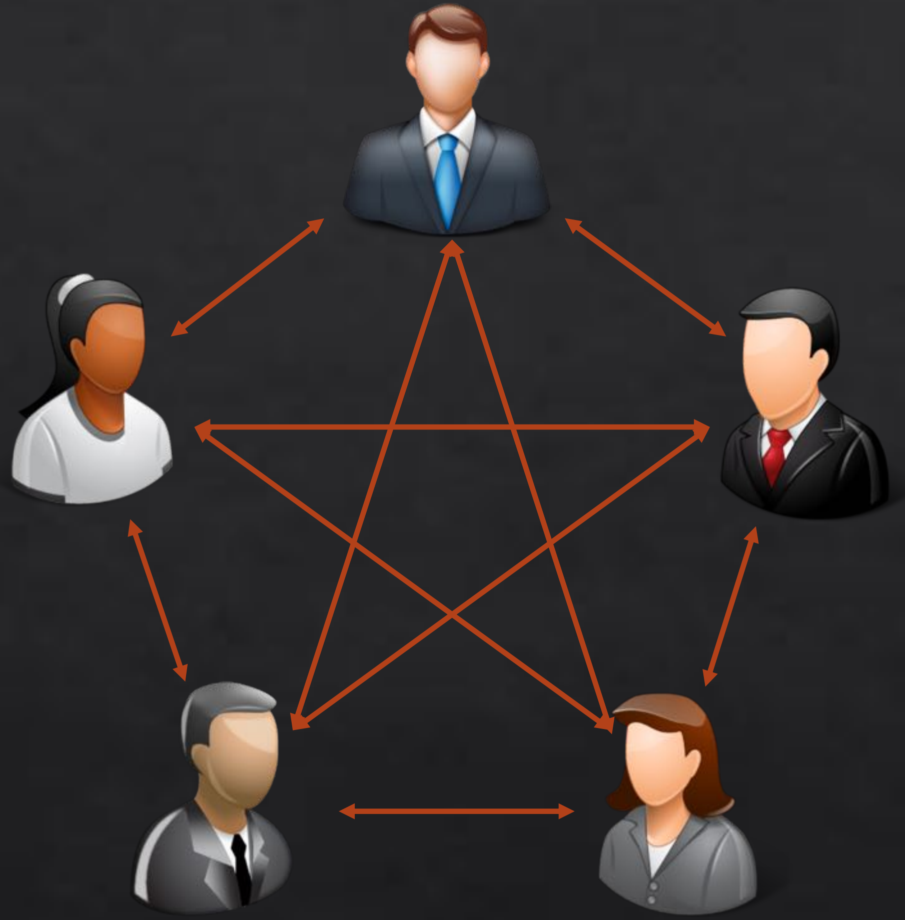
Secure Multi-party Computation (MPC) [Yao’82]



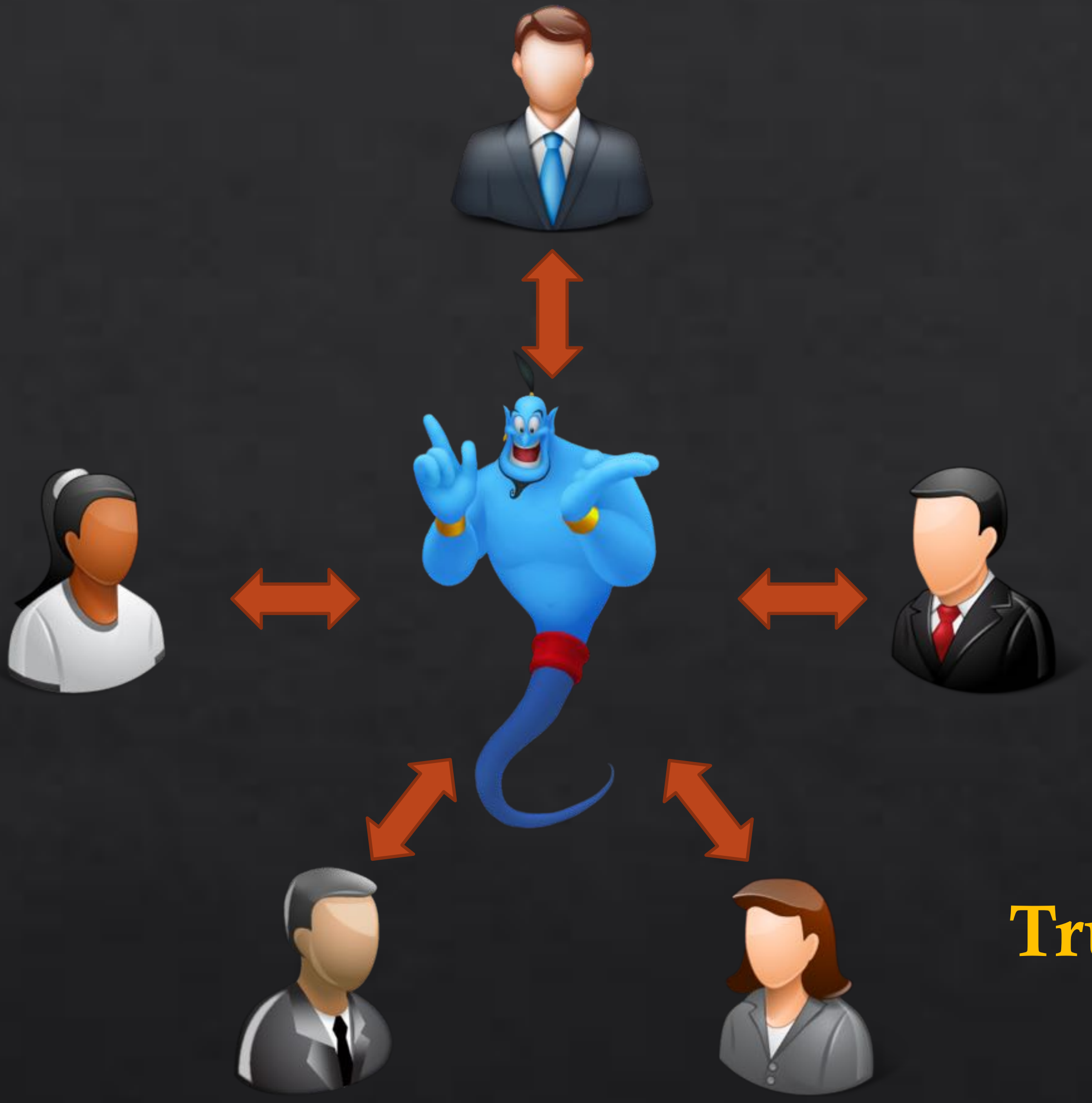
- ✓ A set of parties with private inputs wish to compute some joint function of their inputs.

- ✓ Goals of MPC:
  - **Correctness** – Parties should correctly evaluate the function output.
  - **Privacy** – Nothing more than the function output should be revealed

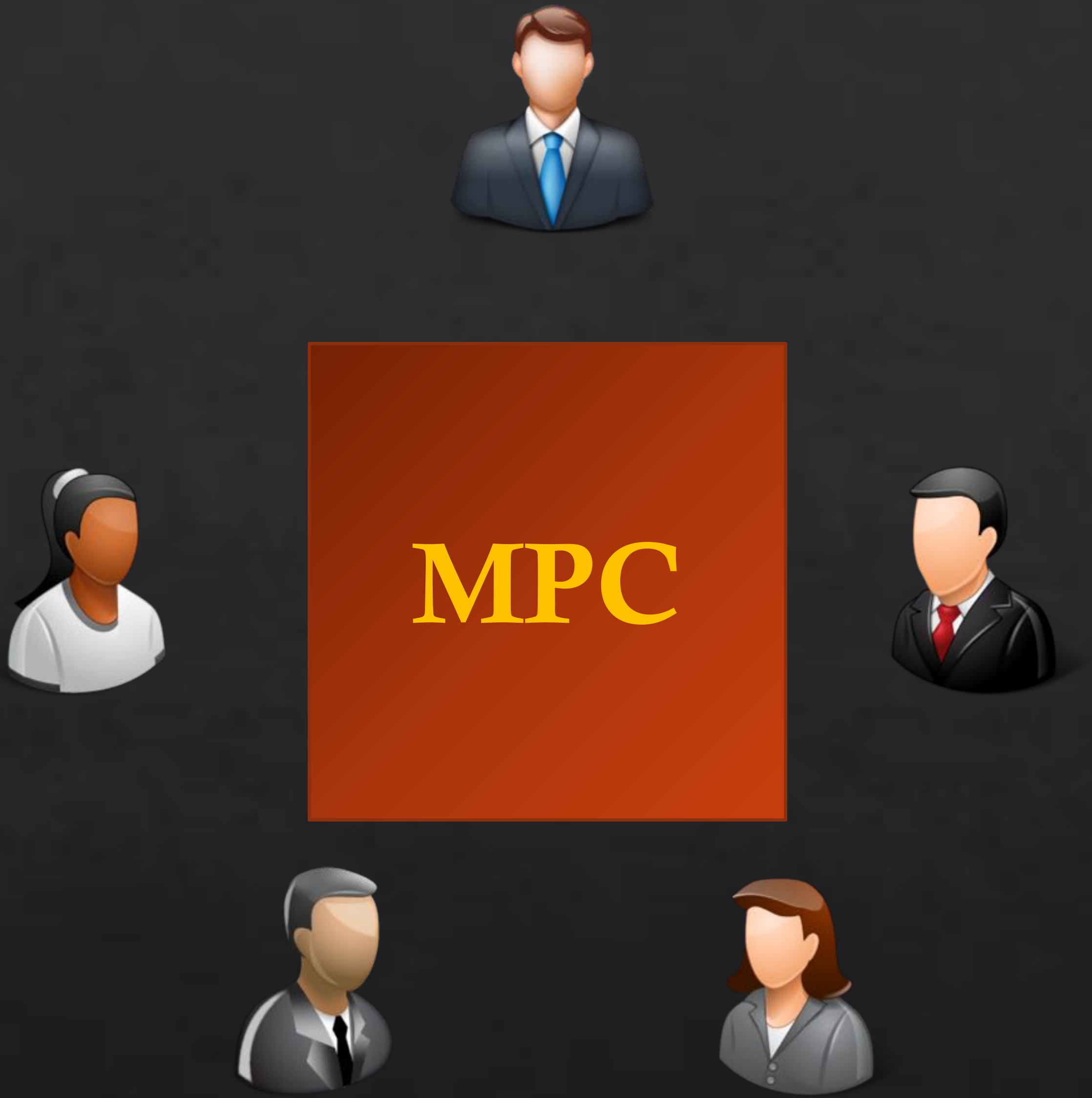
Secure Multi-party Computation (MPC) [Yao'82]



Trusted Third Party (TTP)



Trusted Third Party (TTP)



MPC emulates TTP

TRIDENT PROTOCOL

Trident protocol

- A new 4PC protocol over ring in the pre-processing model

Trident protocol

- A new **4PC protocol** over ring in the pre-processing model

  - 4 parties
  - Honest majority
  - At most 1 corruption

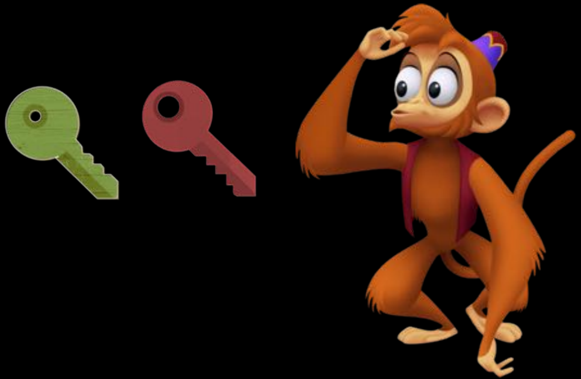
Trident protocol

- A new 4PC protocol over ring in the **pre-processing** model

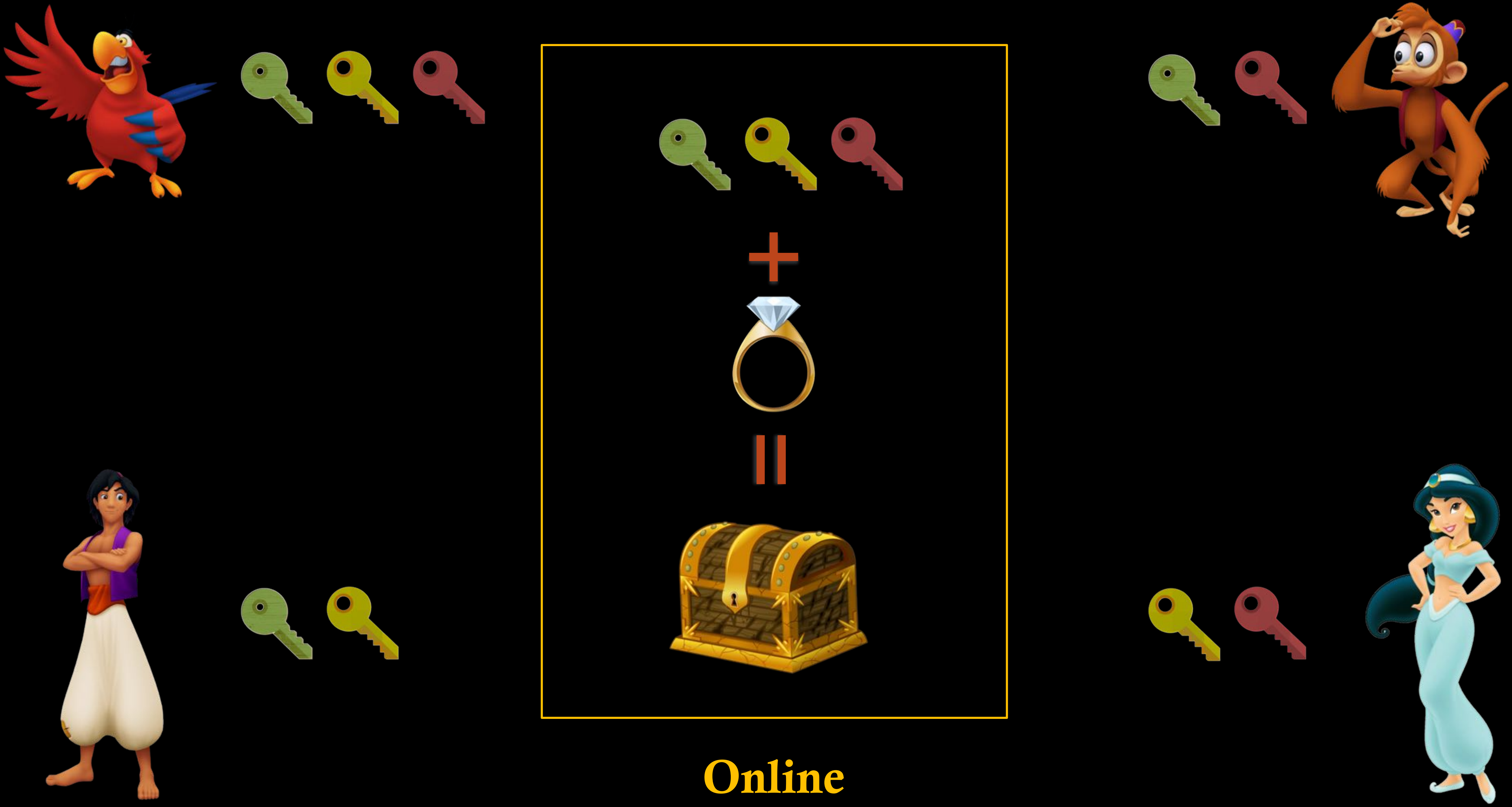
  - Data independent pre-processing
  - Fast online phase

Sharing Semantics

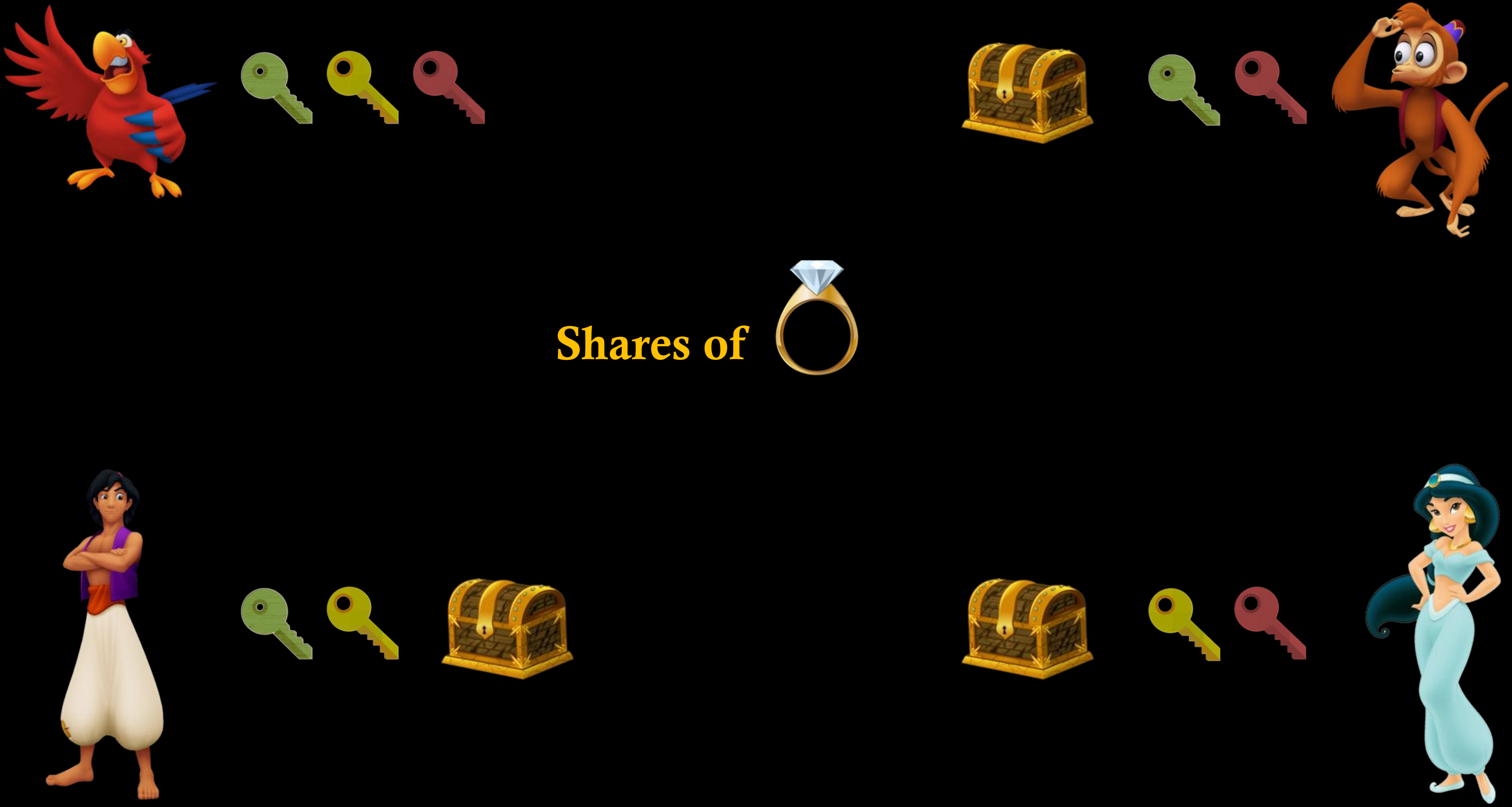
Pre-processing



Pre-processing



Online



Shares of 💍

Trident protocol

- A new 4PC protocol over ring in the pre-processing model
- Malicious security with guarantee of fairness

Trident protocol

- A new 4PC protocol over ring in the pre-processing model
- **Malicious** security with guarantee of fairness

Corrupt parties arbitrarily deviate

Trident protocol

- A new 4PC protocol over ring in the pre-processing model
- Malicious security with guarantee of **fairness**

Honest parties get output whenever corrupt parties get output

Multiplication $(x.y)$

Ref	Pre-processing (#elements)	Online (#elements)	Security
Araki et al'17 (3PC)	12	9	Abort

Multiplication $(x.y)$

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Trident	**3**	**3**	**Fair**

Trident protocol

- A new 4PC protocol over ring in the pre-processing model
- Malicious security with guarantee of fairness
- Efficient Mixed World Conversions

Mixed World Conversions

Boolean

Boolean World

- Comparison, Bit Extraction …

Mixed World Conversions

Boolean

Arithmetic

Boolean World

- Comparison, Bit Extraction …

Arithmetic World

- Addition, Multiplication …

Mixed World Conversions

Boolean

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Garbled

Boolean World

- Comparison, Bit Extraction …

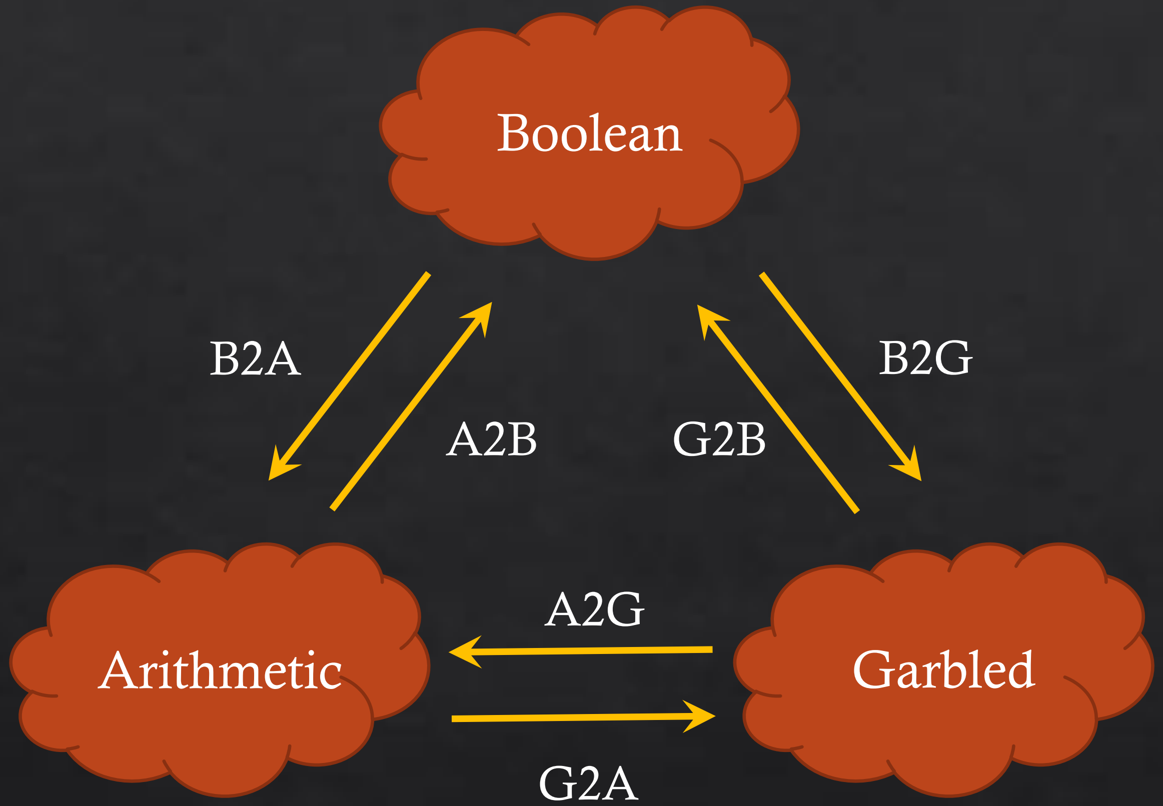
Arithmetic World

- Addition, Multiplication …

Garbled World

- Division over rings …

Mixed World Conversions



Online Rounds	Online Communication
Up to 7x	2x - 67x

Range of improvement over ABY3

Mixed World Conversions – An Example

$$\frac{\min(x_1 + x_2, x_3)}{x_4}$$

Mixed World Conversions – An Example

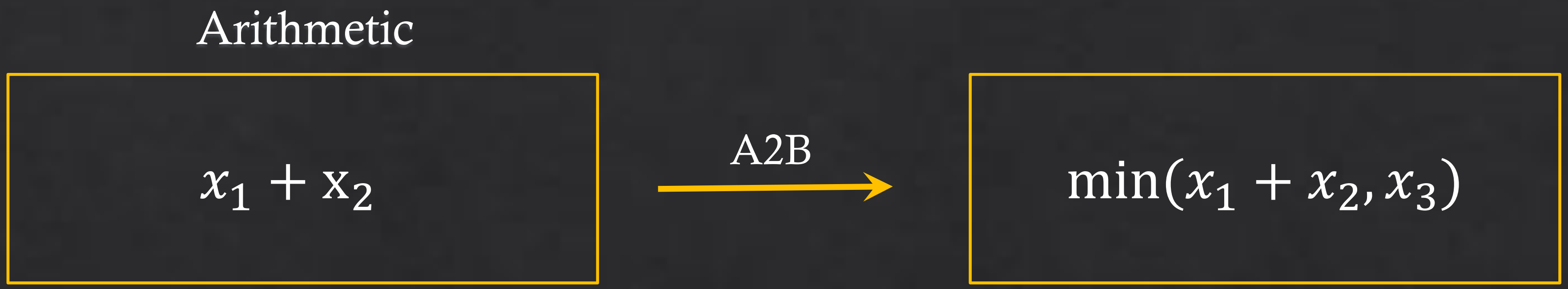
$$x_1 + \mathrm{x}_2$$

Mixed World Conversions – An Example

Arithmetic

$$x_1 + \mathrm{x}_2$$

Mixed World Conversions – An Example



Arithmetic

$x_1 + \mathrm{x}_2$

A2B

$\min(x_1 + x_2, x_3)$

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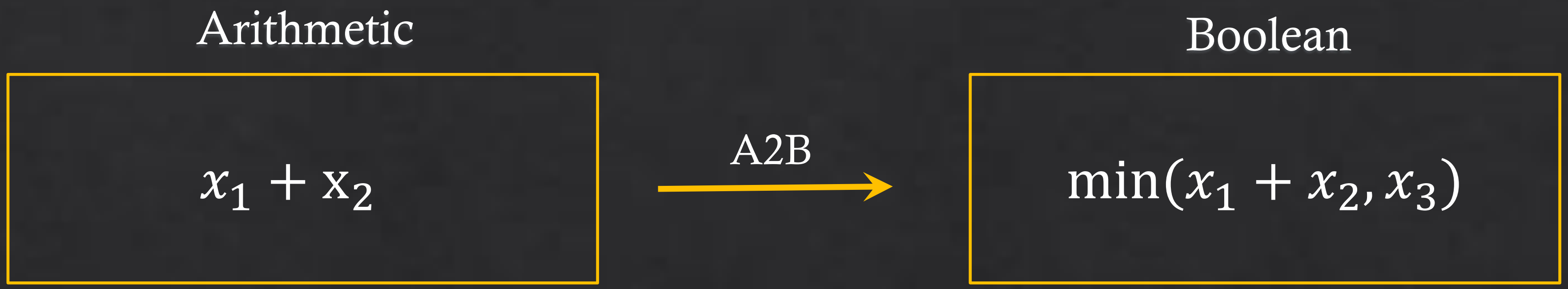

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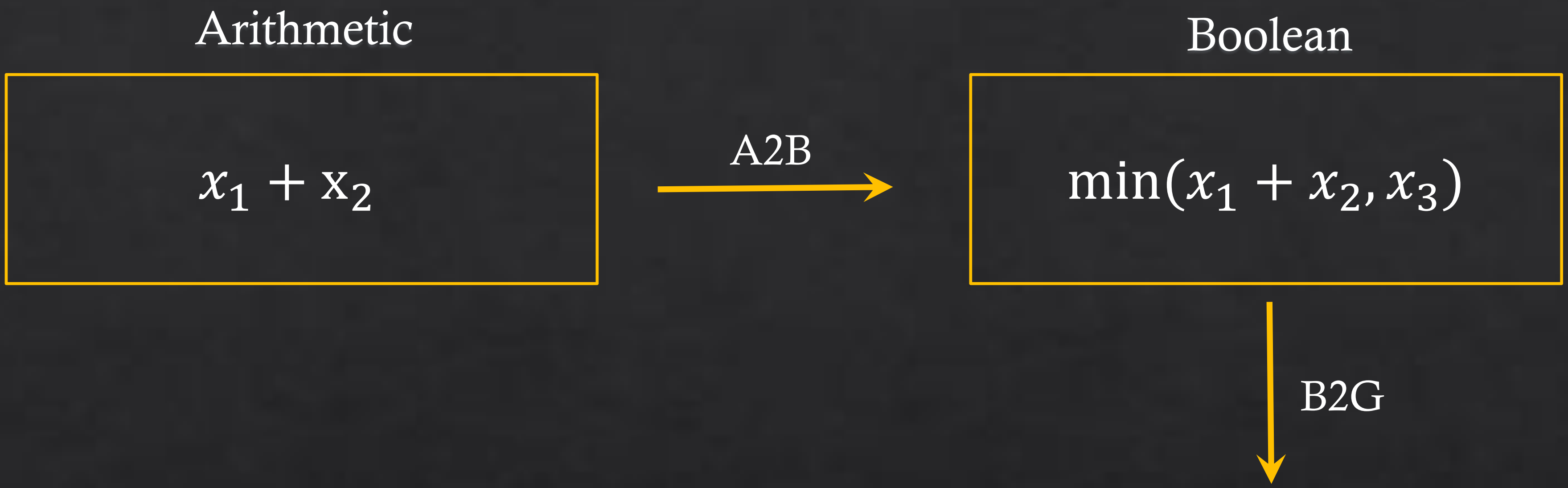

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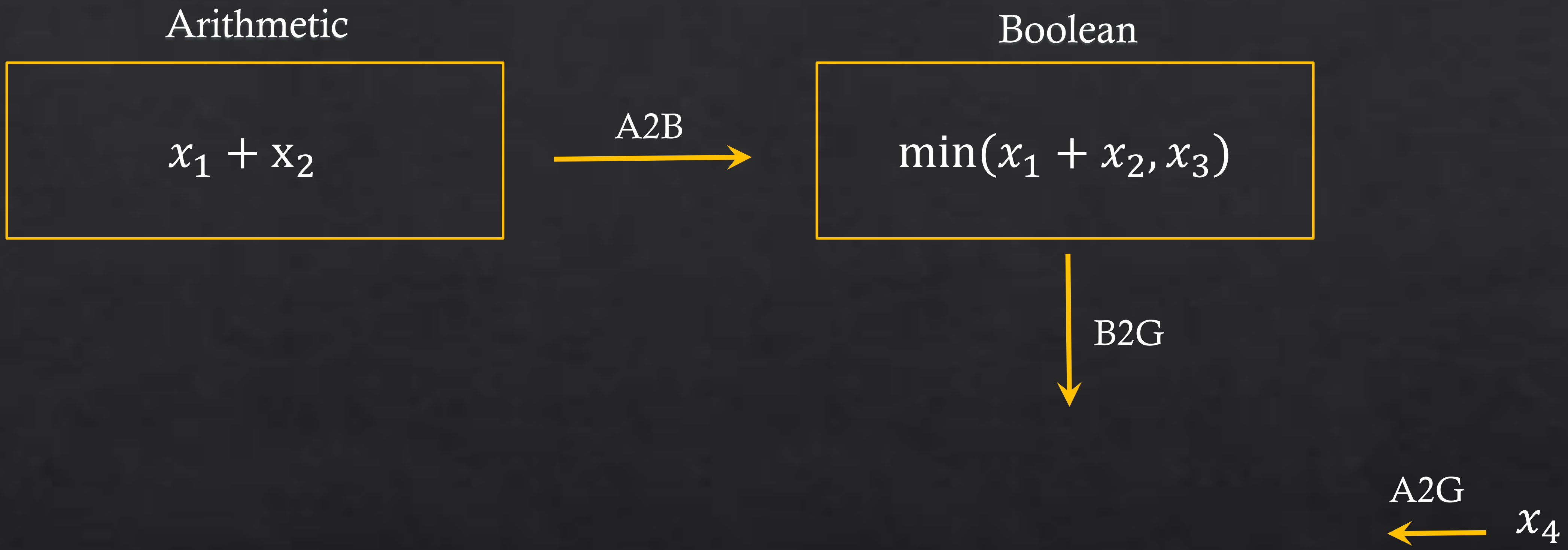

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A2G

x_4

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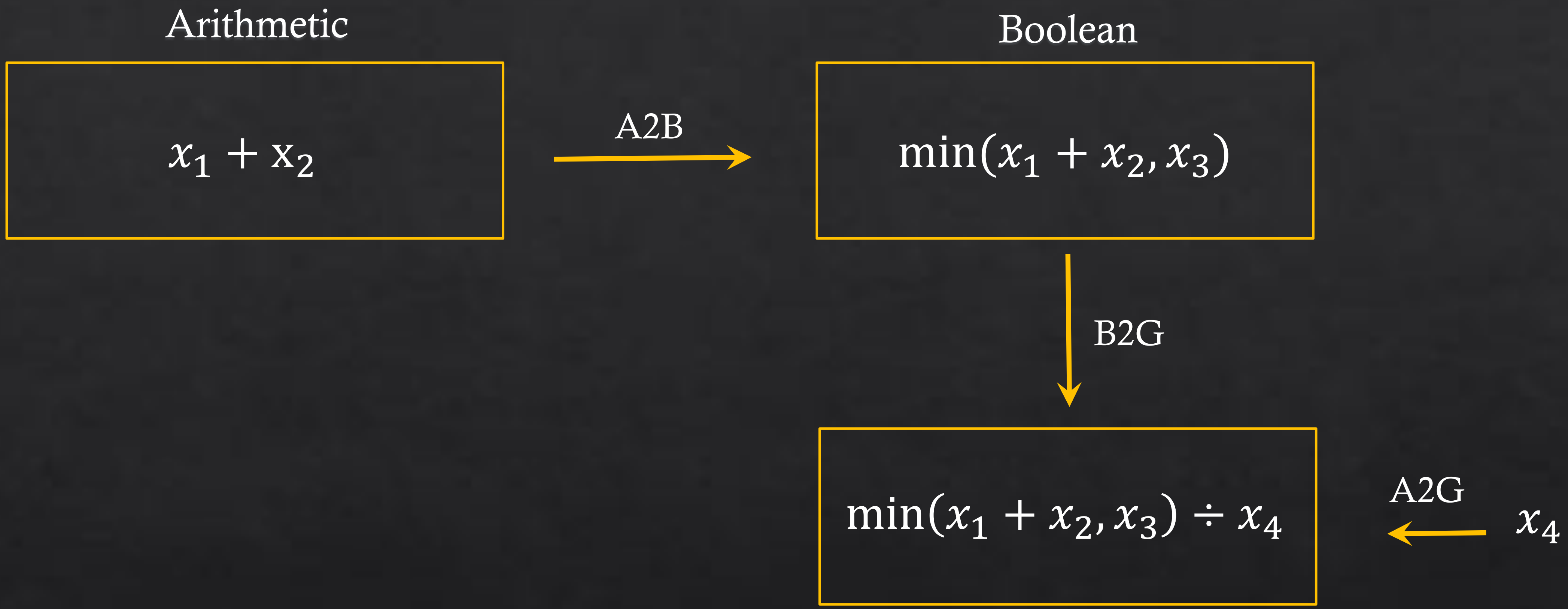

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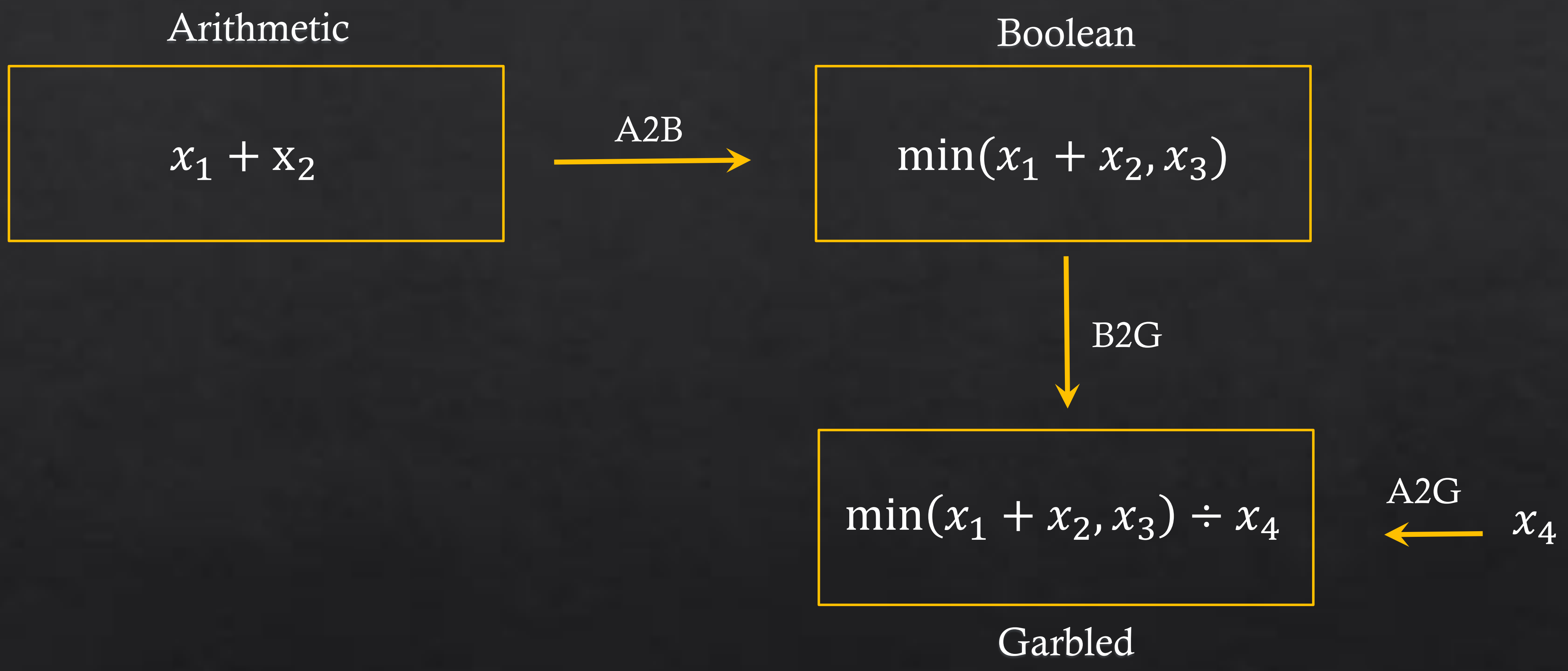

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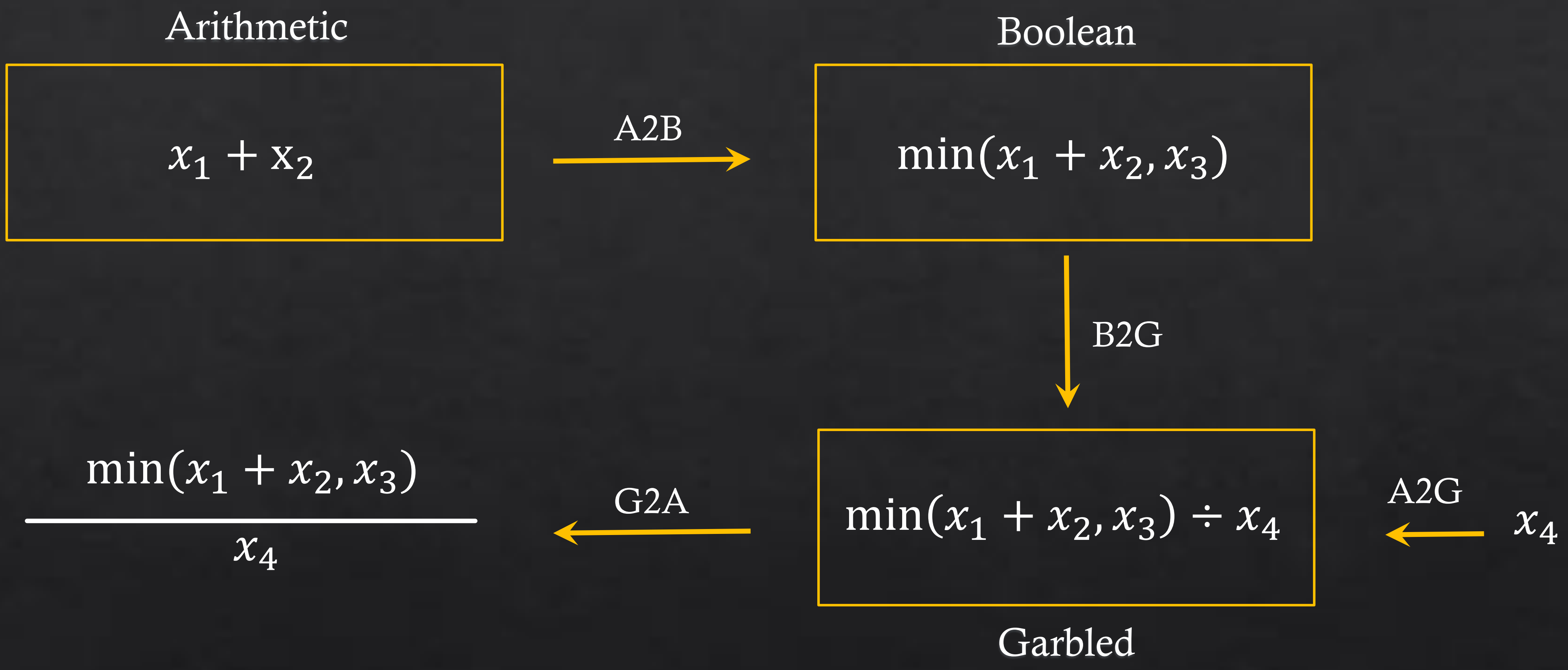

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B2G

$\min(x_1 + x_2, x_3) \div x_4$

Garbled

A2G

x_4

G2A

$$\frac{\min(x_1 + x_2, x_3)}{x_4}$$

Trident protocol

- A new 4PC protocol over ring in the pre-processing model
- Malicious security with guarantee of fairness
- Efficient Mixed World Conversions
- Special tools for PPML

Dot Product

$$X \blacksquare Y = \sum_{i=1}^{d} x_i \, . \, yi$$

Ref	Pre-processing (#elements)	Online (#elements)	Security
ABY3 (3PC)	12d	9d	Abort

d – #elements in each vector

Dot Product

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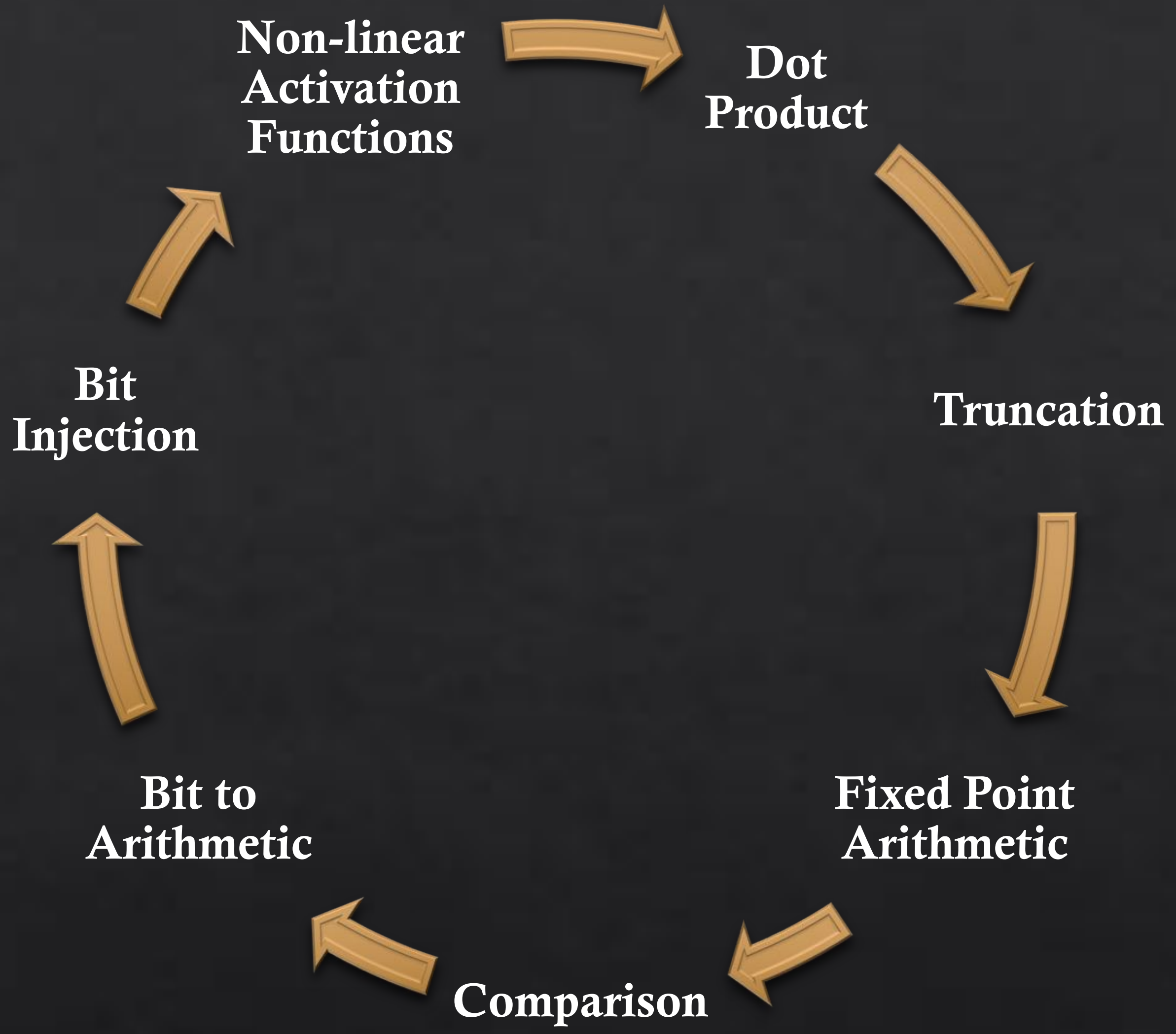
Tools for PPML



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- Lower monetary cost in the **outsourced setting**

Computation is outsourced to a set of hired servers

Benchmarking

- Implemented both Trident and ABY3, using the ENCRYPTO library.
- Benchmarked the protocols over LAN (40 Mbps) and WAN (1 Gbps) with the Google Cloud Platform.
- Servers located in West Europe, East Australia, South Asia, and South East Asia.
- For benchmarking, we used batch sizes up to 512 and feature sizes up to 1000.

Summary of Our Benchmarking Results

ML Algorithm	Improvement in terms of Online Throughput over ABY3	
	Training	Prediction
Linear Regression	251.84x	145.81x
Logistic Regression	34.58x	149.63x
Neural Networks	63.71x	407.12x
Convolutional Neural Networks	42.81x	741.56x

*Throughput for Training - #iterations processed by servers / minute
*Throughput for Prediction - #queries processed by servers / minute

thank you!

References

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