Maliciously Secure SCALES Protocols

Anasuya Acharya [1], Carmit Hazay[1], Vladimir Kolesnikov[2], Manoj Prabhakaran[3]

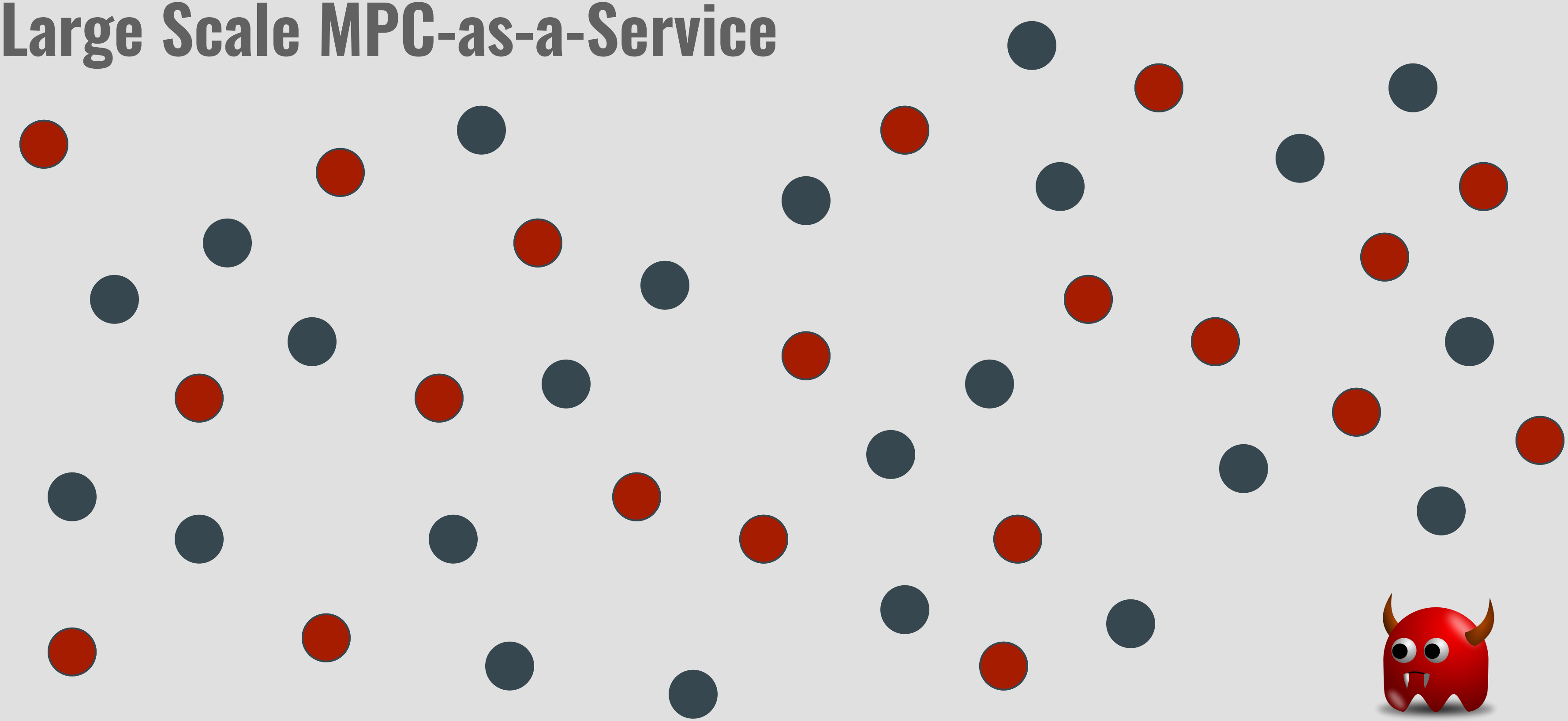
[1]Bar-Ilan University
[2]Georgia Institute of Technology
[3]IIT Bombay

Center for Research in Applied Cryptography and Cyber Security

MPC

MPC-as-a-Service

Large Scale MPC-as-a-Service



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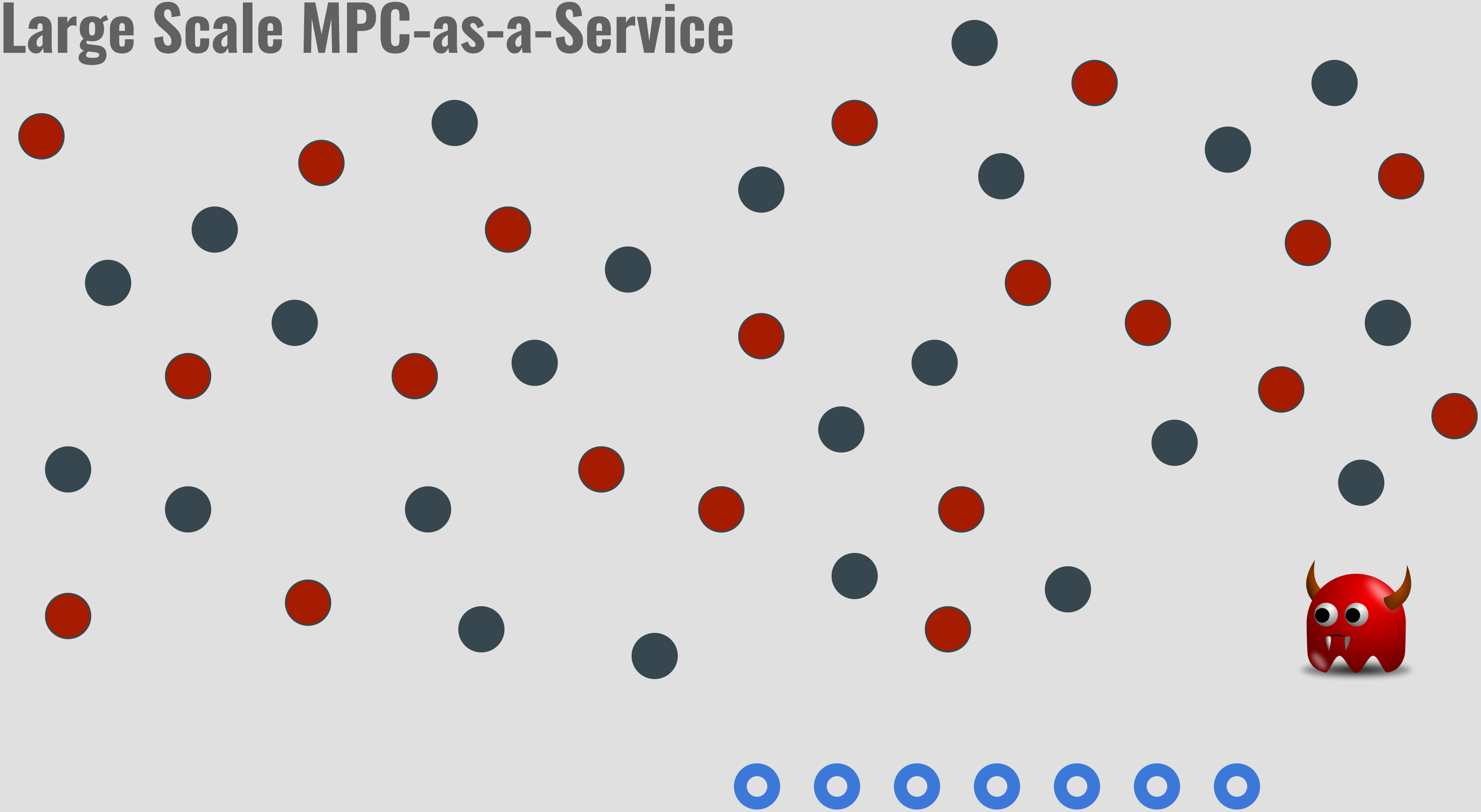

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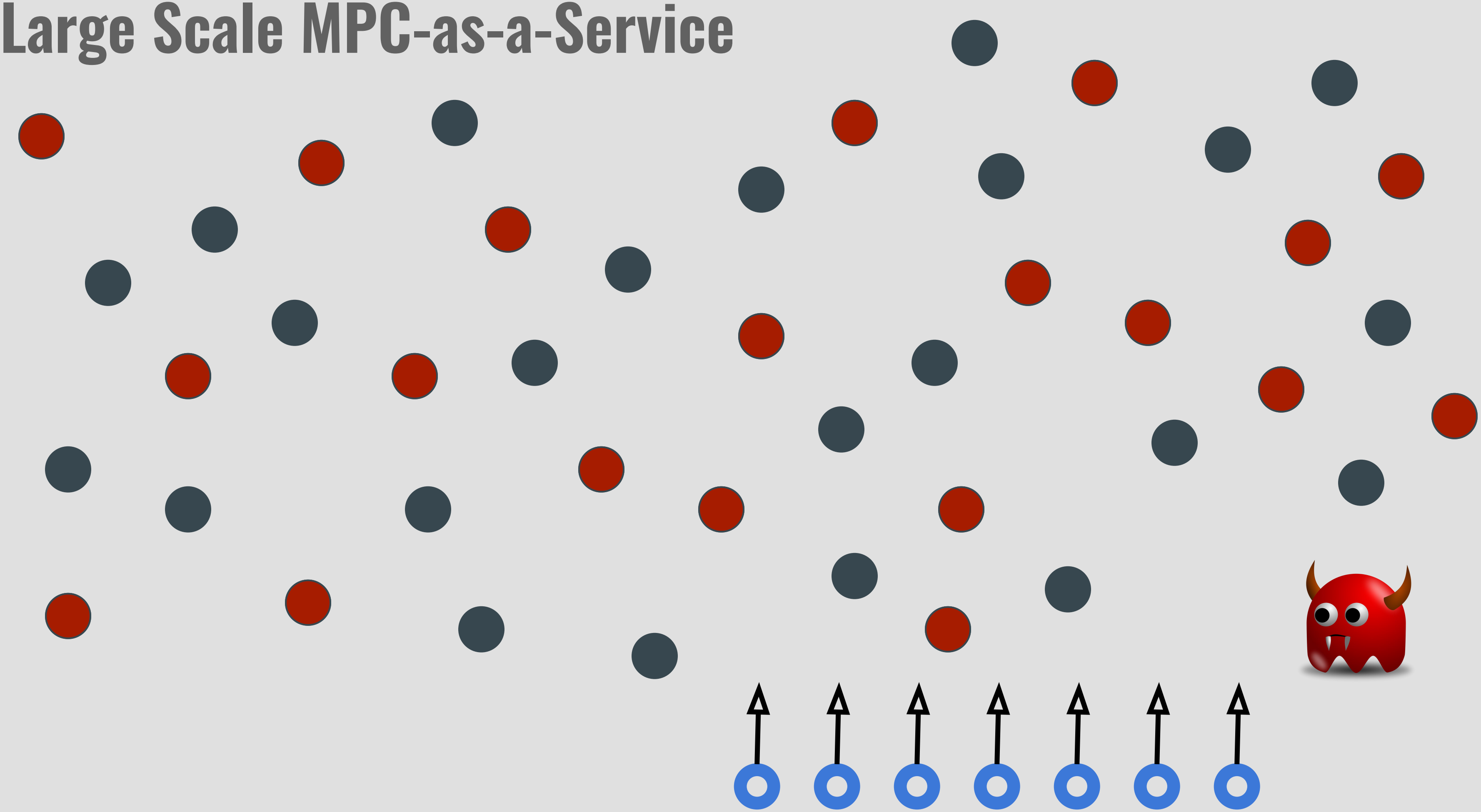

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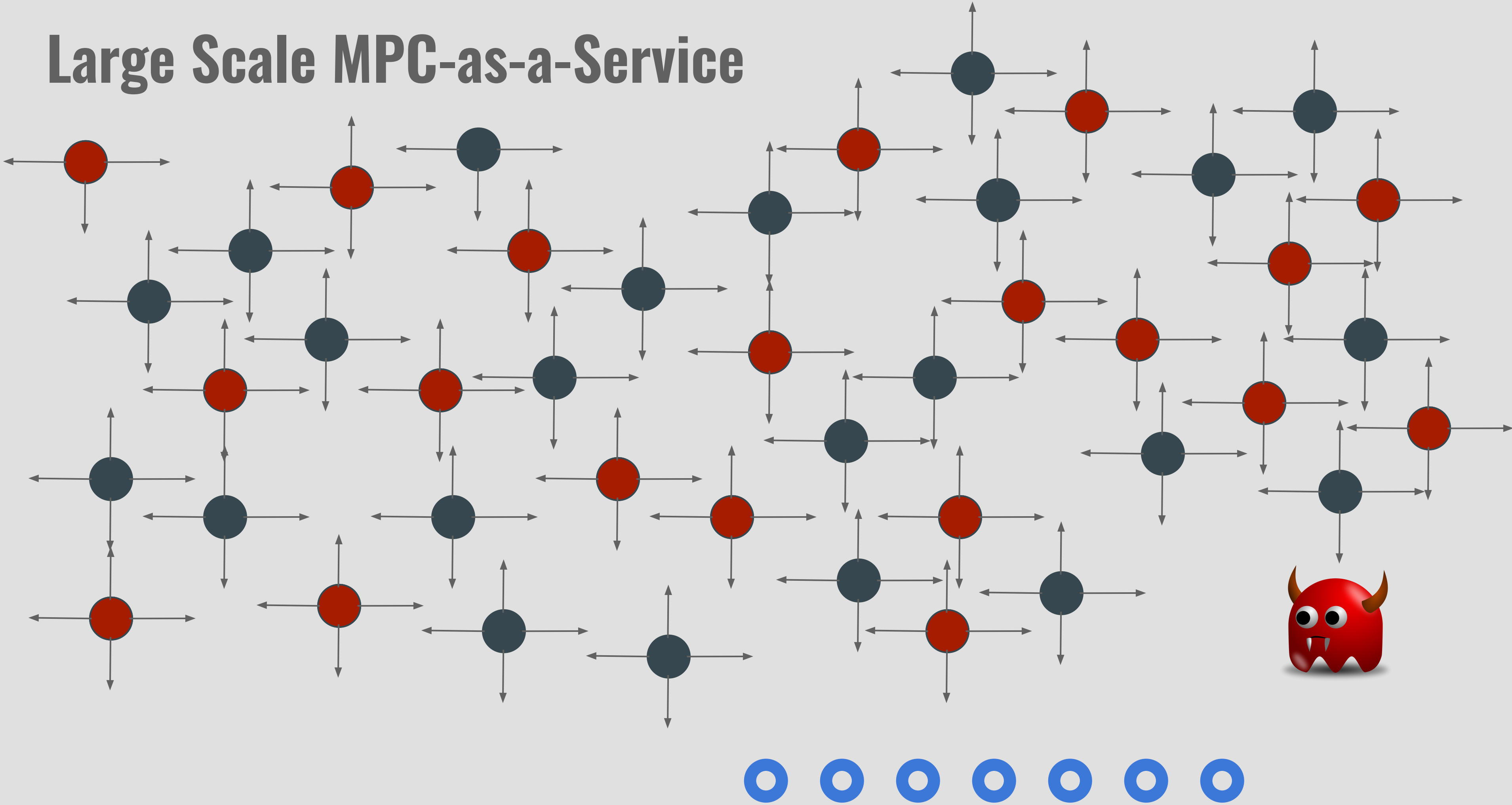

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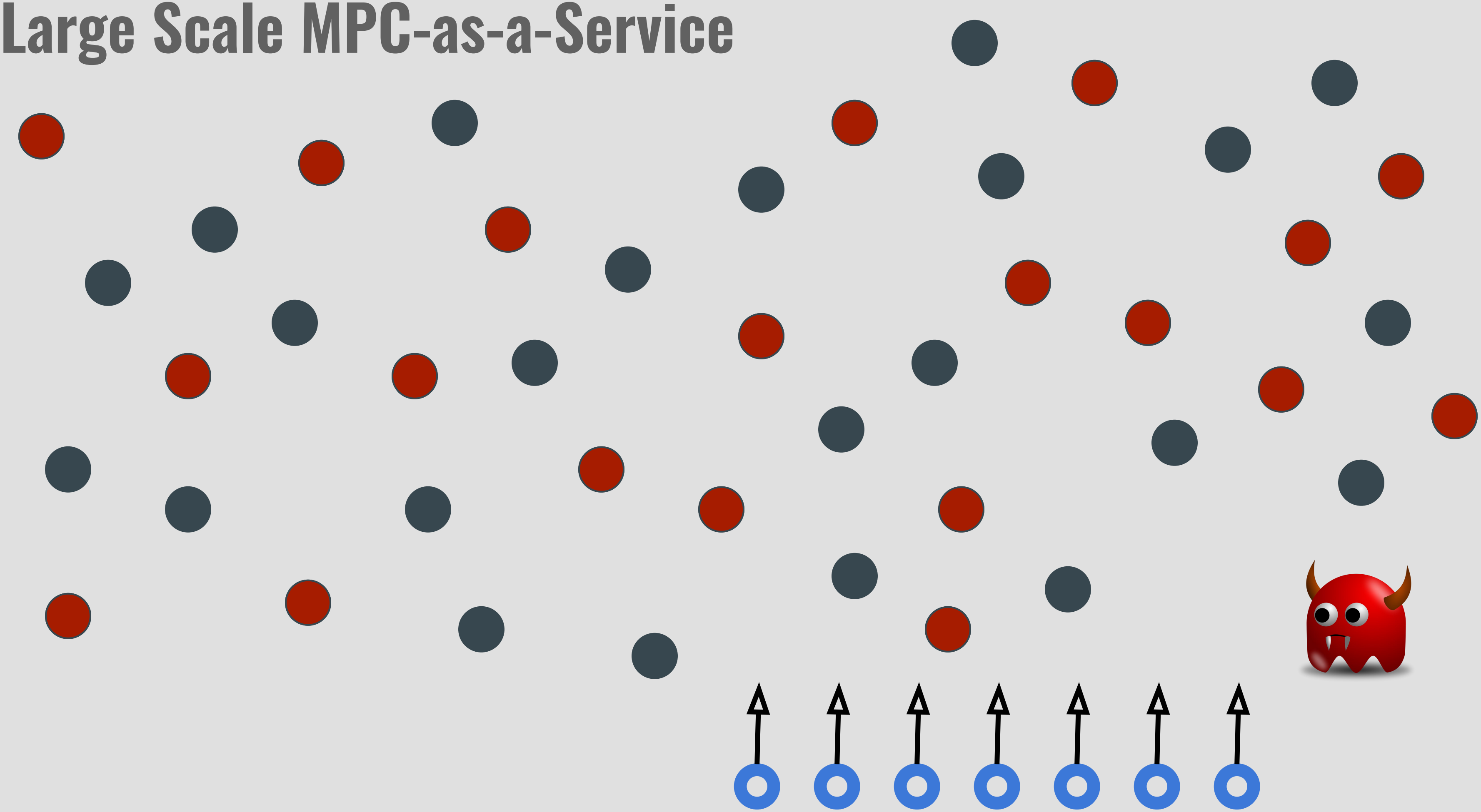

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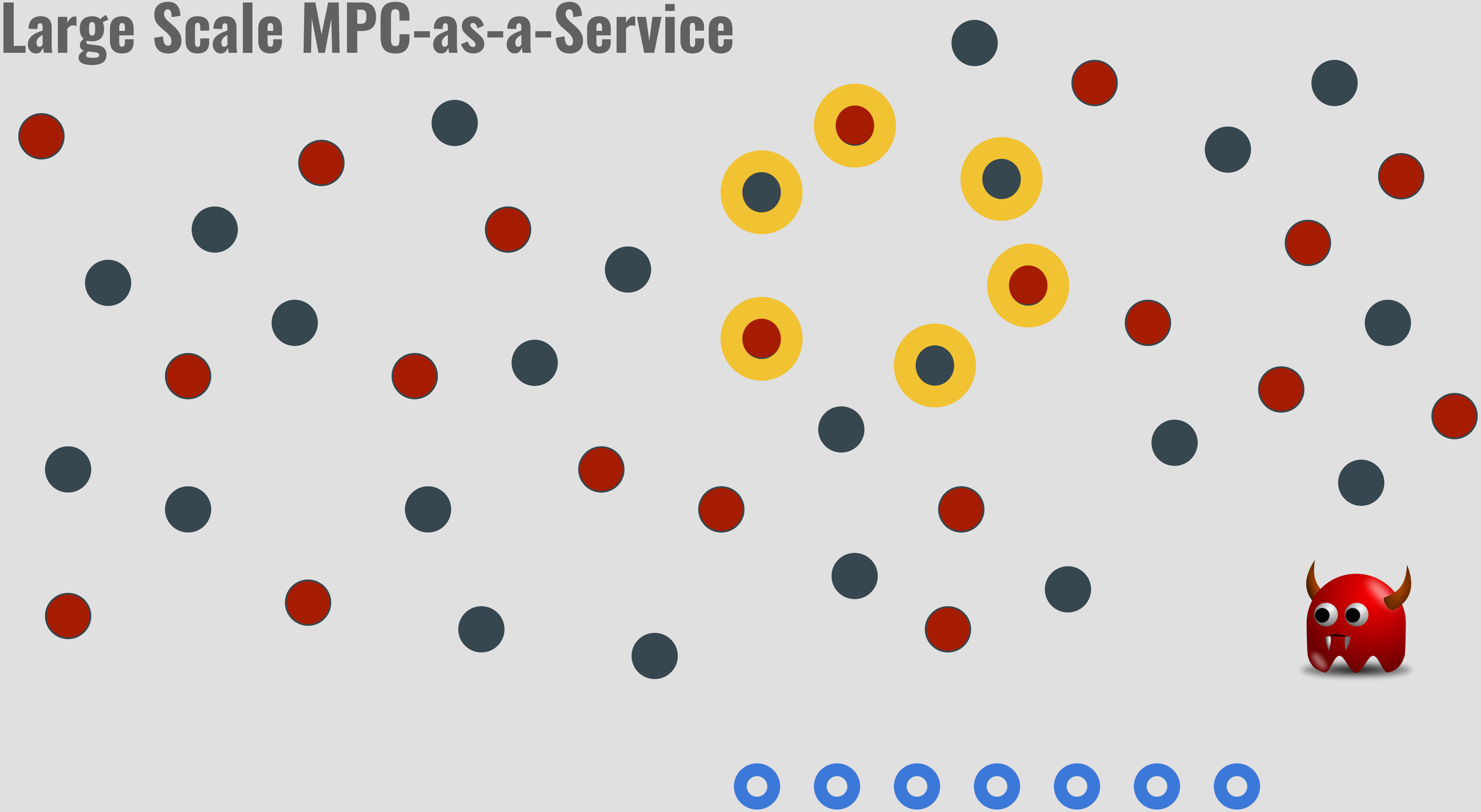

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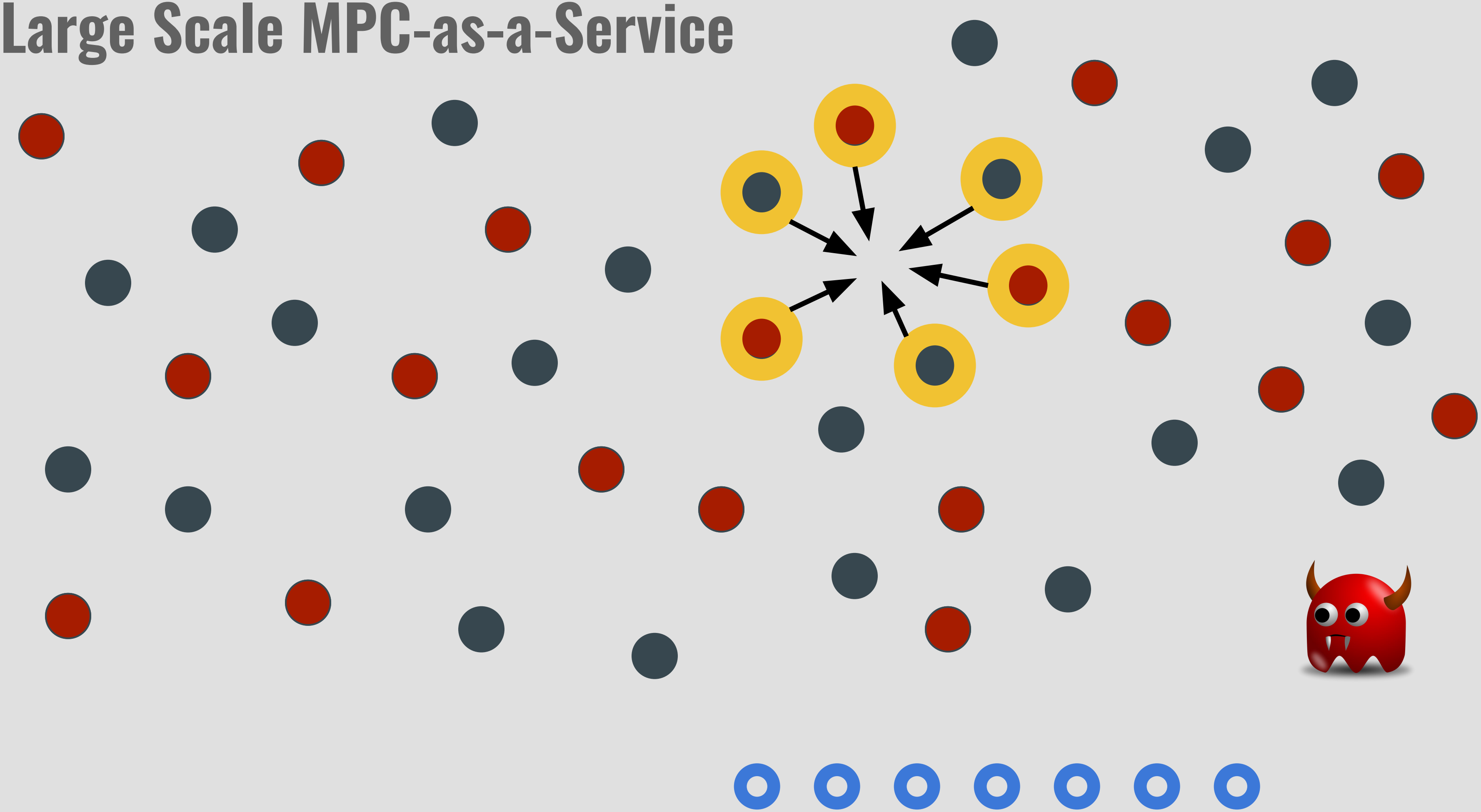

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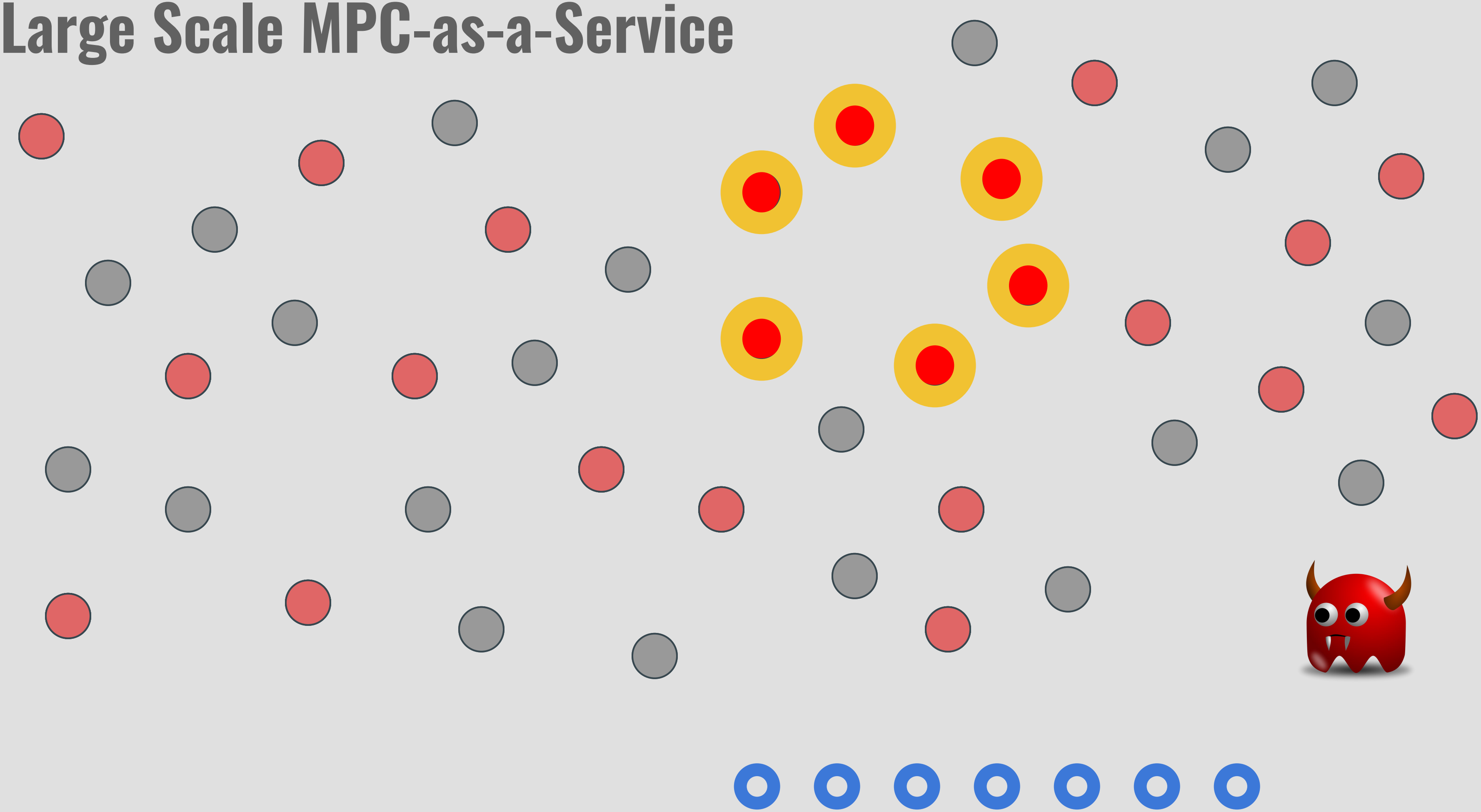

Overview

SCALES Model

Rerandomizable Garbling Schemes

Semi-Honest SCALES Protocol

Lifting to Malicious Security

The SCALES Model

[TCC ’22]

Small **C**lients **A**nd **L**arge **E**phemeral **S**ervers

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Small Clients And Large Ephemeral Servers

Bulletin-Board

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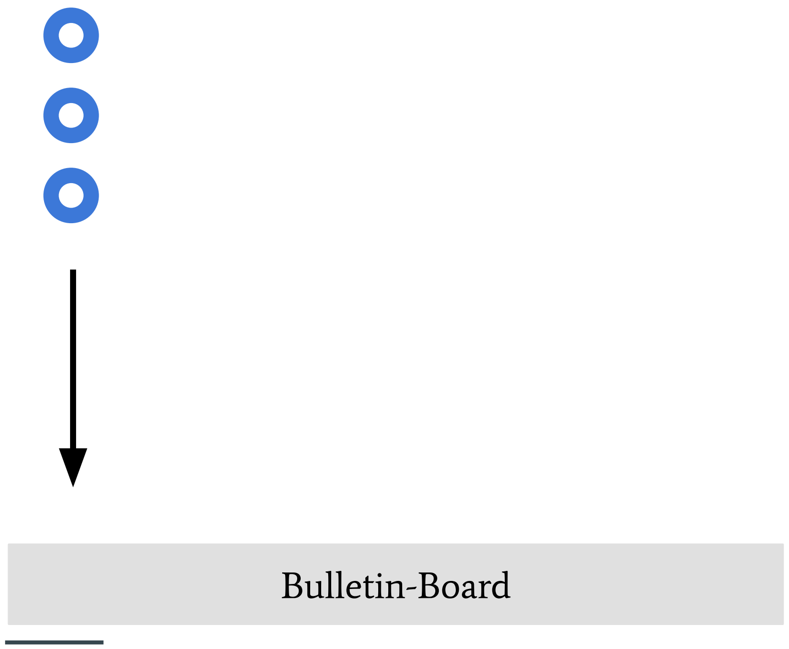

Bulletin-Board

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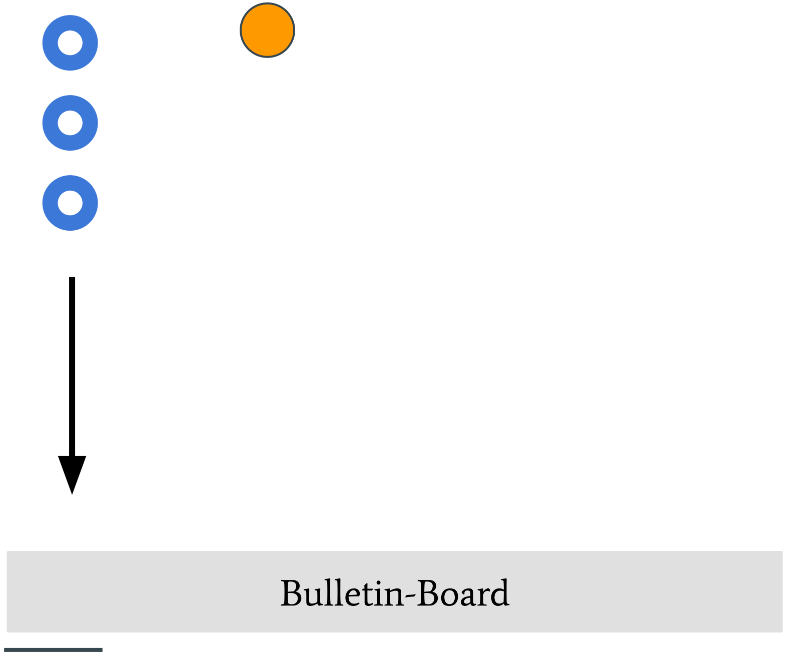
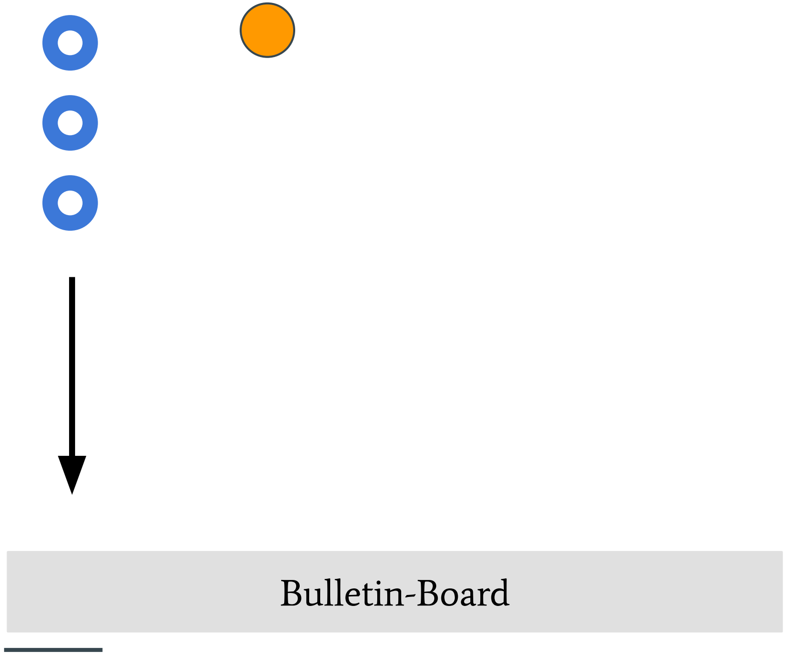


Small Clients And Large Ephemeral Servers

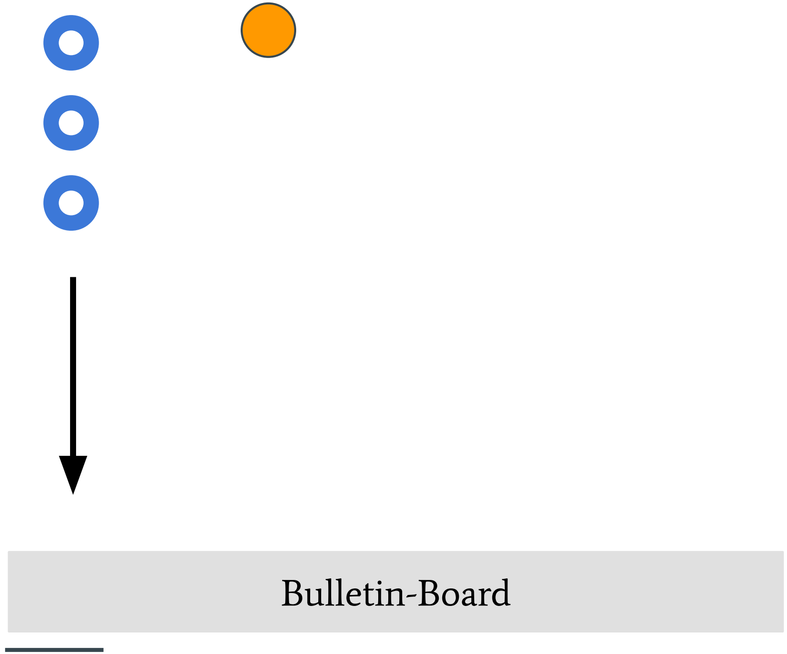
Secretly elected

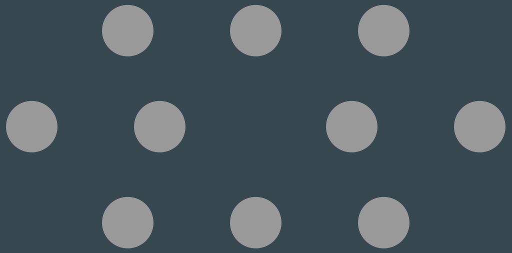


Bulletin-Board

Small Clients And Large Ephemeral Servers

Secretly elected
Silently compute



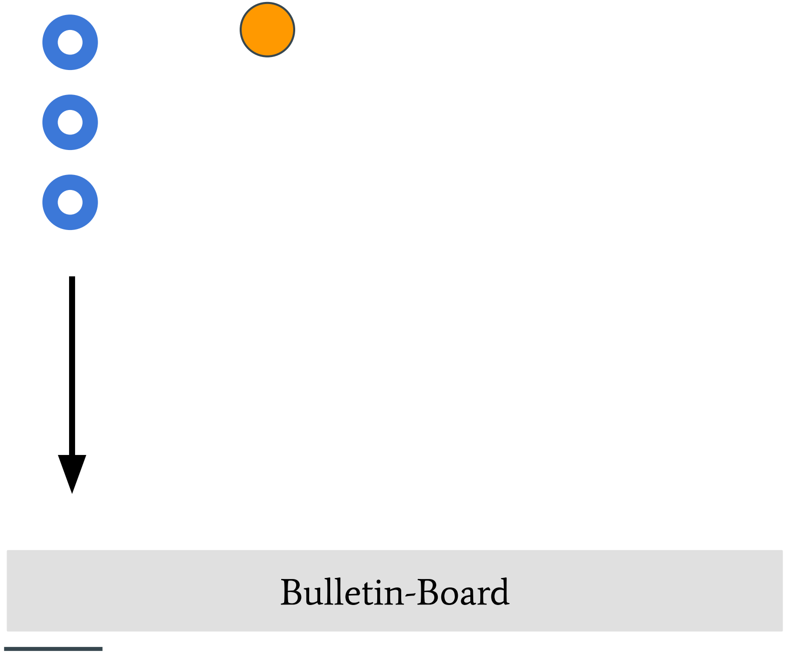


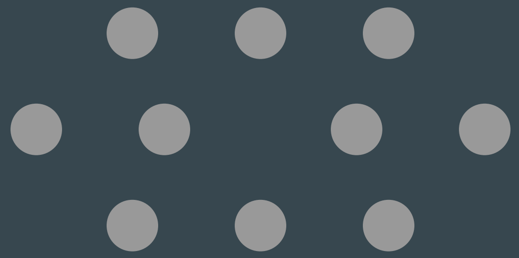
Small Clients And Large Ephemeral Servers

Secretly elected

Silently compute

Erase their state





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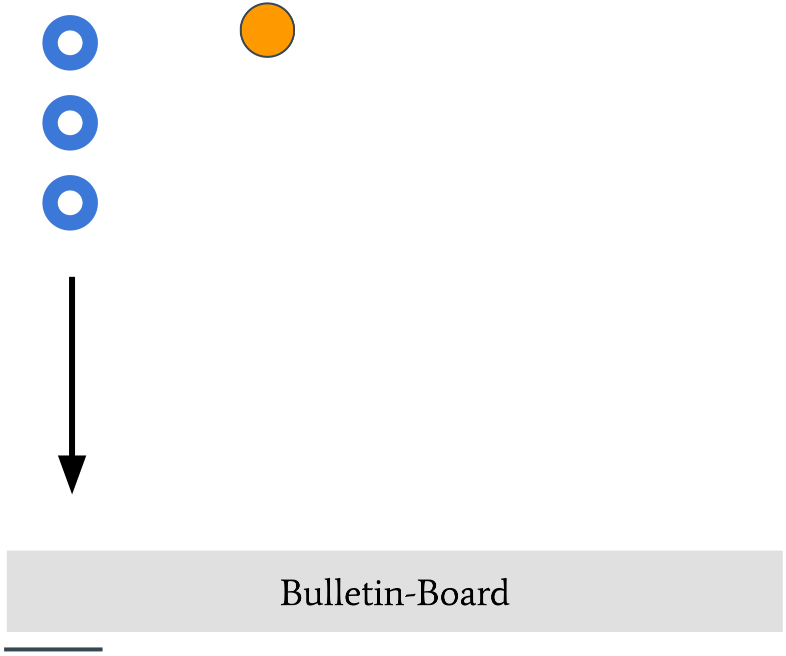
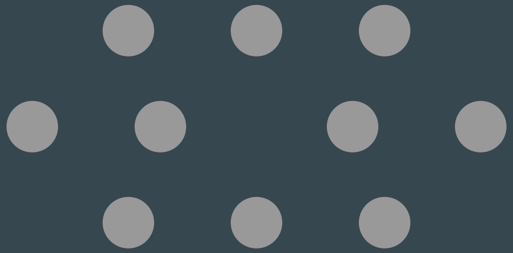
'Speak Once'





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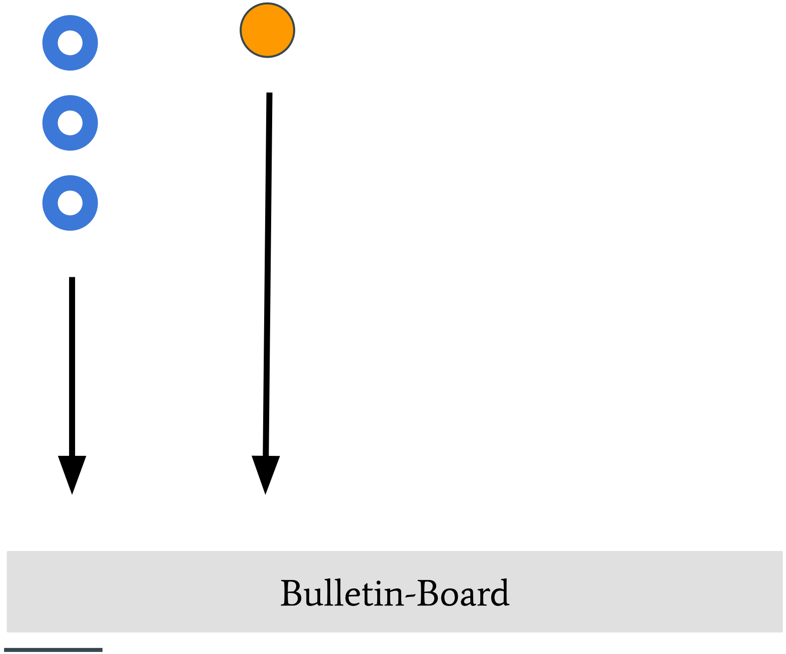
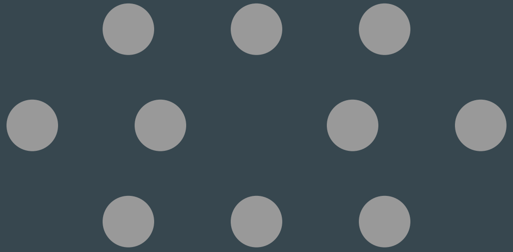


Bulletin-Board



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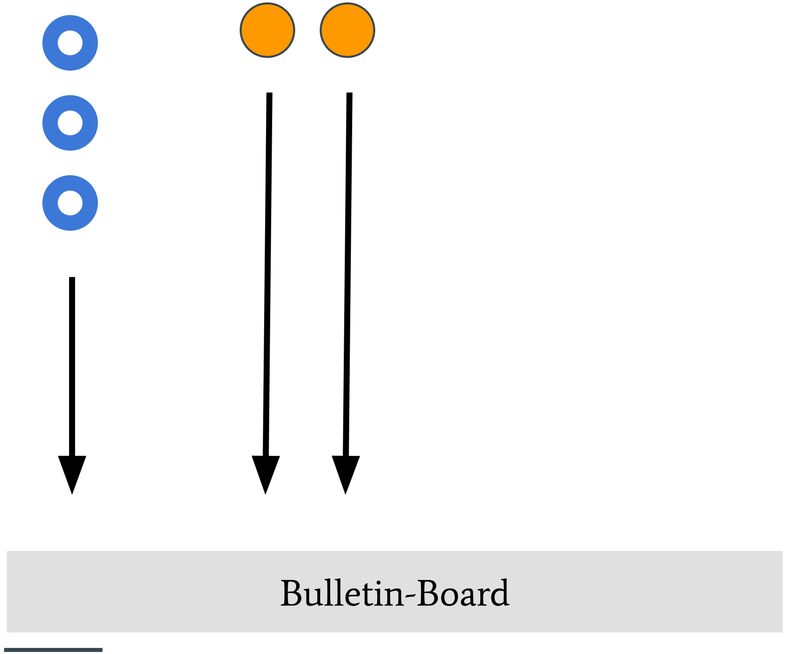

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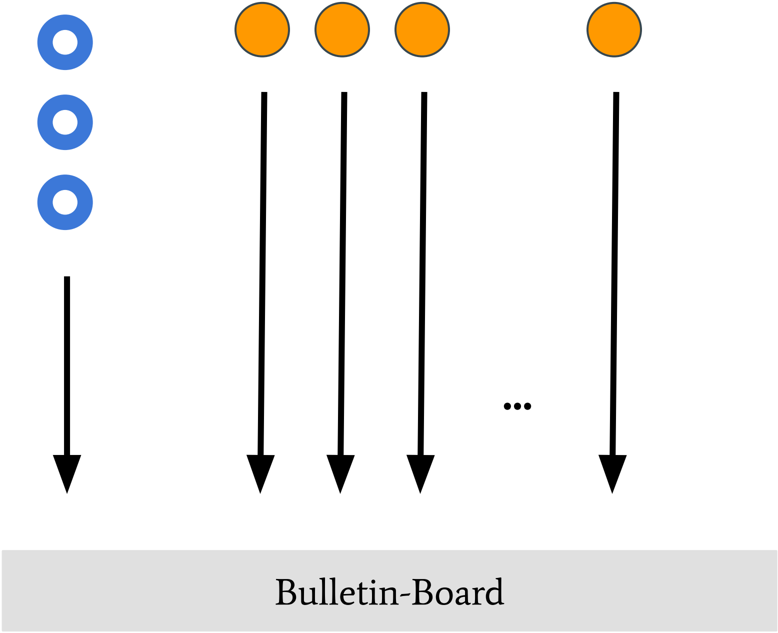

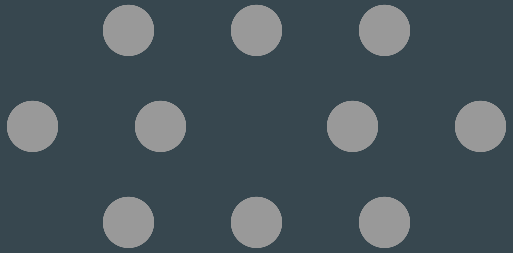

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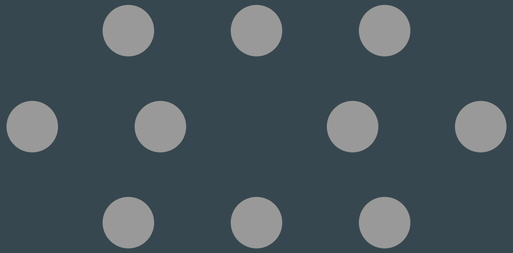

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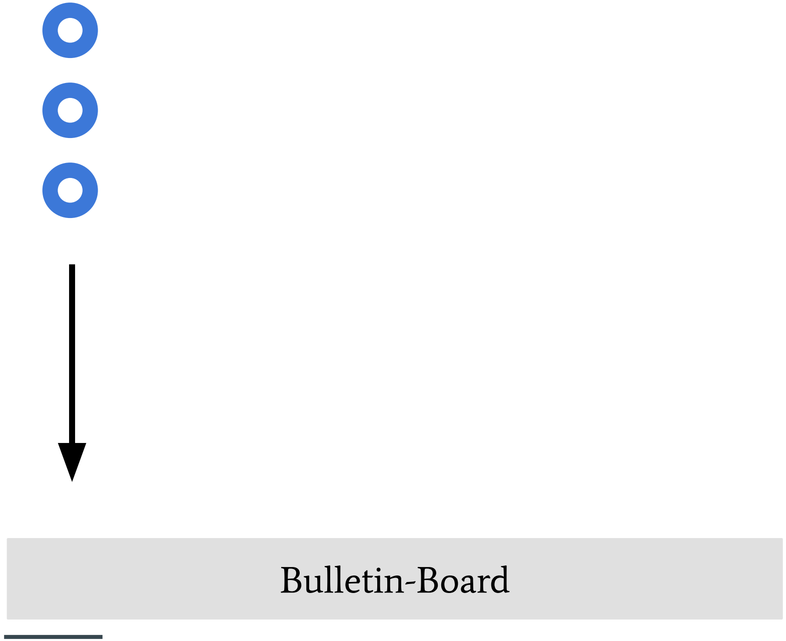

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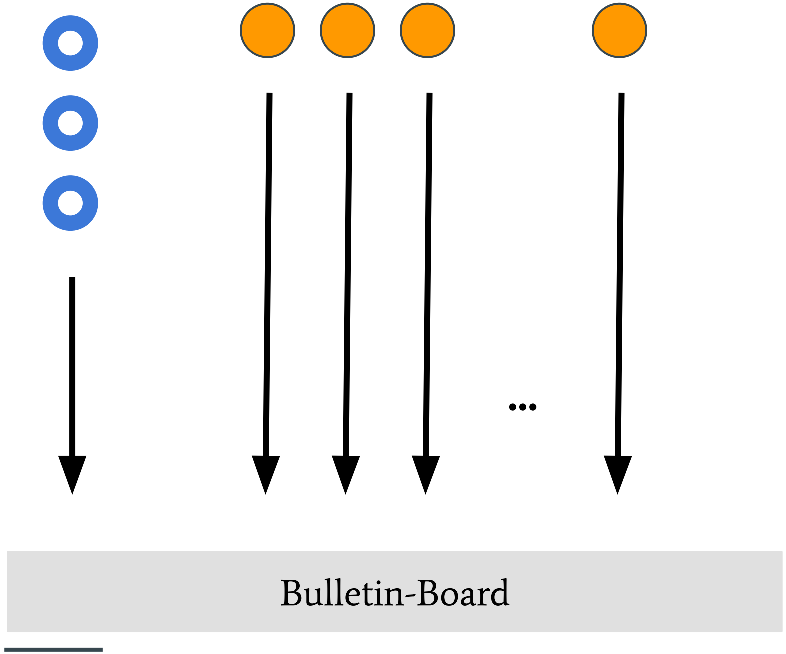

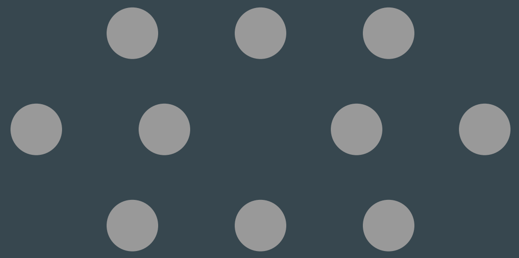

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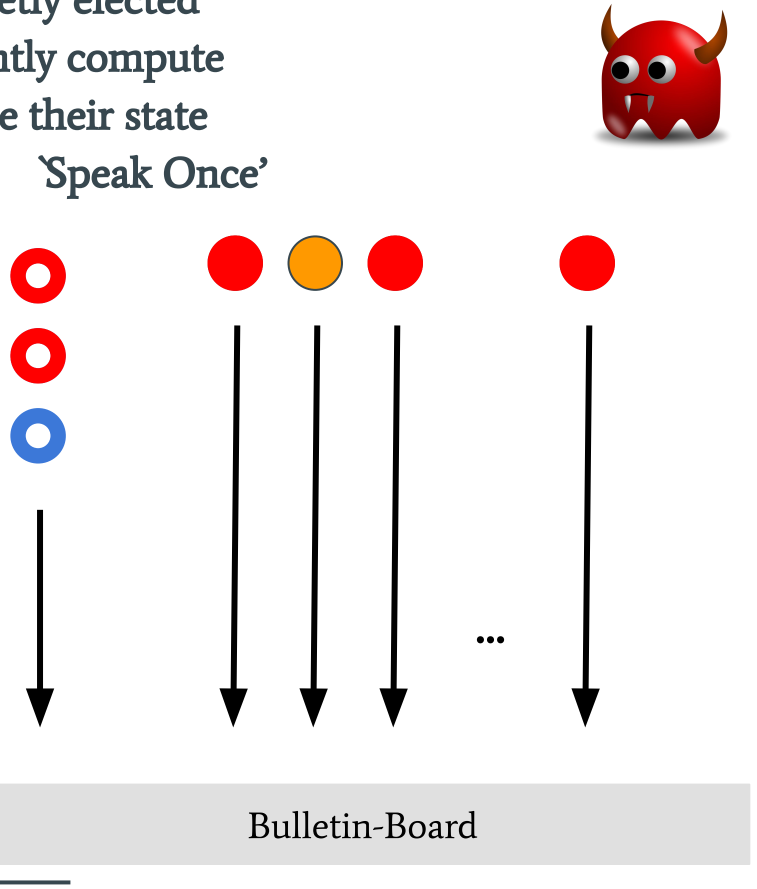


Semi-Honest SCALES Protocol

Garbled Circuits

Garbled Circuits

Garbler

Evaluator

Garbled Circuits

Garbler

$f : \{ 0,1 \}^n \rightarrow \{ 0,1 \}^m$

$x = (x_1 , \dots , x_n)$

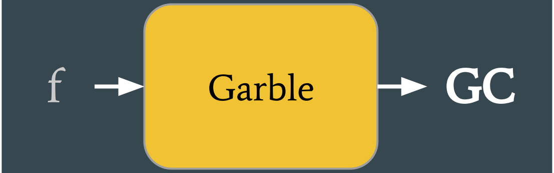
Evaluator

Garbled Circuits

Garbler

$f : \{ 0,1 \}^n \rightarrow \{ 0,1 \}^m$

$x = (x_1 , \dots , x_n)$



f

Garble

GC

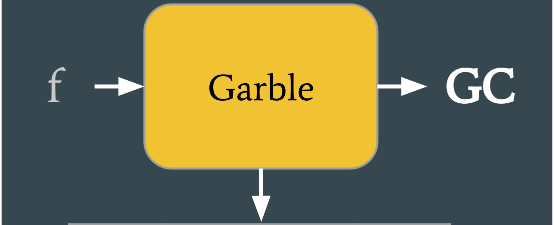
Evaluator

Garbled Circuits

Garbler

$f : \{ 0,1 \}^n \rightarrow \{ 0,1 \}^m$

$x = (x_1 , \dots , x_n)$



L^1_0	L^2_0	…	L^n_0
L^1_1	L^2_1	…	L^n_1

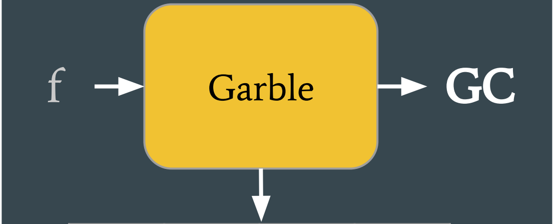
Evaluator

Garbled Circuits

Garbler

$$f : \{ 0,1 \}^n \rightarrow \{ 0,1 \}^m$$

$$x = (x_1 , \dots , x_n)$$



L^1_0	L^2_0	…	L^n_0
L^1_1	**L^2_1**	…	**L^n_1**

Evaluator

Garbled Circuits

Garbler

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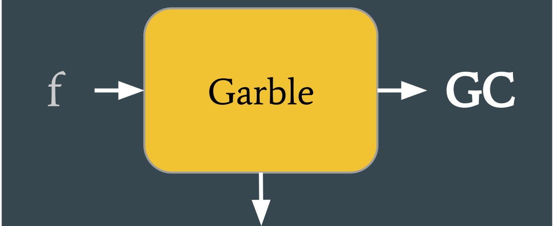
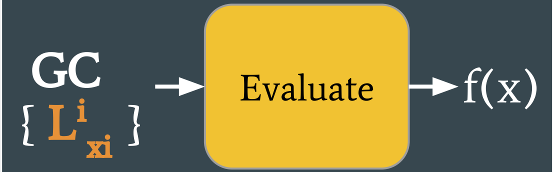


L^1_0	L^2_0	…	L^n_0
L^1_1	L^2_1	…	L^n_1

Evaluator

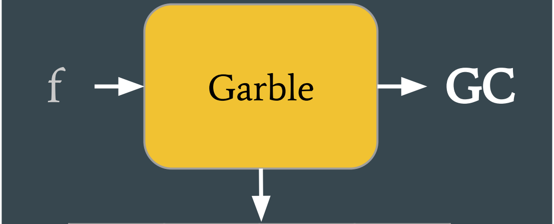


Rerandomizable Garbled Circuits

Garbler

$f : \{ 0,1 \}^n \rightarrow \{ 0,1 \}^m$

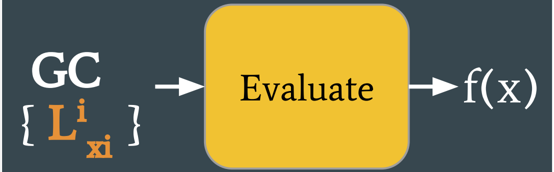
$x = (x_1 , \ldots , x_n)$



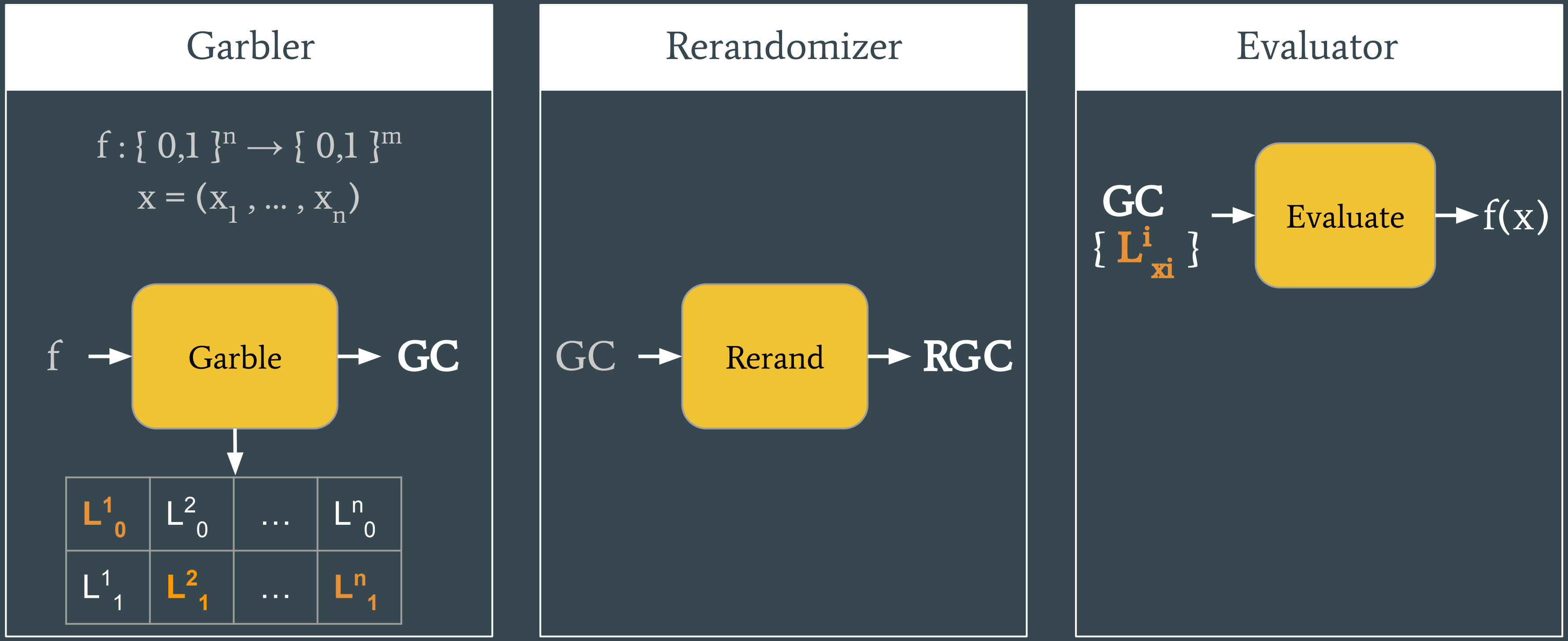
L^1_0	L^2_0	…	L^n_0
L^1_1	L^2_1	…	L^n_1

Rerandomizer

Evaluator



Rerandomizable Garbled Circuits



Garbler

$f : \{ 0,1 \}^n \to \{ 0,1 \}^m$

$x = (x_1 , \dots , x_n)$

f → Garble → GC

L^1_0	L^2_0	…	L^n_0
L^1_1	L^2_1	…	L^n_1

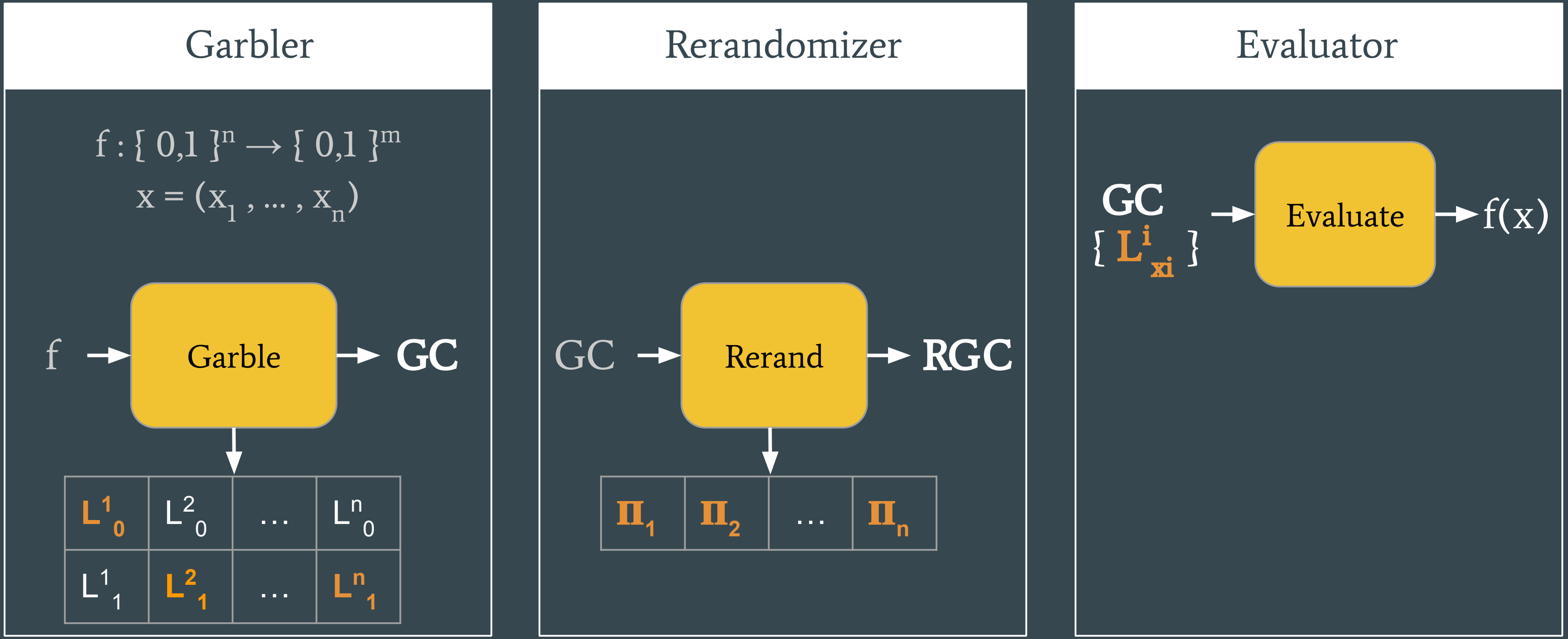
Rerandomizer

GC → Rerand → RGC

Evaluator

GC $\{ L^i_{xi} \}$ → Evaluate → f(x)

Rerandomizable Garbled Circuits



Garbler

$f : \{0,1\}^n \rightarrow \{0,1\}^m$

$x = (x_1 , \dots , x_n)$

$f \rightarrow$ Garble $\rightarrow$ GC

L^1_0	L^2_0	…	L^n_0
L^1_1	L^2_1	…	L^n_1

Rerandomizer

GC $\rightarrow$ Rerand $\rightarrow$ RGC

π_1	π_2	…	π_n

Evaluator

GC $\{ L^i_{xi} \}$ $\rightarrow$ Evaluate $\rightarrow f(x)$

Rerandomizable Garbled Circuits

Garbler

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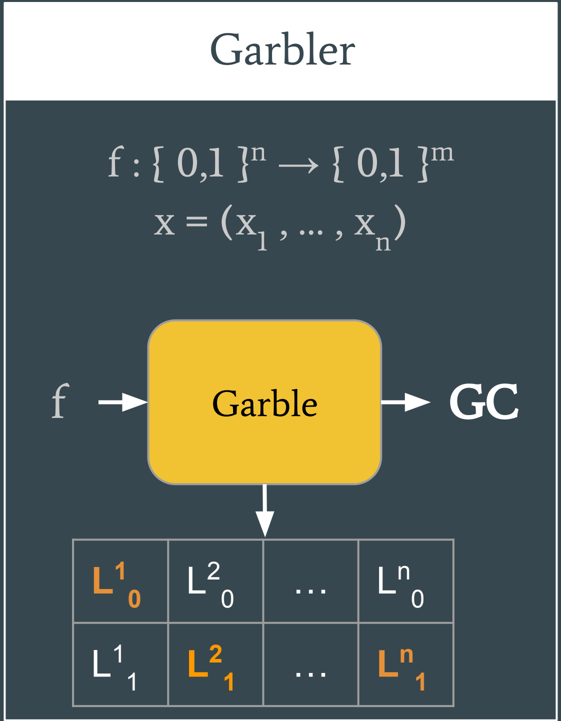
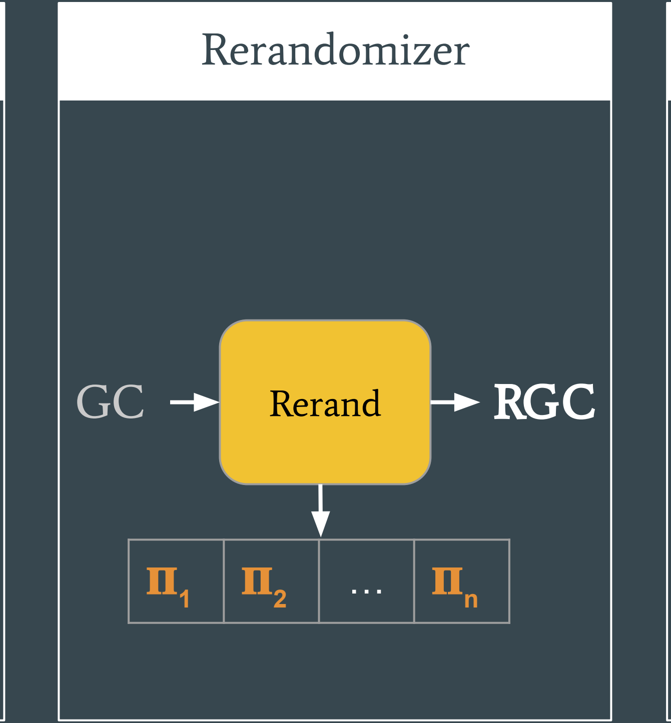


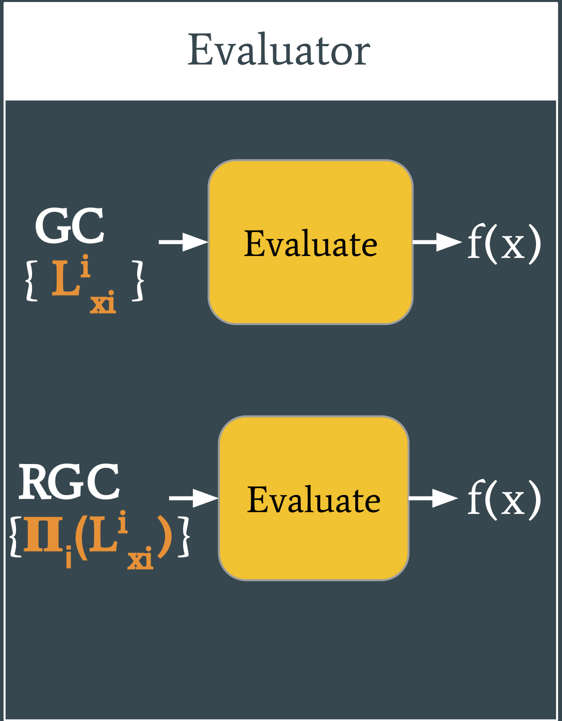
L^1_0	L^2_0	…	L^n_0
L^1_1	L^2_1	…	L^n_1

Rerandomizer



Π_1	Π_2	…	Π_n

Evaluator



Rerandomizable Garbled Circuits

Garbler

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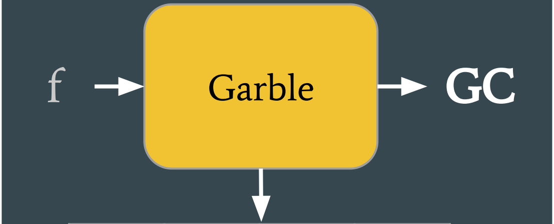
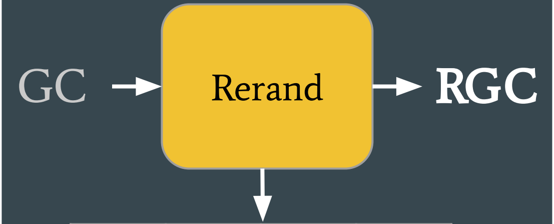


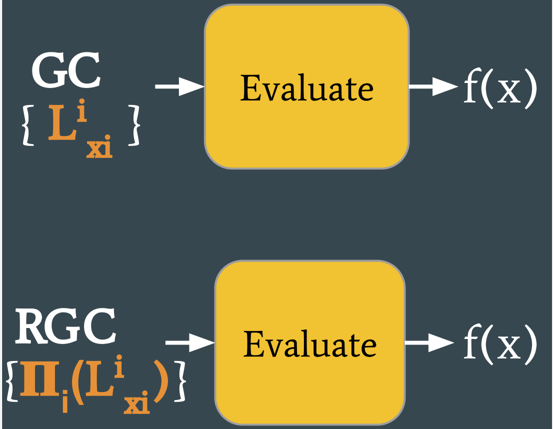
L^1_0	L^2_0	…	L^n_0
L^1_1	L^2_1	…	L^n_1

Rerandomizer



Π_1	Π_2	…	Π_n

Evaluator



Semi-Honest Protocol

Semi-Honest Protocol

Phase 1

Garble the circuit

Phase 2

Evaluate the garbling

Bulletin-Board

Semi-Honest Protocol

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Semi-Honest Protocol

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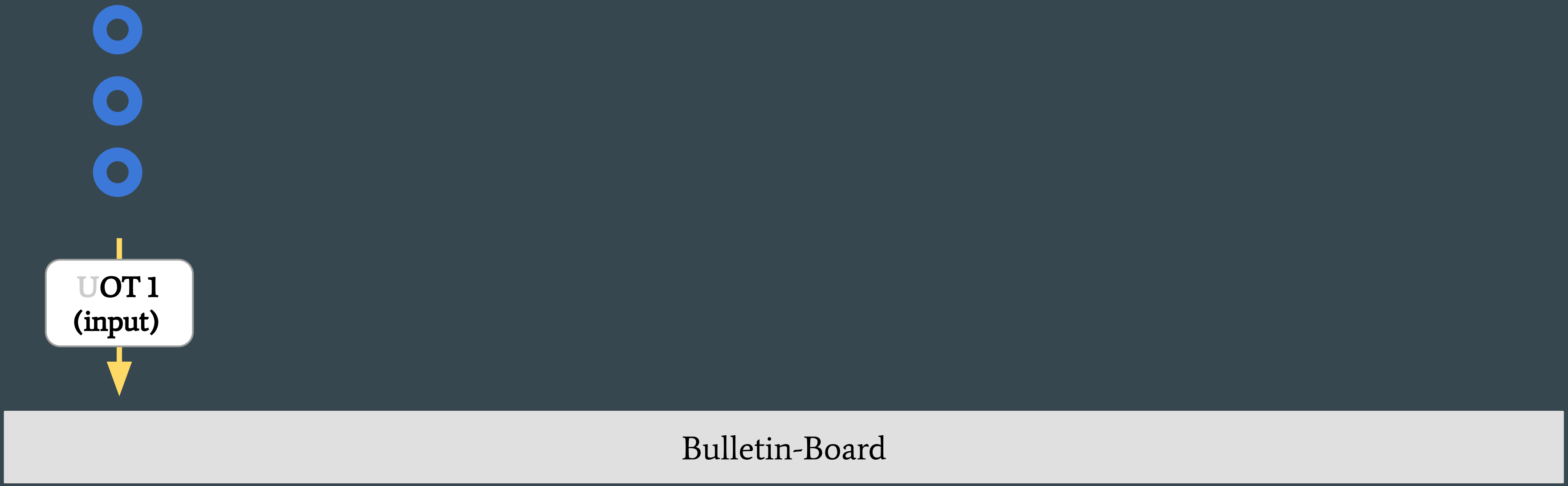


UOT 1
(input)

Bulletin-Board

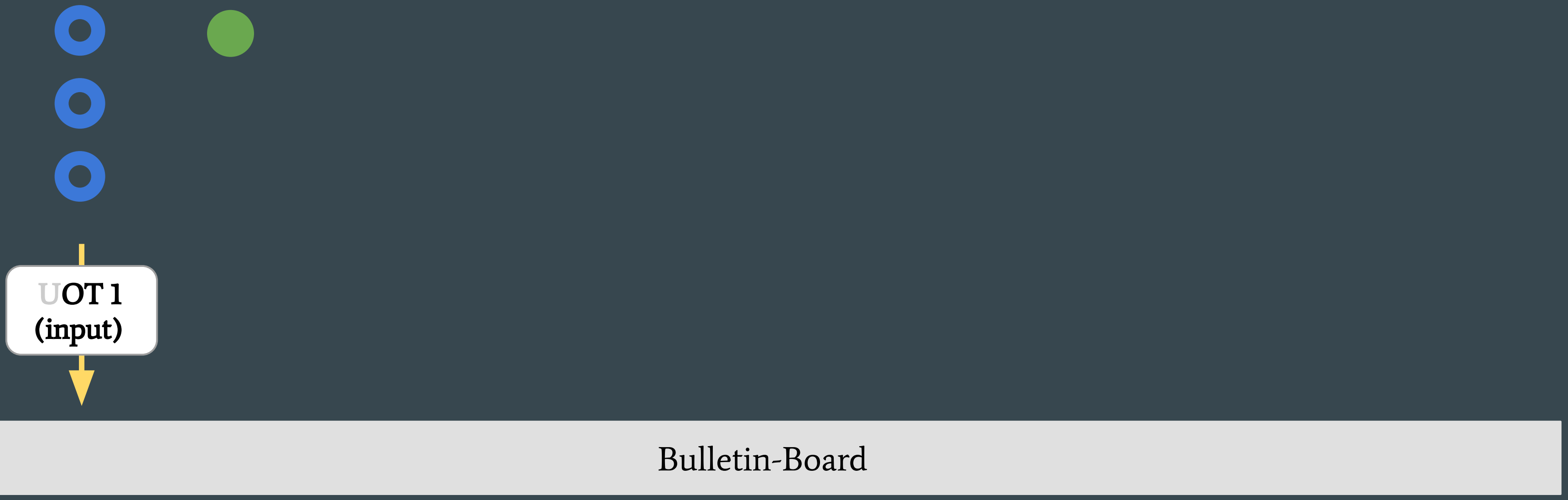
Semi-Honest Protocol

Phase 1

Garble the circuit

Phase 2

Evaluate the garbling



UOT 1
(input)

Bulletin-Board

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Phase 1

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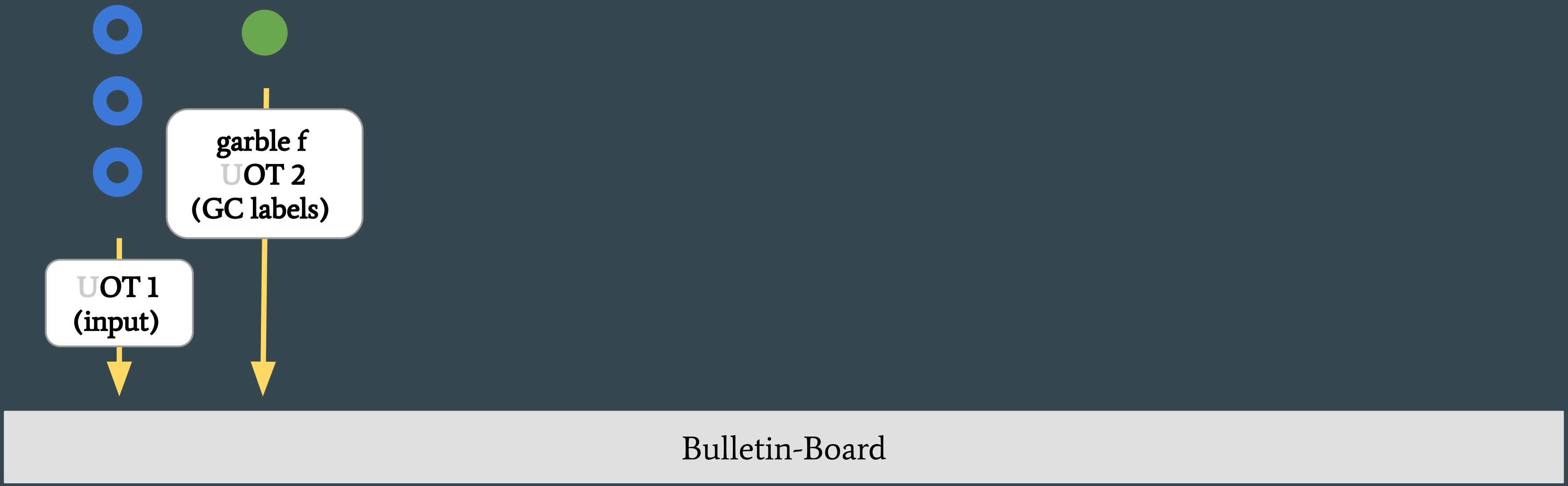
Phase 2

Evaluate the garbling



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Phase 1

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Phase 2

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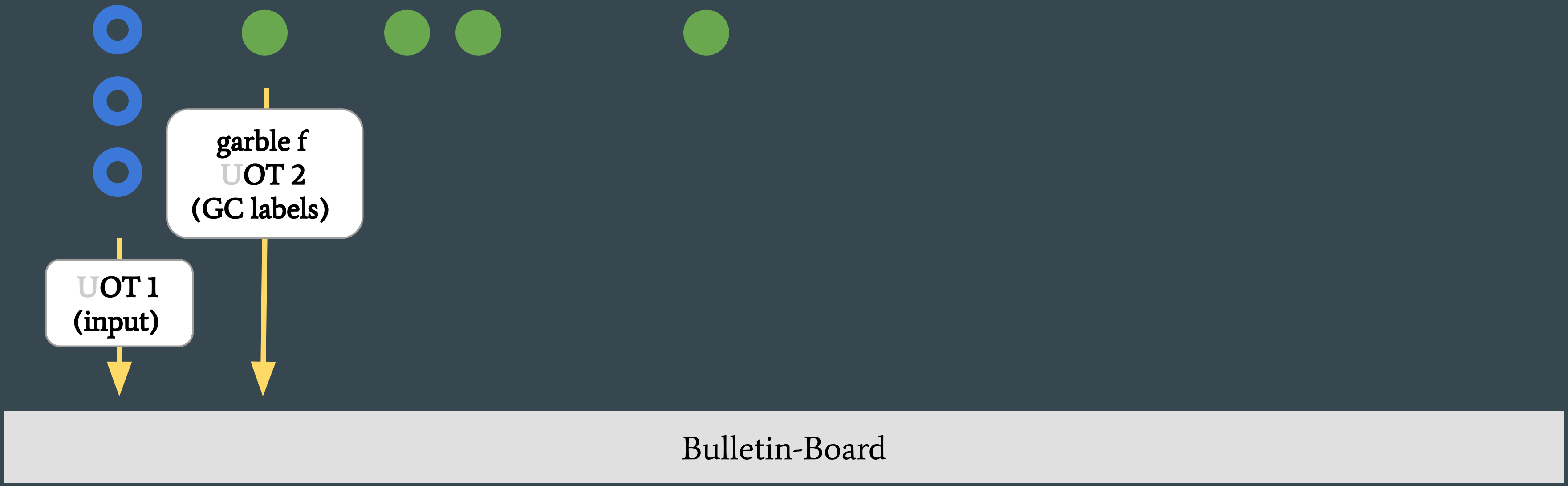


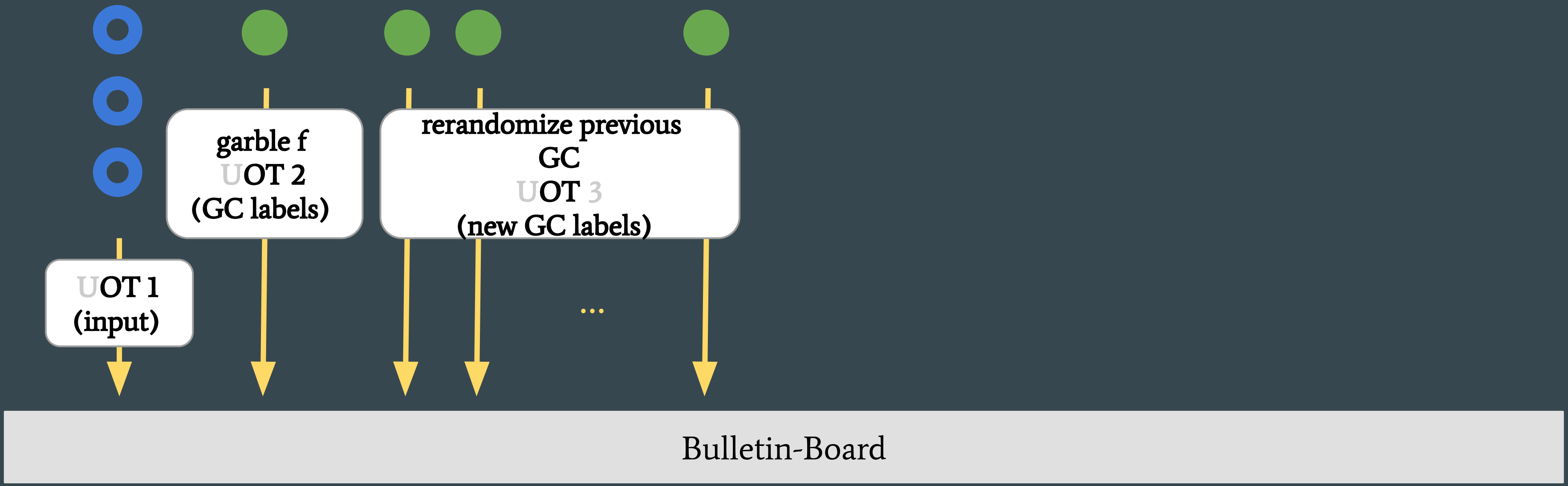
Semi-Honest Protocol

Phase 1

Garble the circuit

Phase 2

Evaluate the garbling



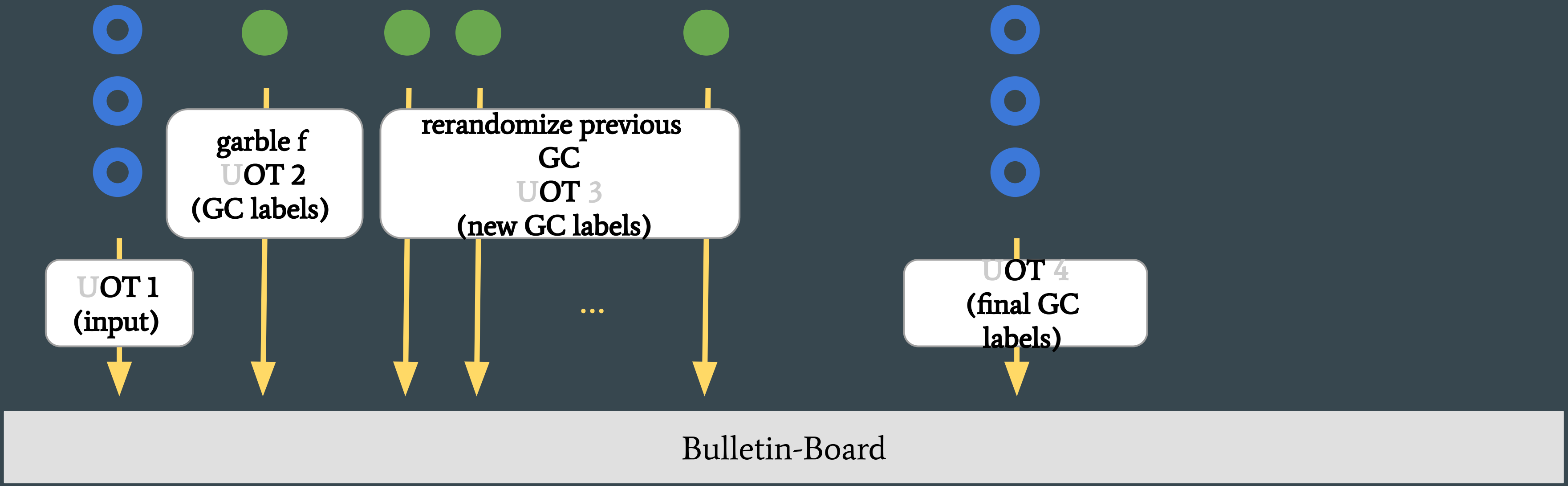
Semi-Honest Protocol

Phase 1

Garble the circuit

Phase 2

Evaluate the garbling



UOT 1
(input)

garble f
UOT 2
(GC labels)

rerandomize previous
GC
UOT 3
(new GC labels)

...

UOT 4
(final GC
labels)

Bulletin-Board

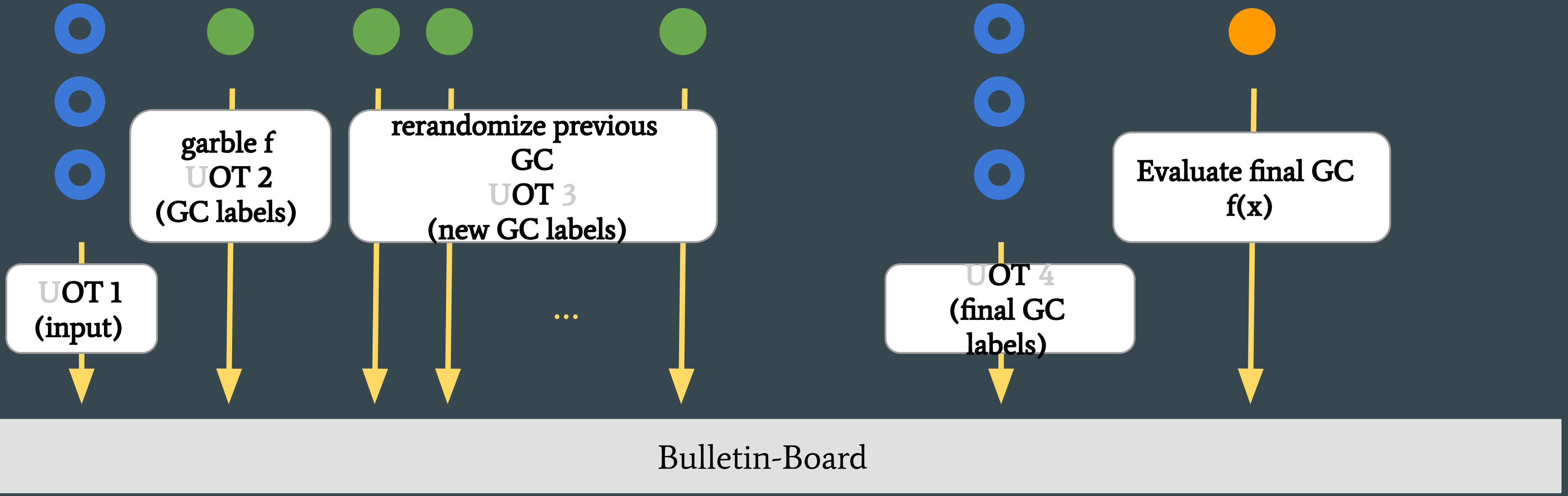
Semi-Honest Protocol

Phase 1

Garble the circuit

Phase 2

Evaluate the garbling



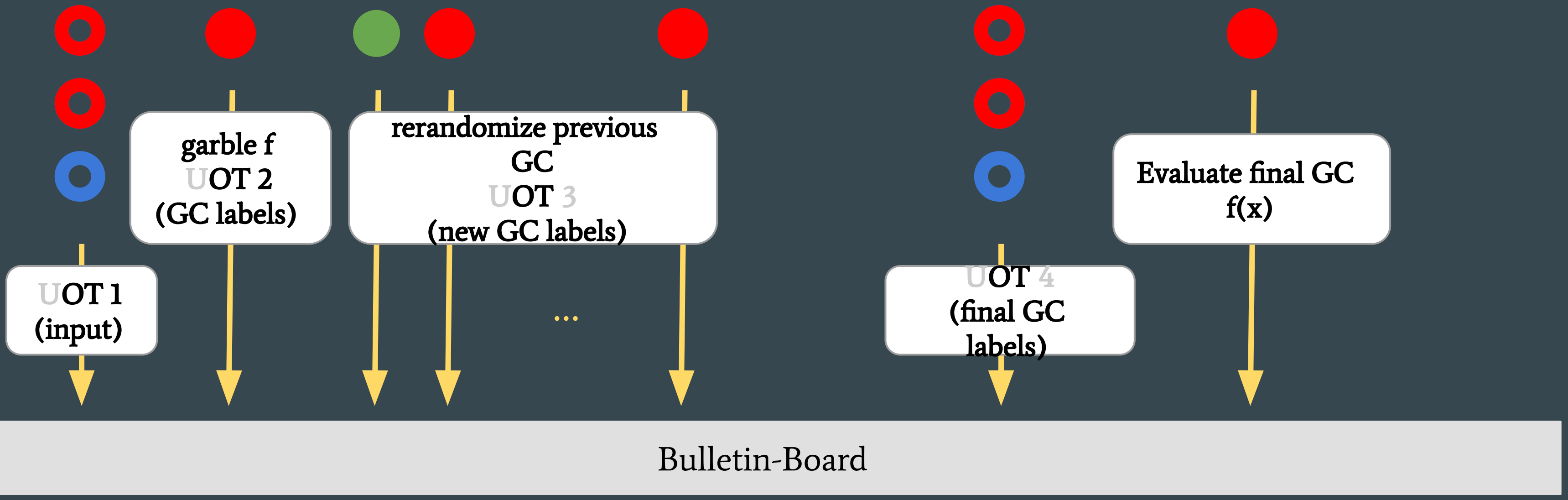
Semi-Honest Protocol

Phase 1

Garble the circuit

Phase 2

Evaluate the garbling



UOT 1
(input)

garble f
UOT 2
(GC labels)

rerandomize previous GC
UOT 3
(new GC labels)

…

UOT 4
(final GC labels)

Evaluate final GC
f(x)

Bulletin-Board

Lifting to Malicious Security

Lifting to Malicious Security

Security with Abort

Lifting to Malicious Security

Lifting to Malicious Security

Semi-honest secure UOT → Maliciously secure UOT

Lifting to Malicious Security

Semi-honest secure UOT → Maliciously secure UOT

2-round OT (with special structure) : CRS model

Lifting to Malicious Security

Semi-honest secure UOT → Maliciously secure UOT

2-round OT (with special structure) : CRS model

Forcing Semi-honest behaviour

Lifting to Malicious Security

Semi-honest secure UOT → Maliciously secure UOT

2-round OT (with special structure) : CRS model

Forcing Semi-honest behaviour

Approach 1: Generic SNARKs (CRS/RO model)

Lifting to Malicious Security

Semi-honest secure UOT → Maliciously secure UOT

2-round OT (with special structure) : CRS model

Forcing Semi-honest behaviour

Approach 1: Generic SNARKs (CRS/RO model)

Expensive Prover Computation

Custom Made ZK Proofs

•••

Black-Box in RGS

ZK Proof for Correct Garbling

ZK Proof for Correct Garbling

Prover

Verifier

ZK Proof for Correct Garbling

Prover	**Verifier**
Witness: randomness **r**	Public: **f, GC**

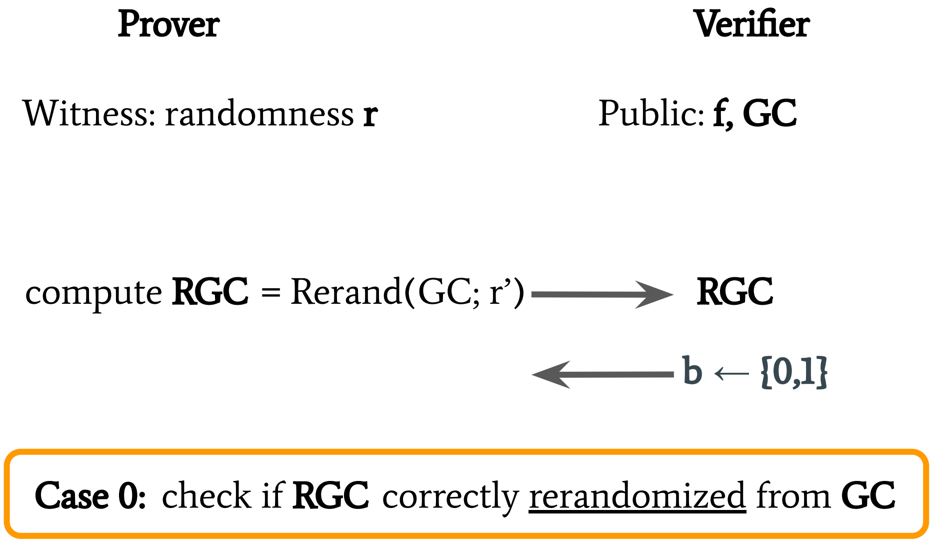
ZK Proof for Correct Garbling

Prover	**Verifier**
Witness: randomness **r**	Public: **f, GC**
compute **RGC** = Rerand(GC; r’) →	**RGC**

ZK Proof for Correct Garbling

Prover		**Verifier**
Witness: randomness **r**		Public: **f, GC**
compute **RGC** = Rerand(GC; r’)	→	**RGC**
	←	**b ← {0,1}**

ZK Proof for Correct Garbling



Prover

Verifier

Witness: randomness **r**

Public: **f, GC**

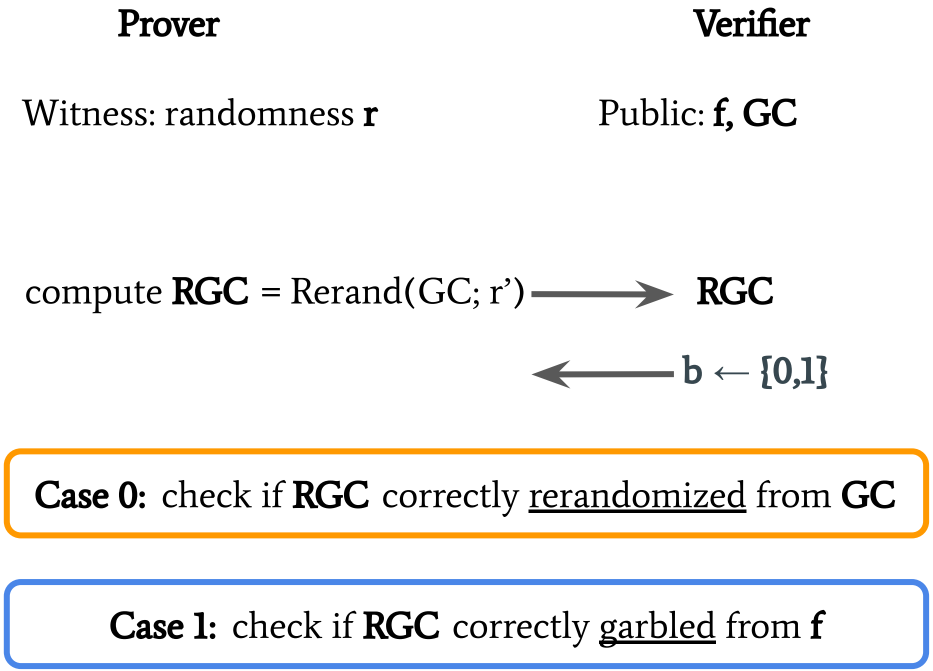
compute **RGC** = Rerand(GC; r’)

RGC

b ← {0,1}

Case 0: check if **RGC** correctly <u>rerandomized</u> from **GC**

ZK Proof for Correct Garbling



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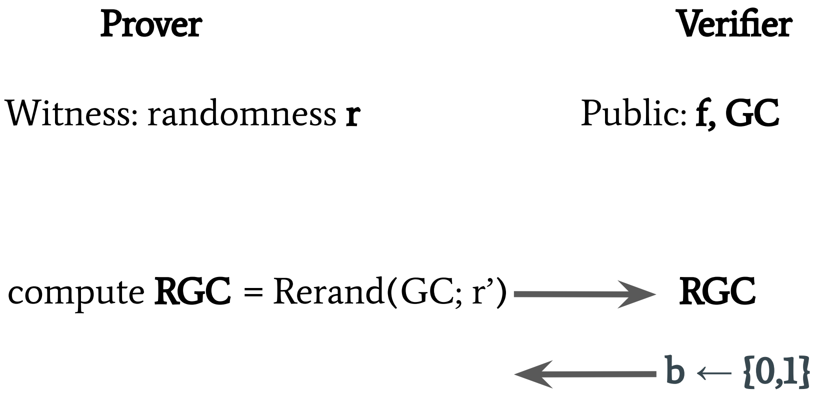

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Case 0: check if **RGC** correctly rerandomized from **GC**

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soundness ½
amplify by parallel repetition

Approach 2: Ephemeral Prover Zero-Knowledge

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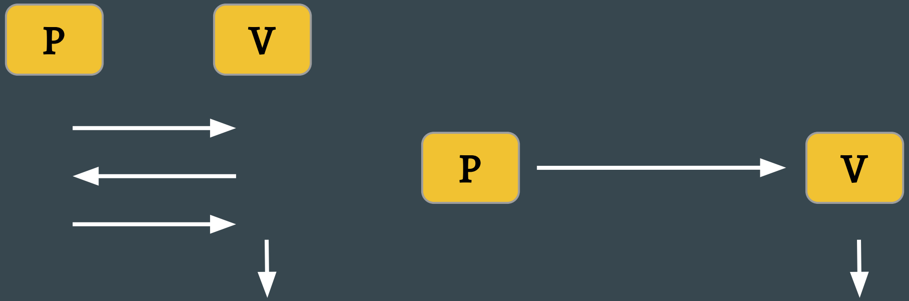
Option 1

RO Model – Fiat-Shamir transform



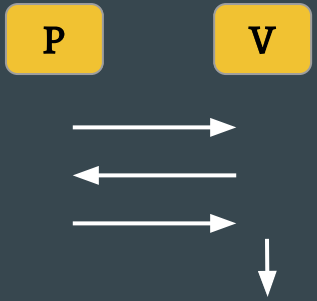
Approach 2: Ephemeral Prover Zero-Knowledge

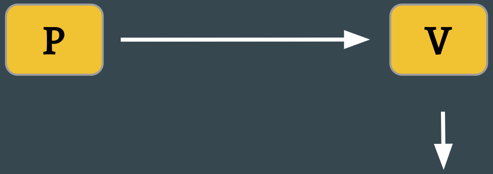
Option 1

RO Model – Fiat-Shamir transform

Option 2

CRS Model – Distributed Committed-Index OT





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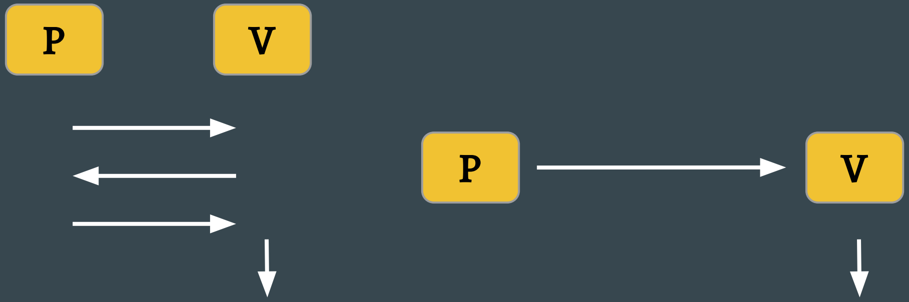

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multi-receiver **OT Protocol:**

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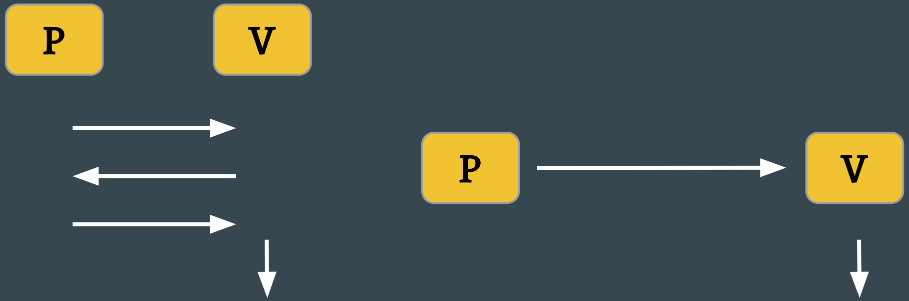

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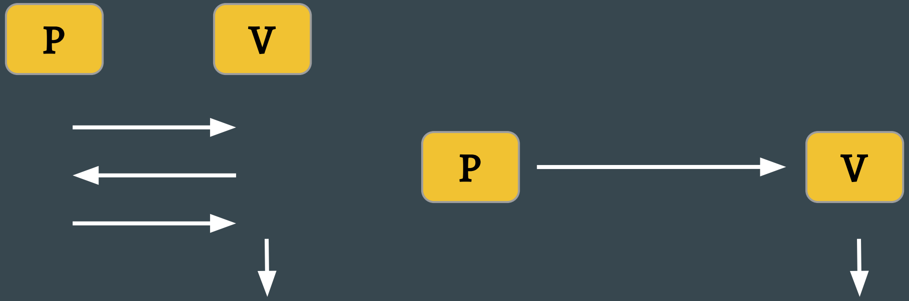

Option 2

CRS Model – Distributed Committed-Index OT

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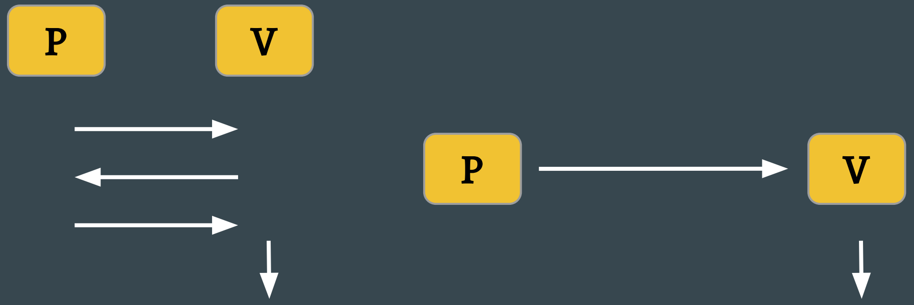

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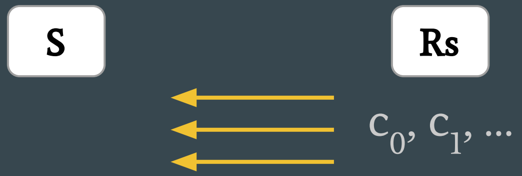

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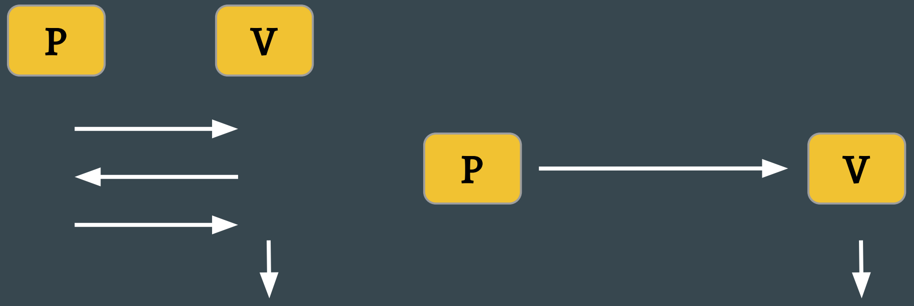
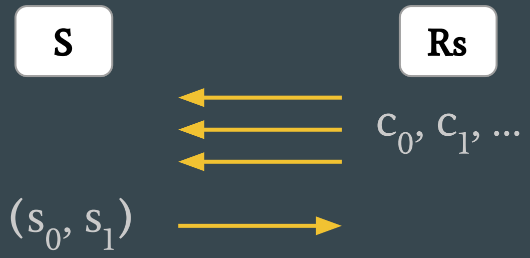


Option 2

CRS Model – Distributed Committed-Index OT

multi-receiver **OT Protocol:**

- choice bit is XOR of all receiver inputs
- choice bit committed before sender message
- server sends **first** proof message and OTs the **third** proof message



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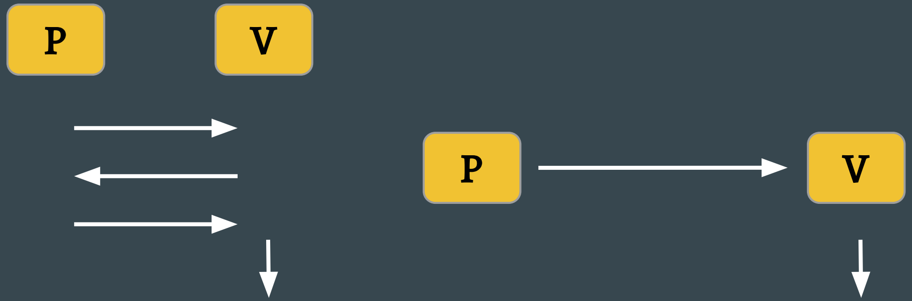

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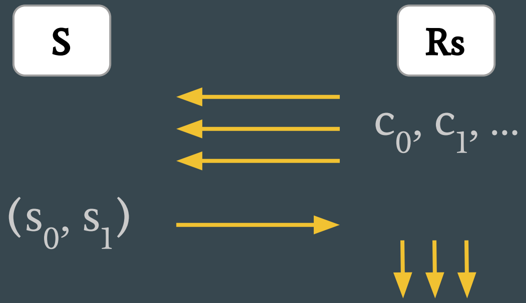

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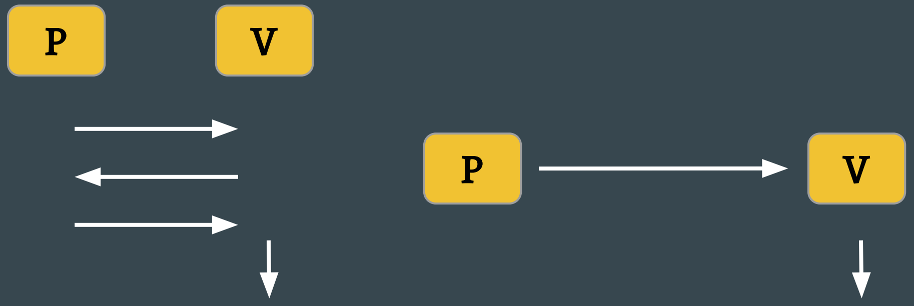

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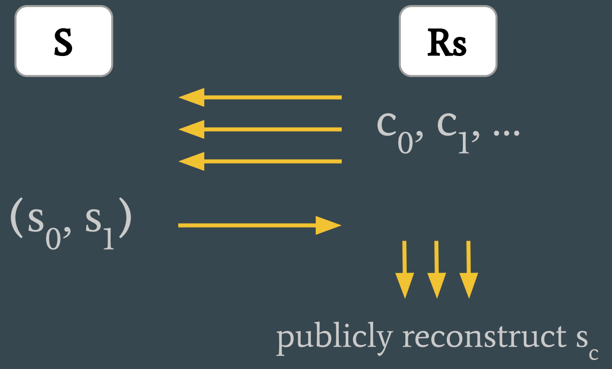
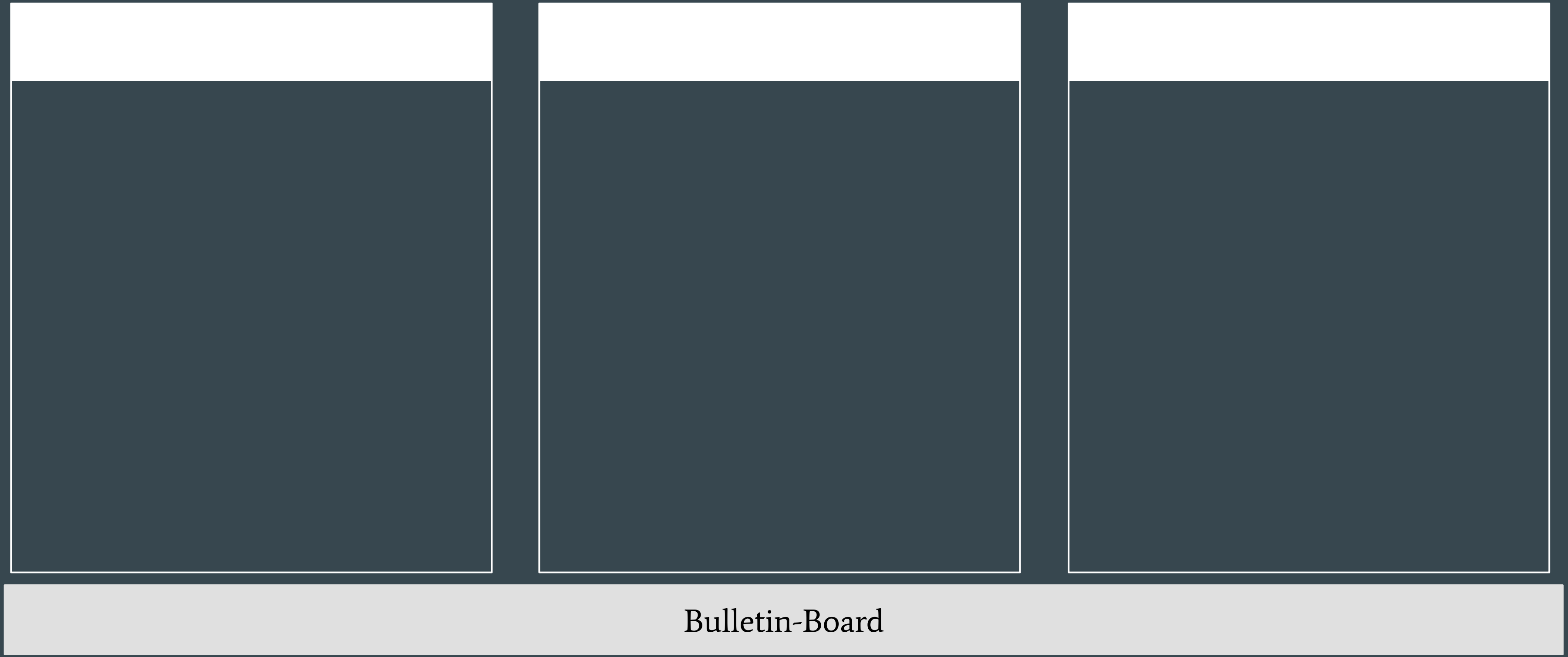
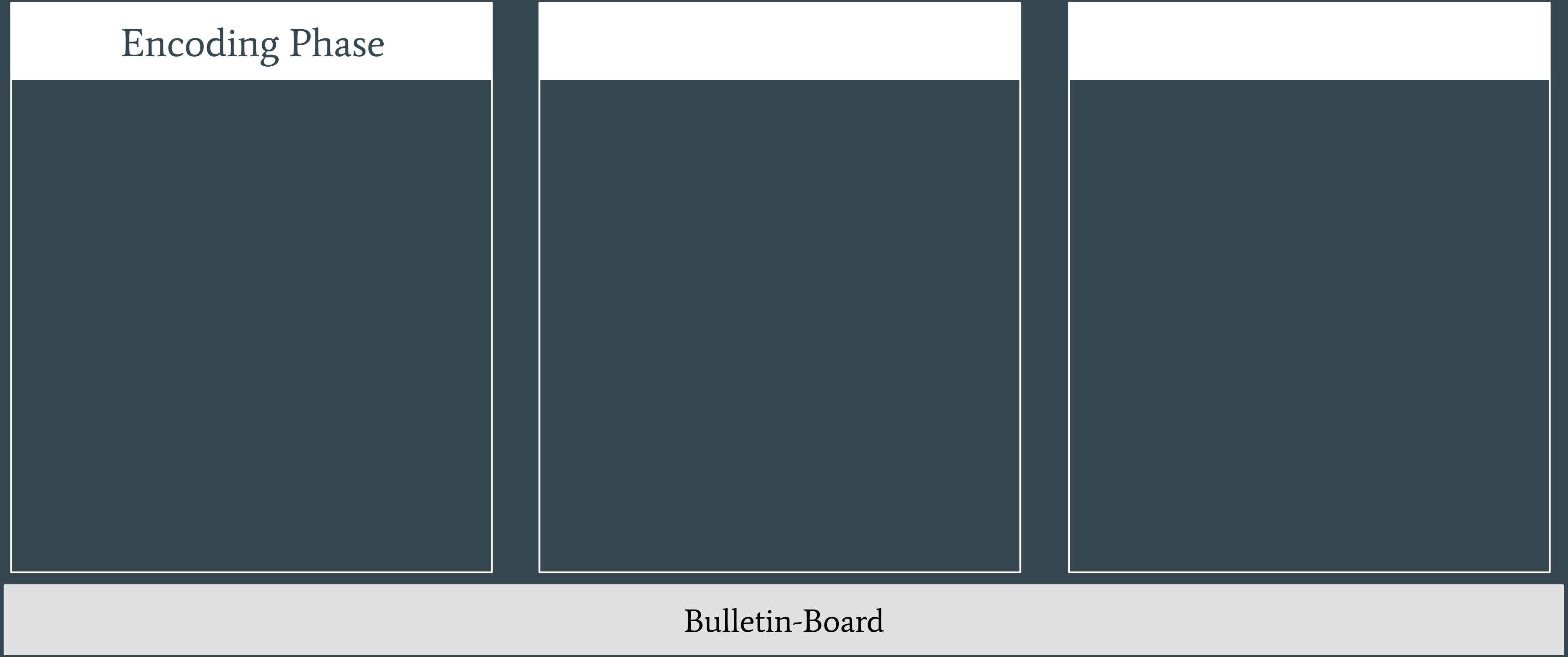


Maliciously Secure SCALES Protocol



Bulletin-Board

Maliciously Secure SCALES Protocol



Encoding Phase

Bulletin-Board

Maliciously Secure SCALES Protocol

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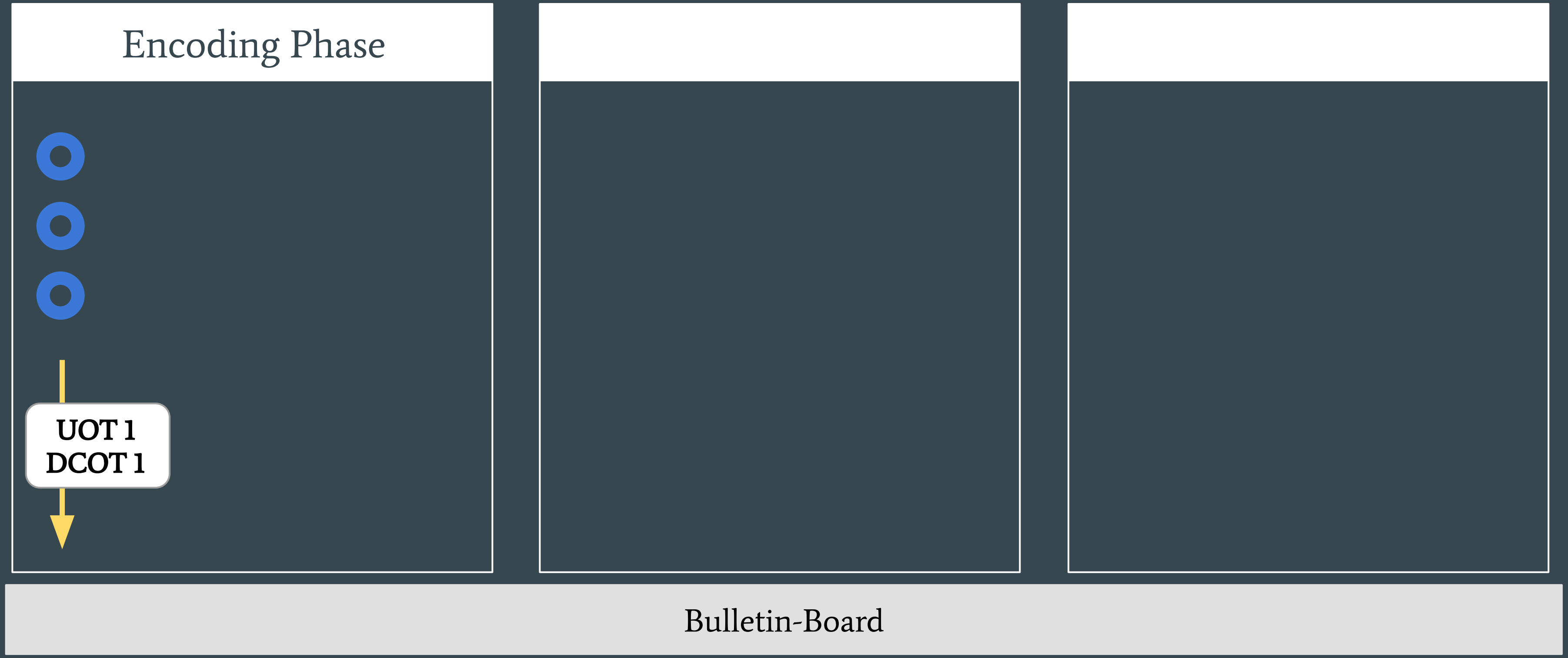
Maliciously Secure SCALES Protocol

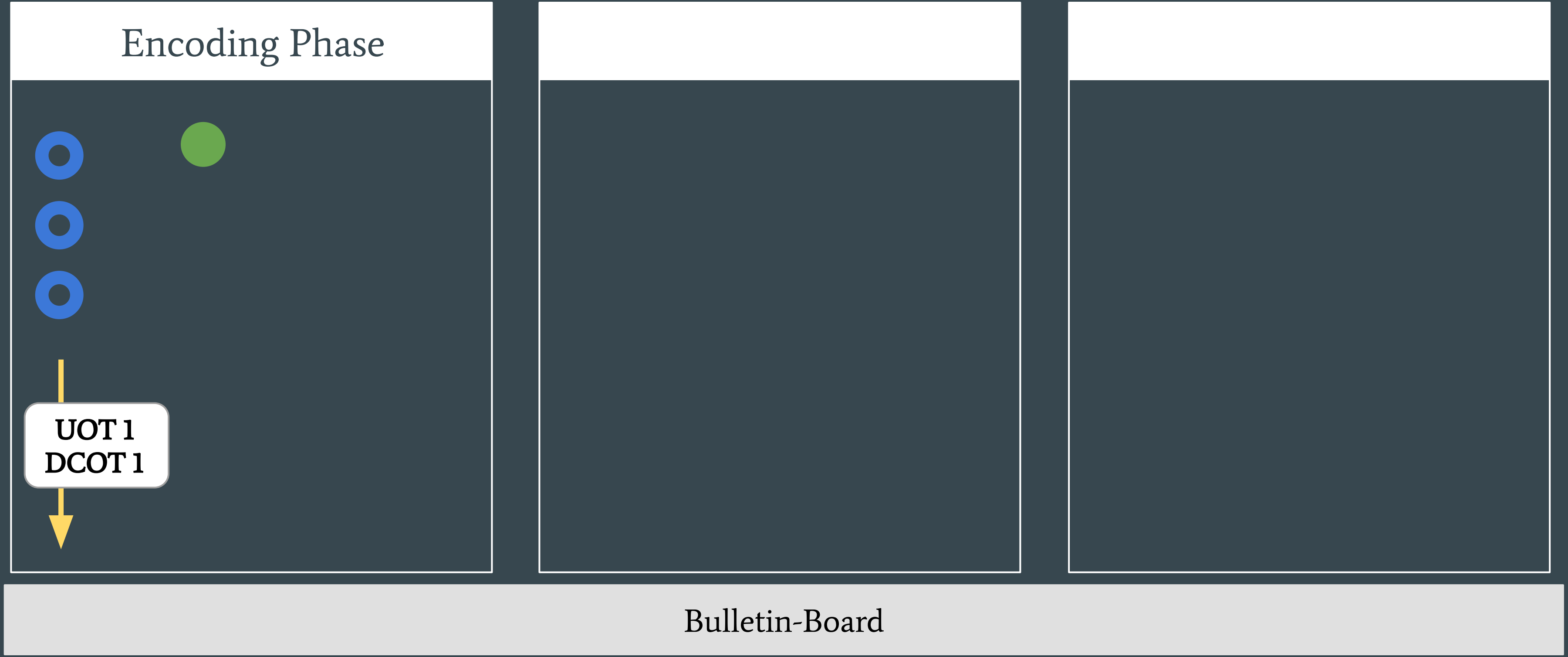


Encoding Phase

UOT 1
DCOT 1

Bulletin-Board

Maliciously Secure SCALES Protocol



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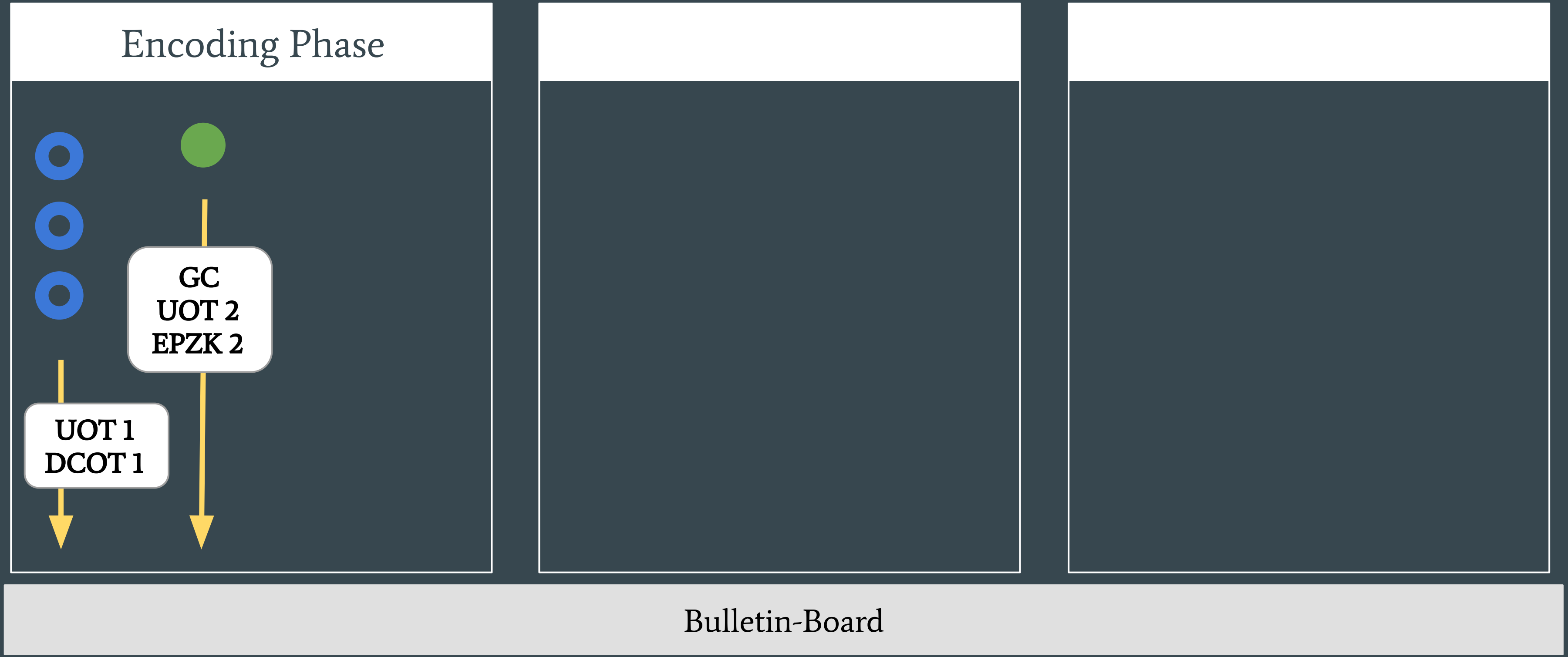


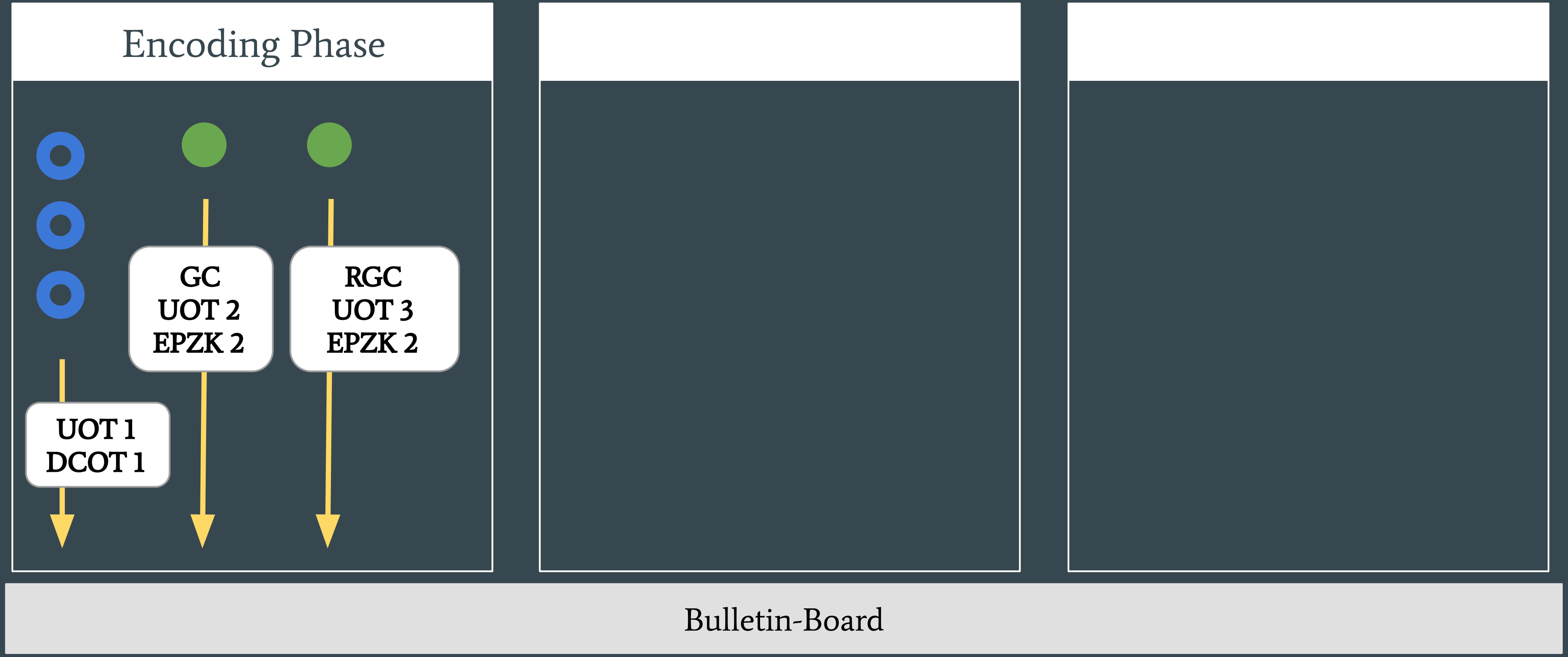
Encoding Phase

GC
UOT 2
EPZK 2

UOT 1
DCOT 1

Bulletin-Board

Maliciously Secure SCALES Protocol



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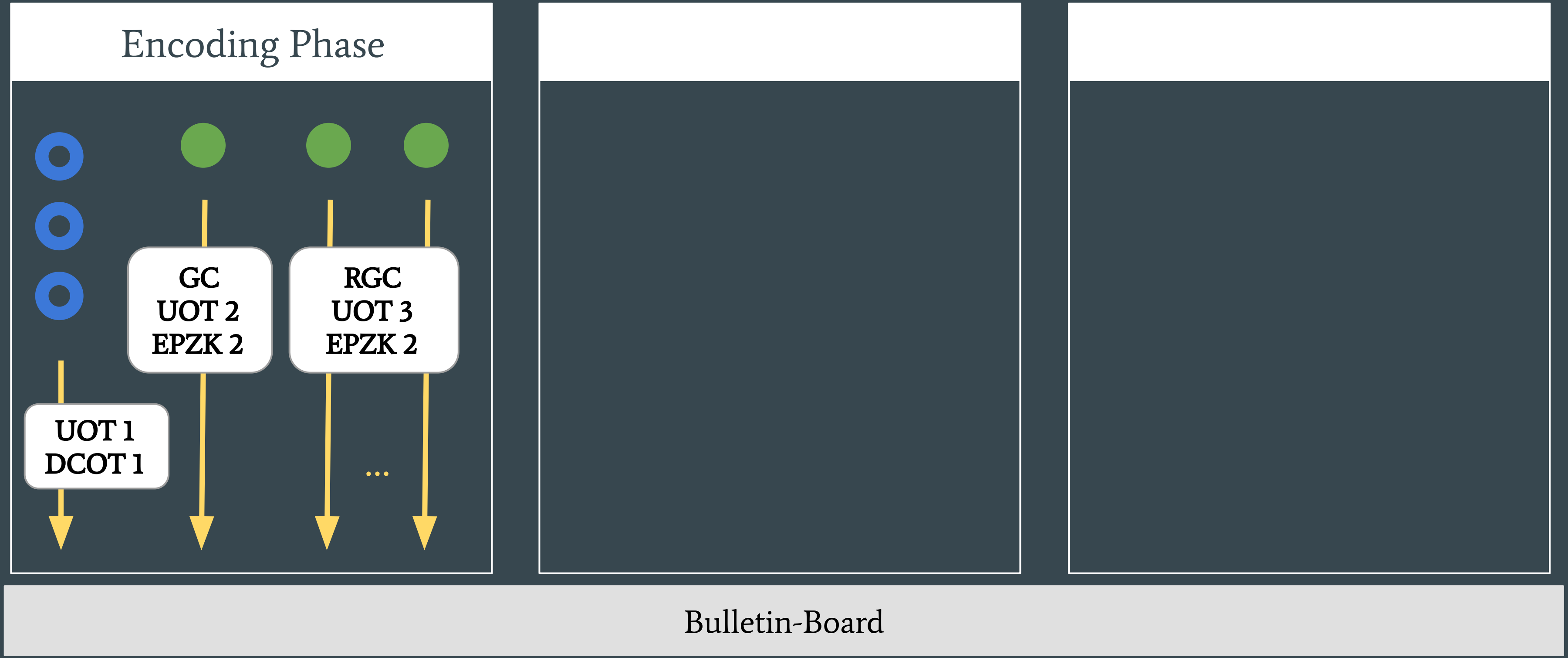

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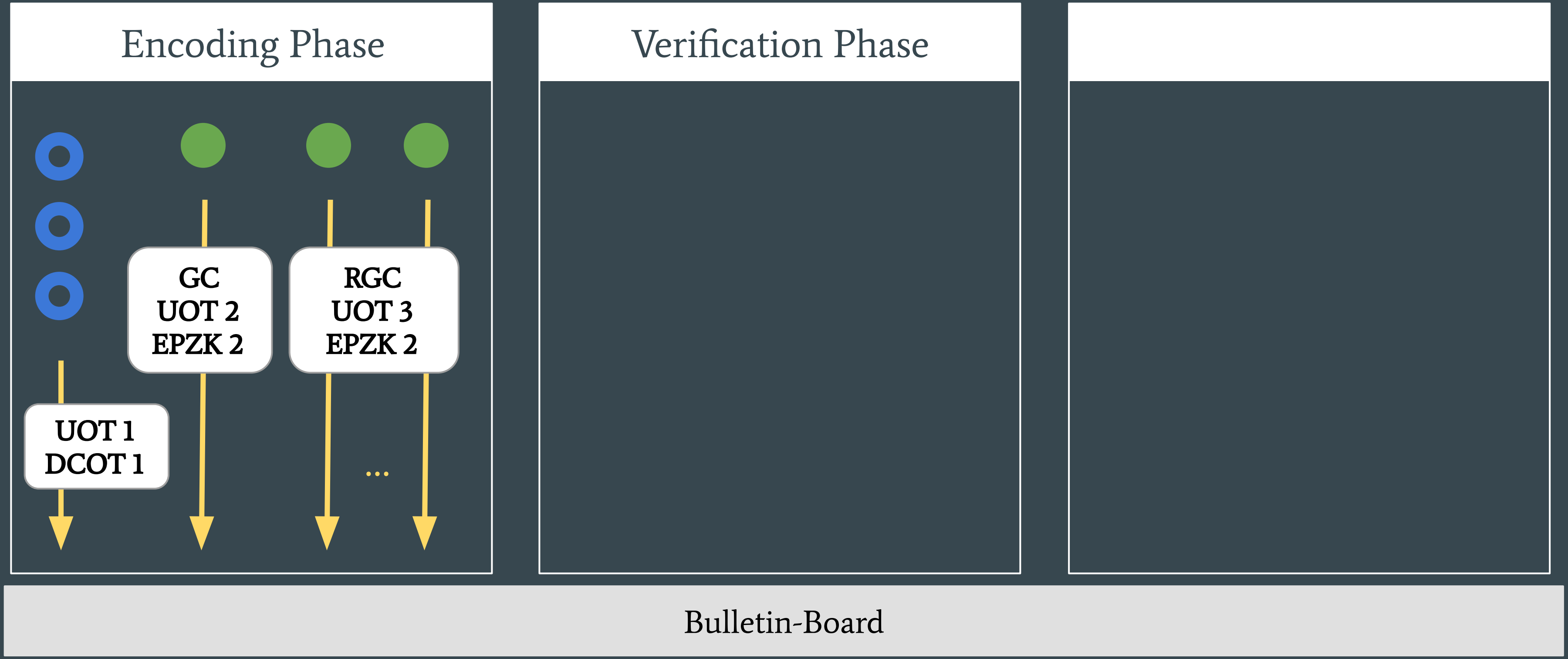

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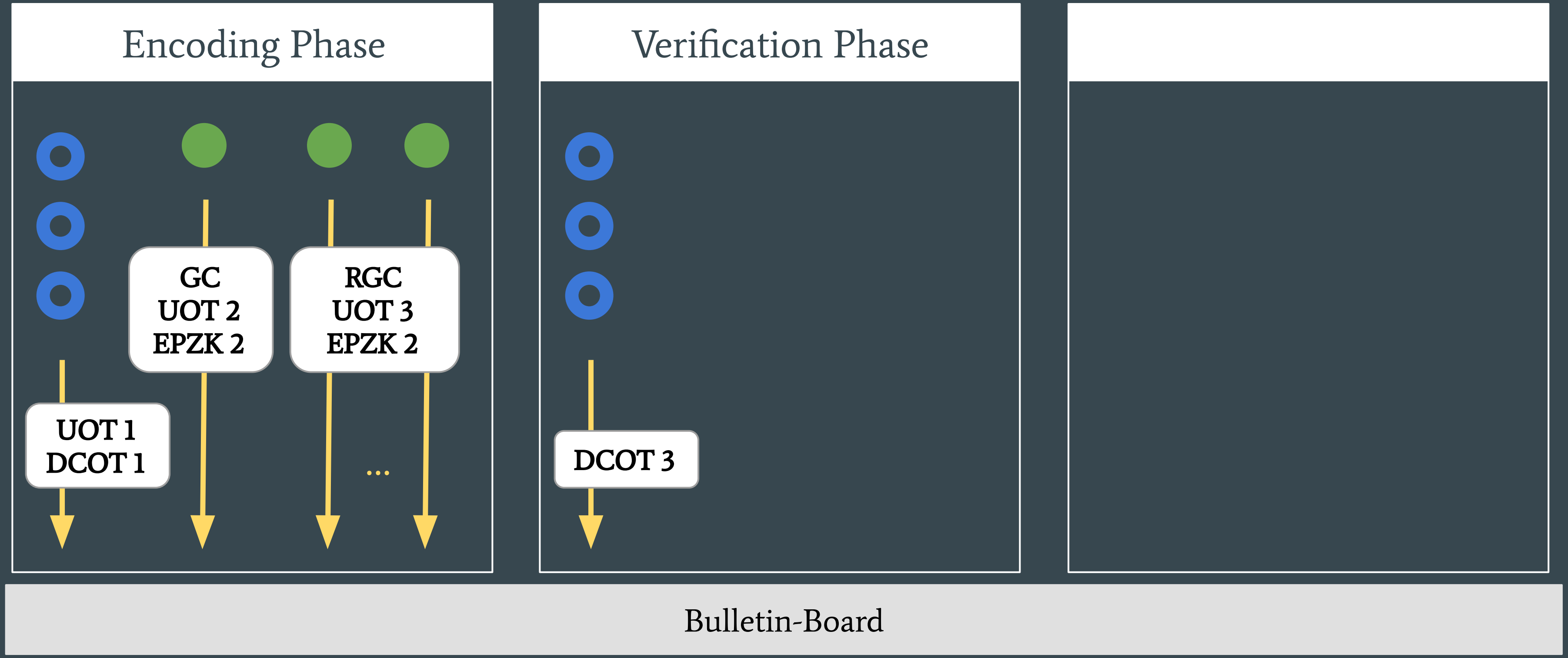

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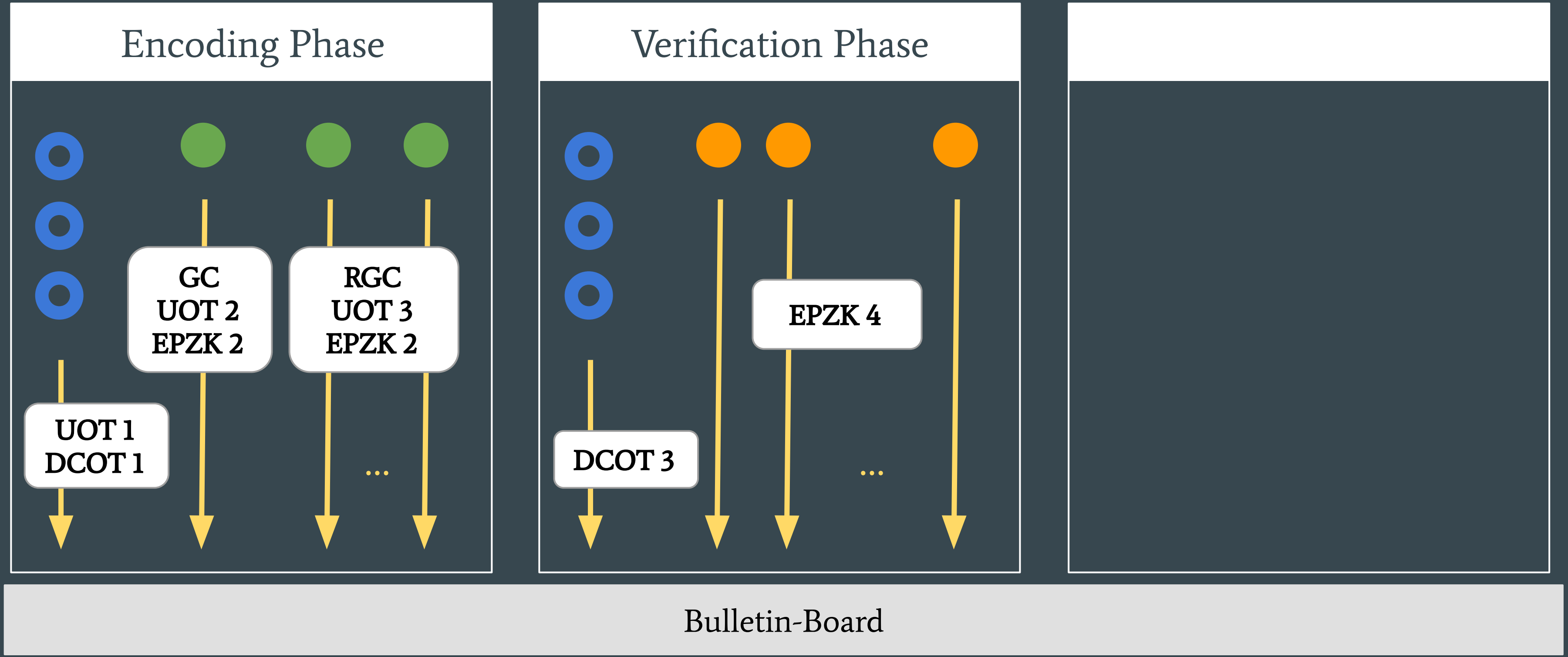

Encoding Phase

GC
UOT 2
EPZK 2

RGC
UOT 3
EPZK 2

UOT 1
DCOT 1

...

Verification Phase

EPZK 4

DCOT 3

...

Bulletin-Board

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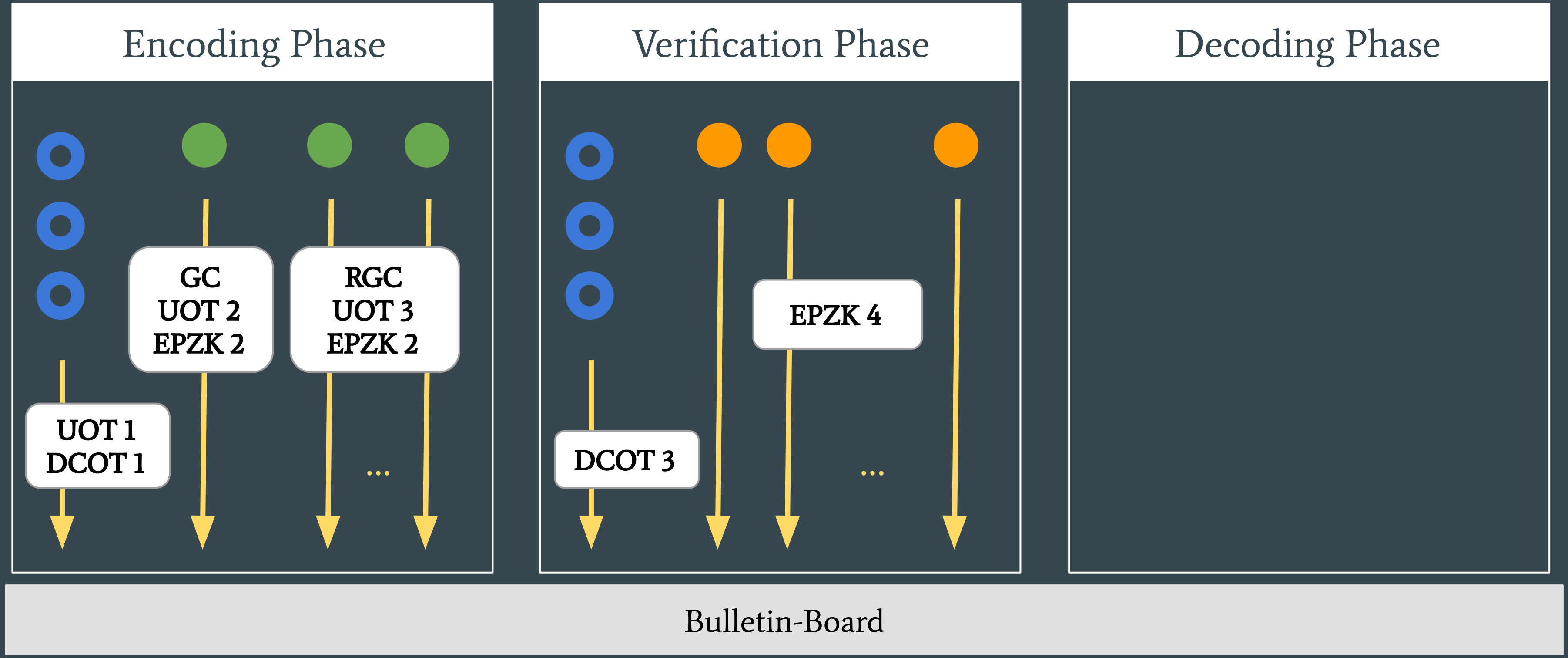

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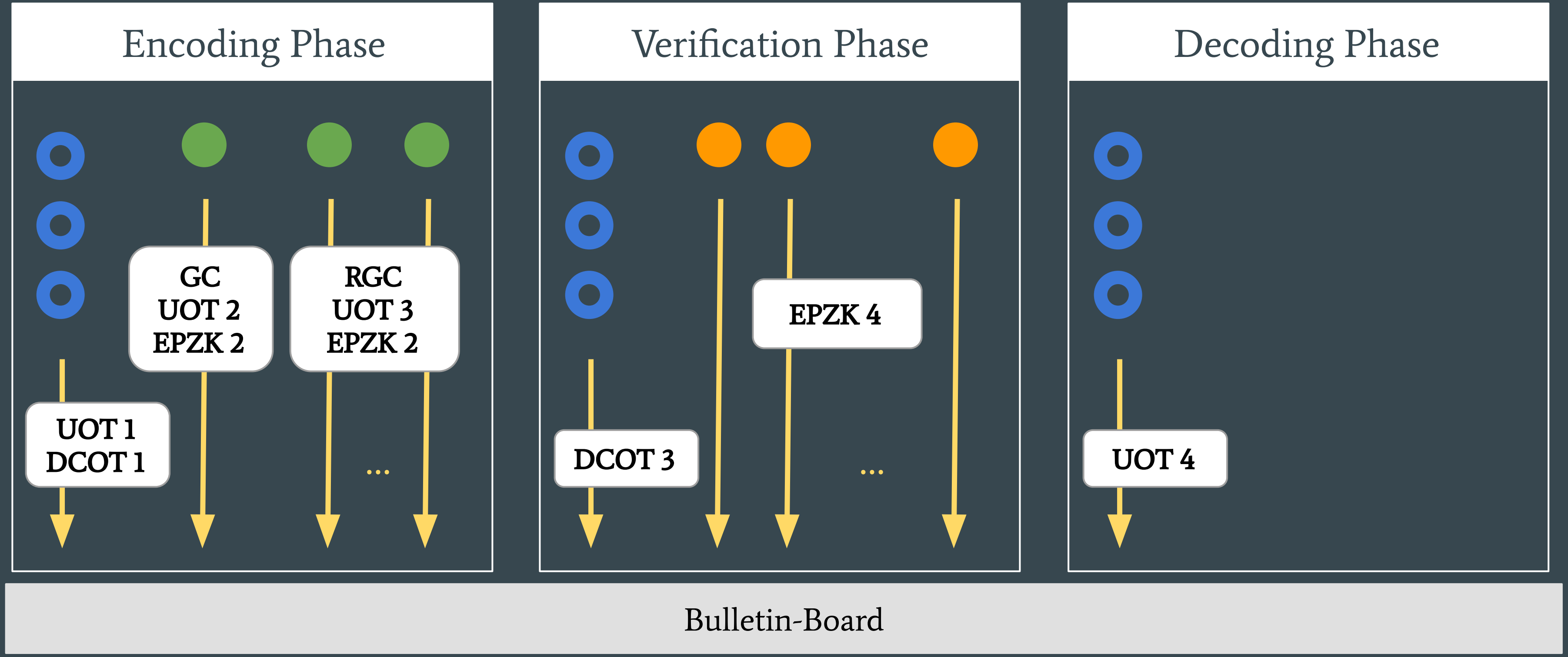

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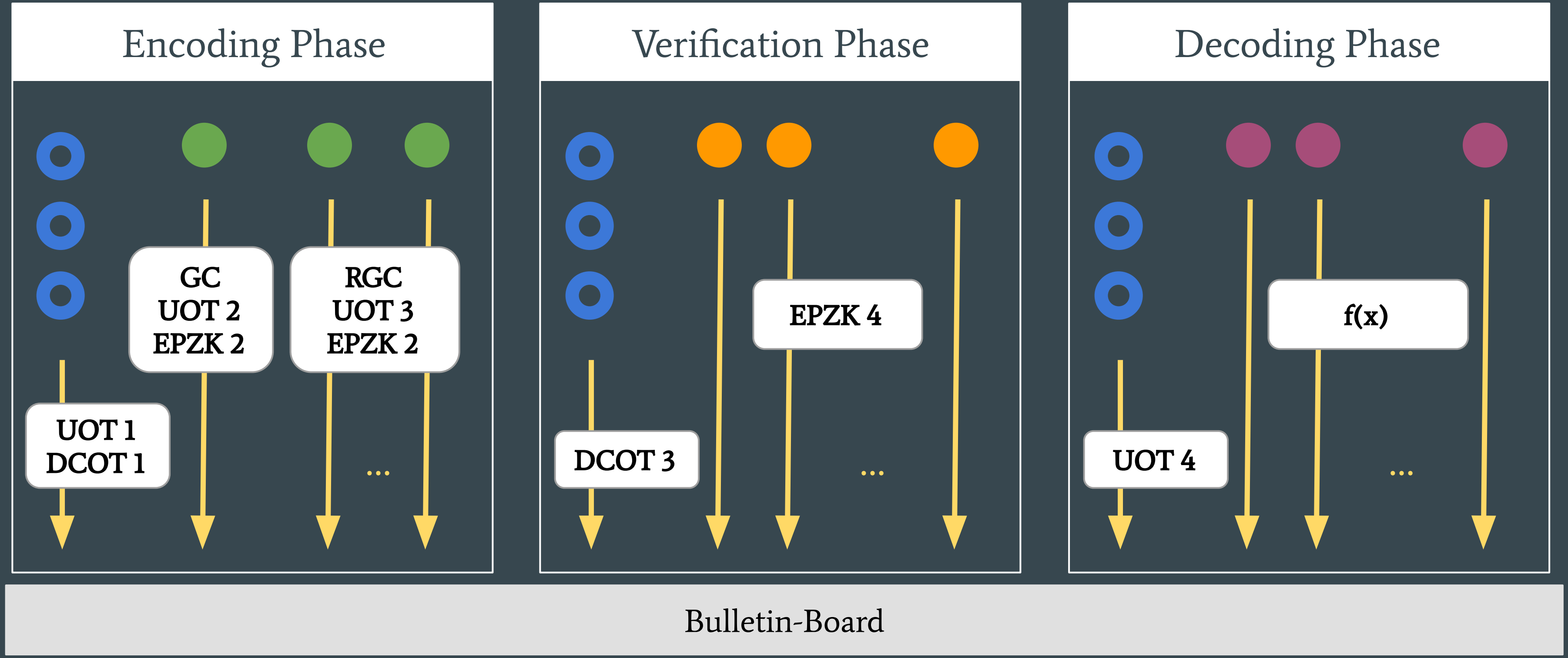

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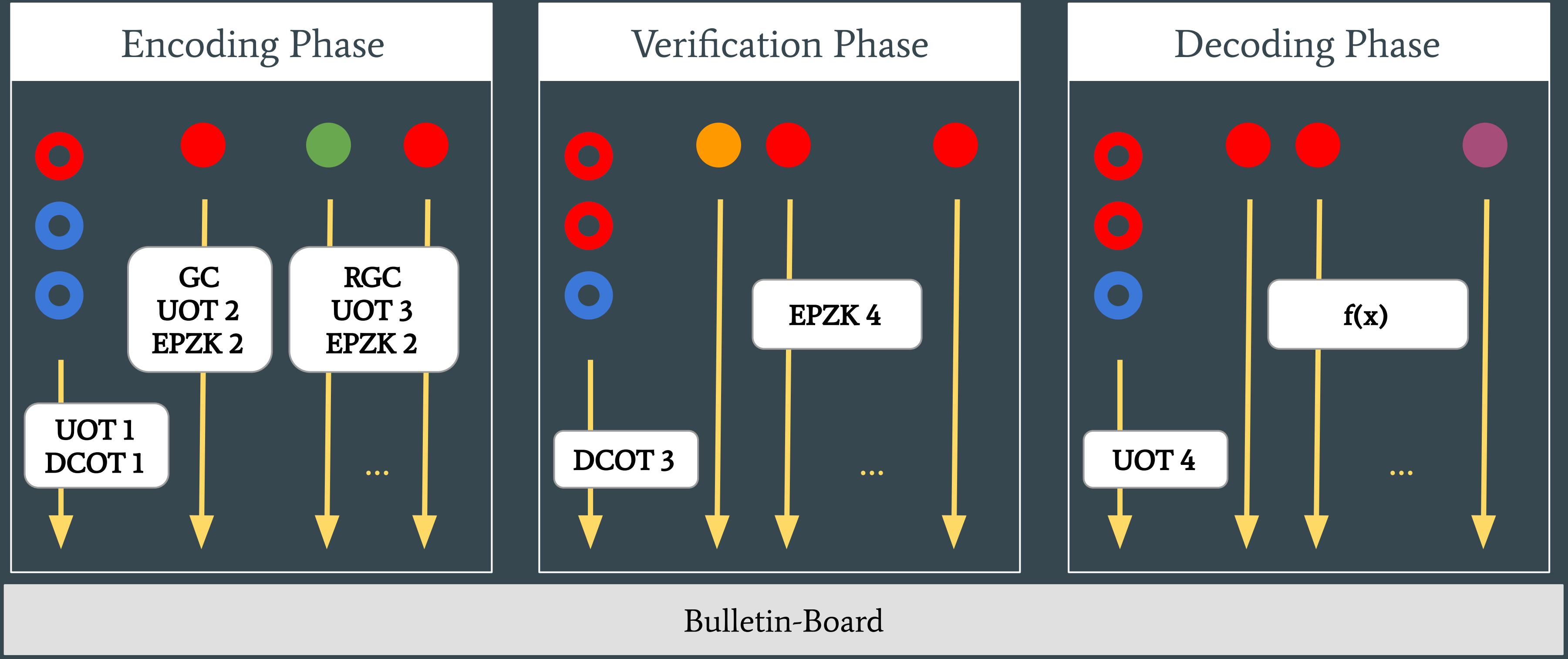

Summary

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Assuming DDH

Maliciously Secure SCALES Protocols –

Summary

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- using Custom ZK proofs   2 phases – CRS + RO model

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Universally Composable

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Open Problems –

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Universally Composable

Open Problems –

- SCALES protocols with Guaranteed Output Delivery
- SCALES protocols in the RO model only (or in the plain model)
- SCALES from other hardness assumptions

Thank You!

https://eprint.iacr.org/2024/383