# Curl: Private LLMs through Wavelet-Encoded Look-Up Tables

**Manuel B. Santos**[1], Dimitris Mouris[1], Mehmet Ugurbil[1], Stanislaw Jarecki[1,2], José Reis[1], Shubho Sengupta[3] and Miguel de Vega[1]

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ssengupta@meta.com

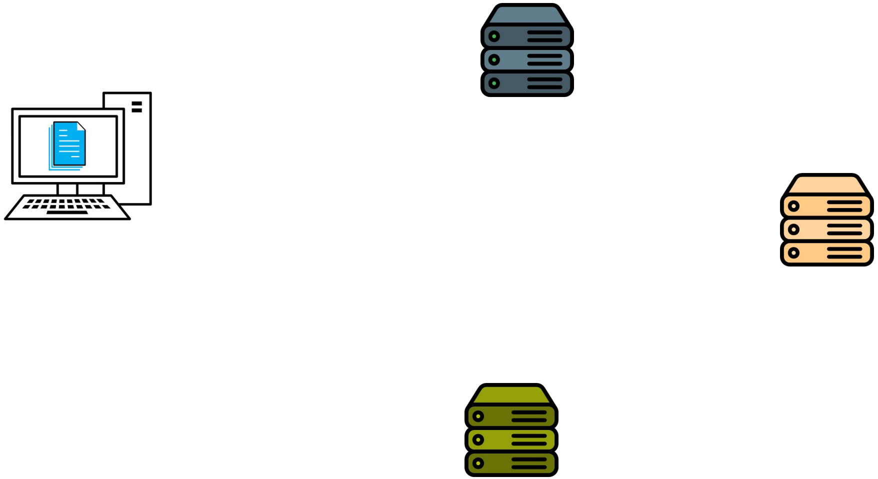
*https://ia.cr/2024/1127*

*https://github.com/jimouris/curl*

1 nillion 2 The University of California Irvine 3 Meta

# Secure Multiparty Computation (MPC)

**MPC enables computing directly on private data!**



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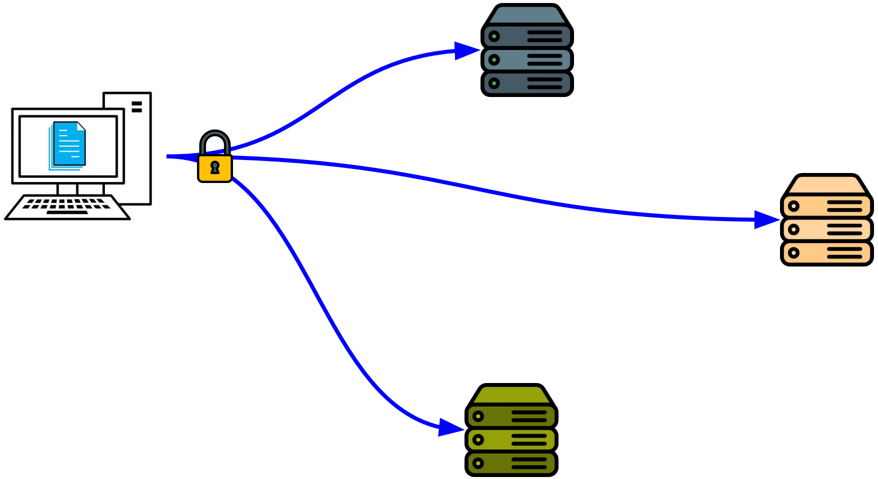

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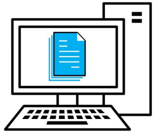

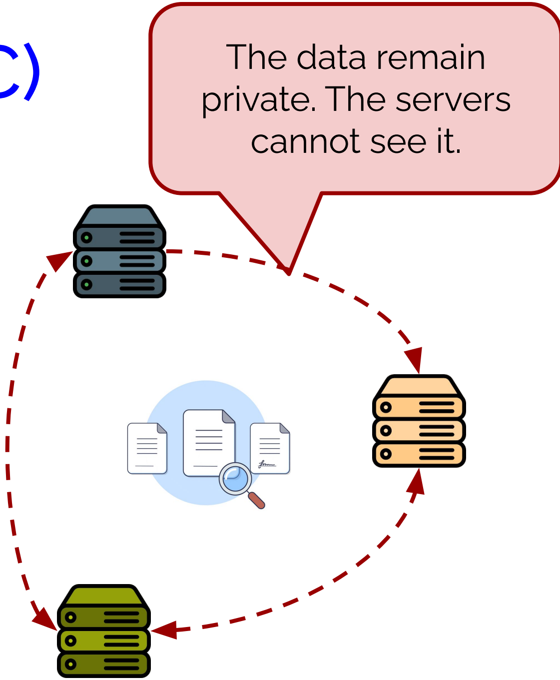

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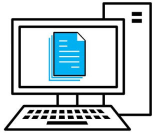

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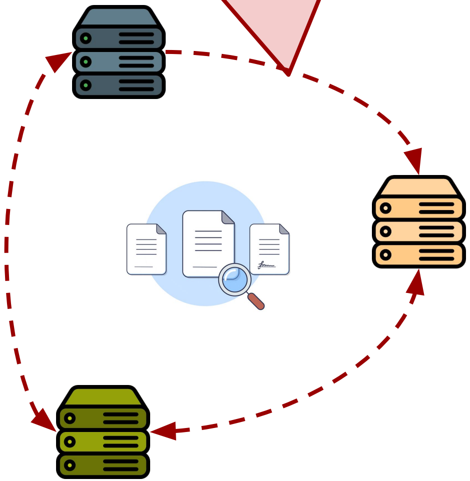

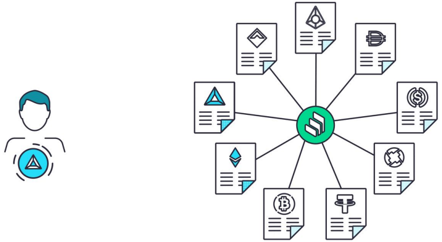

Threshold Signatures

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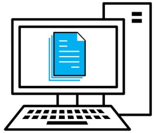
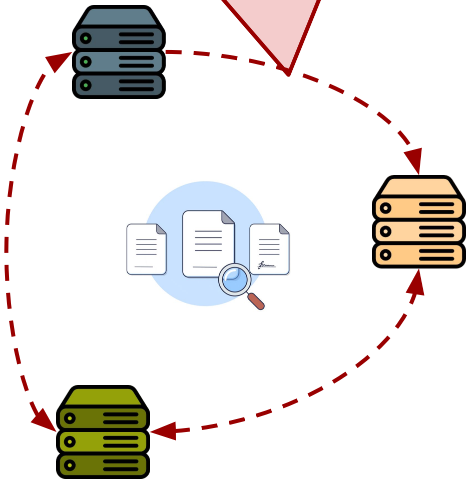
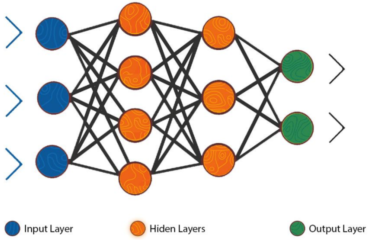
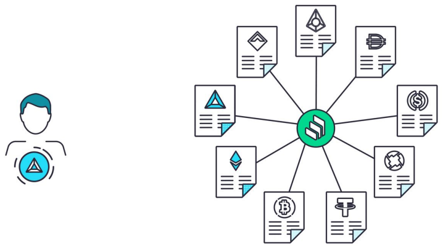







Privacy-preserving ML



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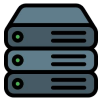

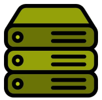

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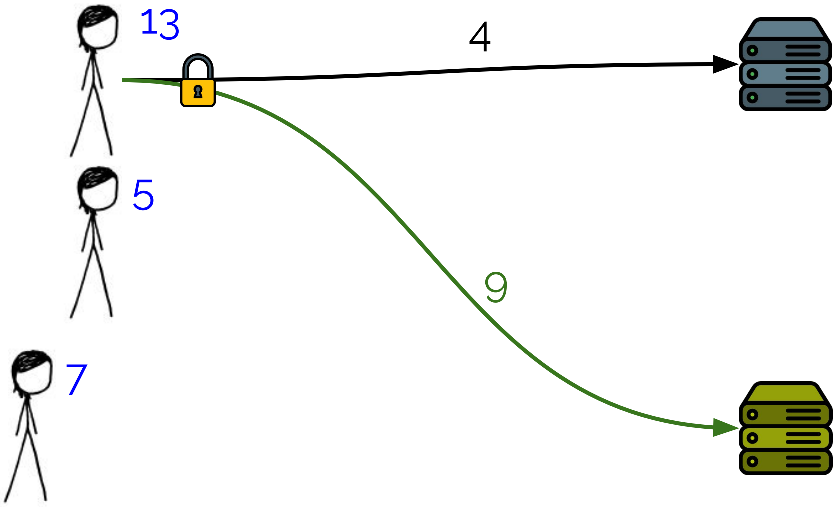

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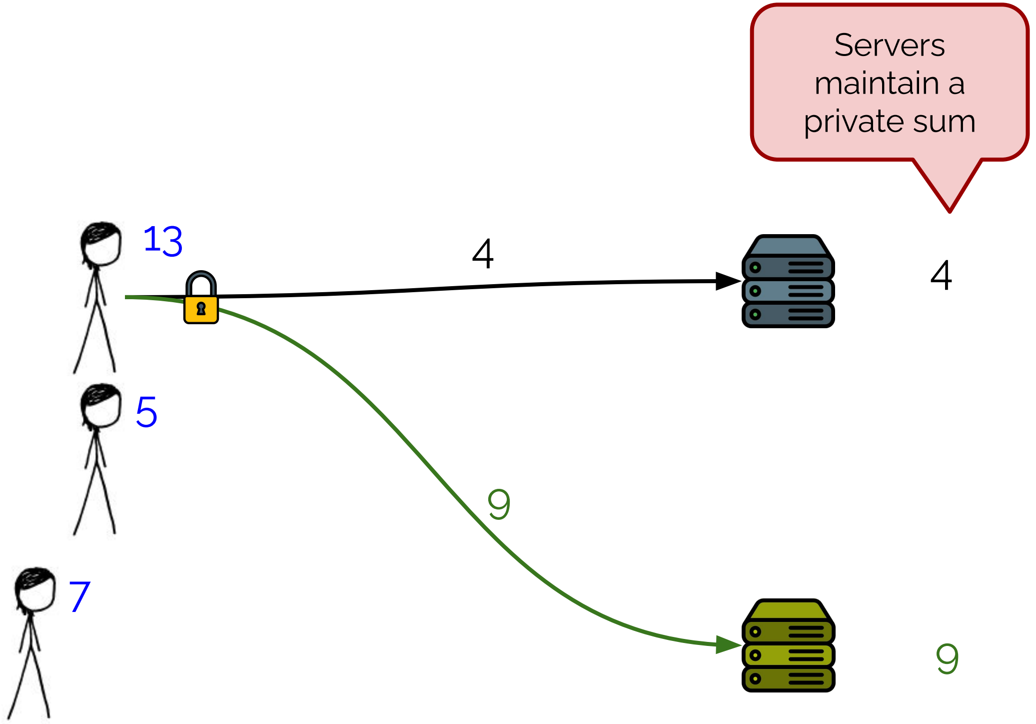

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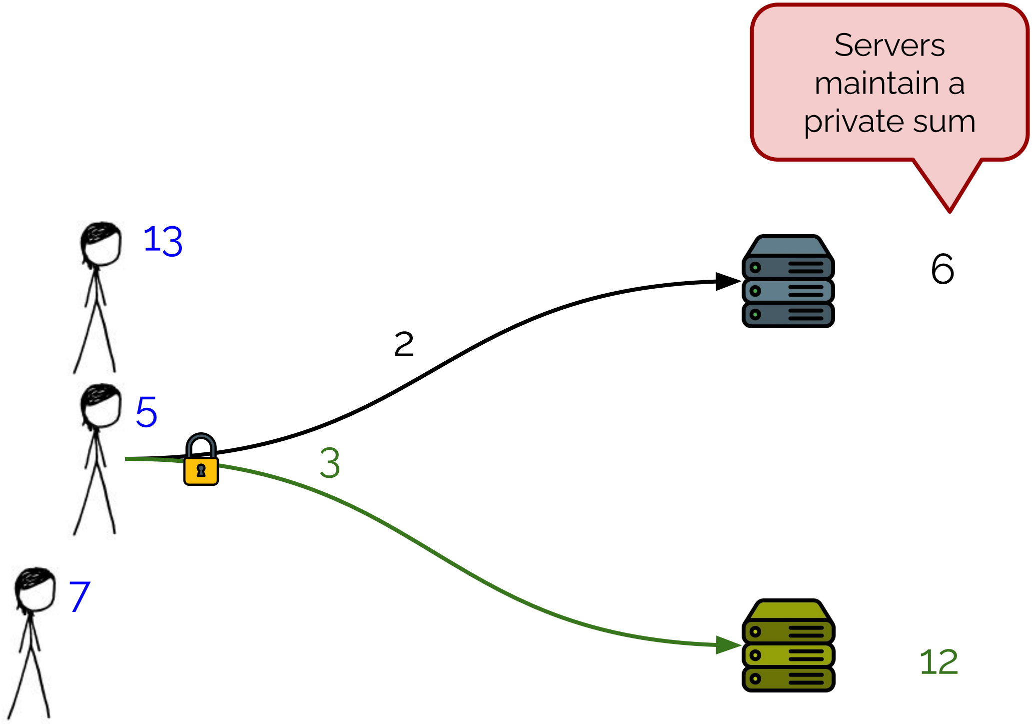

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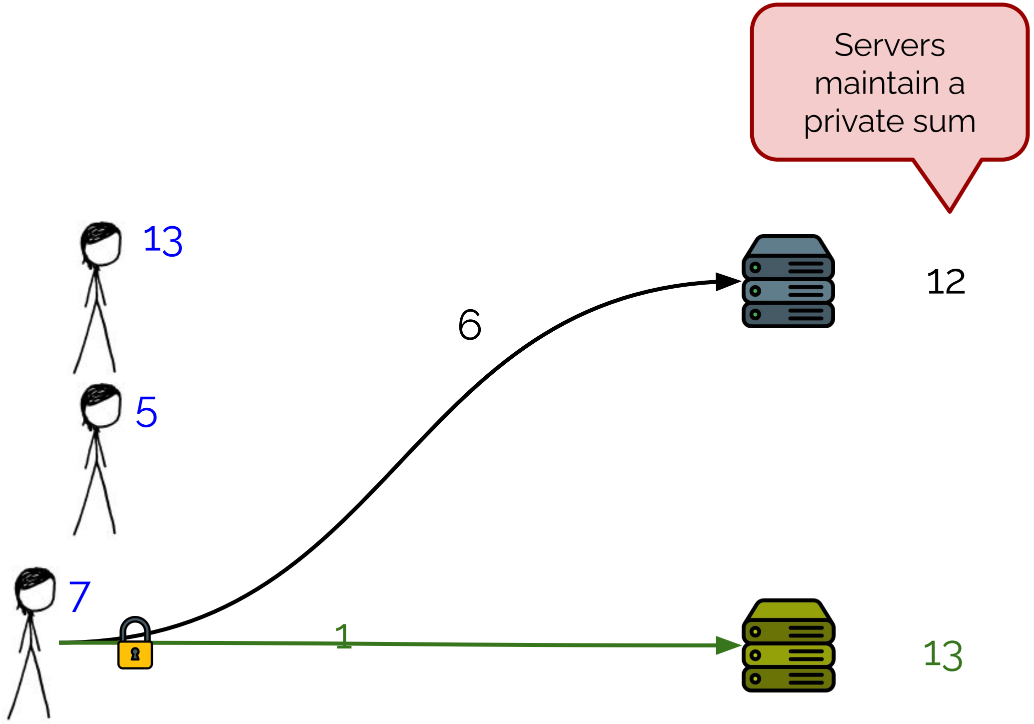

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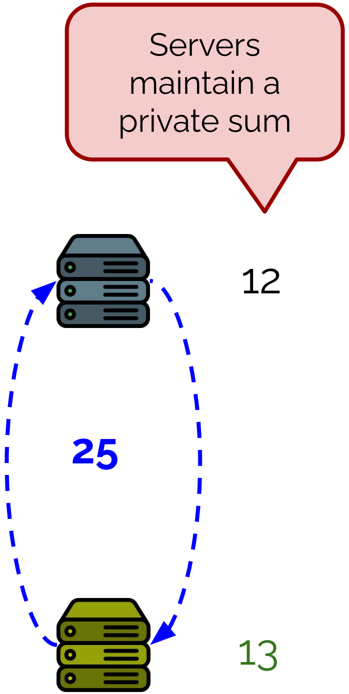

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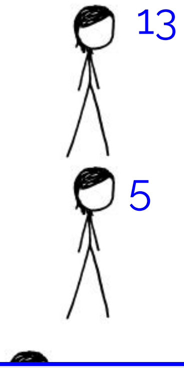


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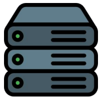
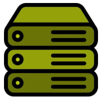


**Server 1**


Private model

Private inputs



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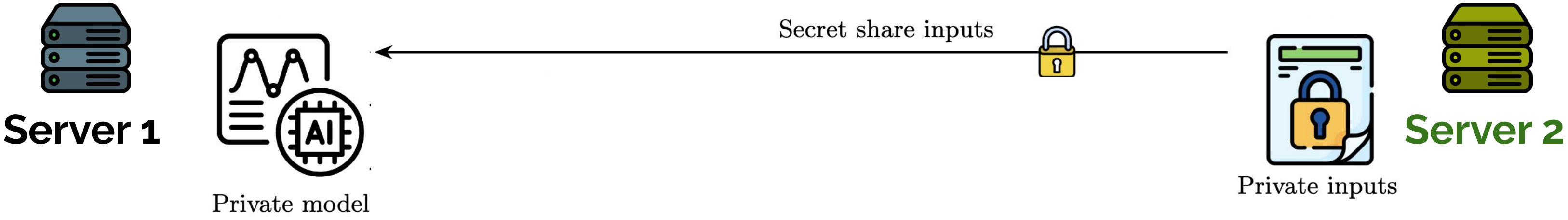

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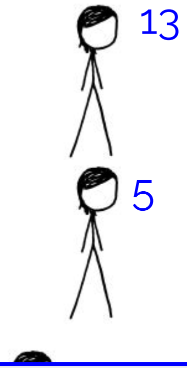


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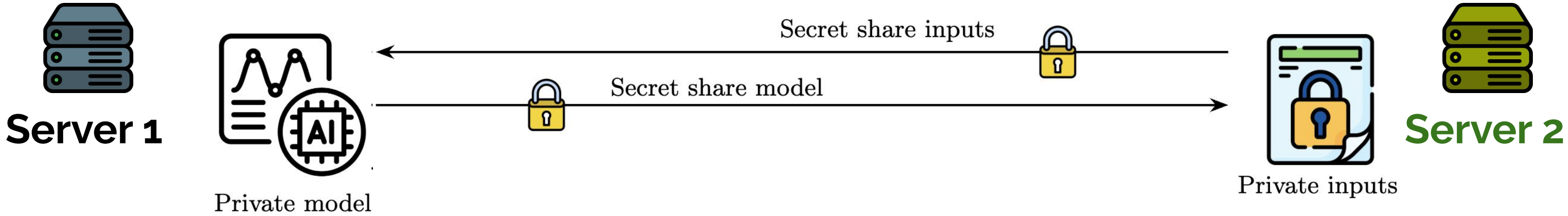

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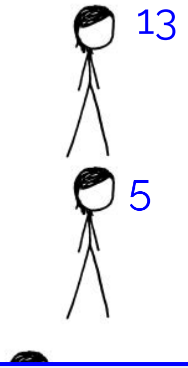


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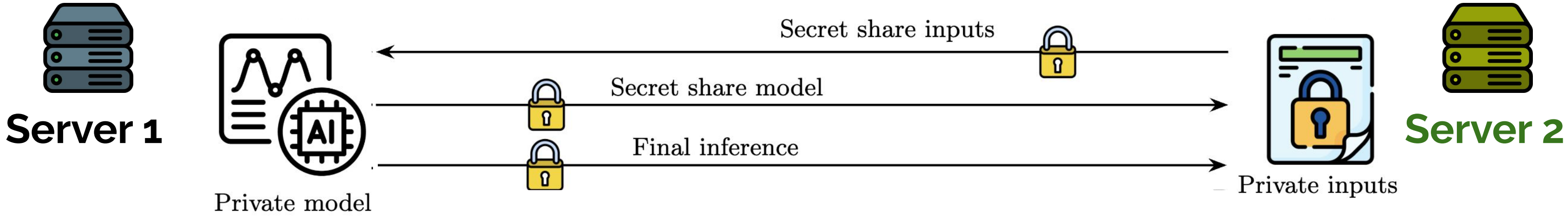

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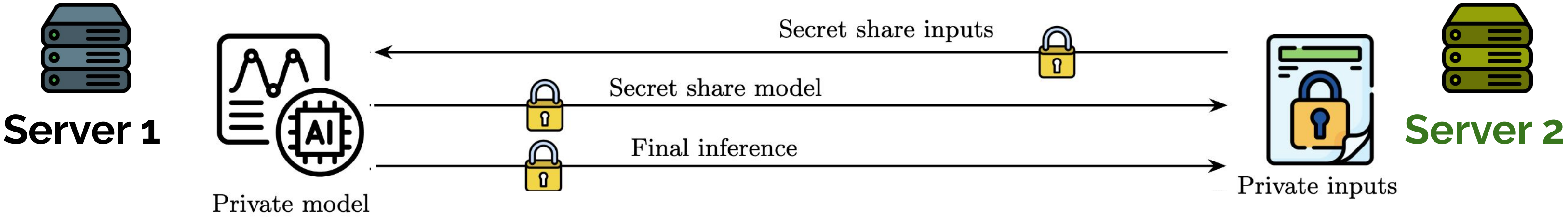
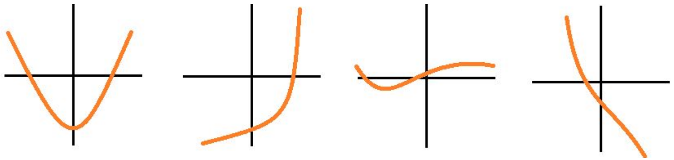
**Almost**



# Non-Linear Functions in MPC



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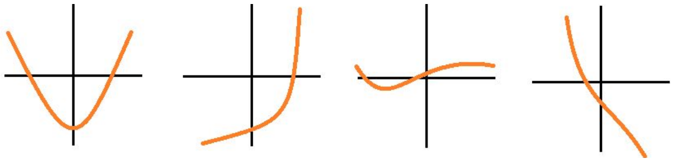

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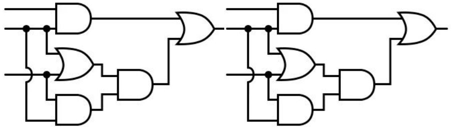

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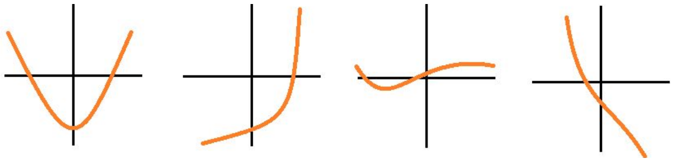

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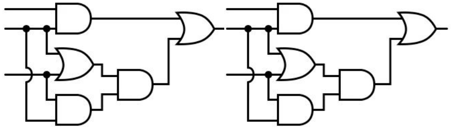

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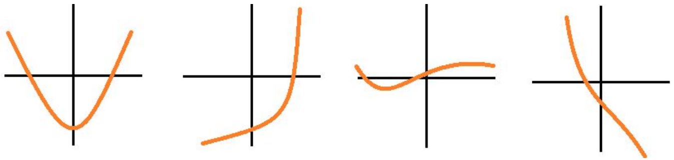

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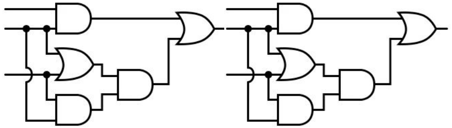

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SOTA MPC protocols evaluate non-linearities as lookup tables (LUTs), but

LUTs **scale poorly** for high precision → **very high communication**

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Curl

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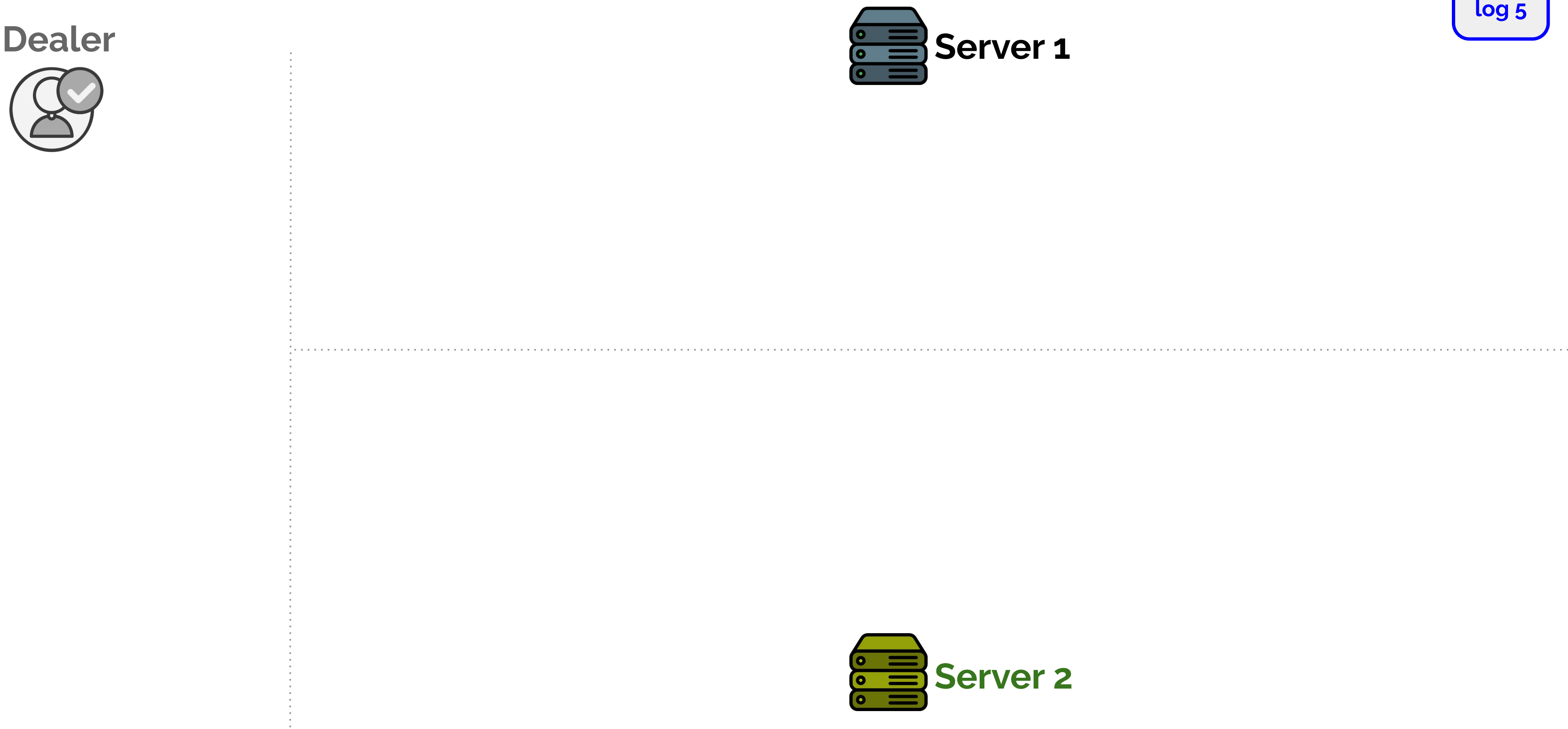
- Experiments over a suite of commonly used non-linear functions + LLMs.

# Secure Look-Up Table

log 1
log 2
log 3
log 4
log 5



# Secure Look-Up Table

Public LUT for log

| |
|---|
| 0 |
| 1 |
| 1.6 |
| 2 |
| 2.3 |

Dealer

Server 1

Server 2

# Secure Look-Up Table

Secret Input

$x = 4$

Public LUT for log

| |
|---|
| 0 |
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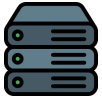
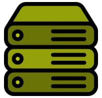
Dealer



Server 1



Server 2

# Secure Look-Up Table

Secret Input

x = 4

Public LUT for log

| |
|---|
| 0 |
| 1 |
| 1.6 |
| 2 |
| 2.3 |

**Dealer**

**Server 1**

**Server 2**

# Secure Look-Up Table

Secret Input
x = 4

Public LUT for log

| |
|---|
| 0 |
| 1 |
| 1.6 |
| 2 |
| 2.3 |

**Dealer**

Input
[x] = 3
**Server 1**

Input
[x] = 1
**Server 2**

# Secure Look-Up Table

Secret Input
x = 4

Public LUT for log

| |
|---|
| 0 |
| 1 |
| 1.6 |
| 2 |
| 2.3 |

Dealer

Random
r ← 2

Input
[x] = 3

Server 1

Input
[x] = 1

Server 2

# Secure Look-Up Table

# Secure Look-Up Table

Secret Input
x = 4

Public LUT for log

| |
|---|
| 0 |
| 1 |
| 1.6 |
| 2 |
| 2.3 |

**Dealer**

Random
r ← 2

1-hot vector encoding **r**

| |
|---|
| 0 |
| **1** |
| 0 |
| 0 |
| 0 |

**Server 1**

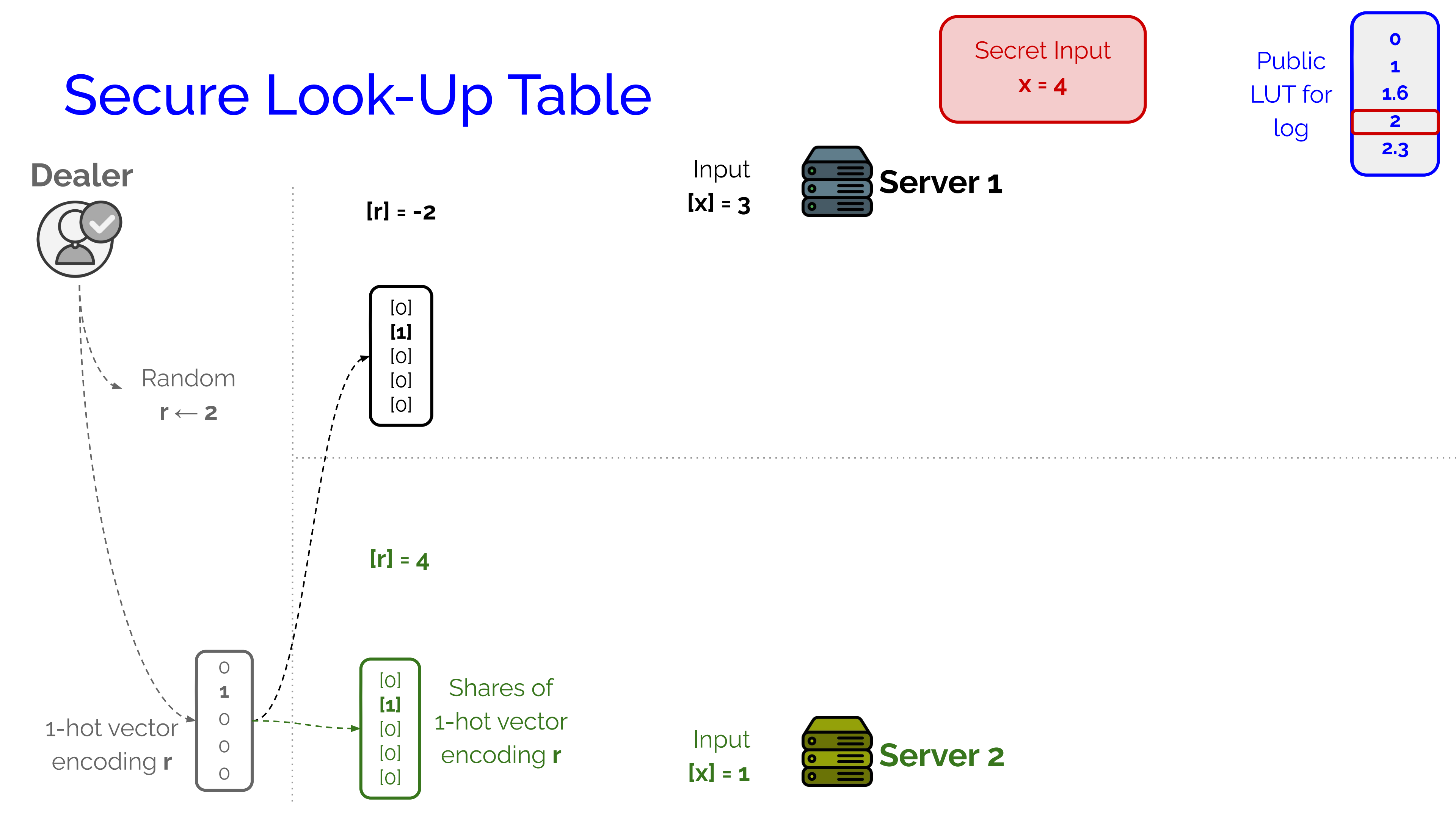
Input
[x] = 3

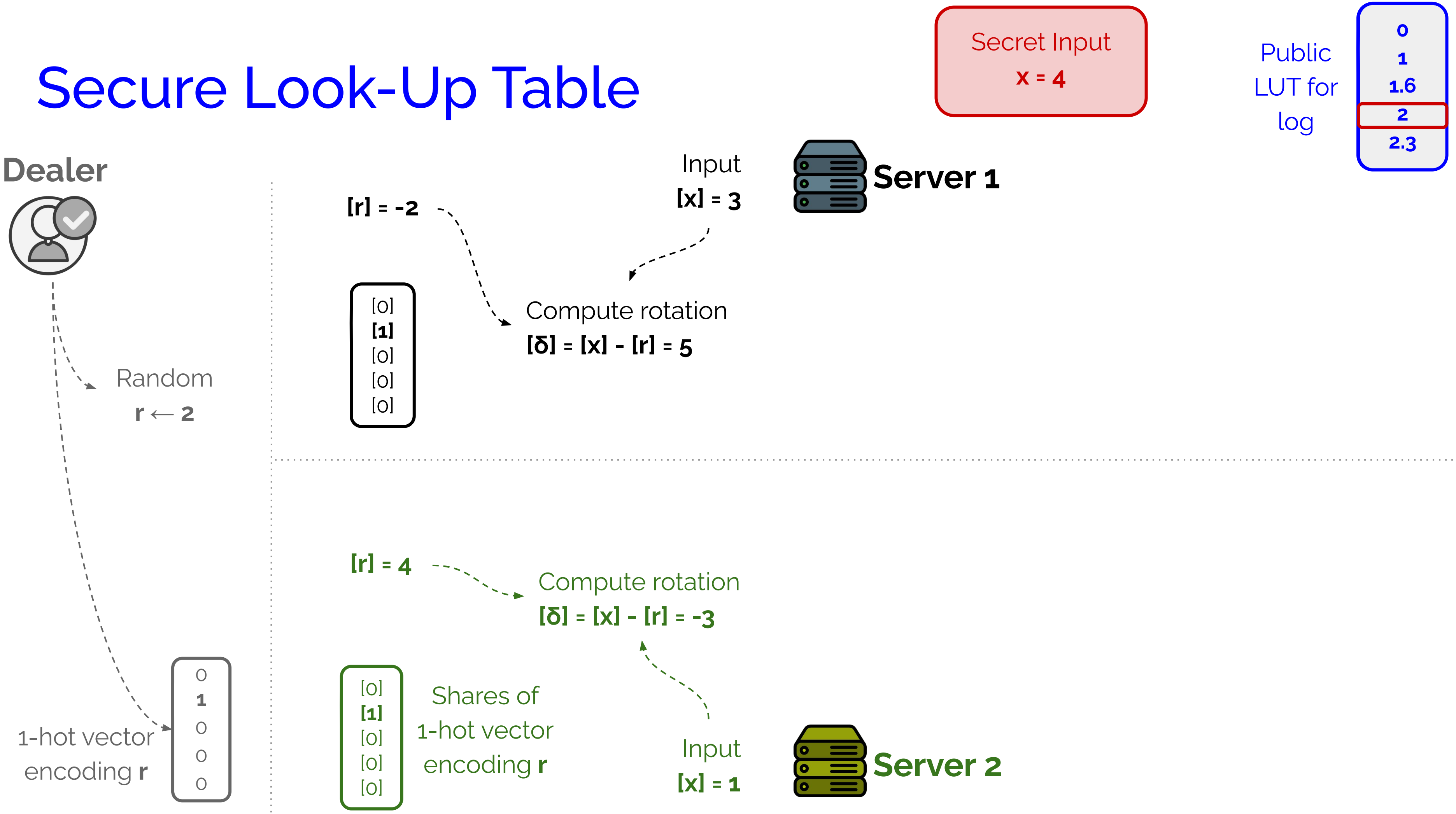
[r] = -2

**Server 2**

Input
[x] = 1

[r] = 4


Secure Look-Up Table
Secret Input
x = 4
Public
LUT for
log
0
1
1.6
2
2.3
Dealer
Random
r ← 2
1-hot vector
encoding r
0
1
0
0
0
[r] = -2
[0]
[1]
[0]
[0]
[0]
Input
[x] = 3
Server 1
[r] = 4
[0]
[1]
[0]
[0]
[0]
Shares of
1-hot vector
encoding r
Input
[x] = 1
Server 2



Secure Look-Up Table
Secret Input
x = 4
Public
LUT for
log
0
1
1.6
2
2.3
Dealer
Random
r ← 2
1-hot vector
encoding r
0
1
0
0
0
Server 1
Input
[x] = 3
[r] = -2
Compute rotation
[δ] = [x] - [r] = 5
[0]
[1]
[0]
[0]
[0]
[r] = 4
Compute rotation
[δ] = [x] - [r] = -3
[0]
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[0]
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Shares of
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encoding r
Input
[x] = 1
Server 2

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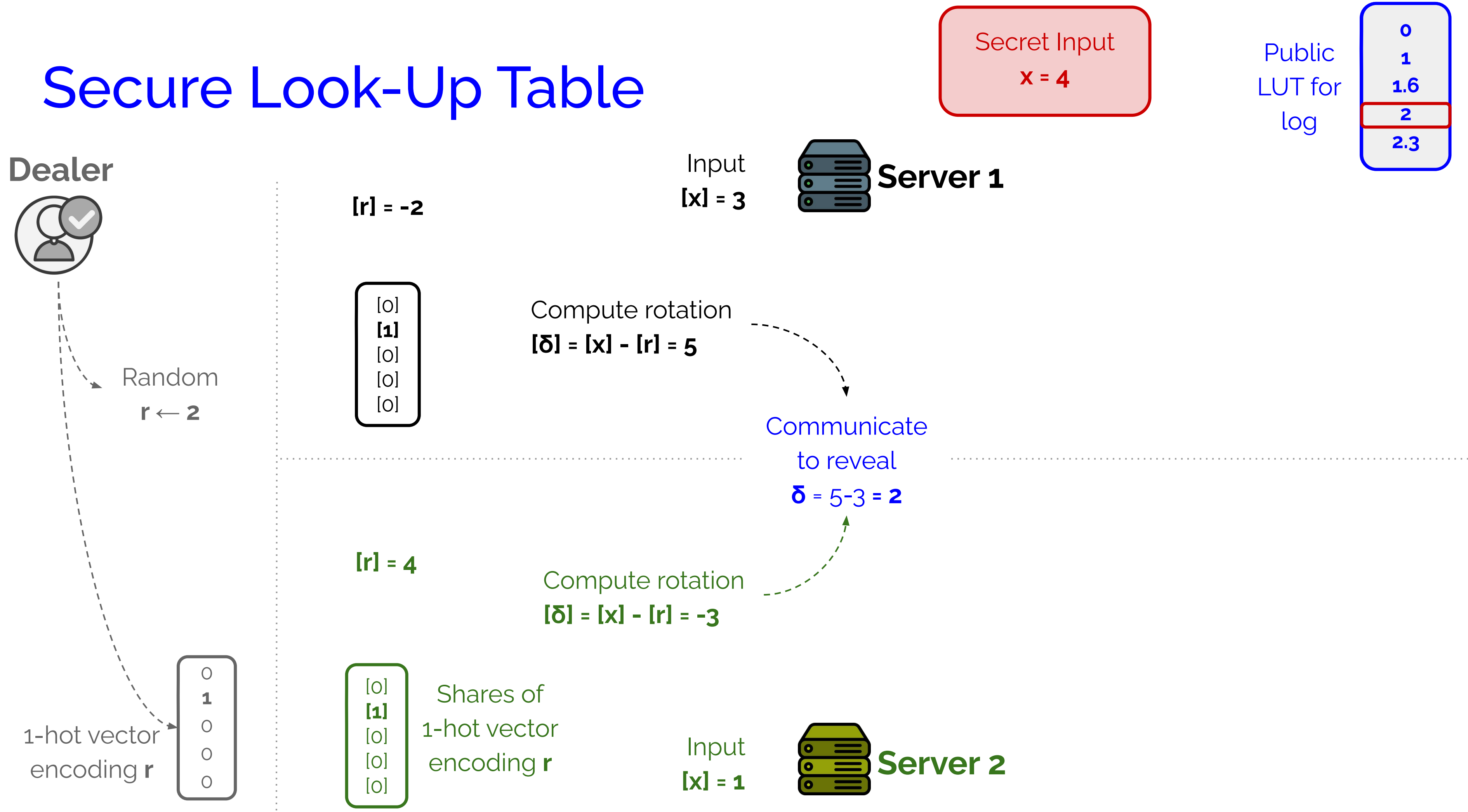

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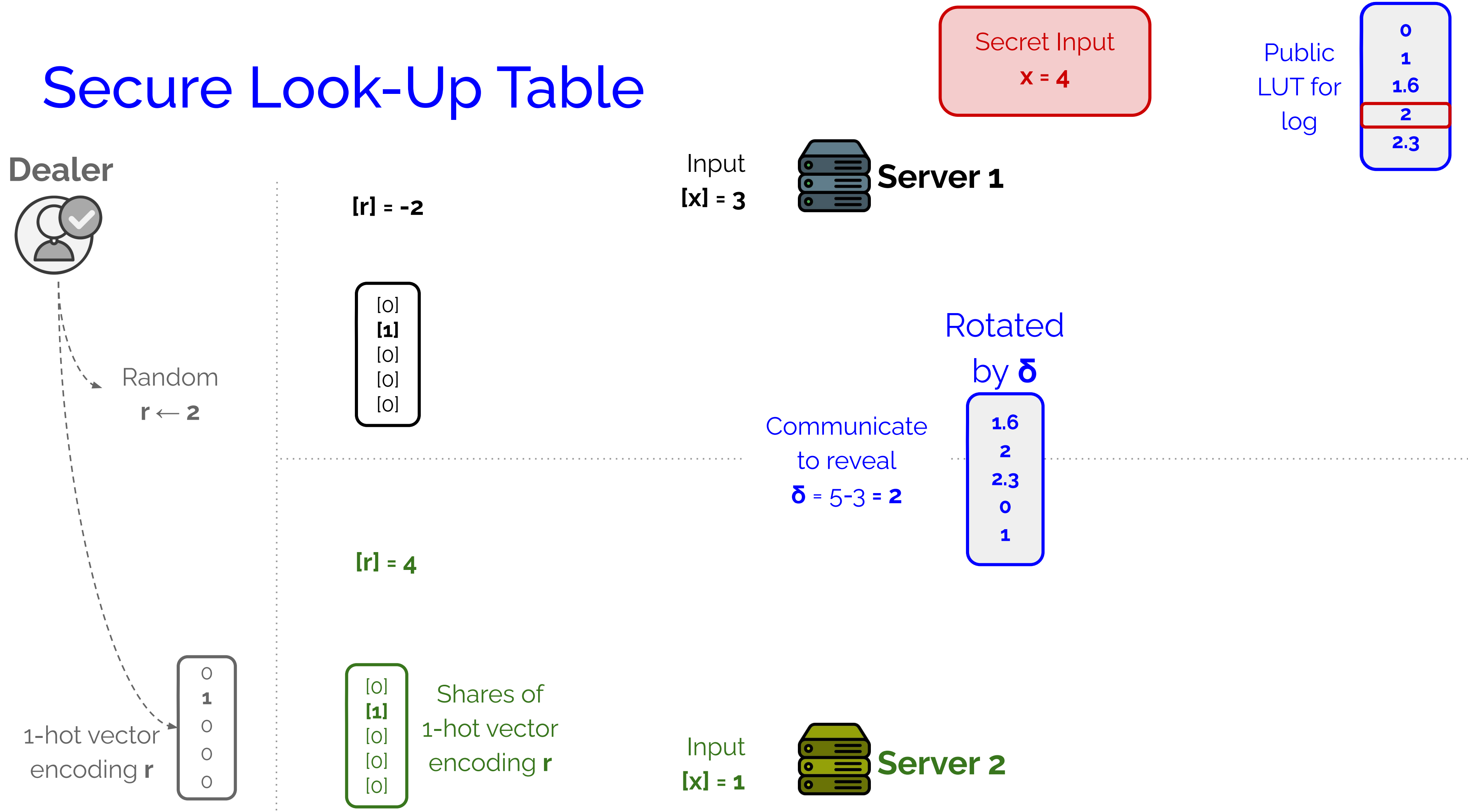

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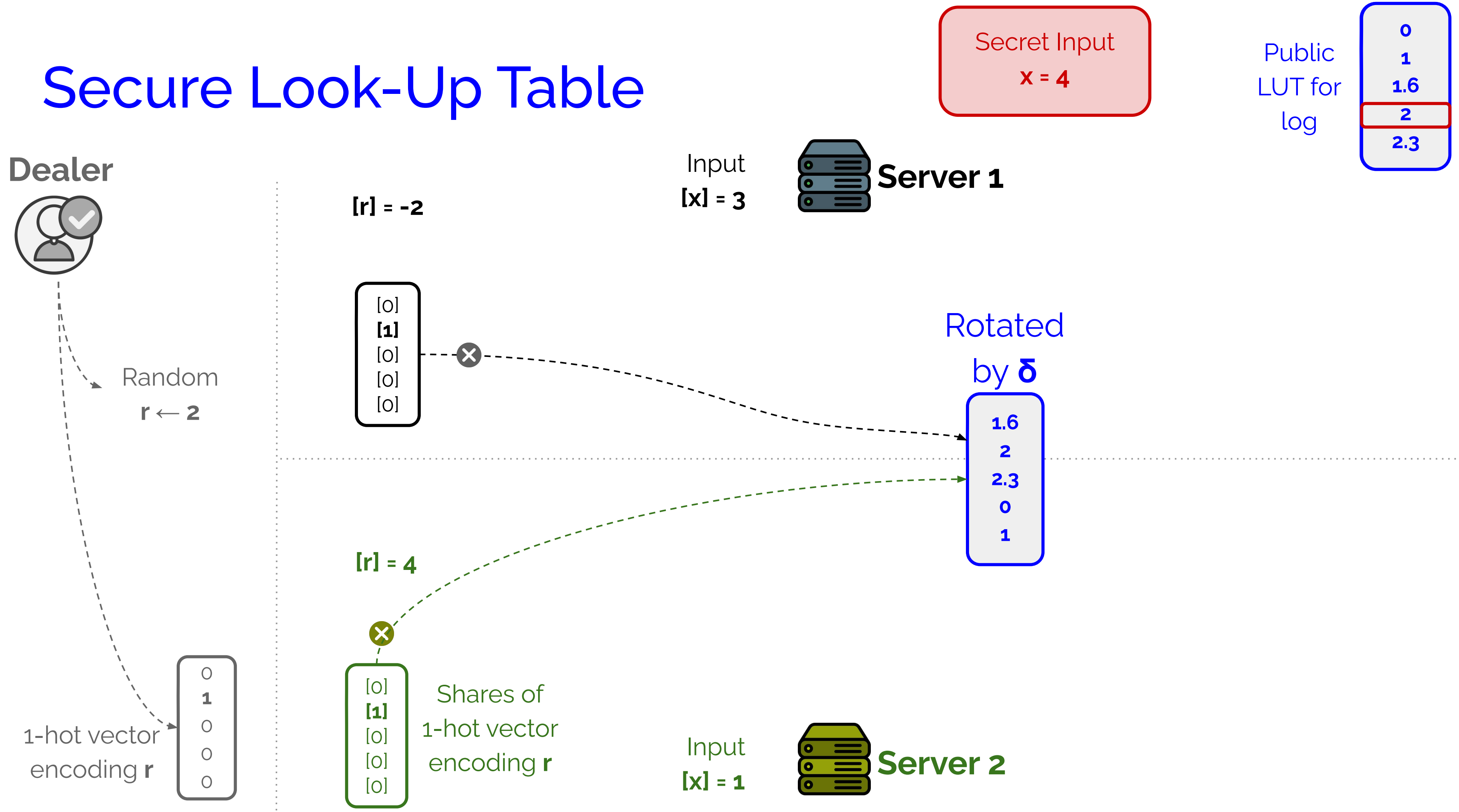

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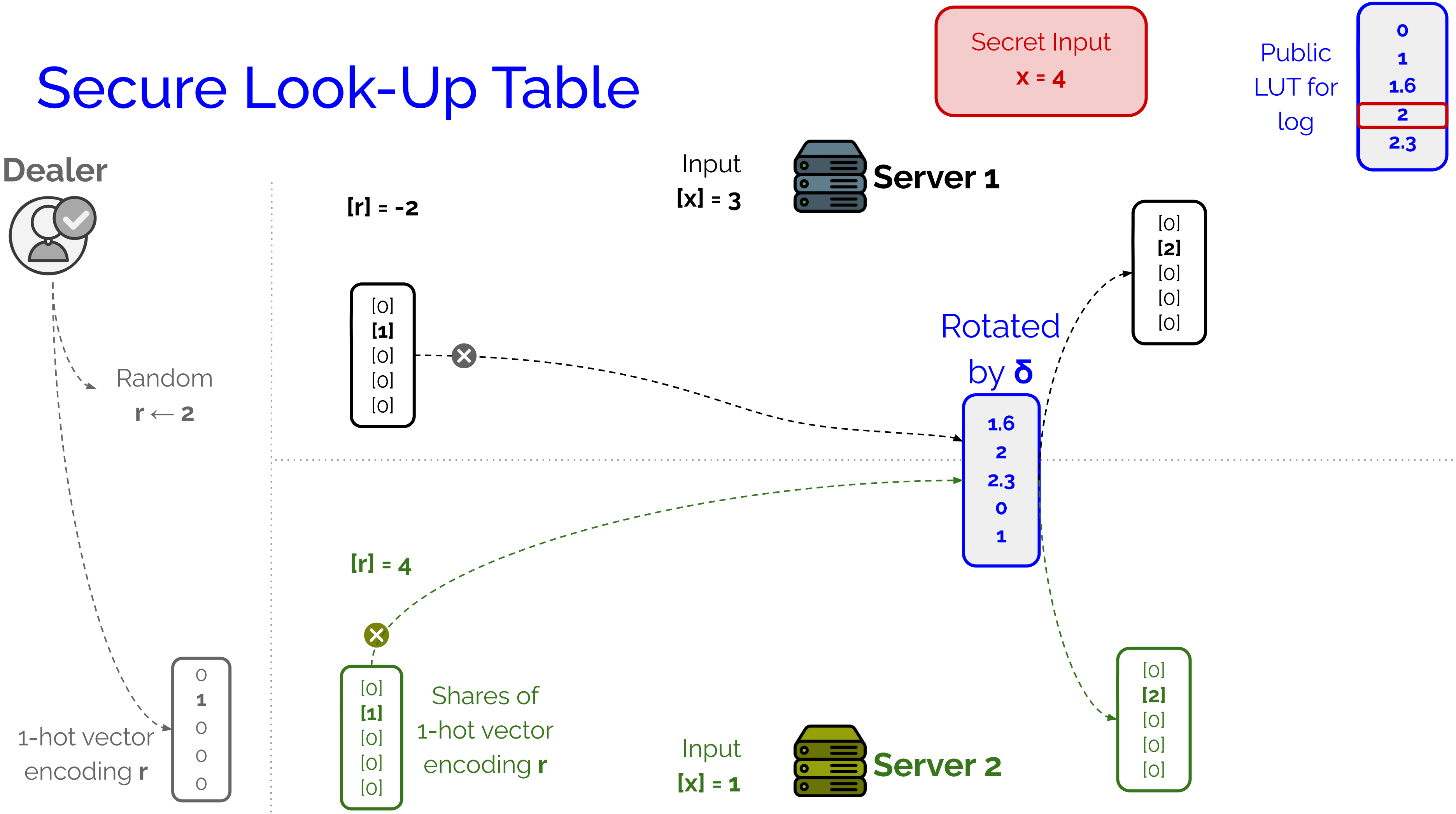

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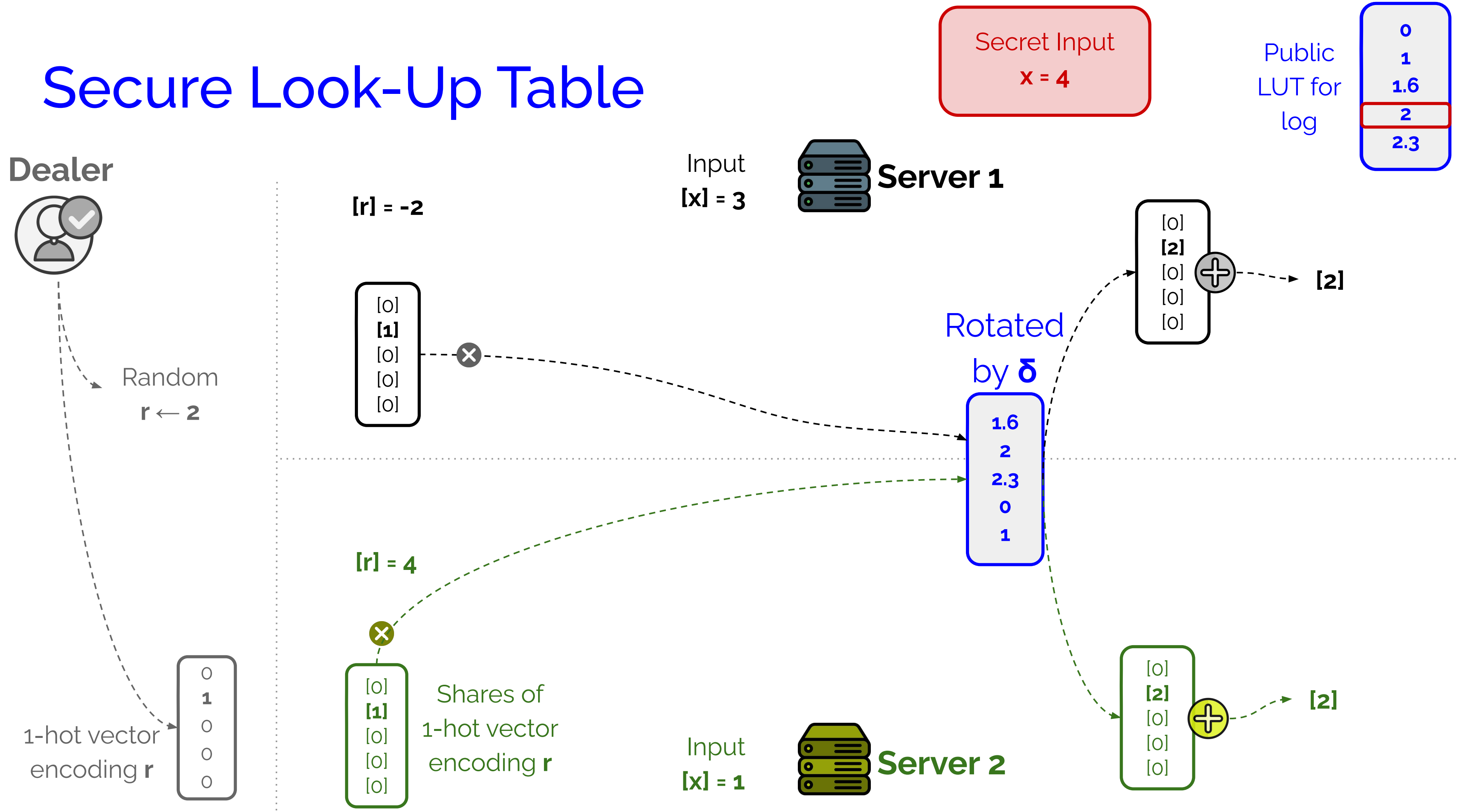

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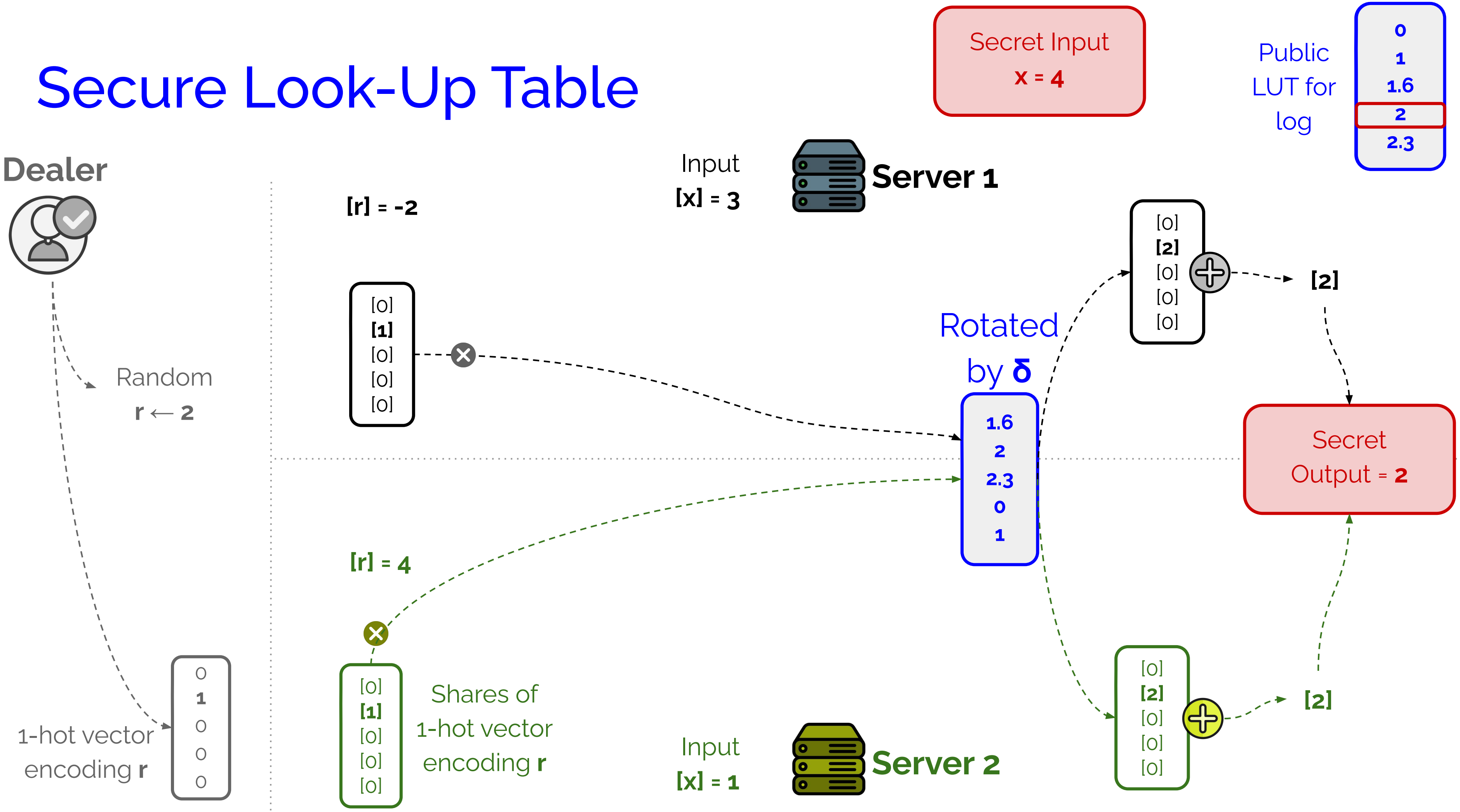
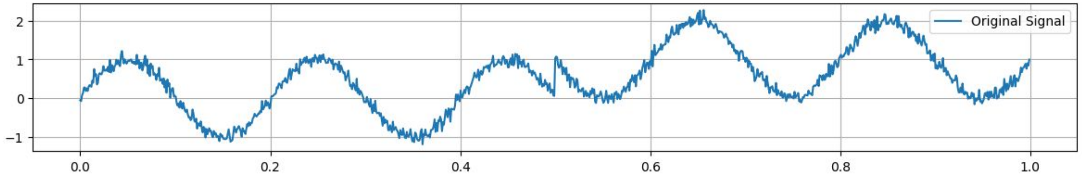


# Discrete Wavelet Transform (DWT)

Initial signal **s**



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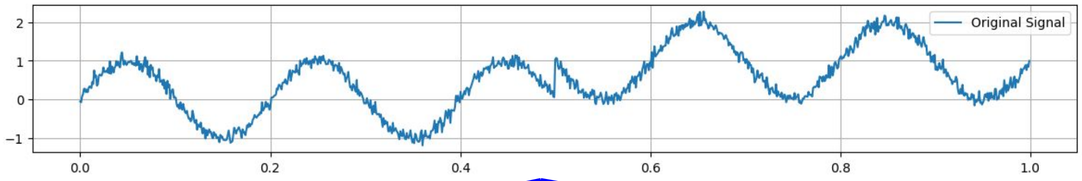
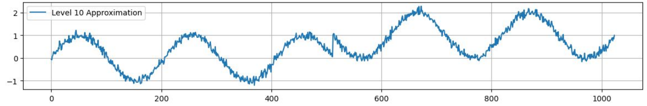
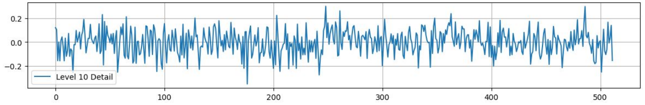



**Approximations** $\boldsymbol{a}$

**Details** $\boldsymbol{d}$



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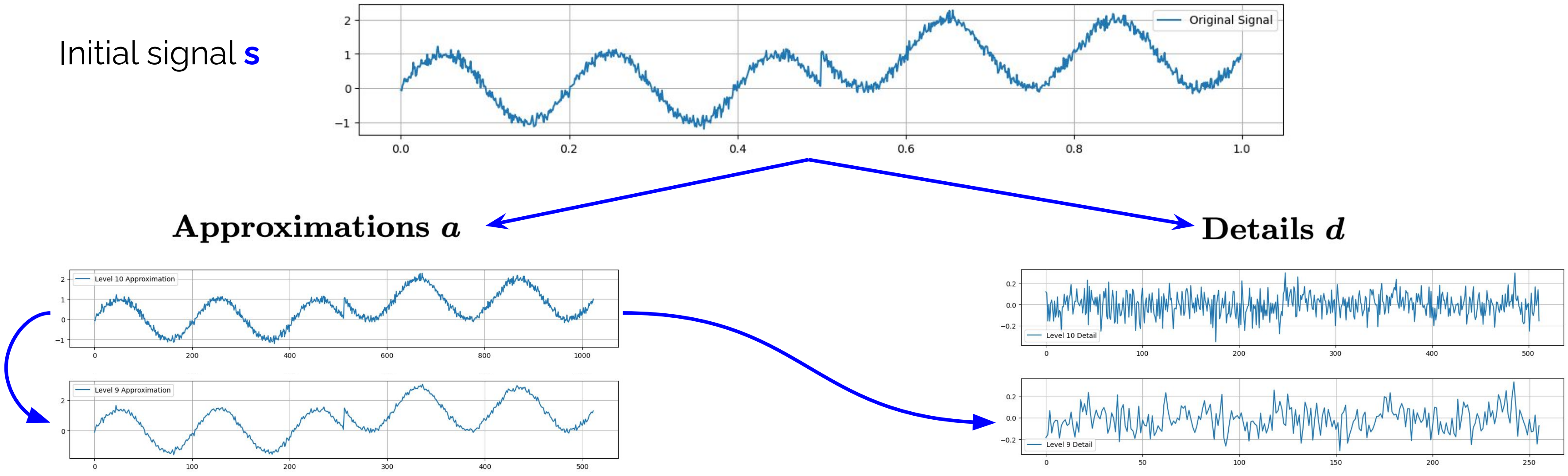

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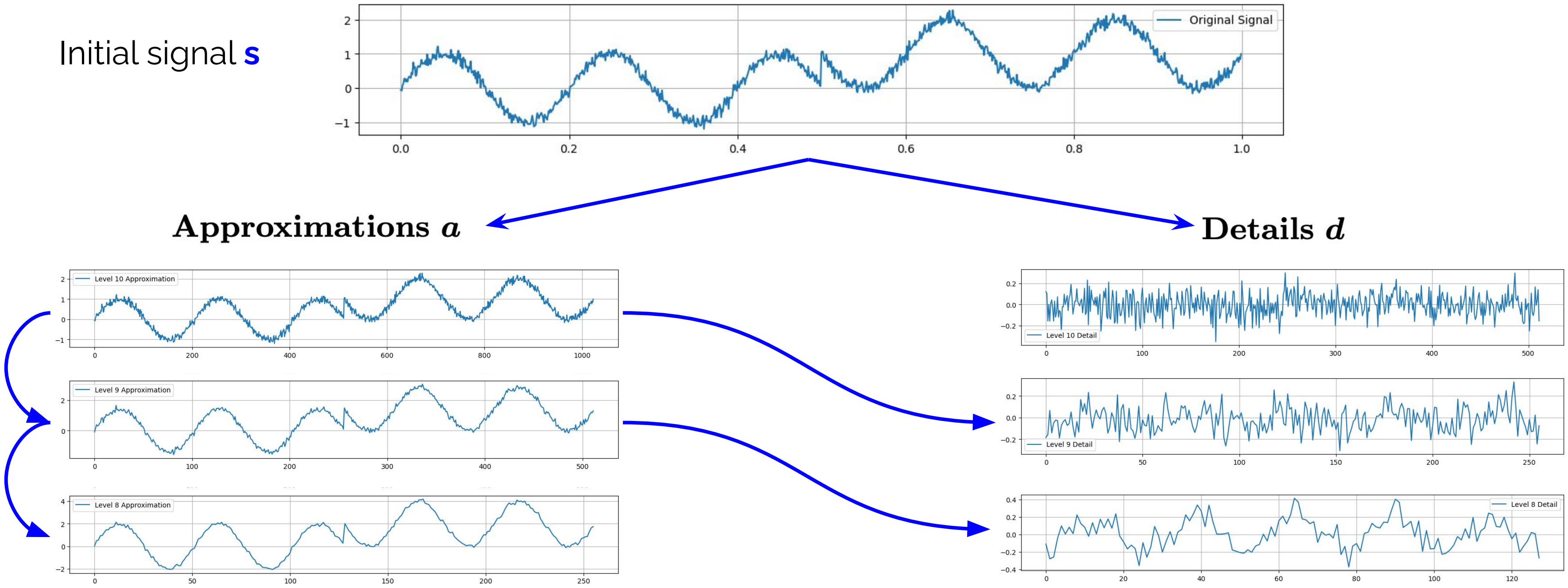

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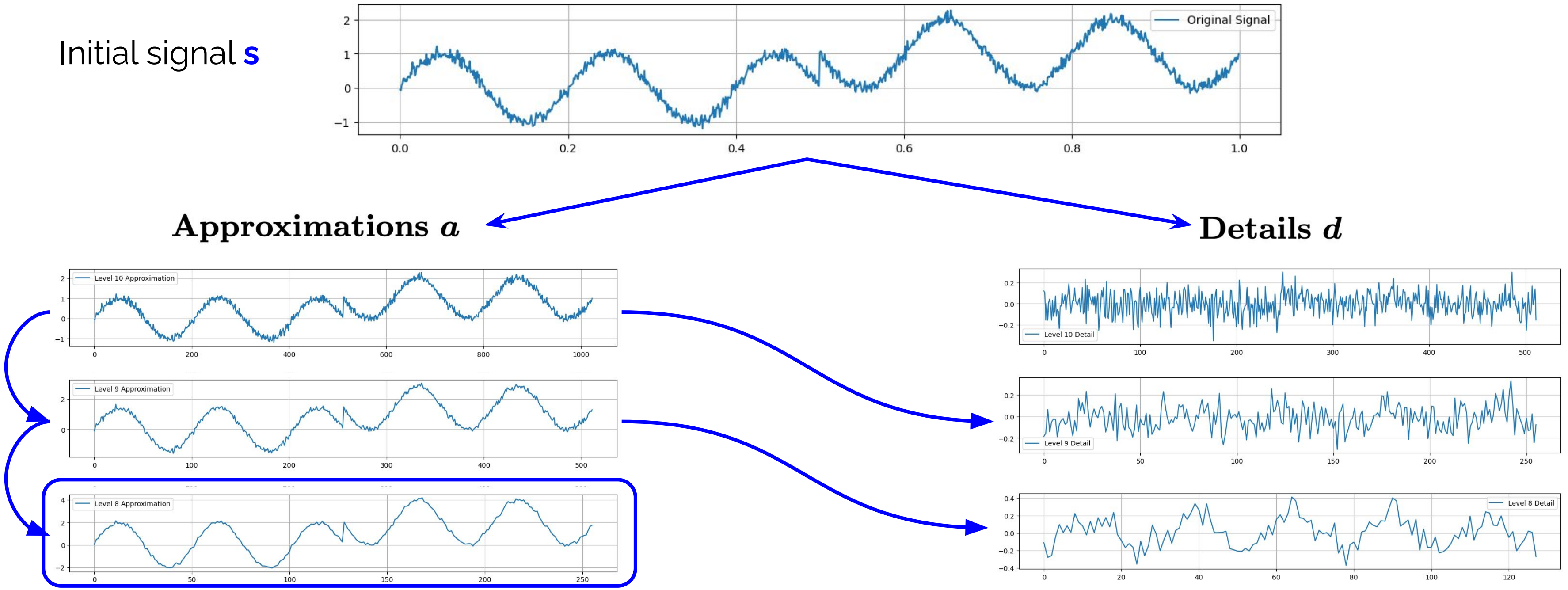


Smooth part of **s** remains unchanged!

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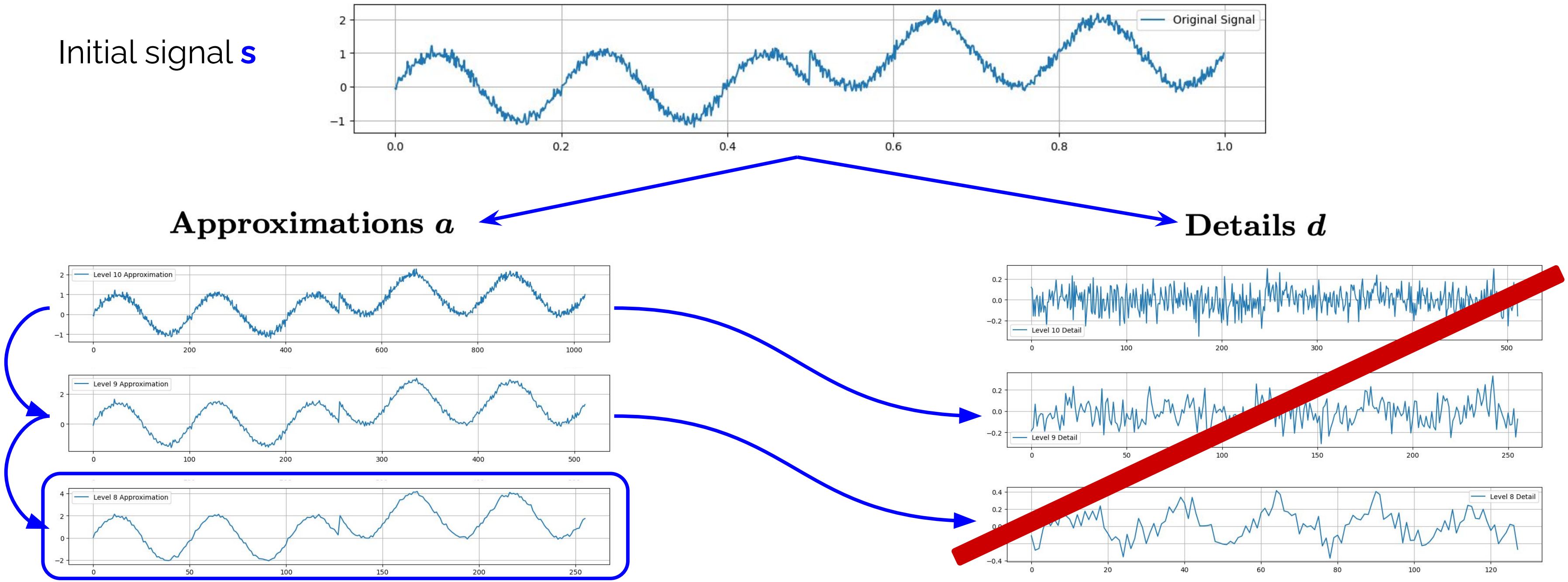


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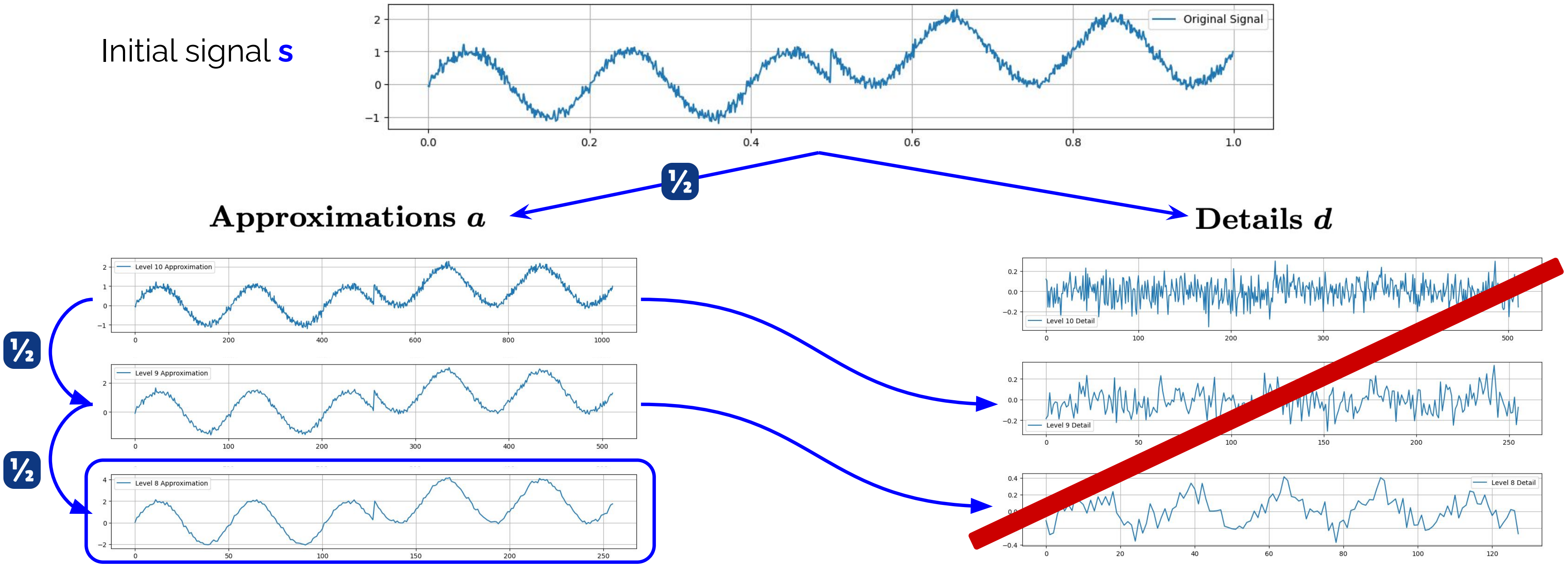


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**Goal:** Evaluate  y = LUT(x) for W bits (e.g. 32)

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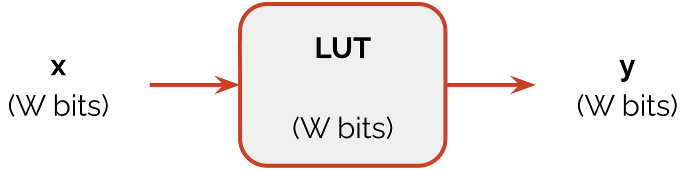

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High runtime ($2^{32}$)

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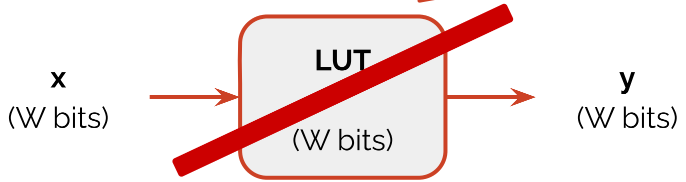

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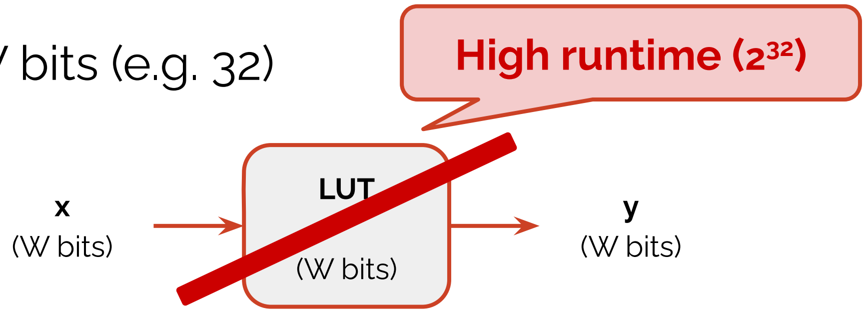


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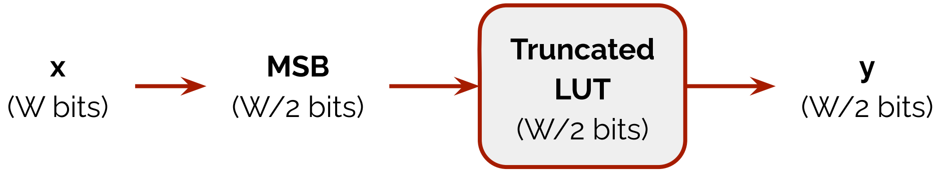

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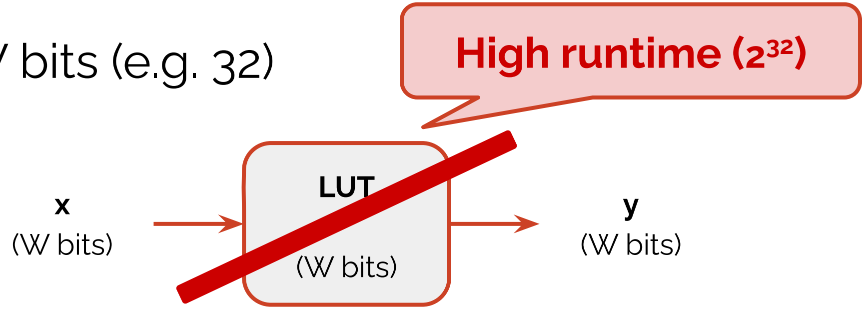


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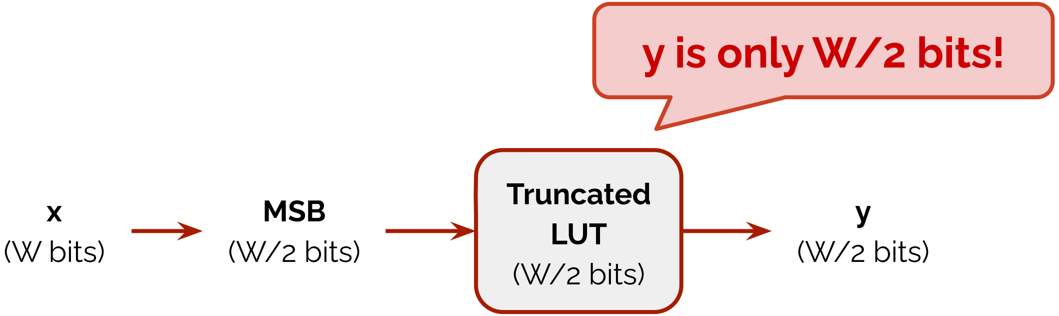

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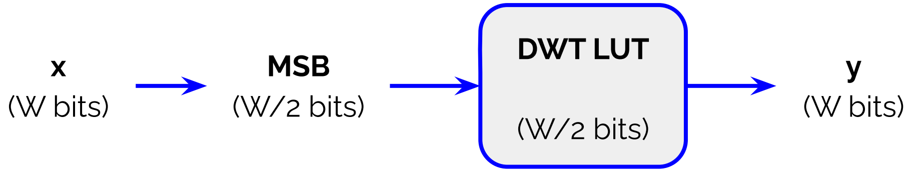

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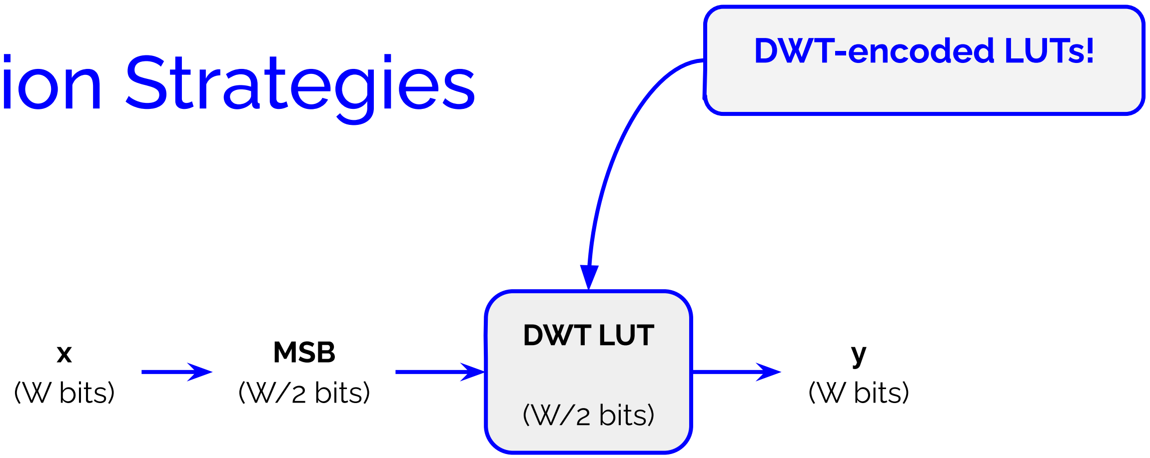

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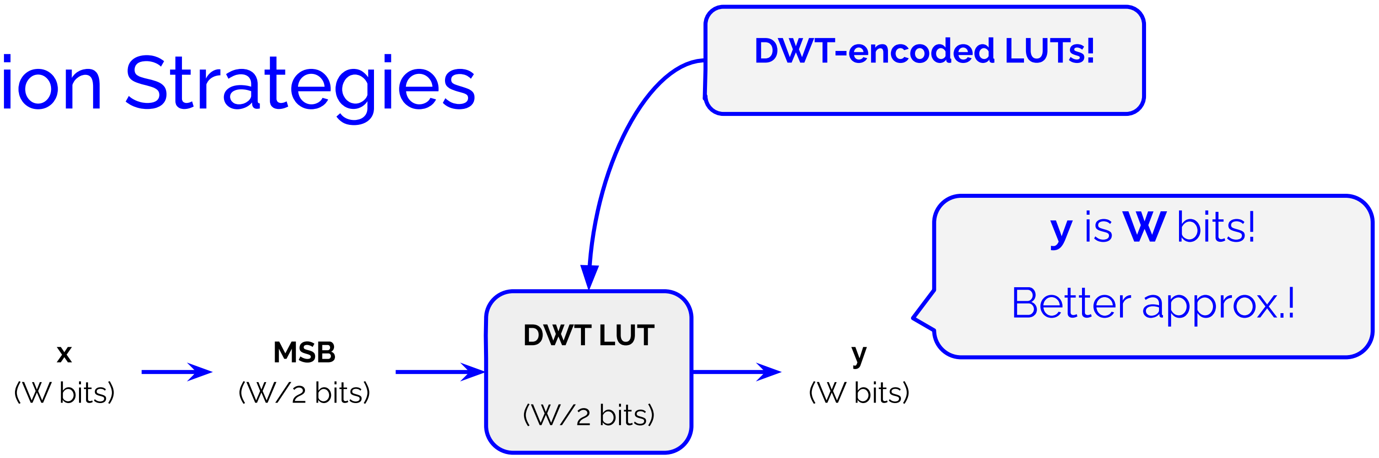

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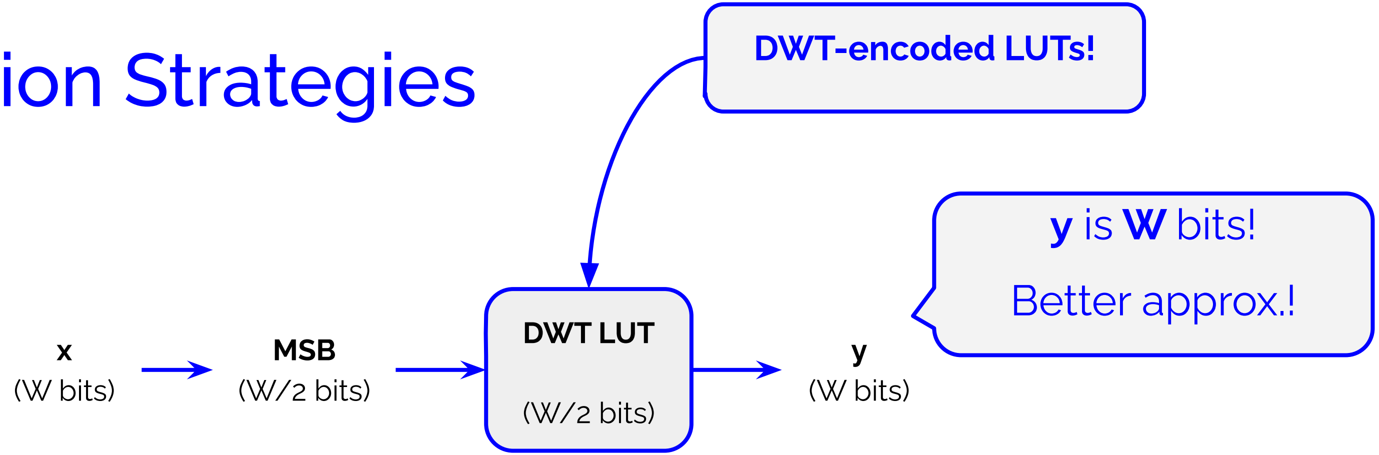


**3) Biorthogonal DWT**

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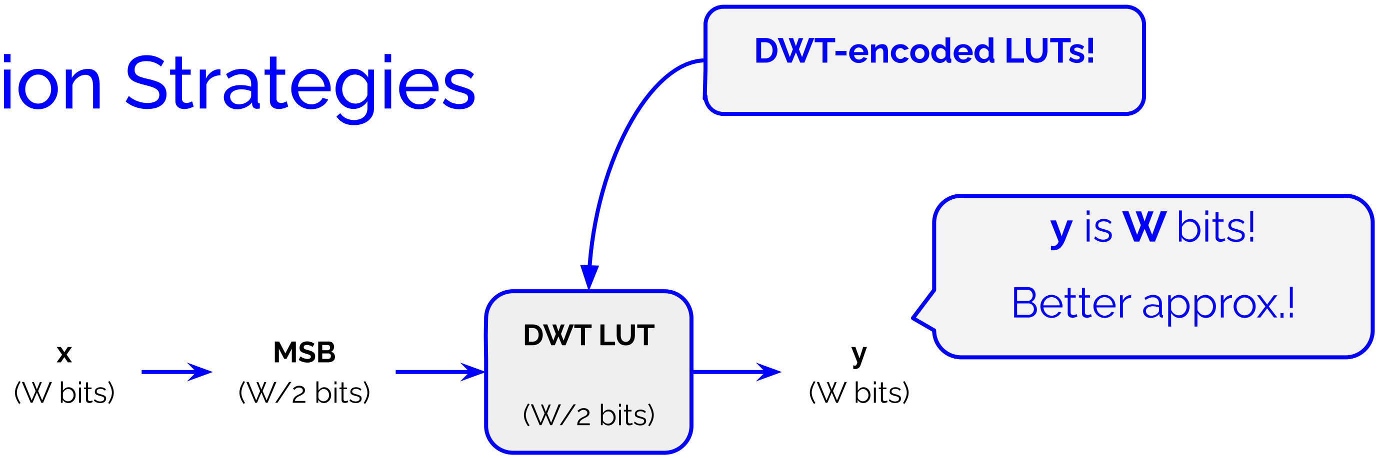


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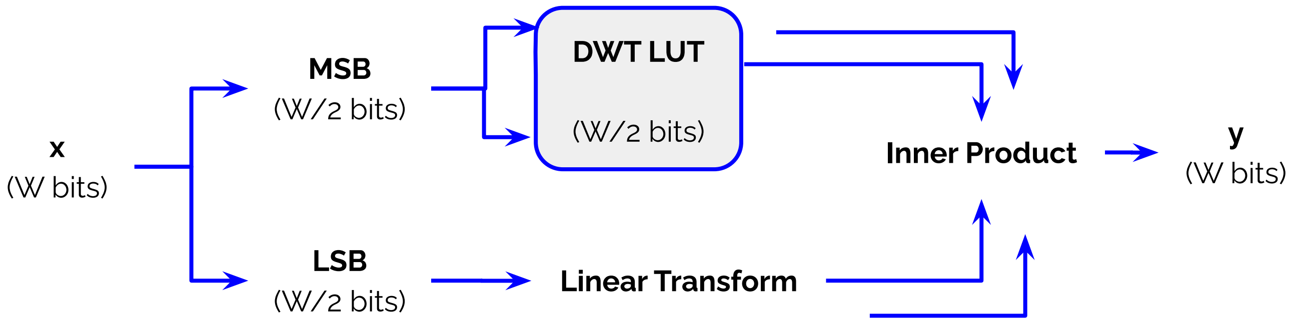

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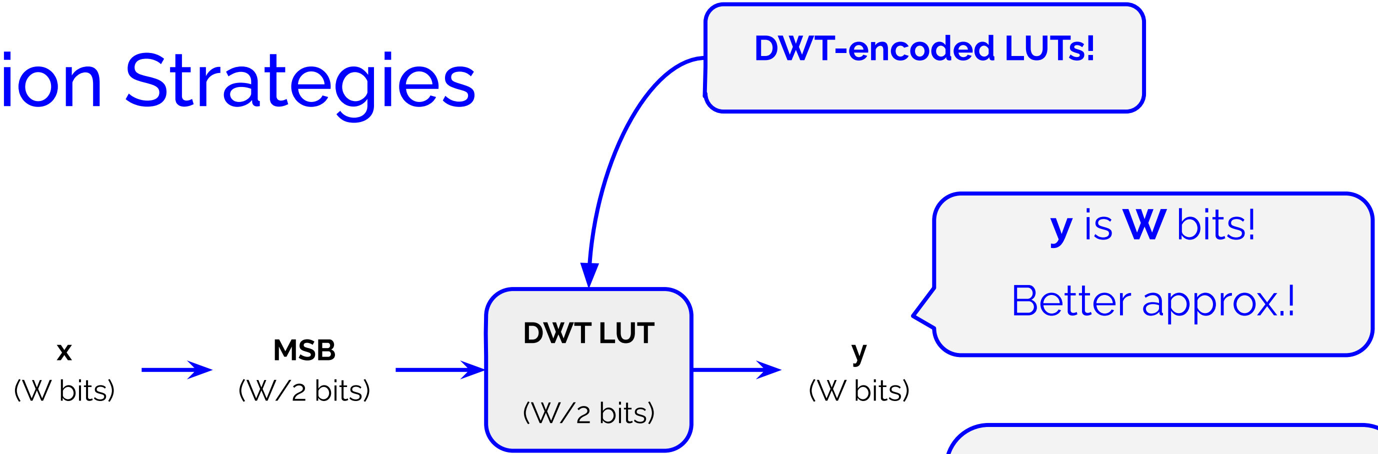


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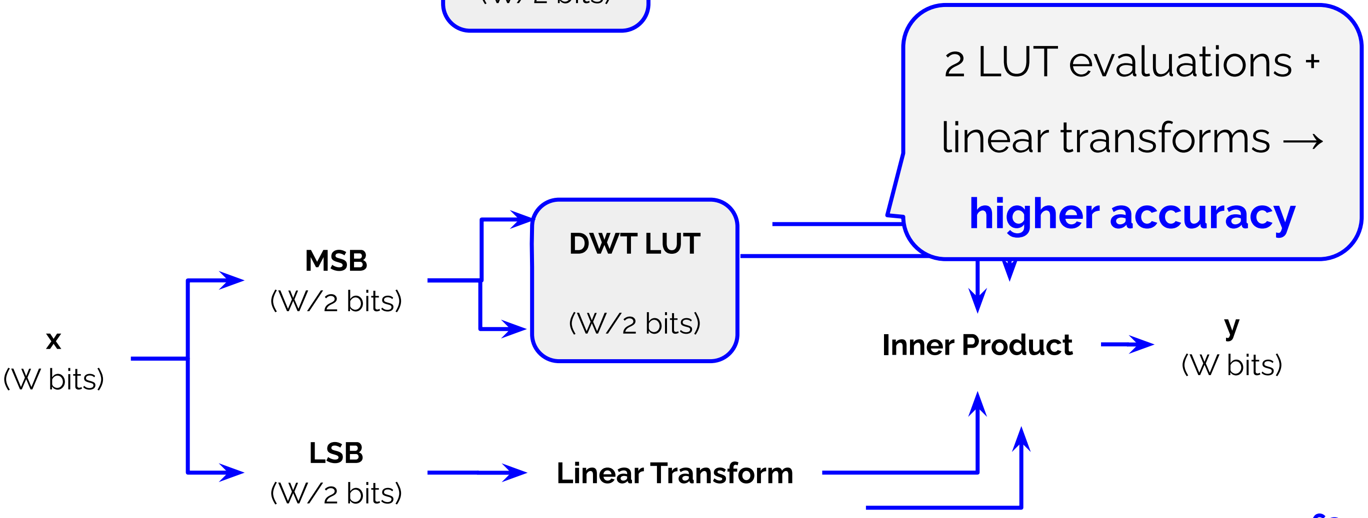
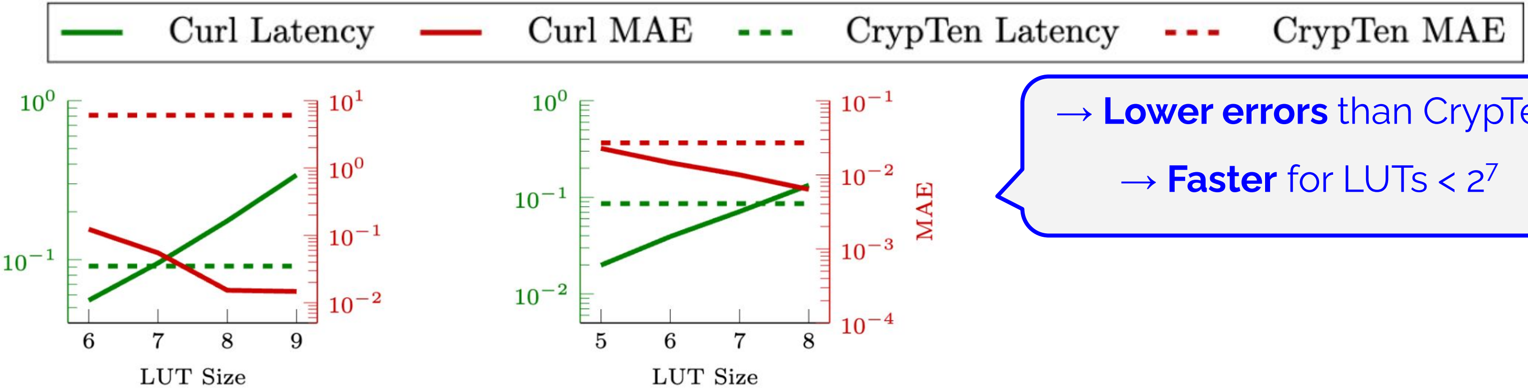


# **Evaluations:** Approximations




Square Root

Inverse Square Root

→ **Lower errors** than CrypTen

→ **Faster** for LUTs < $2^7$

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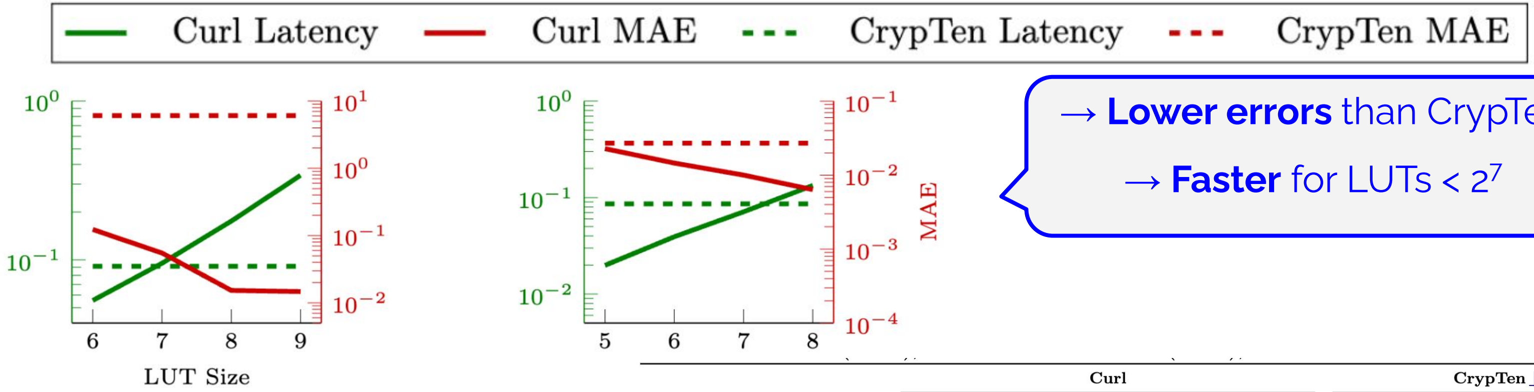


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| Op. | Protocol | Domain | LUT | Curl Latency (sec.)[†] | Curl Com.[‡] Rounds | Curl Com. MB | Curl Error[§] MAE | Curl Error MRE | CrypTen [45] Latency (sec.) | CrypTen Com. Rounds | CrypTen Com. MB | CrypTen Error MAE | CrypTen Error MRE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| log | Fig. 7 | (0, 64) | $2^8$ | 0.17 | 4 | 2.6 | 2.09e-2 | 5.48e-2 | 0.17 | 40 | 39.8 | 2.14e-2 | 6.36e-3 |
| reciprocal | Fig. 7 | (1, 64) | $2^7$ | 0.09 | 4 | 2.6 | 7.18e-4 | 1.43e-3 | 0.11 | 59 | 38.3 | 1.7e-4 | 7.05e-3 |
| sqrt | Fig. 7 | (0, 256) | $2^6$ | 0.06 | 4 | 2.6 | 1.23-1 | 1.11e-2 | 0.09 | 26 | 17.3 | 6.09e+0 | 4.04e-1 |
| invsqrt | Fig. 6 | (0, 256) | $2^6$ | 0.04 | 2 | 1.0 | 1.45e-2 | 1.14e-1 | 0.09 | 24 | 15.7 | 2.69e-2 | 0.405e-1 |
| sin | App. B.3 | (−64, 64) | $2^5$ | 0.08 | 16 | 20.4 | 4.55e-3 | 1.14e-2 | 0.11 | 37 | 24.1 | 8.52e-1 | 1.58e+0 |
| cos | App. B.3 | (−64, 64) | $2^5$ | 0.08 | 16 | 20.4 | 4.77e-3 | 9.85e-2 | 0.10 | 37 | 24.1 | 8.86e-1 | 1.45e+0 |
| sigmoid | Fig. 11<br>Fig. 7 | (−64, 64)<br>(−64, 64) | $2^6$<br>$2^6$ | 0.10<br>0.10 | 22<br>4 | 33.6<br>2.6 | 4.70e-5<br>1.11e-2 | 7.83e-2<br>6.59e-2 | 0.11<br>0.11 | 26<br>26 | 26.2<br>26.2 | 7.00e-5<br>7.00e-5 | 3.49e+0<br>3.49e+0 |
| tanh | Fig. 11 | (−64, 64) | $2^5$ | 0.09 | 22 | 33.6 | 2.31e-4 | 3.96e-4 | 0.13 | 26 | 26.2 | 8.60e-5 | 1.19e-4 |
| erf | Fig. 11 | (−64, 64) | $2^3$ | 0.09 | 22 | 33.6 | 8.98e-4 | 1.83e-3 | 0.21 | 56 | 36.2 | 3.39e+7 | 3.40e+7 |
| GeLU | App. B.2<br>Fig. 7 | (−64, 64)<br>(−4, 4) | $2^4$<br>$2^4$ | 0.10<br>0.11 | 30<br>4 | 47.7<br>2.6 | 5.95e-3<br>2.60e-3 | 2.79e+0<br>5.02e-2 | N/A<br>N/A | N/A<br>N/A | N/A<br>N/A | N/A<br>N/A | N/A<br>N/A |
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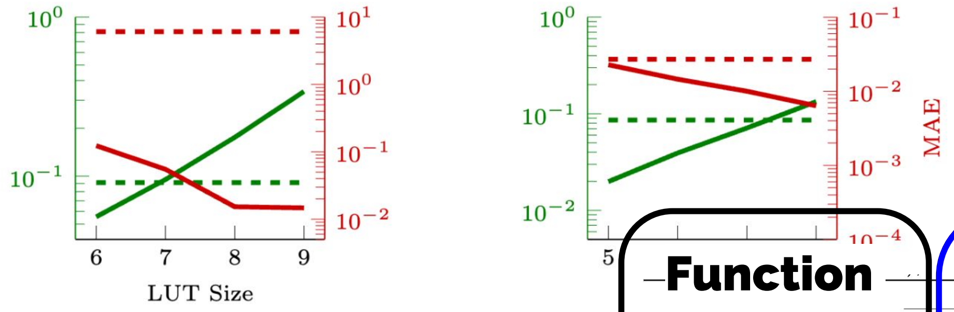


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**(seq. len = 128)**

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[1] C. Gouert, M. Ugurbil, D. Mouris, M. de Vega, and N. G. Tsoutsos. **Ripple: Accelerating Programmable Bootstraps for FHE with Wavelet Approximations.** In International Conference on Information Security (ISC), 2024.

[2] J. Reis, M. Ugurbil, S. Wagh, R. Henry, M. de Vega. **Wave Hello to Privacy: Efficient Mixed-Mode MPC using Wavelet Transforms**, accepted to PoPETs 2025.

Portugal Crypto Day

December 13, 2024, Lisbon

# Curl: Private LLMs through Wavelet-Encoded Look-Up Tables

**Manuel B. Santos**[1], Dimitris Mouris[1], Mehmet Ugurbil[1], Stanislaw Jarecki[1,2], José Reis[1], Shubho Sengupta[3] and Miguel de Vega[1]

{ manuel.santos, dimitris, memo, stanislaw.jarecki, jose.reis, miguel }@nillion.com

ssengupta@meta.com

*https://ia.cr/2024/1127*

*https://github.com/jimouris/curl*

1 nillion

2 THE UNIVERSITY OF CALIFORNIA · IRVINE

3 Meta