Faster Secure Multi-Party Computation of AES and DES Using Lookup Tables

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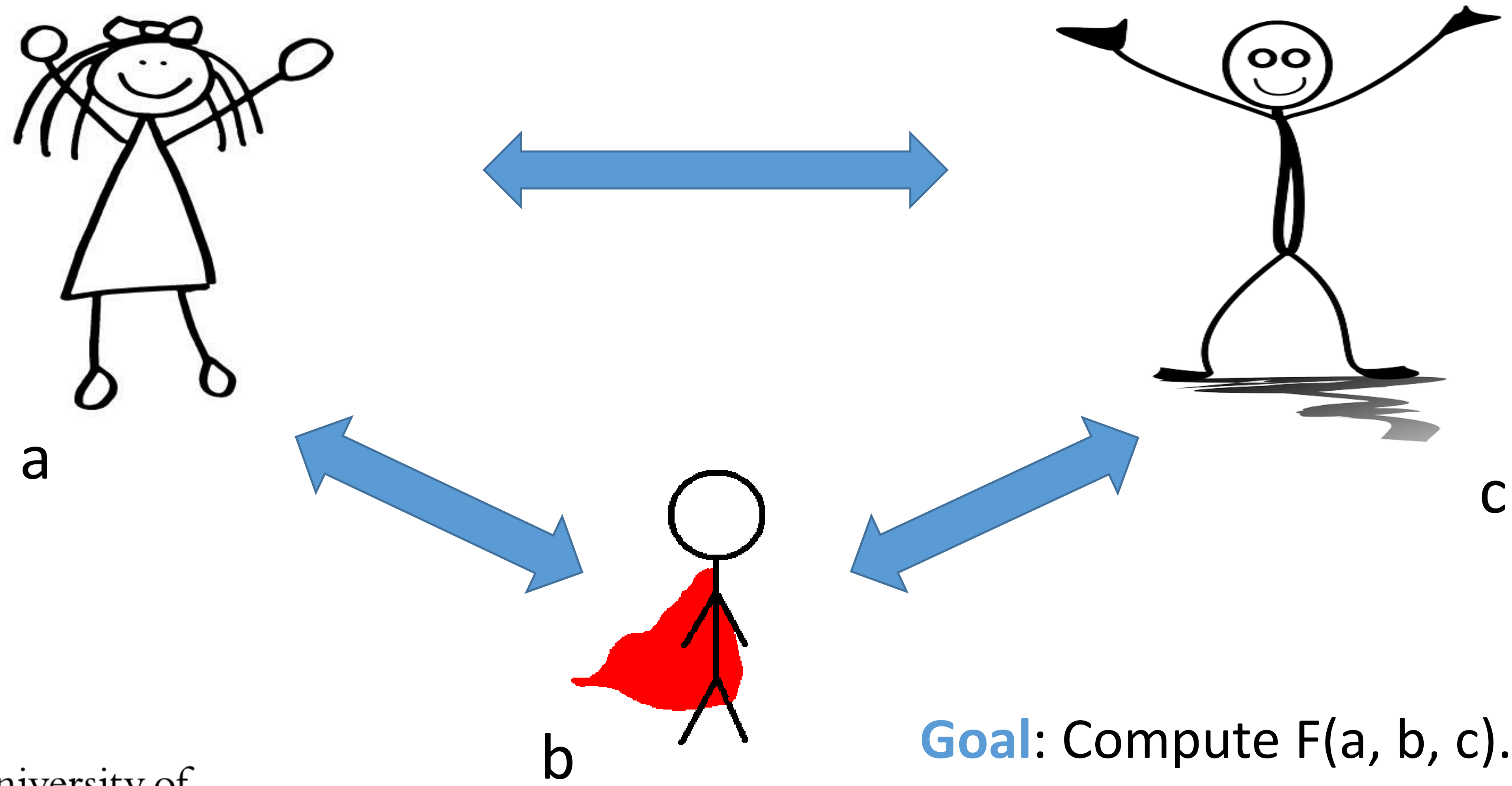
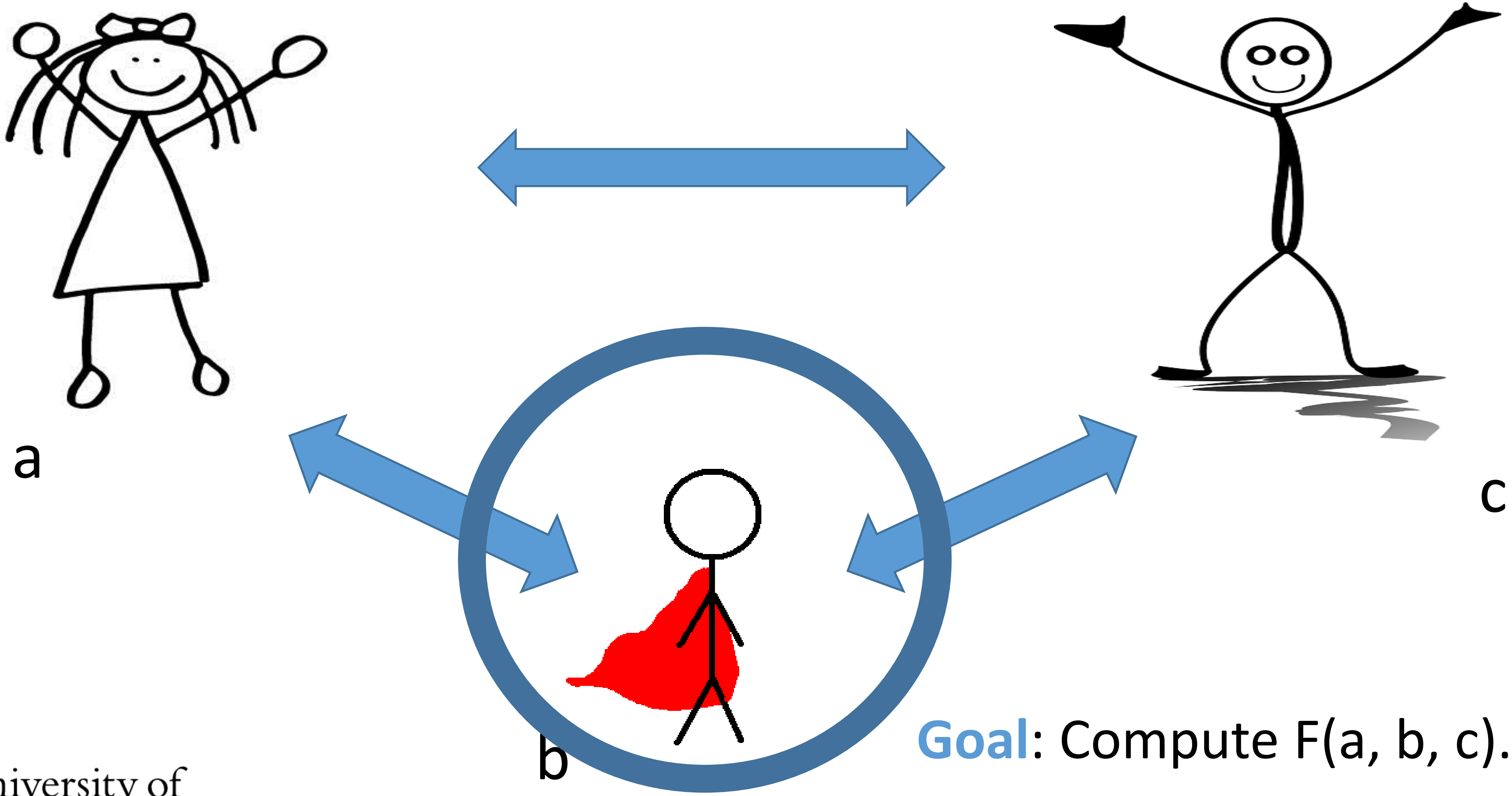
Multi-Party Computation



Goal: Compute F(a, b, c).

Multi-Party Computation



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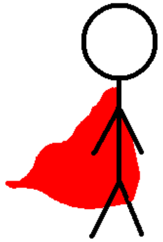
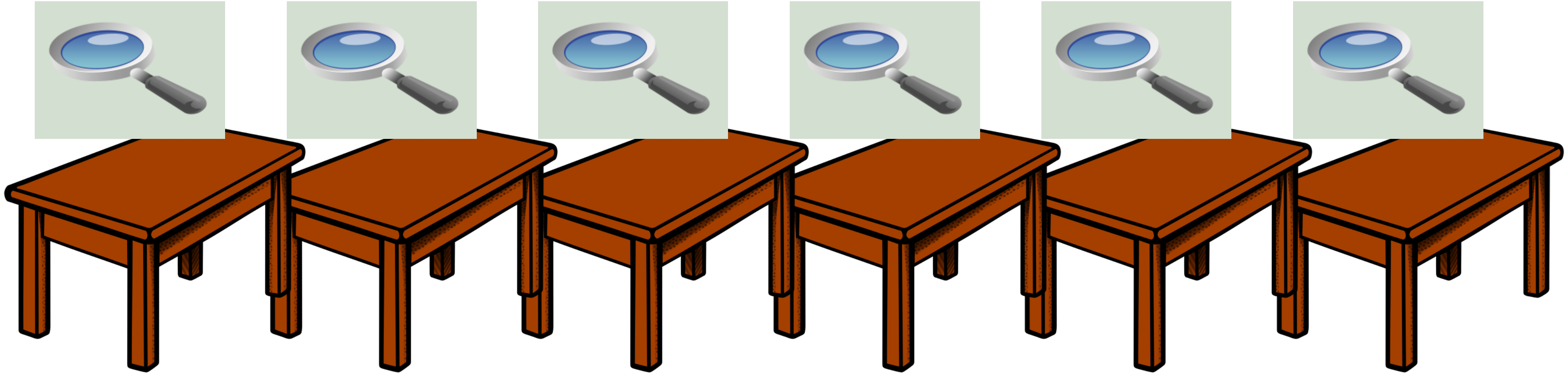
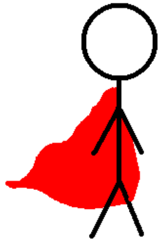


Bob has problems.





has problems?

Look-up tables are everywhere in MPC.

- Floating Point
- Oblivious RAM
- Non-linear functions

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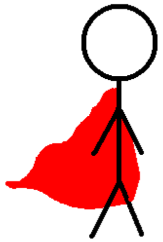 has problems?

Look-up tables are everywhere in MPC.

Floating Point

Oblivious RAM

Non-linear functions

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Non-linear? AES and 3-DES

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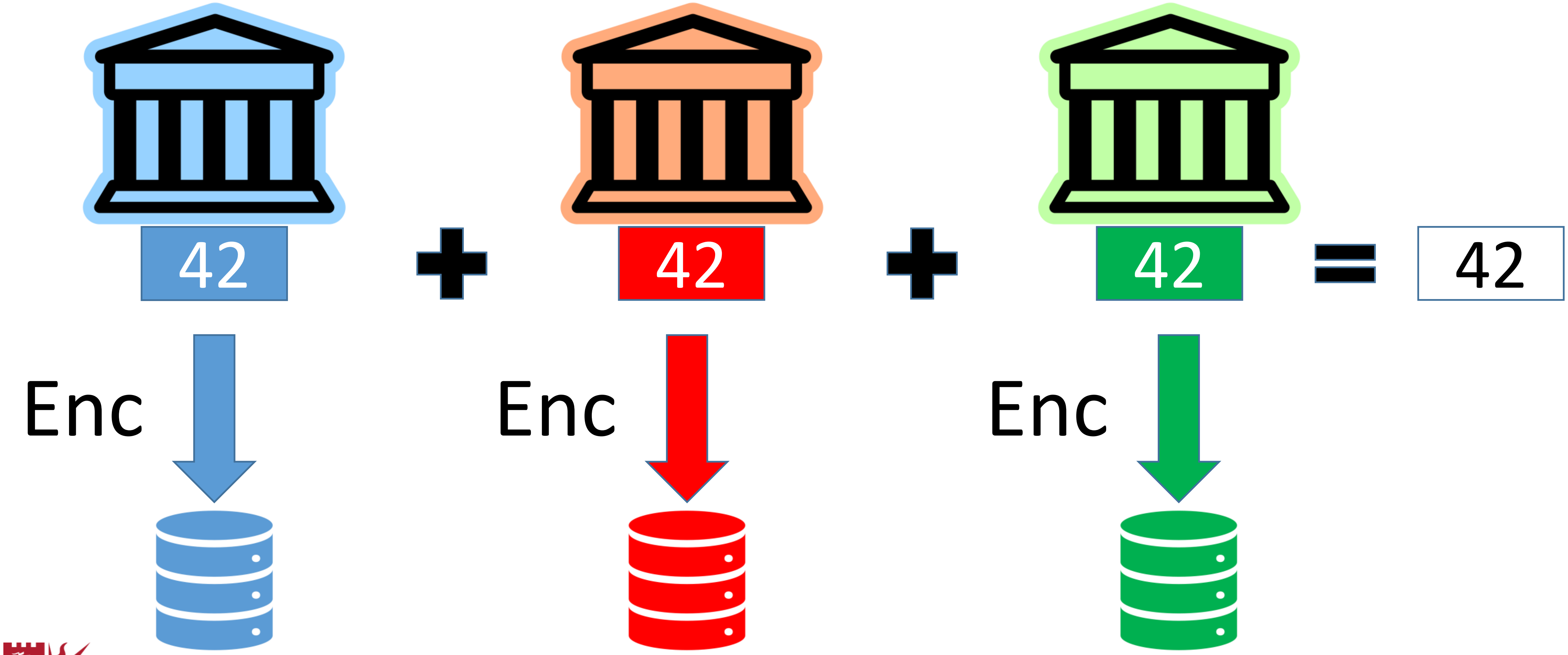
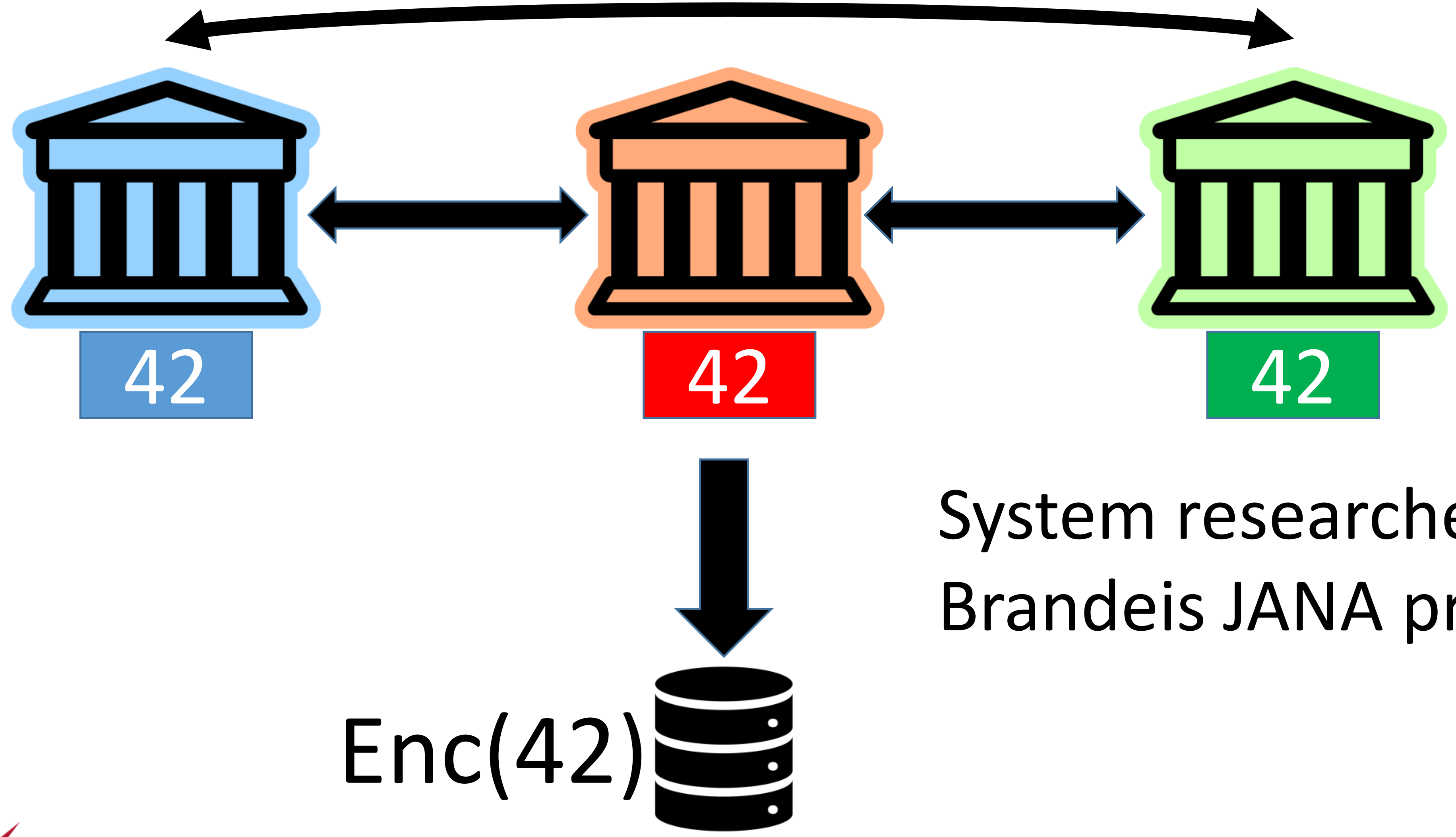


Non-linear? AES and 3-DES



System researched in Brandeis JANA project.

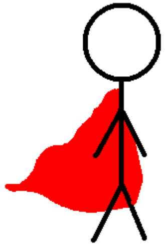
Fastest AES and 3-DES in MPC with malicious security

- Apply side-channel countermeasures in the MPC land.
- Improve on previous AES TinyTable by at least 50 times.
- 3-DES has now 100 times faster online time.

Concurrent Work

- [DNNR16] – TinyTable. Improved version now at CRYPTO17.
- [DKS+17] – Dessouky et al. in NDSS17. Semi-Honest setting based on 1-out-of-N OT. Also built a compiler which can be used with our protocol.

MPC with Secret Sharing



$$x = x_1 + \cdots + x_n$$

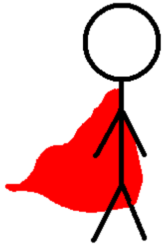
Each P_i has $[x] \leftarrow x_i$

$[x] \leftarrow x_2$

$[x] \leftarrow x_1$

$[x] \leftarrow x_3$

MPC Preprocessing Phase



Generate Triples.

[c] = [a][b]

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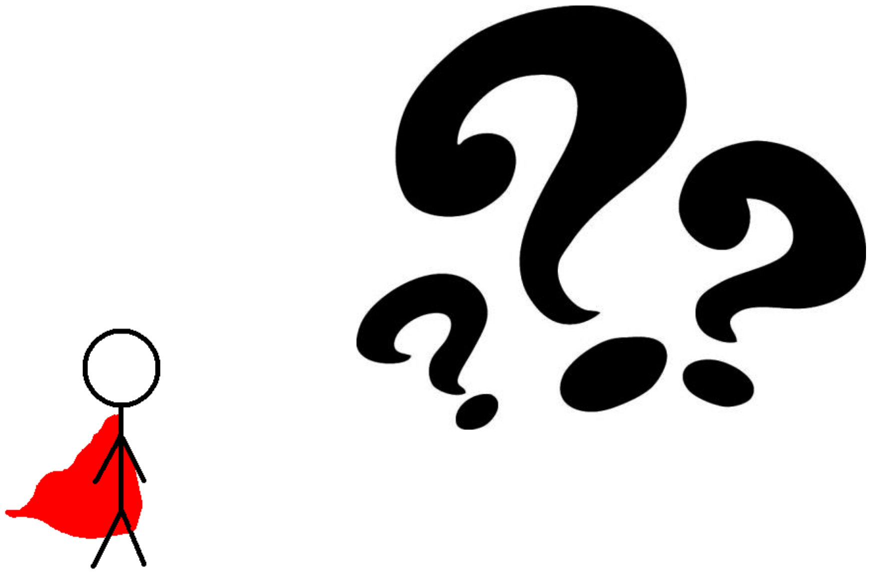

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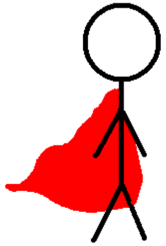

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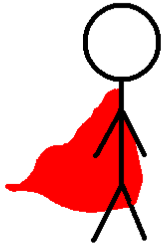
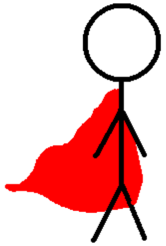


MPC Online Phase

Use Triples.

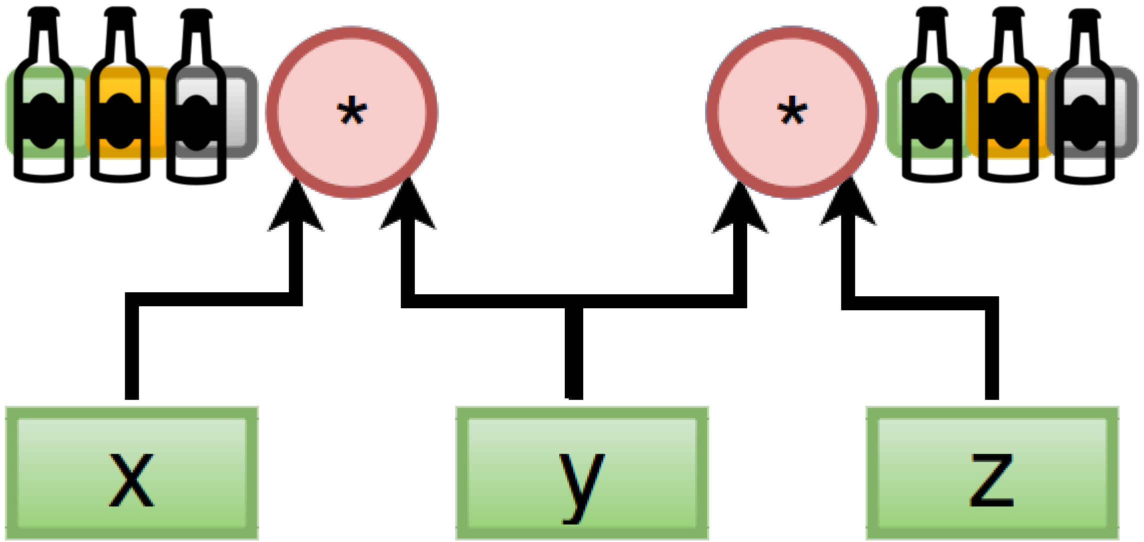
MPC Online Phase



MPC Circuit Evaluation

x y z

MPC Circuit Evaluation



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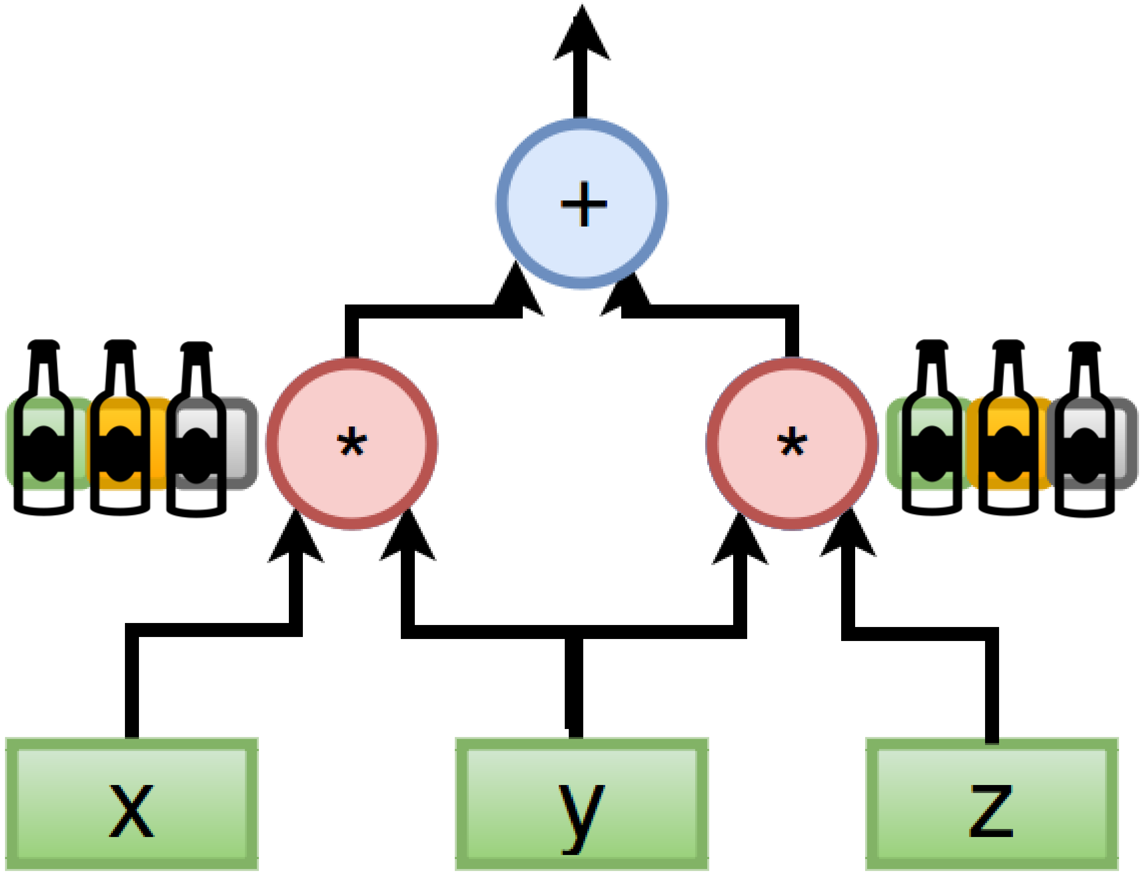

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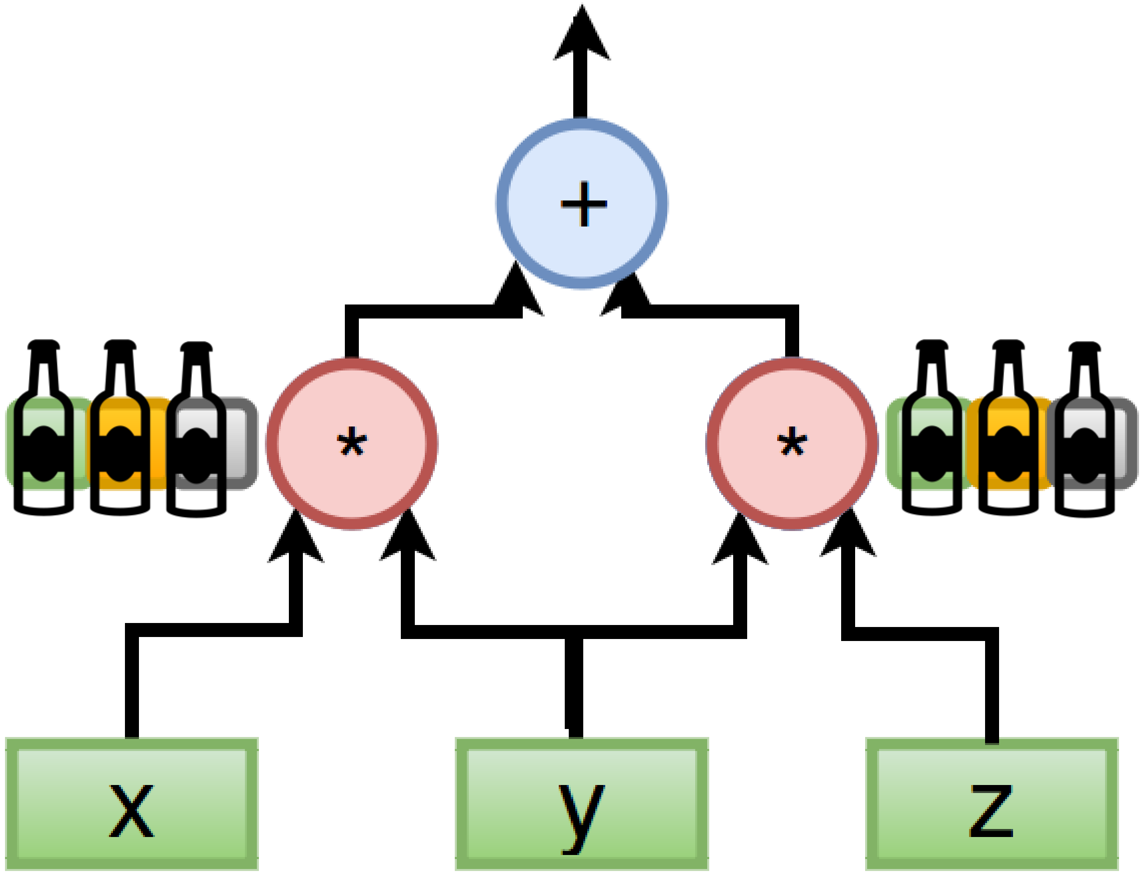

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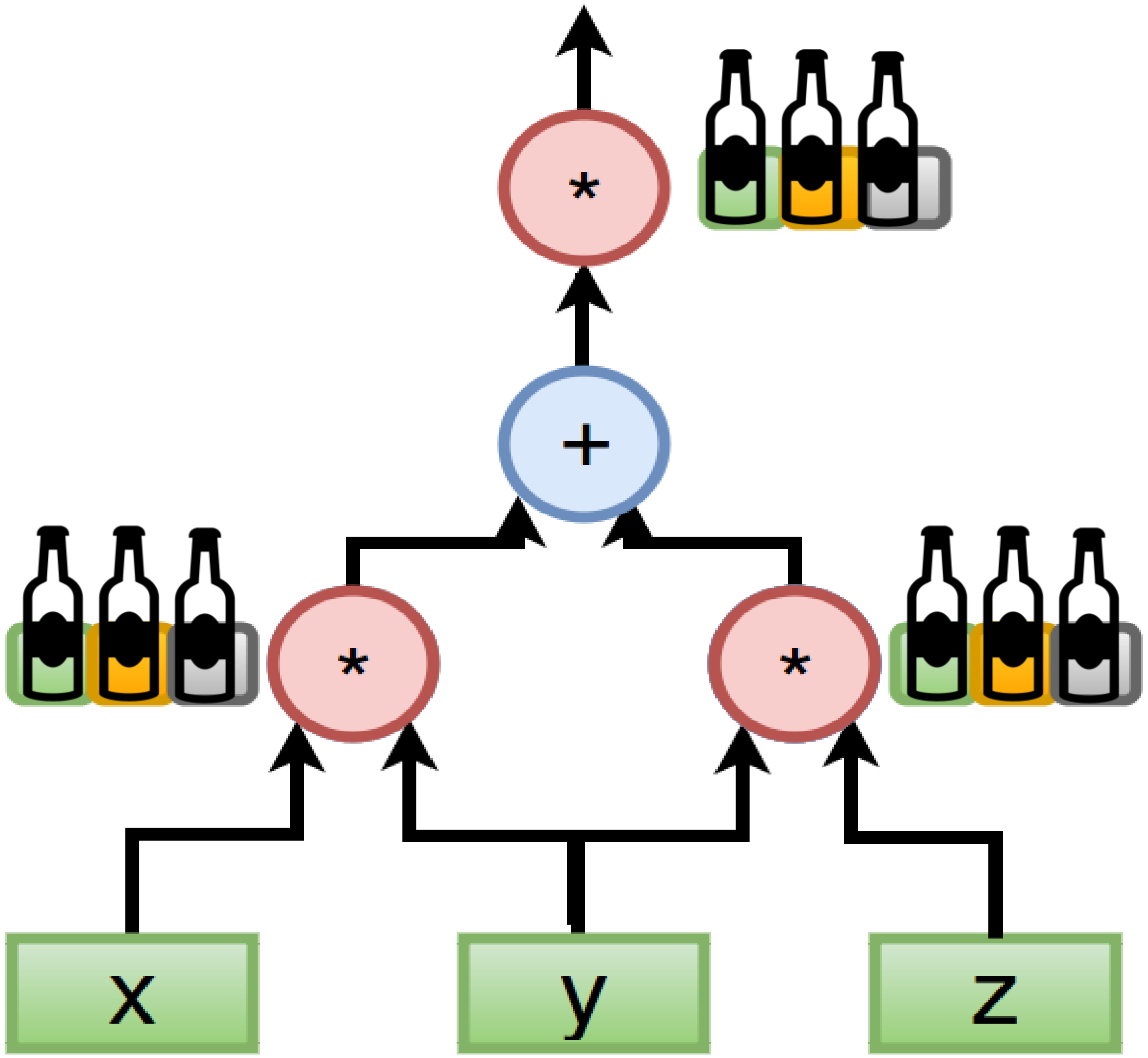

3 triples.

2 rounds.

Side-Channel inspired

[x] → [Sbox(x)]

- Write Sbox(x) as a poly with minimal non-linear multiplications, i.e. squares are (almost) for free
- AES Sbox requires 4 non-linear mults [RP10].

$$\{X, X^2\} \xrightarrow{\times} \{X^3, X^{12}\} \xrightarrow{\times} \{X^{14}\} \xrightarrow{\times} \{X^{15}, X^{240}\} \xrightarrow{\times} X^{254}$$

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Side-Channel inspired

[x] → [Sbox(x)]

- Write Sbox(x) as a poly with minimal non-linear multiplications, i.e. squares are (almost) for free
- AES Sbox requires 4 non-linear mults [RP10].
- DES Sbox requires 3 non-linear mults [PV16].

$$\{X, X^2\} \xrightarrow{\times} \{X^3, X^{12}\} \xrightarrow{\times} \{X^{14}\} \xrightarrow{\times} \{X^{15}, X^{240}\} \xrightarrow{\times} X^{254}$$

Side-Channel inspired

[x] → [Sbox(x)]

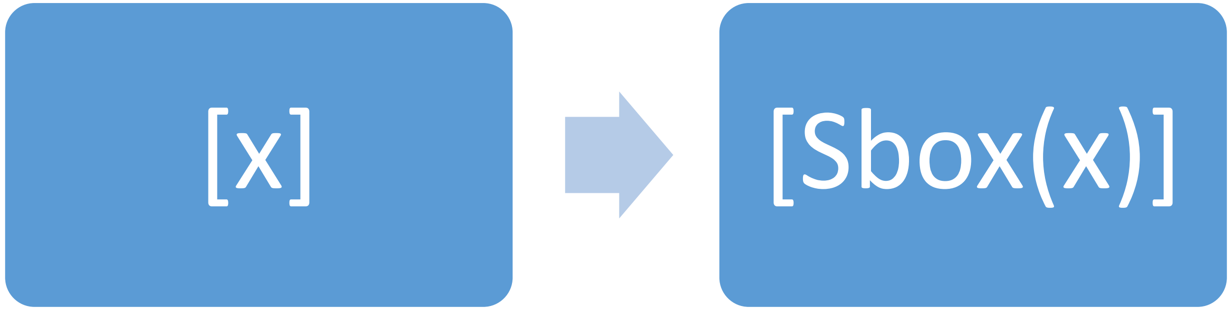
- [RR16] - AES latency around 15-20ms in 1GB/s LAN.
- Our AES-RP has 23ms over 1GB/s LAN network.

AES-128

10 rounds

16 Sbox([x]) → … → 16 Sbox([x])

How to Sbox – online



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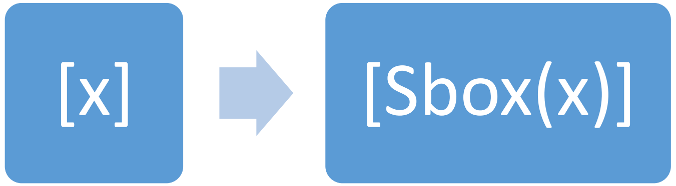

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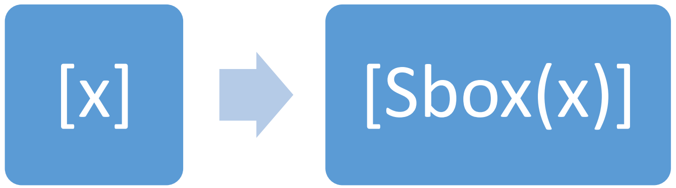
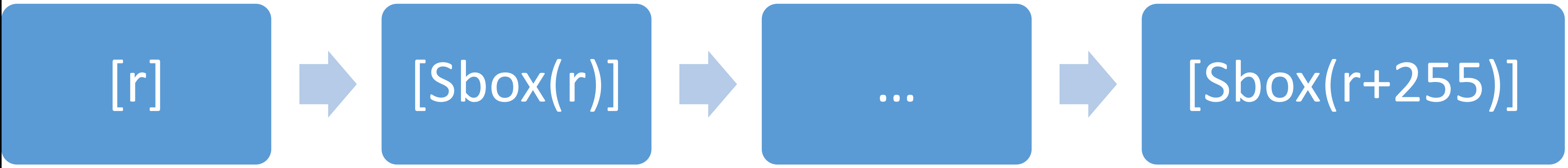




How to Sbox – online [x] → [Sbox(x)]

[r] → [Sbox(r)] → … → [Sbox(r+255)]

x+r → [Sbox(x)]

How to Sbox – online

[x] → [Sbox(x)]

[r] → [Sbox(r)] → … → [Sbox(r+255)]

x+r → [Sbox(x)]

At pos (x+r) => Sbox(r + x + r)

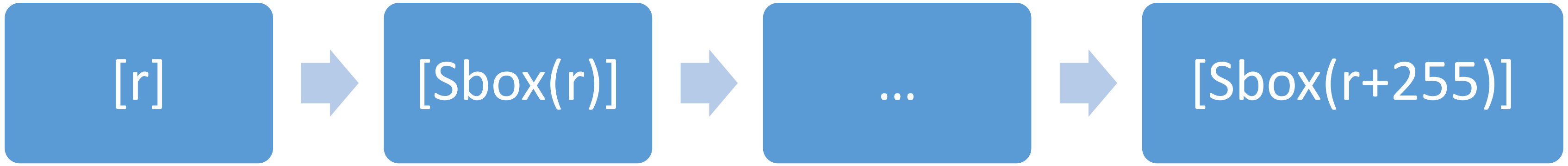
How to Sbox - preprocessing

[r] → [Sbox(r)] → … → [Sbox(r+255)]

Take random [r].

Compute [Sbox(r)], … [Sbox(r+255)]

How to Sbox - preprocessing



Take random [r].

Compute [Sbox(r)], … [Sbox(r+255)]

7 mults.

How to Sbox - preprocessing

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1792 mults.

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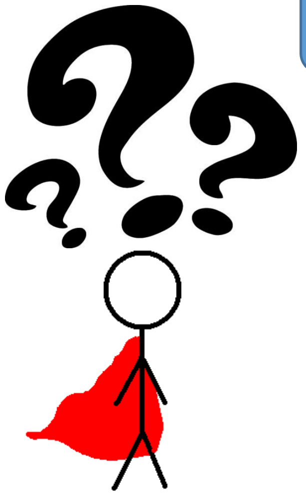

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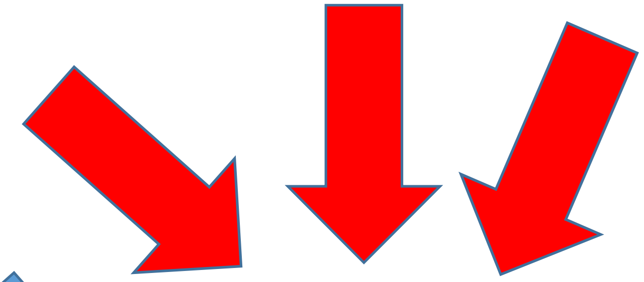

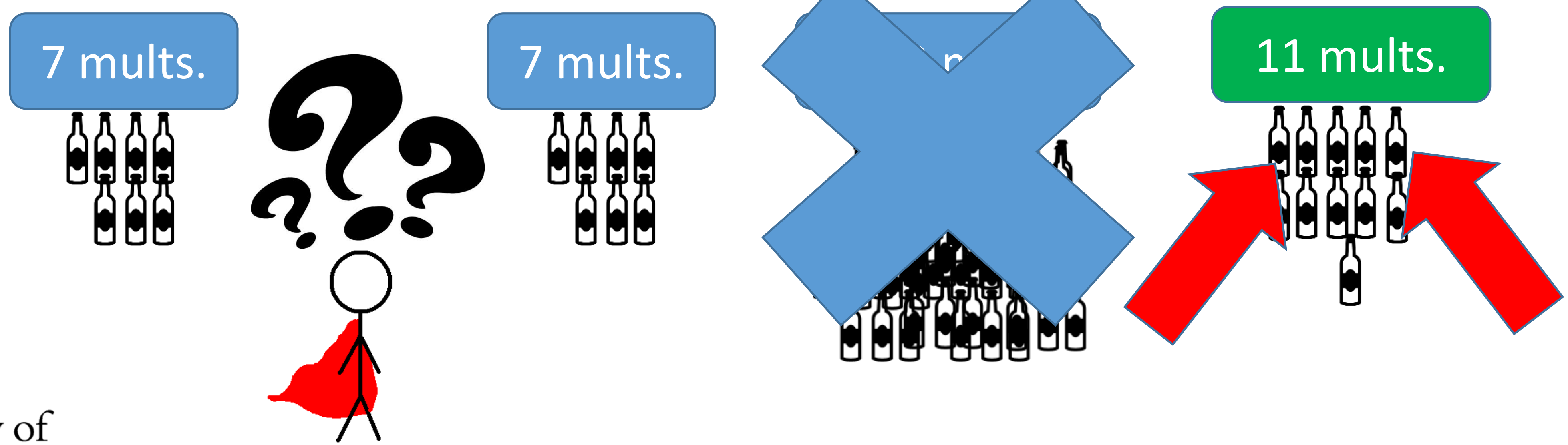

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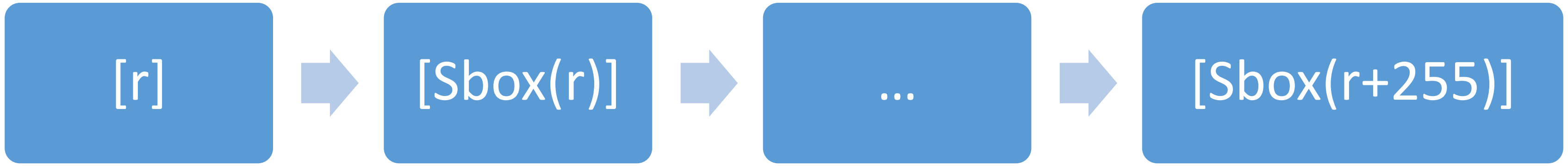

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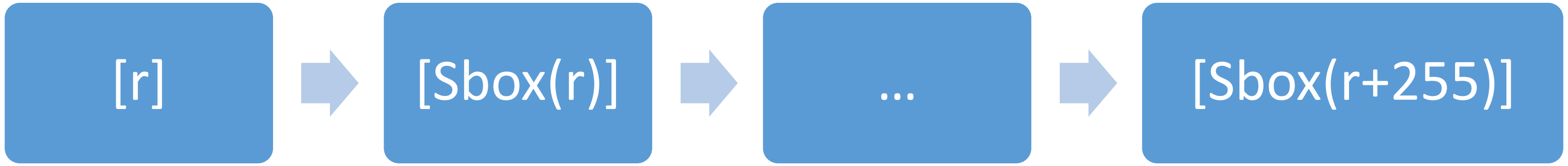
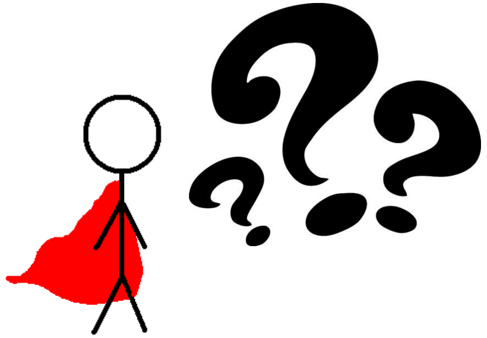


- Demultiplex on secret data with few multiplications.
- Multiplex Sbox is (almost) for free

How to Sbox - preprocessing

[r] → [Sbox(r)] → … → [Sbox(r+255)]

[2**r]



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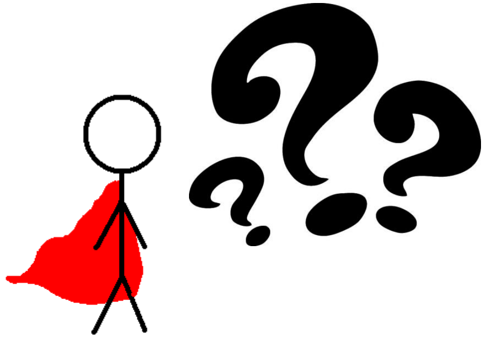

[r]   [1] → [0] → [1] → … → [1]

$$[X^r] = [2^r] \in GF(2^n)$$

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How to Sbox - preprocessing

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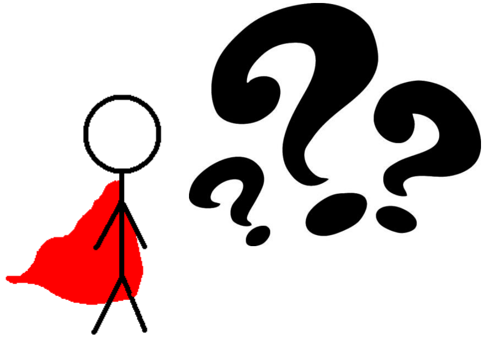

[r]

[1] → [0] → [1] → … → [1]

X^{2^0} → [1] → X^{2^2} → … → X^{2^7}

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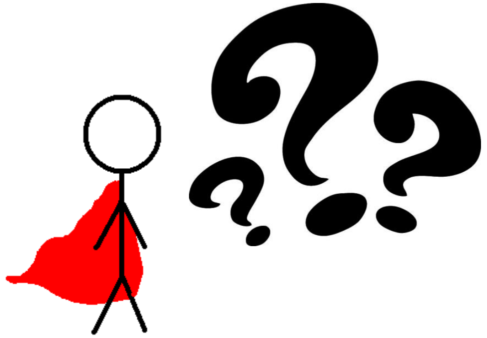


[r]

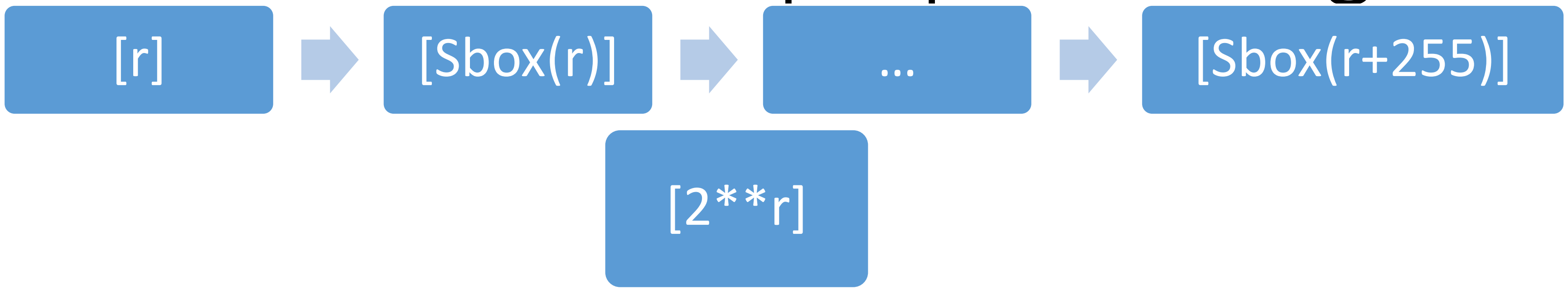
[1] → … → [1]

X^{2^0} → … → X^{2^7}

7 mults in $GF(2^{256})$

$[X\ ] = [2\ ] \in GF(2\ )$

How to Sbox - preprocessing



How to Sbox - preprocessing

[r] → [Sbox(r)] → … → [Sbox(r+255)]

[2**r]

[0] → … → [1] → … → [0]

How to Sbox - preprocessing

[r] → [Sbox(r)] → … → [Sbox(r+255)]

[2**r]

[0] → … → [1] → … → [0]

Sbox(0) → … → Sbox(r) → … → Sbox(255)

[Sbox(r)]

Mult. with public scalars is cheap

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How to Sbox - preprocessing

[r] → [Sbox(r)] → … → [Sbox(r+255)]

[2**r]

[0]	…	[1]	…	[0]
Sbox(1)	…	Sbox(r+1)	…	Sbox(0)

[Sbox(r)] [Sbox(r+1)] …

Mult. with public scalars is cheap

How to Sbox - preprocessing

[r] → [Sbox(r)] → … → [Sbox(r+255)]

[KOS16]

7 mults. in $GF(2^{256})$
850kB

How to Sbox - preprocessing

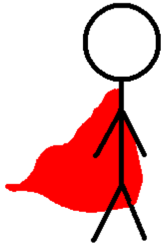
[r] → [Sbox(r)] → … → [Sbox(r+255)]

[KOS16]

7 mults. in $GF(2^{256})$
850kB

↓ View ops. as polys in $GF(2^k)$

11 mults. in $GF(2^{40})$
47kB

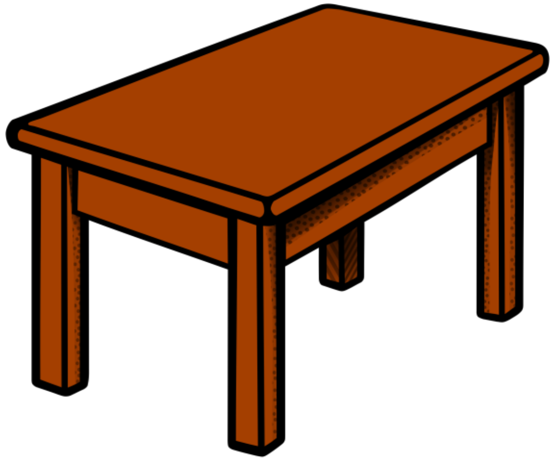


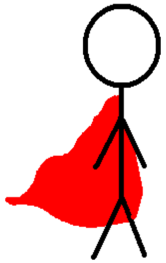
TL;DR

N	$k = 1$	8	40	64	128
64	62	9	5	5	5
128	126	17	7	6	6
256	254	33	11	8	7
512	510	65	18	12	9
1024	1022	129	31	20	13

Table 1. Number of $\mathbb{F}_2 \times \mathbb{F}_{2^k}$ multiplications for creating a masked lookup table of size N, for varying k.

So many choices…





Faster is…faster.

Protocol	Online		Comms.	Notes
	Latency (ms)	Throughput (/s)	(total)	
TinyTable (binary) [DNNR16]	4.18	24500	3.07 MB	
TinyTable (optim.) [DNNR16]	1.02	339000	786.4 MB	
Wang et al. [WRK17]	0.93	1075	2.57 MB	10 Gbps
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OP-LUT [DKS+17]	5	41670	0.103 MB	passive
SP-LUT [DKS+17]	6	2208	0.044 MB	passive
AES-LT	0.93	236200	8.4 MB	
AES-RP	7.19	940	2.9 MB	

Table 6. Performance comparison with other 2-PC protocols for evaluating AES in a LAN setting.

Faster is...faster.

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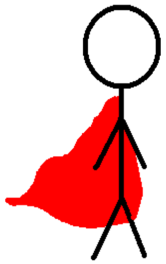
Thank you! #triples



LAN results.

Cipher	Online (single-thread)			Online (multi-thread)			Preprocessing[a]
	Latency (ms)	Batch size	ops/s	Batch size	ops/s	Threads	ops/s
AES-BD	5.20	64	758	1024	3164	16	30.7
AES-RP	7.19	1024	940	64	3872	16	**46.1**
AES-LT	**0.928**	1024	51654	512	**236191**	32	16.79
3DES-Raw	270	512	130	-	-	-	1.24
3DES-PV	36.98	512	86	512	366	32	**25.6**
3DES-LT	**4.254**	1024	10883	512	**45869**	16	15.3

Table 3. 1 Gbps LAN timings for evaluating AES and 3DES in MPC.

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#party #party #party