Rerandomizable Garbling, Revisited

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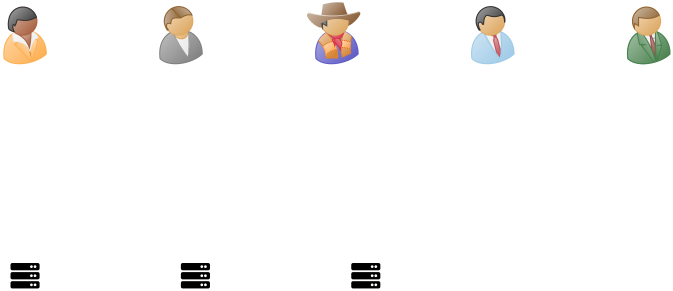

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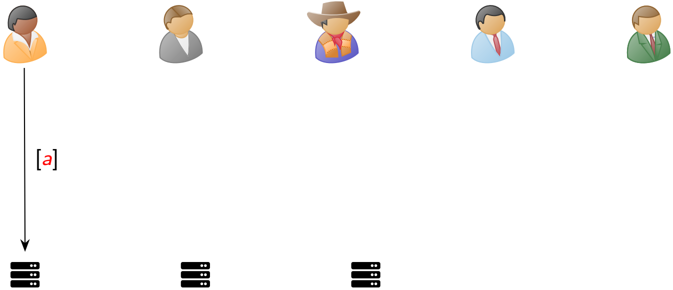

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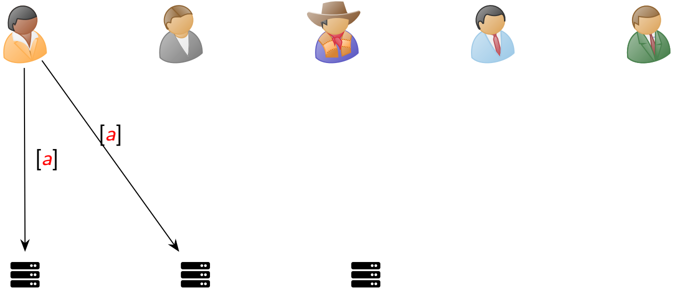

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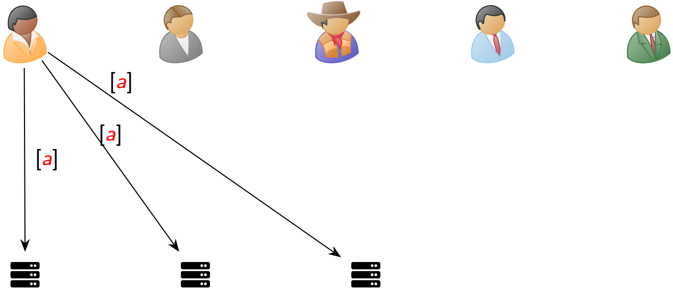

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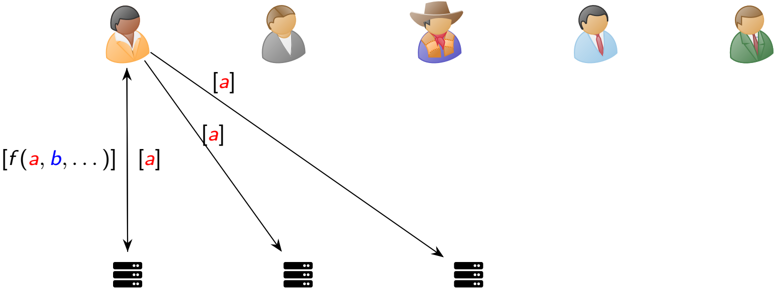

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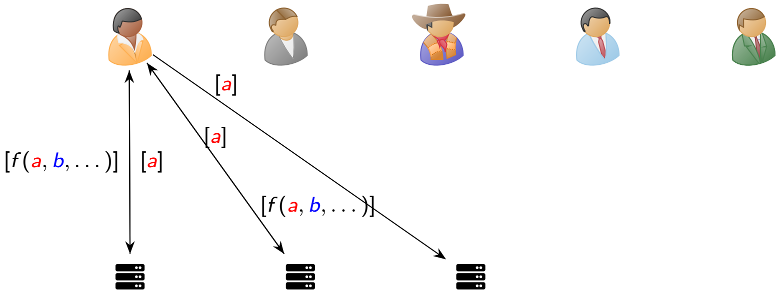

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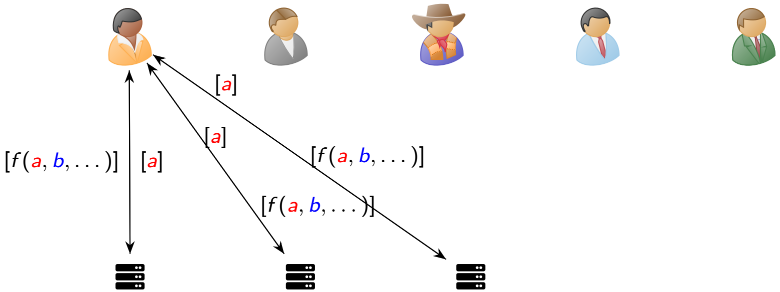

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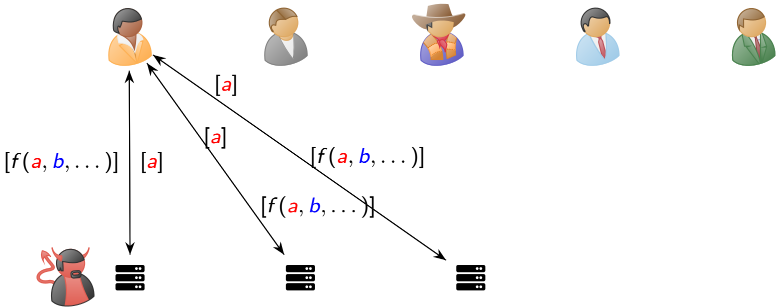

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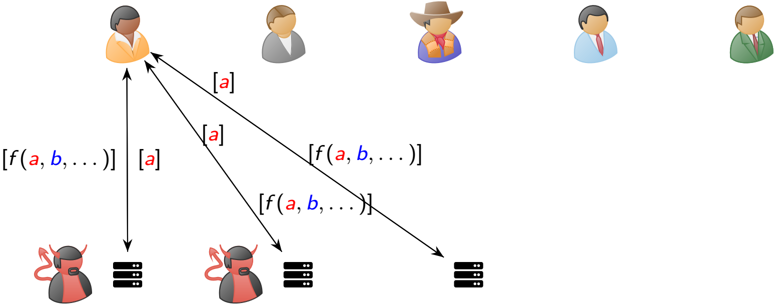

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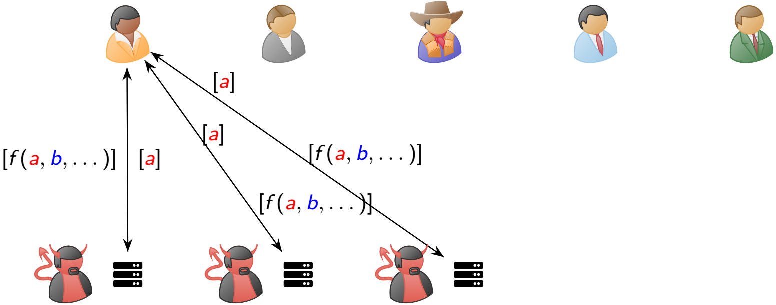

Outsourced MPC with Semi-Honest Security Against Adaptive Server Corruptions: State of the Art

Feature		**FHE-based** [MTBH21]	**Garbling-based** ("SCALES") [AHKP22]
Adaptive security	**Clients**	✗	✗
	Servers	Only one server required	✓
Constant-round		✓	✓
Corruption threshold t	**Clients**	$t < n$	$t < n$
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Table: Comparison of FHE- and garbling-based outsourced MPC with n clients and m servers.

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We improve this by 4 orders of magnitude!

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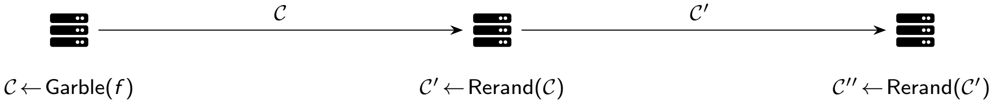

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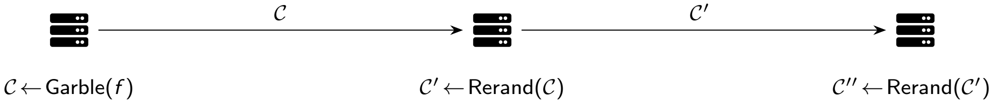

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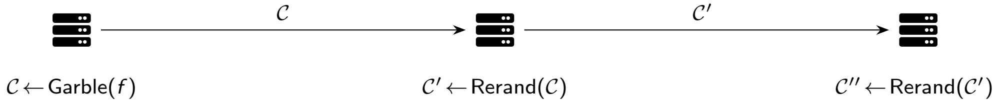

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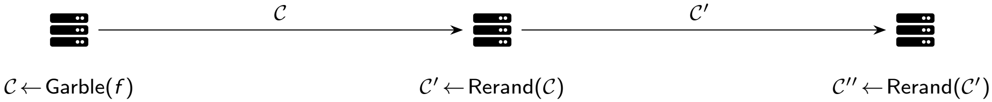

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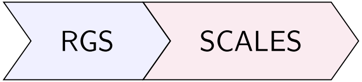

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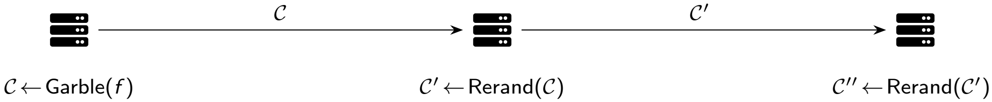

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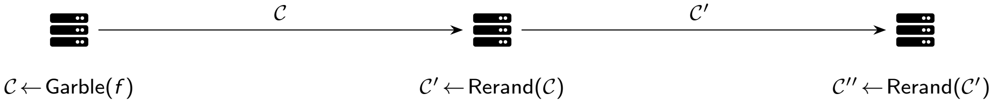

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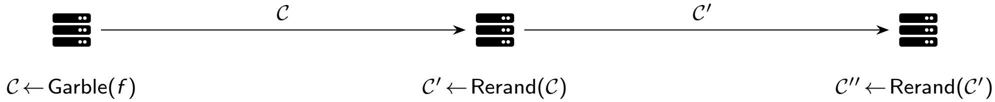

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Our Goal

Improve efficiency of the KMHE building block.

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- New Gate KMHE primitive allowing for randomness reuse across garbling table ciphertexts.

Performance Estimates for [AHKP22] and our RGS

Table: Comparison of the RGS from [AHKP22] and our work in bytes and clock cycles (cc).

	BHHO-based	Our work	Improvement
Size of one garbled gate	133.43 MB	1.35 MB	98.99 %
Size of one garbled Max circuit	125.87 GB	1.27 GB	98.99 %
Size of one garbled Mult circuit	1.74 TB	18.04 GB	98.99 %
Size of one garbled AES circuit	4.4 TB	45.60 GB	98.99 %
Garbling one gate (cc)	1.28×10^{14} (33 min)	2.44×10^{9} (0.04 s)	99.998 %
Garbling a Max circuit (cc)	1.24×10^{17} (22 d)	2.36×10^{12} (37 s)	99.998 %
Garbling a Mult circuit (cc)	1.75×10^{18} (317 d)	3.33×10^{13} (9 min)	99.998 %
Garbling an AES circuit (cc)	4.43×10^{18} (2 yr)	8.43×10^{13} (20 min)	99.998 %
Rerand. a garbled gate (cc)	5.13×10^{14} (2.23 h)	3.35×10^{9} (0.05 s)	99.9993 %
Rerand. a garbl. Max circuit (cc)	4.95×10^{17} (90 d)	3.24×10^{12} (51 s)	99.9993 %
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   - E.g. $(\mathbb{Z}_p, +)$ does not work: Key $\mathsf{k} \in \mathbb{Z}_p$ and $\sigma(\mathsf{k}) = \mathsf{k} + \sigma$ leak function σ.
3. Rerandomization indistinguishable from fresh ciphertext.

Encryption Algorithm of our KMHE (Simplified)

- Setup sets up the bilinear group $\mathsf{pp} = (q, g, h, g_T, \mathbb{G}, \mathbb{H}, \mathbb{G}_T, \mathsf{e})$ and $\mathsf{KGen}(\mathsf{pp})$ samples key $\mathsf{k} \leftarrow\$ \{0,1\}^\kappa$ with Hamming weight $\kappa/2$.

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From Quadratic to Linear Size Ciphertexts

The BHHO scheme needed to store every combination $g_i^{a_j}$ (κ^2 many) for decryption, using pairings we can supply the g_i and h^{a_j} separately and then compute their combinations on the fly.

Gate KMHE

Garbling requires some kind of encryption with two keys per ciphertext:

$$
\begin{aligned}
\mathsf{ct}_{00} &= \mathsf{Enc}(\mathsf{k}_0^{(A)}, \mathsf{k}_0^{(B)}, \mathsf{k}_{f(0,0)}) \\
&\vdots \qquad\qquad\qquad \vdots \\
\mathsf{ct}_{11} &= \mathsf{Enc}(\mathsf{k}_1^{(A)}, \mathsf{k}_1^{(B)}, \mathsf{k}_{f(1,1)})
\end{aligned}
$$

Figure: Garbled Table Example.

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Figure: Garbled Table Example.

Gate KMHE

Gate KMHE primitive encrypts entire garbled table in single operation, halves ciphertext size compared to secret-sharing approach from [AHKP22].

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Thank you!

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Gate KMHE

- Our (Simplified) KMHE is only a single-key scheme; garbling requires a double-key variant (e.g. [LP09])
- Double-key variant possible via secret-sharing (as in [AHKP22]) or direct construction (a bit more efficient)
- We introduce the Gate KMHE primitive which encrypts the entire garbled table in a single operation, even more efficient

$$\mathsf{ct}_{00} = \mathsf{Enc}(\mathsf{k}_0^{(A)}, \mathsf{k}_0^{(B)}, \mathsf{k}_{f(0,0)})$$

$$\vdots \qquad\qquad \vdots$$

$$\mathsf{ct}_{11} = \mathsf{Enc}(\mathsf{k}_1^{(A)}, \mathsf{k}_1^{(B)}, \mathsf{k}_{f(1,1)})$$

Approach	Size of Garbled Table
Secret-sharing	$8\kappa\ \mathbb{G}, 8\kappa\ \mathbb{H}, 8(\kappa+1)\ \mathbb{G}_T$
Direct double-key	$8\kappa\ \mathbb{G}, 4\kappa\ \mathbb{H}, 4(\kappa+1)\ \mathbb{G}_T$
Gate KMHE	$2\kappa\ \mathbb{G}, 4\kappa\ \mathbb{H}, 4(\kappa+1)\ \mathbb{G}_T$