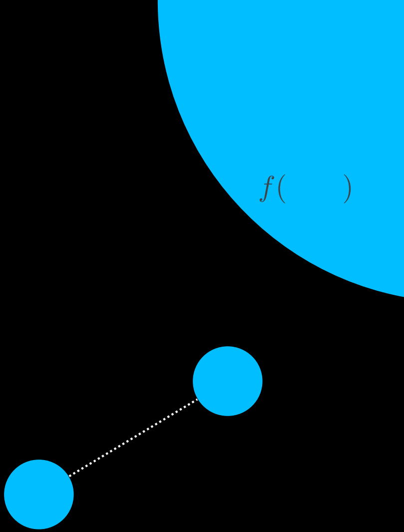
University of Stuttgart
Germany

Marc Rivinius

MPC with Publicly Identifiable Abort from Pseudorandomness and Homomorphic Encryption

Multiparty Computation

- Multiple parties want to compute a function



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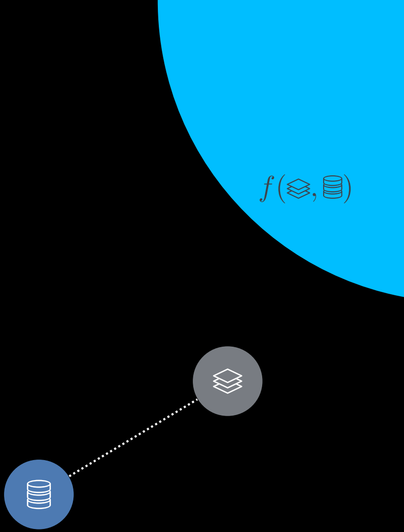

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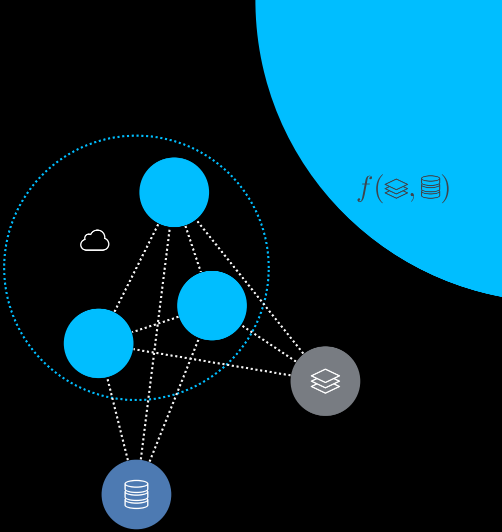

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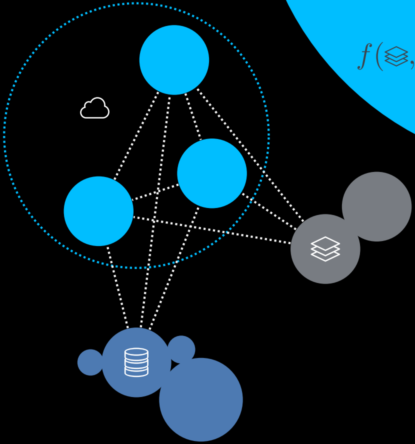
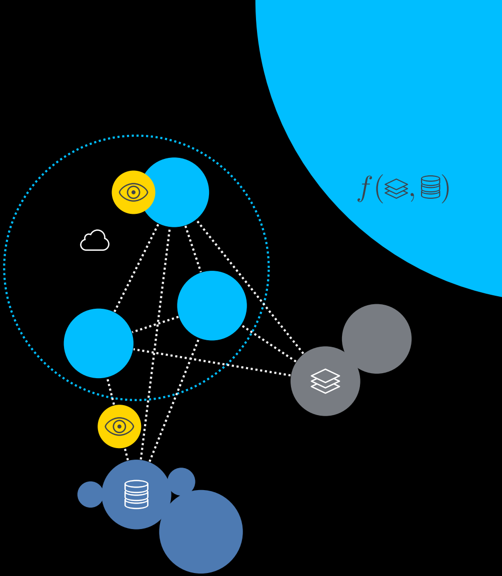


$f(\,\cdot\,,\,\cdot\,)$

Multiparty Computation

- Multiple parties want to compute a function
- Adversaries
  - semi-honest



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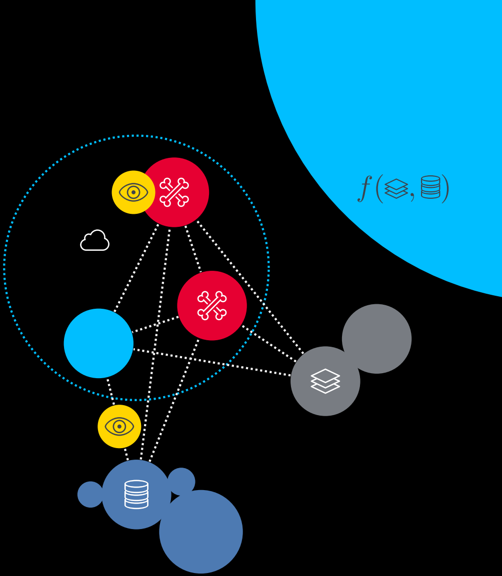

Multiparty Computation

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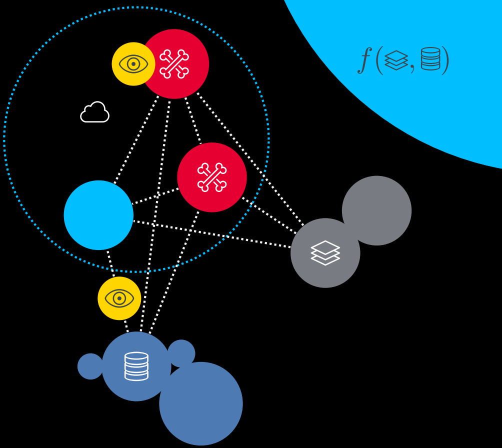

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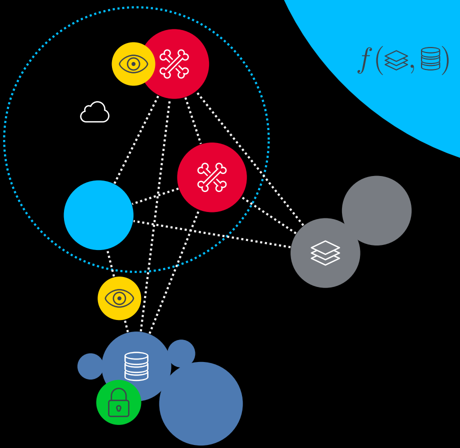

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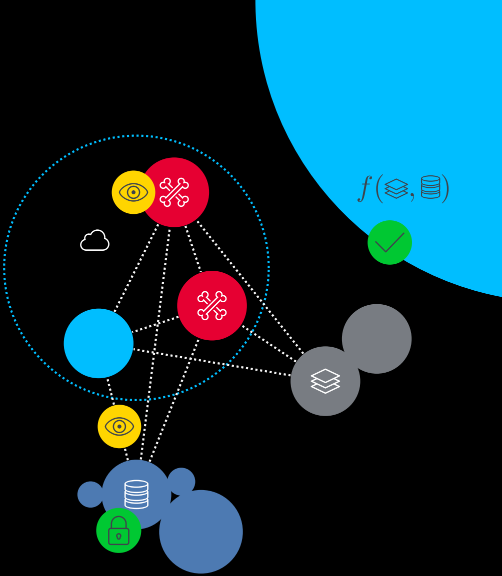

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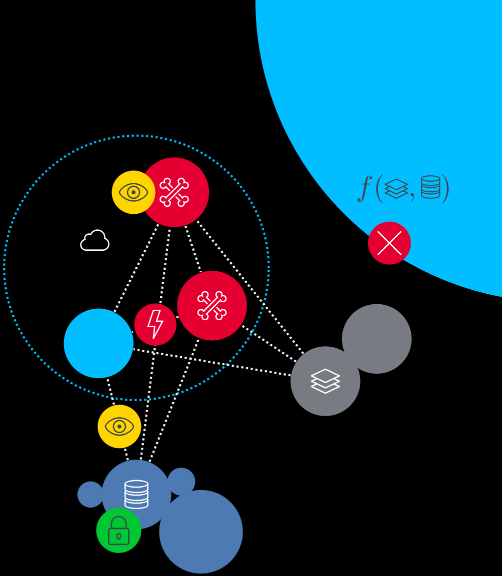

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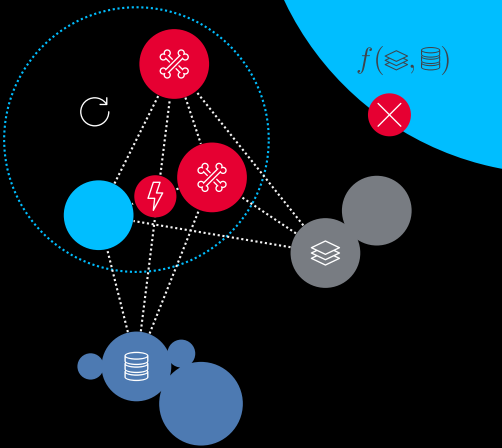

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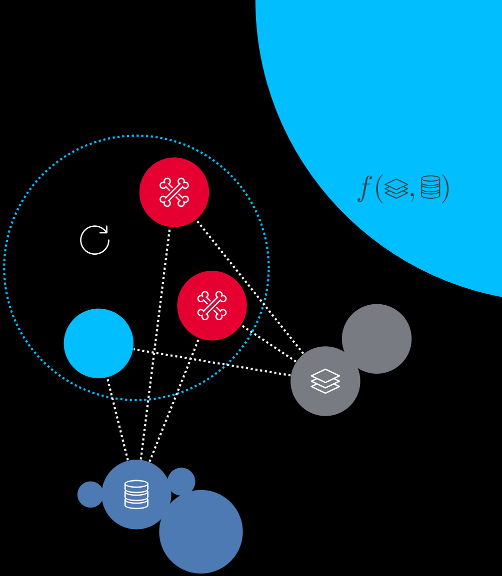

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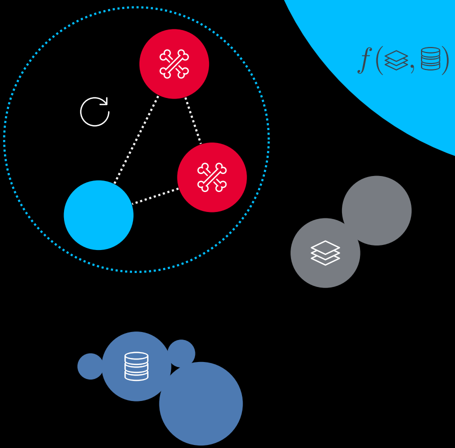

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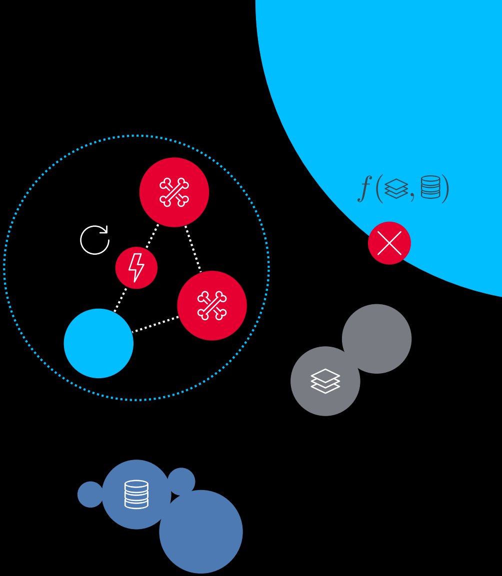

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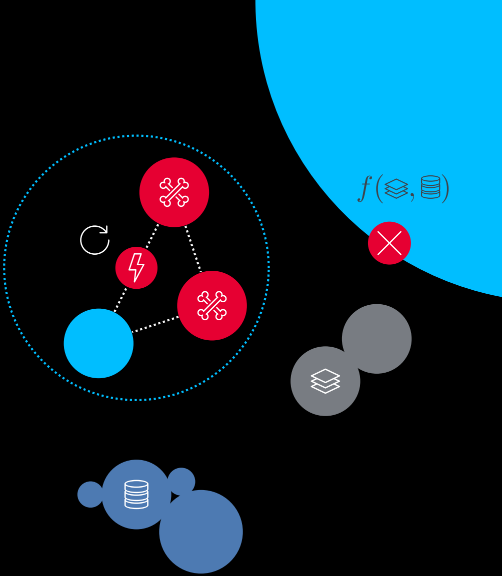

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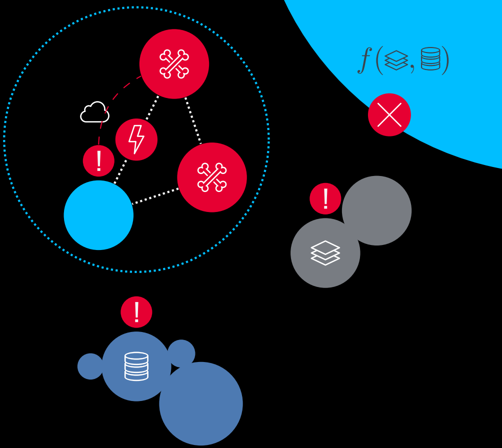

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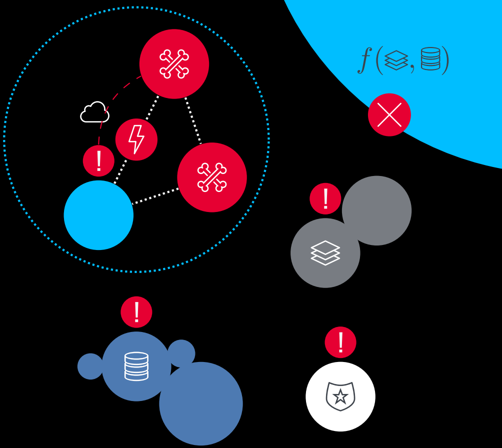
    → **publicly identifiable abort**

    everyone agrees on audit

    {: ok, : !, : ok}



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    $[x+y]_i = [x]_i + [y]_i$

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  $\rightarrow$ faster computation of the function in the **online phase**

Identifiable Abort MPC

- Make values verifiable, e.g., with MACs [DPSZ12]

$$\sum_{i=0}^{n-1} [x]_i = x \mapsto \begin{cases} \mathtt{ok} \\ ! \end{cases}$$

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- Verification at share-level [BOS16; CFY17; CDKS24; BMRS24]

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  - inputs, outputs, multiplications, ...

Identifiable Abort Techniques

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→ our work: global (non-pairwise) MACs

→ combines advantages of both methods

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$$\mathsf{MAC}(\alpha, \mathsf{fk}, [x]_i, \mathsf{ctx}) \ := \ \alpha \cdot [x]_i + \mathsf{PRF}(\mathsf{fk}, \mathsf{ctx})$$

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MAC key

share

PRF key

context, e.g., `counter++`

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$$\mathsf{MACCheck}(\alpha, \mathsf{fk}, [x]_i, \tau, \mathsf{ctx}) \;:=\; \begin{cases} \mathtt{ok} & \text{if } \tau = \mathsf{MAC}(\alpha, \mathsf{fk}, [x]_i, \mathsf{ctx}) \\ ! & \text{otherwise} \end{cases}$$

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→ equivalent to the MAC of [CF13] and similar to what is used in [BMRS24]

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$$\Sigma$$

$$[\alpha]_0 \cdot [x]_i + \mathsf{PRF}(\mathsf{fk}_0, \mathsf{ctx}) \quad + \quad \ldots \quad + \quad [\alpha]_j \cdot [x]_i + \mathsf{PRF}(\mathsf{fk}_j, \mathsf{ctx}) \quad + \quad \ldots$$

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computed by P_0

computed by P_j

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$$[\alpha]_j \cdot \mathsf{Enc}(\mathsf{pk}_i, [x]_i) + \mathsf{EncDrown}(\mathsf{pk}_i, \mathsf{PRF}(\mathsf{fk}_j, \mathsf{ctx}))$$

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encrypted by P_i encrypted by P_j

Verification

$$\alpha \cdot [x]_i + \mathsf{PRF}(\mathsf{fk}, \mathsf{ctx})$$

$$\Sigma$$

$$\ldots \quad + \quad [\alpha]_j \cdot [x]_i + \mathsf{PRF}(\mathsf{fk}_j, \mathsf{ctx}) \quad + \quad \ldots$$

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Verification

- MAC check only requires

$$\begin{gathered}
\alpha \cdot [x]_i + \mathsf{PRF}(\mathsf{fk}, \mathsf{ctx}) \\
\Big\uparrow \Sigma \\
\ldots \quad + \quad [\alpha]_j \cdot [x]_i + \mathsf{PRF}(\mathsf{fk}_j, \mathsf{ctx}) \quad + \quad \ldots \\
\Big\uparrow \mathsf{Dec} \\
[\alpha]_j \cdot \mathsf{Enc}(\mathsf{pk}_i, [x]_i) + \mathsf{EncDrown}(\mathsf{pk}_i, \mathsf{PRF}(\mathsf{fk}_j, \mathsf{ctx}))
\end{gathered}$$

Verification

- MAC check only requires
  - MAC key α

$$\alpha \cdot [x]_i + \mathsf{PRF}(\mathsf{fk}, \mathsf{ctx})$$

$$\Big\uparrow \Sigma$$

$$\ldots \quad + \quad [\alpha]_j \cdot [x]_i + \mathsf{PRF}(\mathsf{fk}_j, \mathsf{ctx}) \quad + \quad \ldots$$

$$\Big\uparrow \mathsf{Dec}$$

$$[\alpha]_j \cdot \mathsf{Enc}(\mathsf{pk}_i, [x]_i) + \mathsf{EncDrown}(\mathsf{pk}_i, \mathsf{PRF}(\mathsf{fk}_j, \mathsf{ctx}))$$

Verification

- MAC check only requires
  - MAC key α
  - PRF key fk

$$
\begin{tikzcd}
\alpha \cdot [x]_i + \mathsf{PRF}(\mathsf{fk}, \mathsf{ctx}) \\
\ldots \quad + \quad [\alpha]_j \cdot [x]_i + \mathsf{PRF}(\mathsf{fk}_j, \mathsf{ctx}) \quad + \quad \ldots \arrow[u, "\Sigma"] \\
[\alpha]_j \cdot \mathsf{Enc}(\mathsf{pk}_i, [x]_i) + \mathsf{EncDrown}(\mathsf{pk}_i, \mathsf{PRF}(\mathsf{fk}_j, \mathsf{ctx})) \arrow[u, "\mathsf{Dec}"]
\end{tikzcd}
$$

Verification

- MAC check only requires
  - MAC key α
  - PRF key fk
- MAC tag generation requires

$$\begin{tikzcd}
\alpha \cdot [x]_i + \mathsf{PRF}(\mathsf{fk}, \mathsf{ctx}) \\
\ldots \quad + \quad [\alpha]_j \cdot [x]_i + \mathsf{PRF}(\mathsf{fk}_j, \mathsf{ctx}) \quad + \quad \ldots \arrow[u, "\Sigma"] \\
[\alpha]_j \cdot \mathsf{Enc}(\mathsf{pk}_i, [x]_i) + \mathsf{EncDrown}(\mathsf{pk}_i, \mathsf{PRF}(\mathsf{fk}_j, \mathsf{ctx})) \arrow[u, "\mathsf{Dec}"]
\end{tikzcd}$$

Verification

- MAC check only requires
  - MAC key α
  - PRF key fk
- MAC tag generation requires
  - MAC key share $[\alpha]_j$

$$\alpha \cdot [x]_i + \mathsf{PRF}(\mathsf{fk}, \mathsf{ctx})$$

$$\uparrow \Sigma$$

$$\ldots \quad + \quad [\alpha]_j \cdot [x]_i + \mathsf{PRF}(\mathsf{fk}_j, \mathsf{ctx}) \quad + \quad \ldots$$

$$\uparrow \mathsf{Dec}$$

$$[\alpha]_j \cdot \mathsf{Enc}(\mathsf{pk}_i, [x]_i) + \mathsf{EncDrown}(\mathsf{pk}_i, \mathsf{PRF}(\mathsf{fk}_j, \mathsf{ctx}))$$

Verification

- MAC check only requires
  - MAC key α
  - PRF key fk
- MAC tag generation requires
  - MAC key share $[\alpha]_j$
  - partial PRF key fk_j

$$\alpha \cdot [x]_i + \mathsf{PRF}(\mathsf{fk}, \mathsf{ctx})$$

$$\ldots \quad + \quad [\alpha]_j \cdot [x]_i + \mathsf{PRF}(\mathsf{fk}_j, \mathsf{ctx}) \quad + \quad \ldots$$

$$[\alpha]_j \cdot \mathsf{Enc}(\mathsf{pk}_i, [x]_i) + \mathsf{EncDrown}(\mathsf{pk}_i, \mathsf{PRF}(\mathsf{fk}_j, \mathsf{ctx}))$$

Verification

- MAC check only requires
  - MAC key α
  - PRF key fk
- MAC tag generation requires
  - MAC key share $[\alpha]_j$
  - partial PRF key fk_j
  - encryption randomness that hides $[\alpha]_j$ and fk_j

$$\alpha \cdot [x]_i + \mathsf{PRF}(\mathsf{fk}, \mathsf{ctx})$$

$$\Sigma$$

$$\ldots \quad + \quad [\alpha]_j \cdot [x]_i + \mathsf{PRF}(\mathsf{fk}_j, \mathsf{ctx}) \quad + \quad \ldots$$

$$\mathsf{Dec}$$

$$[\alpha]_j \cdot \mathsf{Enc}(\mathsf{pk}_i, [x]_i) + \mathsf{EncDrown}(\mathsf{pk}_i, \mathsf{PRF}(\mathsf{fk}_j, \mathsf{ctx}))$$

Verification

- MAC check only requires
  - MAC key α
  - PRF key fk
- MAC tag generation requires
  - MAC key share $[\alpha]_j$
  - partial PRF key fk_j
  - encryption randomness that hides $[\alpha]_j$ and fk_j

→ Verification only requires **3 field elements*** per party for any number of tags

$$\alpha \cdot [x]_i + \mathsf{PRF}(\mathsf{fk}, \mathsf{ctx})$$

$$\Big\uparrow \Sigma$$

$$\dots \quad + \quad [\alpha]_j \cdot [x]_i + \mathsf{PRF}(\mathsf{fk}_j, \mathsf{ctx}) \quad + \quad \dots$$

$$\Big\uparrow \mathsf{Dec}$$

$$[\alpha]_j \cdot \mathsf{Enc}(\mathsf{pk}_i, [x]_i) + \mathsf{EncDrown}(\mathsf{pk}_i, \mathsf{PRF}(\mathsf{fk}_j, \mathsf{ctx}))$$

*plus other information to decommit commitments

Protocol Overview

Setup

Protocol Overview

Setup

Offline phase

Protocol Overview

Generate tags with α

Setup

Offline phase

Protocol Overview

Generate tags with α

Setup

Offline phase

Online phase

Protocol Overview

Setup	Offline phase	Online phase
	Generate tags with α	Publish tagged values

Protocol Overview

Publish α, fk

Setup	Offline phase	Online phase
	Generate tags with α	Publish tagged values

Protocol Overview

Publish α, fk

Setup	Offline phase	Online phase	Verify offline phase
	Generate tags with α	Publish tagged values	

Protocol Overview

Publish α, fk

Generate tags with α

Publish tagged values

$c \stackrel{?}{=} [\alpha]_j \cdot \mathsf{Enc}([x]_i) + \mathsf{EncDrown}(\mathsf{PRF}(\mathsf{fk}_j))$

Setup

Offline phase

Online phase

Verify offline phase

Protocol Overview

Publish α, fk

Generate tags with α

Publish tagged values

$$c \stackrel{?}{=} [\alpha]_j \cdot \mathsf{Enc}([x]_i) + \mathsf{EncDrown}(\mathsf{PRF}(\mathsf{fk}_j))$$

Setup

Offline phase

Online phase

Verify offline phase

Verify online phase

Protocol Overview

Publish α, fk

Generate tags with α

Publish tagged values

$\tau \stackrel{?}{=} \alpha \cdot [x]_i + \mathrm{PRF}(\mathrm{fk})$

Setup

Offline phase

Online phase

Verify offline phase

Verify online phase

Protocol Overview

Publish α, fk

Generate tags with α

Publish tagged values

$\tau \stackrel{?}{=} \alpha \cdot [x]_i + \mathsf{PRF}(\mathsf{fk})$

Setup

Offline phase

Online phase

Verify offline phase

Verify online phase

Output phase

Protocol Overview

Publish α, fk

Generate tags with α

Publish tagged values

Publish tagged output

Setup

Offline phase

Online phase

Verify offline phase

Verify online phase

Output phase

Protocol Overview

Publish α, fk

Generate output tags with ω

Generate tags with α

Publish tagged values

Publish tagged output

Setup

Offline phase

Online phase

Verify offline phase

Verify online phase

Output phase

Protocol Overview

Publish α, fk

Publish ω, fk$'$

Generate output tags with ω

Generate tags with α

Publish tagged values

Publish tagged output

Setup

Offline phase

Online phase

Verify offline phase

Verify online phase

Output phase

Protocol Overview

Publish α, fk

Publish ω, fk$'$

Generate output tags with ω

Generate tags with α

Publish tagged values

Publish tagged output

Setup

Offline phase

Online phase

Verify offline phase

Verify online phase

Output phase

Verify offline phase

Protocol Overview

Publish α, fk

Publish ω, fk$'$

Generate output tags with ω

$c \stackrel{?}{=} [\omega]_j \cdot \mathsf{Enc}([x]_i) + \mathsf{EncDrown}(\mathsf{PRF}(\mathsf{fk}'_j))$

Generate tags with α

Publish tagged values

Publish tagged output

Setup

Offline phase

Online phase

Verify offline phase

Verify online phase

Output phase

Verify offline phase

Protocol Overview

Publish α, fk

Publish ω, fk$'$

Generate output tags with ω

$$c \stackrel{?}{=} [\omega]_j \cdot \mathsf{Enc}([x]_i) + \mathsf{EncDrown}(\mathsf{PRF}(\mathsf{fk}'_j))$$

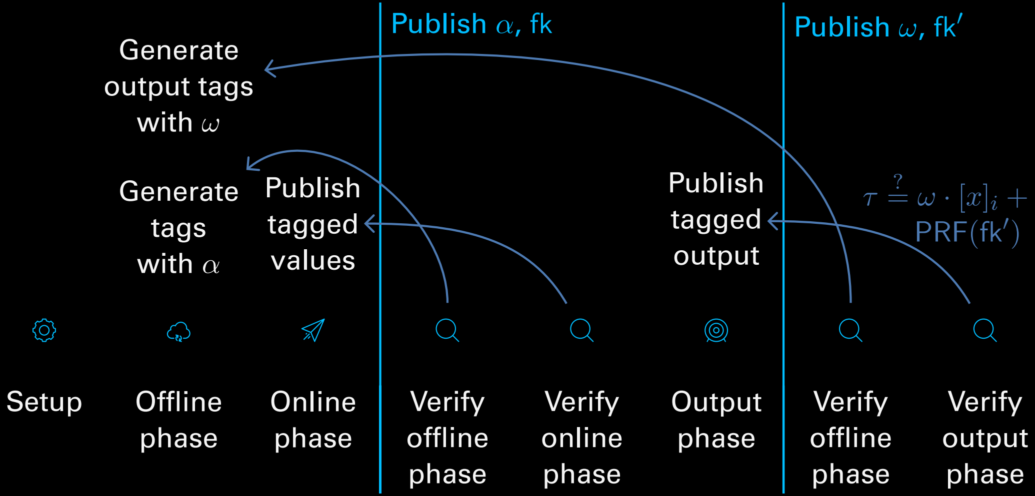
Generate tags with α

Publish tagged values

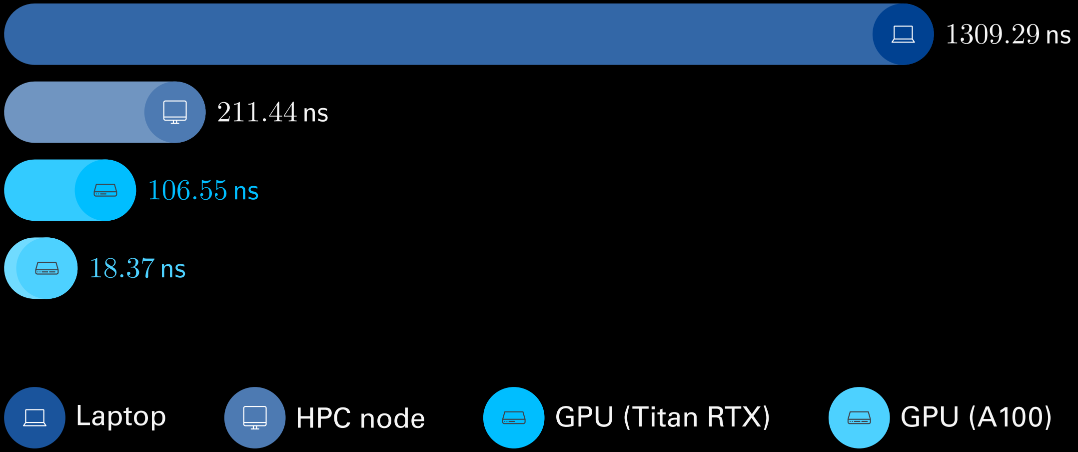
Publish tagged output

Setup | Offline phase | Online phase | Verify offline phase | Verify online phase | Output phase | Verify offline phase | Verify output phase

Protocol Overview



Evaluation: Homomorphic Encryption Verification

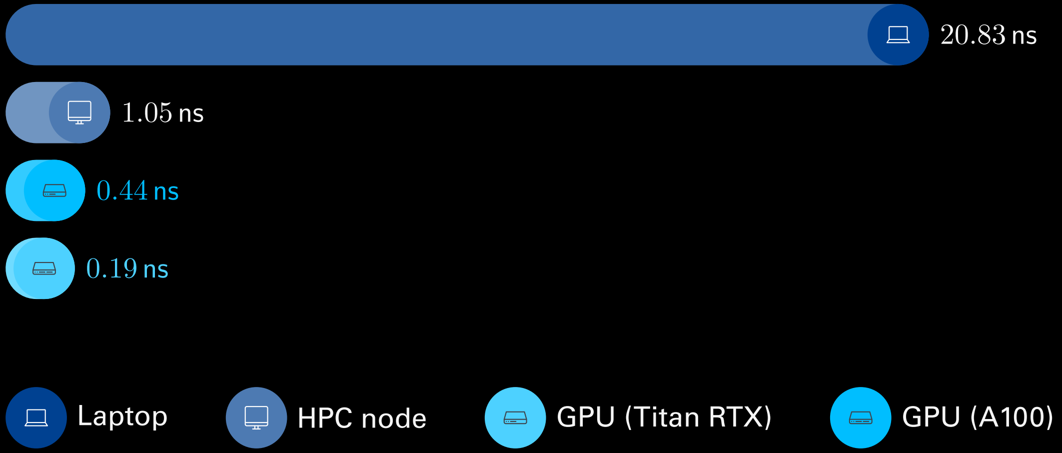


Evaluation: MAC Verification

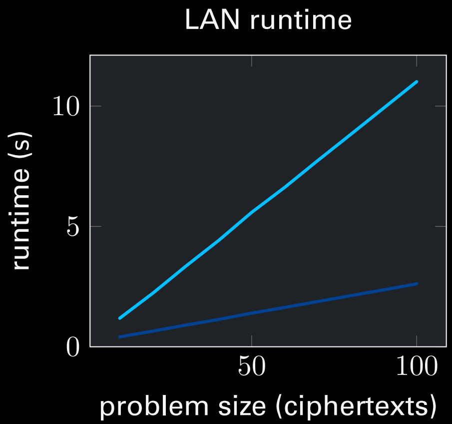
- 20.83 ns
- 1.05 ns
- 0.44 ns
- 0.19 ns

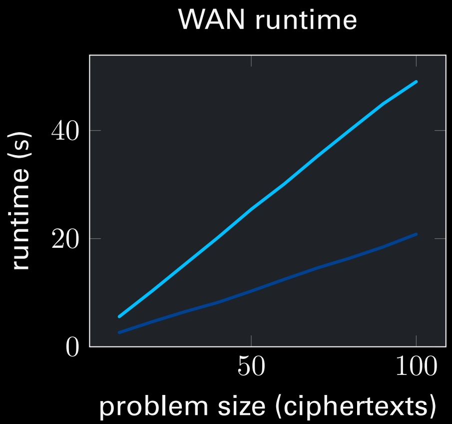
Laptop | HPC node | GPU (Titan RTX) | GPU (A100)

Evaluation: MAC Verification



Evaluation: Multiplication (Online)

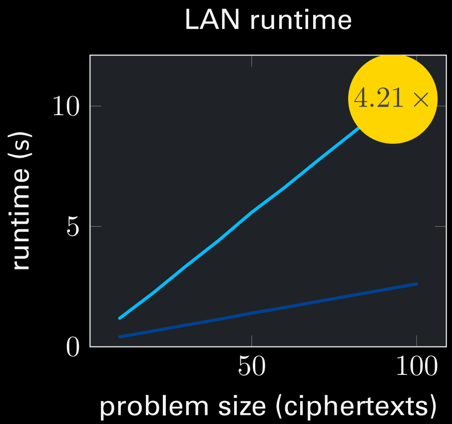


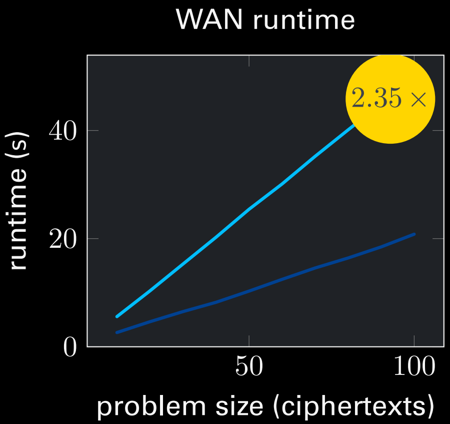


SPDZ (server)

Ours (server)

Evaluation: Multiplication (Online)



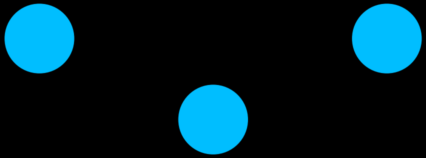


SPDZ (server)

Ours (server)

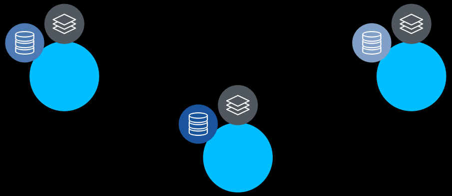
Use-Case: Federated Learning with Secure Aggregation

- Parties want to **train** an ML model



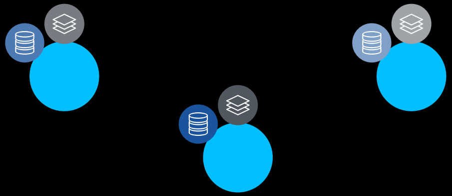
Use-Case: Federated Learning with Secure Aggregation

- Parties want to **train** an ML model
  - on private data
  - sharing the same model



Use-Case: Federated Learning with Secure Aggregation

- Parties want to **train** an ML model
  - on private data
  - sharing the same model
- Parties train model with local data



Use-Case: Federated Learning with Secure Aggregation

- Parties want to **train** an ML model
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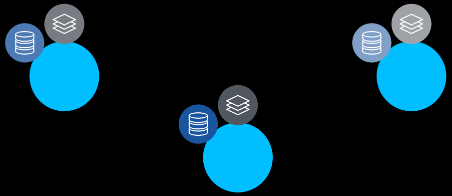
  - sharing the same model
- Parties train model with local data
- Aggregate model (gradients) securely



Use-Case: Federated Learning with Secure Aggregation

- Parties want to **train** an ML model
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- Parties train model with local data
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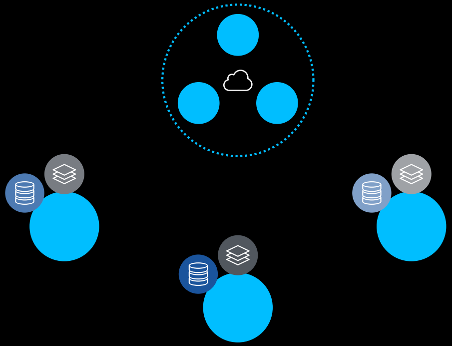
  - e.g., via MPC servers



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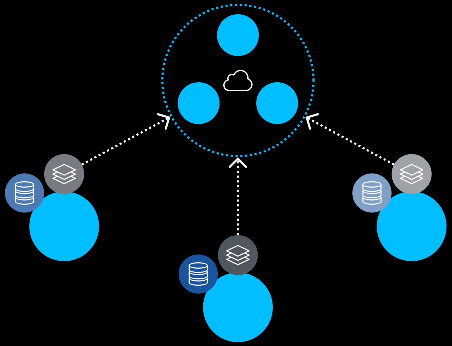

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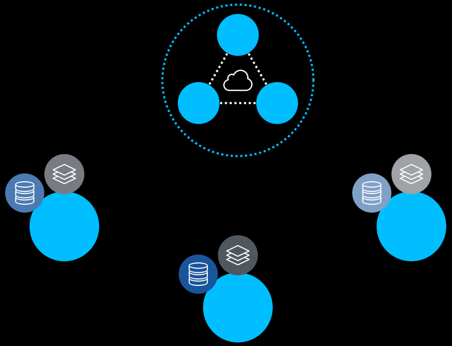

Use-Case: Federated Learning with Secure Aggregation

- Parties want to **train** an ML model
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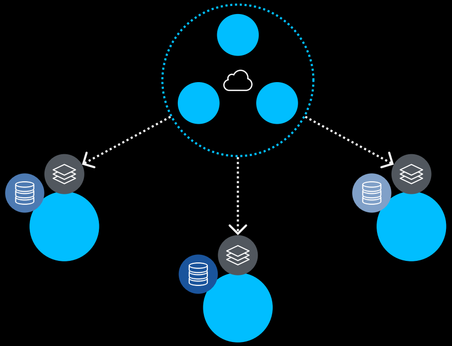
  - sharing the same model
- Parties train model with local data
- Aggregate model (gradients) securely
  - e.g., via MPC servers
- Obtain updated model



Use-Case: Federated Learning with Secure Aggregation

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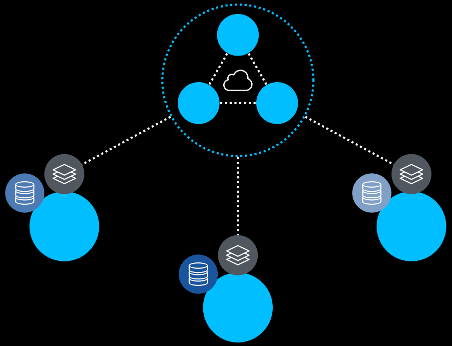
  - e.g., via MPC servers
- Obtain updated model

Repeat



Use-Case: Federated Learning with Secure Aggregation

- Parties want to **train** an ML model
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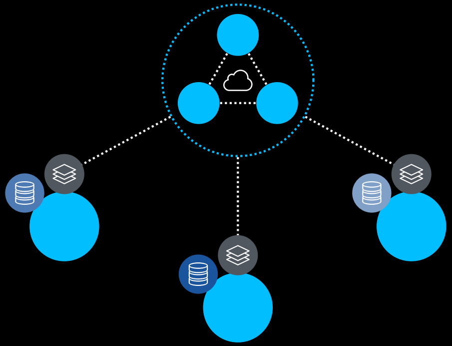
  - e.g., via MPC servers
- Obtain updated model

⟳ Repeat

→ **publicly identifiable abort** for clients



Use-Case: Federated Learning with Secure Aggregation

- Parties want to **train** an ML model
  - on private data
  - sharing the same model
- Parties train model with local data
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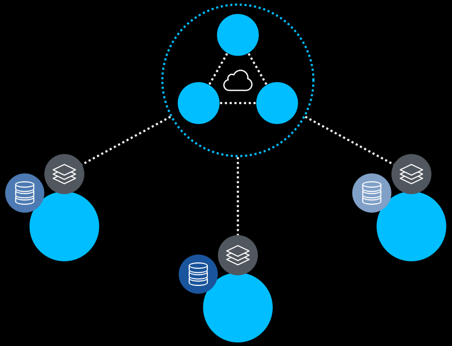
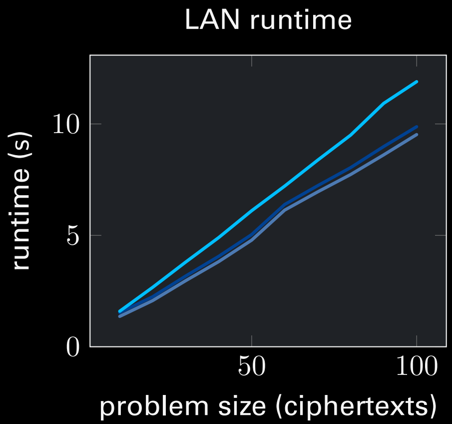
  - e.g., via MPC servers
- Obtain updated model
- Repeat

→ **publicly identifiable abort** for clients

→ **more efficient client I/O** protocols

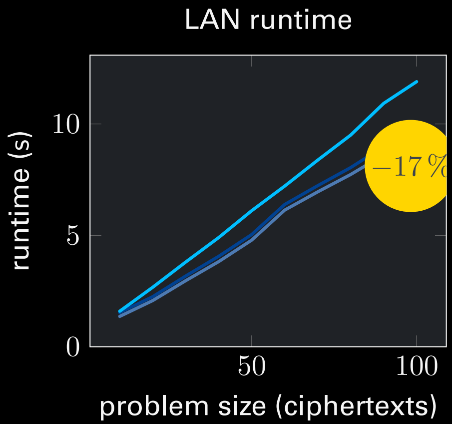


Evaluation: Secure Aggregation (Online)



SPDZ (server) SPDZ (client) Ours (client / server)

Evaluation: Secure Aggregation (Online)

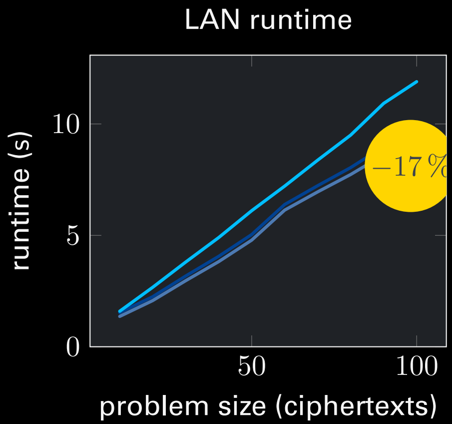


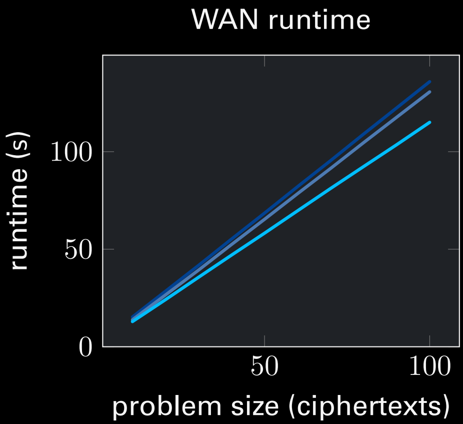
SPDZ (server)

SPDZ (client)

Ours (client / server)

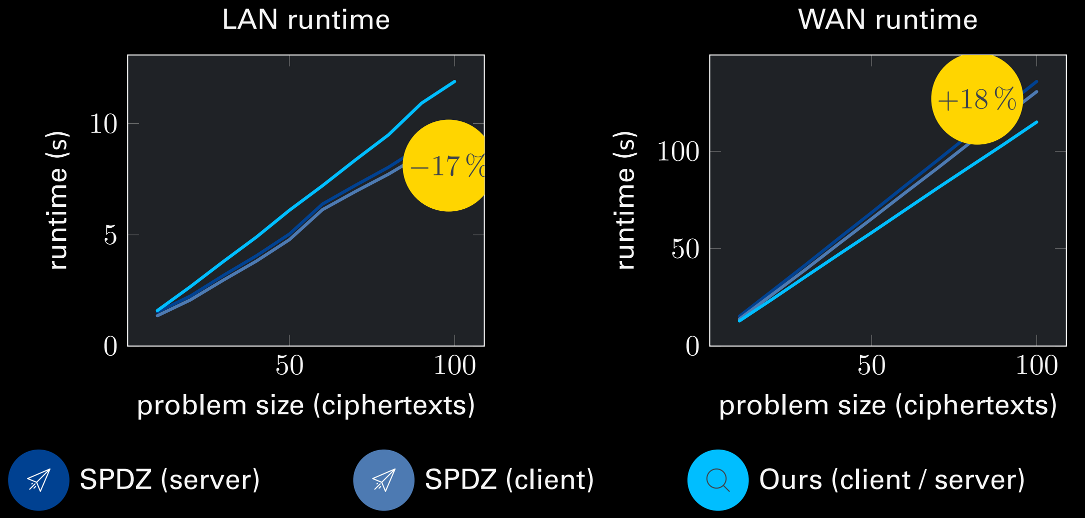
Evaluation: Secure Aggregation (Online)



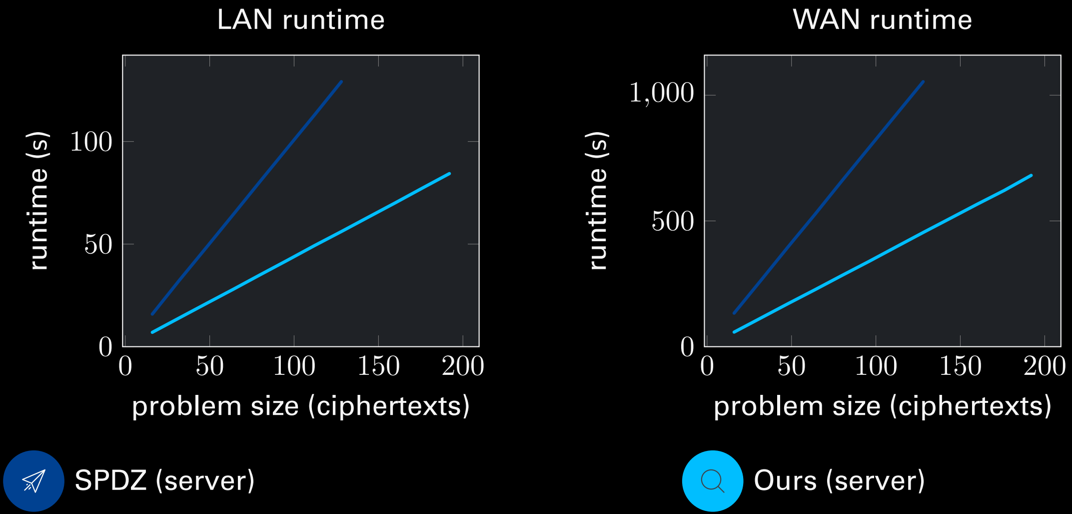


SPDZ (server) SPDZ (client) Ours (client / server)

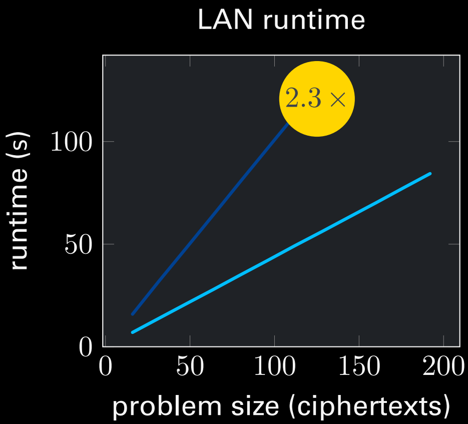
Evaluation: Secure Aggregation (Online)

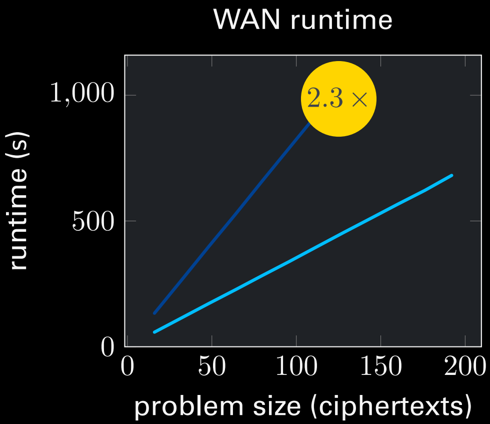


Evaluation: Secure Aggregation (Offline)



Evaluation: Secure Aggregation (Offline)





SPDZ (server)

Ours (server)

Conclusion

- First MPC protocol using global MACs for individual shares

Conclusion

- First MPC protocol using global MACs for individual shares
  - **publicly identifiable abort**

Conclusion

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  - **publicly identifiable abort**
  - **client-server** computations

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Conclusion

- First MPC protocol using global MACs for individual shares
  - **publicly identifiable abort**
  - **client-server** computations
- **Same complexity** as HE-based SPDZ
- **Low concrete overhead** compared to SPDZ
- Efficient input/output for **outsourced computation**

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[Icons] from 1001FreeDownloads.com

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Thank you!

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Institute of Information Security (SEC)

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Paper eprint.iacr.org/2025/258
Code github.com/sec-stuttgart/pia-mpc

Appendix: Online Phase

- Linear operations: directly on shares and tags
- Multiplication of x and y using triple (a, b, c)
  - Open $[\![u]\!] = [\![x - a]\!]$ and $[\![v]\!] = [\![y - b]\!]$
  - Use $[\![x \cdot y]\!] = [\![c]\!] + [\![a]\!] \cdot v + u \cdot [\![b]\!] + u \cdot v \cdot \delta_i$
- Open
  - Broadcast $[x]$ and symmetric encryption to tag of $[x]$
  - Use $x = \sum_{i=0}^{n-1} [x]_i$

Appendix: Input/Output

- Input
  - Servers use random $[\![r]\!]$ from the offline phase
  - Servers open $[\![r]\!]$ to input party
  - Input party broadcasts $u = x - r$ for input x
  - Servers use $[\![x]\!] = [\![r]\!] + \delta_i \cdot u$
- Output
  - Servers use double authenticated random $[\![r]\!]$ from offline phase
  - Servers open $[\![u]\!] = [\![x - r]\!]$ for output x under α
  - Verification using α
  - Servers open $[\![r]\!]$ under ω
  - Verification using ω