Don't Eject the Impostor
Fast Three-Party Computation With a Known Cheater

ENCRYPTO Cryptography and Privacy Engineering

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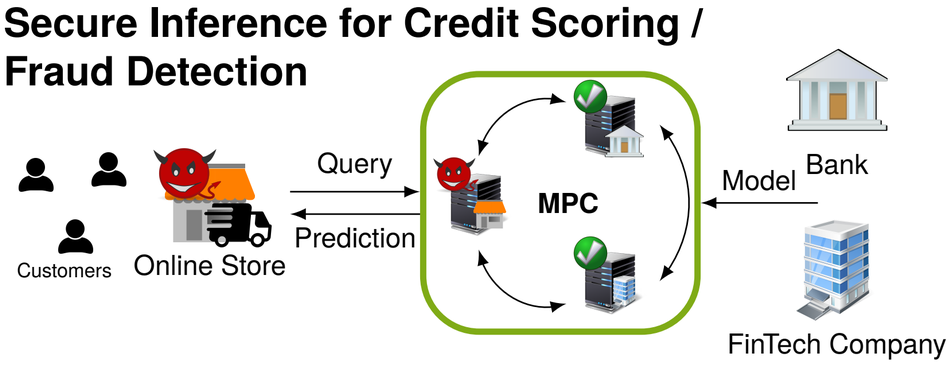
Motivating Example

Secure Inference for Credit Scoring / Fraud Detection



Lower trust in online store ⇒ might behave maliciously😈

- Semi-honest security model (✅) ⇒ insufficient
- Malicious security model (😈) ⇒ inefficient

⇒ **Mixed model (✅ + 😈) fits best**

Are symmetric security models really a good fit for any real-world application with diverse parties?

Setting

- Three parties (**3PC**)
- Parties do not collude ⇒ **honest majority**
- Only one **fixed and known party susceptible to malicious corruption**, others semi-honest

Extension of prior works for an asymmetric 2PC setting:

- Yao's garbled circuits [Yao86] when using maliciously secure OT: semi-honest garbler, malicious evaluator
- **client-malicious setting** [LMS+21; CGO+22]: malicious client, semi-honest server
- malicious server, semi-honest client [DWL+23]

Our Contributions

- **Auxiliator & Socium**, 3PC protocols with asymmetric security model
- **Streamlined online** phase between two evaluators
- Multiple options for **efficient preprocessing**
- **ML-friendly**, but multi-purpose design
- **Open-source** implementation

⇒ **Bridging the gap between symmetric semi-honest and malicious security model**

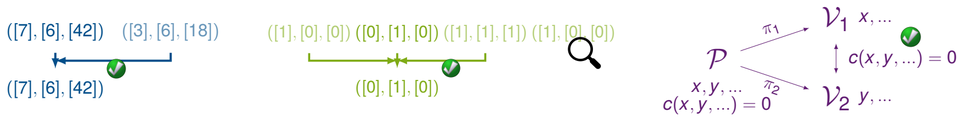
Detection and Prevention of Cheating

Majority of verification done during preprocessing using

- Triple Sacrificing (ring version) [CDE+18]
  Including novel **Matrix Triple Sacrificing**
- Cut-and-Choose (binary) [ABF+17]
- Distributed ZKPs [BBC+19; BGI+19]

adapted to our asymmetric setting; requiring either low computation or low communication overhead.

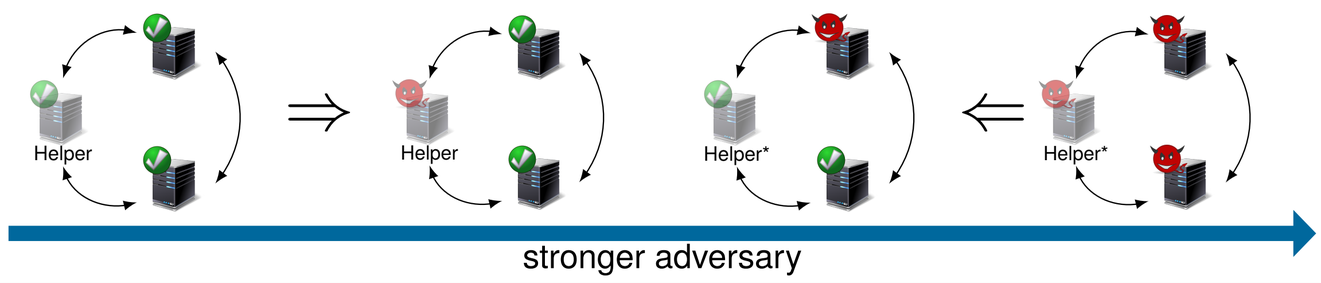
Outsource verification to semi-honest parties!



The World Between Astra & Swift

Auxiliator and Socium are based on the 3PC protocols Astra and Swift for the symmetric semi-honest respectively malicious security model.

Astra [CCP+19] **Auxiliator (new)** **Socium (new)** Swift [KPP+21]



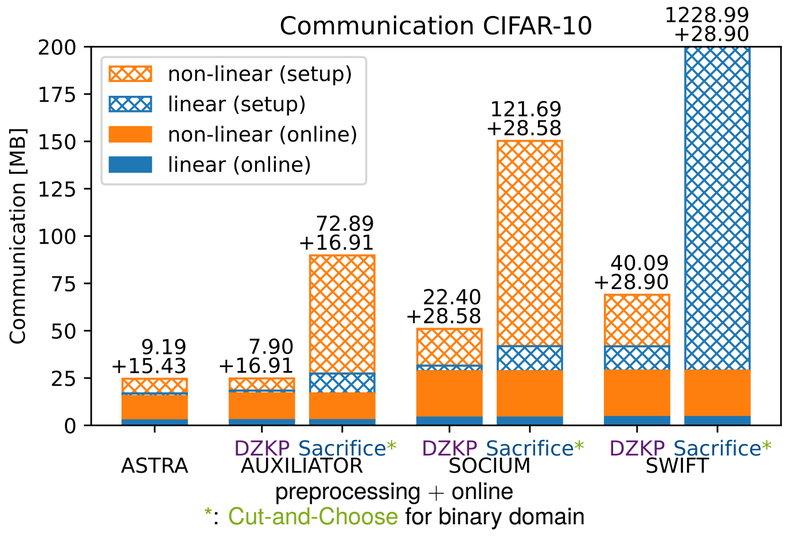
Communication per Operation

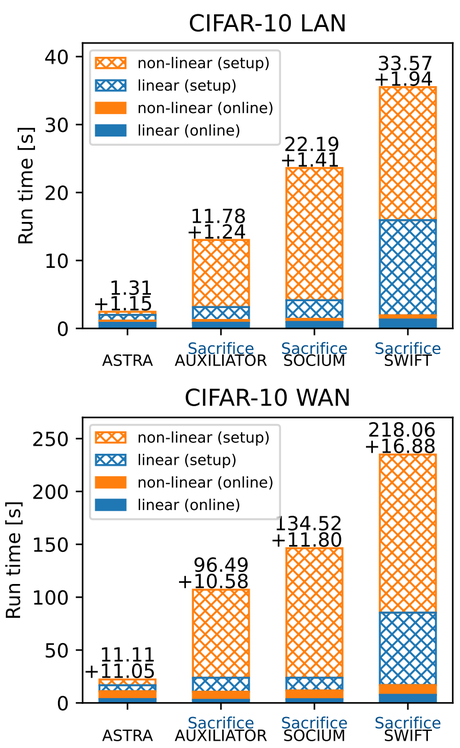
Operation / Verification	$\mathbf{a} \cdot \mathbf{b} = \mathbf{c}$ Sacrifice	$\mathbf{a} \cdot \mathbf{b} = \mathbf{c}$ DZKP	$\square \cdot \square = \square$ Sacrifice	$\square \cdot \square = \square$ DZKP	$\mathbf{x} \wedge \mathbf{y} = \mathbf{z}$ Cut-and-Choose	$\mathbf{x} \wedge \mathbf{y} = \mathbf{z}$ DZKP
Preprocessing						
Astra [CCP+19]	$1 \times \mathbb{Z}_\ell$		$\square$		1 bit	
Auxiliator (**this work**)	$4 \times \mathbb{Z}_{\ell+\sigma}$	$1 \times \mathbb{Z}_\ell$	$2\square + 2\square$	$\square$	11 bits	1 bit
Socium (**this work**)	$5 \times \mathbb{Z}_{\ell+\sigma}$	$2 \times \mathbb{Z}_\ell$	$3\square + 2\square$	$2\square$	12 bits	2 bits
Swift [KPP+21]	$9 \times \mathbb{Z}_{\ell+\sigma}$	$3 \times \mathbb{Z}_\ell$	$6\square + 3\square$	$3\square$	21 bits	3 bits
Online						
Astra/Auxiliator	$2 \times \mathbb{Z}_\ell$		$2\square$		2 bits	
Swift/Socium	$3 \times \mathbb{Z}_\ell$		$3\square$		3 bits	

ℓ: ring size σ: statistical security parameter

Performance for Secure Inference

We benchmarked Astra, Auxiliator, Socium & Swift for secure inference using the 7-layer CNN from MiniONN [LJL+17] trained on the CIFAR-10 dataset.





What is the advantage of extending semi-honest 2PC by a malicious helper? (setup only, same online phase)

Layers	ABY2.0 [PSS+21] original	ABY2.0 [PSS+21] improved OT	Auxiliator (this work) Sacrifice*	Auxiliator (this work) DZKP
Linear	178.97 GB	60.59 GB	10.46 MB	1.48 MB
Non-linear	524.25 MB	23.04 MB	62.43 MB	6.42 MB
Total	179.50 GB	60.61 GB	72.89 MB	7.90 MB

What is the advantage of extending the client-malicious setting by a semi-honest helper?

Layers	SIMC [CGO+22]	Socium (this work) Sacrifice*	Socium (this work) DZKP
Linear	140 MB	20.01 MB	7.08 MB
Non-linear	2.24 GB	148.33 MB	43.90 MB
Total	2.38 GB	168.34 MB	50.98 MB

References

[ABF+17] T. Araki, A. Barak, J. Furukawa, T. Lichter, Y. Lindell, A. Nof, K. Ohara, A. Watzman, and O. Weinstein. "Optimized Honest-Majority MPC for Malicious Adversaries - Breaking the 1 Billion-Gate Per Second Barrier". In: *IEEE S&P*. 2017.

[BBC+19] D. Boneh, E. Boyle, H. Corrigan-Gibbs, N. Gilboa, and Y. Ishai. "Zero-Knowledge Proofs on Secret-Shared Data via Fully Linear PCPs". In: *CRYPTO*. 2019.

[BGI+19] E. Boyle, N. Gilboa, Y. Ishai, and A. Nof. "Practical Fully Secure Three-Party Computation via Sublinear Distributed Zero-Knowledge Proofs". In: *CCS*. 2019.

[CCP+19] H. Chaudhari, A. Choudhury, A. Patra, and A. Suresh. "ASTRA: High Throughput 3PC over Rings with Application to Secure Prediction". In: *CCSW@CCS*. 2019.

[CDE+18] R. Cramer, I. Damgård, D. Escudero, P. Scholl, and C. Xing. "SPD $\mathbb{Z}_{2^k}$: Efficient MPC mod 2^k for Dishonest Majority". In: *CRYPTO*. 2018.

[CGO+22] N. Chandran, D. Gupta, S. L. B. Obbattu, and A. Shah. "SIMC: ML Inference Secure Against Malicious Clients at Semi-Honest Cost". In: *USENIX Security*. 2022.

[DWL+23] C. Dong, J. Weng, J.-N. Liu, Y. Zhang, Y. Tong, A. Yang, Y. Cheng, and S. Hu. "Fusion: Efficient and Secure Inference Resilient to Malicious Servers". In: *NDSS*. 2023.

[KPP+21] N. Koti, M. Pancholi, A. Patra, and A. Suresh. "SWIFT: Super-fast and Robust Privacy-Preserving Machine Learning". In: *USENIX Security*. 2021.

[LJL+17] J. Liu, M. Juuti, Y. Lu, and N. Asokan. "Oblivious Neural Network Predictions via MiniONN Transformations". In: *CCS*. 2017.

[LMS+21] R. Lehmkuhl, P. Mishra, A. Srinivasan, and R. A. Popa. "Muse: Secure Inference Resilient to Malicious Clients". In: *USENIX Security*. 2021.

[PSS+21] A. Patra, T. Schneider, A. Suresh, and H. Yalame. "ABY2.0: Improved Mixed-Protocol Secure Two-Party Computation". In: *USENIX Security*. 2021.

[Yao86] A. C.-C. Yao. "How to Generate and Exchange Secrets (Extended Abstract)". In: *FOCS*. 1986.

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CROSSING

Privacy and Trust for Mobile Users

Paper https://ia.cr/2023/1744

Code https://encrypto.de/code/MOTION-FD

Website https://encrypto.de