# ABY - A Framework for Efficient Mixed-Protocol Secure Two-Party Computation

TECHNISCHE UNIVERSITÄT DARMSTADT

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joint work with
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published at NDSS 2015



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# Secure Two-Party Computation

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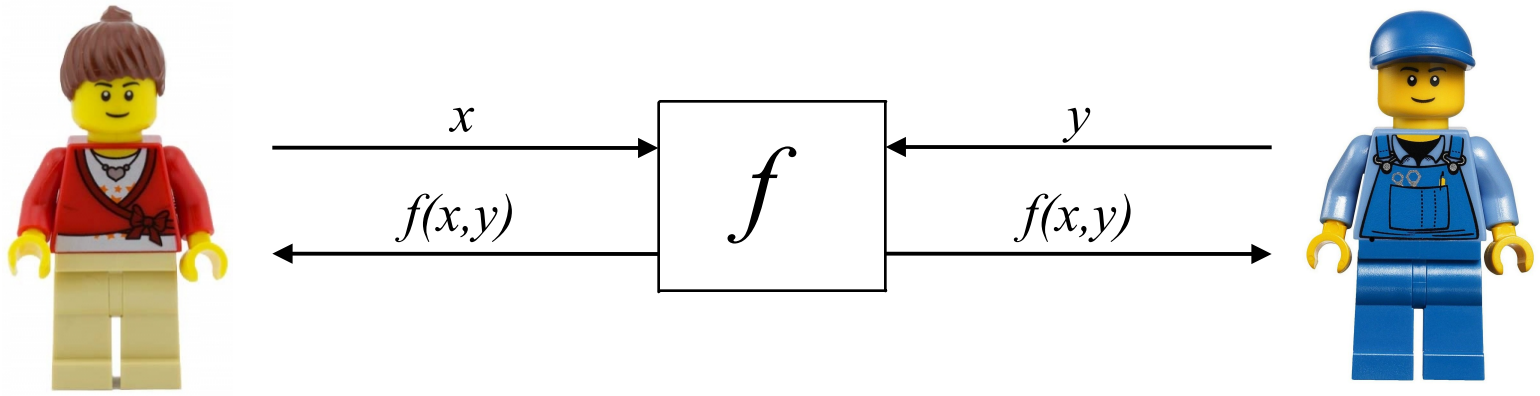


Here we consider only **semi-honest** (passive) adversaries.

# Privacy-Preserving Applications

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Private Set Intersection [Meadows86], ...

Auctions [Naor-Pinkas-Sumner99], ...

Biometric Identification [Erkin-Franz-Guajardo-Katzenbeisser-Langendijk-Toft09], …

Machine Learning [Bost-Popa-Tu-Goldwasser15], …

etc.

# An Application Developer's Perspective

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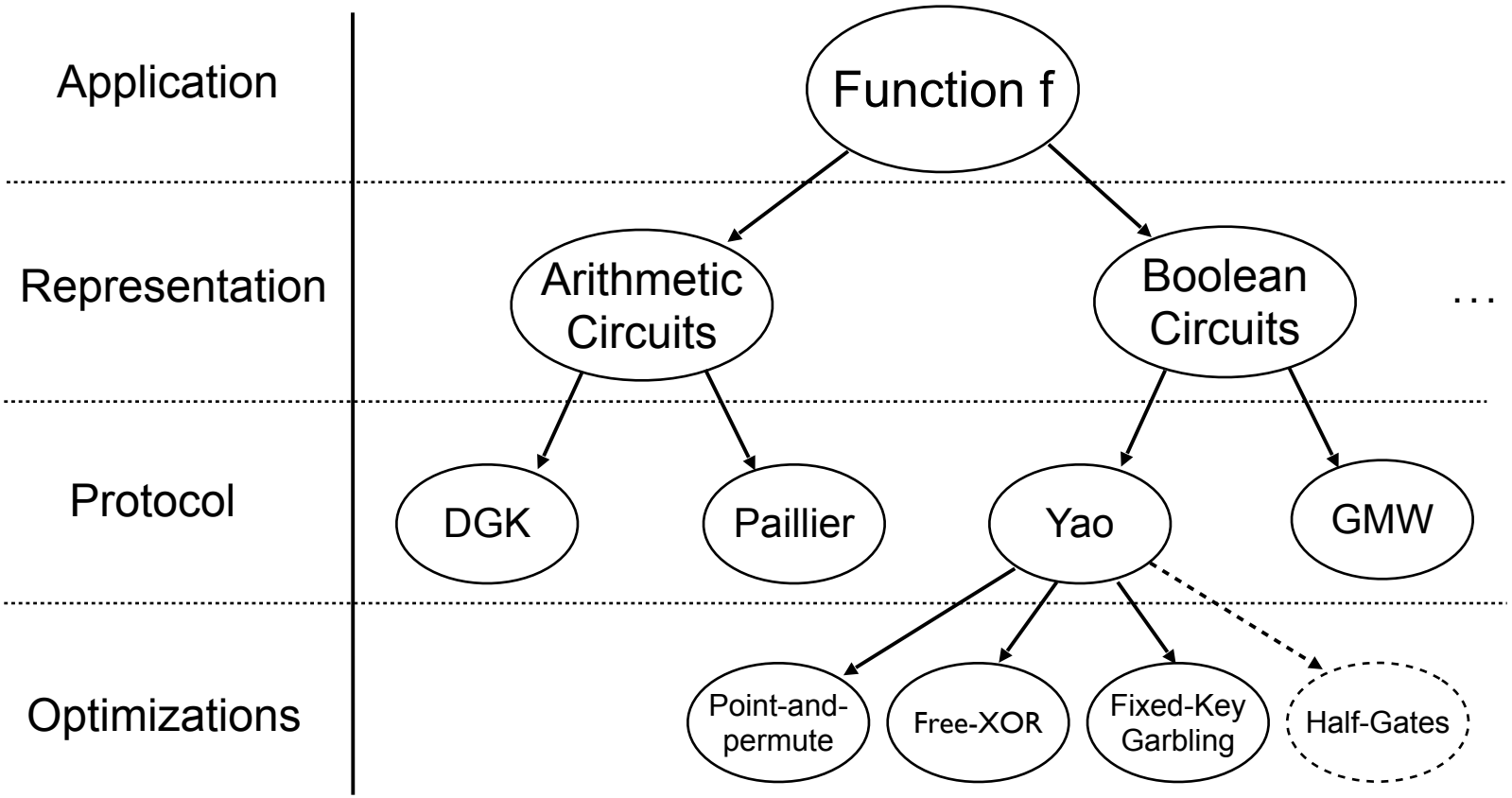


DGK: Damgård-Geisler-Krøigaard, GMW: Goldreich-Micali-Wigderson



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# Motivating Example for Mixed Protocols: Minimum Euclidean Distance

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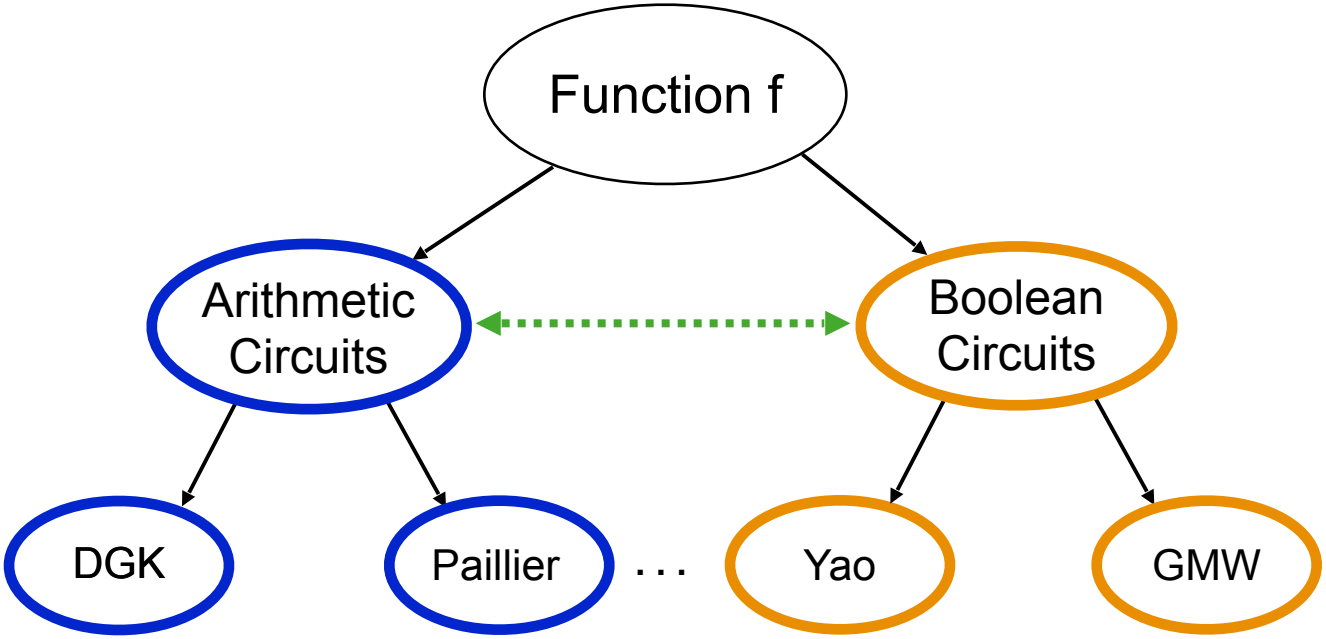
- Application: biometric matching (face-recognition, fingerprint, …)
- Server holds database $\mathbf{S_1}, \ldots, \mathbf{S_n}$, client holds query $\mathbf{C}$
- Minimum Euclidean Distance: f = $\min(\sum^{d}_{i=1}(\mathbf{S_{1,i}} - \mathbf{C_i})^2, \ldots, \sum^{d}_{i=1}(\mathbf{S_{n,i}} - \mathbf{C_i})^2)$



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# Mixed-Protocol Secure Computation

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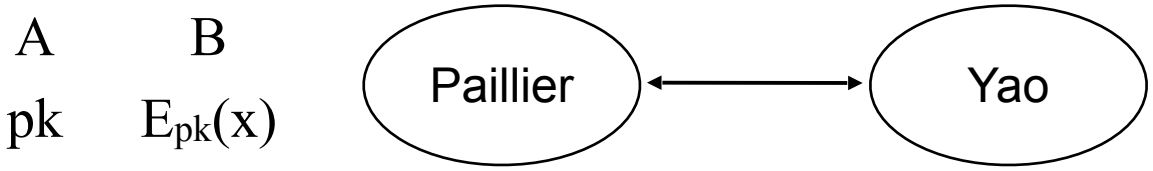
- Some functionalities are particularly expensive in one representation
  - Addition: Boolean circuit: O($\ell$) gates vs. Arithmetic circuit: 1 gate
  - Multiplication: Boolean circuit: **O($\ell^2$)** gates vs. Arithmetic circuit: 1 gate

- TASTY [Henecka-Kögl-Sadeghi-**S**-Wehrenberg10] combines Paillier (Arithmetic) and Yao (Boolean)




- **Multiplication** and **conversion** previously used expensive PK operations
  - Yao is often more efficient than Paillier [Kerschbaum-**S**-Schröpfer14]

  - **Our goal**: completely avoid PK operations & use Beaver multiplication triples to precompute symmetric crypto!

# Roadmap / Our Contributions

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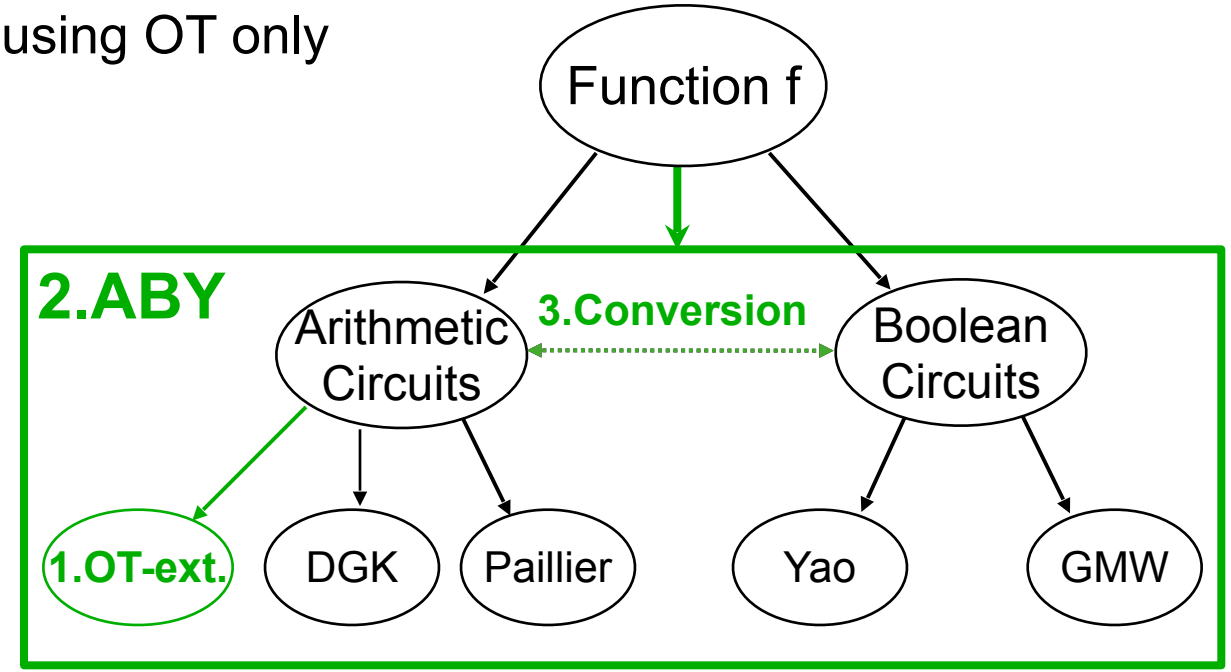
1) OT-based multiplication is substantially faster than using PK crypto

2) Mixed-protocol framework ABY

3) Efficient conversions using OT only



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# 1) Multiplication using OT [Gilboa99]

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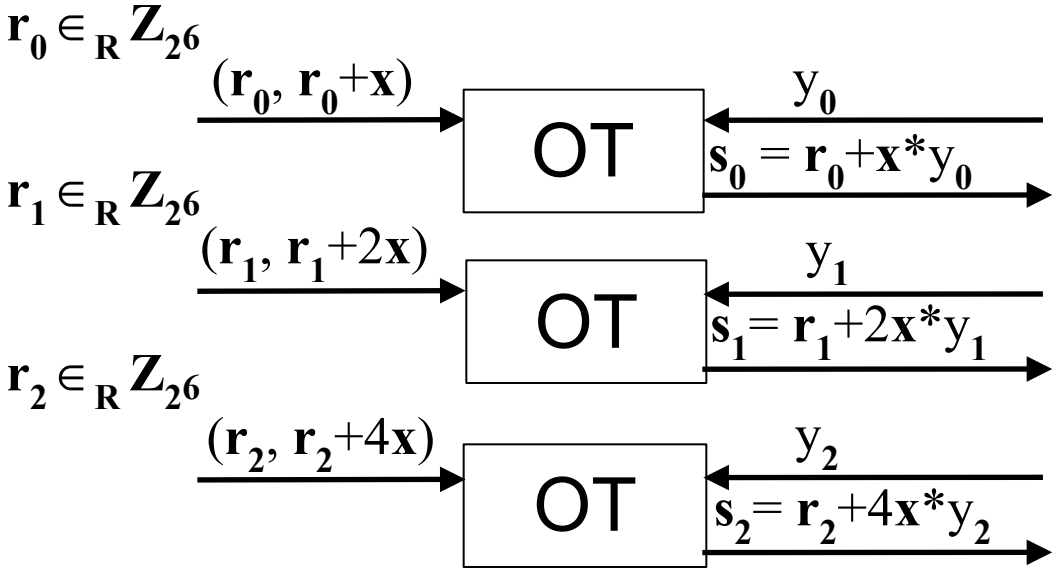
Schoolbook Multiplication $z = x * y$ with $x=x_2x_1x_0$ and $y=y_2y_1y_0$:

$z = x*y_0 + 2x*y_1 + 4x*y_2$




$[z]_A = -\sum^2_{i=0} r_i$ $\qquad$ $[z]_B = \sum^2_{i=0} s_i = \sum^2_{i=0} r_i + \sum^2_{i=0} 2^i x*y_i$

$$z = [z]_A + [z]_B = x * y$$



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# 1) Multiplication using OT Benchmarks

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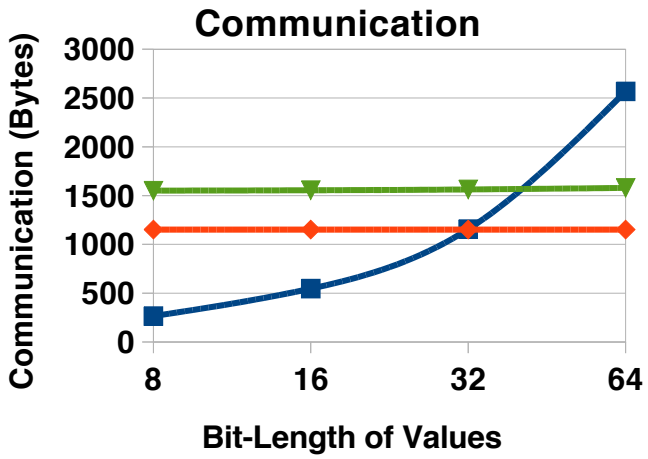
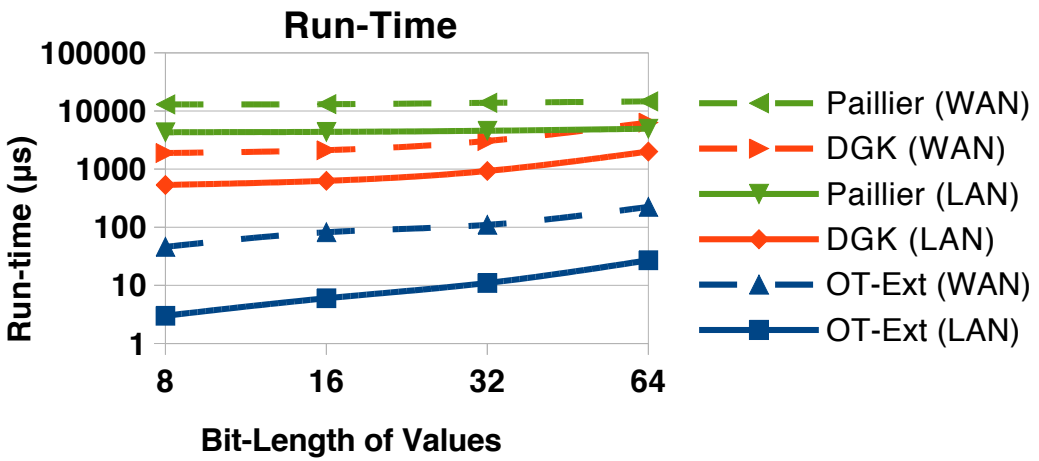
Instantiate OT efficiently with OT extension [Ishai-Kilian-Nissim-Petrank03, Asharov-Lindell-**S**-Zohner13]

Compare one amortized multiplication using Paillier, DGK, and OT extension




Communication and run-time for 1 multiplication in LAN and WAN for long-term security



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# 2) The ABY framework

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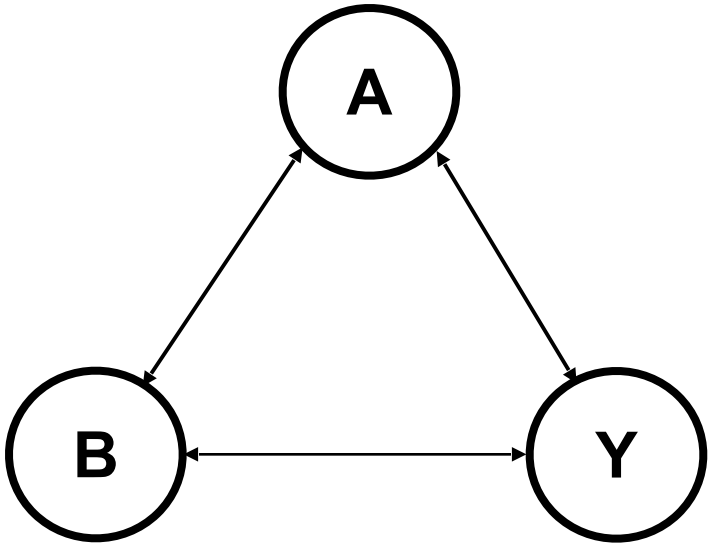
Combine:

- **A**rithmetic sharing
- **B**oolean sharing (GMW)
- **Y**ao's garbled circuits




Efficient conversions between schemes

Implement using state-of-the-art optimizations:

- batch pre-compute crypto operations
- use strong assumptions for maximum efficiency
- use fixed-key AES where possible (with AES-NI instruction set)

# 2) The ABY framework

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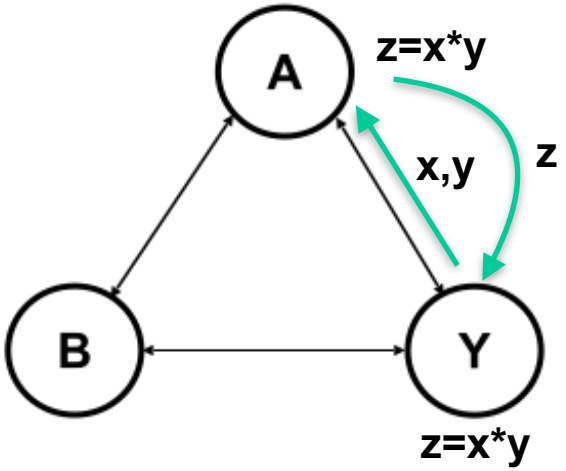
**A** rithmetic sharing: $v = a + b \bmod 2^{\ell}$
- Free addition / cheap multiplication (1 msg)
- Good for multiplication

**B** oolean sharing: $v = a \oplus b$
- Free XOR / 1 online msg per AND
- Good for multiplexing (using 2 OTs)

**Y** ao's garbled circuits: A: $k_0, k_1$; B: $k_v$
- Free XOR / no interaction per AND
- Good for comparisons

Benchmark primitive operations (+,*,>,=,...)




***32-bit Multiplication*** *(amortized)*

| ***Protocol*** | ***Yao*** |
|---|---|
| ***LAN [ms]*** | 1.1 |
| ***Comm. [KB]*** | 100 |
| ***#Msg*** | ***0*** |



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# 3) Efficient Conversions

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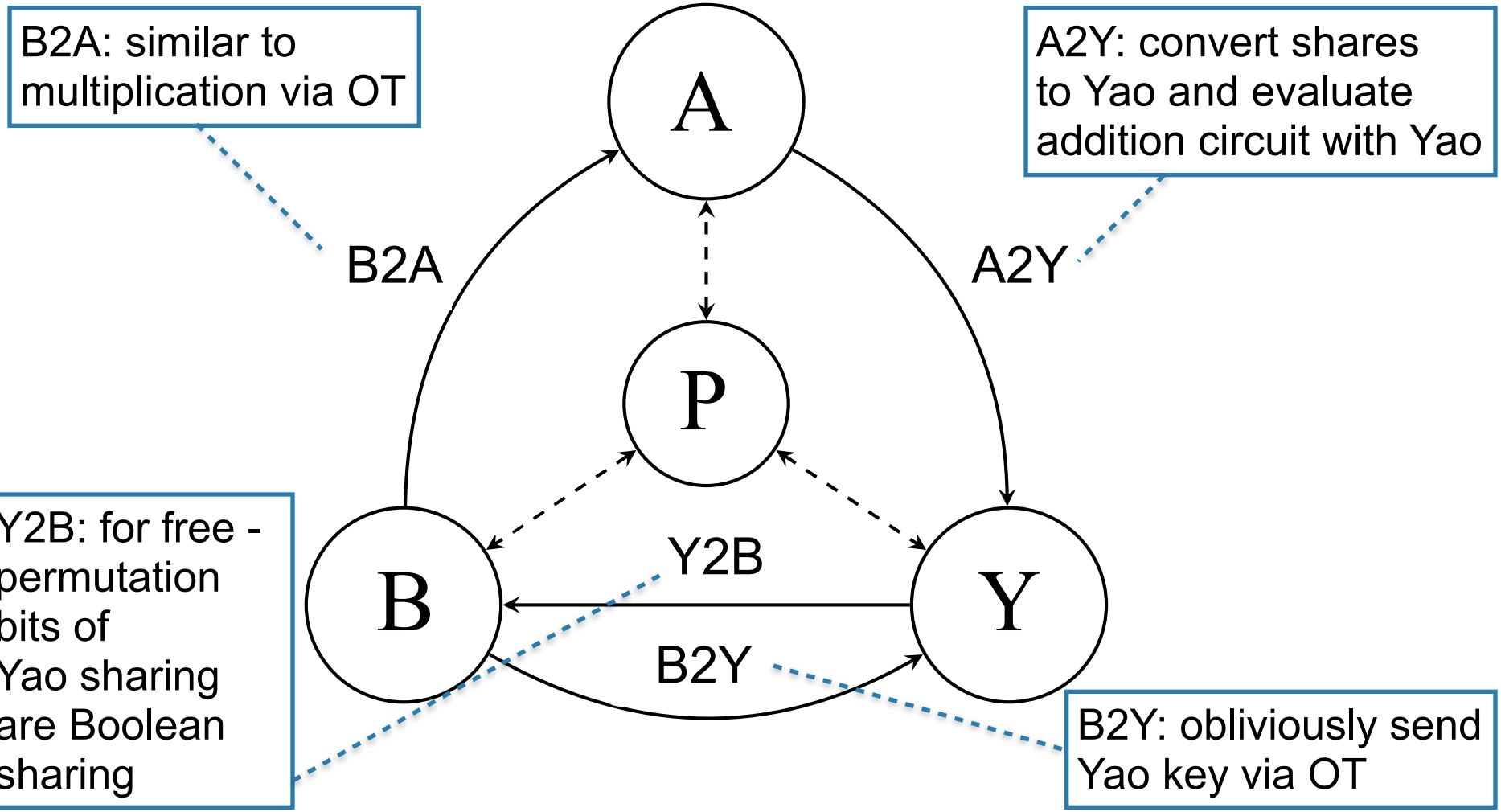




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# 3) Efficient Conversions

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Conversion of $\ell$-bit values for symmetric security parameter $\kappa$

| Conversion | Computation [#symm] | Communication [bits] | #Msg |
|---|---|---|---|
| Y2B | 0 | 0 | 0 |
| P2A, P2B, *2P | 0 | $\ell$ | 1 |
| $P2Y_A$ | $\ell$ | $\ell\kappa$ | 1 |
| B2A | $6\ell$ | $\ell\kappa+(\ell^2+\ell)/2$ | 2 |
| B2Y, $P2Y_B$ | $6\ell$ | $2\ell\kappa$ | 2 |
| A2Y | $12\ell$ | $6\ell\kappa$ | 2 |

} OT



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# Application 1: Minimum Euclidean Distance

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Minimum Euclidean Distance: $\min(\sum^{d}_{i=1}(S_{1,i} - C_i)^2, \ldots, \sum^{d}_{i=1}(S_{n,i} - C_i)^2)$

| dist | min | LAN [s] | WAN [s] | Comm [MB] | #Msg |
|---|---|---|---|---|---|
| **Y** | **Y** | 2.55 | 24.62 | 147.7 | **2** |
| **B** | **B** | 2.43 | 39.41 | 99.9 | 129 |
| **A** | **Y** | **0.19** | **3.42** | 5.0 | 8 |
| **A** | **B** | 0.21 | 26.41 | **4.6** | 101 |

Minimum Euclidean distance for n = 512 values of 32-bit length and d = 4.

LAN: Two standard PCs connected via Gigabit Ethernet.
WAN: Two Amazon EC2 c3.large instances - one located at US east cost and the other one in Japan.

# Application 2: Private Set Intersection

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PSI using Sort-Compare-Shuffle Circuit of [Huang-Evans-Katz12]

contains many multiplexers ⇒ benefits from Boolean sharing

| Sort + Compare | Shuffle | LAN [s] | WAN [s] | Comm [MB] | #Msg |
|---|---|---|---|---|---|
| **Y** | **Y** | 4.3 | 34.0 | 247 | **2** |
| **B** | **B** | **2.6** | 34.1 | **163** | 123 |
| **Y** | **B** | 3.3 | **30.0** | 182 | 27 |

PSI on 4096 elements of length 32 bit



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# Summary

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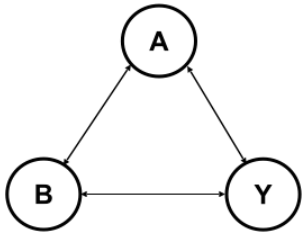
ABY = framework for **mixed-protocol** secure computation




**Abstract** from details of underlying secure computation protocol

Use **only fast symmetric key crypto**

Code is available on **GitHub**: http://encrypto.de/code/ABY

# Future Work

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Use ABY framework for further **applications**

**Automatically** assign operations to sharing types

Extend mixed protocols to **stronger adversaries**



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# ABY - A Framework for Efficient Mixed-Protocol Secure Two-Party Computation

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Thanks!

Questions?

Contact: http://encrypto.de
Code: http://encrypto.de/code/ABY



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