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

TECHNISCHE UNIVERSITÄT DARMSTADT

Thomas Schneider

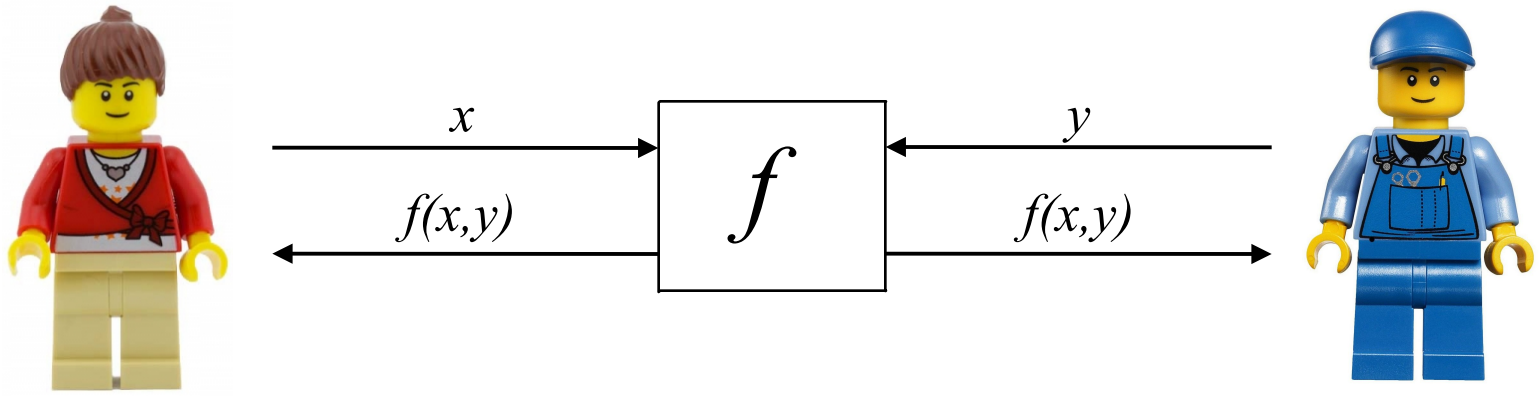
joint work with
Daniel Demmler and Michael Zohner

published at NDSS 2015

EC SPRIDE

Secure Two-Party Computation

TECHNISCHE UNIVERSITÄT DARMSTADT



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

Privacy-Preserving Applications

TECHNISCHE UNIVERSITÄT DARMSTADT

Private Set Intersection [Meadows86], ...

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

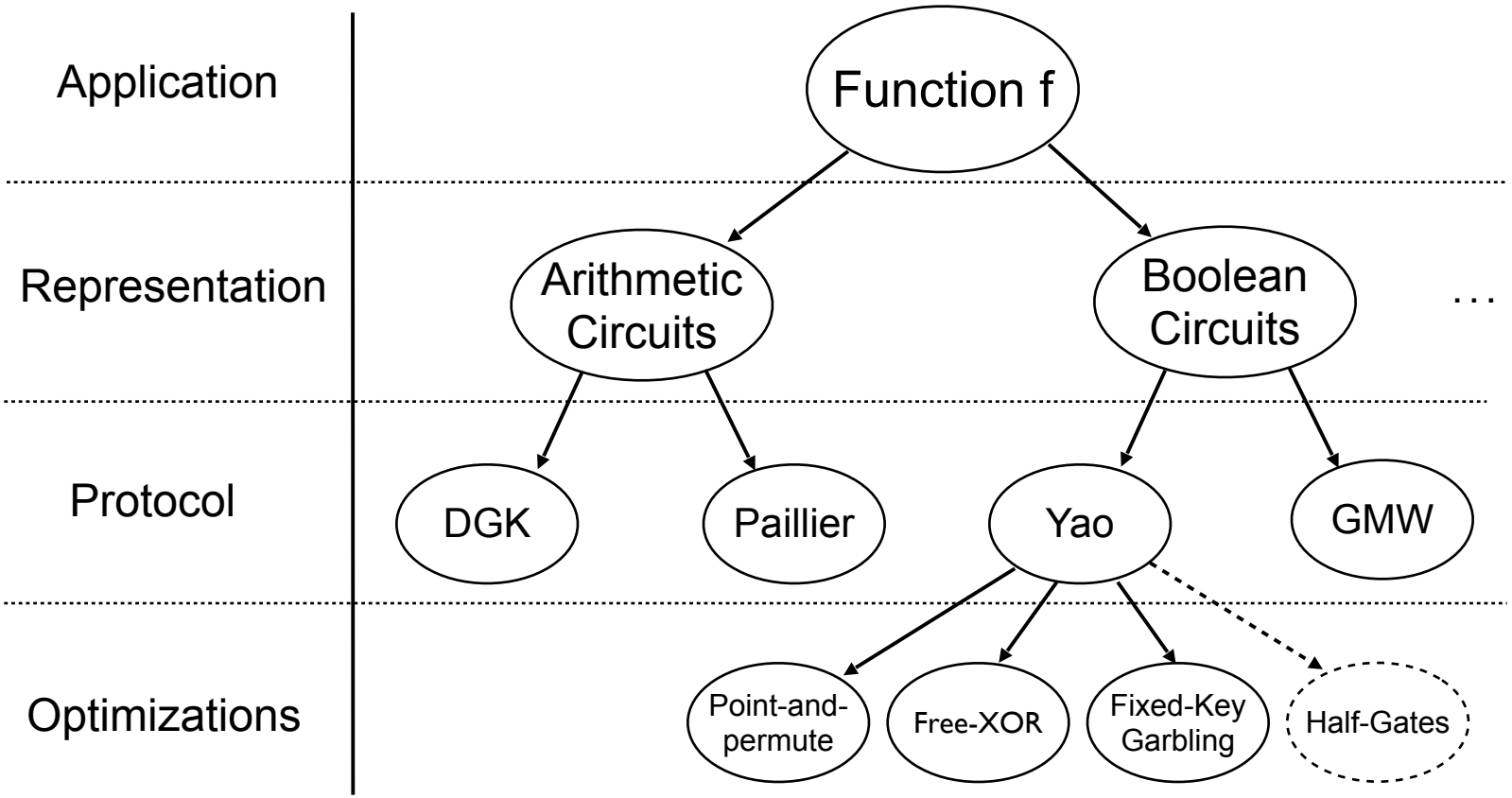
Biometric Identification [Erkin-Franz-Guajardo-Katzenbeisser-Langendijk-Toft09], …

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

etc.

An Application Developer's Perspective

TECHNISCHE UNIVERSITÄT DARMSTADT



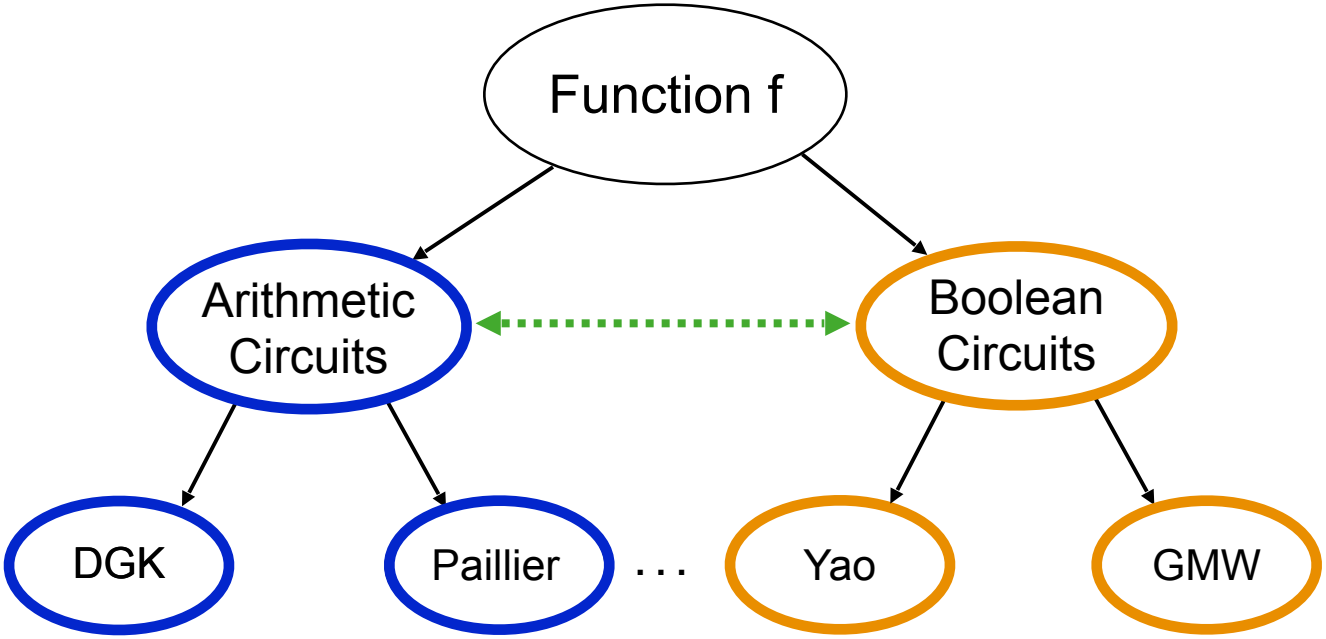
DGK: Damgård-Geisler-Krøigaard, GMW: Goldreich-Micali-Wigderson

EC SPRIDE

Motivating Example for Mixed Protocols: Minimum Euclidean Distance

TECHNISCHE UNIVERSITÄT DARMSTADT

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



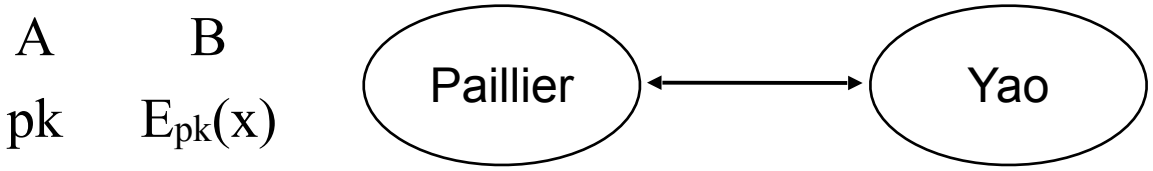
EC SPRIDE

Mixed-Protocol Secure Computation

TECHNISCHE UNIVERSITÄT DARMSTADT

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

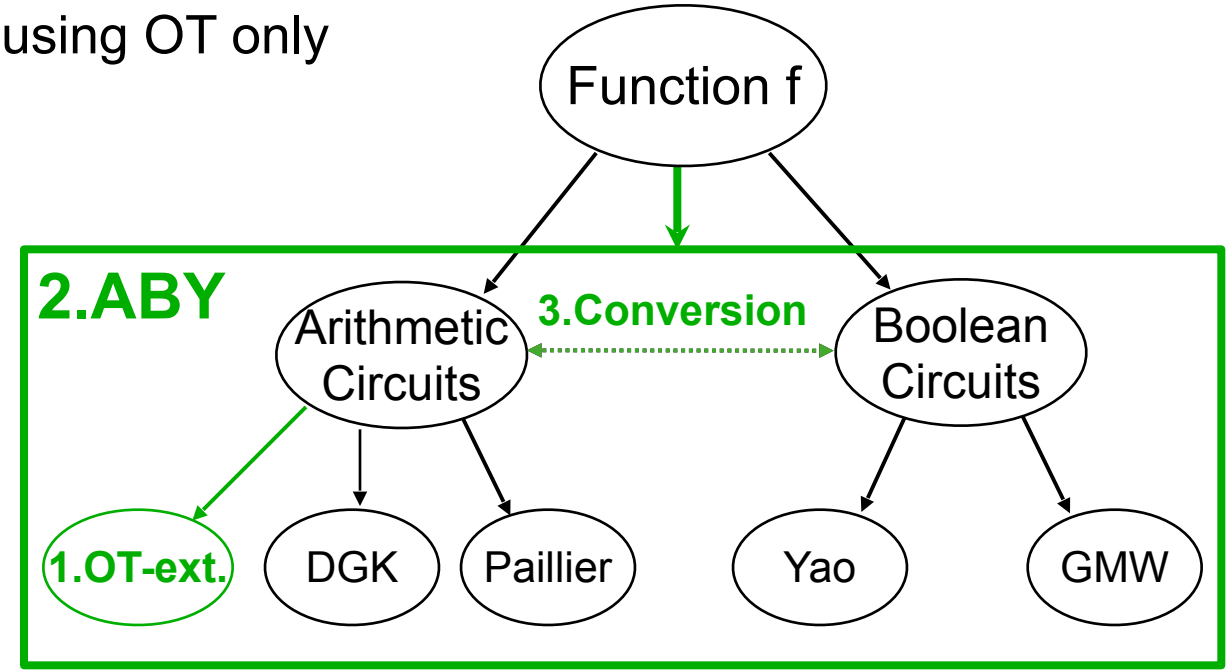
Roadmap / Our Contributions

TECHNISCHE UNIVERSITÄT DARMSTADT

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

2) Mixed-protocol framework ABY

3) Efficient conversions using OT only



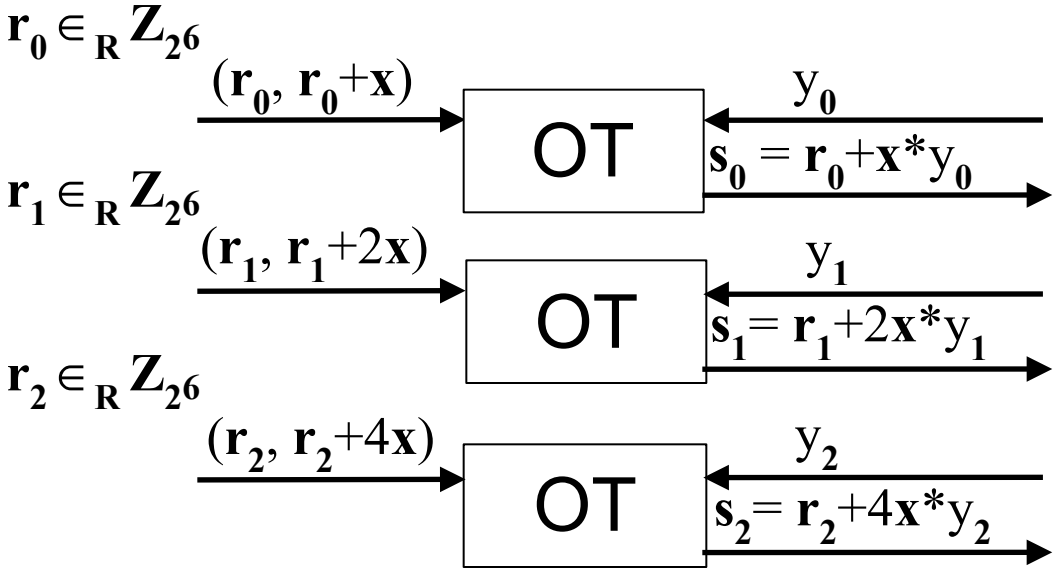
EC SPRIDE

1) Multiplication using OT [Gilboa99]

TECHNISCHE UNIVERSITÄT DARMSTADT

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

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



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

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

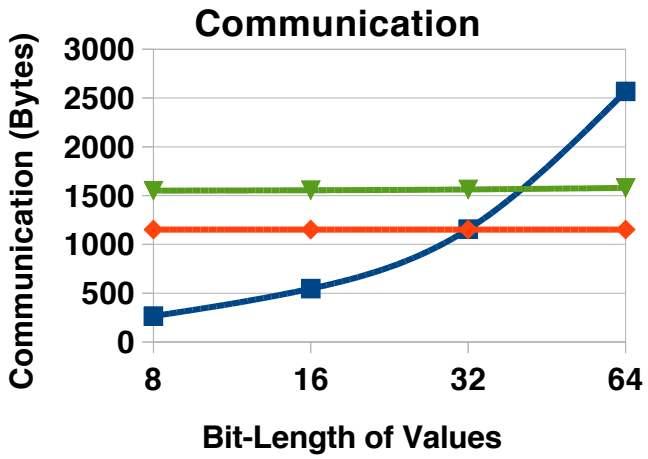
EC SPRIDE

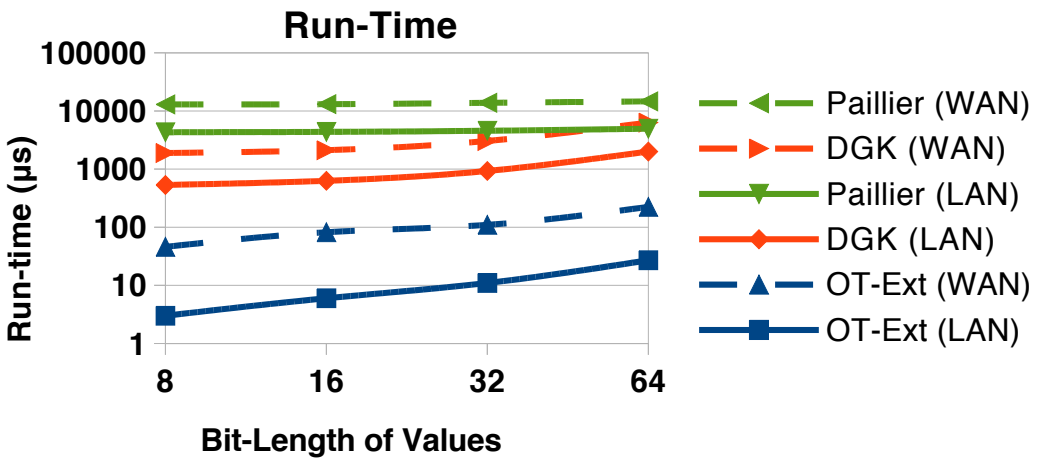
1) Multiplication using OT Benchmarks

TECHNISCHE UNIVERSITÄT DARMSTADT

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

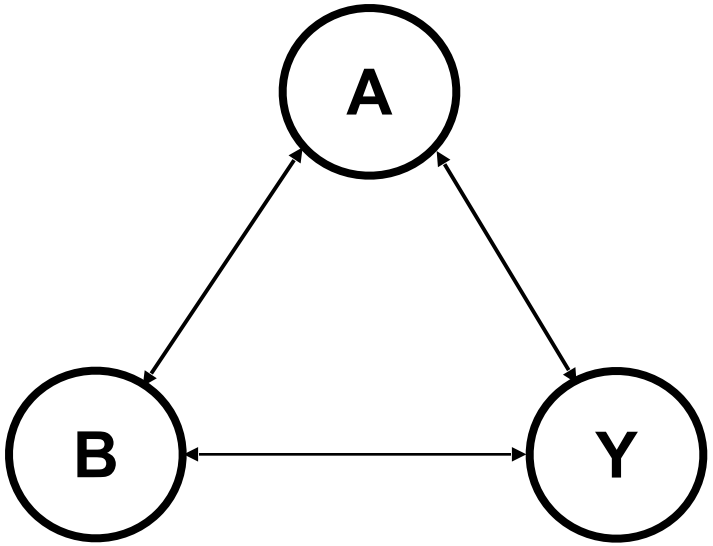
EC SPRIDE

2) The ABY framework

TECHNISCHE UNIVERSITÄT DARMSTADT

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

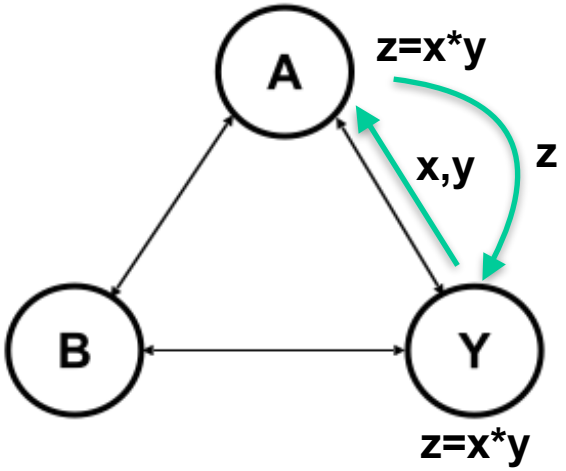
TECHNISCHE UNIVERSITÄT DARMSTADT

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 (+,*,>,=,...)



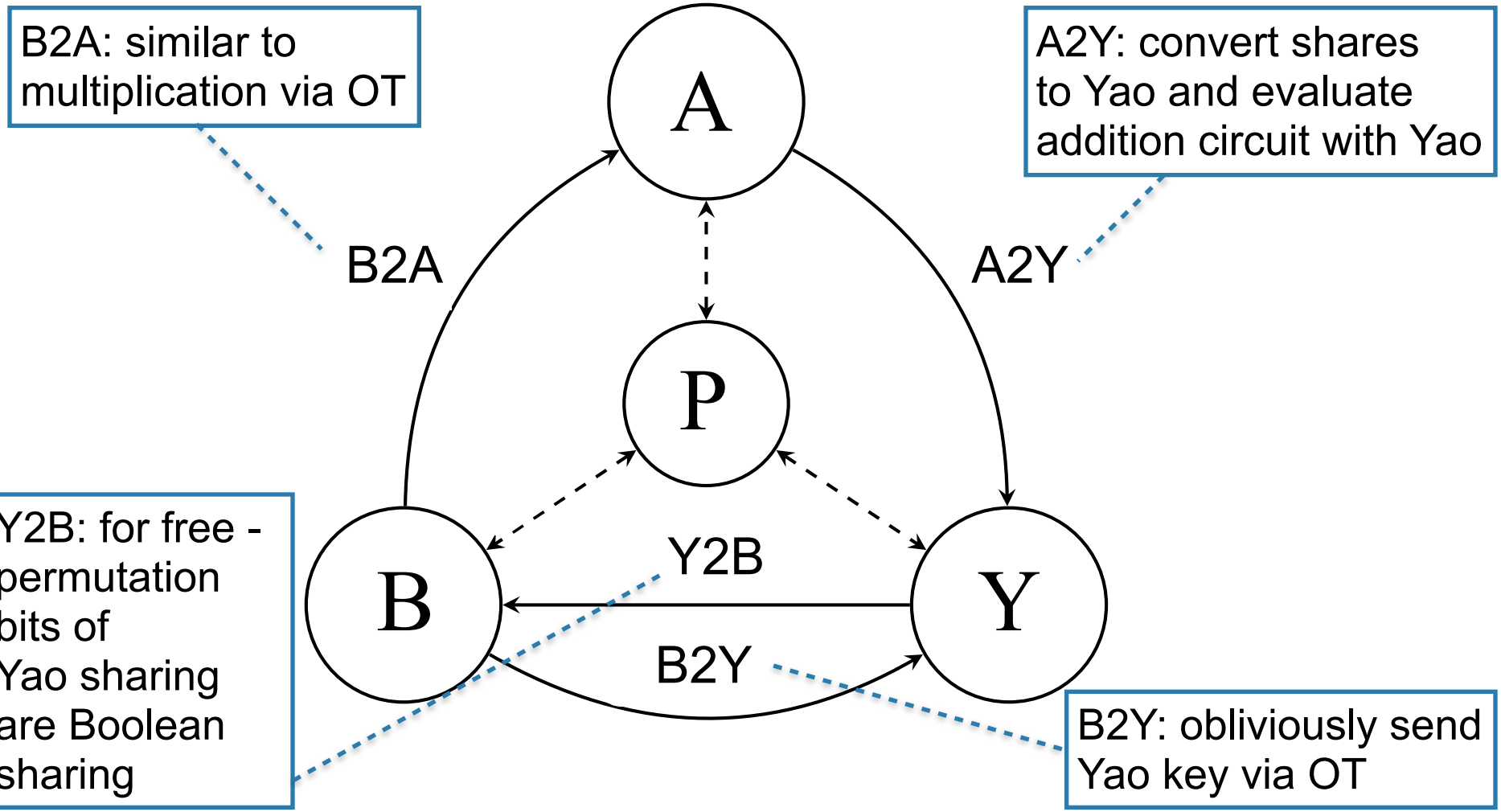
32-bit Multiplication *(amortized)*

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

EC SPRIDE

3) Efficient Conversions

TECHNISCHE UNIVERSITÄT DARMSTADT



EC SPRIDE

3) Efficient Conversions

TECHNISCHE UNIVERSITÄT DARMSTADT

Conversion of ℓ-bit values for symmetric security parameter κ

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

} OT

EC SPRIDE

Application 1: Minimum Euclidean Distance

TECHNISCHE UNIVERSITÄT DARMSTADT

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

TECHNISCHE UNIVERSITÄT DARMSTADT

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

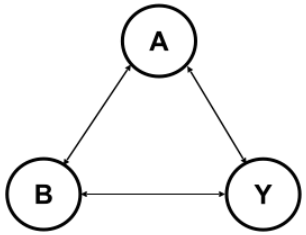
PSI on 4096 elements of length 32 bit

EC SPRIDE

Summary

TECHNISCHE UNIVERSITÄT DARMSTADT

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

TECHNISCHE UNIVERSITÄT DARMSTADT

Use ABY framework for further **applications**

Automatically assign operations to sharing types

Extend mixed protocols to **stronger adversaries**

EC SPRIDE

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

TECHNISCHE UNIVERSITÄT DARMSTADT

Thanks!

Questions?

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

EC SPRIDE