Phasing: Private Set Intersection using Permutation-based Hashing

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Joint work with
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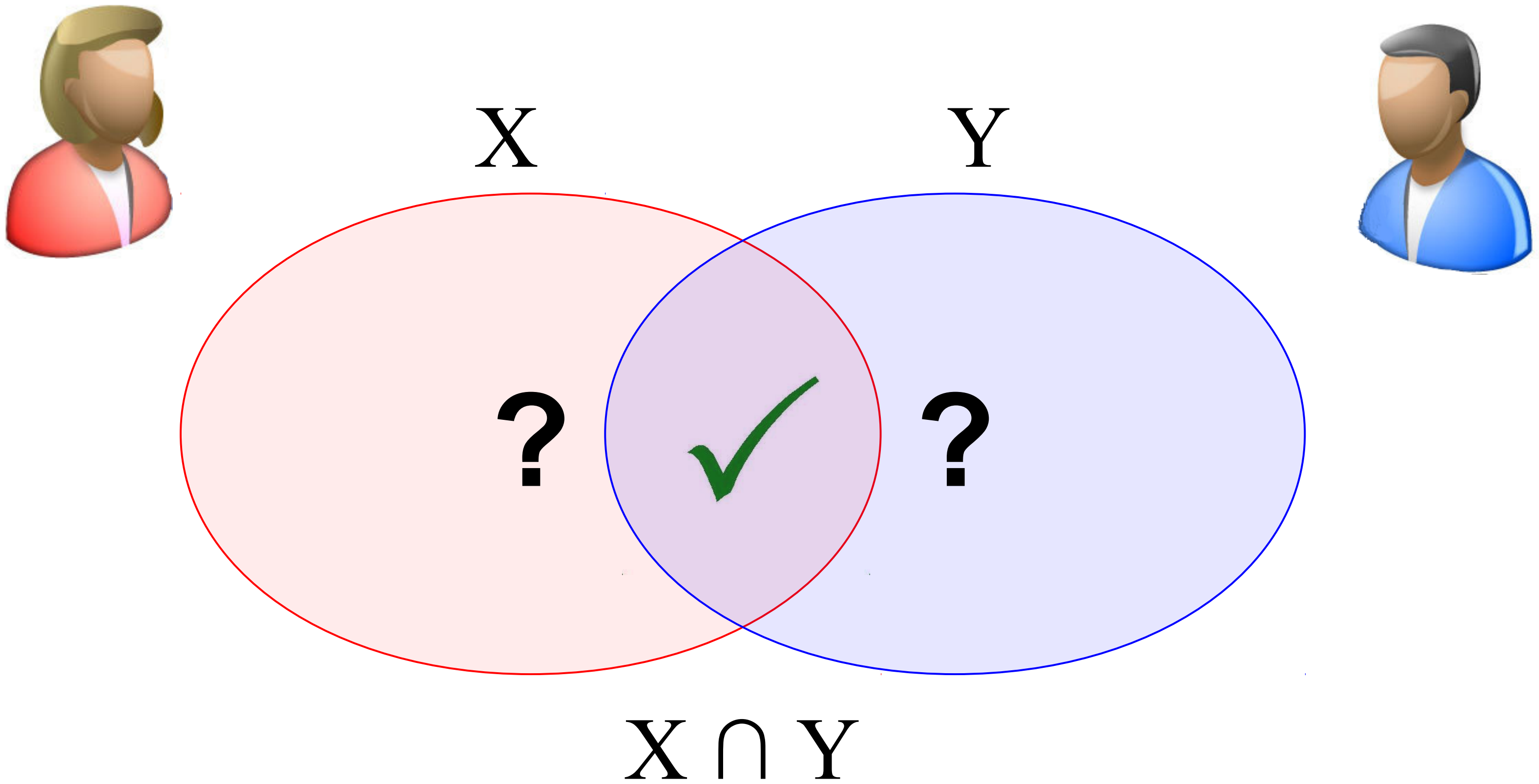
Private Set Intersection (PSI)



Application: Common Contacts

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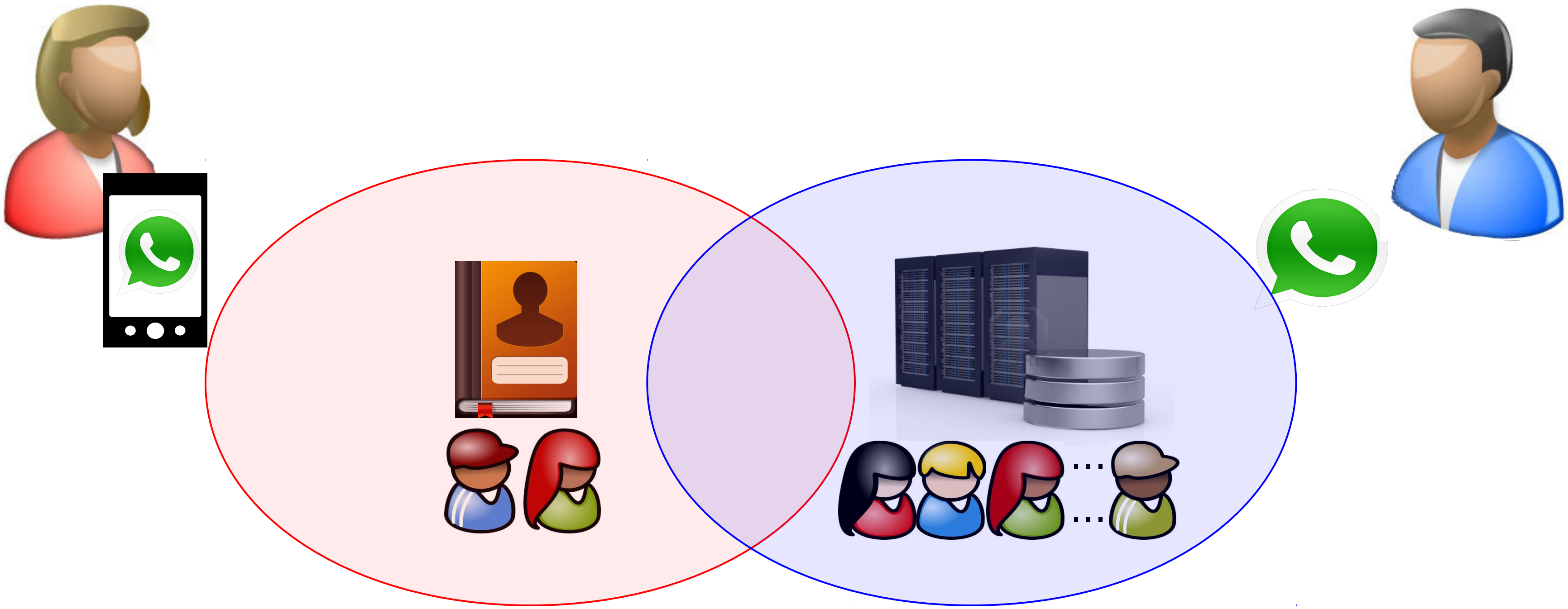

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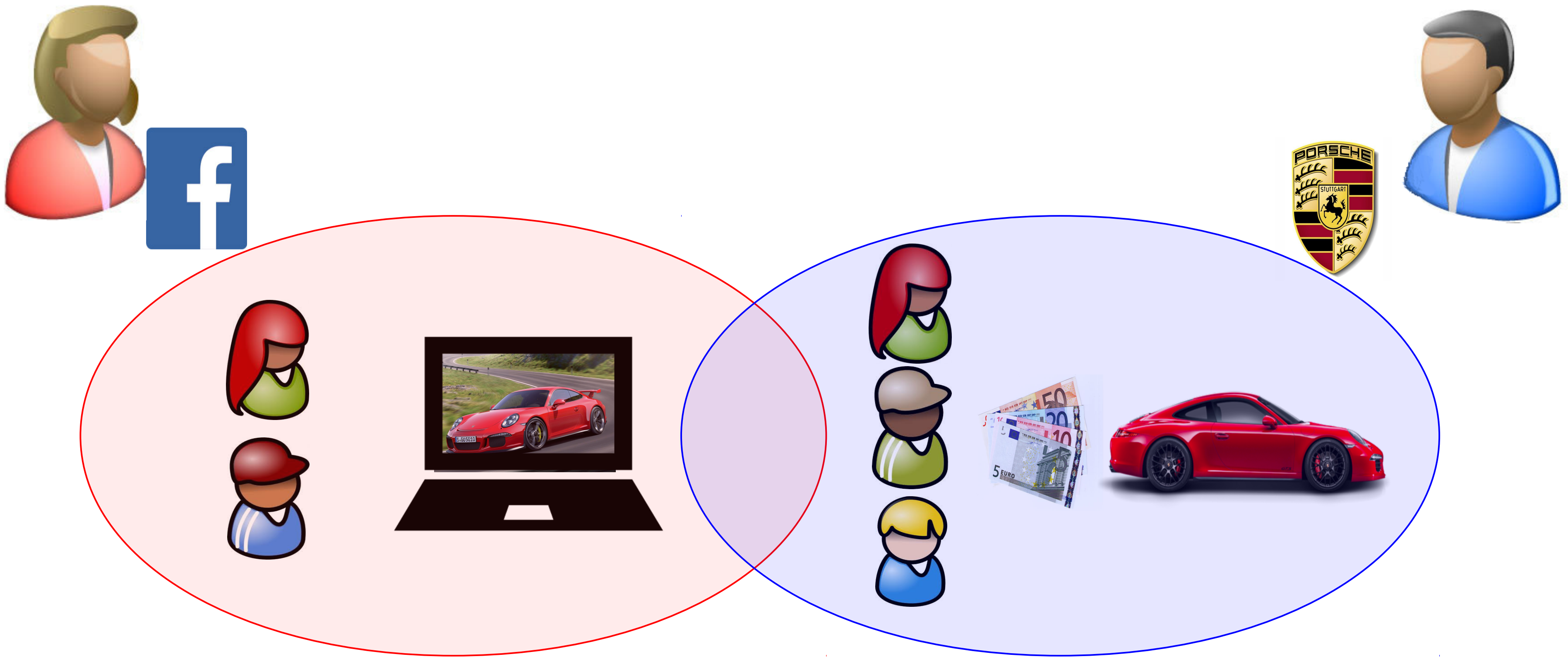
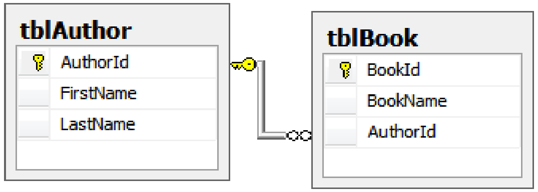
Application: Online Advertisement



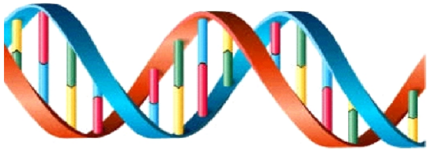
Additional Applications



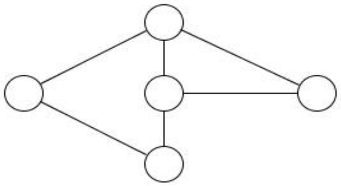
Secure database join

Botnet detection

Cheater detection in online games



Testing human genomes



Relationship path discovery

A naïve but insecure PSI protocol

Input: $x_1, \ldots, x_n$

Input: $y_1, \ldots, y_n$

$H(x_1), \ldots, H(x_n)$

$H(y_1), \ldots, H(y_n)$ ← $H(y_1), \ldots, H(y_n)$

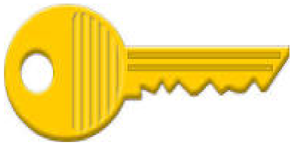
$H(x_i) \stackrel{?}{=} H(y_j)$, for $0 < i , j < n$

Pro: fast, little communication

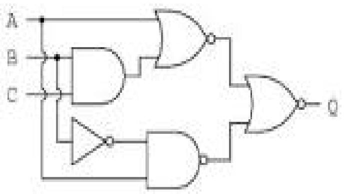
Con: insecure, can leak privacy of Bob's inputs

PSI Classification [PSZ14]

Public-key Cryptography



Generic Secure Computation



Oblivious Transfer

This talk: semi-honest (passive) adversaries

Public-key Cryptography

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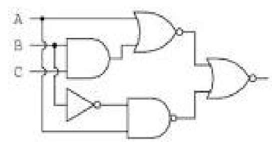
Protocols have existed for three decades

Encrypt elements using public-key crypto

Protocols based on public-key cryptography

- DH-based Protocol [M86], O(n) pk-crypto & comm
- Blind RSA Protocol [CT10], O(n) pk-crypto & comm

Generic Secure Computation

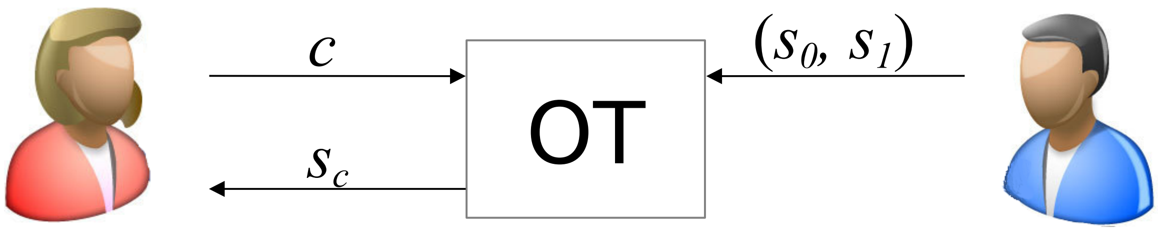


Generic Secure Computation techniques represent a function as Boolean circuit and operate on single bits

Techniques are Yao's garbled circuits and GMW

The sort-compare-shuffle circuit [HEK12] for PSI requires O($n\sigma \log n$) sym-crypto & comm, for element bit-length σ and set size n

Oblivious Transfer (OT)



Input: Bob holds two strings (s_0, s_1), Alice holds a choice bit c

Output: Alice only learns s_c; Bob learns nothing about c

OT-based PSI protocols for sec. param. κ ; σ bit elements:

- Bloom-filter [DCW13], O($n\kappa$) sym-crypto, O($n\kappa^2$) comm
- OT+Hashing [PSZ14], O($n\sigma$) sym-crypto & comm

Performance Classification [PSZ14]

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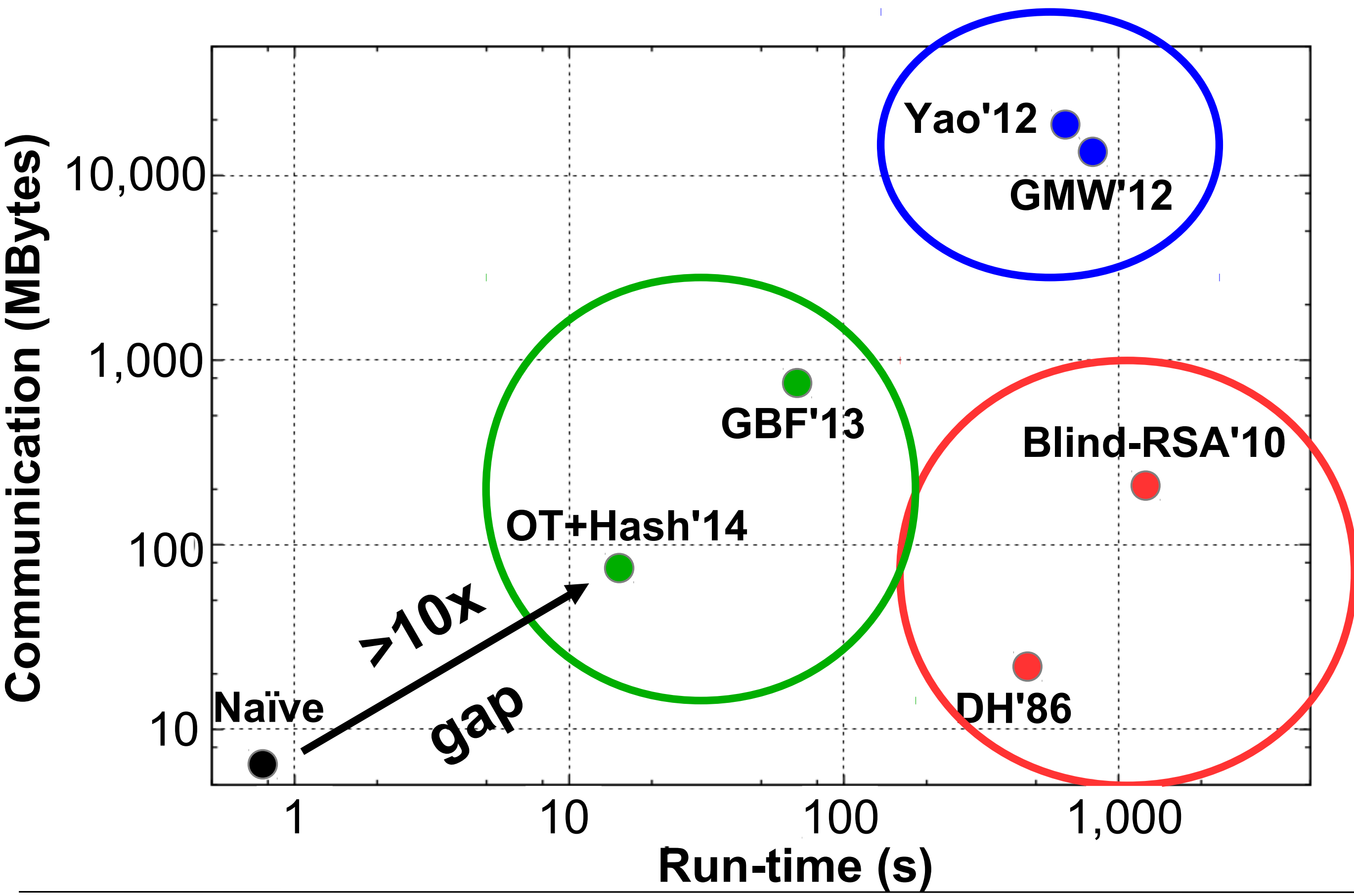
PSI on $n = 2^{18}$ elements of $\sigma=32$-bit length for 128-bit security on Gbit LAN



PK-Based:
- high run-time for large security parameters
+ best communication

Circuit-Based:
- high run-time & communication
+ easily extensible to arbitrary functions

OT-Based:
+ good communication and run-time

OT-Based:
+ good communication and run-time

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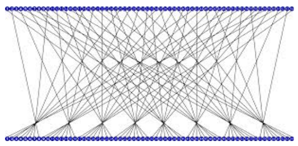
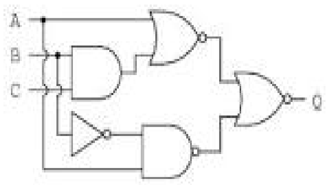
Our Contributions

Goal: Make PSI protocols more practical

Phasing:
PSI using Permutation-based Hashing



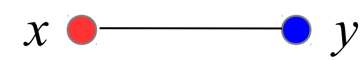
Circuit-Phasing:
Improvements on Circuit-based PSI [HEK12]



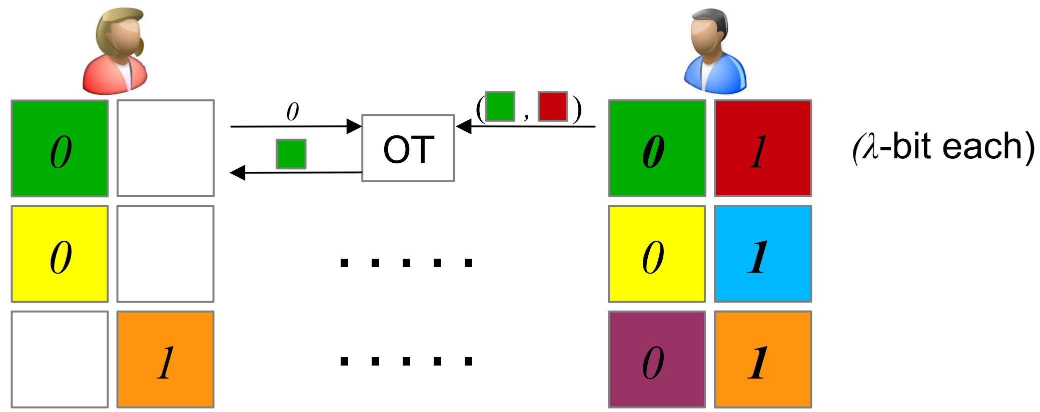
OT-Phasing:
Improvements on OT+Hashing [PSZ14]

OT+Hashing PSI [PSZ14]

Input: Alice has x, Bob has y. **Output:** $x \stackrel{?}{=} y$



Example: $x = 001$, $y = 011$, $\sigma = 3$, stat. sec. param. λ

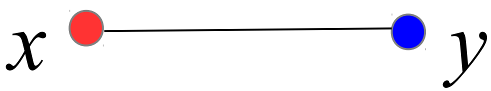


Bob sends λ-bit mask $0 \oplus 1 \oplus 1$ to Alice

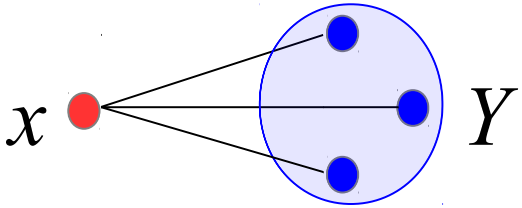
Alice computes $0 \oplus 0 \oplus 1$ and compares

OT+Hashing PSI [PSZ14] (cont.)

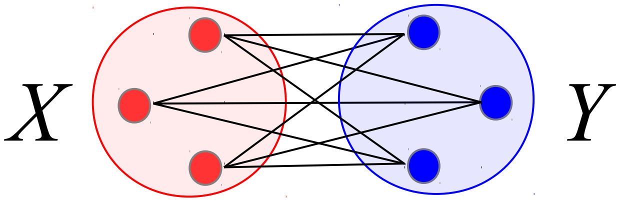
Private Equality Test:



Private Set Inclusion:



Private Set Intersection:



$O(n^2)$ comparisons!

Hashing to Bins [PSZ14]

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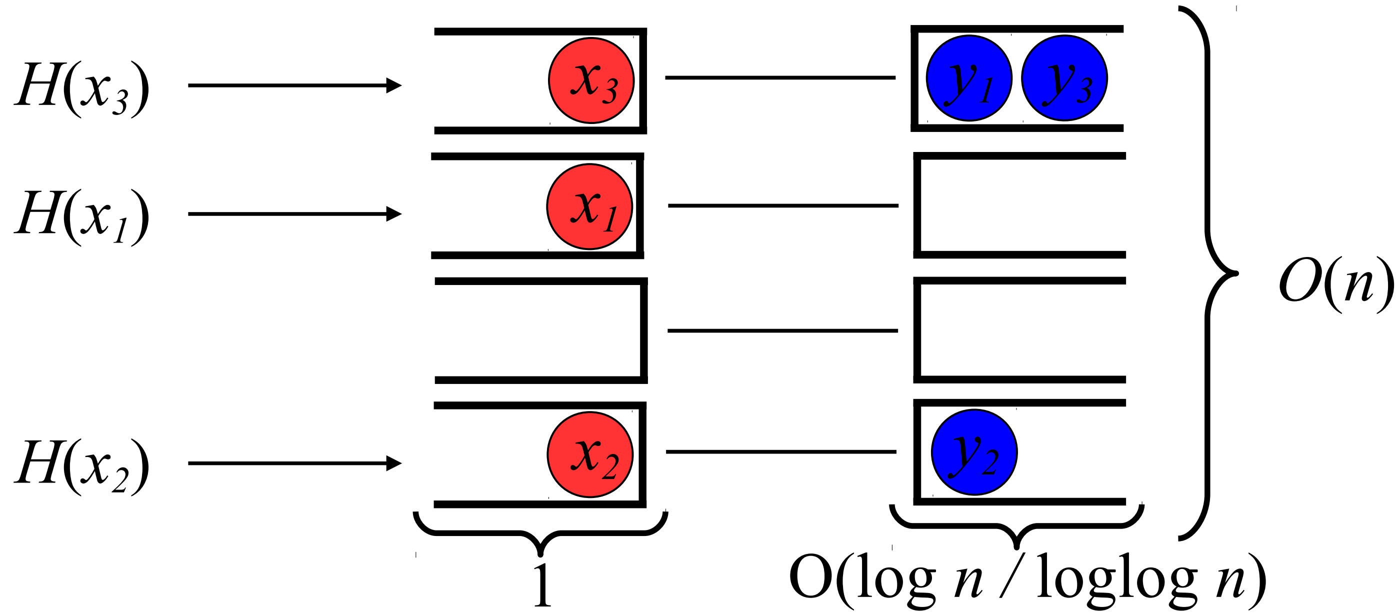
Hash elements to bins to reduce comparisons

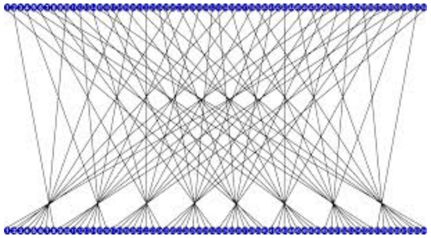
Example: Alice holds $X=\{x_1, x_2, x_3\}$, Bob holds $Y=\{y_1, y_2, y_3\}$



Reduces comparisons from $O(n^2)$ to $O(n \log n / \log\log n)$

Our Contributions (1)

Phasing:
PSI using Permutation-based Hashing



Permutation-based Hashing

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In [PSZ14] elements are **compared bit-wise**

- Hence, smaller elements require less overhead

Idea: "hash" elements to a **smaller representation**

- To avoid collisions the birthday paradox states that the hash must be $\lambda+2\log(n)$ bit

Instead: use a permutation to map elements to bins and store a shorter representation

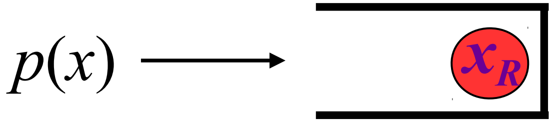
- Used for smaller hash tables [ANS10]
- Here: first use in crypto

Permutation-based Hashing (cont.)

Split $x = x_L | x_R$ with $|x_L| = O(\log n)$ bit

Let f: $[1 \ldots 2^{|x_R|}] \rightarrow [1 \ldots 2^{|x_L|}]$ and $p(x) = x_L \oplus f(x_R)$

Hashing is done by storing x_R in bin $p(x)$

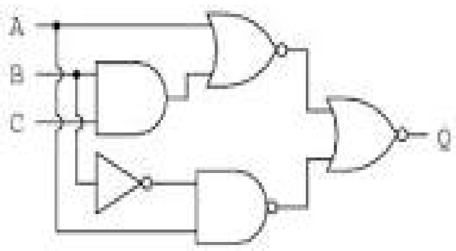


Securely compare x_R which is only σ-$|x_L|$ bit long

- Less complexity for comparison
- Larger sets mean less complexity for comparison

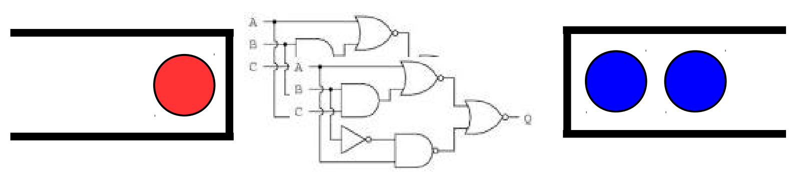
Our Contributions (2)

Circuit-Phasing



Circuit-Phasing

Idea: Use **permutation-based hashing** to hash elements into bins and compare bins on elements with reduced length



For each bin compare the element of Alice with each element in the same bin of Bob using bit-wise comparison circuit

Advantages:

- Communication rounds independent of set sizes
- Same circuit evaluated multiple time allows SIMD

Circuit-Phasing (cont.)

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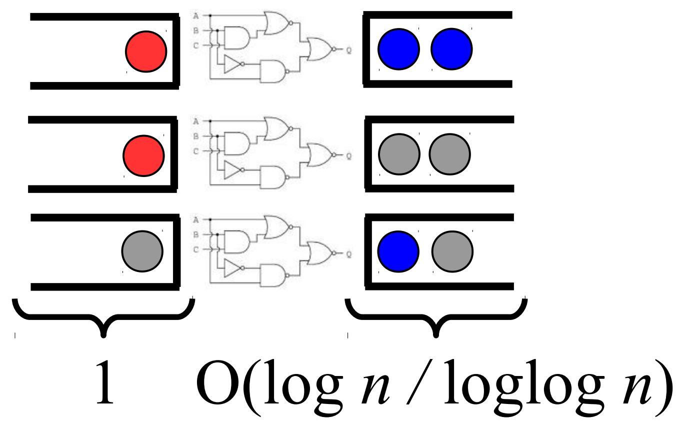
However, bins have to be padded to a to avoid information leakage



In total $O(n \log n / \log\log n)$ comparison circuits

- Per comparison: $O(\sigma\text{-}\log n)$ sym-crypto & comm
- Total: $O(n\ (\sigma\text{-}\log n) \log n / \log\log n)$ sym-crypto & comm
- SCS circuit [HEK12]: $3n\sigma \log n$ sym-crypto & comm

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Improvements Circuit-based PSI

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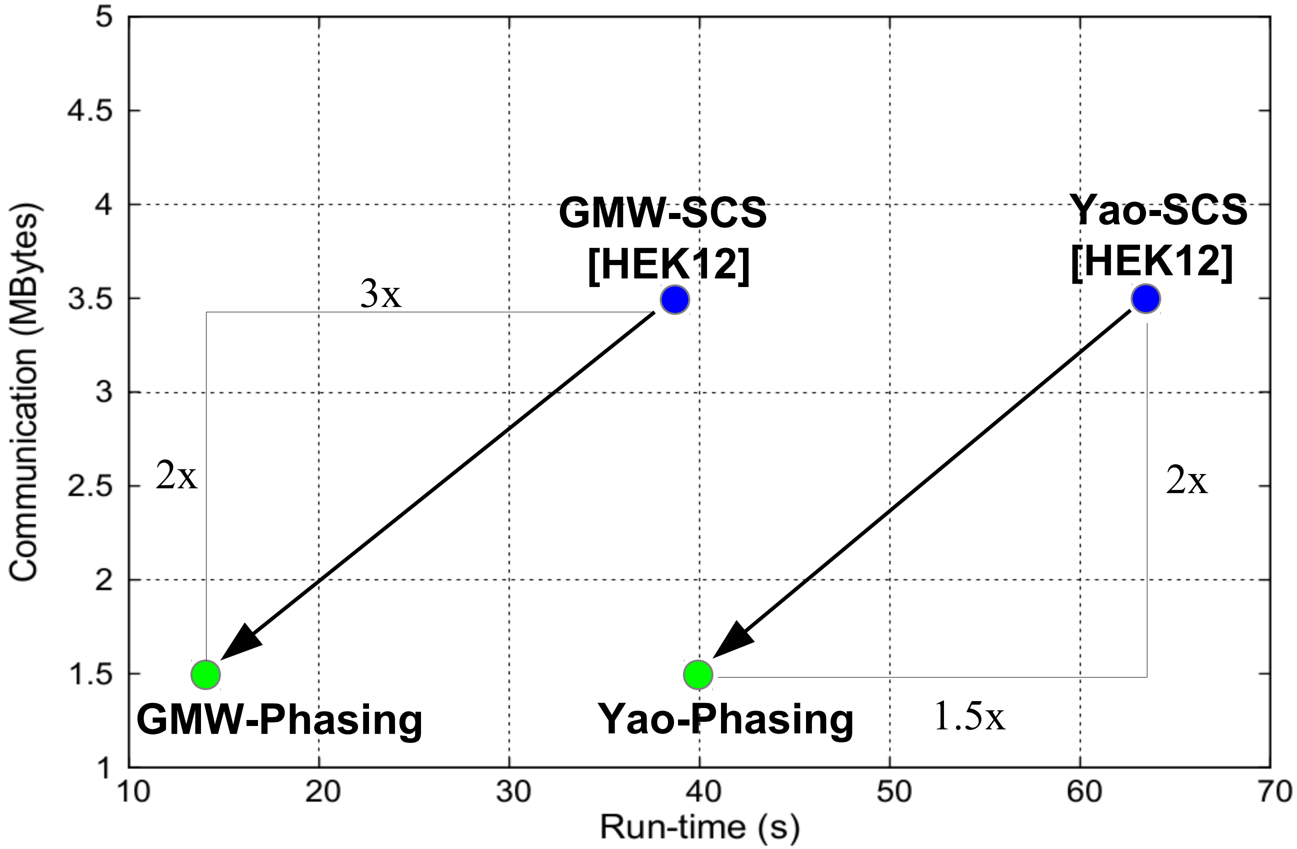
PSI on $n = 65.000$ elements of $\sigma=32$-bit length for 128-bit security on Gbit LAN



Our Contributions (3)

OT-Phasing

OT-Phasing

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Use permutation hashing in OT+Hasing protocol [PSZ14]

Further protocol optimizations:

Use more hash functions for the hashing-to-bins routine

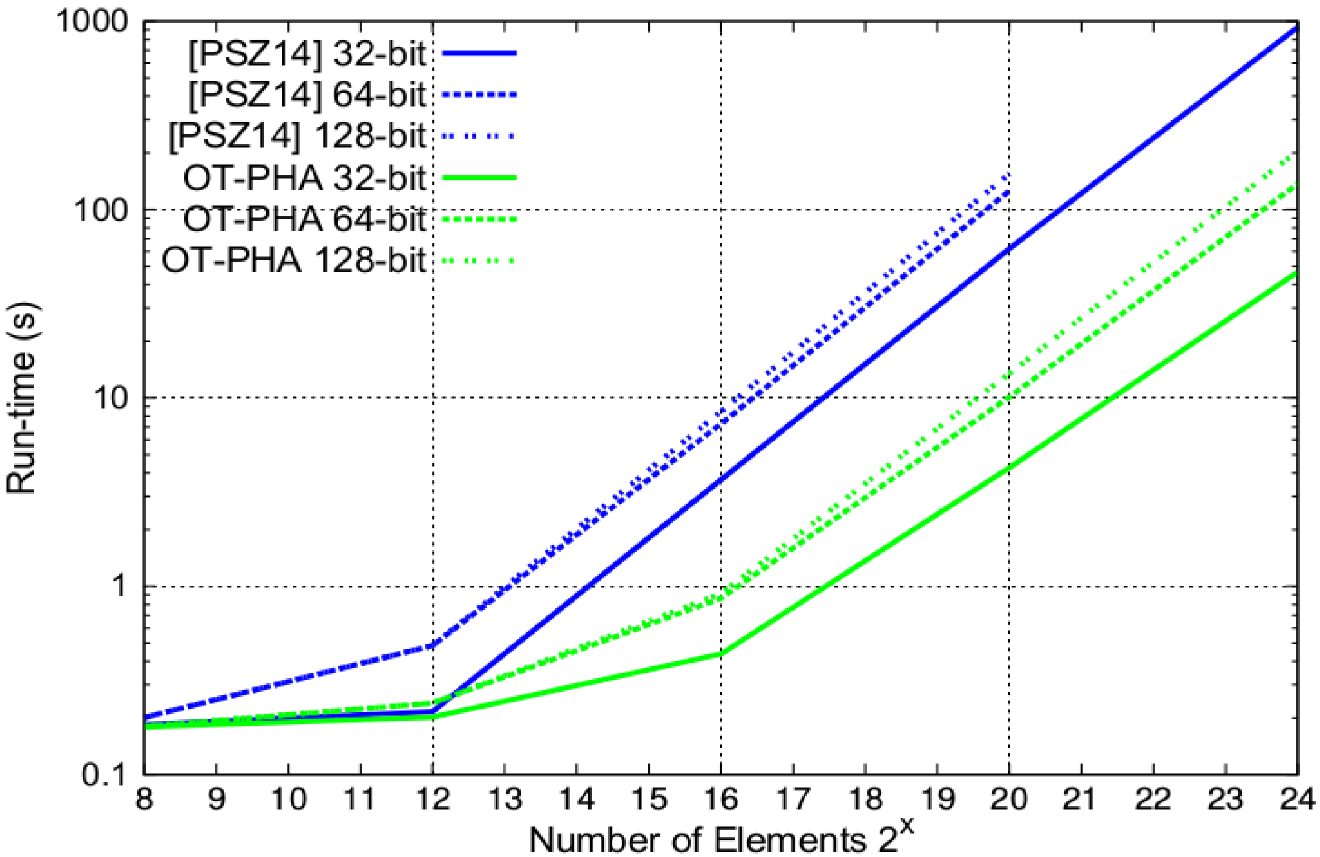
- decreases number of bins by factor 2

Generate only one random string per bin

- decreases client's work for larger sets

Improvements OT-based PSI

PSI on varying set sizes of different length for 128-bit security on Gbit LAN



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Improvements OT-based PSI (cont.)

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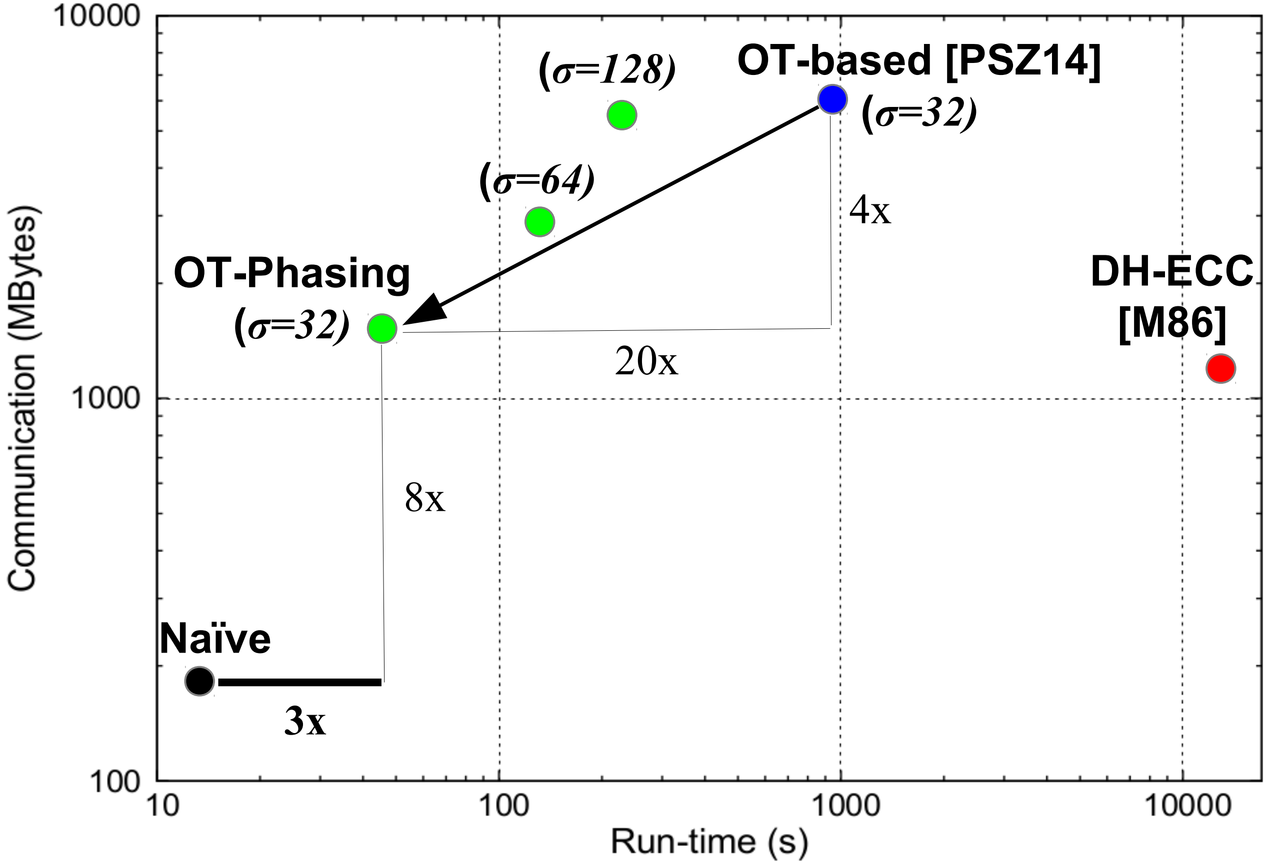
PSI on $n=16$ mio elements of different length for 128-bit security on Gbit LAN



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Conclusion

More efficient PSI protocols with reduced overhead

- Only factor 3 slower than currently used (insecure) solutions

Permutation hashing to reduce bit-length of elements

More efficient and scalable Circuit-based PSI

Code is online on GitHub http://encrypto.de/PSI

Phasing: Private Set Intersection using Permutation-based Hashing

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Questions?

References

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[DCW13] C. Dong, L. Chen, Z. Wen: When private set intersection meets big data: An efficient and scalable protocol. In ACM CCS'13.

[PSZ14] B. Pinkas, T. Schneider, M. Zohner: Faster PSI based on OT extension. In USENIX'14.

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