Laconic Function Evaluation for Turing Machines

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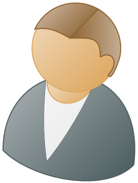
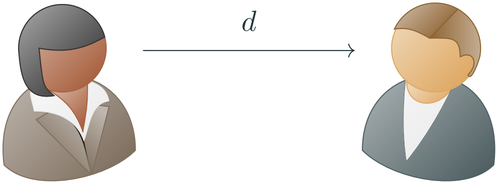
PKC 2023: 26th International Conference on Theory and Practice of Public Key Cryptography, Atlanta, USA

- Laconic function evaluation and applications
- Prior work and problem statement
- Our results and new applications

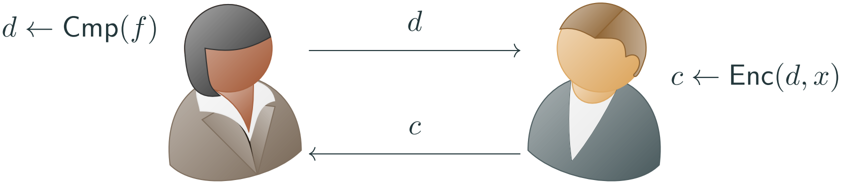
LACONIC FUNCTION EVALUATION

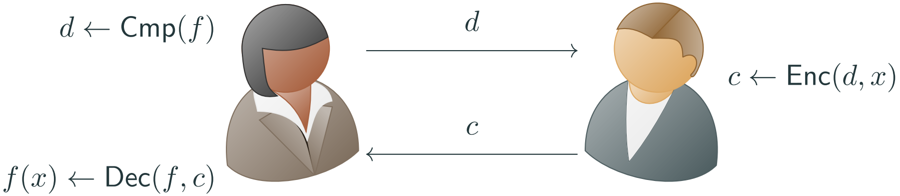


$d \leftarrow \mathsf{Cmp}(f)$



LACONIC FUNCTION EVALUATION [QWW18]

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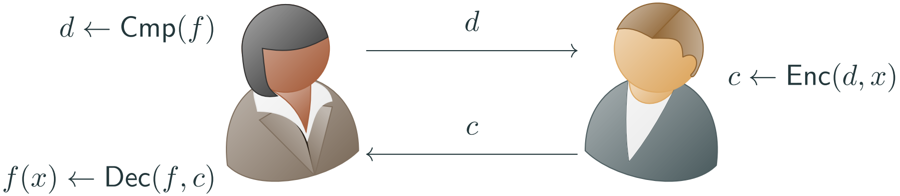
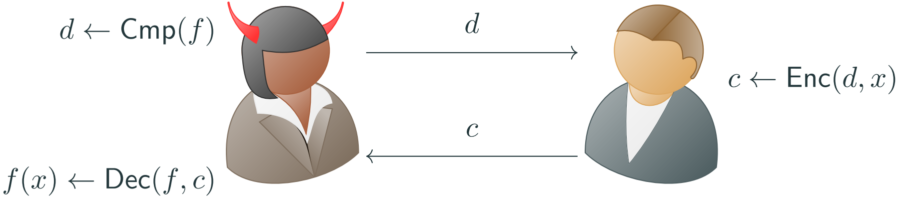
c
$f(x) \leftarrow \mathsf{Dec}(f, c)$



Alice's digest:

- Depends on f
- Is short (Bob has to read it)



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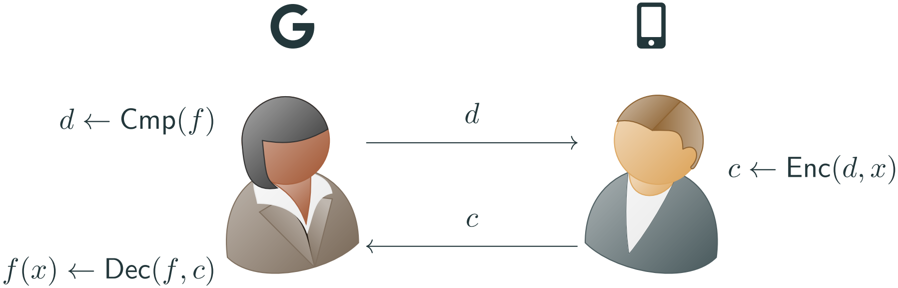
Bob's ciphertext:

- Hides x (not $f(x)$)
- Efficient to compute



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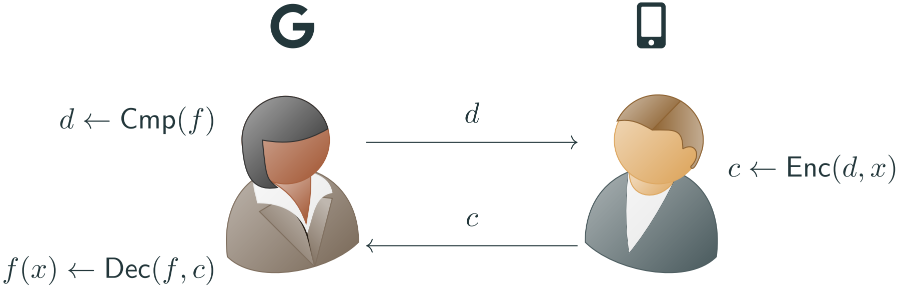
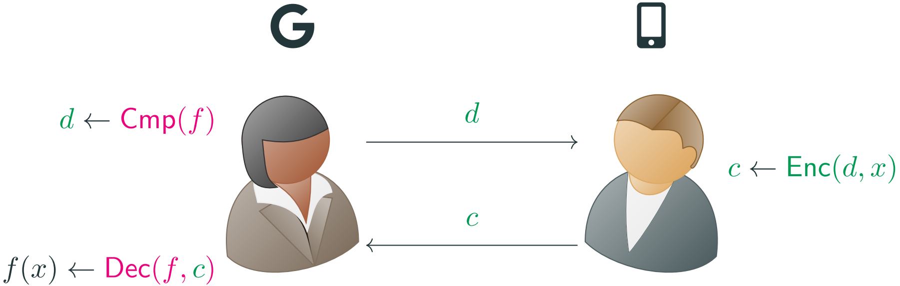


Correctness:

- $\mathsf{Dec}(f, c) = f(x)$



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Efficiency:

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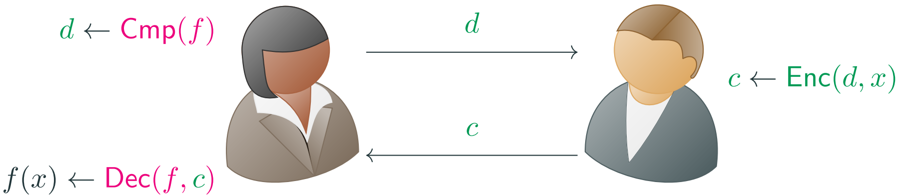

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- $\mathsf{Dec}(f, c) = f(x)$

Efficiency:

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Security:

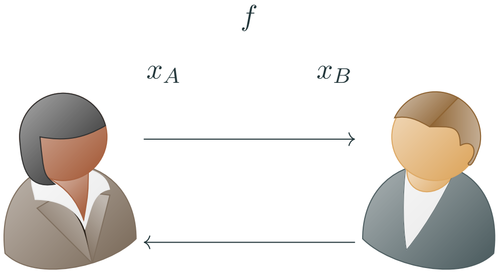
- c hides x - only reveals $f(x)$

APPLICATIONS

f

x_A x_B

APPLICATION: SUCCINCT 2-PARTY COMPUTATION



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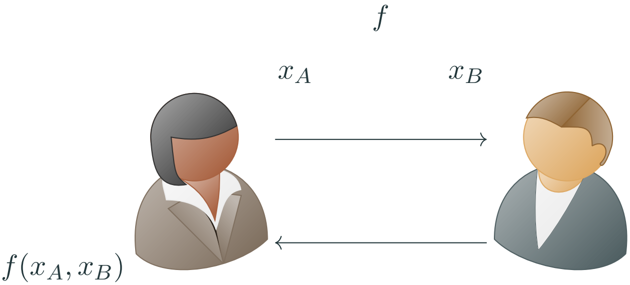
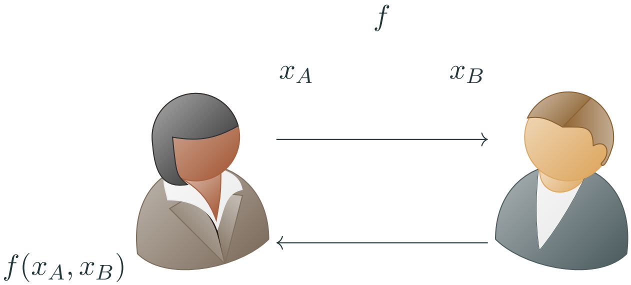




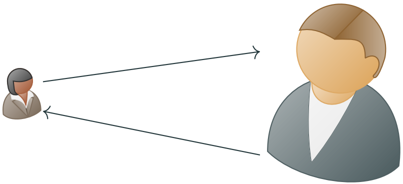
Security:

- Alice only learns $f(x_A, x_B)$ and Bob doesn't learn anything

Efficiency:

- Communication + computation $\ll$ computing $f(x_A, x_B)$

SUCCINCT 2-PC: ALICE-OPTIMISED PROTOCOL VIA FHE



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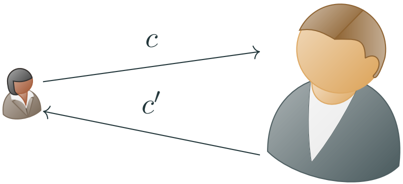
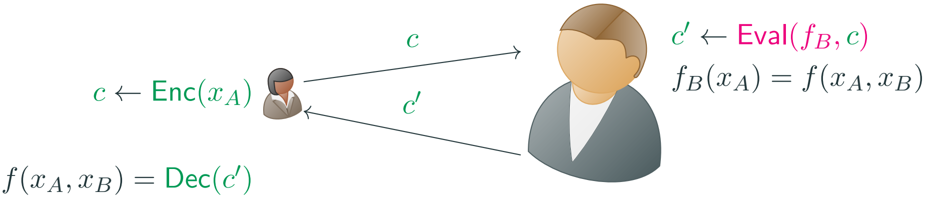


$c' \leftarrow \mathsf{Eval}(f_B, c)$

$f_B(x_A) = f(x_A, x_B)$

$f(x_A, x_B) = \mathsf{Dec}(c')$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SUCCINCT 2-PC: BOB-OPTIMISED PROTOCOL VIA FUNCTION HIDING LFE

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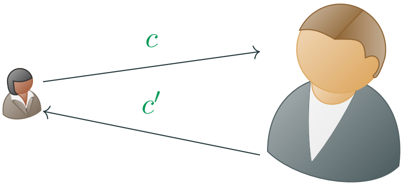

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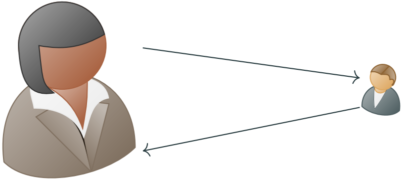

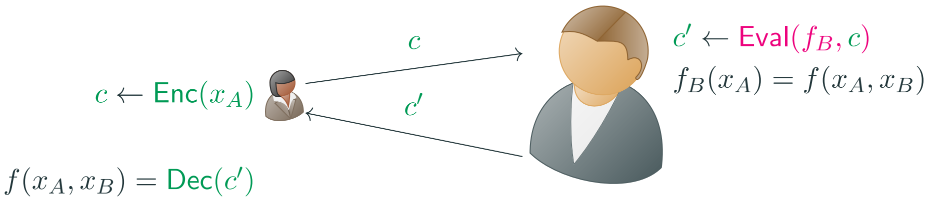
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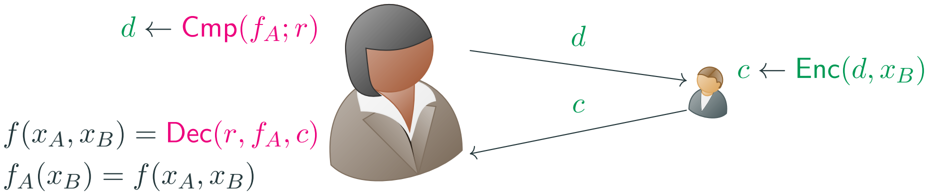
$d \leftarrow \mathsf{Cmp}(f_A; r)$
d
c
$c \leftarrow \mathsf{Enc}(d, x_B)$
$f(x_A, x_B) = \mathsf{Dec}(r, f_A, c)$
$f_A(x_B) = f(x_A, x_B)$

Direct applications:

- MPC with low online computation [QWW18]
- Adaptively secure MPC with sublinear communication complexity [CsW19]
- Compact NIZKs from various assumptions [KNYY19]

Techniques used for laconic cryptography have led to:

- Laconic Conditional Disclosure of Secrets [DGGM19]
- Single-server private-information retrieval from weaker assumptions [DGI+19]
- Identity-based encryption from weaker assumptions [DG17a, DG17b, BLSV18]
- Two-round MPC from minimal assumptions [GS17, GS18c, BL18]
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PRIOR WORK

[**QWW18**] First construction of LFE from LWE

[**PCFT20**] Generalisations and construction from iO

[**Ros22**] Stronger security for specific class of circuits

Problem: Ciphertext (and runtime of Enc) grow polynomially with depth of circuit

Think of: "Leveled" FHE vs. "pure" FHE

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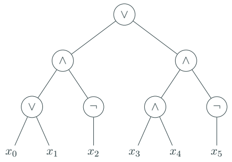

Problem: Ciphertext (and runtime of Enc) grow polynomially with depth of circuit

Think of: “Leveled” FHE vs. “pure” FHE

"Is it possible to construct LFE where the size of the ciphertext and the runtime of Enc ***are independent of the circuit depth?"***

CONTRIBUTIONS

Theorem (Informal)

$$\boldsymbol{iO} + \boldsymbol{ULOT} \implies \boldsymbol{LFE}$$

- $|d| = \mathsf{poly}(\lambda)$
- $\mathsf{Enc} = \mathcal{O}(|x|) \cdot \mathsf{poly}(\lambda)$
- $|c| = \mathcal{O}(|x|) \cdot \mathsf{poly}(\lambda)$

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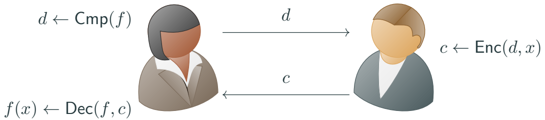

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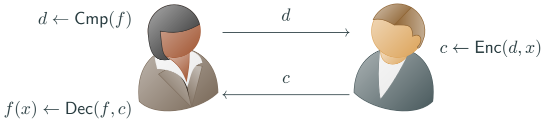

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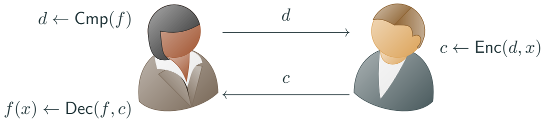

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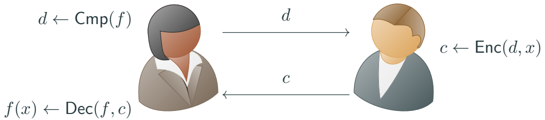


CONSTRUCTION

Indistinguishability Obfuscation

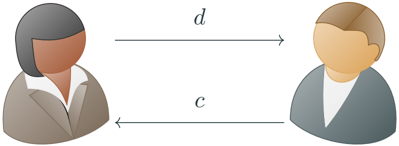
$$C_0(x) \quad = \quad C_1(x) \quad \Longrightarrow \quad i\mathcal{O}(C_0)(x) \quad \approx \quad i\mathcal{O}(C_1)(x)$$

Indistinguishability Obfuscation

$$C_0(x) = C_1(x) \implies i\mathcal{O}(C_0)(x) \approx i\mathcal{O}(C_1)(x)$$

Updatable Laconic Oblivious Transfer

$d \leftarrow \mathsf{ULOT.Hash}(D)$



$c \leftarrow \mathsf{ULOT.Send}\,(d, L, \{m_0, m_1\})$

$m_{D[L]} \leftarrow \mathsf{ULOT.Receive}(L, c)$

$d \leftarrow \mathsf{Cmp}(f)$

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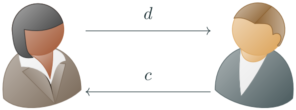

$f(x) \leftarrow \mathsf{Dec}(f, c)$

- **while** $i \neq T$
- Run obfuscated Step Circuit at i
- $\mathsf{ULOT.Receive}$ returns the inputs for $i\mathcal{O}(\mathsf{SC}_{i+1})$
- $f(x) \leftarrow$ last output from Step Circuit

$c \leftarrow \mathsf{Enc}(d, x)$

- Obfuscate Step Circuit SC as

  $i\mathcal{O}(\mathsf{SC}) \leftarrow$ Step Circuit SC
  - Perform 1 step of the computation
  - Write outputs to DB using $\mathsf{ULOT.Send}$
- Encrypt input x
- $c \leftarrow (i\mathcal{O}(\mathsf{SC}), \mathsf{Sym.Enc}(x))$

- The proof follows from a pebbling strategy similar to [GS18b]

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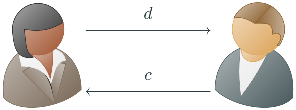

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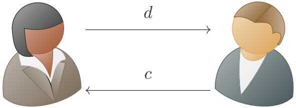

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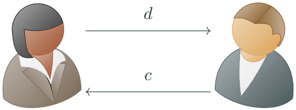

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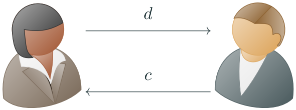

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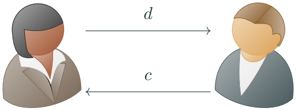

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- Witness encryption [GGSW13] where $|c|$ depends only on $|w|$ and λ
- First ABE for Turing machines [GKP+13] from falsifiable assumptions

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CONCLUSION

Contributions:

- Asymptotically optimal Laconic Function Evaluation for Turing machines
- New applications:
  - NIZK with optimal prover complexity
  - WE and ABE for Turing machines from falsifiable assumptions

ia.cr/2023/502

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PKC 2023

Contributions:

- Asymptotically optimal Laconic Function Evaluation for Turing machines
- New applications:
  - NIZK with optimal prover complexity
  - WE and ABE for Turing machines from falsifiable assumptions

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PKC 2023

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