Ferret: Fast extension for correlated OT with small communication

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Part 0 Overview

Contributions

Protocol

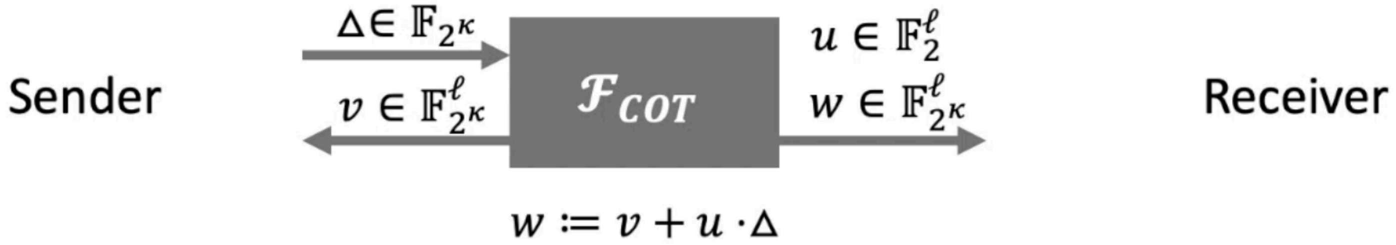
- Efficient correlated OT for ***semi-honest*** and ***malicious security***
- Based on Learning Parity with Noise (LPN) assumption

Open-sourced ***implementation***

- Communication: 0.45 bits per COT
- Computation:
  - 50 Mbps = 17 ns per COT
  - 10 Gbps = 13 ns per COT

Pre-knowledge

Correlated Oblivious Transfer (COT)

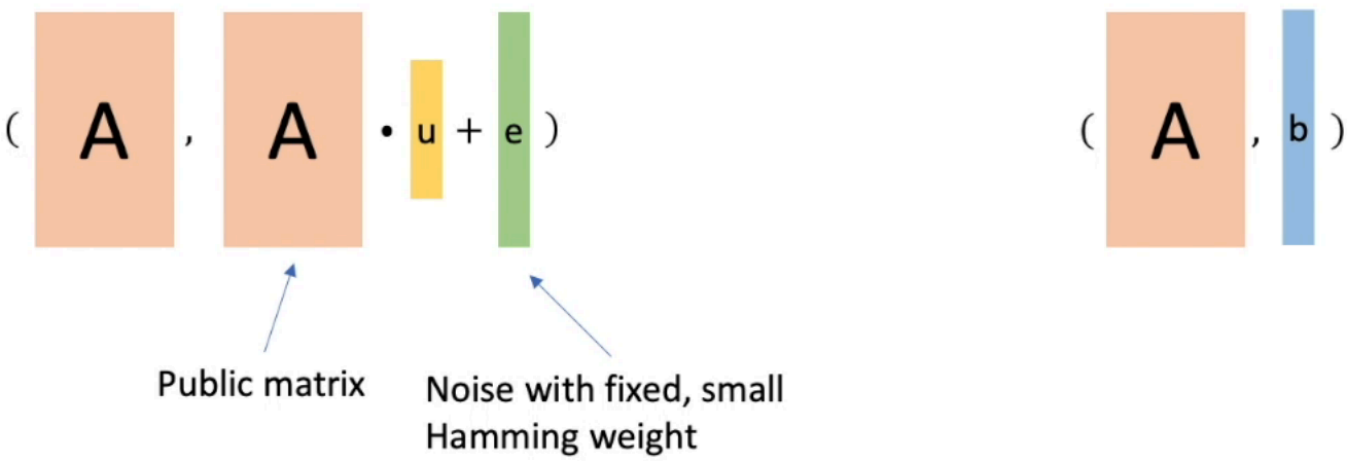


Application:

- Other variations of OT, ROT, OT...
- Semi-honest protocols: Garbled Circuit, GWM, ...
- Malicious protocols: SPDZ(MASCOT), TinyOT, Authenticated Garbling, ...
- Zero-knowledge proofs: GC-based ZK, ...
- Specific protocols: PSI, threshold ECDSA, ...

The primal-LPN assumption

$$\{(A,b) \mid A \leftarrow C(k,n,\mathbb{F}_2),\ e \in D_{k,n},\ u \in \mathbb{F}_2^k,\ b = u \cdot A + e\} \approx \{(A,b) \mid A \leftarrow C(k,n,\mathbb{F}_2),\ b \in \mathbb{F}_2^k\}$$



Steps:

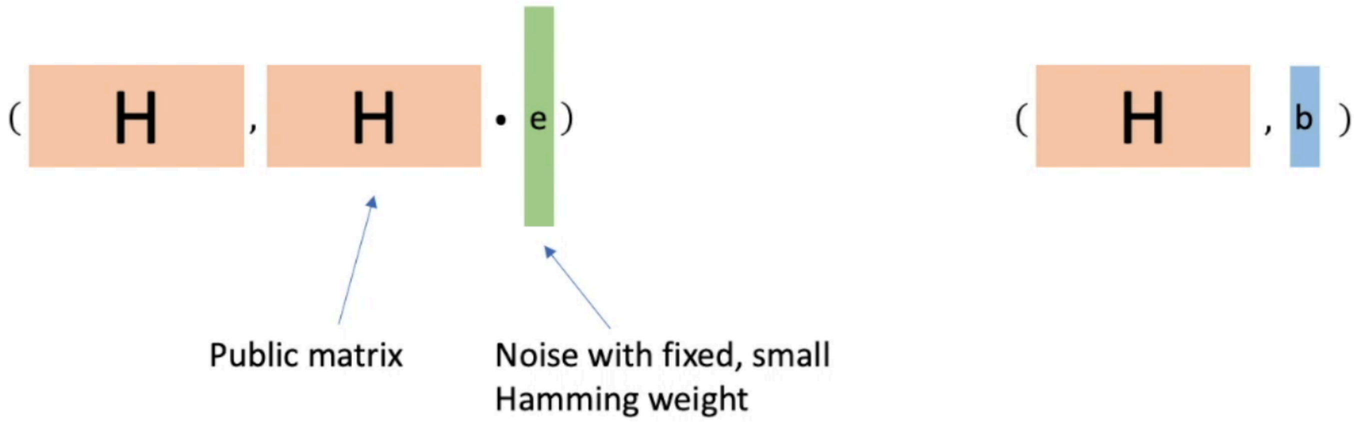
1. Obtain k COTs with choice bits **u.** (k<<n)
   - $w = v + u \cdot \Delta$;
   - 

2. Obtain n COTs with choice bits ***e***. (Comm. = $O(logn)$)
   - $r = s + e \cdot \Delta$;

3. Combine them based on LPN assumption.
   - $z = y + x \cdot \Delta$;

The dual-LPN assumption

$\{(H, b) \mid H \leftarrow C^{\perp}(N, n, \mathbb{F}_2),\ e \in D_{k,n},\ u \in \mathbb{F}_2^k,\ b = e \cdot H\} \approx \{(H, b) \mid A \leftarrow C^{\perp}(N, n, \mathbb{F}_2),\ b \in \mathbb{F}_2^k$

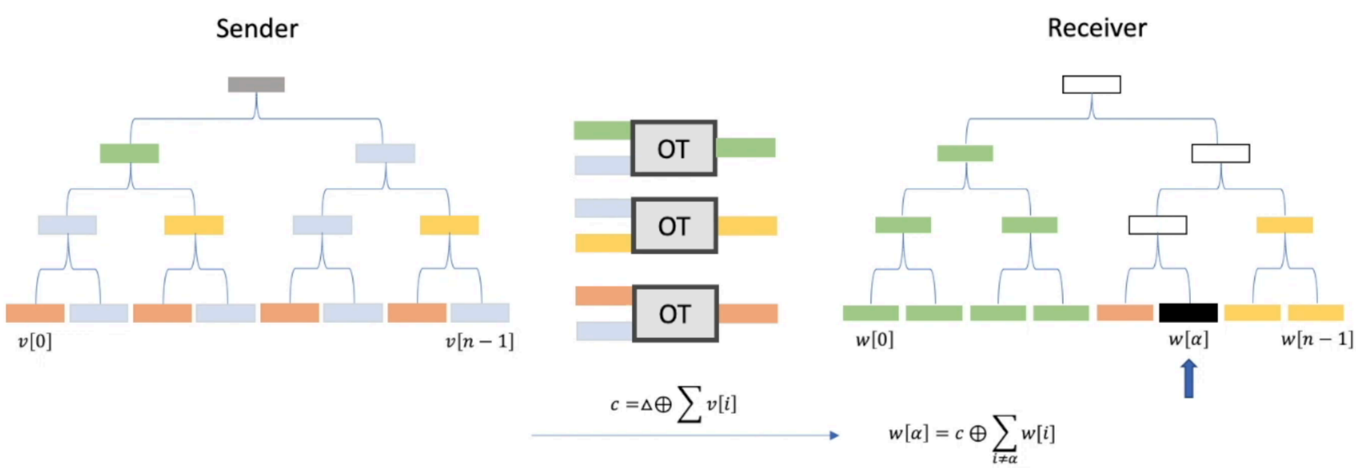


Cheap communication: $O(t)$;

Heavy computation: e.g. FFT

Single-point correlated OT (SPCOT)

General idea: The receiver's choice bit is "1" at only one position



$$w[i] = \begin{cases} v[i], & i \neq \alpha \\ v[i] \oplus \Delta, & i = \alpha \end{cases}$$

Result: VOLE based on LPN assumption

Protocol	Assumption	Security	Communication	Computation
Boyle et al. [BCG19]	Dual-LPN	Malicious	Low	High
Schoppmann et al. [SGRR19]	Primal-LPN	Semi-honest	High	Low
Ferret	Primal-LPN	Malicious	Low	Low

Noise type	Security	Comm./COT (bits)	Time/COT (ns)	
			50Mbps	10Gbps
Regular	Semi-honest	0.44	21.5	16.0
	malicious		22.0	18.5

50Mbps	10Gbps
16.7	11.8
17.0	13.5

Key ideas

1. Iteration
2. SPCOT with malicious security for free (1ns)
   - Prior approach
     - Too many calls to PRG & hash a long string
   - Their approach - random correlation check
     - The S and R have
       - $v + w = l(n, \{\alpha\}) \cdot \Delta$
     - Check the random linear combination
       - $\sum_{i \in [n]} x_i \cdot v[i] + \sum_{i \in [n]} x_i \cdot w[i] = x_\alpha \cdot \Delta$
   - Performance gain from local computation + hardware support

Performance

Security	Protocol	Comm./COT (bits)	Time/COT (ns)	
			50Mbps	1Gbps
Semi-honest	[ALSZ13]	128	2570.4	32.4
	[BCG+19] (regular)	0.1	196.1	196.6
	Ferret (regular)	0.44	21.5	16.0
Malicious	[KOS15]	128	2573.6	34.4
	[BCG+19] (regular)	0.1	209.9	209.5
	Ferret (regular)	0.44	22.0	18.5

Setup time
< 184 ms (50 Mbps)
< 30 ms (10 Gbps)

Uniform noise-LPN supported with some performance penalty

Follow up work

- Subfield VOLE for prime field $\mathbb{F}_p$. (malicious, $p = 2^{61} - 1$)
  - 87 ns/field element at 50 Mbps
- Zero-knowledge proofs of boolean & arithmetic circuits
  - Information-Theoretic MACs
  - In the pre-processing model

Circuit Type	Bandwidth	Performance
Binary	50 Mbps	<0.50 us/gate
Arithmetic (61-bit prime)	500 Mbps	<1 us/gate

Part 1 Preliminaries

- $x \leftarrow S$: denotes sampling ? uniformly at random from a finite set S;
- $x \leftarrow D$: denotes sampling ? according to the distribution D;
- $u = I(n, S)$: For any $n \in \mathbb{N}$ and a subset $S \subseteq [n]$, u denotes an n-bit vector, where $u[i] = 0$ for all $i \in \{[n] \wedge \bar{S}\}$ and $u[i] = 1$ for all $i \in S$;
- $X \approx^c Y$: X and Y are computationally indistinguishable.

Functionality $\mathcal{F}_{\mathsf{COT}}$

Initialize: Upon receiving (init, Δ) from a sender S where global key $\Delta \in \mathbb{F}_{2^\kappa}$, and (init) from a receiver R, store Δ and ignore all subsequent (init) commands.

Extend: Upon receiving (extend, ℓ) from S and R, this functionality operates as follows:

- Sample $\boldsymbol{v} \leftarrow \mathbb{F}_{2^\kappa}^{\ell}$. If S is corrupted, instead receive $\boldsymbol{v} \in \mathbb{F}_{2^\kappa}^{\ell}$ from the adversary.
- Sample $\boldsymbol{u} \leftarrow \mathbb{F}_2^{\ell}$ and compute $\boldsymbol{w} := \boldsymbol{v} + \boldsymbol{u} \cdot \Delta \in \mathbb{F}_{2^\kappa}^{\ell}$.
- If R is corrupted, receive $\boldsymbol{u} \in \mathbb{F}_2^{\ell}$ and $\boldsymbol{w} \in \mathbb{F}_{2^\kappa}^{\ell}$ from the adversary, and recompute $\boldsymbol{v} := \boldsymbol{w} + \boldsymbol{u} \cdot \Delta$.

Outputs: Send $\boldsymbol{v}$ to S and $(\boldsymbol{u}, \boldsymbol{w})$ to R.

Figure 1: Correlated OT functionality.

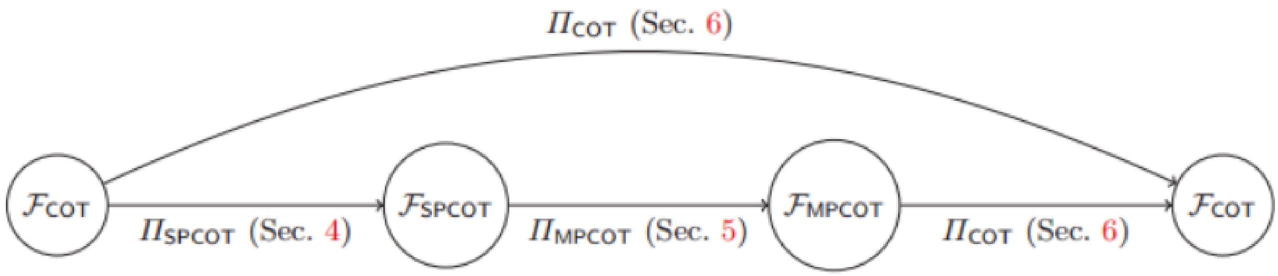


Figure 2: Relations of the functionalities and protocols considered in this paper. $A \xrightarrow{C} B$ denotes that protocol C securely realizes functionality B in the A-hybrid model.

Part 2 SPCOT

General Idea:

> The semi-honest SPCOT protocol works by the sender computing a GGM tree with n leaves (namely {v[i]} i�� [n]) and the receiver obtaining all-but-one of the leaves (namely {v[i]}i �� [n]\{α}) using an OT protocol. Then the sender can send �� +$\sum_{i\in[n]}$v[i] to the receiver who can compute v[α] + �� locally, which completes the semi-honest protocol.

Detailed Protocol Discription:

Parameters

- a length doubling PRG $G: \{0,1\}^\kappa \rightarrow \{0,1\}^{2\kappa}$;

- a tweakble CRHF $H : \{0,1\}^{2\kappa} \to \{0,1\}^{\kappa}$;
- a cryptographic hash function $H' : \mathbb{F}_{2^\kappa} \to \{0,1\}^{2\kappa}$ as a random oracle.

Inputs

Sender

- a gloabal secret key $\Delta \in \mathbb{F}_{2^\kappa}$;
- an integer $n = 2^h, h \in \mathbb{N}$.

Receiver

- same integer $n = 2^h, h \in \mathbb{N}$;
- a single point $\alpha \in [n]$.

Protocol

Initialize: (one time only execution)

- S sends (init, ��) to F_{COT};
- R sends (init) to F_{COT}.

Extend: (multiple execution allowed)

1. This step is preparing the corelated vectors over $\mathbb{F}_b^\kappa$. Later in step 3 we will use those vectors to mask the information online, and reconstruct the GGM tree locally at the receiver site in step 4.
    - S and R send (extend, h) to F_{COT};
    - The functionality returns $q_i \in \{0,1\}^\kappa$ to S;
    - The functionality returns $(r_i, t_i) \in \{0,1\} \times \{0,1\}^\kappa$ to R, where $t_i = q_i \oplus r_i \cdot \Delta$, for $i \in \{1, ..., h\}$.
2. This step is generating the GGM tree by using a length doubling PRG, and compute seeds K_0^i and K_1^i both locally at the sender's site.
    - S picks a random $s_0^0 \in \{0,1\}^\kappa$.
    - S computes $(s_{2j}^i, s_{2j+1}^i) = G(s_j^{i-1})$, for each $i \in \{1, ..., h\}, j \in [2^{i-1}]$;
    - S computes $K_0^i = \oplus_{j \in [2^{i-1}]} s_{2j}^i$, and $K_1^i = \oplus_{j \in [2^{i-1}]} s_{2j+1}^i$;
    - (need a picture here)
3.

Part 3 MPCOT

Part 4 Final COT

Part 5 Evaluation