Ontario Cryptography Day 2026

Non-Interactive Secure Computation with Constant Communication Overhead

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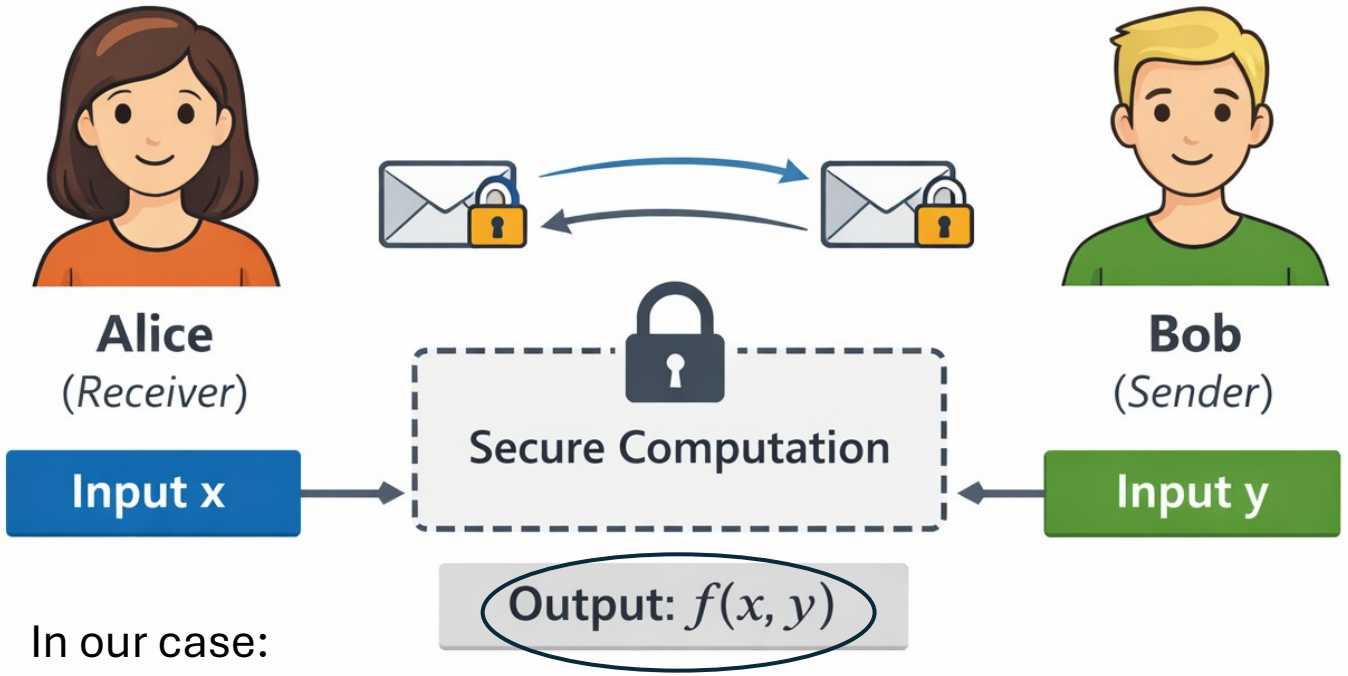
*This work is not associated with AWS

Secure Two-Party Computation

Alice learns nothing beyond x and *f*(x,y)

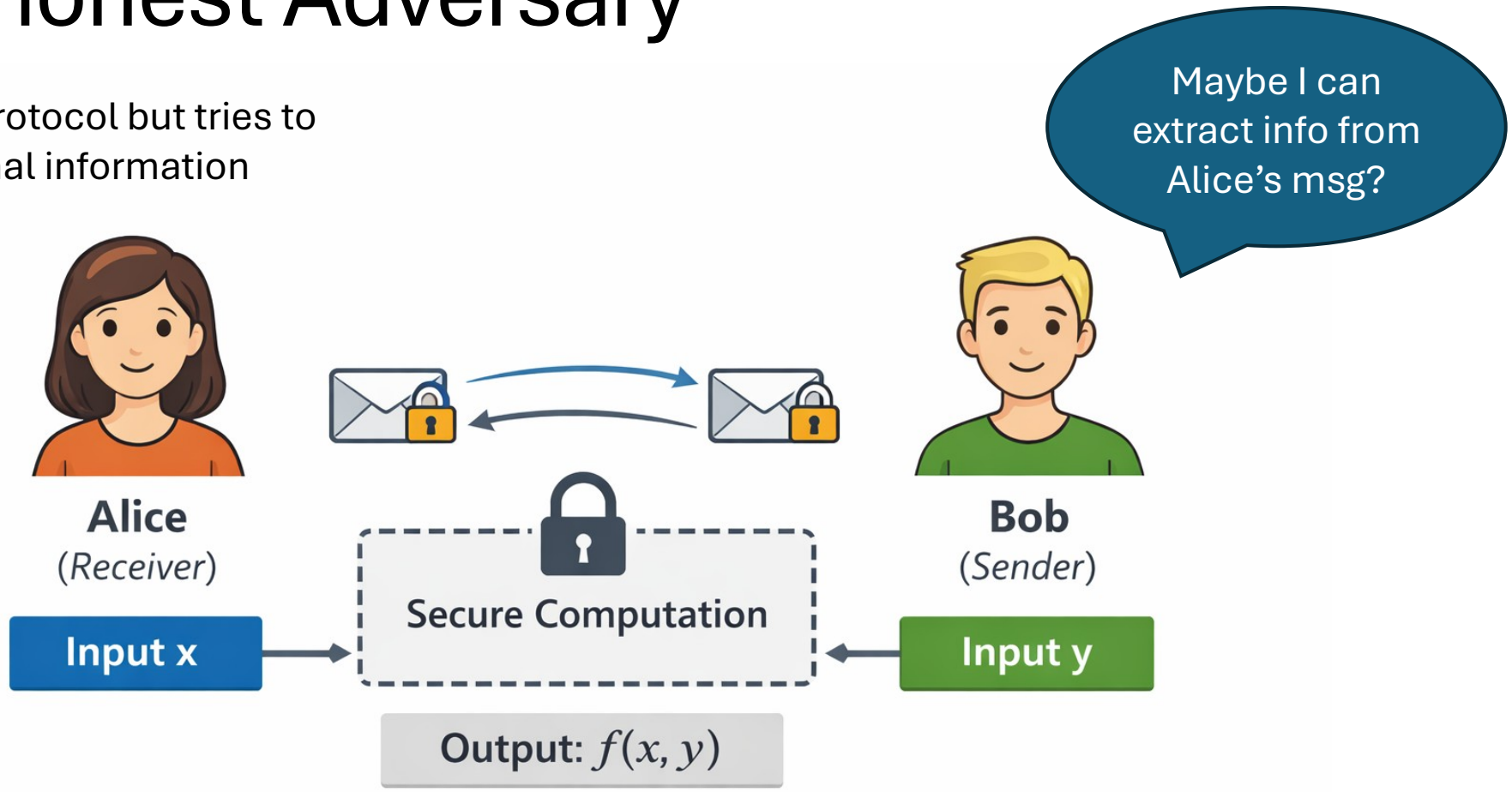
Bob learns nothing beyond y



In our case: only Alice learns the output.

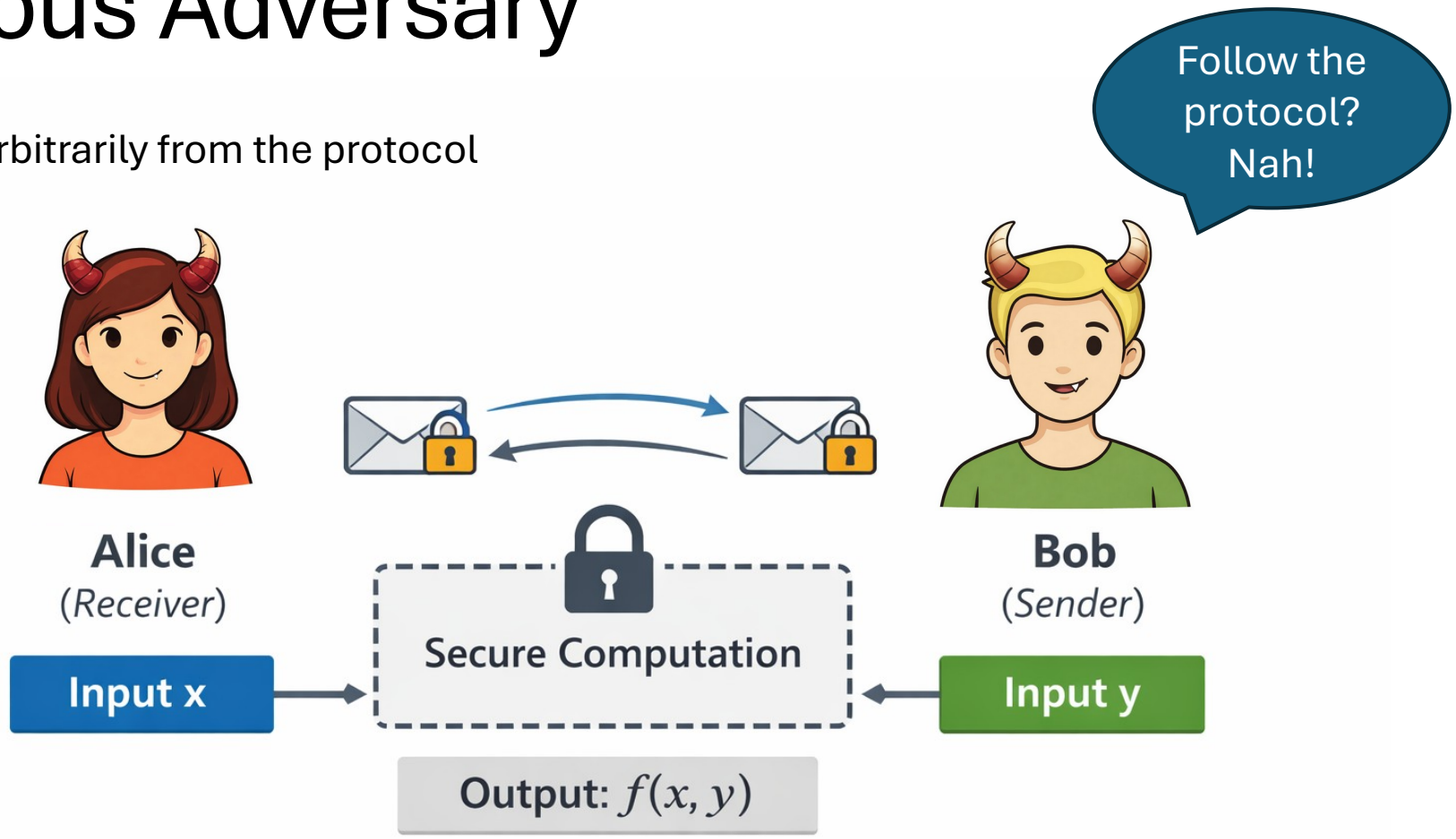
Semi-honest Adversary

Follows the protocol but tries to learn additional information from its view

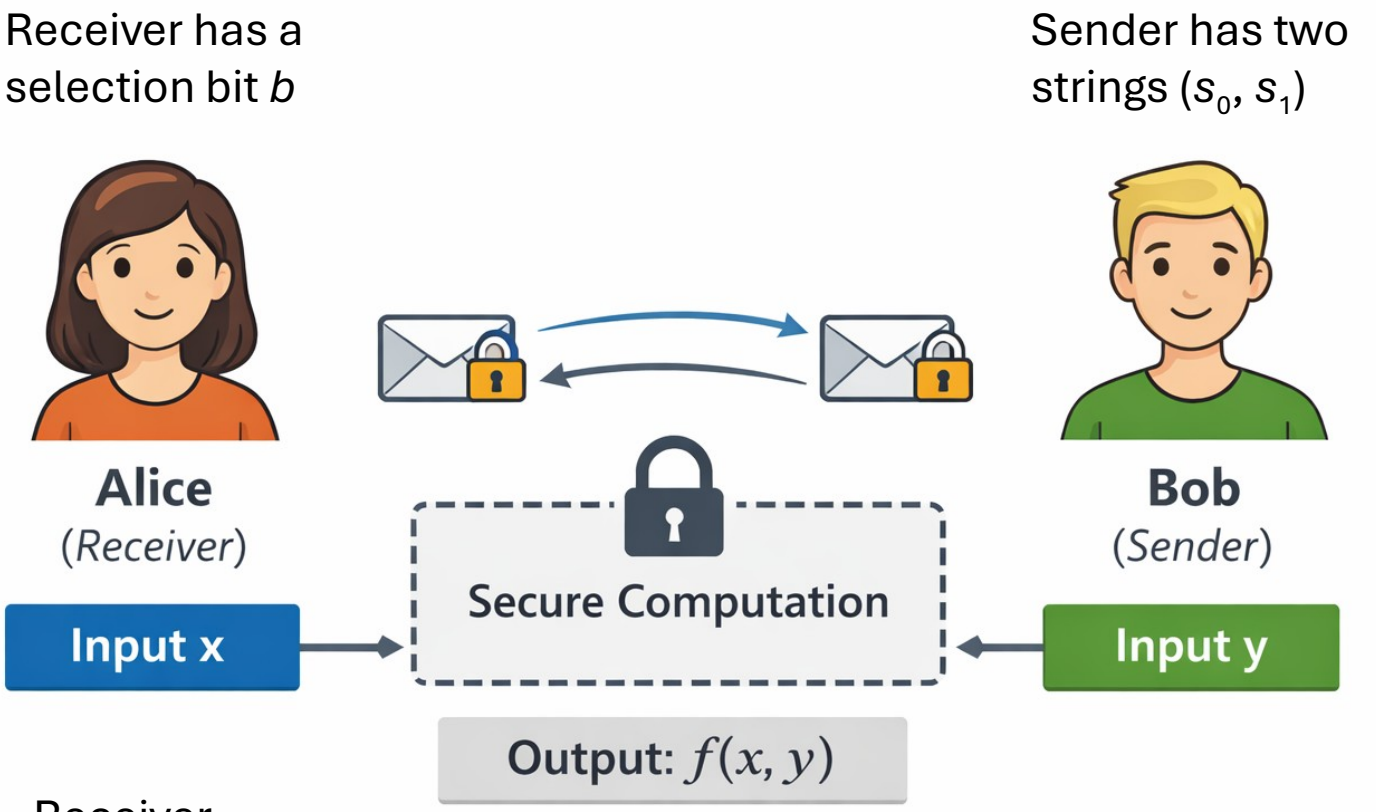


Malicious Adversary

Can deviate arbitrarily from the protocol



Oblivious Transfer (OT)



Garbled Circuits [Yao 86]

λ: computational security parameter

First-round OT msg to obtain keys for Alice's input

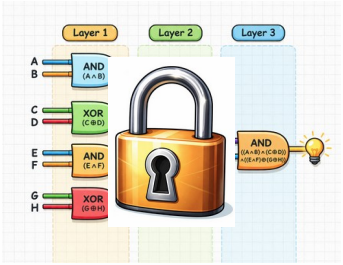
Alice
(Receiver)

Evaluates the garbled circuit to obtain $C(x,y)$

Bob
(Sender)

Generates the garbled circuit + all the keys

OT response



keys for Bob's input

Input x

Input y

Semi-Honest

Two rounds (NISC)

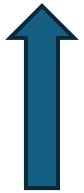
Communication: $O(|C|\lambda)$

Assume two-round OT

Can malicious NISC protocols match the communication complexity of the semi-honest Yao's garbled circuits?

Generic Transformation [GMW 87]

- Using a generic non-interactive zero-knowledge proof, we can upgrade semi-honest security to malicious security.
  - Can be constructed in the random oracle model.
  - However, it makes a non-black-box use of cryptographic primitives.



less efficient, less modular

Can we achieve malicious security with only black-box use of cryptographic primitives?

Black-Box Compilers [IPS 08, IKSS 22]

- Malicious security
- Two rounds
- Assumptions: Random Oracle and OT correlations
- Communication: $O(|C|) \cdot \text{poly}(\lambda)$

Consistency checks for Verifiable Secret Sharing
incur a bottleneck in communication cost

Can we construct a two-round, malicious NISC protocol with constant communication overhead $O(|C|\lambda)$?

Our Result

Main Theorem

Assuming a random oracle and random bit OT correlations, there is a malicious-secure, two-party NISC protocol for any Boolean circuit C with a communication cost of $O(|C|\lambda)$ bits.

- Black-box use of underlying cryptographic primitives
- Compatible with FreeXOR optimization

Comparison

Work	Assumptions	Communication Cost	Security
[IKO+11]	OT correlations + PRG	$O(\|C\|\lambda) \cdot \mathrm{polylog}(\|C\|, \sigma)$	Standard
[AMPR14]	2-round batch-committing OT	$O(\|C\| \cdot \lambda\sigma)$	Standard
[IKO+11, HIV17]	OT correlations + RO	$O(\|C\|\lambda)$	Correlated abort
[DILO22]	programmable tensor OLE + RO	$O(\|C\|\lambda)$	Standard
Ours	OT correlations + RO	$O(\|C\|\lambda)$	Standard

Table 1 : Comparison of NISC protocols in prior works. λ is an exact computational security parameter, and σ is a statistical security parameter.

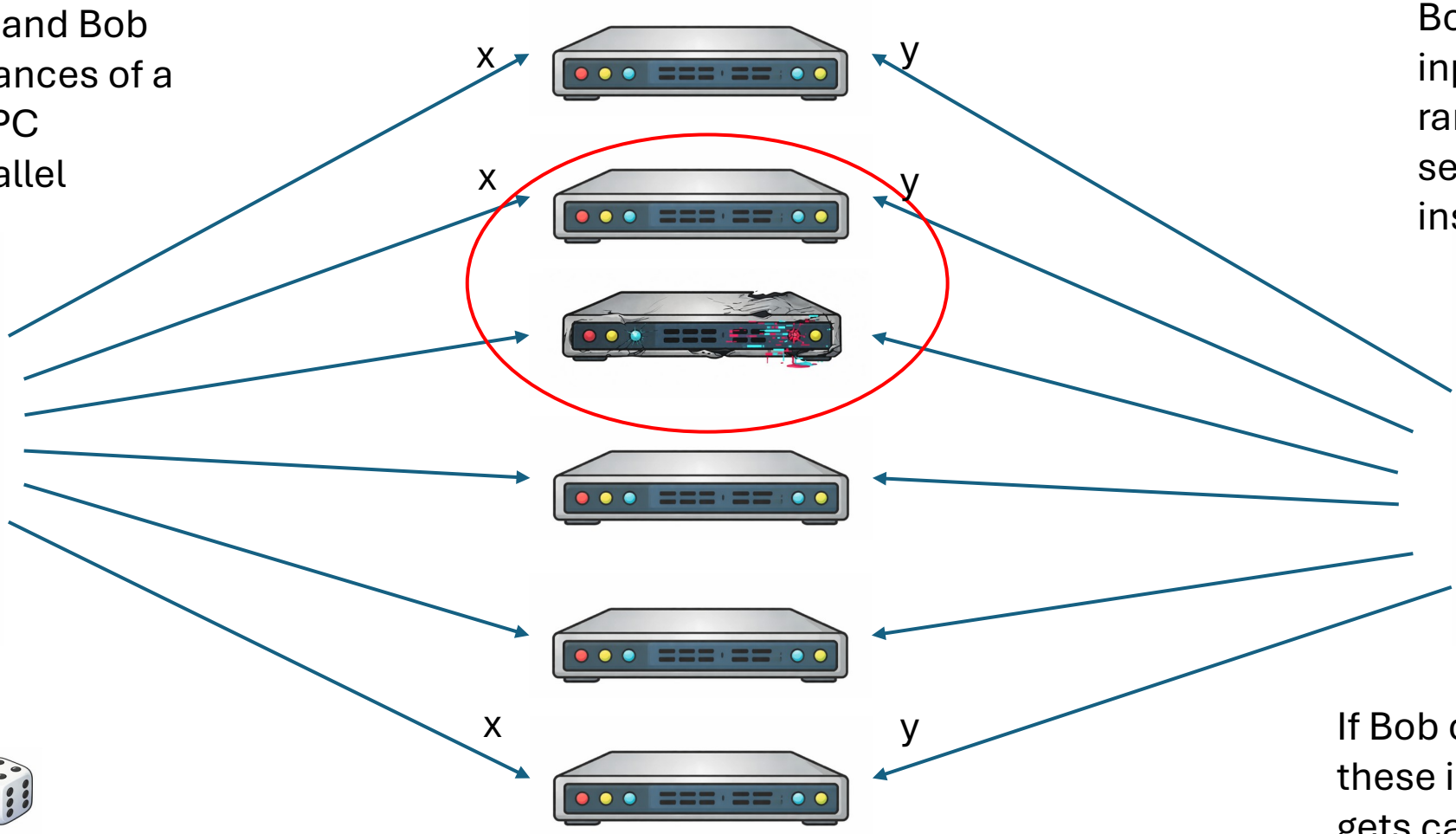
Our Compiler:
A novel combination of
IPS Compiler + Packed SS + Ligero Proofs

Attempt to Achieve Malicious Security

Consider Alice and Bob execute *m* instances of a semi-honest 2PC protocol in parallel

Alice
(*Receiver*)

Alice selects a random subset of instances



Bob reveals his input and randomness to selected instances

Bob
(*Sender*)

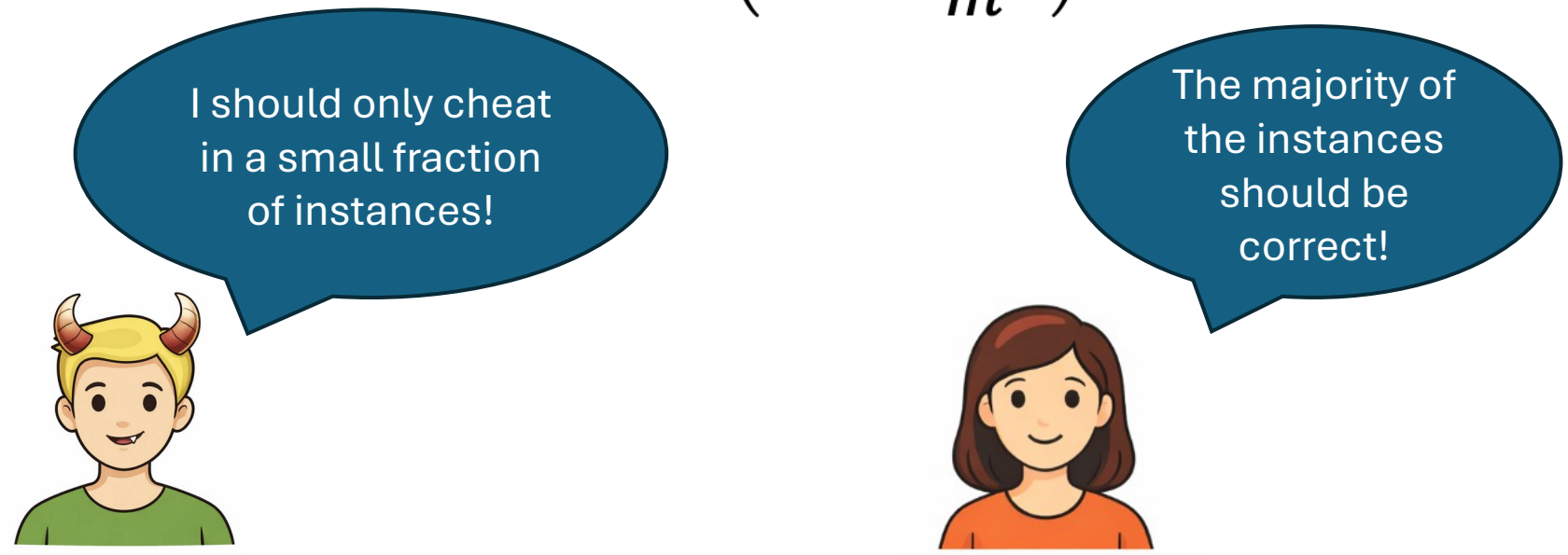
If Bob cheats in these instances, he gets caught

Simple Calculation

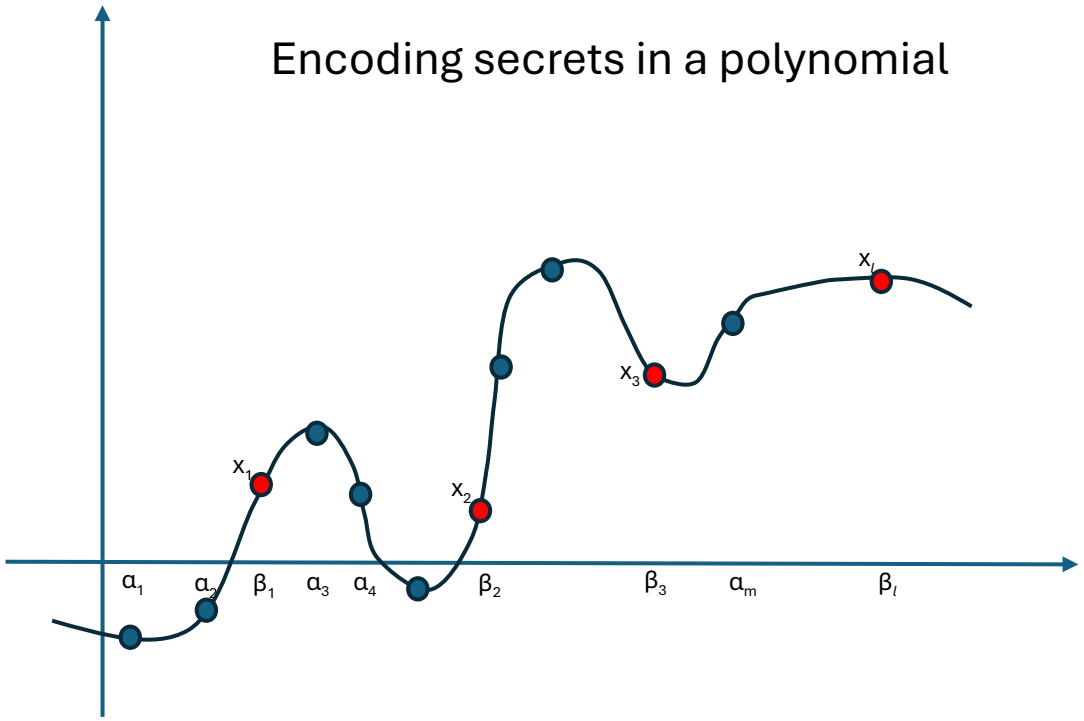
Cut & Choose!

- Suppose Alice and Bob run m instances.
- Suppose the malicious Bob cheats in $0.5m$ instances.
- Alice chooses random subset of size $0.3m$.

$$\Pr[Bob\ gets\ away] \leq \left(1 - \frac{0.5m}{m}\right)^{0.3m} = 2^{-O(m)}$$



Packed Shamir Secret Sharing [FY 92]



Over finite field $\mathbb{F}$

l : packing size

t : corruption threshold

$\mathbf{x} = (x_1, x_2, \ldots, x_l)$ secrets shared to m parties

Fix l distinct points: $\beta_1, \ldots, \beta_l$ ⟵ hide secrets

Fix m distinct points: $\alpha_1, \ldots, \alpha_m$ ⟵ generate shares

*Share(**x**)* algorithm:
1. Sample a random polynomial p of degree k conditioned on $p(\beta_1) = x_1, \ldots, p(\beta_l) = x_l$
2. Distribute the shares by giving $p(\alpha_i)$ to party i

$[\mathbf{x}] := (p(\alpha_1), \ldots, p(\alpha_m))$ is called a *sharing* of $\mathbf{x}$.

Multiplying two sharings gives
a sharing of (entry-wise) product of the secrets!
$[\mathbf{x}]_{(t+l)} \cdot [\mathbf{y}]_{(t+l)} = [\mathbf{xy}]_{2(t+l)}$

Degree-2 Polynomials

- We focus on degree-2 polynomials, as there are standard techniques [IK 00] in the two-party setting to extend this to general circuits.
- Alice has input vector $\mathbf{x} = (x_1, x_2, x_3)$.
- Bob has input vector $\mathbf{y} = (y_1, y_2, y_3, y_4)$.
- Goal: compute the degree-2 polynomial

$$p(\mathbf{x},\mathbf{y}) = 1 + y_1 + x_1y_3 + x_2^2 + x_3y_2 + y_3y_4$$

Decomposition

$$p(\mathbf{x},\mathbf{y}) = 1 + y_1 + x_1y_3 + x_2^2 + x_3y_2 + y_3y_4$$

Vector of monomials p:

1	y_1	x_1y_3	x_2^2	x_3y_2	y_3y_4

$\mathbf{x} = (x_1,x_2,x_3)$

Alice's component p^x:

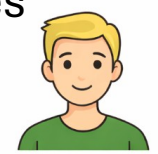
1	1	x_1	x_2^2	x_3	1

Alice
(Receiver)

Assign values

Bob's component p^y:

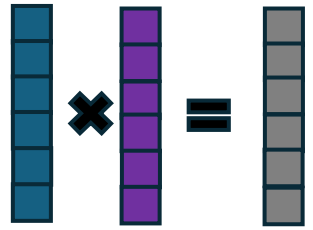
1	y_1	y_3	1	y_2	y_3y_4



Bob
(Sender)

$\mathbf{y} = (y_1,y_2,y_3,y_4)$

Attempt



multiply the shares

Receiver's input p^x:

1	1	x_1	x_2^2	x_3	1

Sender's input p^y:

1	y_1	y_3	1	y_2	y_3 y_4

Alice
(Receiver)

$p^x(\alpha_1)$ $p^y(\alpha_1)$

$p^x(\alpha_2)$ $p^y(\alpha_2)$

Cut-and-choose!

Packed secret share

Packed secret share

$p^x(\alpha_m)$ $p^y(\alpha_m)$

Bob
(Sender)

Reconstruct

1	y_1	x_1y_3	x_2^2	x_3y_2	y_3 y_4

The monomials may reveal information!

m instances of semi-honest protocol

OT ⟵ MFE — Oblivious Linear Evaluation (OLE)

$p^x(\alpha_i) \cdot p^y(\alpha_i) + p^z(\alpha_i)$

Sample a random vector p^z:

z_1	z_2	z_3	z_4	z_5	z_6

where $z_1 + \ldots + z_6 = 0$.

1	1	x_1	x_2^2	x_3	1

Alice

(Receiver)

$p^x(\alpha_1)$

$p^x(\alpha_1) \cdot p^y(\alpha_1) + p^z(\alpha_1)$

$p^x(\alpha_2) \cdot p^y(\alpha_2) + p^z(\alpha_2)$

Packed secret share p^x

$p^x(\alpha_m)$

$p^x(\alpha_m) \cdot p^y(\alpha_m) + p^z(\alpha_m)$

$p^y(\alpha_1), p^z(\alpha_1)$

$p^y(\alpha_2), p^z(\alpha_2)$

Packed secret share p^y, p^z

$p^y(\alpha_m), p^z(\alpha_m)$

1	y_1	y_3	1	y_2	y_3 y_4

Bob

(Sender)

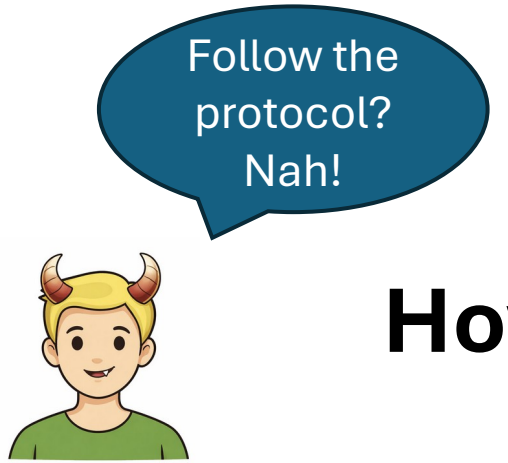
Reconstruct

1	y_1	x_1y_3	x_2^2	x_3y_2	y_3 y_4

masked by

z_1	z_2	z_3	z_4	z_5	z_6

But the sum is still $p(\mathbf{x},\mathbf{y})$ ✓



However, a malicious adversary may cheat in decomposition and packed secret sharing.

Specialized zero-knowledge proofs to enforce the behavior of malicious adversaries.

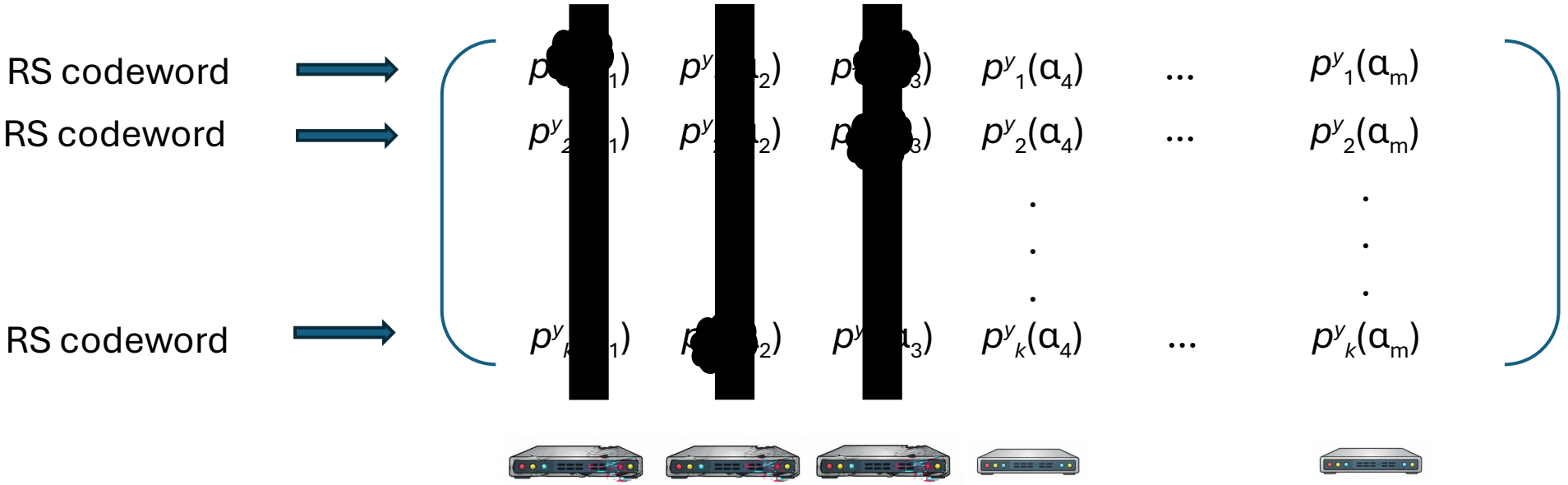
Correctness of Packed Secret Sharing

Shares are evaluations of $p(\alpha_1), \ldots, p(\alpha_m)$ ⟺ Reed-Solomon Code

Not too many corrupted shares ⟺ Proximity of RS codewords

Suppose Bob shares $k = O(|C| / l)$ vectors $p^y_1, p^y_2, \ldots, p^y_k$.

Let's put their packed Shamir sharings row-by-row into a matrix:



Want to prove: Only a small fraction of bad columns.

Even if one share is incorrect, the semi-honest instance will compute a wrong result

Ligero Proofs [AHIV 17]

$|\mathbb{F}| = 2^{\lambda}$

Random coefficients →

$$\begin{pmatrix} r_1 & p^{y}_{1}(\alpha_1) & p^{y}_{1}(\alpha_2) & p^{y}_{1}(\alpha_3) & \dots & p^{y}_{1}(\alpha_m) \\ r_2 & p^{y}_{2}(\alpha_1) & p^{y}_{2}(\alpha_2) & p^{y}_{2}(\alpha_3) & \dots & p^{y}_{2}(\alpha_m) \\ \vdots & \vdots & \vdots & \vdots & & \vdots \\ r_k & p^{y}_{k}(\alpha_1) & p^{y}_{k}(\alpha_2) & p^{y}_{k}(\alpha_3) & \dots & p^{y}_{k}(\alpha_m) \end{pmatrix}$$

Non-Interactive: Use RO to do Fiat-Shamir

folding: u_1 u_2 u_3 … u_m ← linear combination

Prover:

1. commits the matrix column-wise
2. computes $(u_1, \dots, u_m) = r_1 \cdot p^{x}_{1} + r_2 \cdot p^{x}_{2} + \dots + r_k \cdot p^{x}_{k}$
3. opens a random subset of columns

Verifier checks:

1. whether $(u_1, \dots, u_m)$ is a valid RS codeword
2. whether the opened columns follow the computation

accepts → Very few corrupted columns ✓

Proximity Gap Theorem [BCIKS 20]

Enforce Malicious Behavior

A malicious adversary may not perform the packed secret sharing honestly!

Ligero Proofs for Reed-Solomon Proximity!

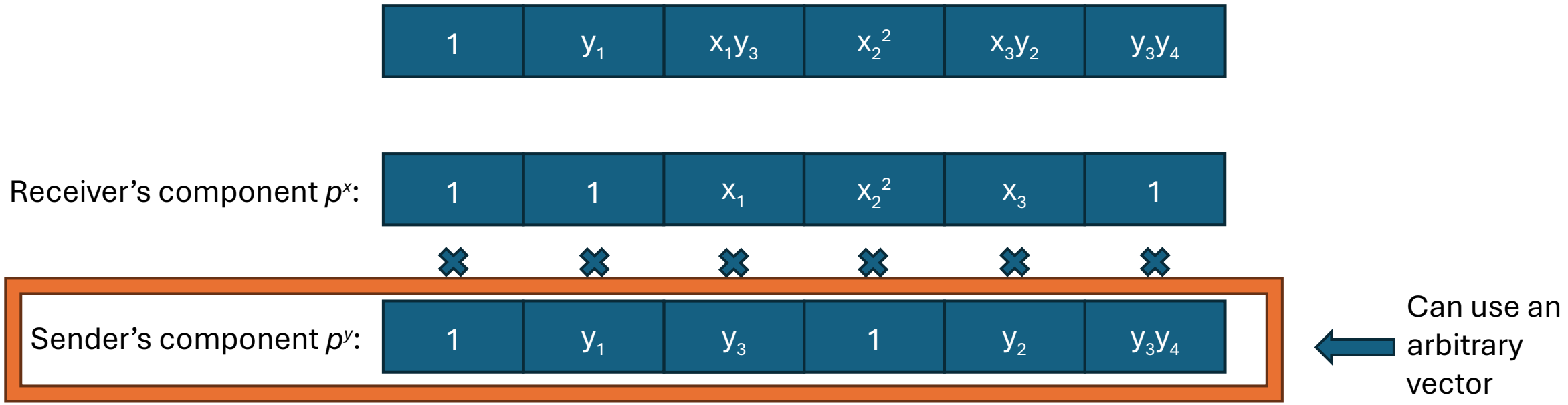
A malicious adversary may not follow the decomposition rule!

Ligero Proofs for Linear Constraints!
(see next)

The original Ligero paper has proofs for row-wise proximity, but our construction requires proofs for a column-corruption guarantee.

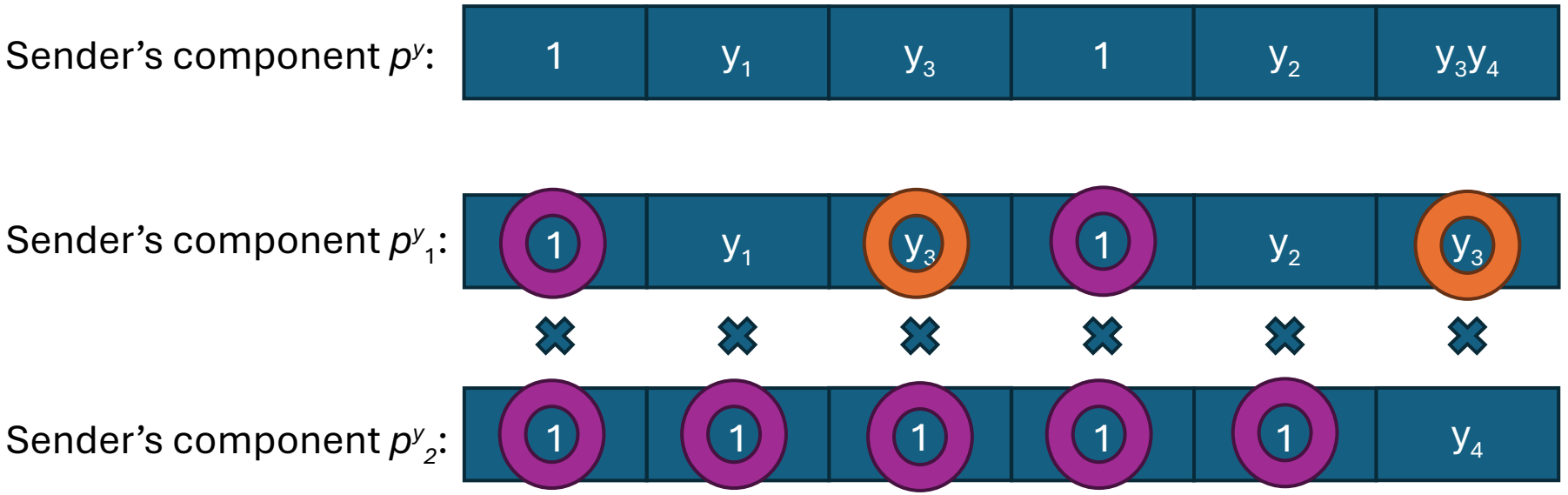
Protect Decomposition

$$p(x,y) = 1 + y_1 + x_1y_3 + x_2^2 + x_3y_2 + y_3y_4$$



Further Decompose

Further decompose until each monomial is linear



Can write linear equations:

- $p^y{}_1[3] - p^y{}_1[6] = 0$
- $p^y{}_1[1] = 1, p^y{}_1[4] = 1$
- $p^y{}_2[1] = 1, \ldots, p^y{}_2[5] = 1$

→ Correctness of decomposition = linear constraints are satisfied → Ligero Proofs for linear constraints ✓

Summary

- **IPS Compiler**: runs *m* parallel semi-honest instances; cut-and-choose limits cheating to a small fraction of instances
- **Packed Secret Sharing:** amortizes the communication cost
- **Ligero Proofs:** enforce valid sharing and decomposition

Alice
(*Receiver*)

Two-round **semi-honest** protocol per instance

Bob
(*Sender*)

Two-round compiled **malicious** protocol

Communication Cost

1. A single instance of semi-honest 2PC has communication cost $O(|C|\lambda)$.
2. We run m parallel semi-honest instances with packing size l.
3. Cost per semi-honest instance is $O(|C|\lambda / l)$ and set $l = O(m)$.
4. Ligero proofs + cut-and-choose: $O(|C|\lambda)$.
5. Total: $m \cdot O(|C|\lambda / l) + O(|C|\lambda) = O(|C|\lambda)$.

Matching semi-honest Yao!

Future Work

1. Extend the 2PC to multiple parties. Under similar assumptions, can we have a two-round malicious MPC with low communication cost?
2. If the communication channel is bi-directional, can we make both parties output in two rounds with the same communication complexity?
3. Can we make the protocol more concretely efficient for real-world applications?

Takeaway

Assuming RO and OT correlations, malicious NISC can match the communication complexity of semi-honest Yao.

Questions?