Two Round Information-Theoretic MPC with Malicious Security

Prabhanjan Ananth   Arka Rai Choudhuri   Aarushi Goel   Abhishek Jain

Massachusetts Institute of Technology

JOHNS HOPKINS UNIVERSITY

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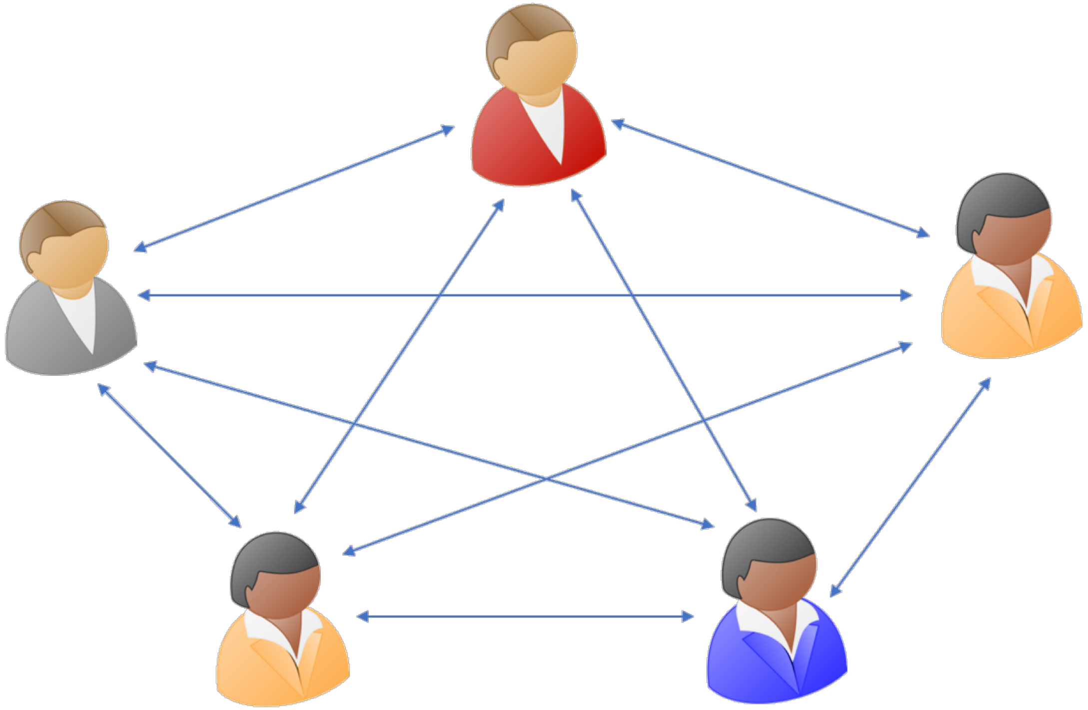
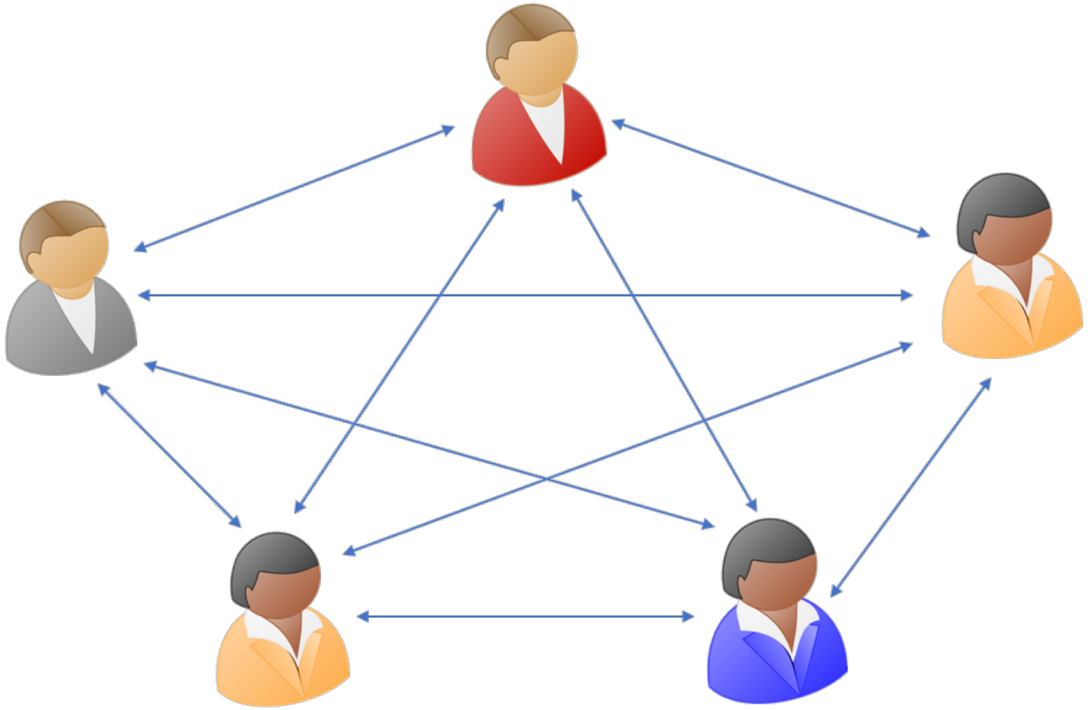
Adversarial Model



Adversarial Model

Malicious Adversary



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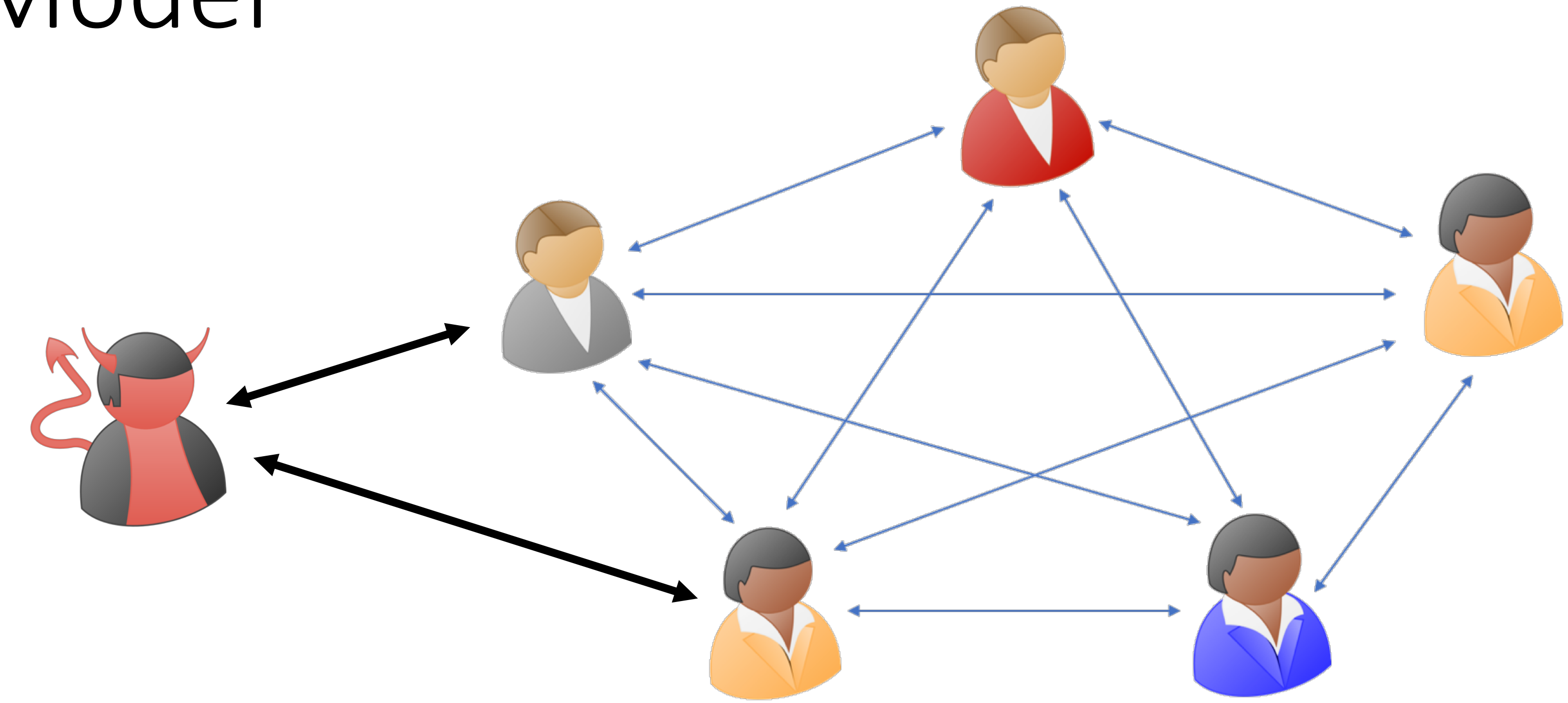

Corrupts $< n/2$ parties (Honest Majority)

Honest Majority MPC

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Information-Theoretic security is possible.

[Ben-Or, Goldwasser, Widgerson’88]

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Typically UC secure

Simulation proofs are typically straight-line

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Round complexity lower bounds for dishonest majority do not apply

4 rounds necessary for dishonest majority in the plain model

[Garg- Mukherjee-Pandey-Polychroniadou16]

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4 rounds necessary for dishonest majority in the plain model

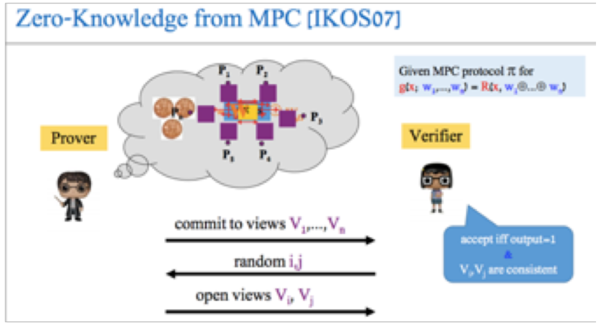
[Garg- Mukherjee-Pandey-Polychroniadou16]

Clean Constructions

Use lightweight tools such as garbling and secret-sharing

Honest Majority MPC: Applications

Efficient Zero-Knowledge
[IKOS'07,…]

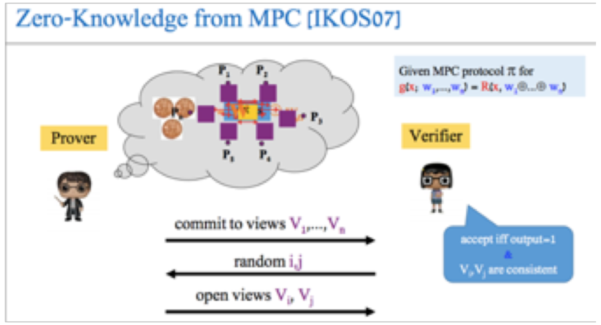


(Courtesy: Carmit Hazay's talk)

Useful for constructing efficient ZK-protocols.

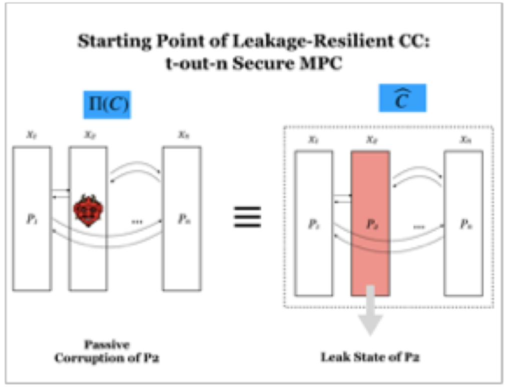
Honest Majority MPC: Applications

Efficient Zero-Knowledge
[IKOS’07,…]

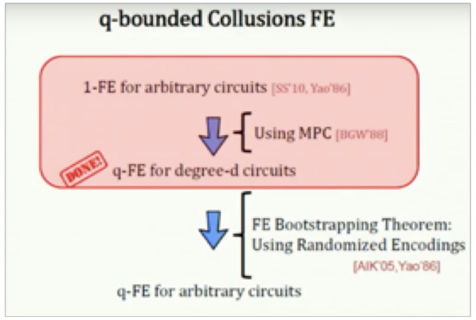


(Courtesy: Carmit Hazay’s talk)

Leakage-Resilient Circuit Compilers
[ISW03,FKKNV10,AIS18]



Bounded-Key Functional Encryption
[GVW12,AV18]



(Courtesy: Sergey Gorbunov’s talk)

History of IT-MPC

	Round Complexity	Class of Functions	Corruption Threshold	Adversary
[BGW’88]	> # of multiplications	P/Poly	t<n/2	Malicious
[BB’89, IK’00, AIK’06]	constant	NC^1	t<n/2	Malicious
[IKP’10]	2	NC^1	t<n/3	Malicious
[GIS’18, ABT’18]	2	NC^1	t<n/2	Semi-honest

Security with selective abort

Our Results

Round Complexity	Class of Functions	Corruption Threshold	Adversary
2	NC^1	$t<n/2$	Malicious

Security with Abort over
Broadcast + P2P

Security with Selective Abort over
P2P

Our Results

Round Complexity	Class of Functions	Corruption Threshold	Adversary
2	NC^1	$t<n/2$	Malicious

Security with Abort over Broadcast + P2P

Security with Selective Abort over P2P

Concurrent Work [ABT19]

Consider security with selective abort.

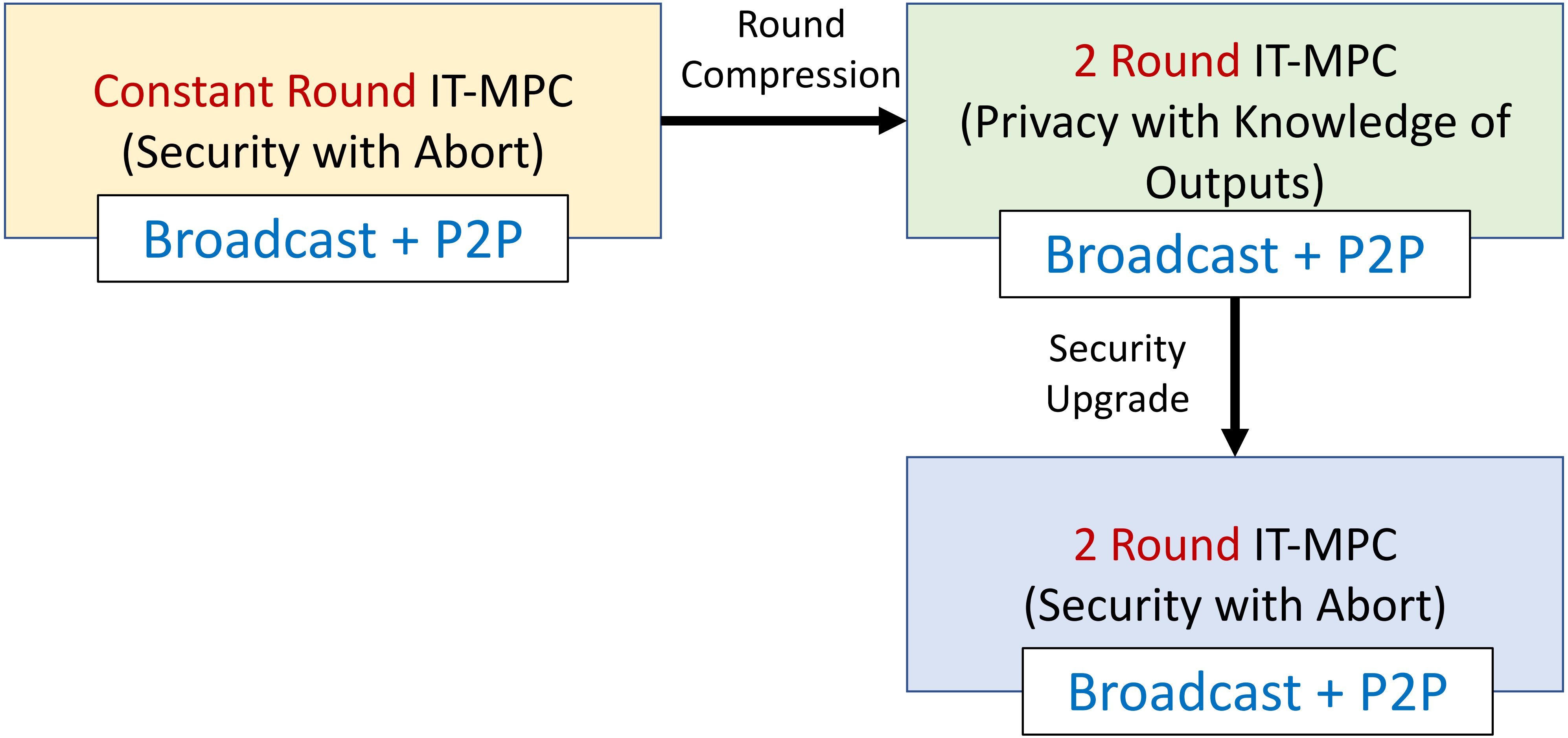
This Talk

Round Complexity	Class of Functions	Corruption Threshold	Adversary
2	NC^1	$t<n/2$	Malicious

Security with Abort over Broadcast + P2P

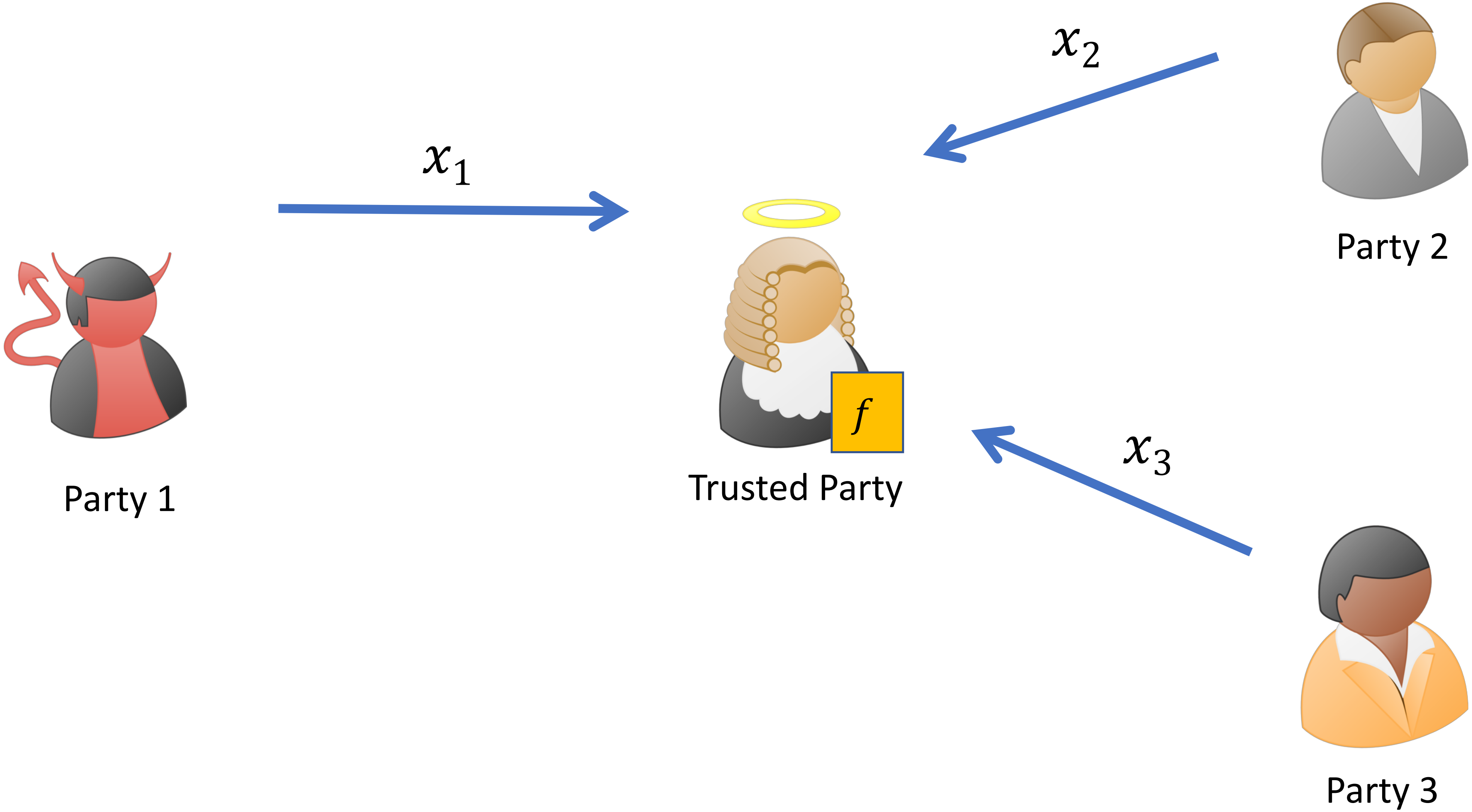
Security with Selective Abort over P2P

Our Strategy



Security with Abort

Security with Abort



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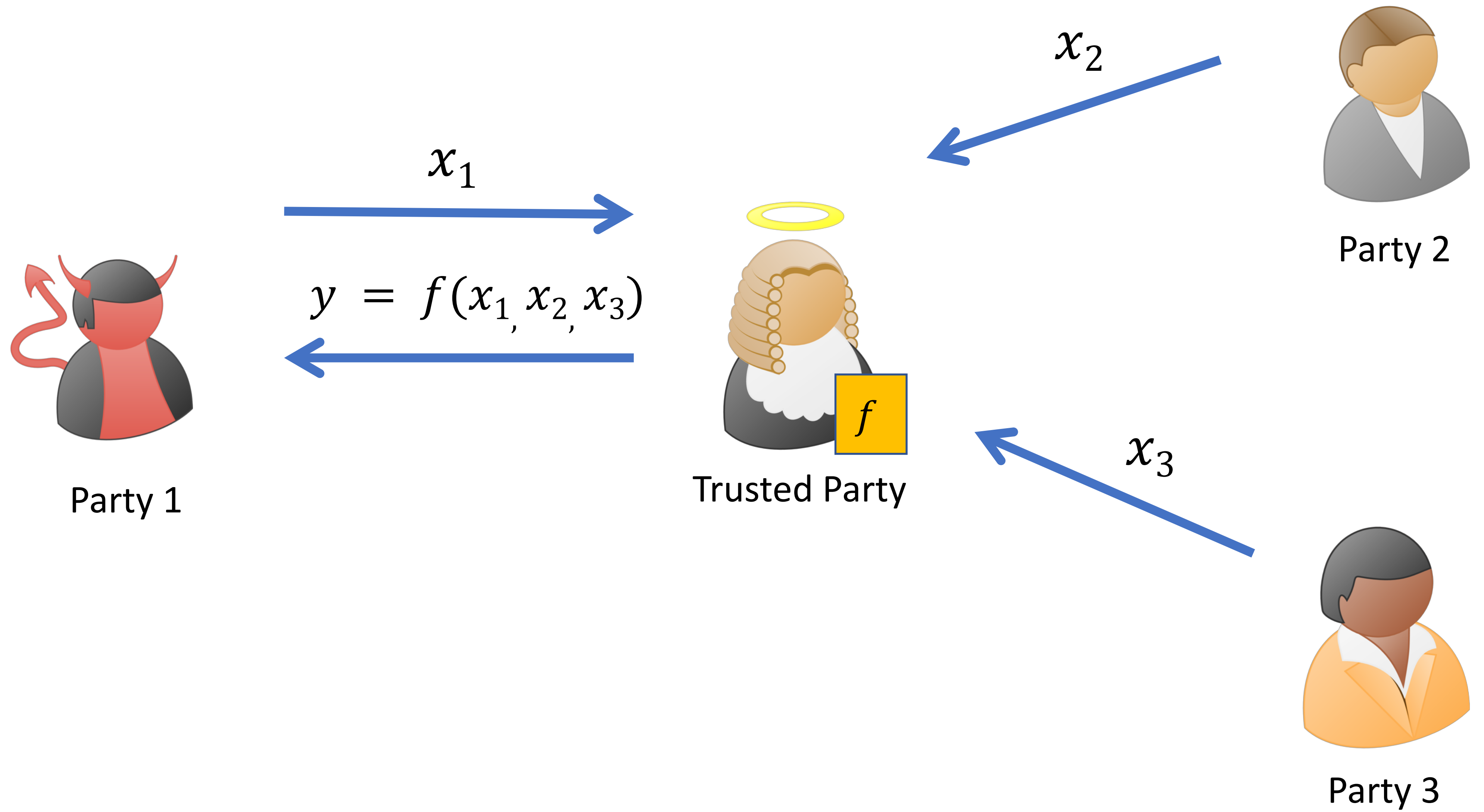

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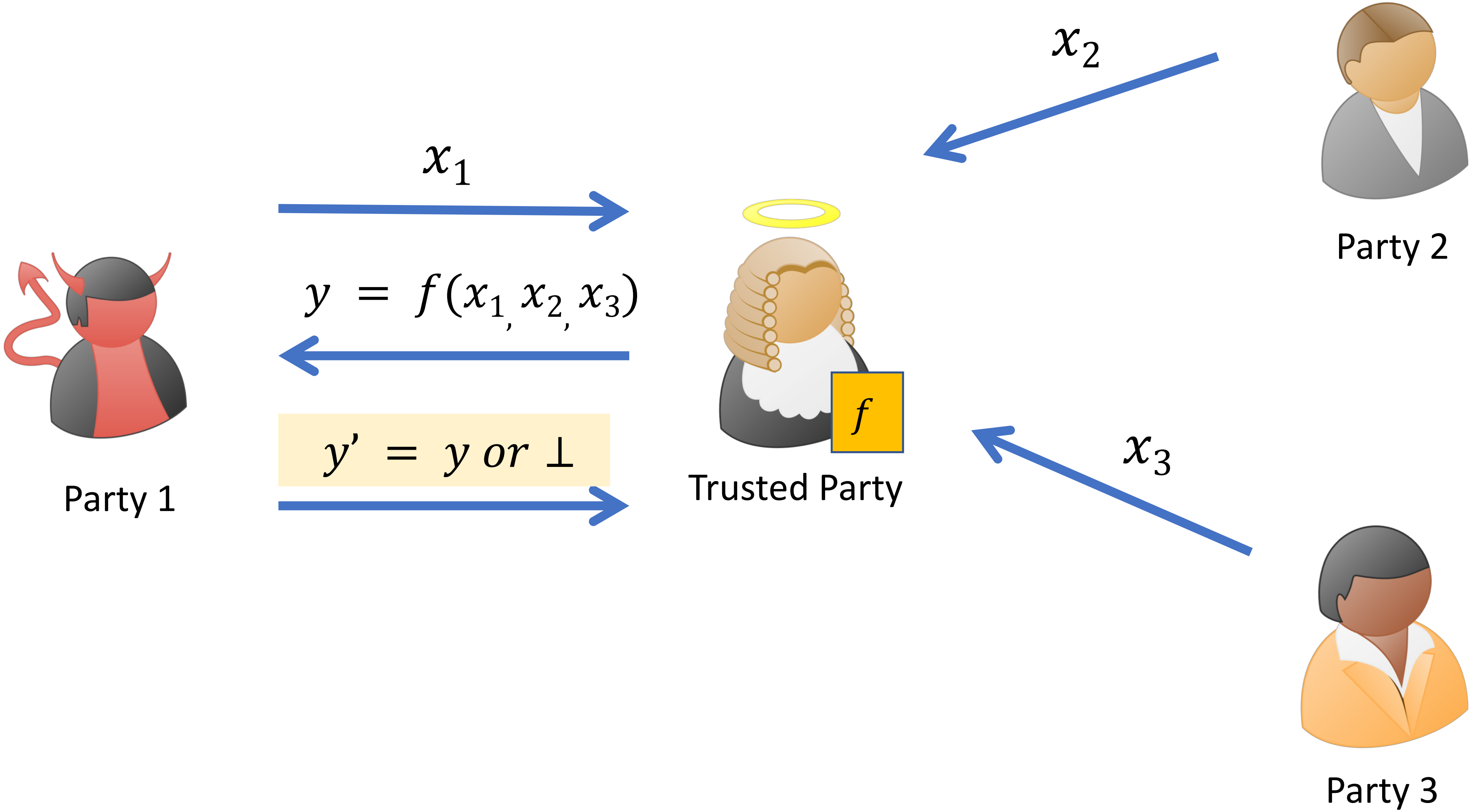

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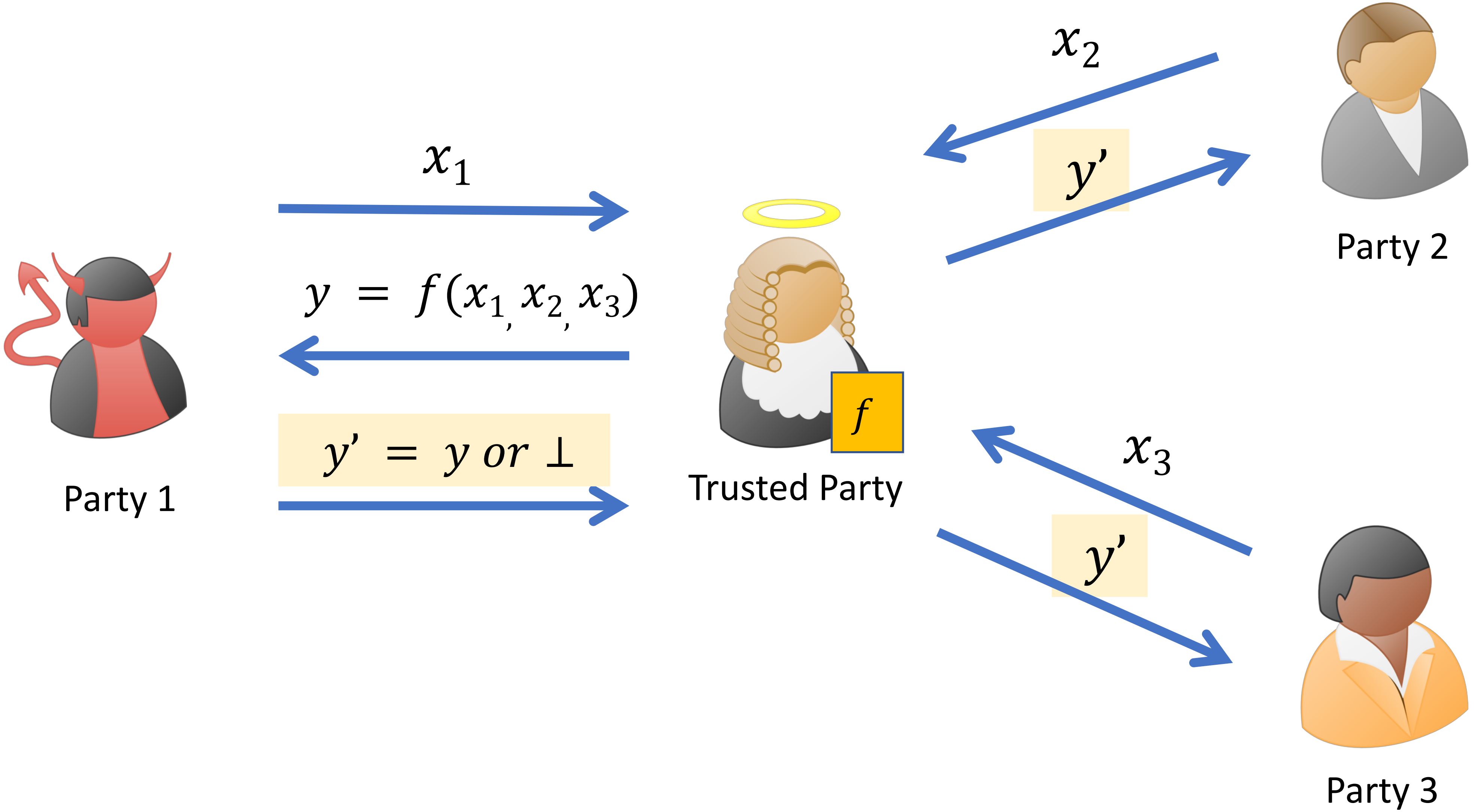

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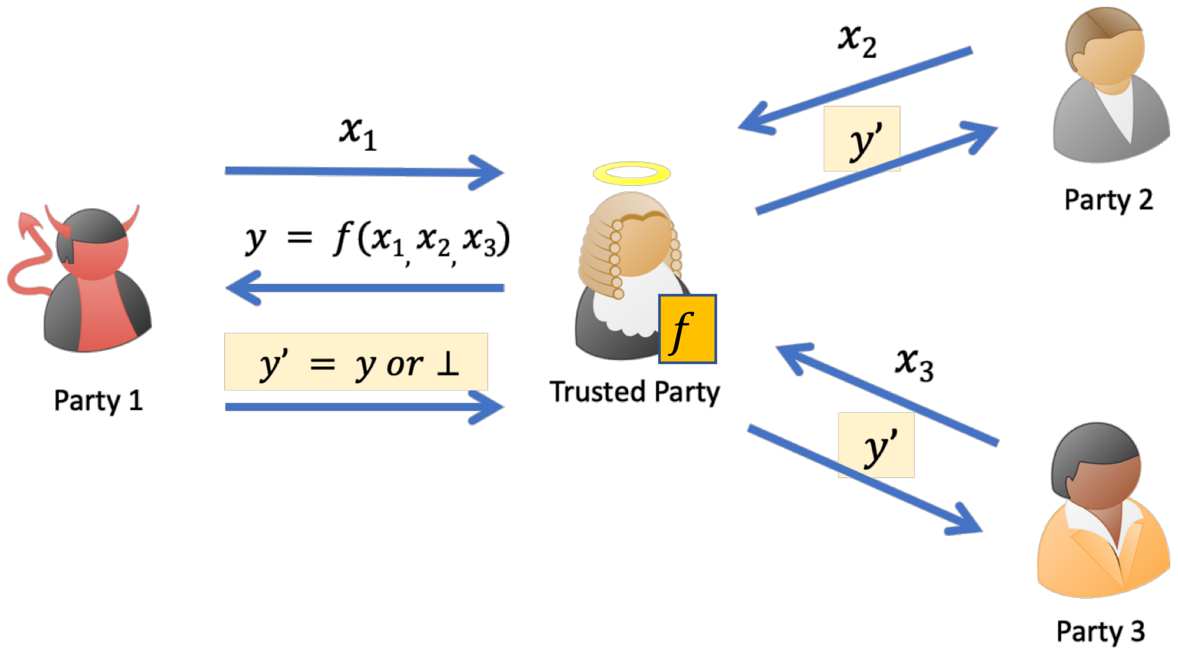
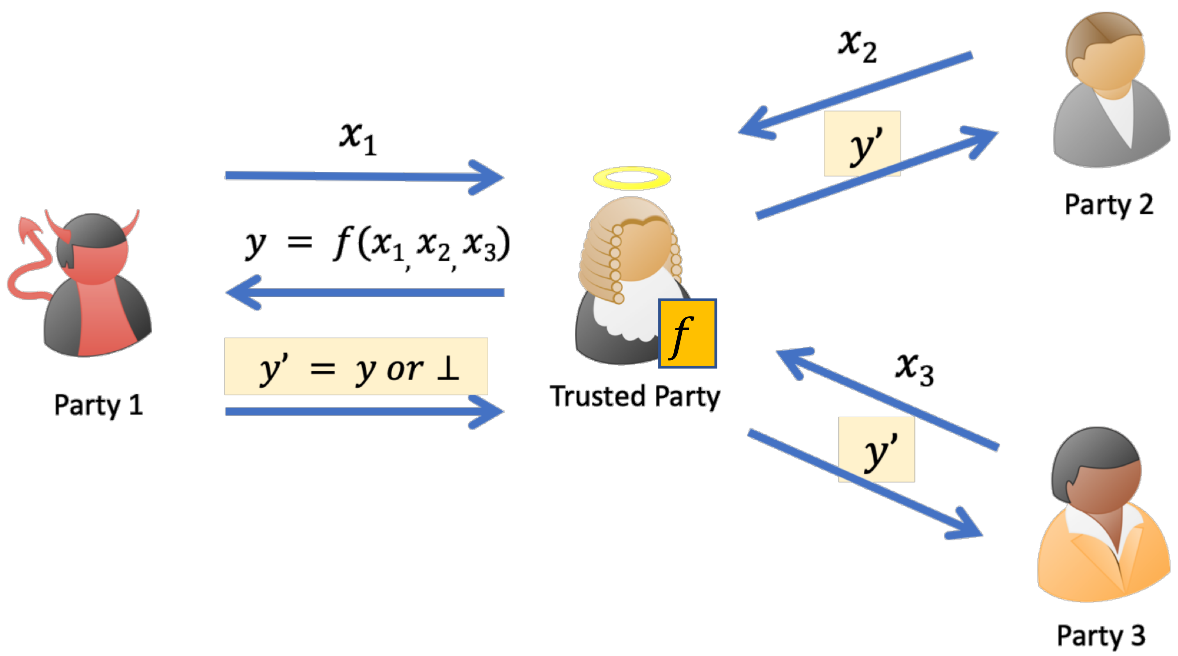


Privacy

x_2 and x_3 remain hidden

Security with Abort



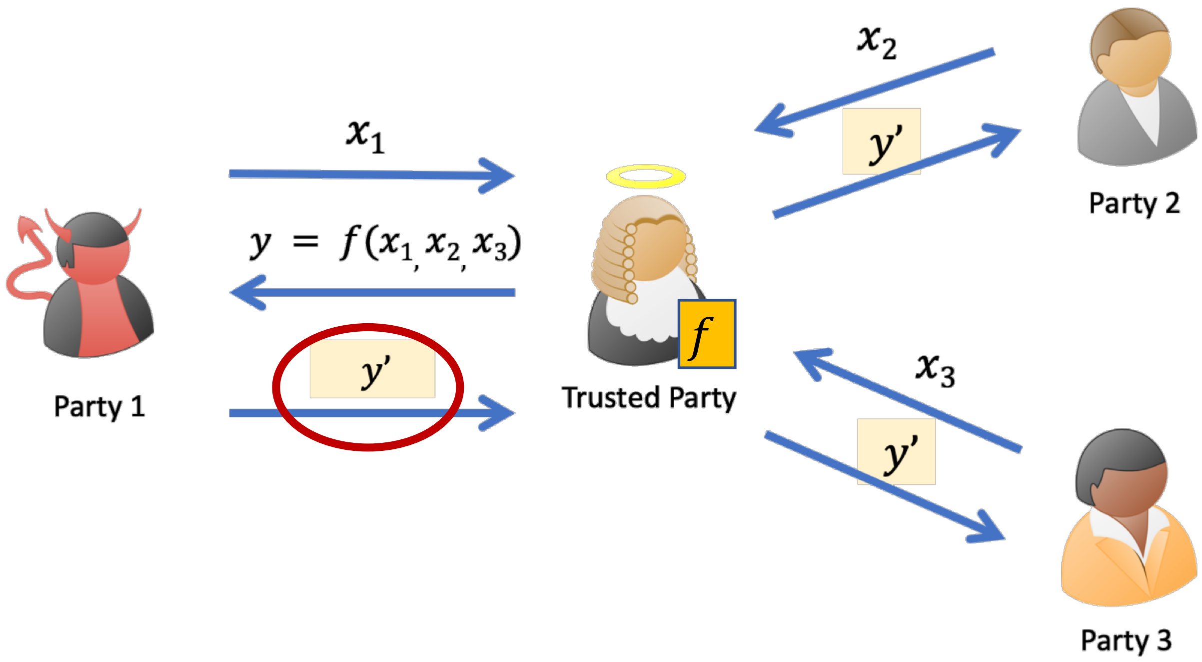
Privacy

x_2 and x_3 remain hidden

Output Correctness

Honest Parties either output $f(x_1, x_2, x_3)$ or $\perp$

Privacy with Knowledge of Outputs



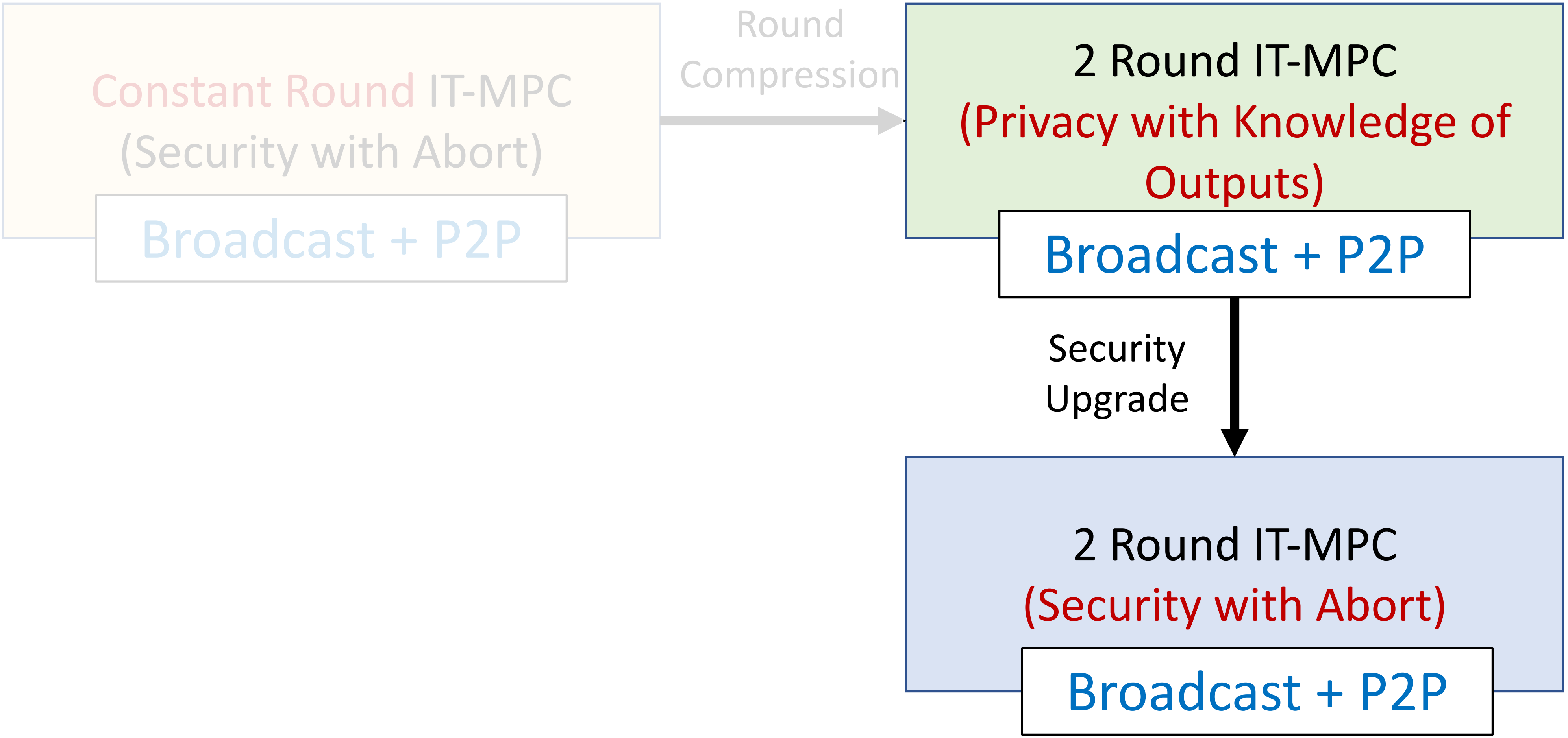
Privacy

x_2 and x_3 remain hidden

~~Output Correctness~~

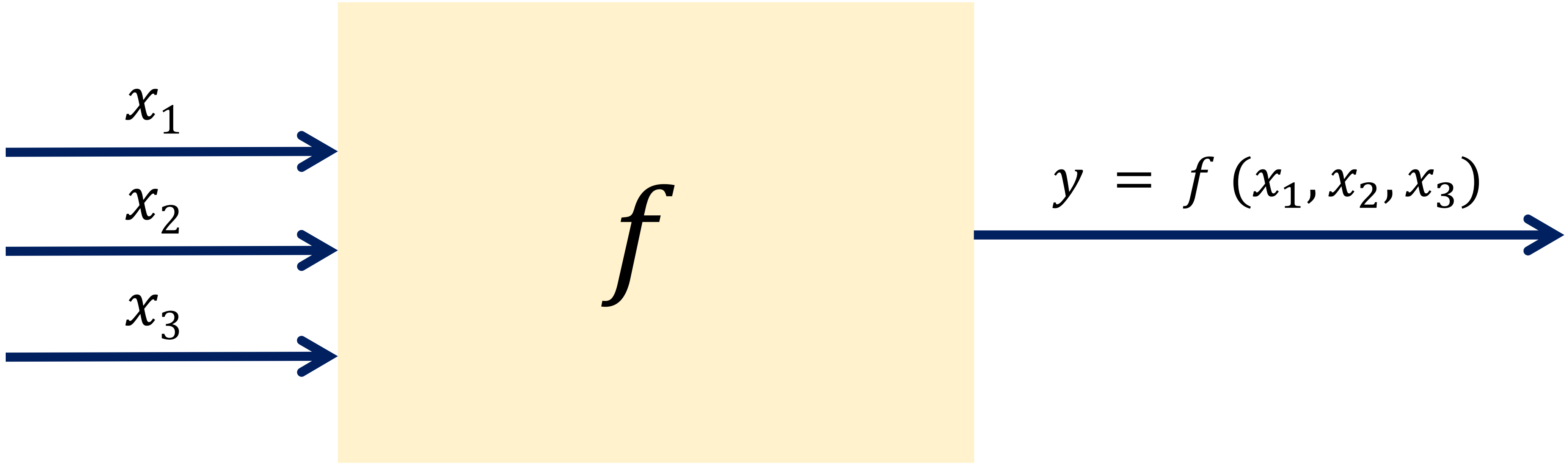
~~Honest Parties either output $f(x_1, x_2, x_3)$ or $\perp$~~

First Step

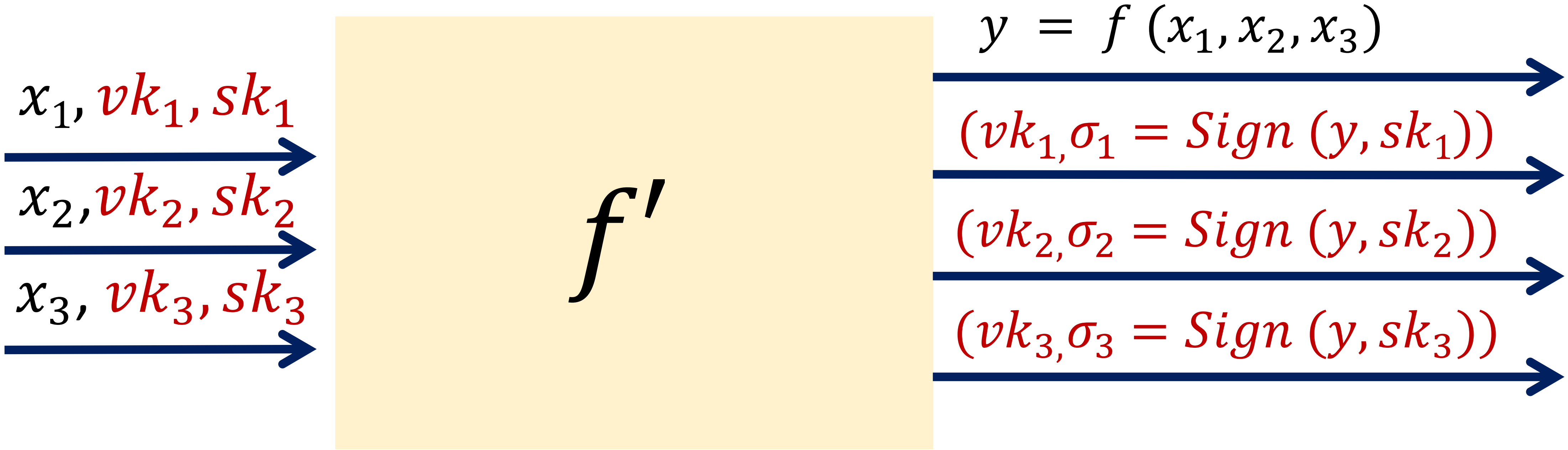


Constant Round IT-MPC
(Security with Abort)
Broadcast + P2P
Round
Compression
2 Round IT-MPC
(Privacy with Knowledge of Outputs)
Broadcast + P2P
Security
Upgrade
2 Round IT-MPC
(Security with Abort)
Broadcast + P2P

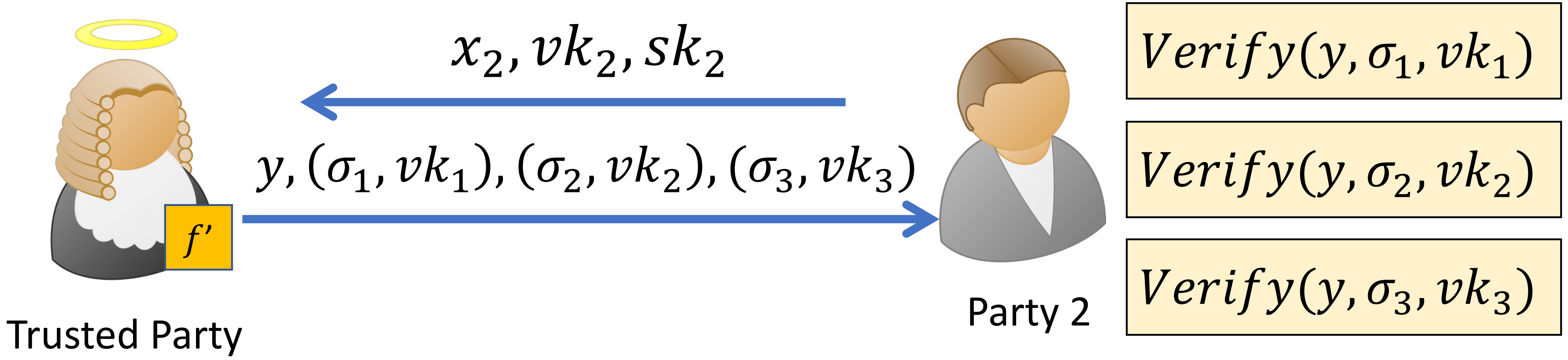
Using Signed Outputs [IKP10]



Using Signed Outputs [IKP10]



Security with abort: Using Signed Outputs



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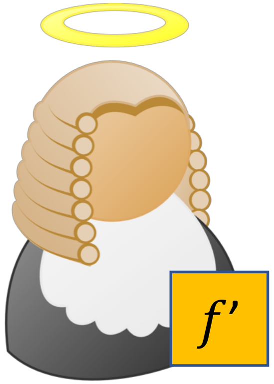
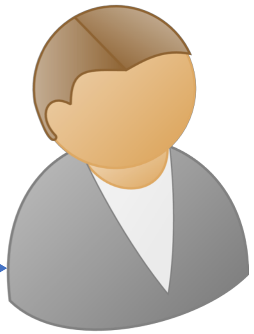


Trusted Party

x_2, vk_2, sk_2

$y, (\sigma_1, vk_1), (\sigma_2, vk_2), (\sigma_3, vk_3)$



Party 2

$Verify(y, \sigma_1, vk_1)$

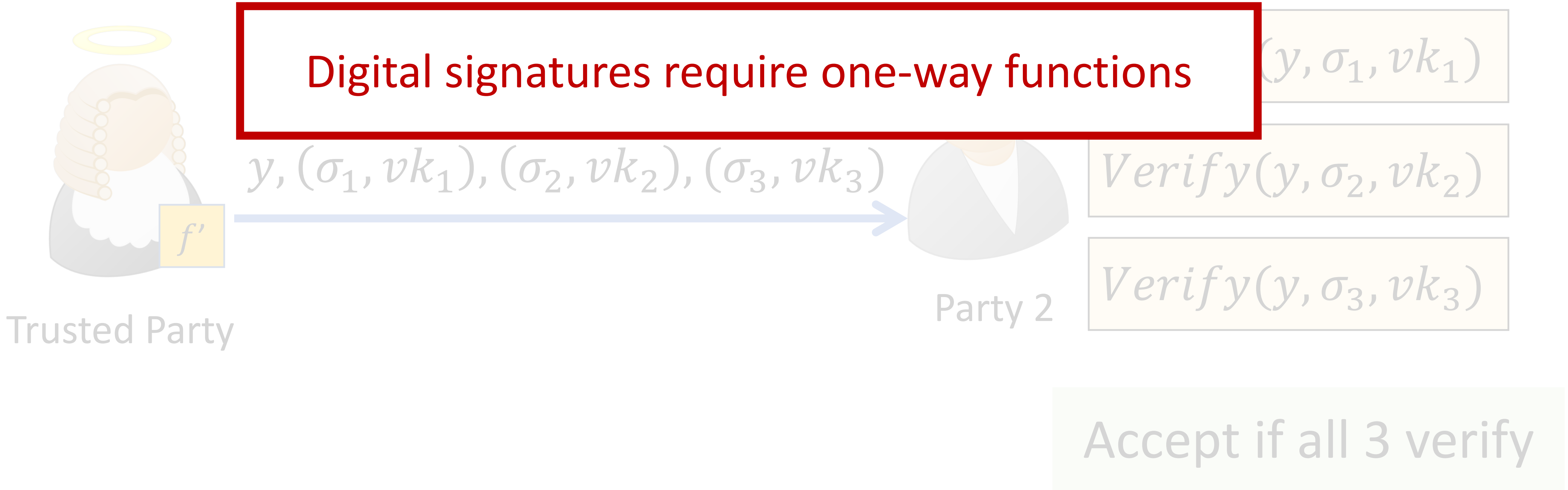
$Verify(y, \sigma_2, vk_2)$

$Verify(y, \sigma_3, vk_3)$

Accept if all 3 verify

Security with abort: Using Signed Outputs

Digital signatures require one-way functions



Security with abort: Using Signed Outputs

Digital signatures require one-way functions

MACs are not sufficient

Trusted Party

$Verify(y, \sigma_2, vk_2)$

Accept if all 3 verify

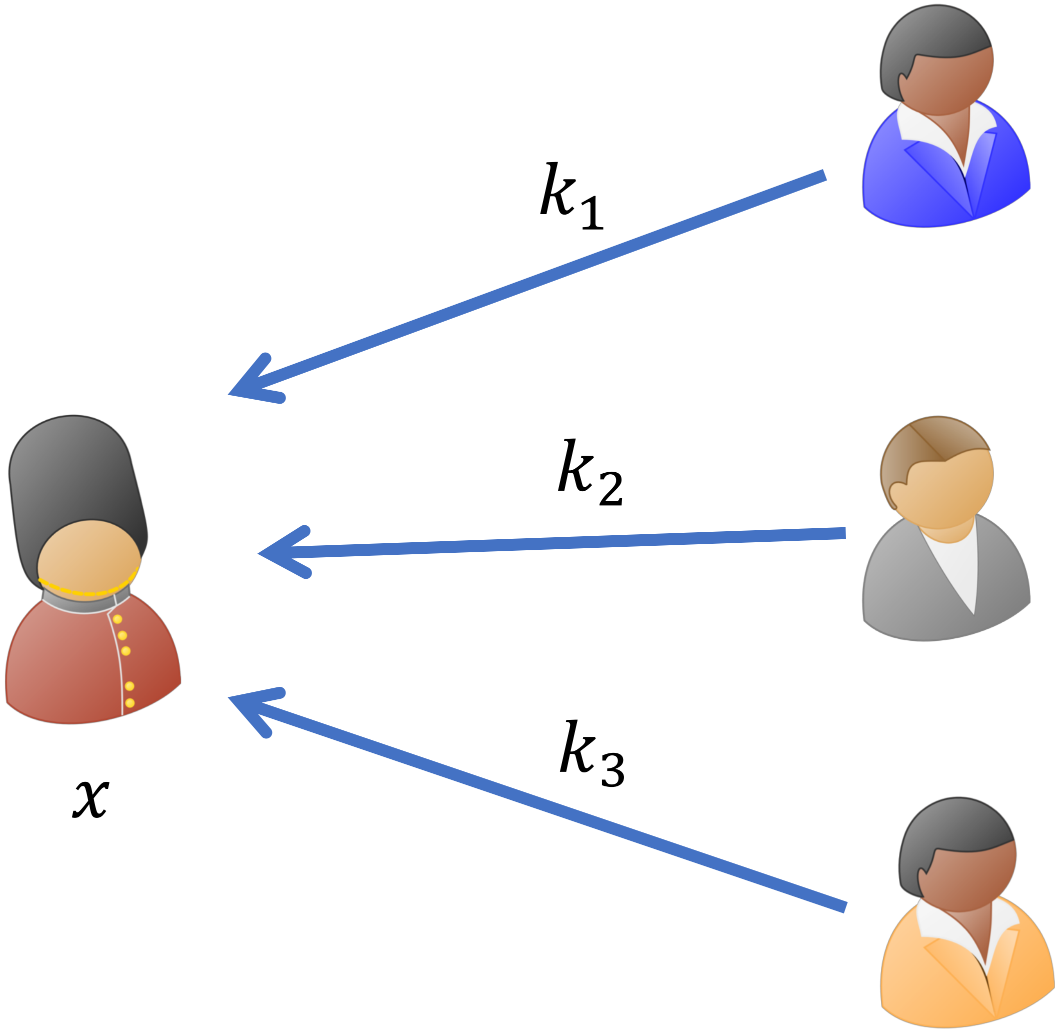
Security with abort: Using Signed Outputs

Digital signatures require one-way functions

MACs are not sufficient

How can we do it information theoretically?

Our Tool: Multi-Key MAC



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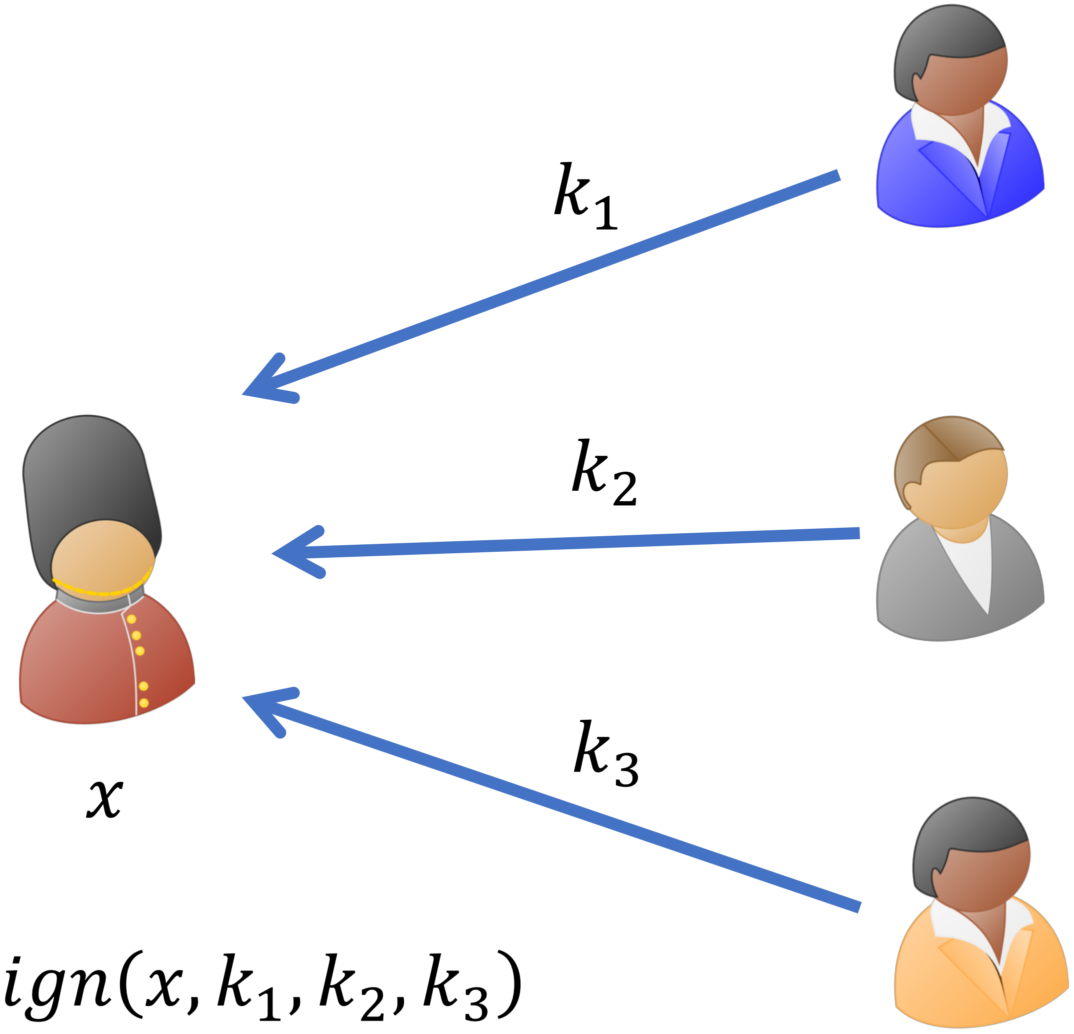
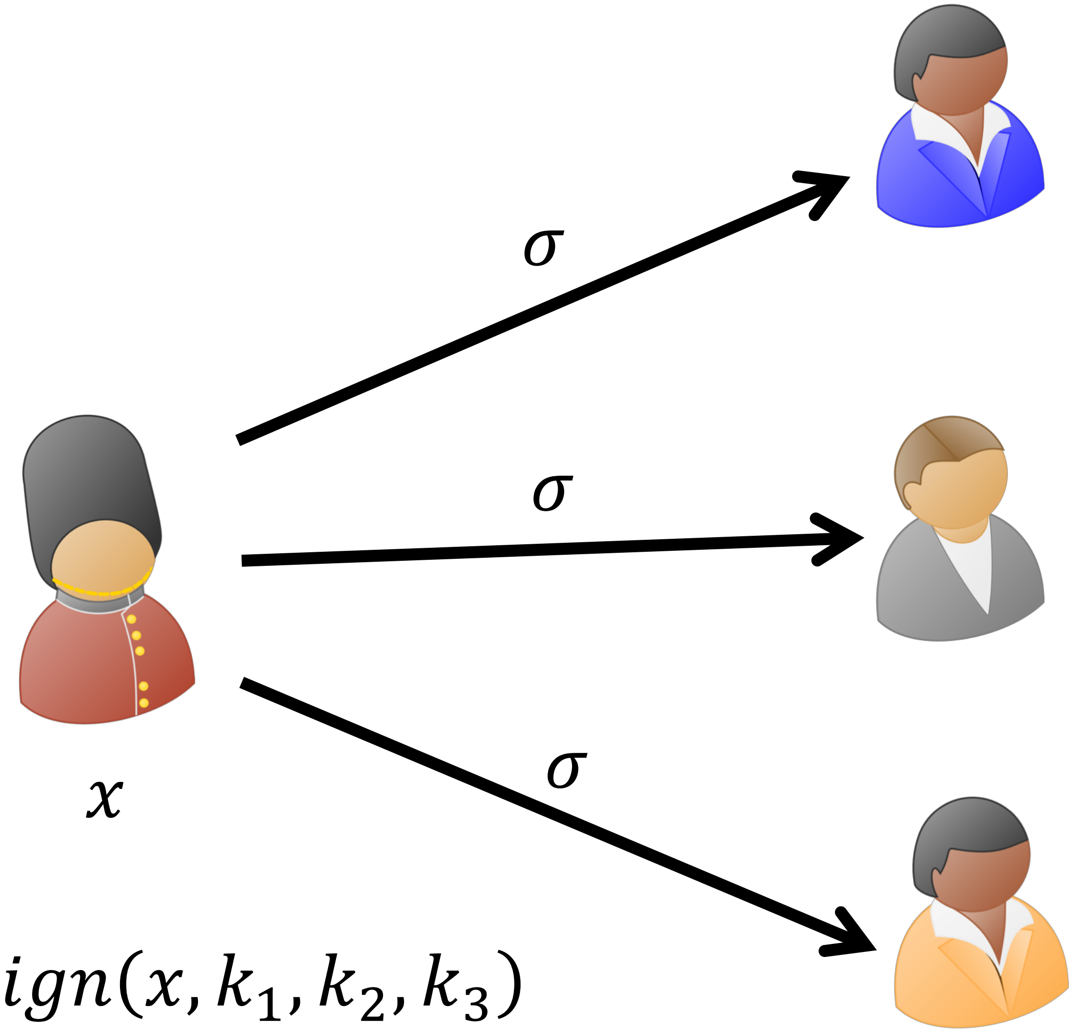


$$\sigma = M.Sign(x, k_1, k_2, k_3)$$

Our Tool: Multi-Key MAC



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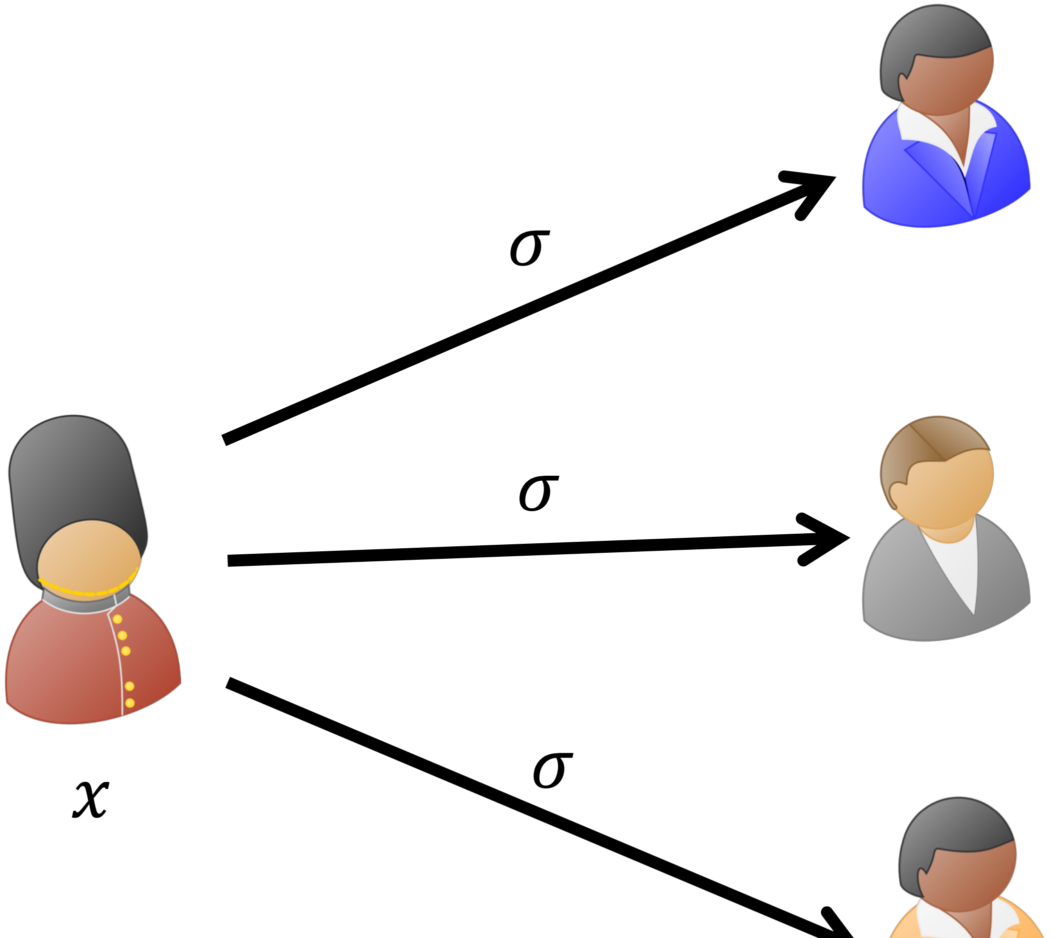


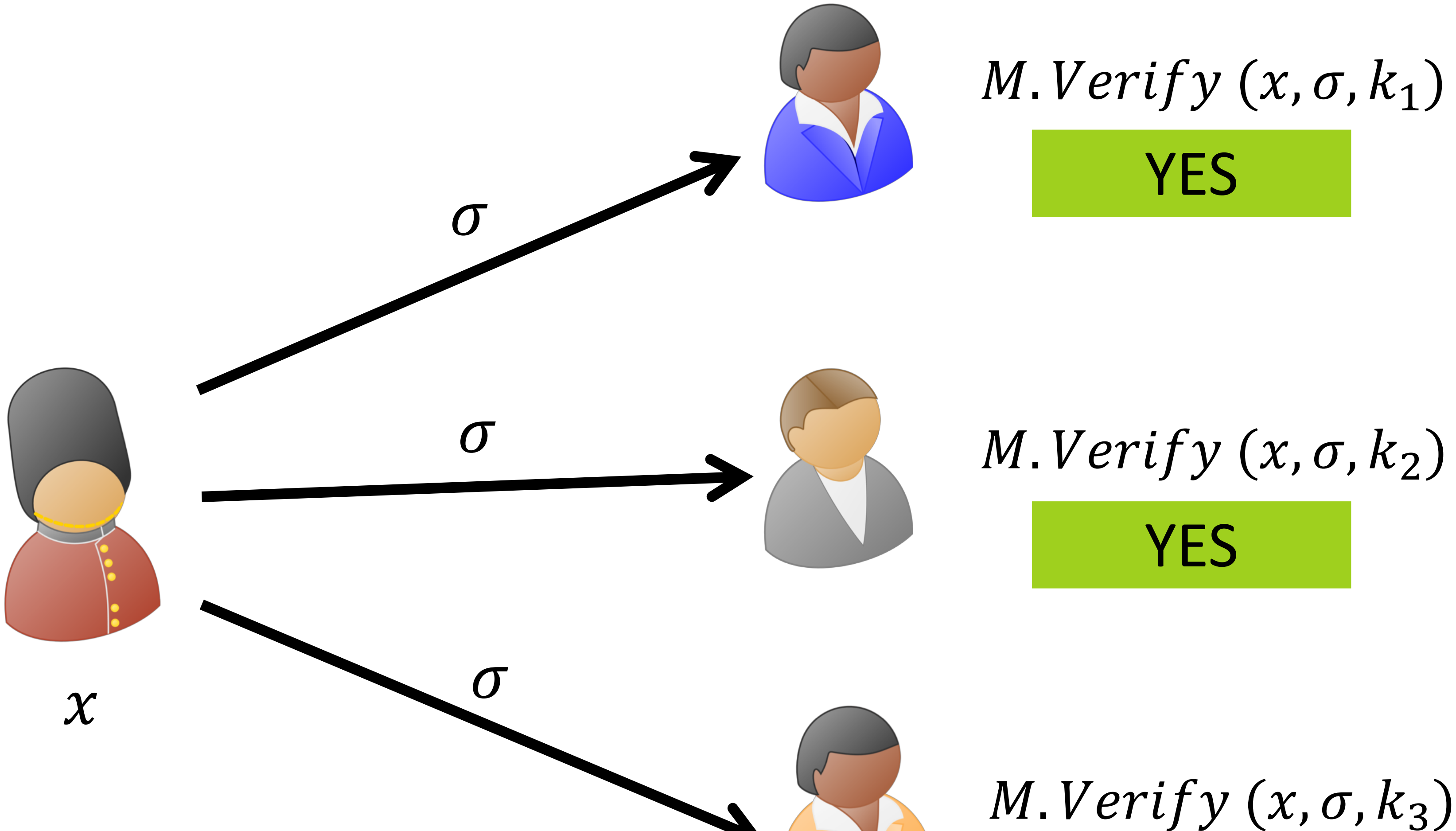
$M.Verify\,(x, \sigma, k_1)$

$M.Verify\,(x, \sigma, k_2)$

$M.Verify\,(x, \sigma, k_3)$

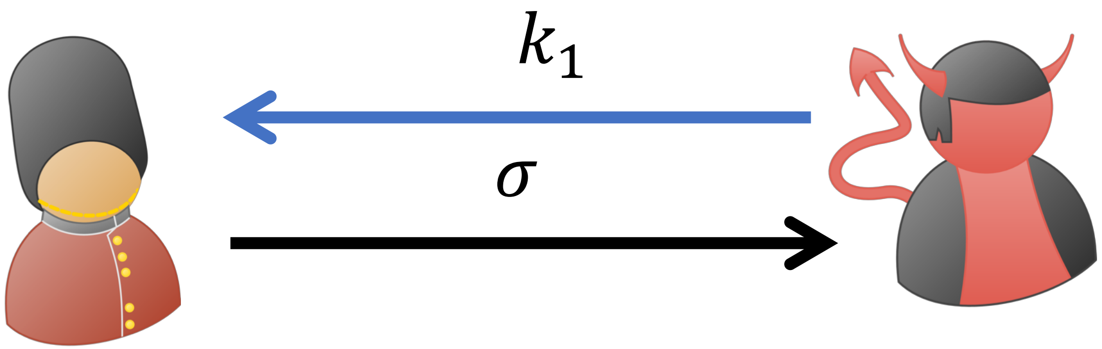
$\sigma = M.Sign(x, k_1, k_2, k_3)$

Our Tool: Multi-Key MAC (Correctness)



$$\sigma = M.Sign(x, k_1, k_2, k_3)$$

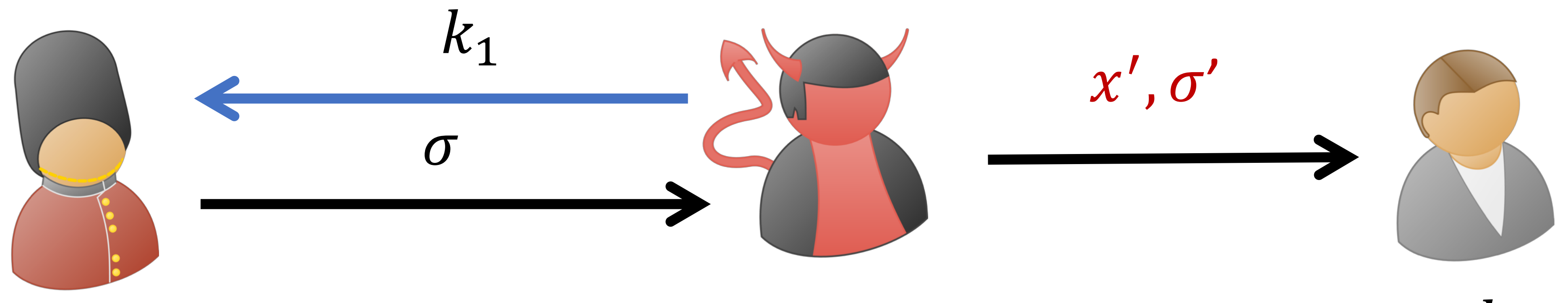
Our Tool: Multi-Key MAC (Security)



x, k_2, k_3

$$\sigma = M.Sign(x, k_1, k_2, k_3)$$

Our Tool: Multi-Key MAC (Security)

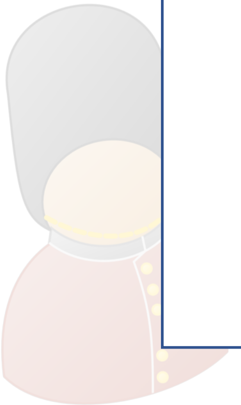


$\sigma = M.Sign(x, k_1, k_2, k_3)$

$M.Verify\,(x', \sigma', k_2)$

NO

Our Tool: Multi-Key MAC (Security)



An adversary cannot output any valid message-signature pair other than the one it received

k_2

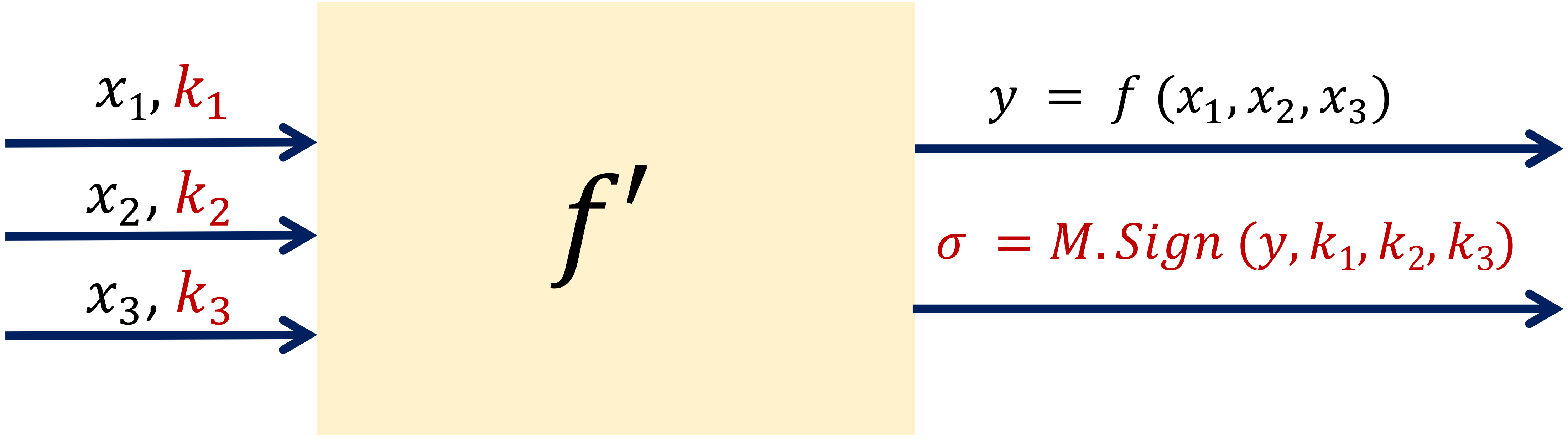
x, k_2, k_3

$M.Verify\,(x', \sigma', k_2)$

$\sigma = Sign(x, k_1, k_2, k_3)$

NO

Security with Abort: Using Multi-Key MAC



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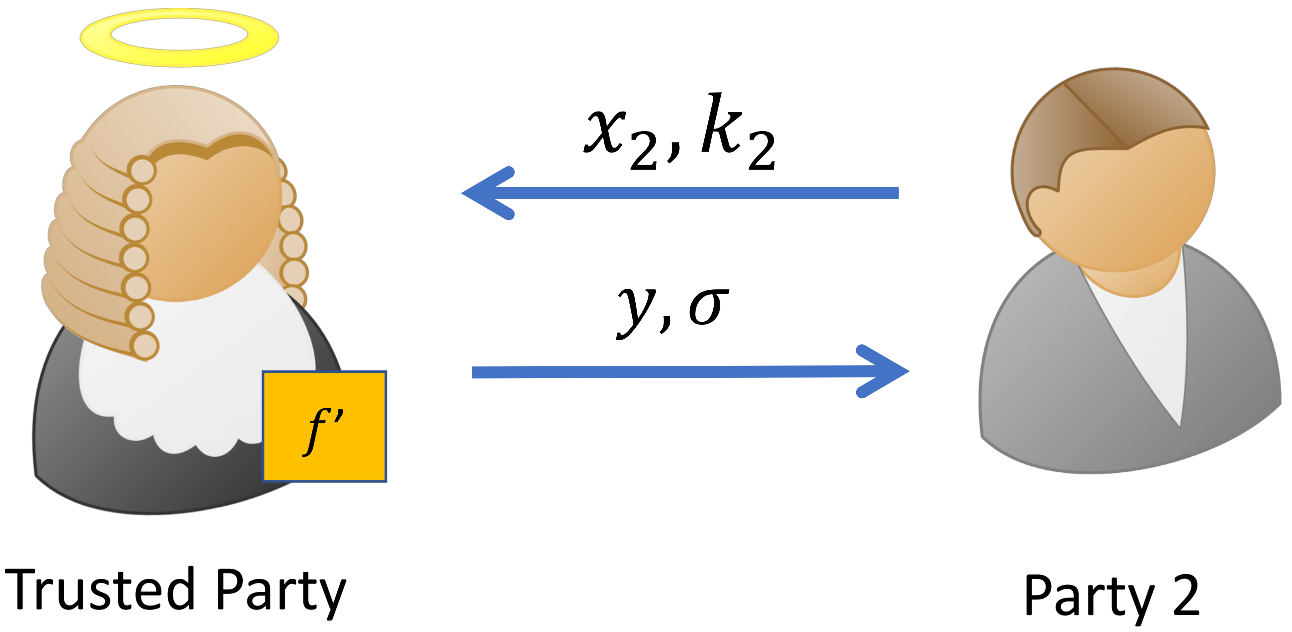
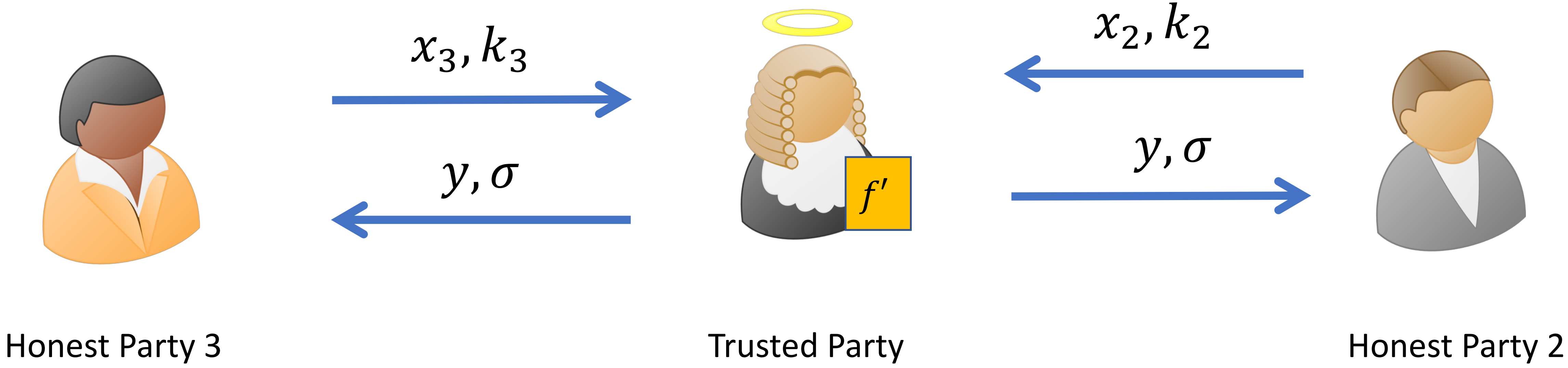


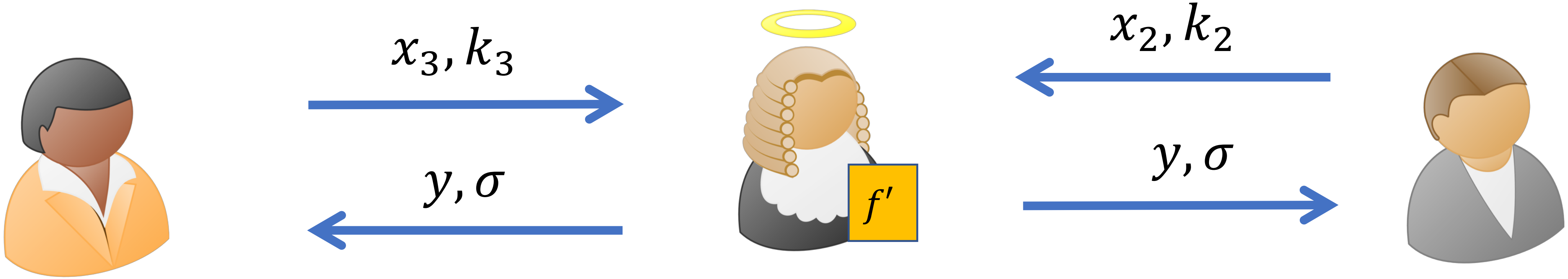
$$M.Verify(y, \sigma, k_2)$$

Security with abort: Using Multi-Key MAC



IF $y, \sigma = f'((x_1 k_1), (x_2, k_2), (x_3, k_3))$

Security with abort: Using Multi-Key MAC



Honest Party 3

Trusted Party

Honest Party 2

$M.Verify(y, \sigma, k_3)$

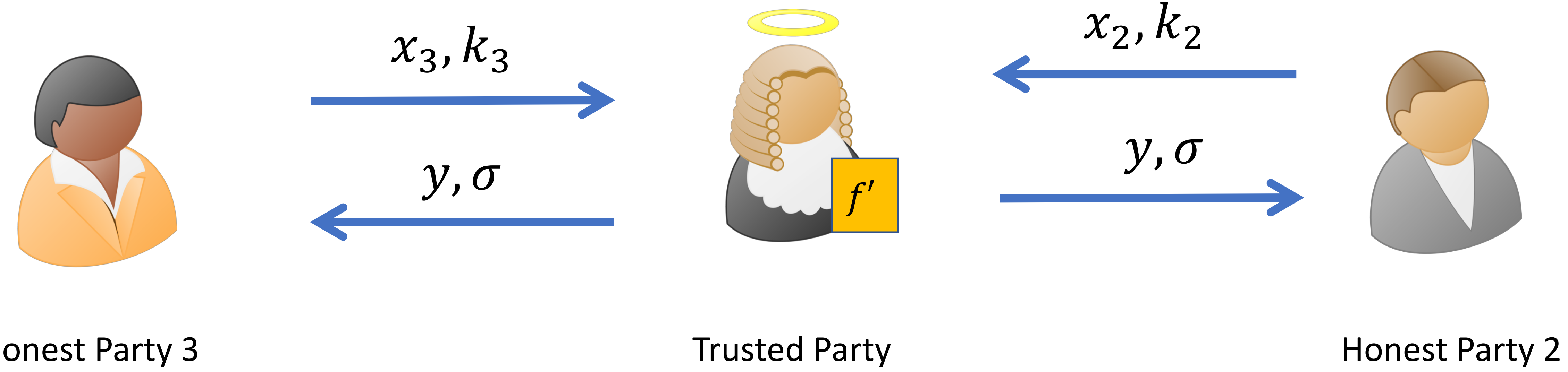
IF $y, \sigma = f'((x_1 k_1), (x_2, k_2), (x_3, k_3))$

$M.Verify(y, \sigma, k_2)$

YES

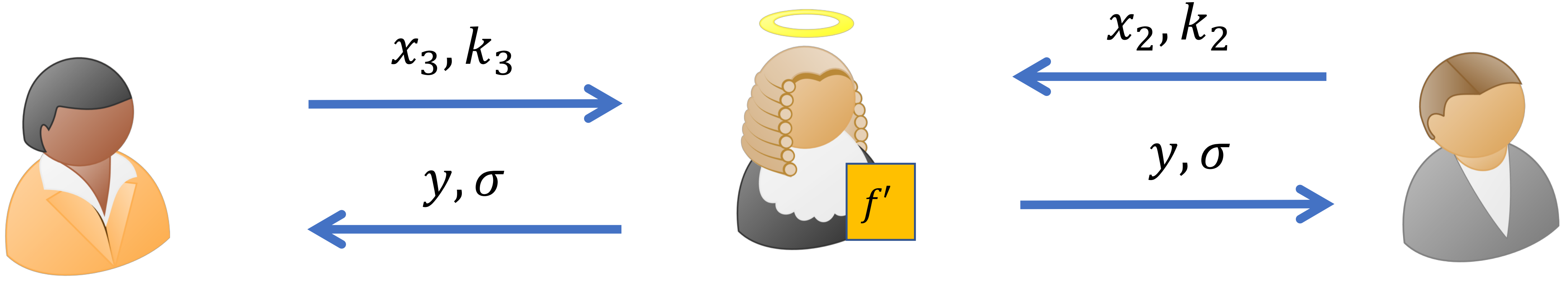
YES

Security with abort: Using Multi-Key MAC



IF $y, \sigma \neq f'((x_1 k_1), (x_2, k_2), (x_3, k_3))$

Security with abort: Using Multi-Key MAC



Honest Party 3

Trusted Party

Honest Party 2

$M.Verify(y, \sigma, k_3)$

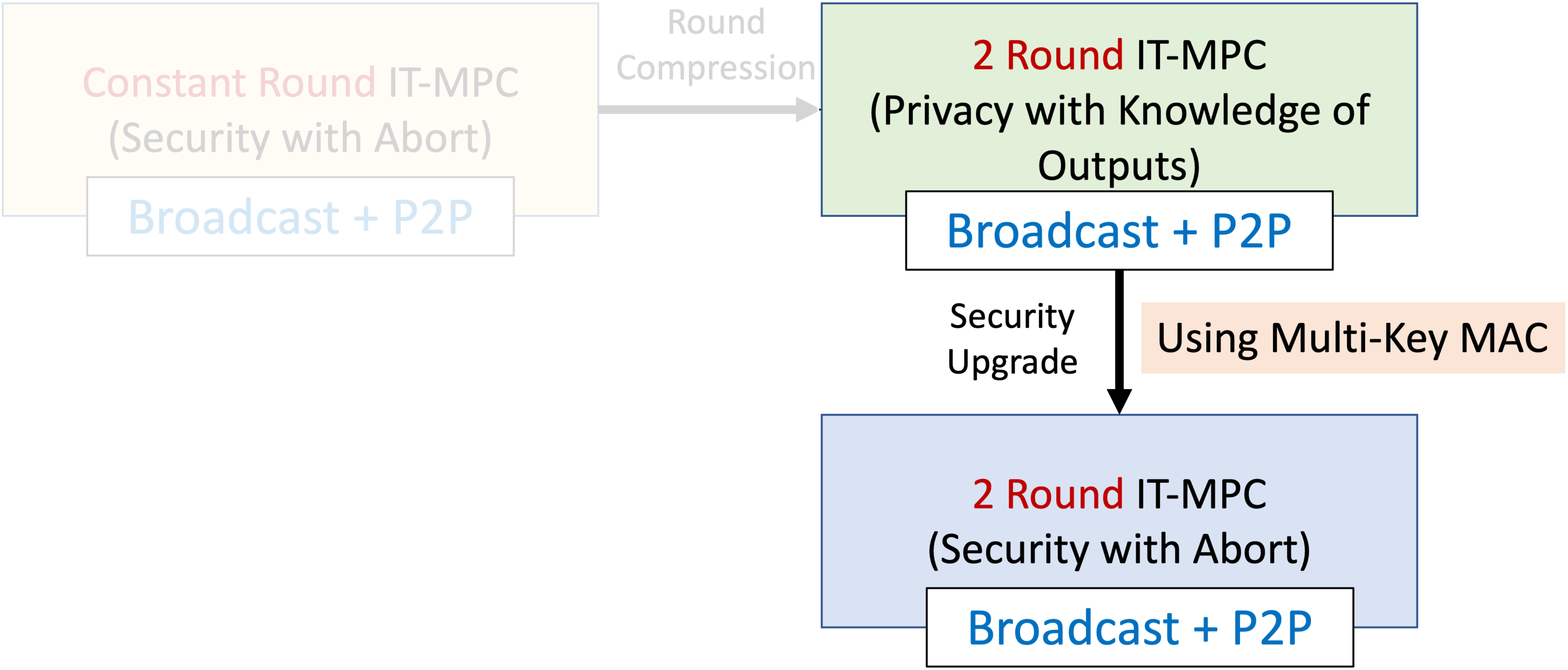
NO

IF $y, \sigma \neq f'((x_1 k_1), (x_2, k_2), (x_3, k_3))$

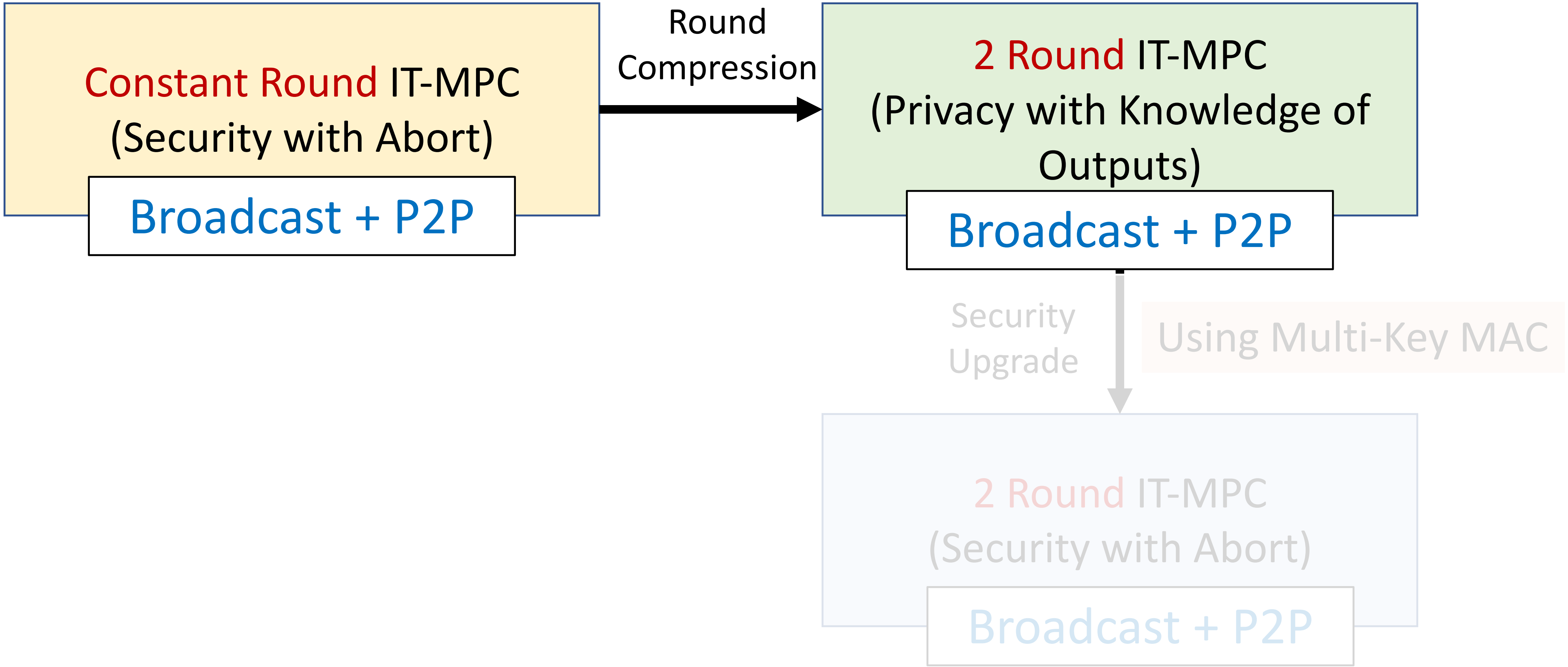
$M.Verify(y, \sigma, k_2)$

NO

Recall: Our Strategy



Second Step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2 Round IT-MPC
(Privacy with Knowledge of
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Broadcast + P2P
Security
Upgrade
Using Multi-Key MAC
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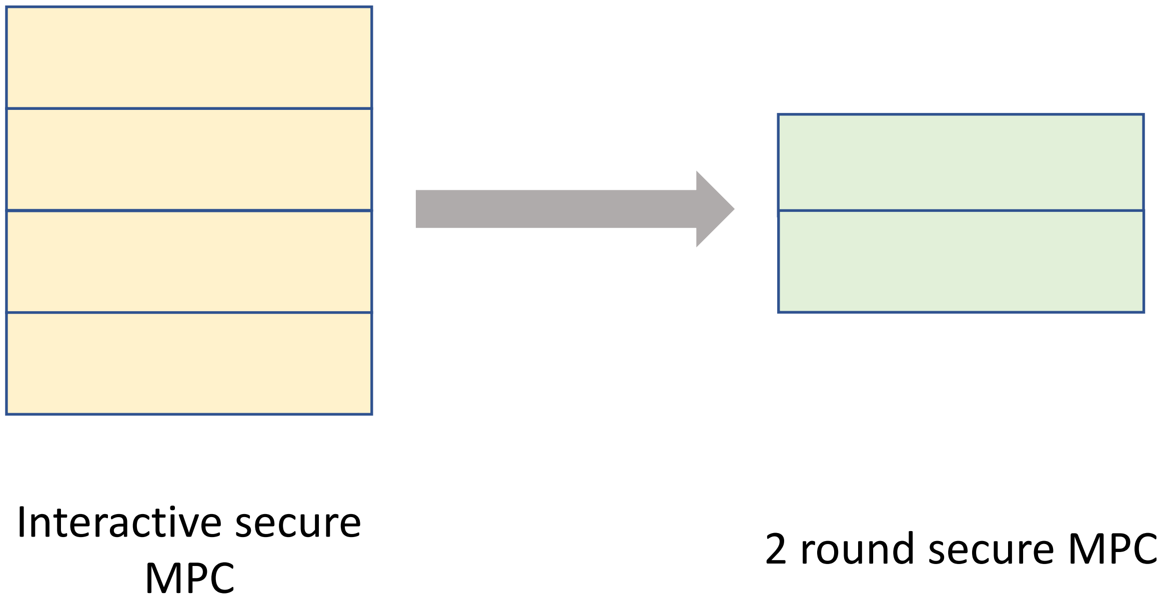
Broadcast + P2P

Technique: Round Compression



[GGHR'13]
Indistinguishability Obfuscation

[GLS'15]
Witness Encryption + Garbled circuits

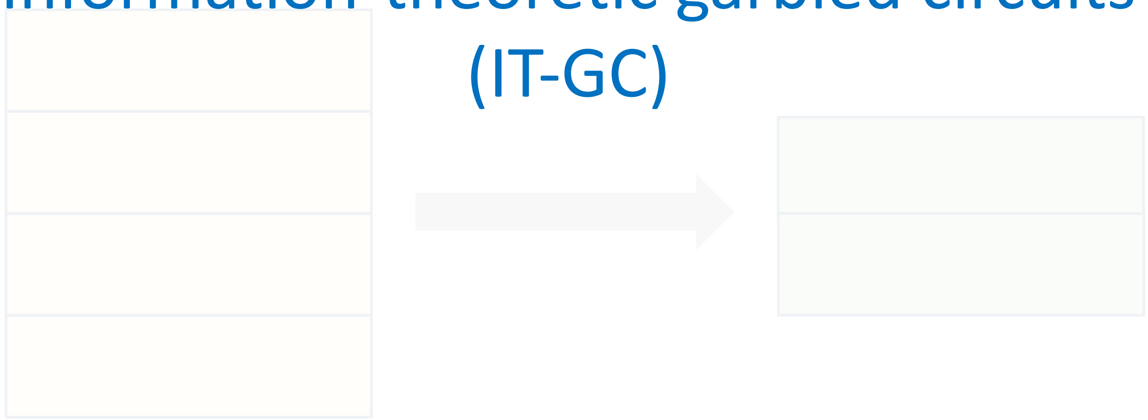
[GS'17]
Bilinear Maps + Garbled circuits

[GS'18, BL'18]
OT + Garbled Circuits

[ACGJ'18]
Garbled circuits

Initial Idea

Replace garbled circuits with
Information-theoretic garbled circuits
(IT-GC)



Interactive secure MPC

2 round secure MPC

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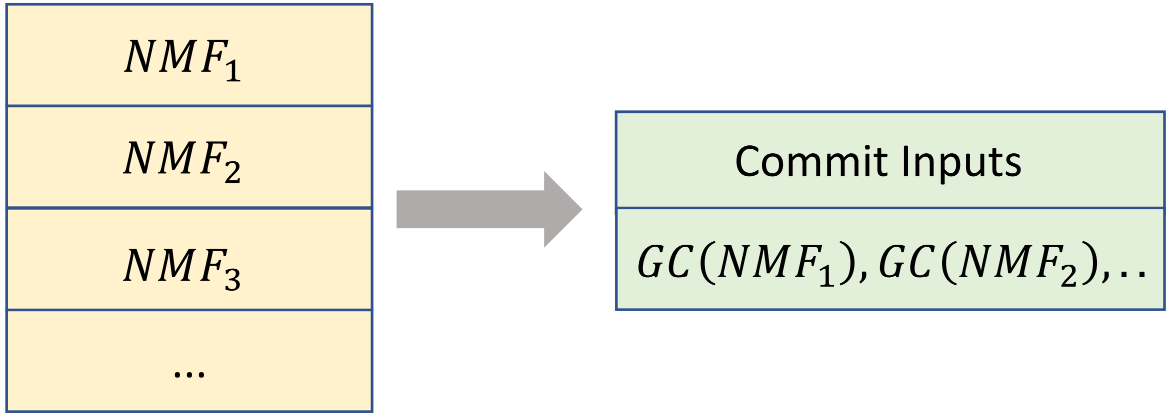
Round Compression Template



Interactive secure MPC

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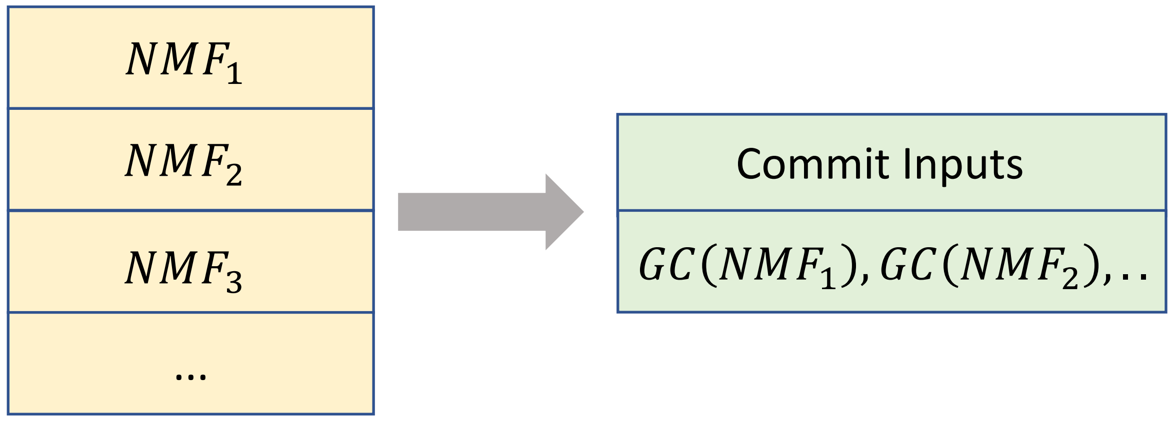
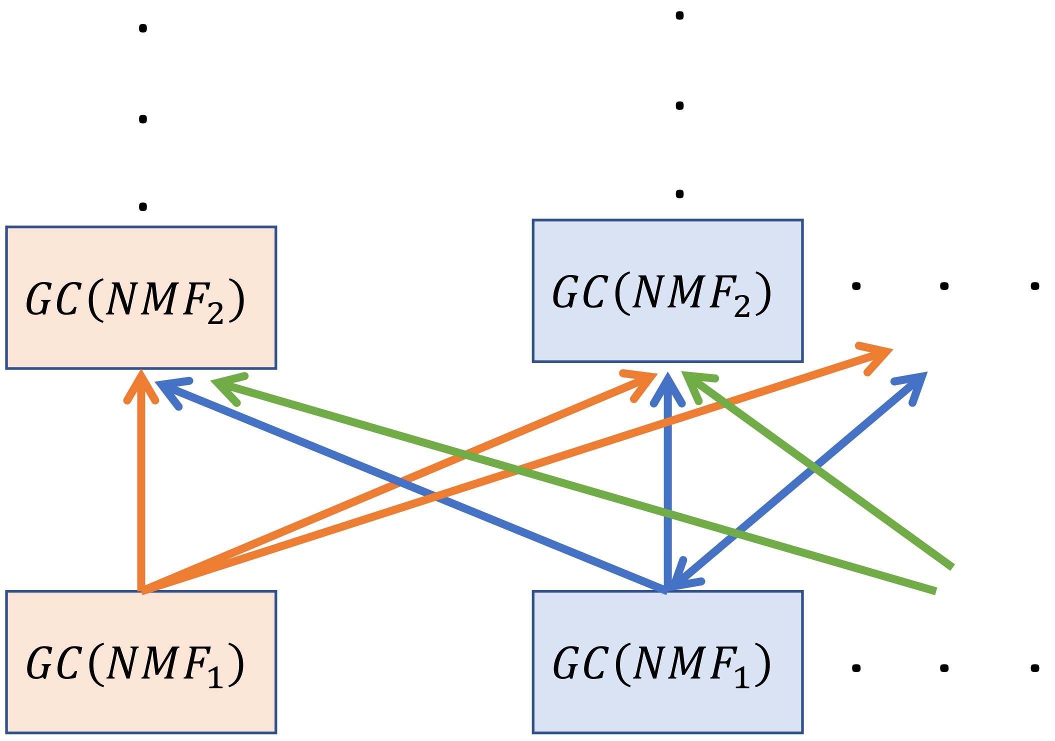


Interactive secure MPC

2 round secure MPC

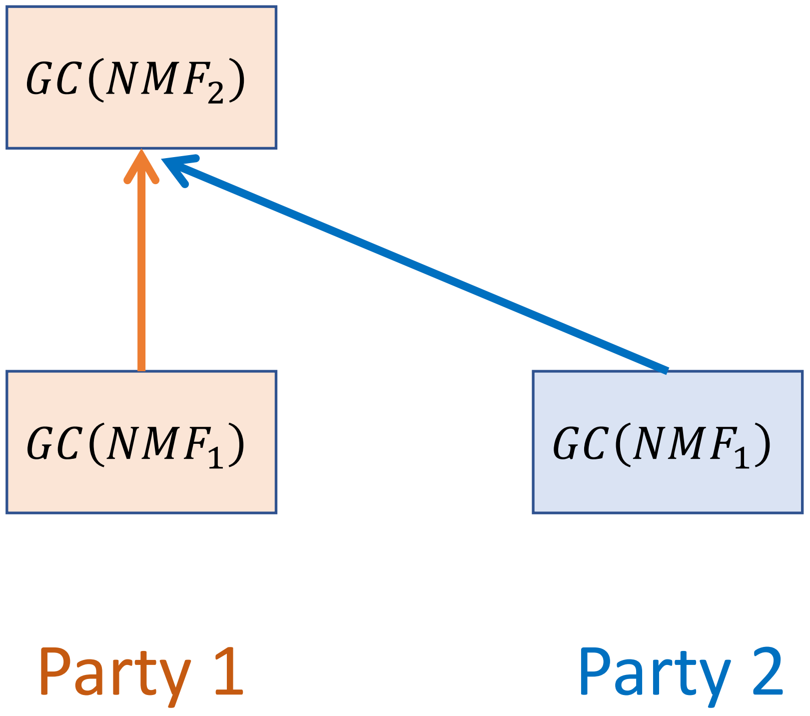
After Round 2



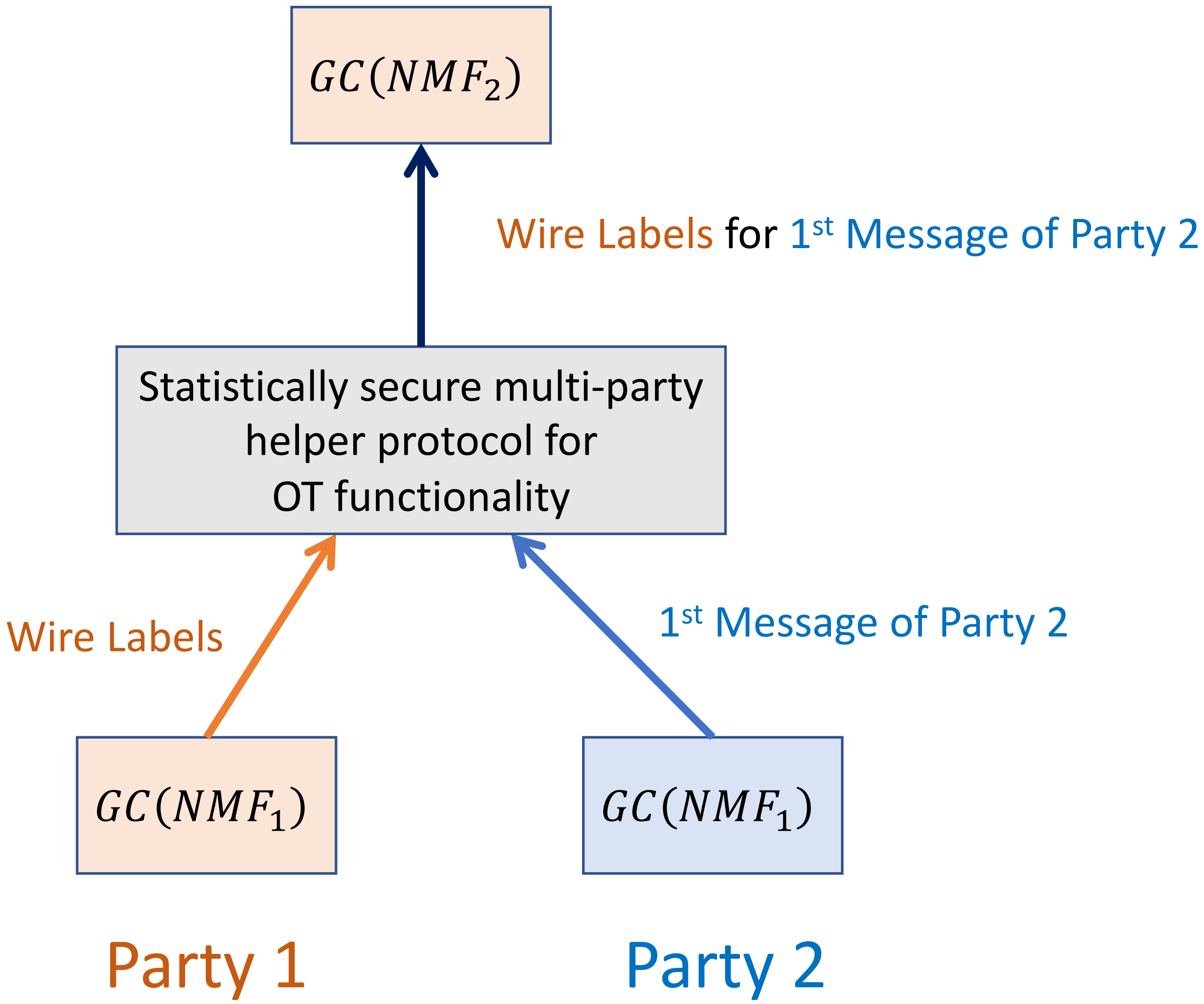
Party 1

Party 2

Round Compression Template: After Round 2



Round Compression Template: After Round 2



Initial Idea: Doesn't Work

Replace garbled circuits with
Information-theoretic garbled circuits
(IT-GC)

Problem
Size of the input wire labels in IT-GC grows exponentially in the depth of the circuit being garbled.

Interactive secure MPC

2 round secure MPC

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Indistinguishability Obfuscation

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Indistinguishability Obfuscation

No. of garbled circuits generated per-party $\geq |C|$

[GS'17]
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Interactive secure MPC

2 round secure MPC

[GGHR'13]
Indistinguishability Obfuscation

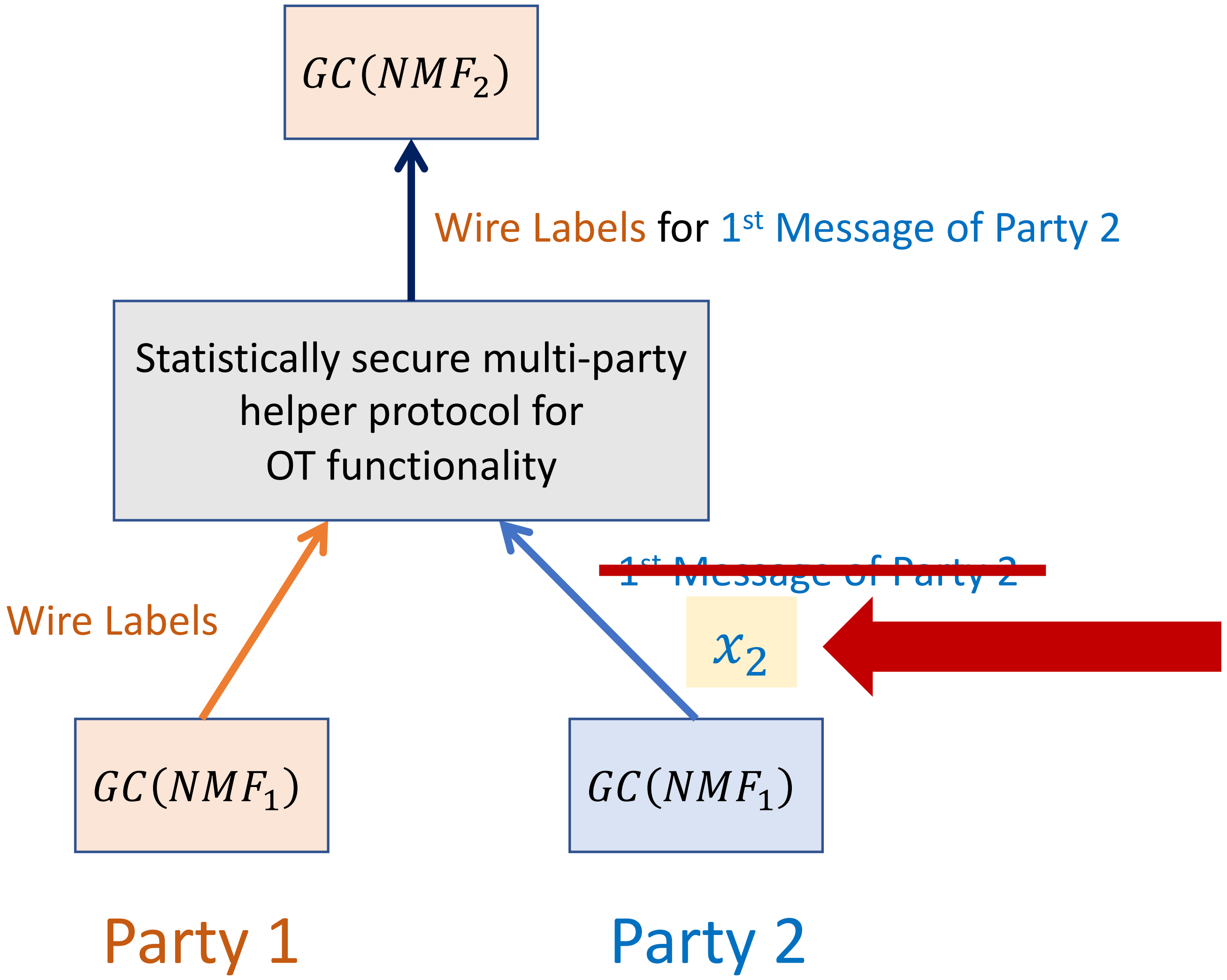
No. of garbled circuits generated per-party $\geq |C|$

Size of bottom-most garbled circuits is $\exp(|C|)$

[GS'18, BL'18]
OT + Garbled Circuits

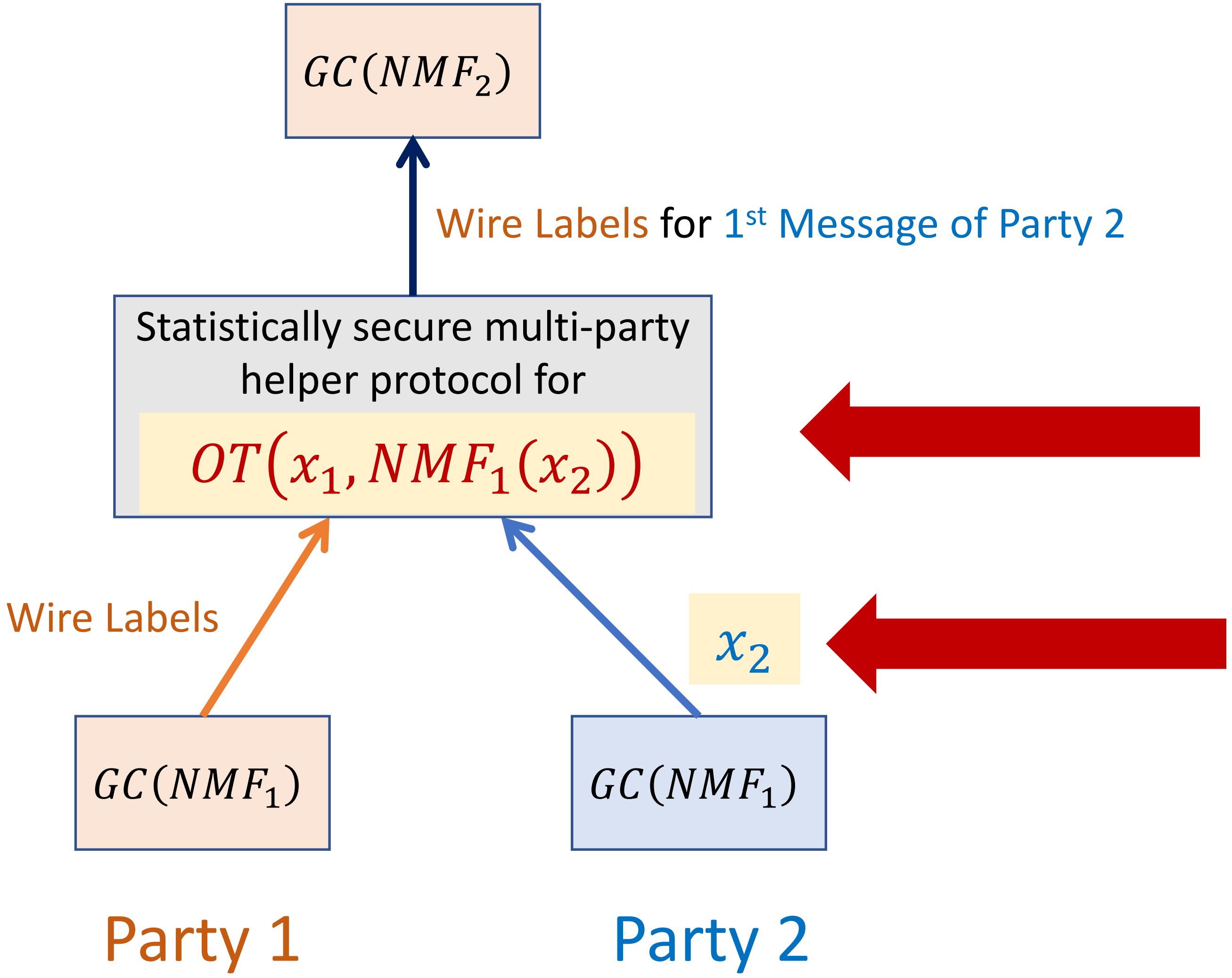
[ACGJ'18]
Garbled circuits

Our Approach



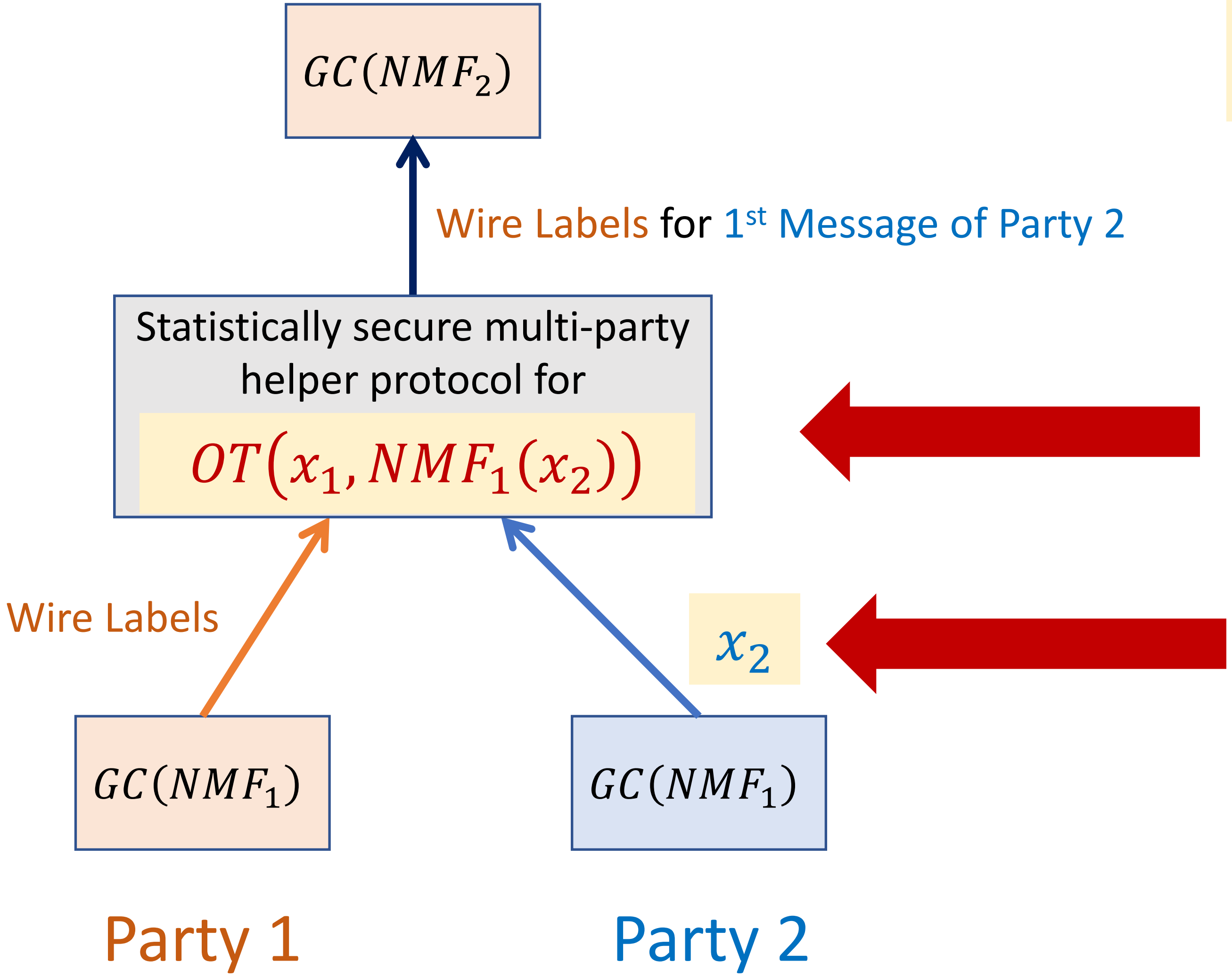
Inspired by the approach used in [BL'18]

Our Approach



Our Approach

Design a 2 round helper protocol for $OT(x_1, NMF_1(x_2))$



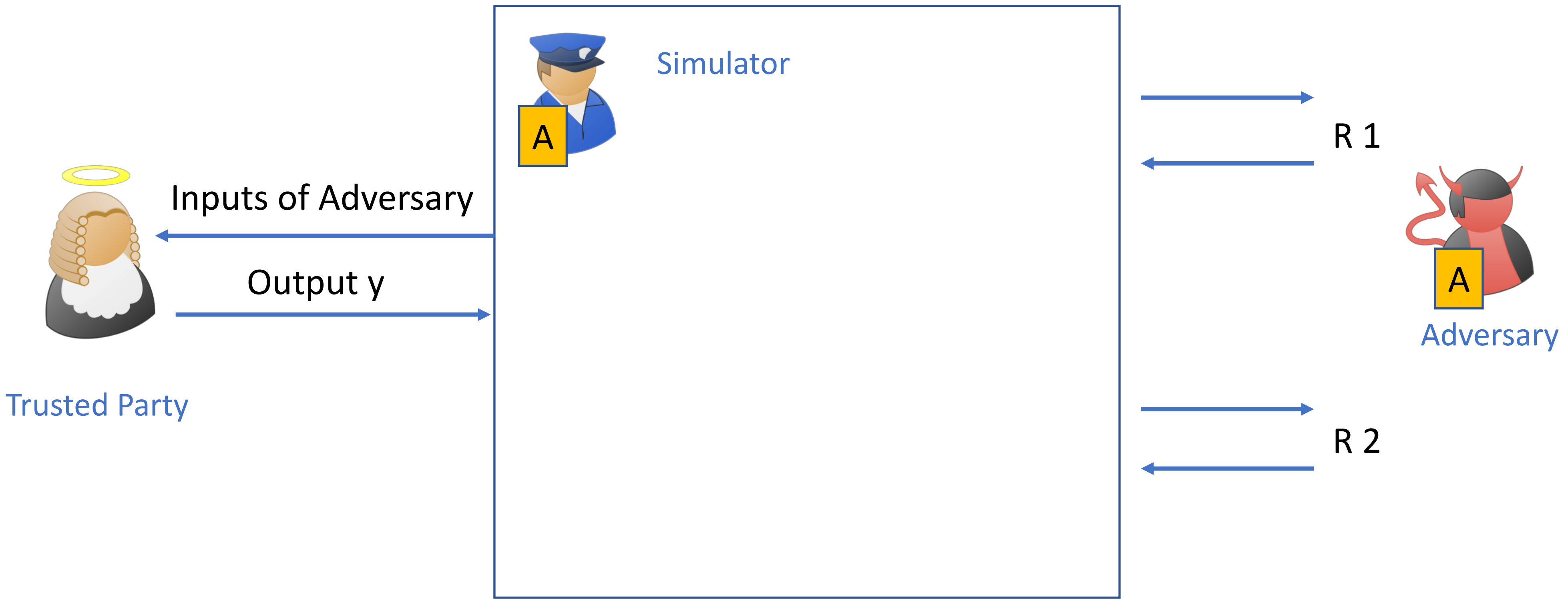
Challenges in Designing such a protocol

2 Round MPC Template using a 2 Round Helper Protocol

R 1	1st round of Helper Protocol (implicitly commits to inputs)
R 2	2nd round of Helper Protocol & $GC(NMF_1), GC(NMF_2), ..$

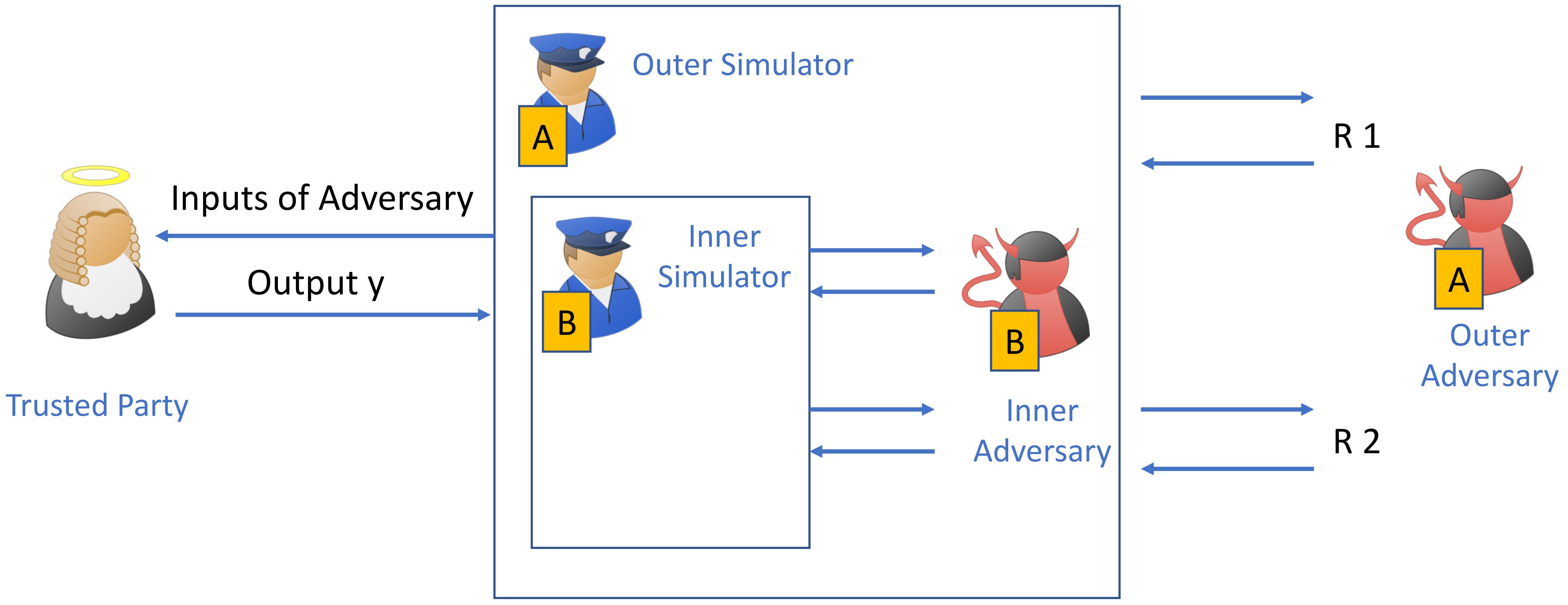
Challenges in Designing such a protocol

Malicious Security



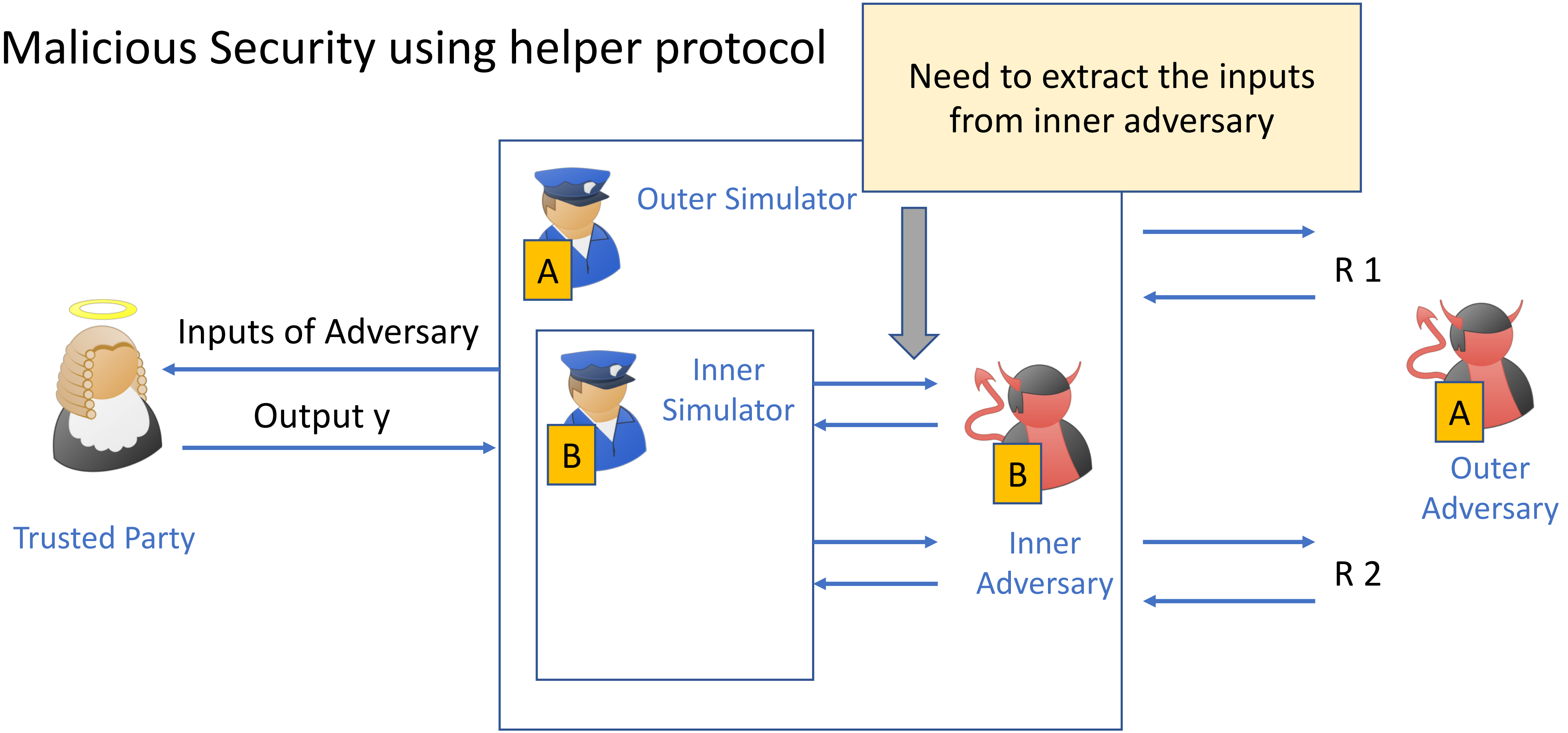
Challenges in Designing such a protocol

Malicious Security using helper protocol



Challenges in Designing such a protocol

Malicious Security using helper protocol

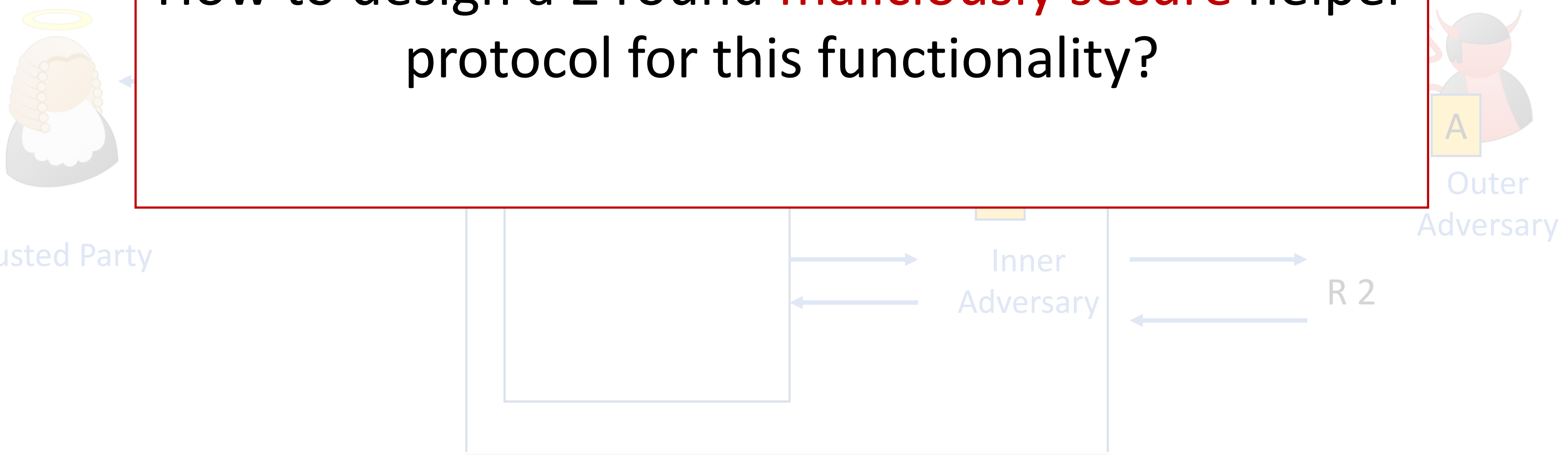


Challenges in Designing such a protocol

For Malicious Security

Need to extract the inputs from inner adversary

How to design a 2 round maliciously secure helper protocol for this functionality?



Our Solution

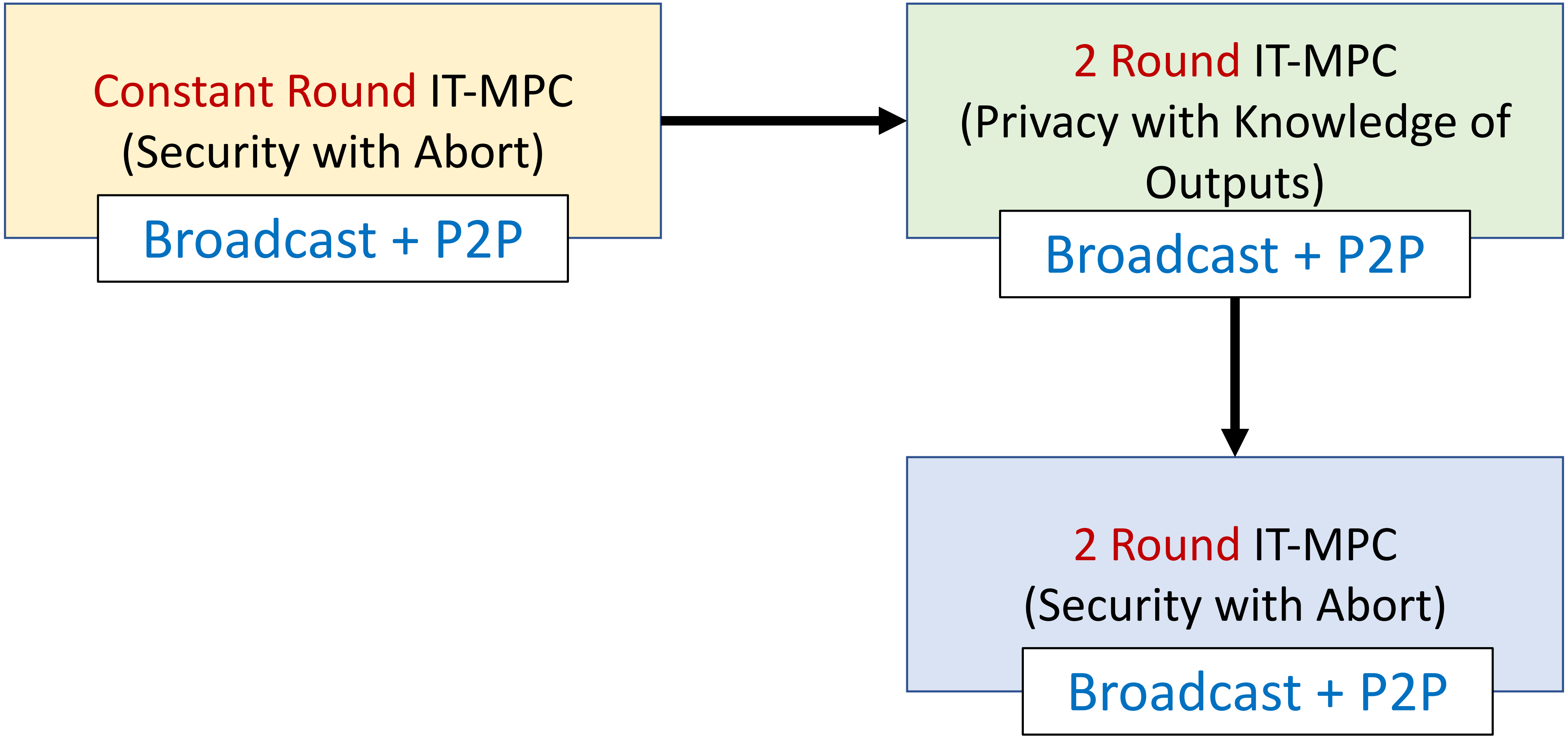
A two-round helper MPC protocol for 2 input delayed-function $OT\left(x_1, NMF_1(x_2)\right)$

NMF_2 is not known in the first round.

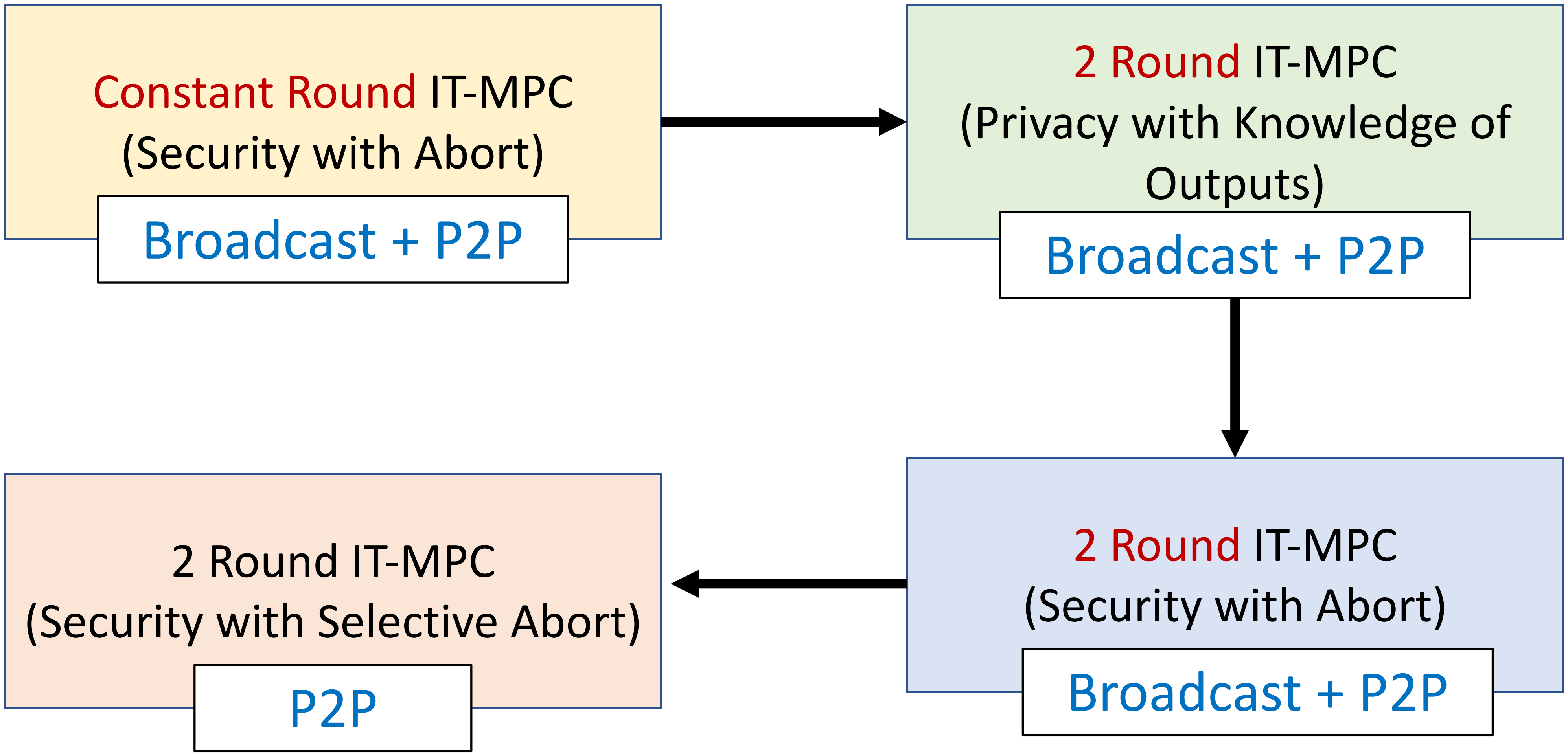
	Party 1	Party 2
HONEST	Nothing beyond the output is leaked	Nothing beyond $NMF_1(x_2)$ is leaked
CORRUPT	Simulator can extract x_1	Simulator can extract $NMF_1(x_2)$

This asymmetric weaker security suffices!

Conclusion


Constant Round IT-MPC
(Security with Abort)
Broadcast + P2P
2 Round IT-MPC
(Privacy with Knowledge of Outputs)
Broadcast + P2P
2 Round IT-MPC
(Security with Abort)
Broadcast + P2P

Conclusion


Constant Round IT-MPC
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(Privacy with Knowledge of Outputs)
Broadcast + P2P
2 Round IT-MPC
(Security with Abort)
Broadcast + P2P
2 Round IT-MPC
(Security with Selective Abort)
P2P

Thank You!

https://eprint.iacr.org/2018/1078

aarushig@cs.jhu.edu