Round Optimal Secure Multiparty Computation from Minimal Assumptions

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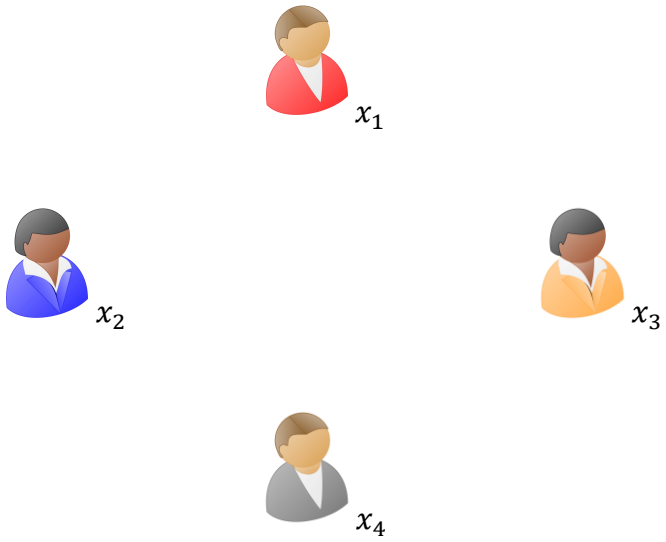
University of California Los Angeles

TCC 2020

Multiparty Computation (MPC)

[Yao'86, Goldreich-Micali-Wigderson'87]



$y = f(x_1, x_2, x_3, x_4)$

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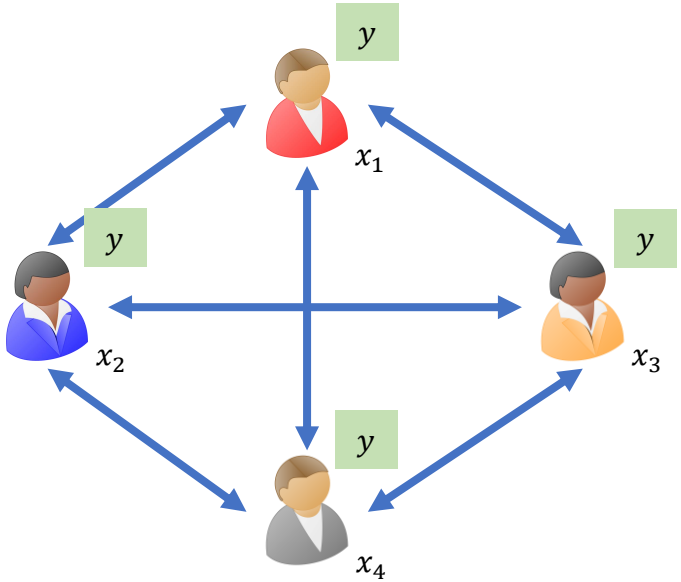

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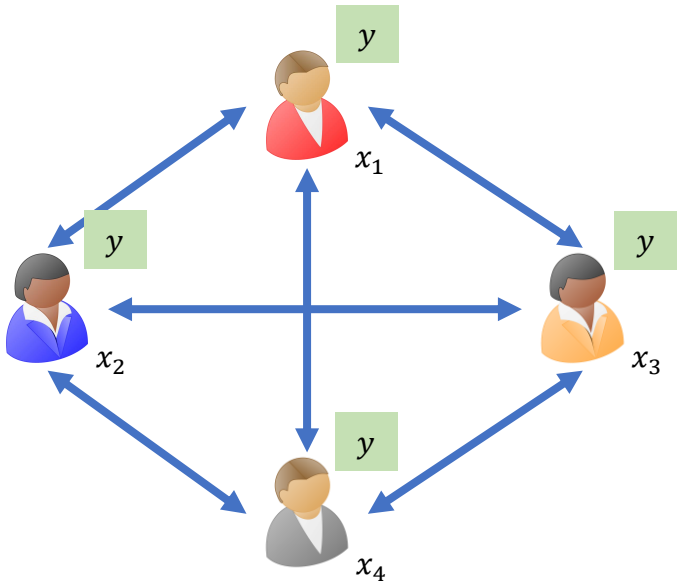

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A **round** constitutes of every participant sending a message.

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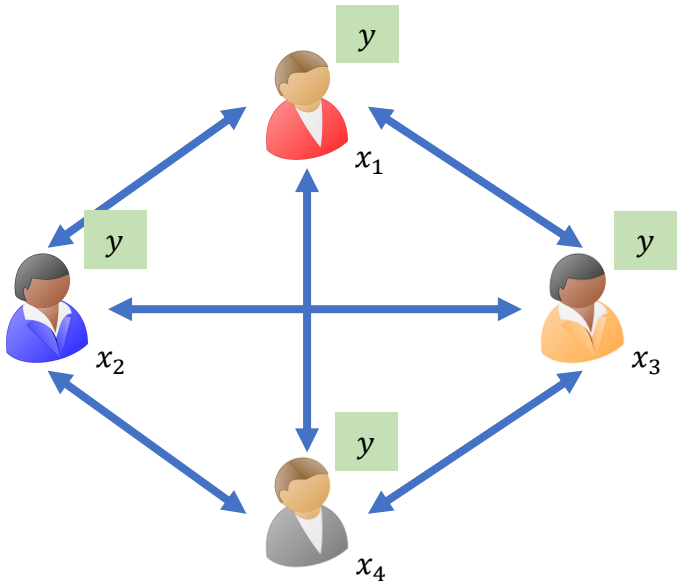

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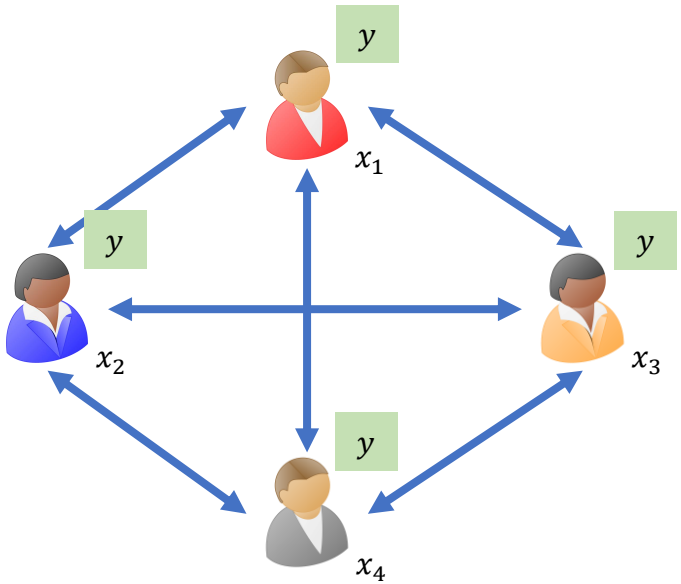
A **round** constitutes of every participant sending a message.

Goal: For efficiency, **minimize rounds of interaction**.

Security



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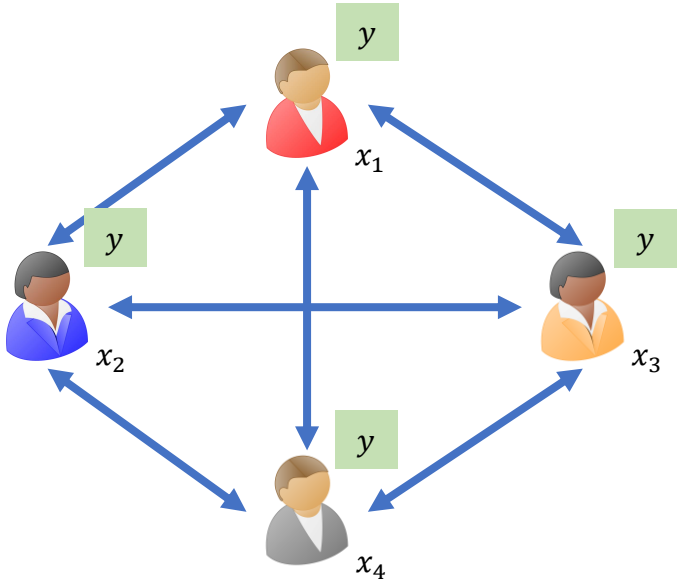
Misbehaving participants should not learn anything beyond the output of the function.

Security



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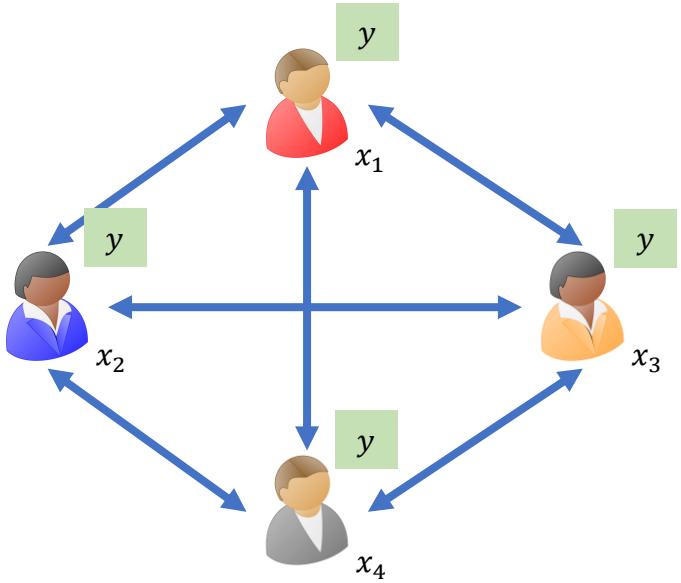
Security

real world



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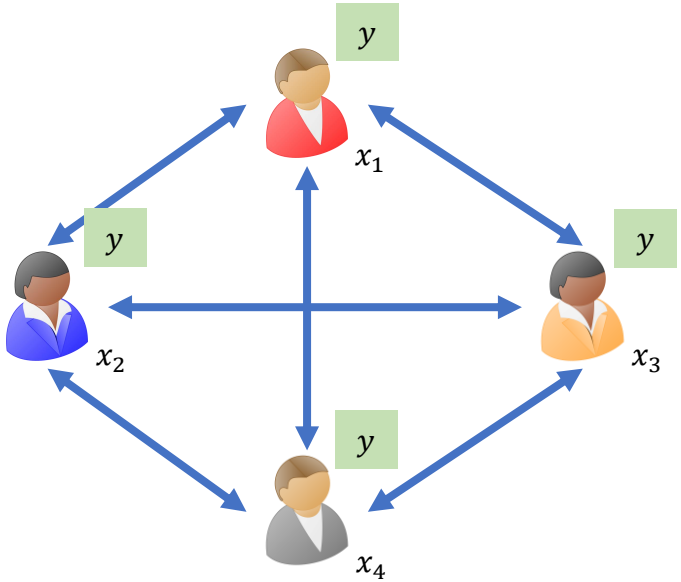

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ideal world

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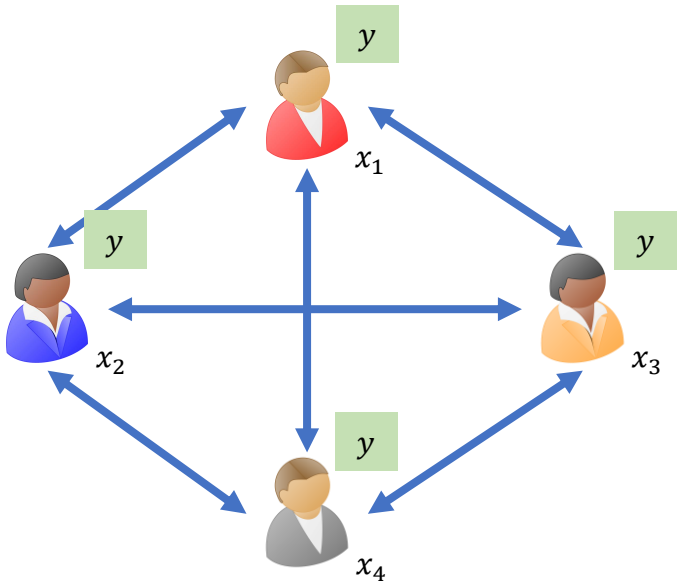

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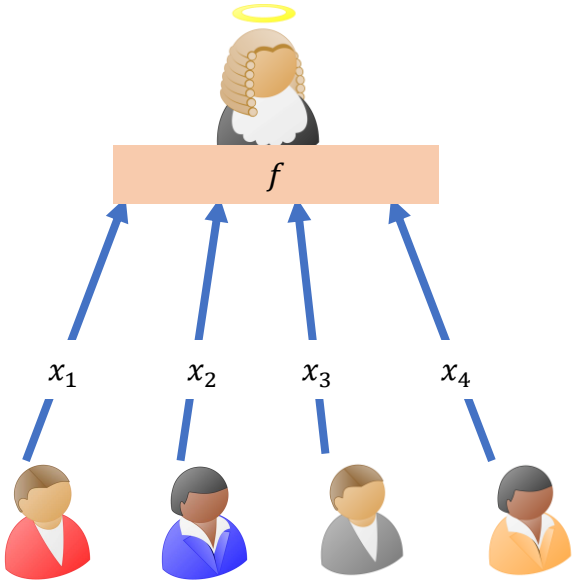

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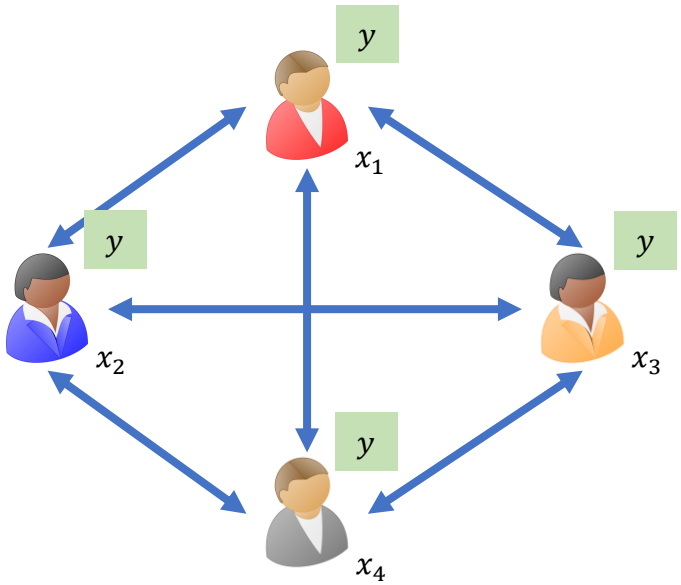

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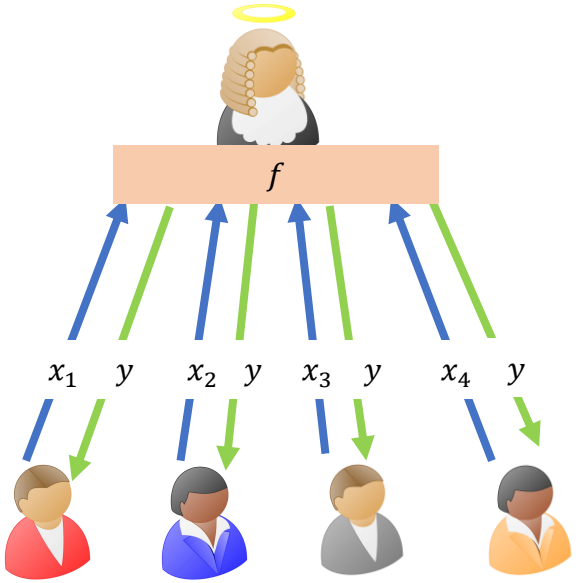

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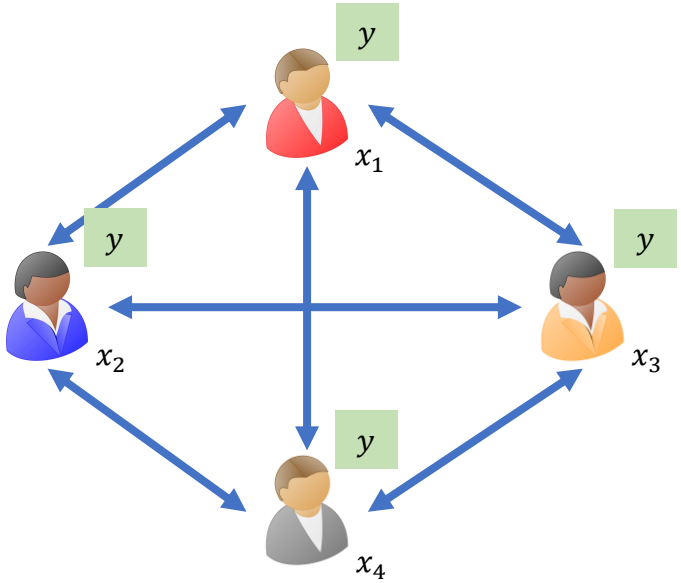

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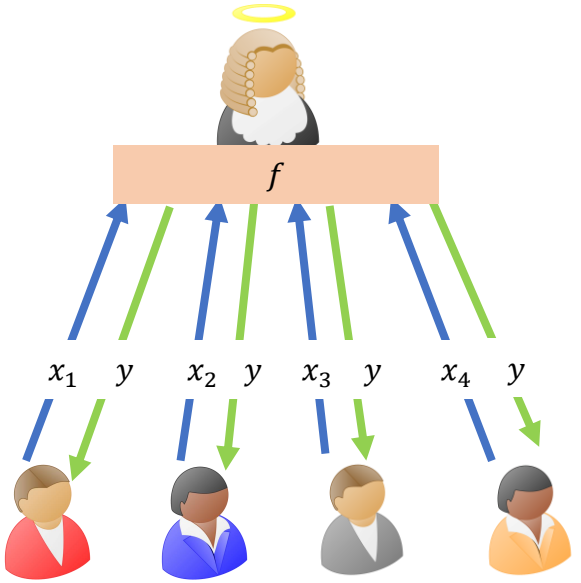

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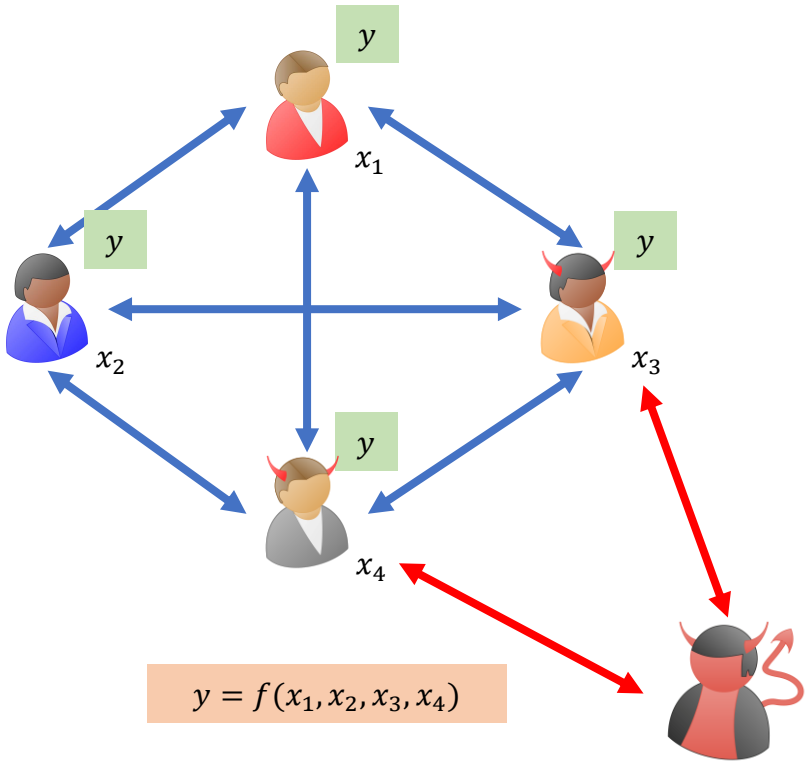

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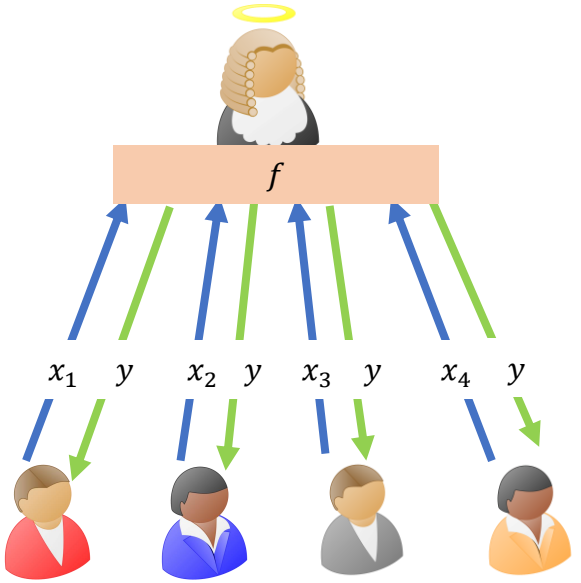

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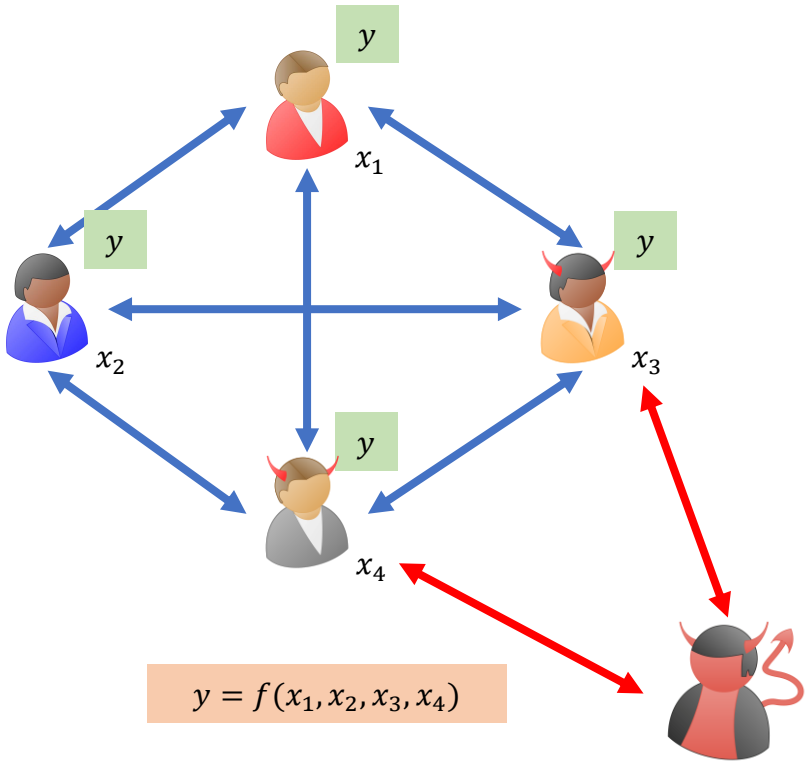

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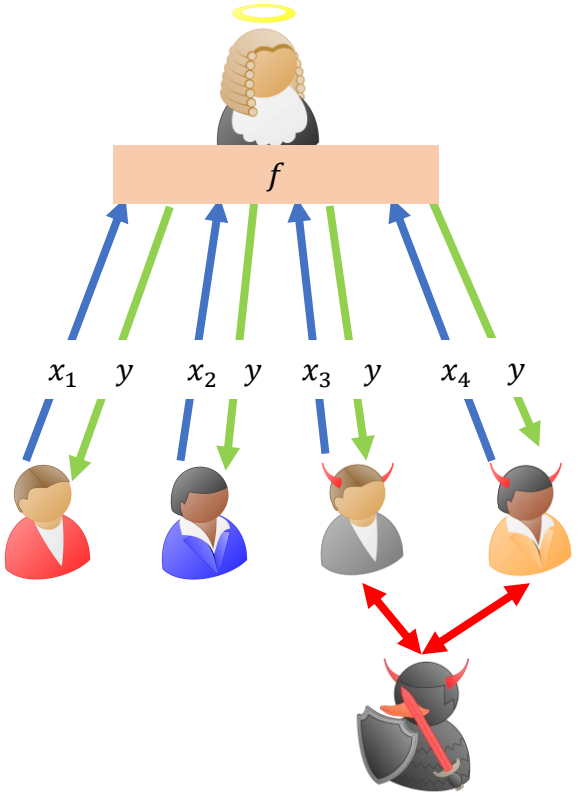

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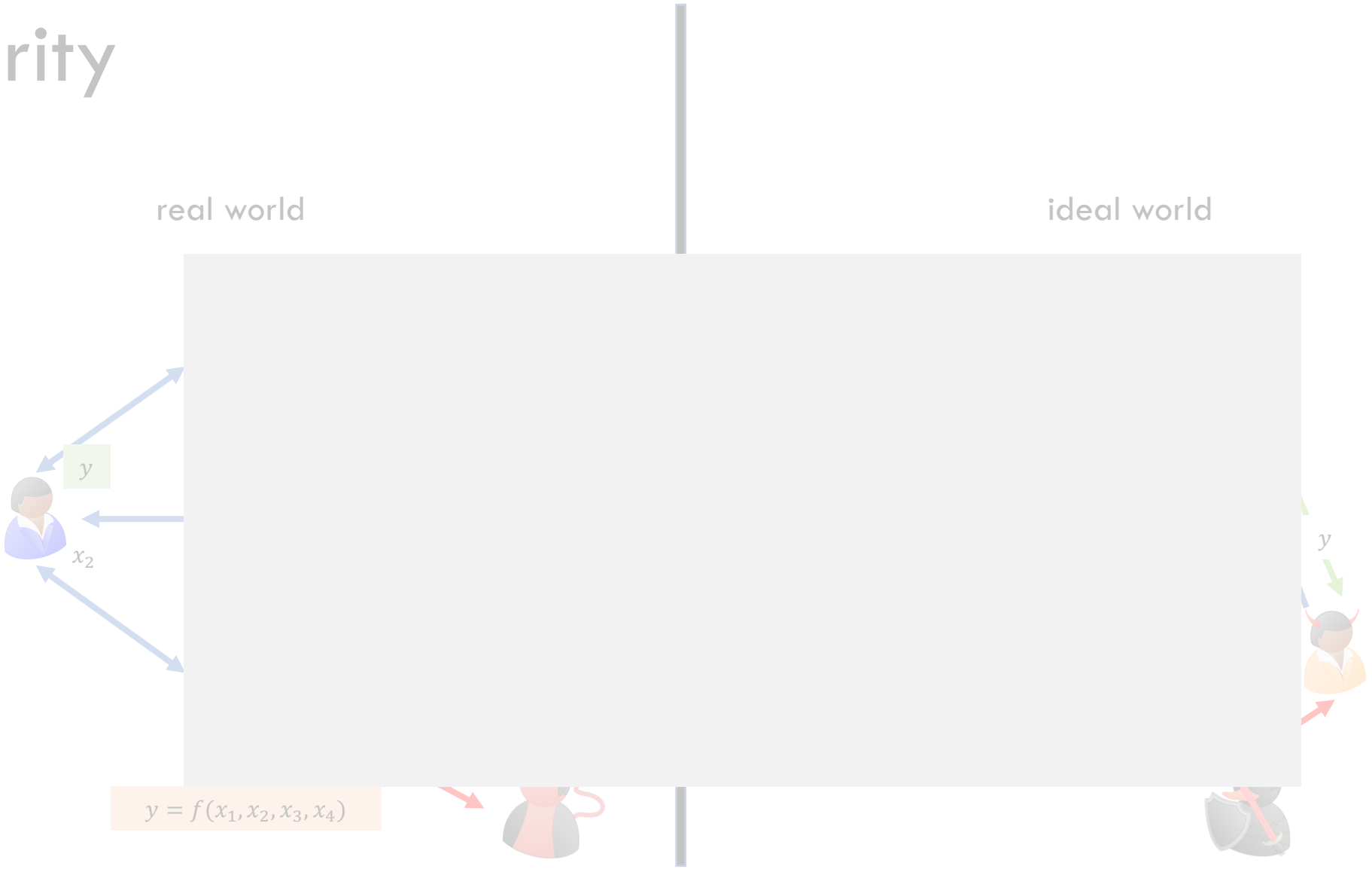
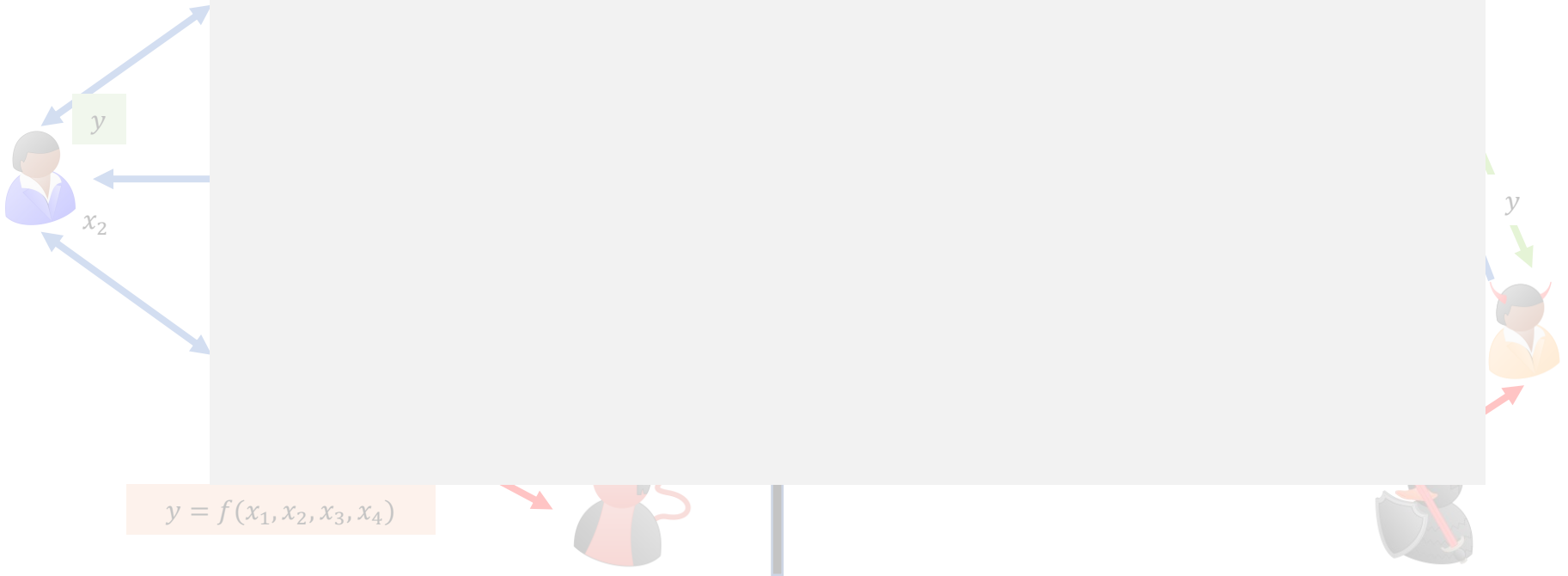


Security

real world

ideal world

Computational security.



Security

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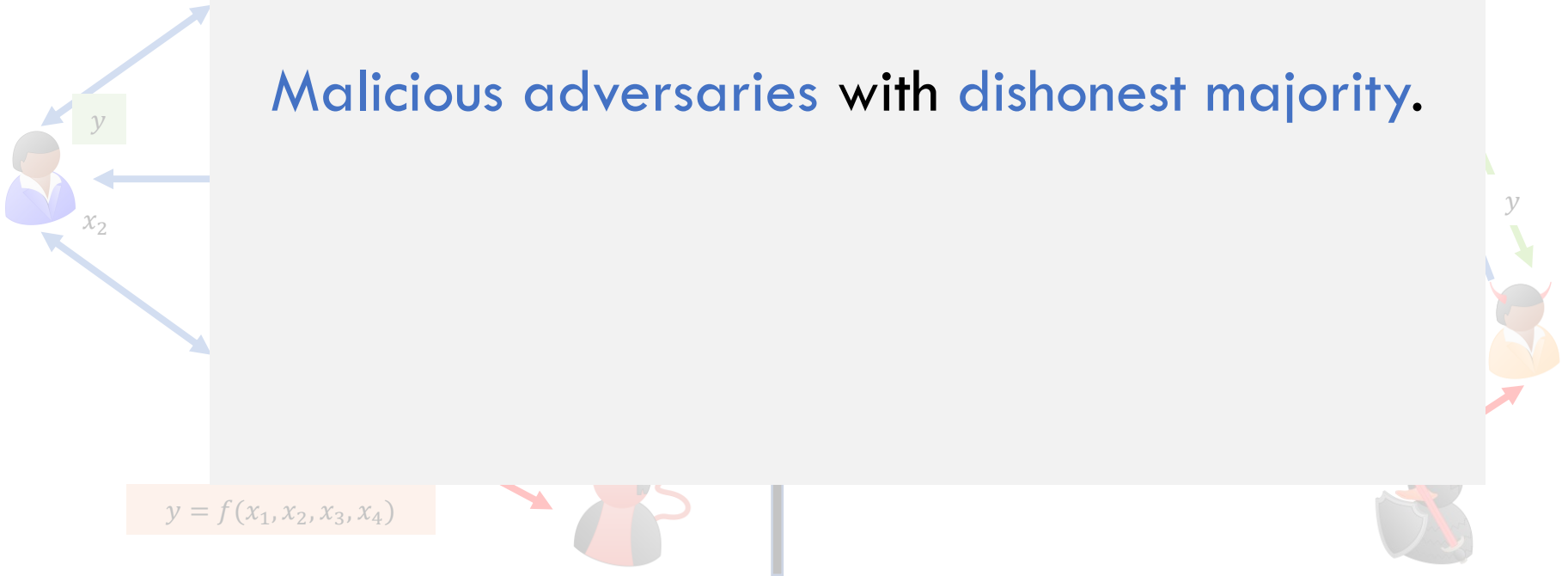
Computational security.

Malicious adversaries with dishonest majority.



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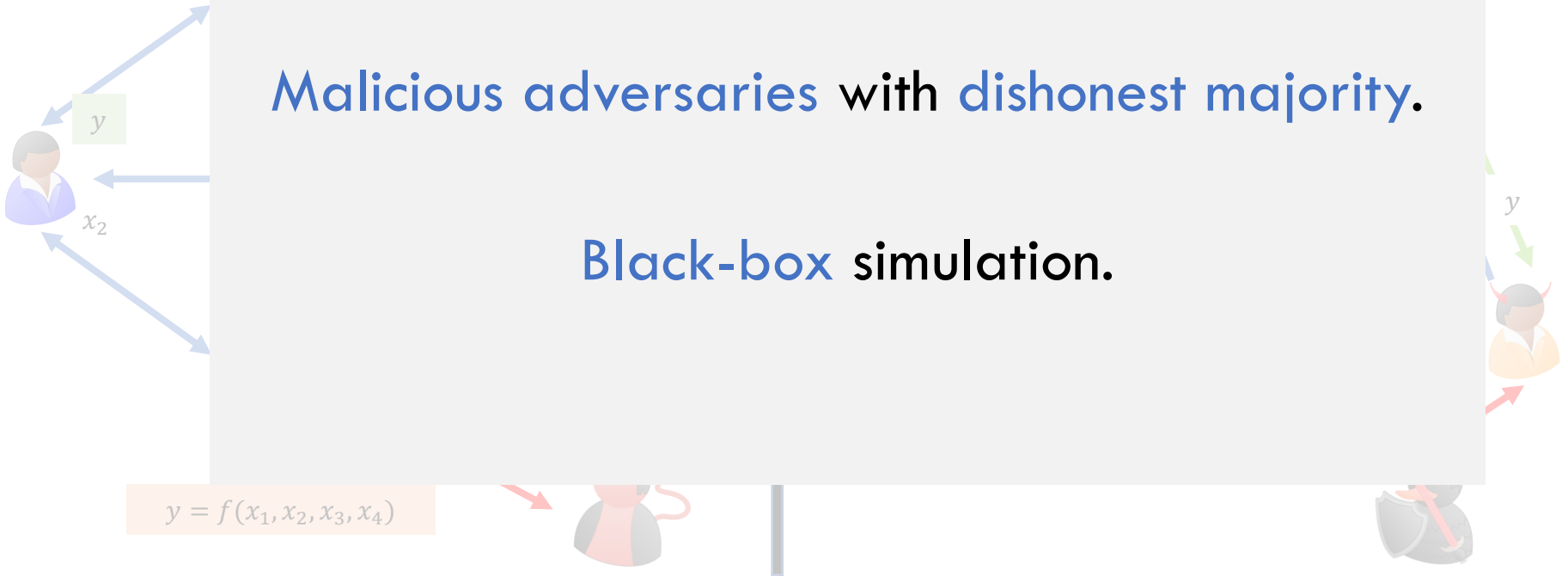
Computational security.

Malicious adversaries with dishonest majority.

Black-box simulation.



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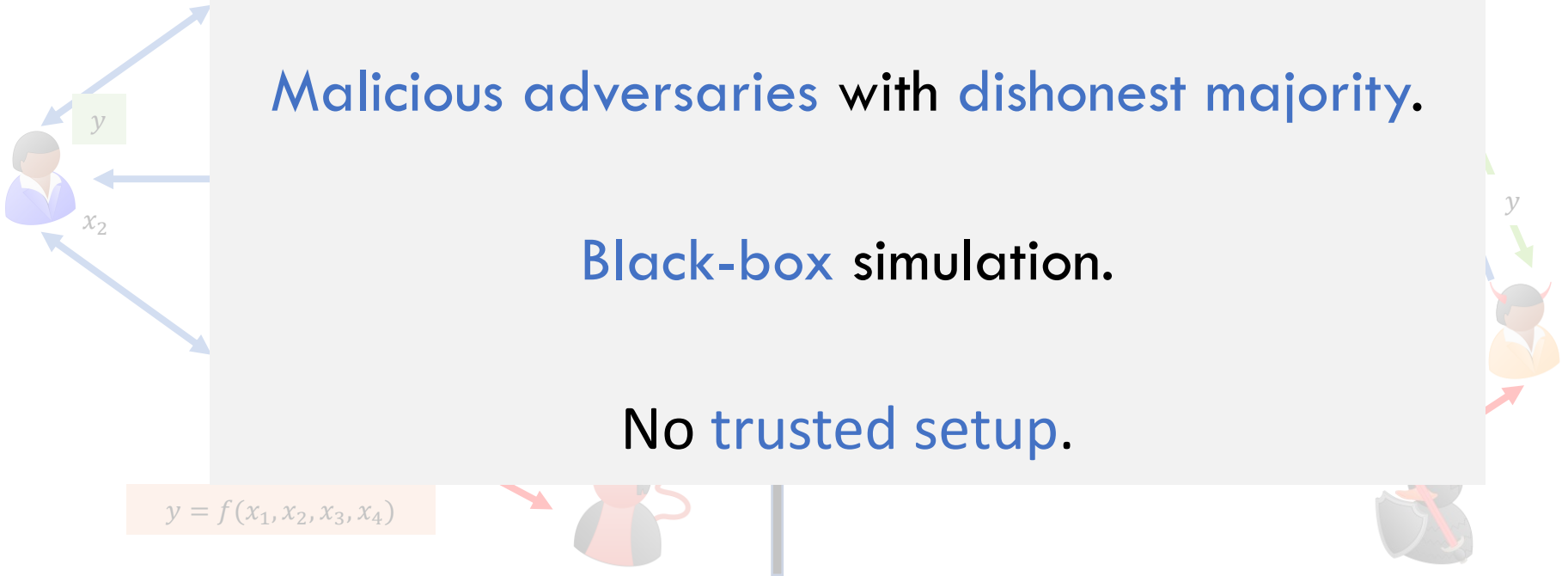

Computational security.

Malicious adversaries with dishonest majority.

Black-box simulation.

No trusted setup.

Can we construct round optimal multiparty computation from minimal assumptions?

Timeline

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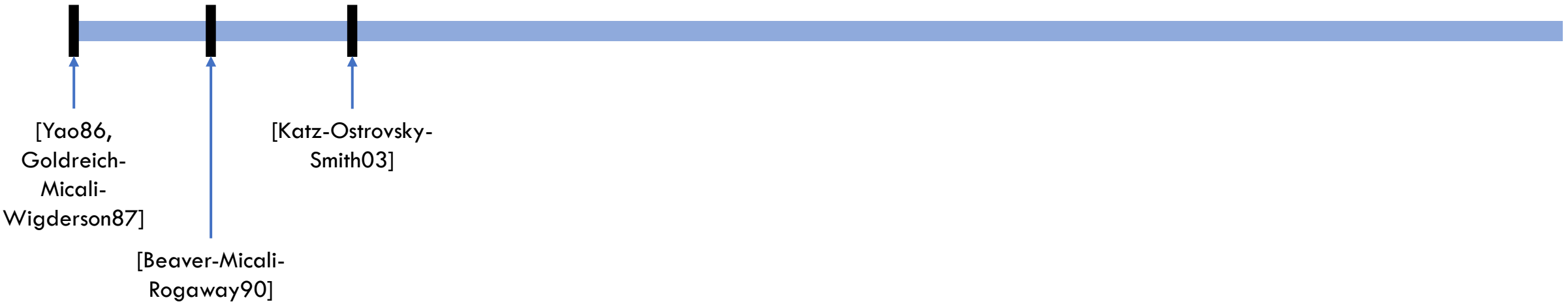
[Yao86, Goldreich-Micali-Wigderson87]
[Beaver-Micali-Rogaway90]
constant round

Timeline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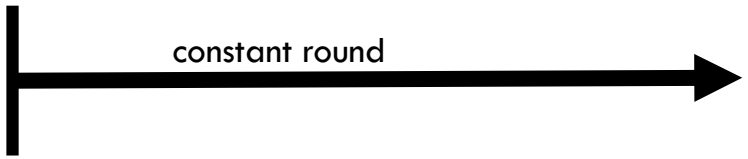
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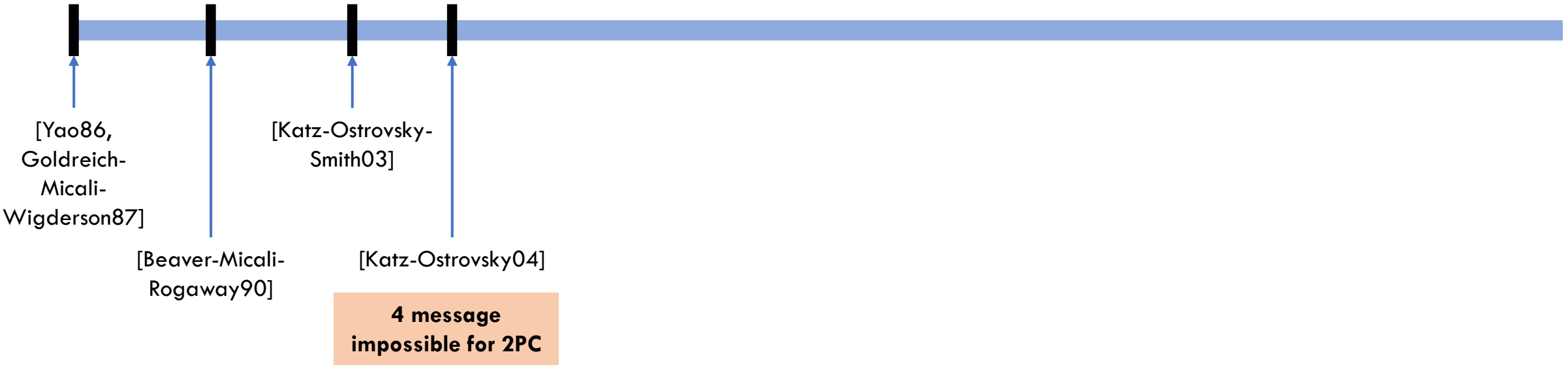
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4 message impossible for 2PC
constant round

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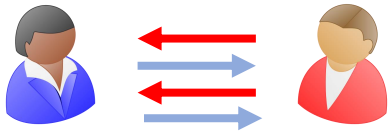

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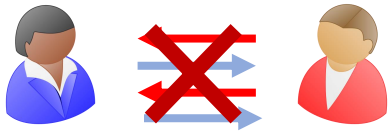

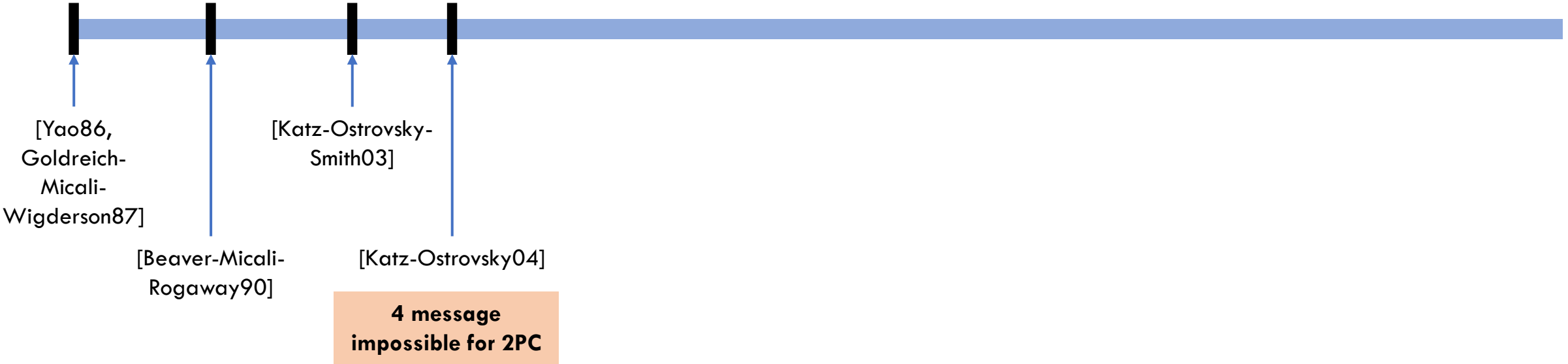
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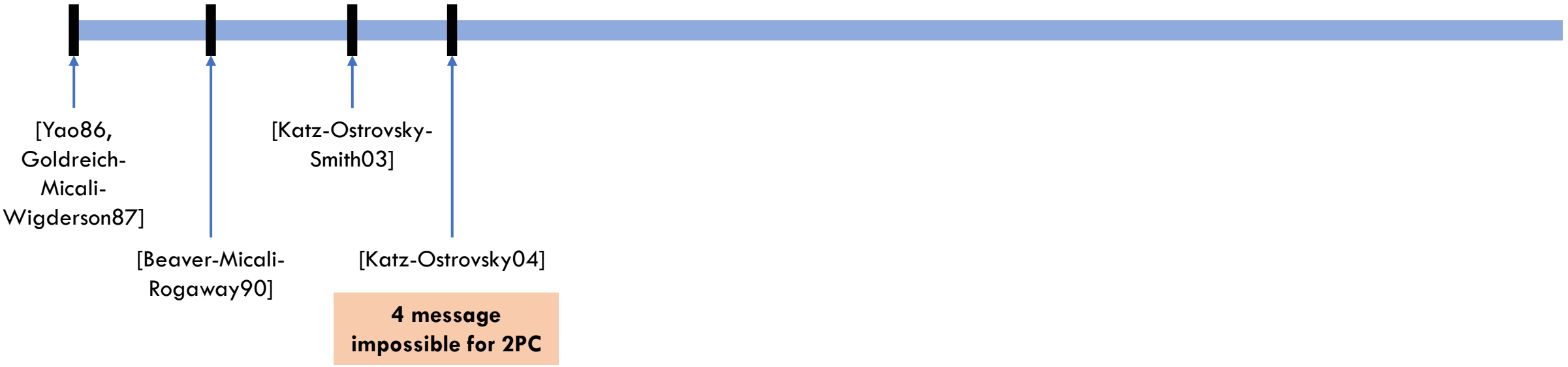
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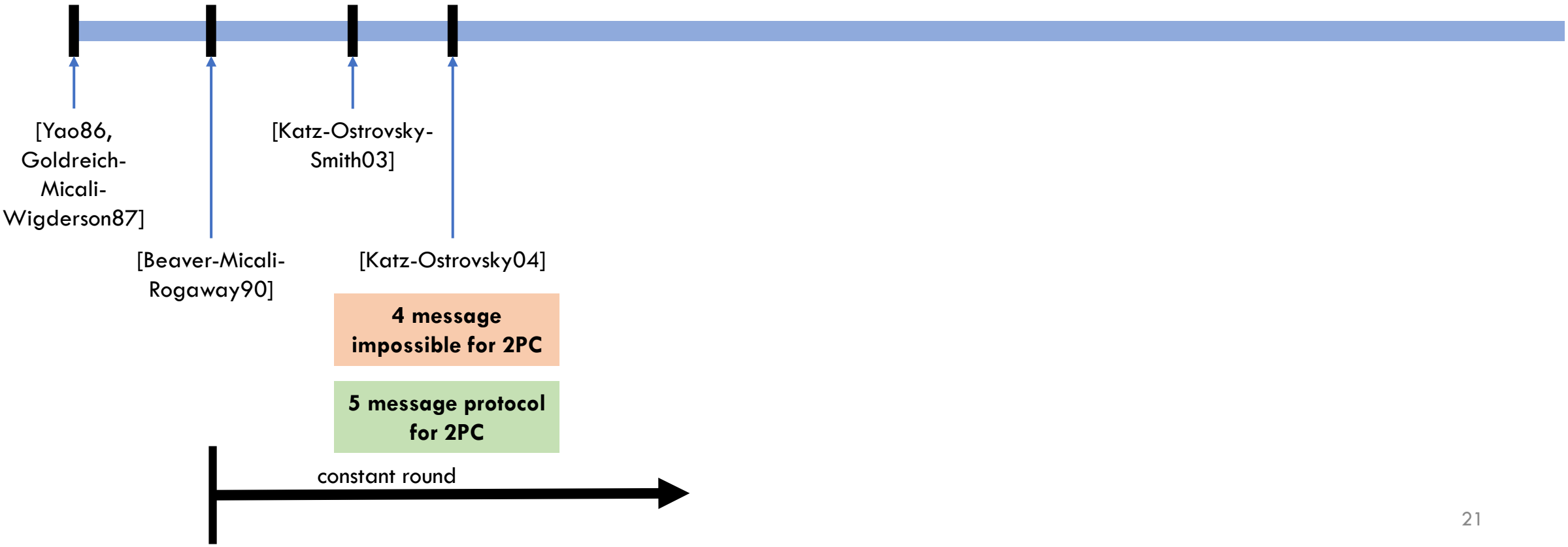
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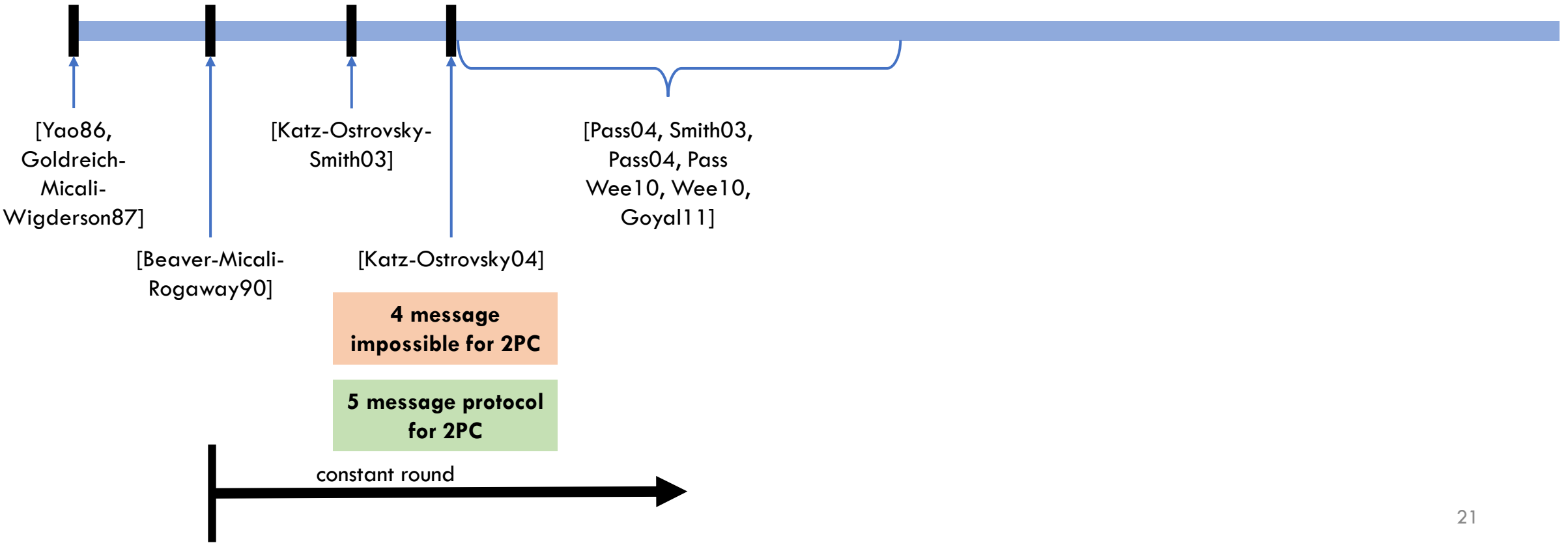
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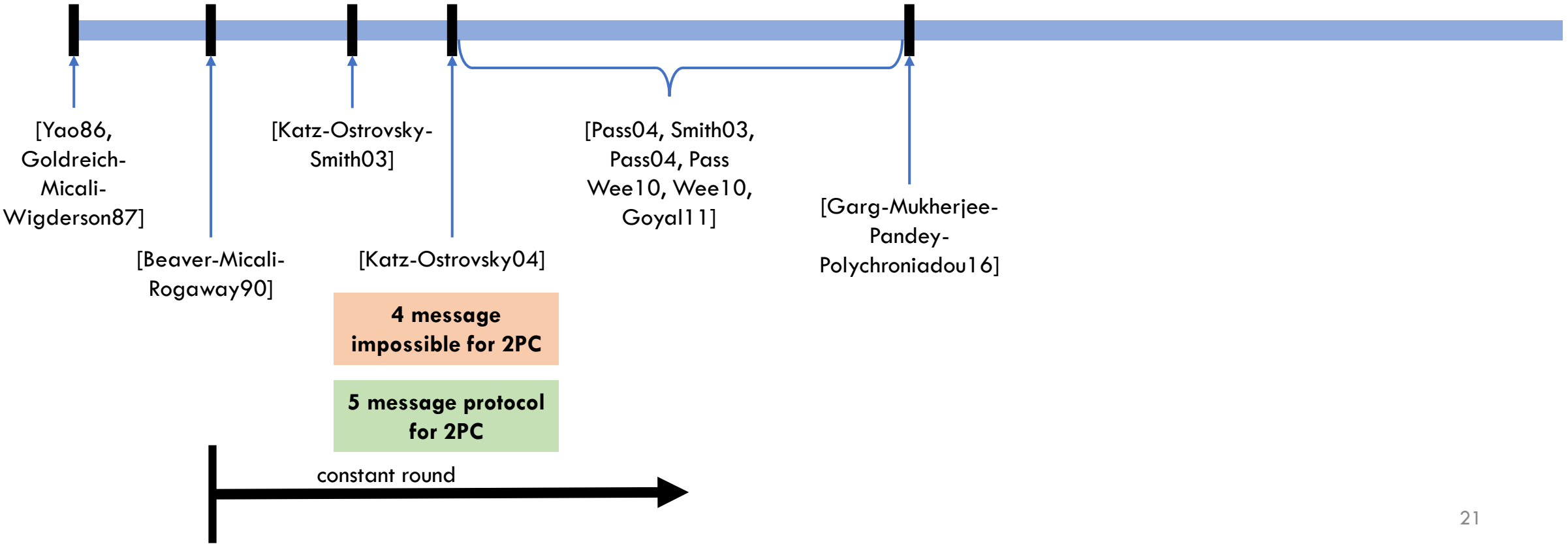
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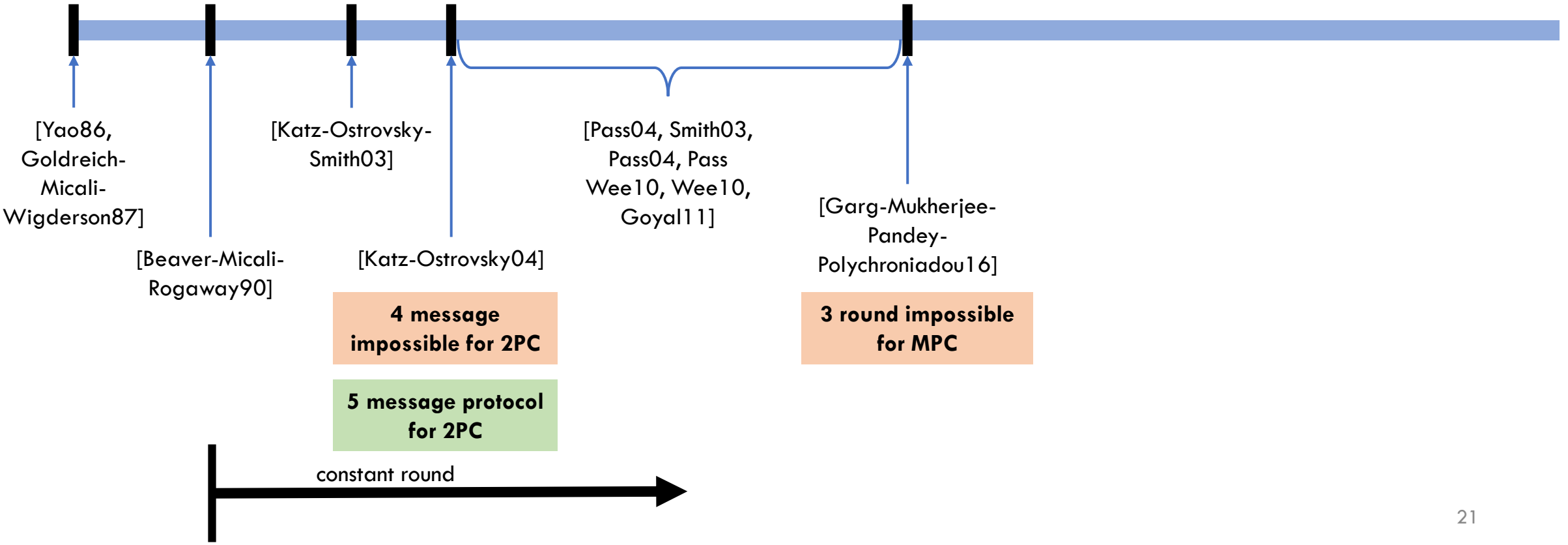
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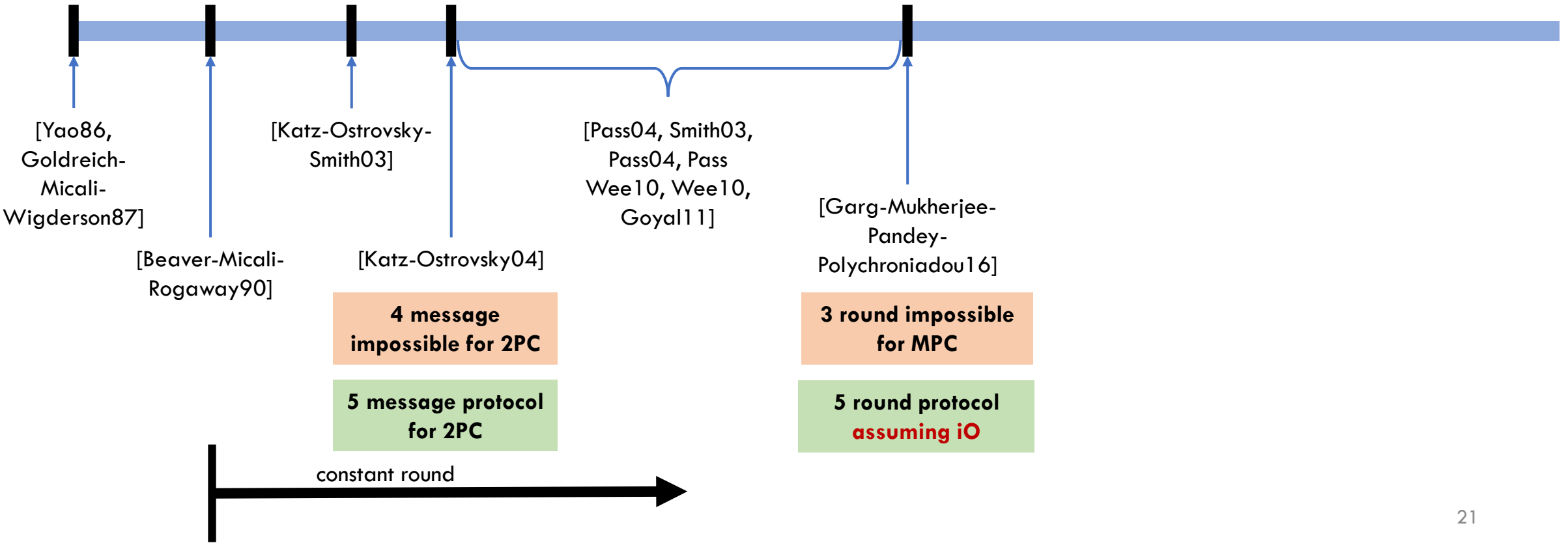
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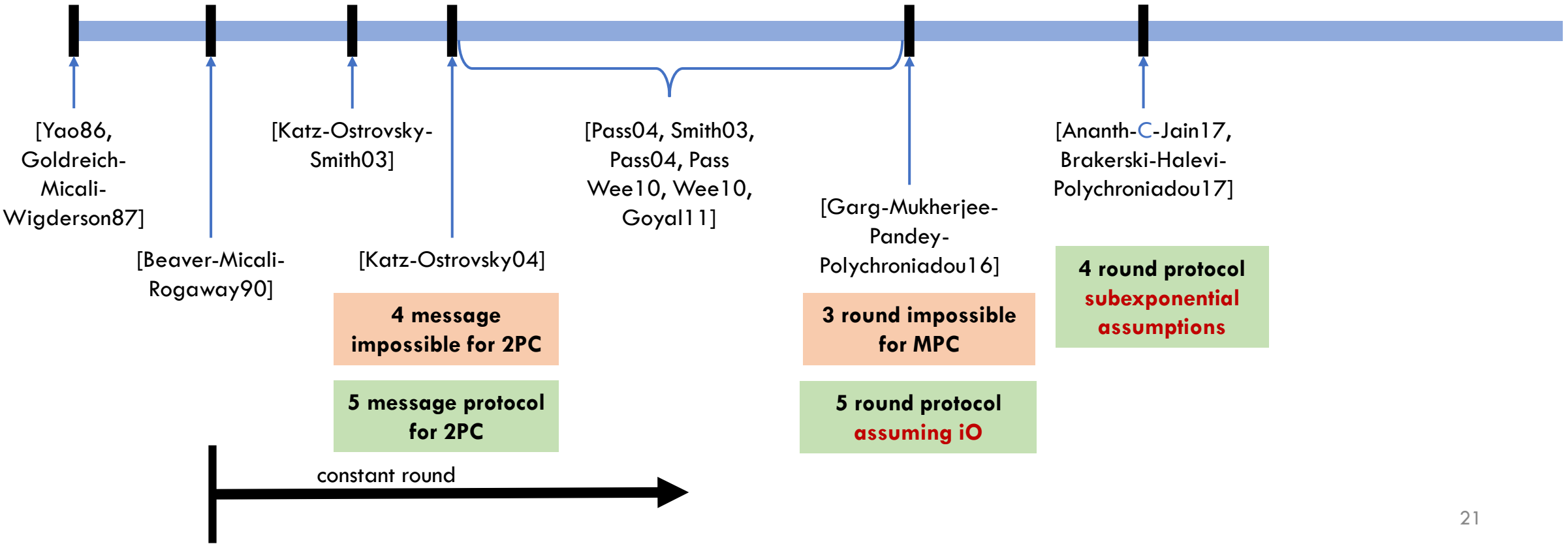
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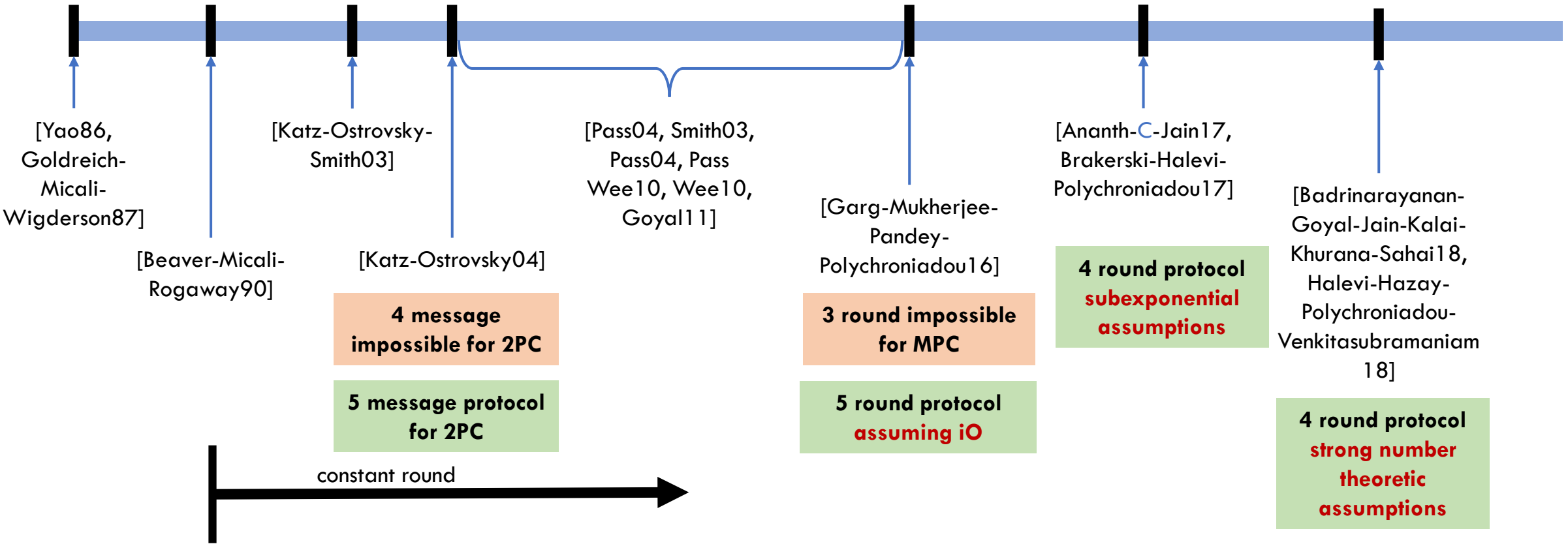
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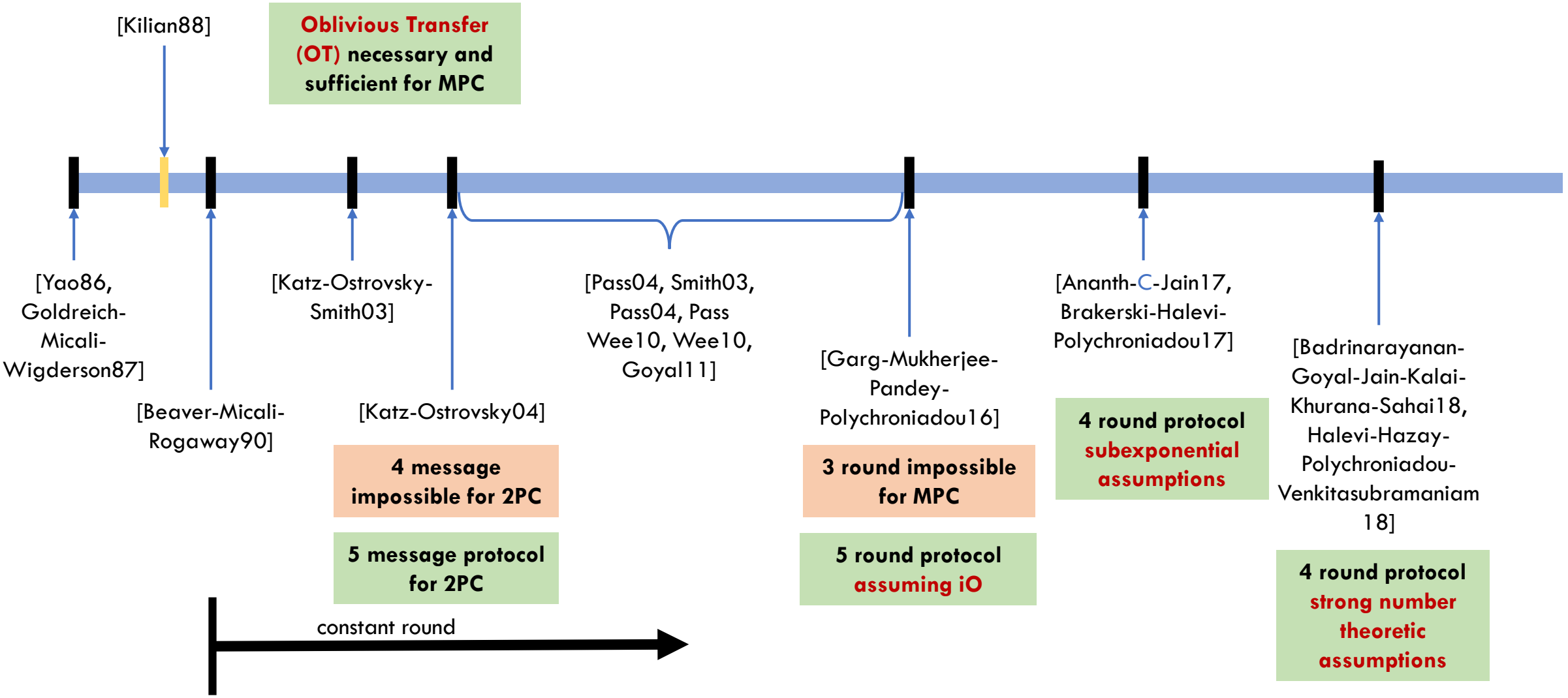
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Oblivious Transfer (OT) necessary and sufficient for MPC
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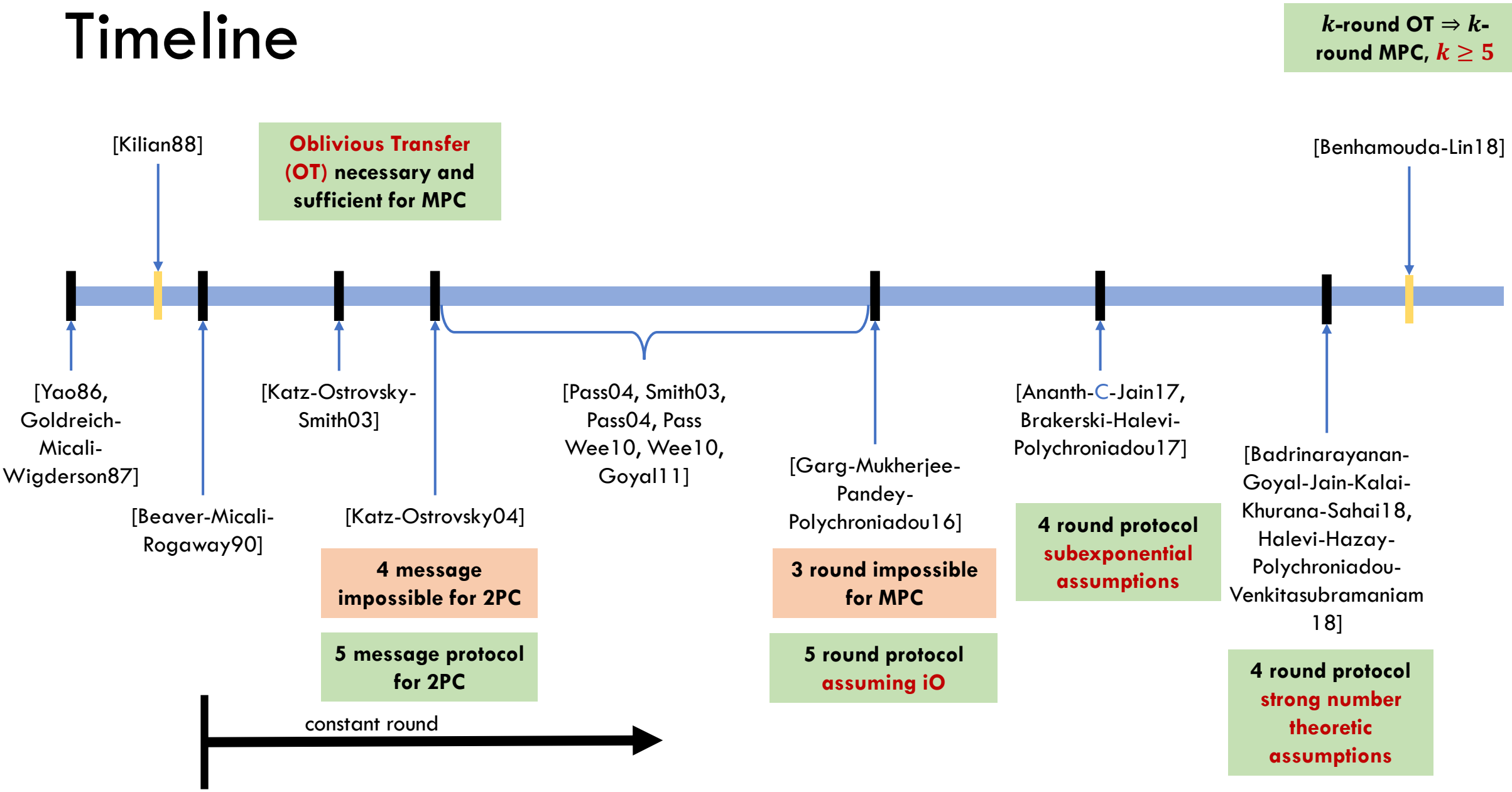
k-round OT ⇒ k-round MPC, $k \geq 5$
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Oblivious Transfer (OT) necessary and sufficient for MPC
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Our results

Assuming 4 round oblivious transfer (OT), there exists a 4 round MPC protocol.

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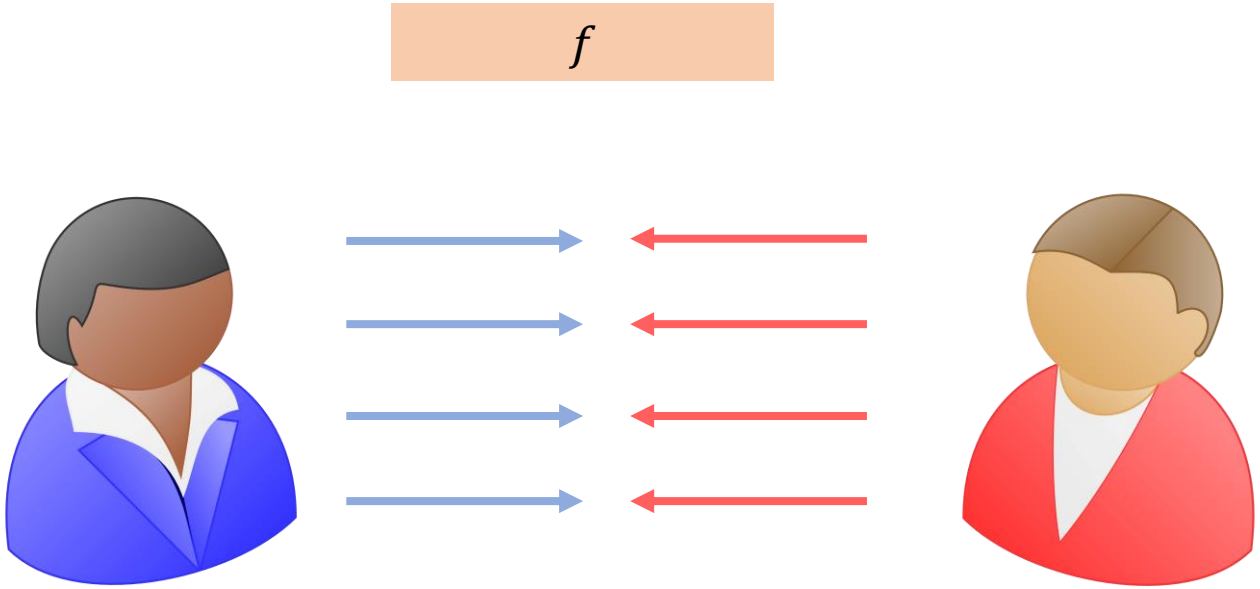
Assuming 4 round oblivious transfer (OT), there exists a 4 round MPC protocol.

OT: Indistinguishability security against malicious sender, and extraction of receiver bit.

OT protocols satisfying such properties are indeed known.

Protecting the 4^{th} round message

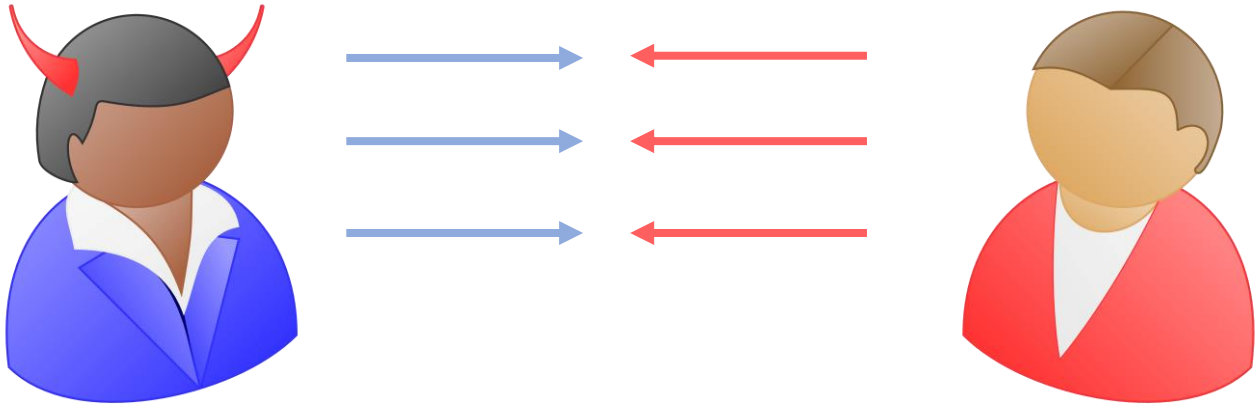
Challenge: Enforcing Honest Behavior



Any 4 round protocol computing a function f.

Challenge: Enforcing Honest Behavior

f



Rushing adversary

May decide not to send its message after it sees Bob's message.

Challenge: Enforcing Honest Behavior

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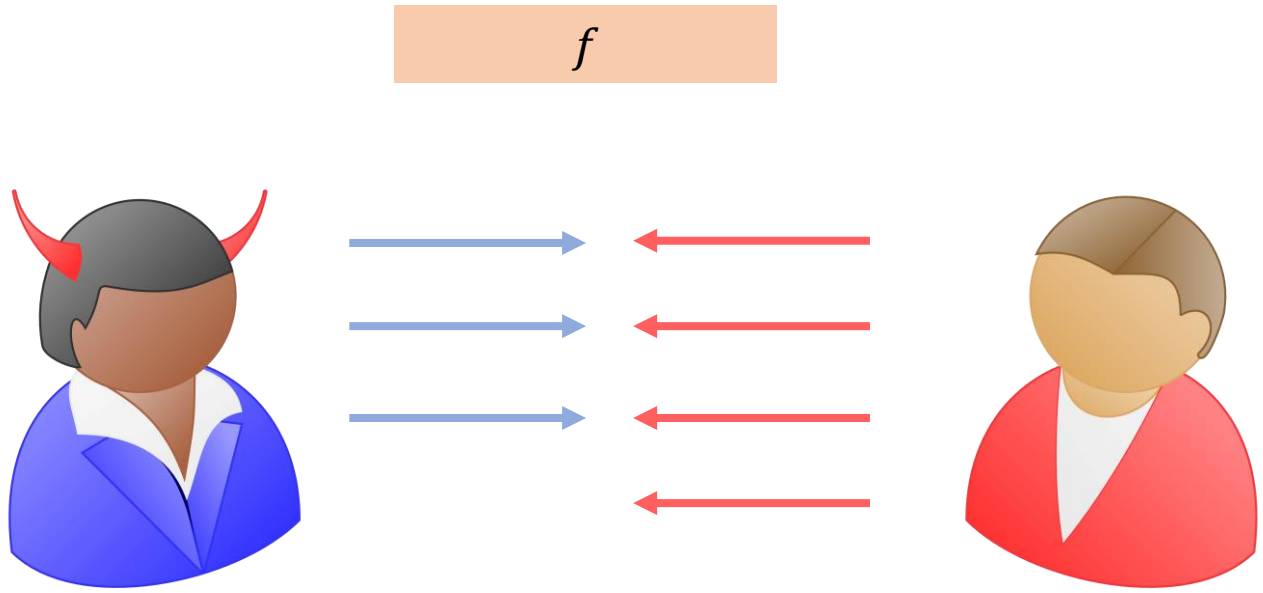

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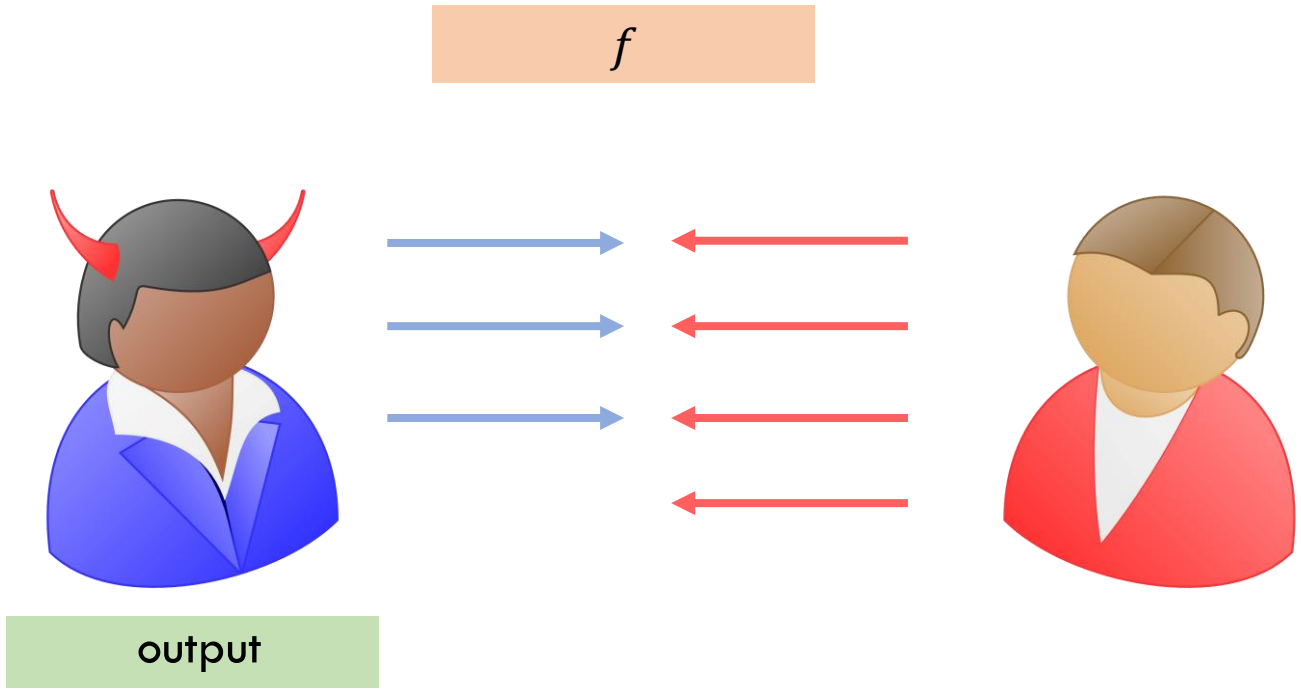

Only Alice learns the output.

Challenge: Enforcing Honest Behavior

identity

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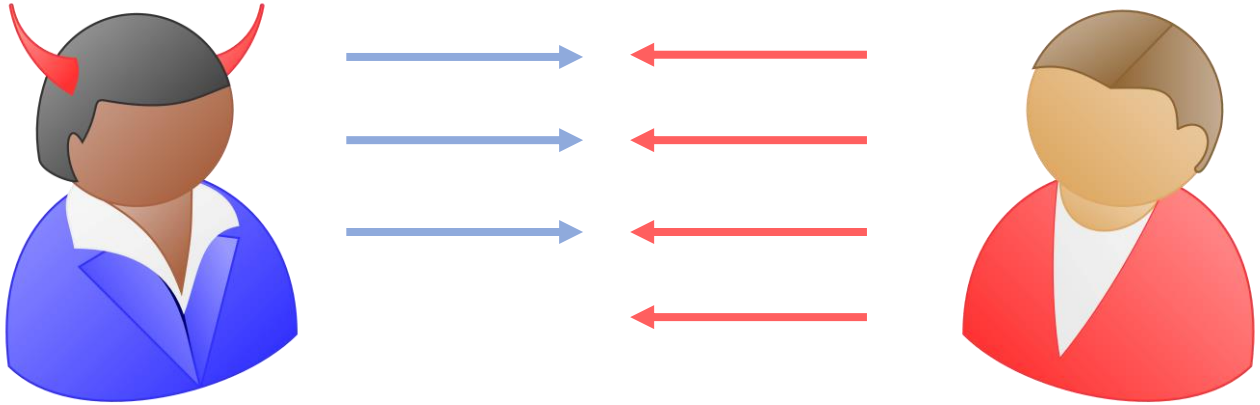
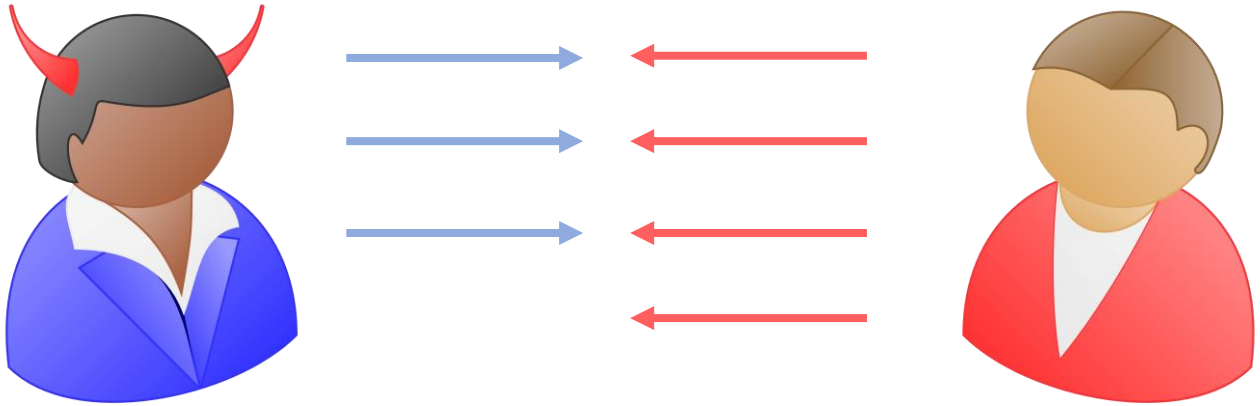


output

Challenge: Enforcing Honest Behavior

identity



Bob's input

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Challenge: Enforcing Honest Behavior

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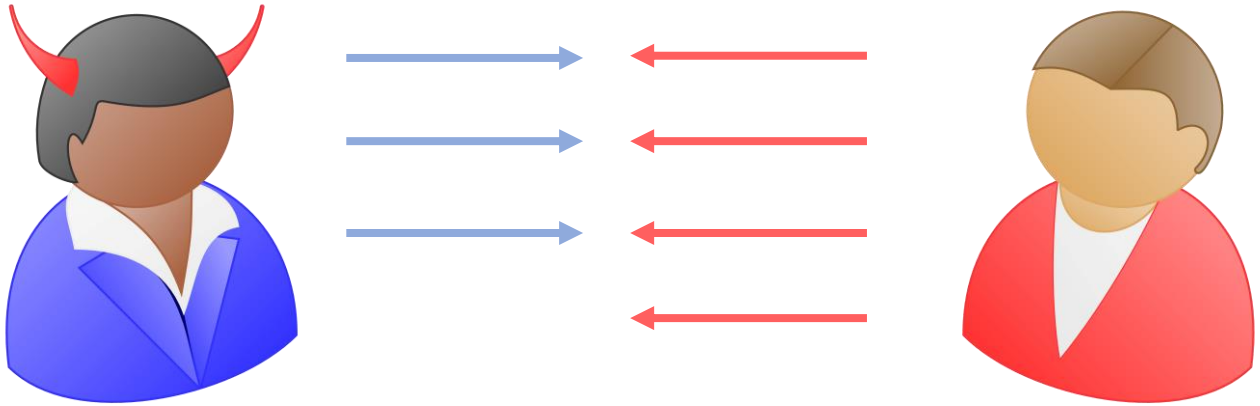

Bob's input

Don't send fourth round message unless Alice proves honest behavior.

Challenge: Enforcing Honest Behavior

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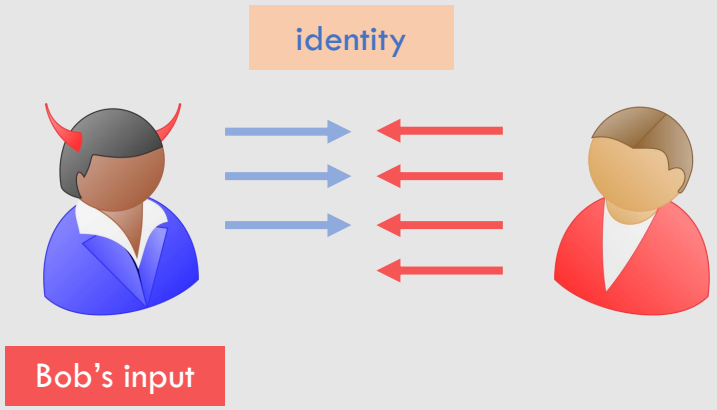

Typical approach:

Alice convinces Bob of honest behavior via zero-knowledge proof before Bob sends his fourth round message.

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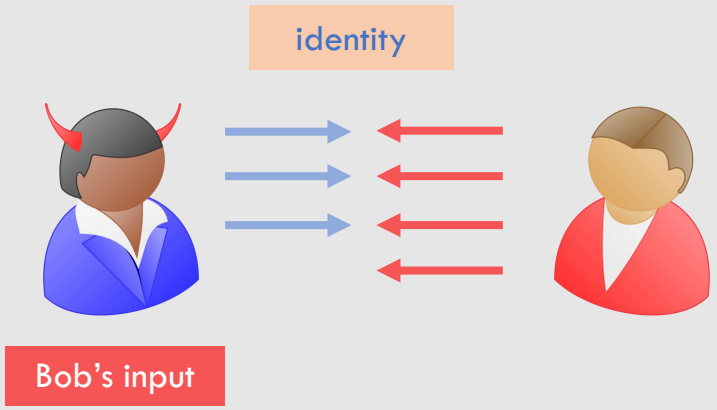

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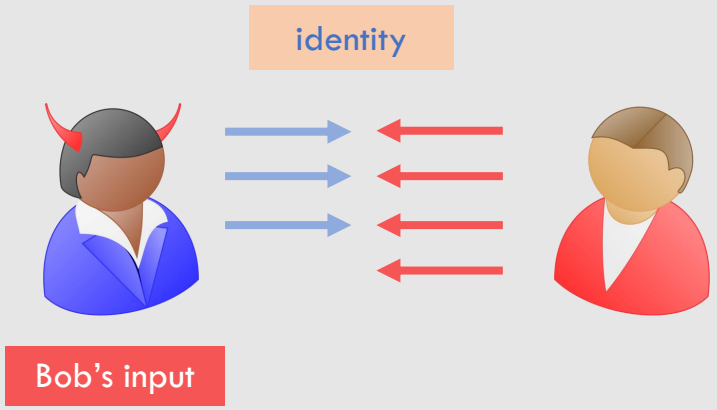

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Many other challenges, but for this talk, we focus on solving this challenge.

Interactive Multiparty Conditional Disclosure of Secret (MCDS)

Conditional Disclosure of Secrets (CDS)

Conditional Disclosure of Secrets (CDS)

message

Conditional Disclosure of Secrets (CDS)

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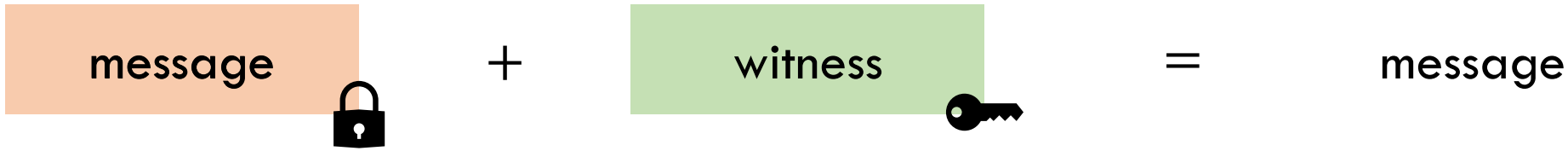
If witness satisfies specified condition.

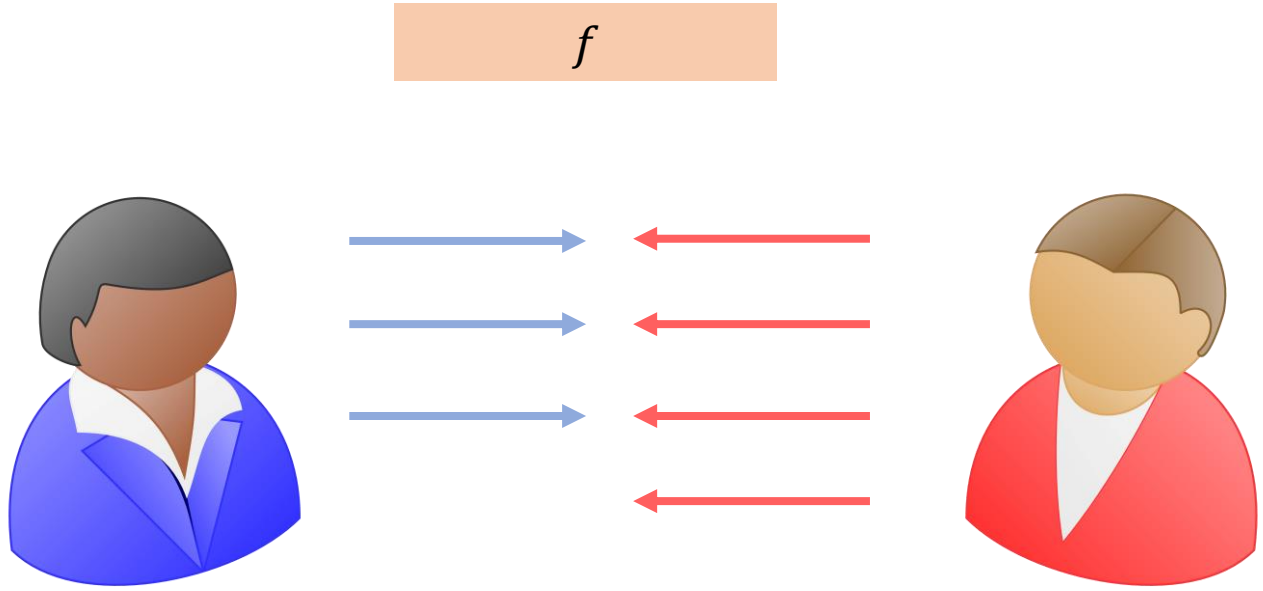
Conditional Disclosure of Secrets (CDS)



If witness satisfies specified condition.

[Gertner-Ishai-Kushilevitz-Malkin98, Aiello-Ishai-Reingold01]

CDS as safety net



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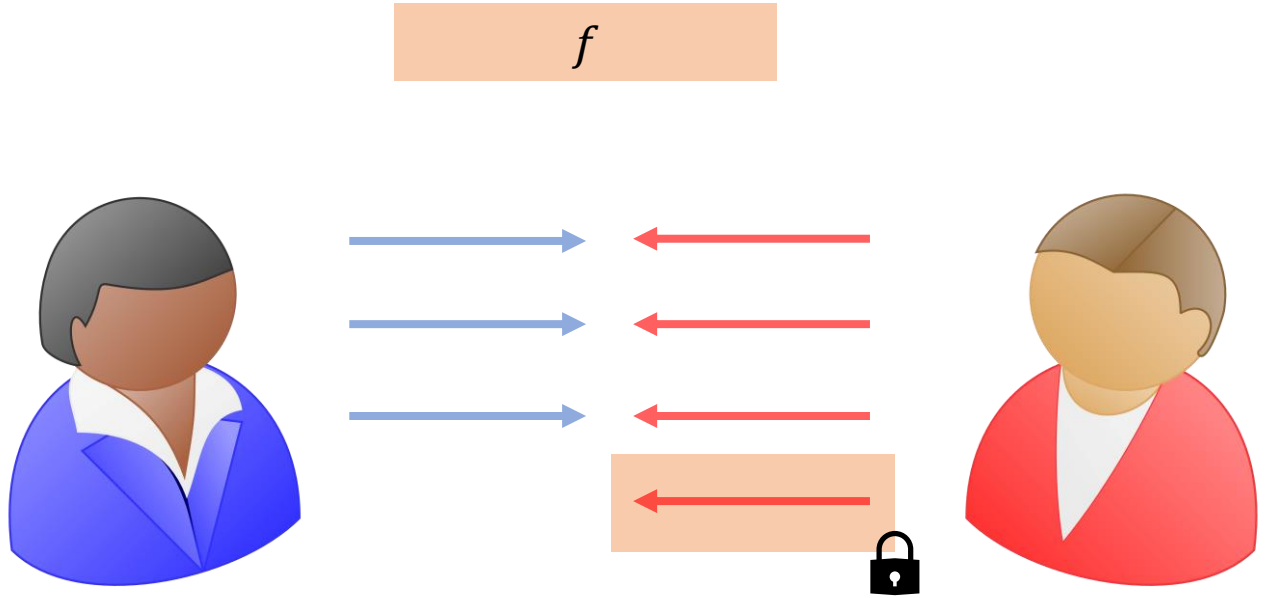

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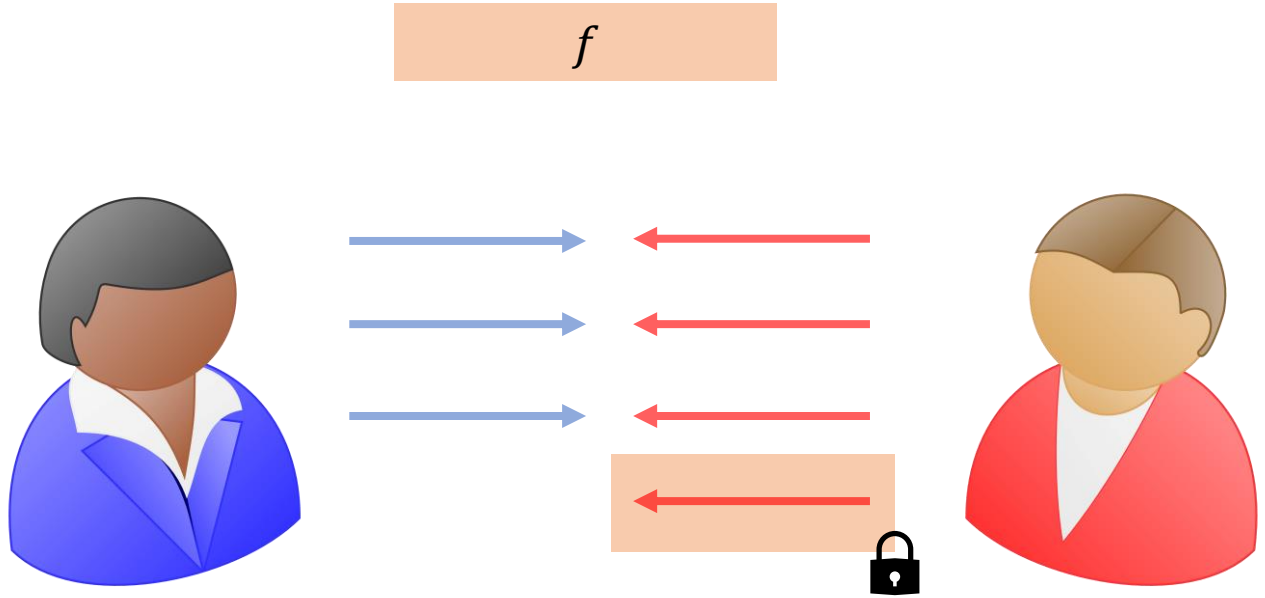

"I behaved honestly"

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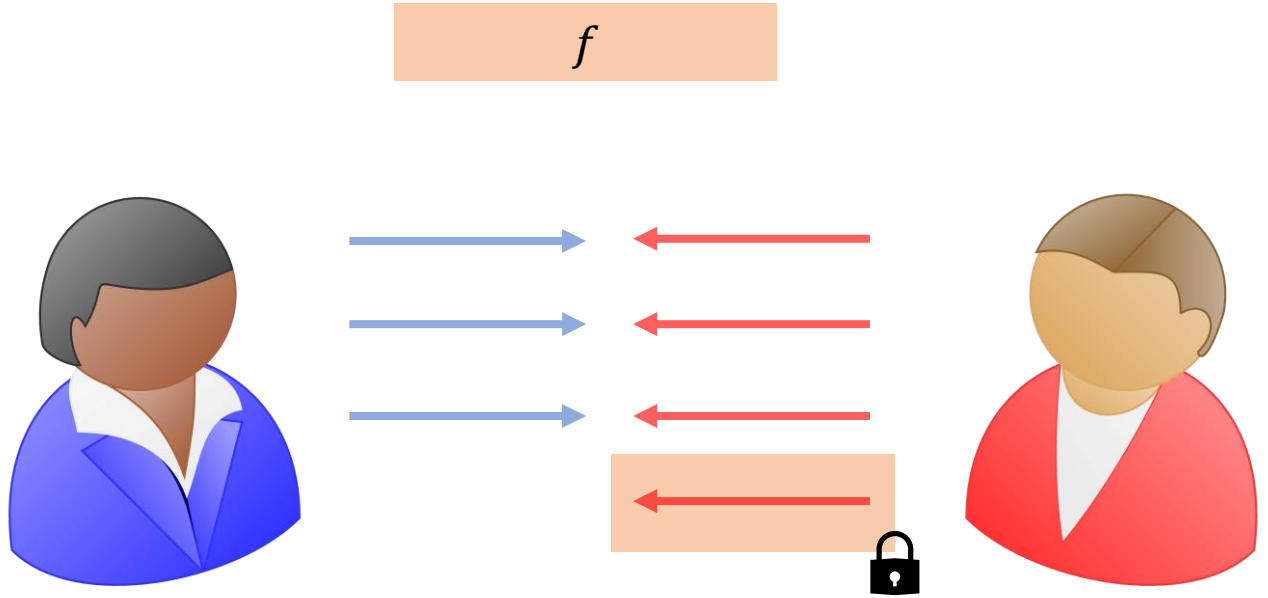
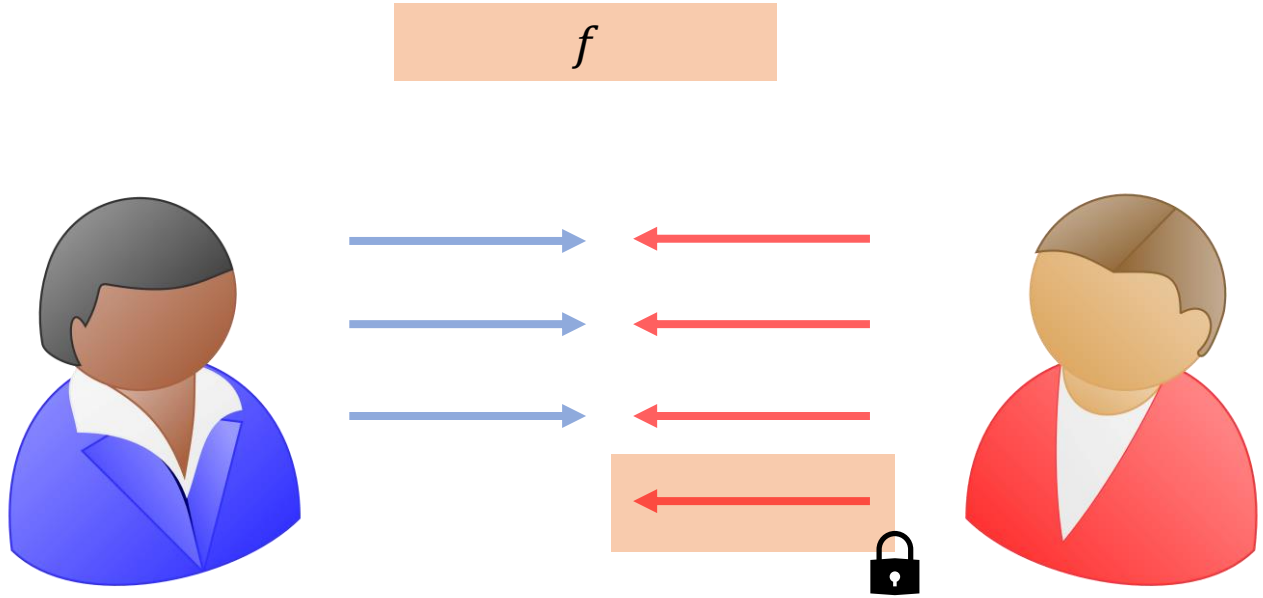


"I behaved honestly"

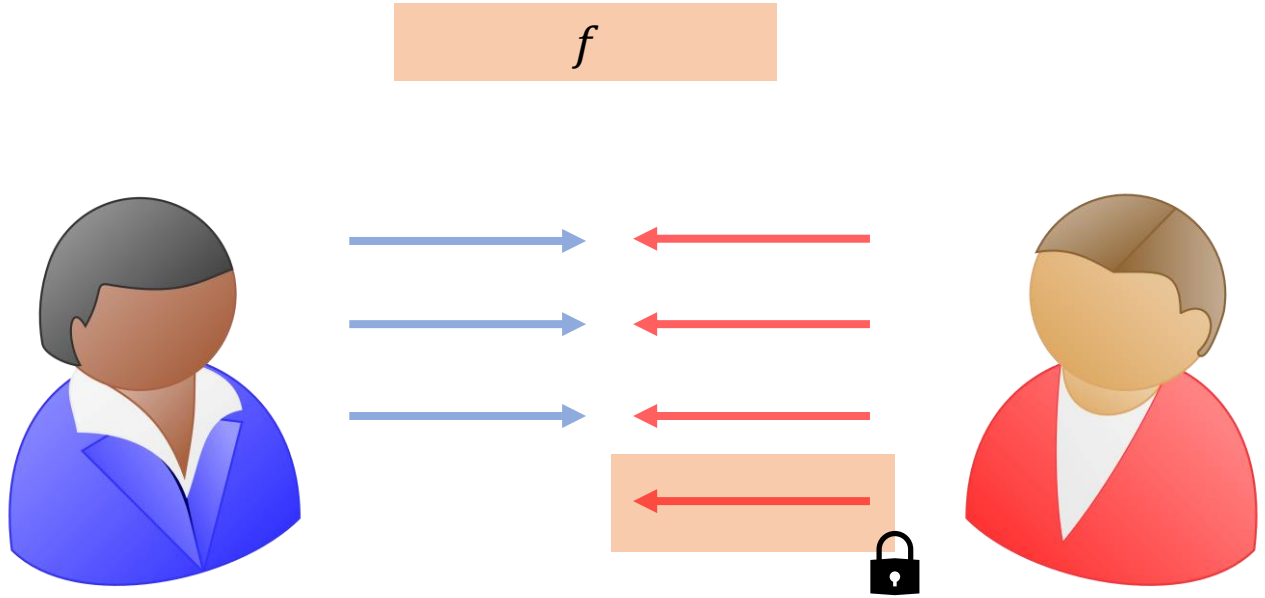
How do we prove honest behavior?

CDS as safety net



input and randomness

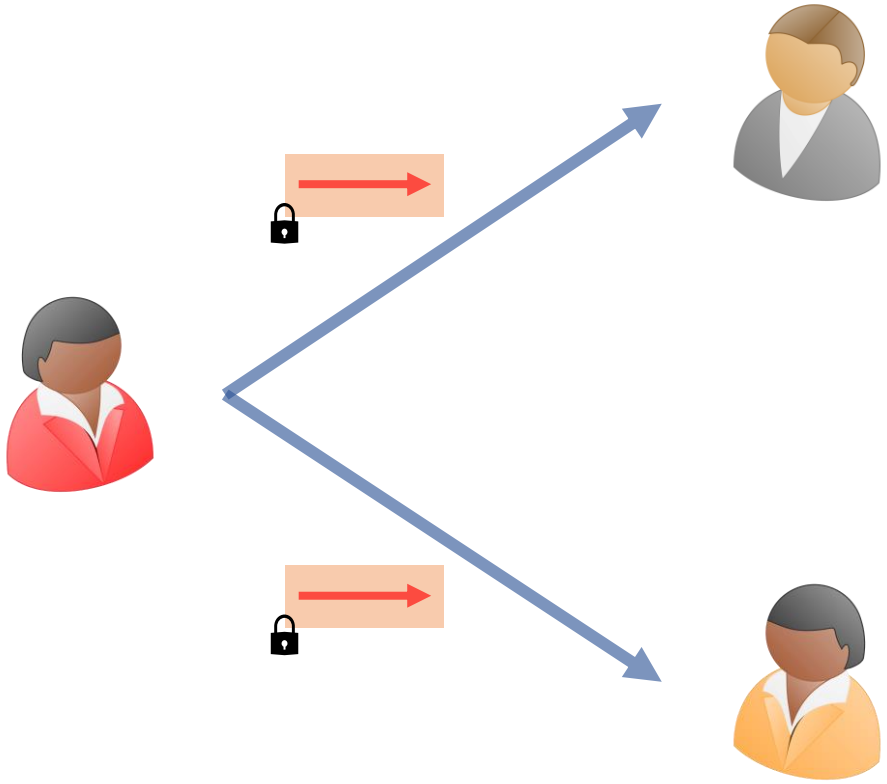
CDS as safety net



input and randomness

Does this work with more than 2 parties?

CDS as safety net



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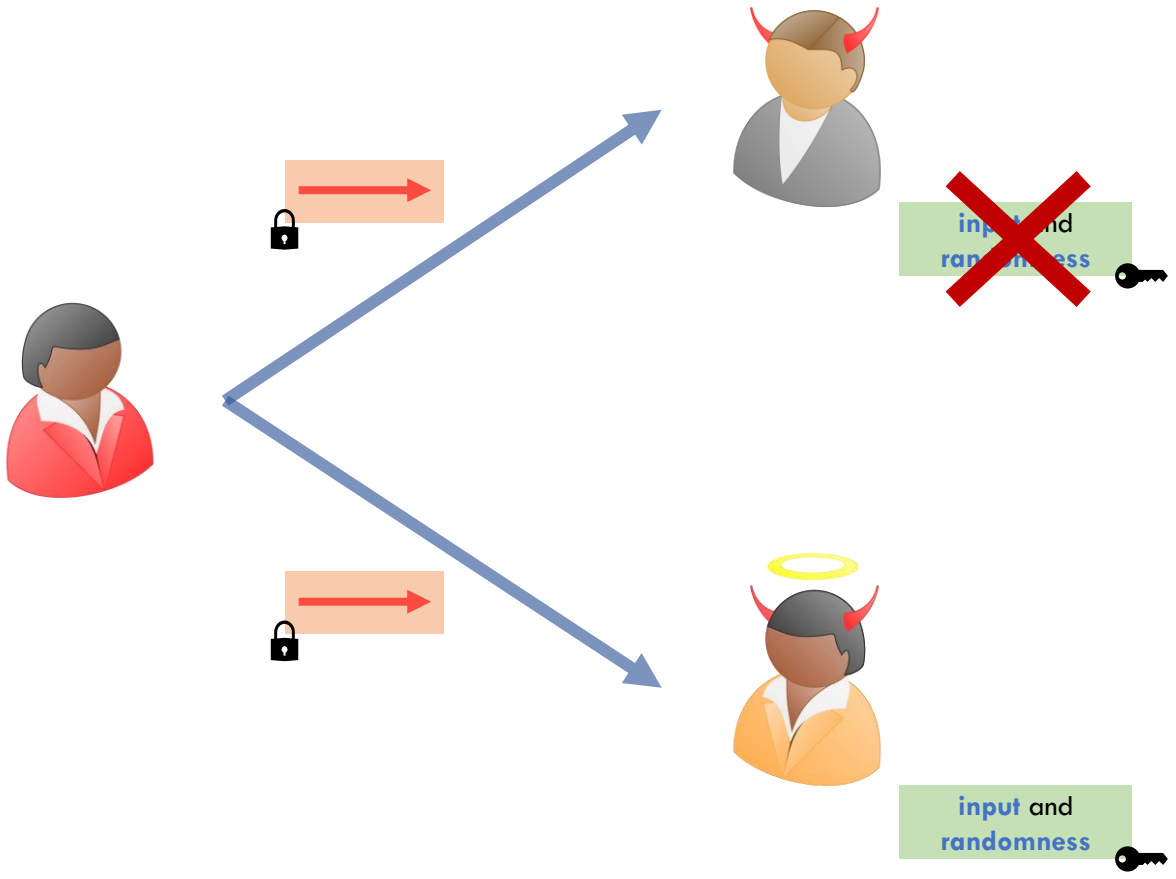

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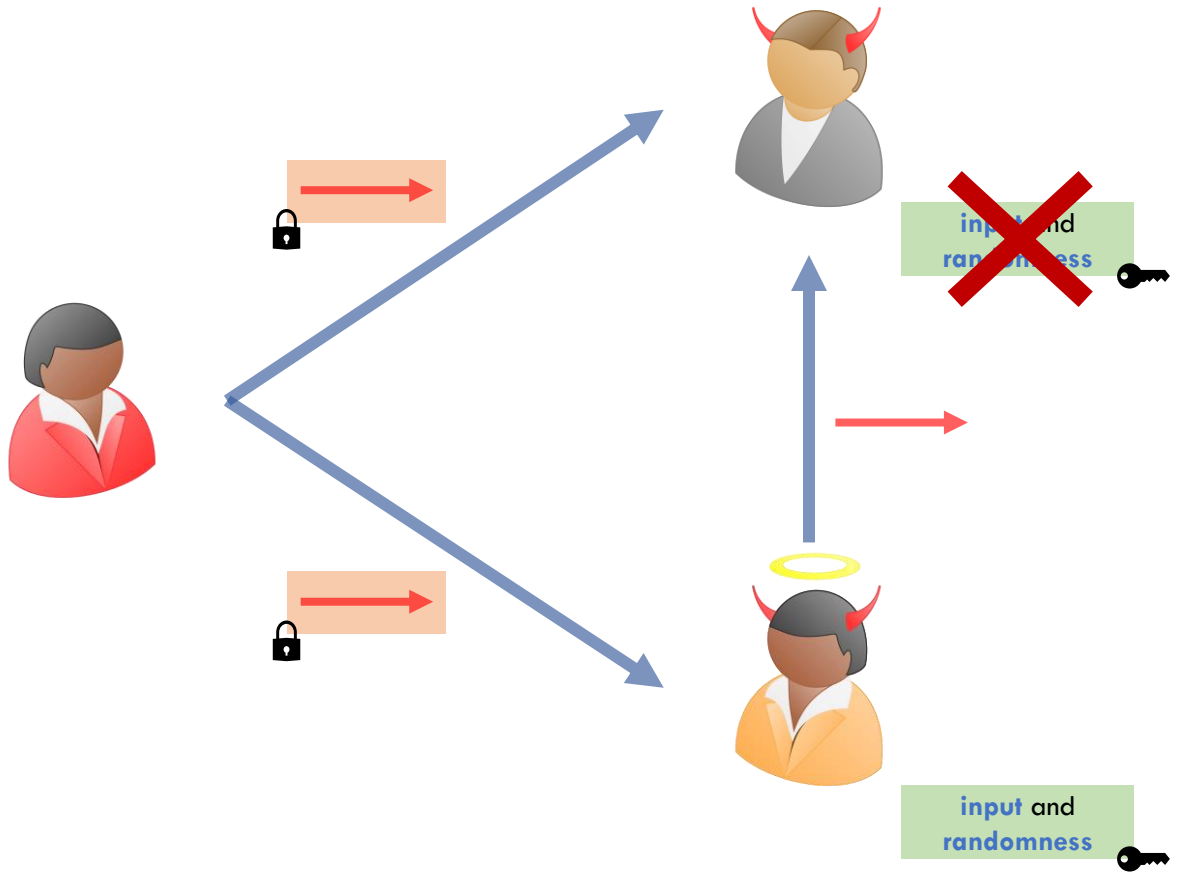

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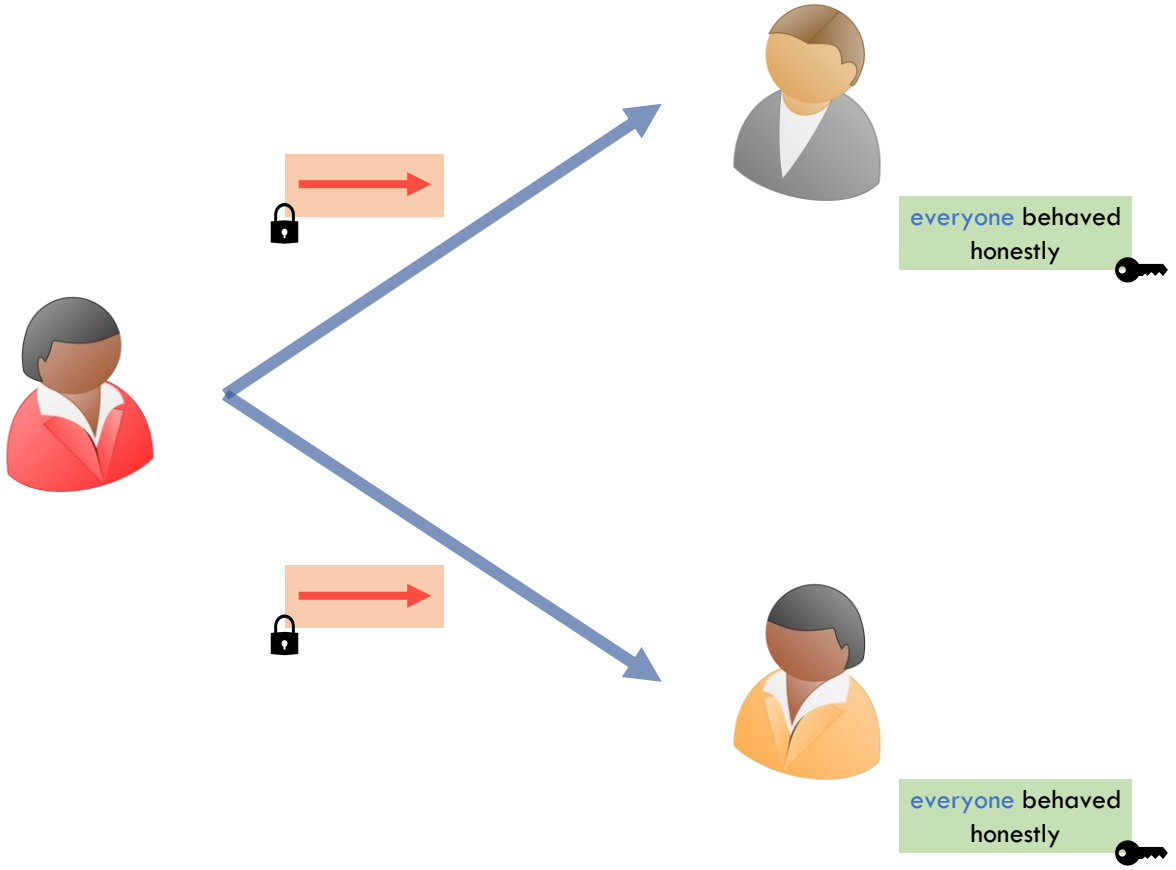

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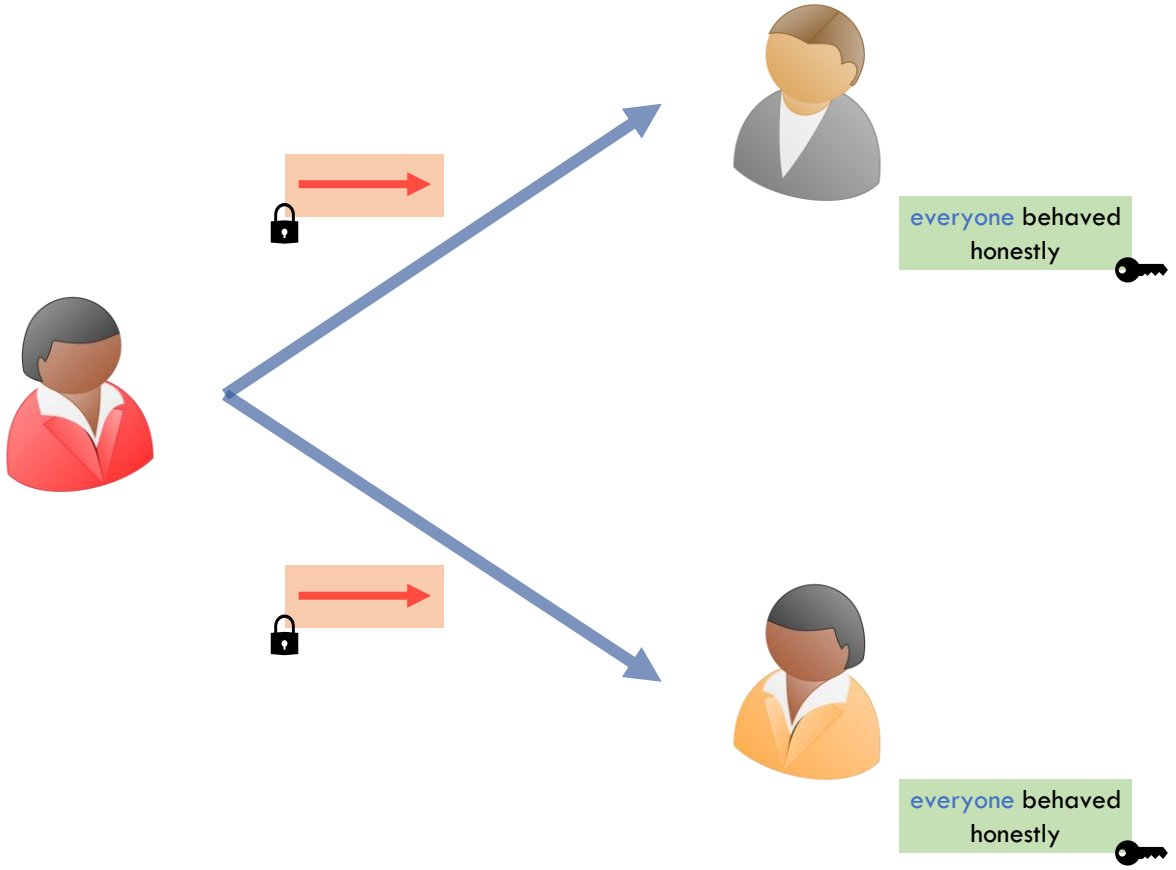
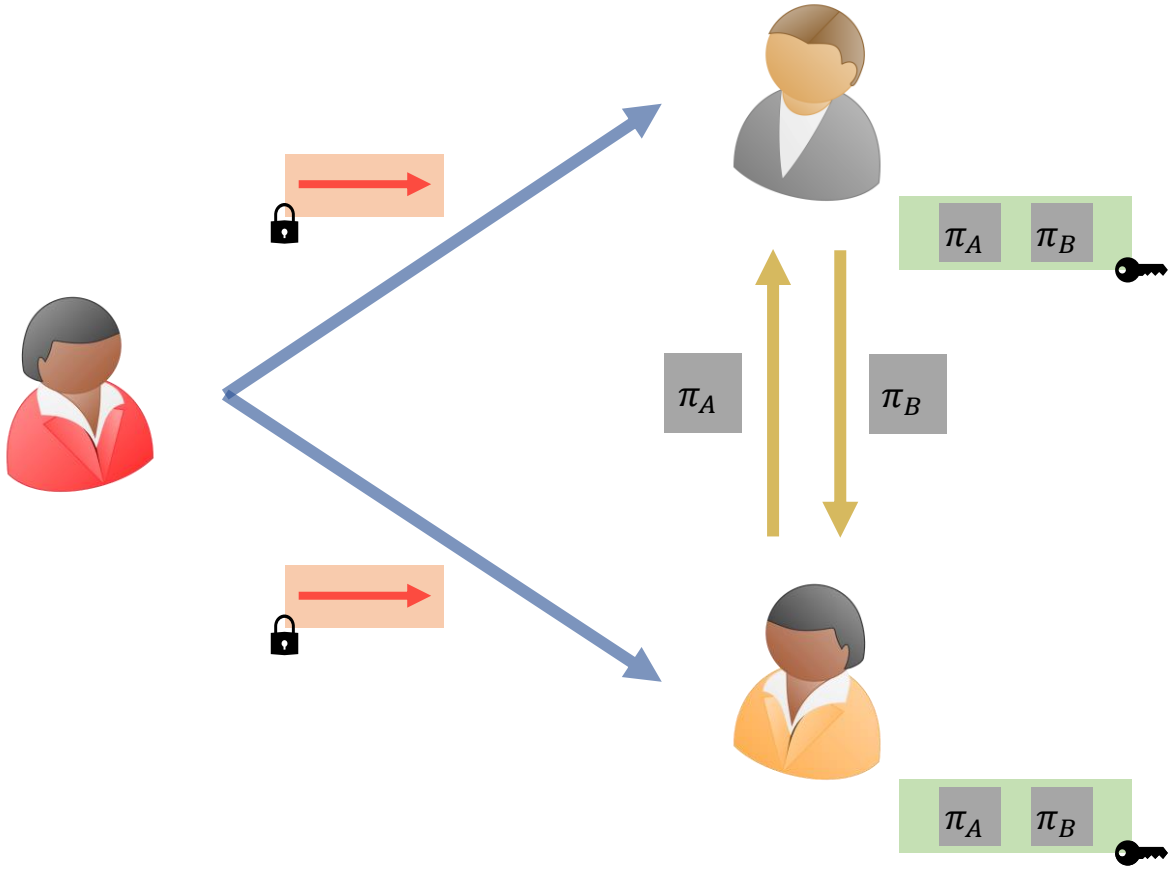


Want a public witness at the end of the fourth round.

Use 4 round zero-knowledge proofs.

CDS as safety net



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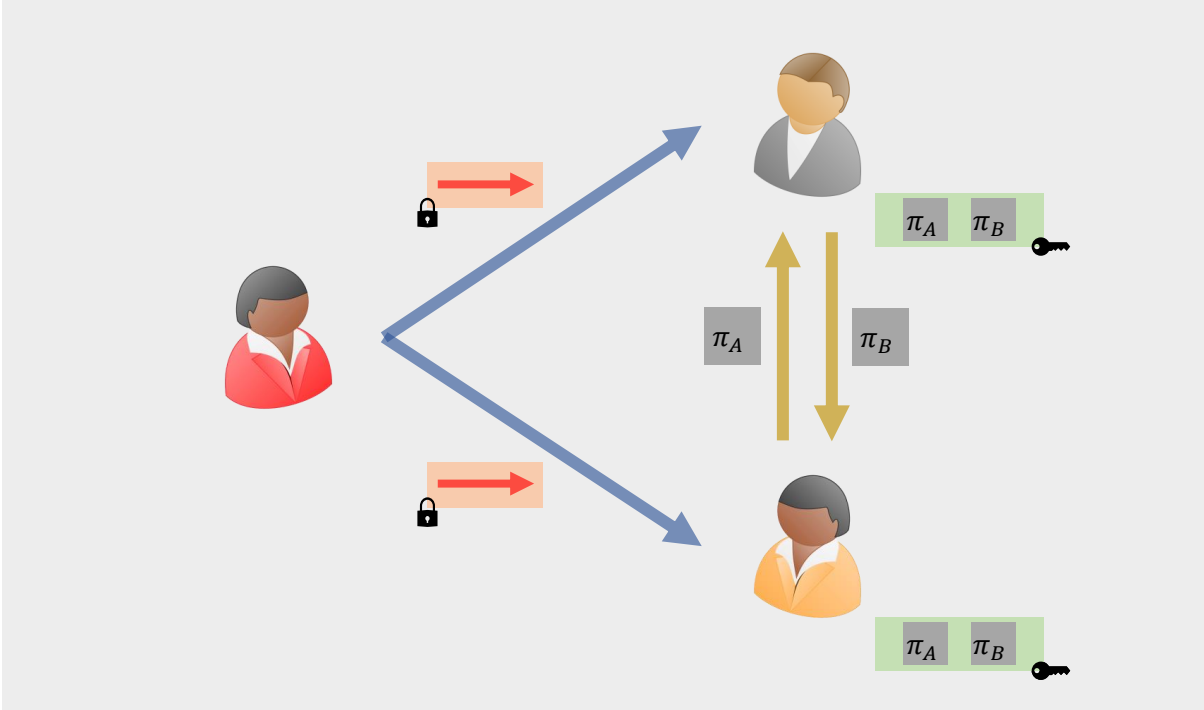
Use 4 round zero-knowledge proofs.

Implementing CDS?

We want to build a CDS based on OT.

Only known non-interactive realization is Witness Encryption, which is known assuming Indistinguishability Obfuscation (iO).



Interactive Multiparty CDS (MCDS)

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Oblivious Transfer (OT)

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Garbled Circuit

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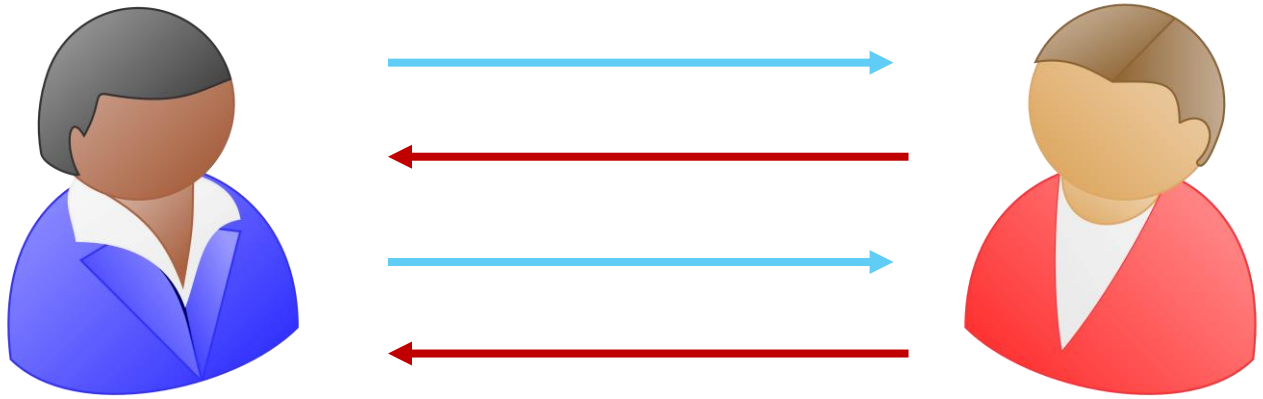
Garbled Circuit

1-out-of-2 OT [Even-Goldreich-Lempel'82]



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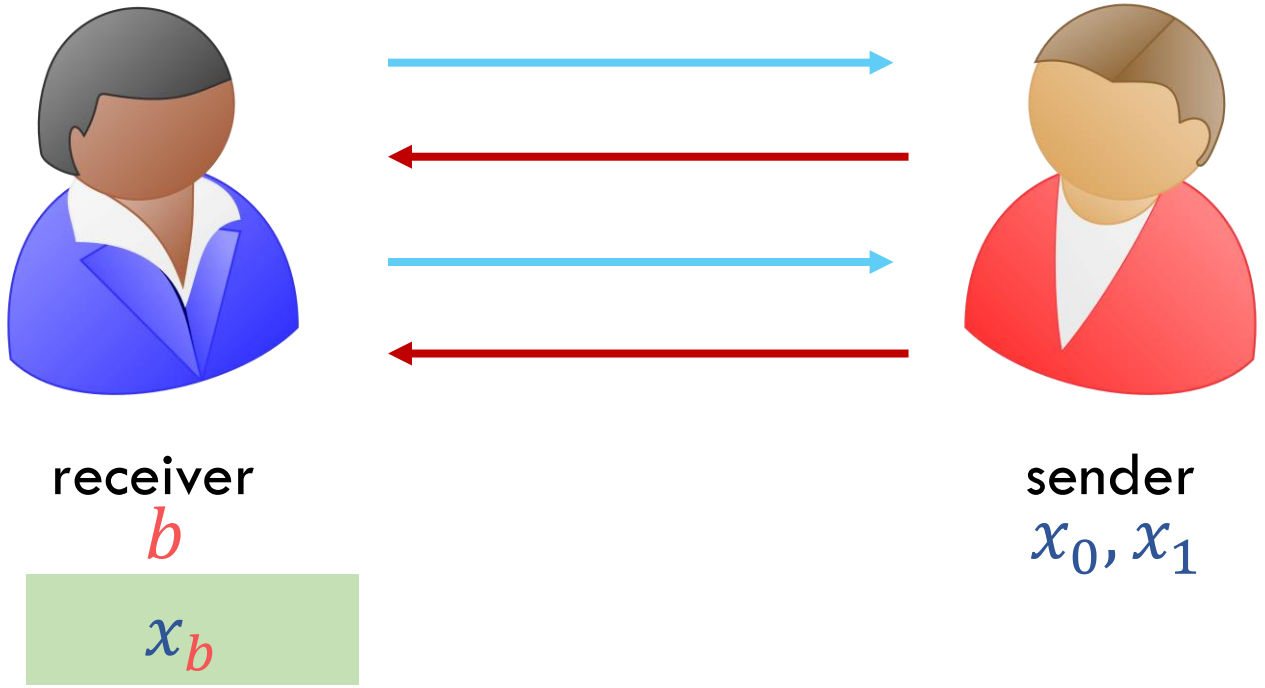

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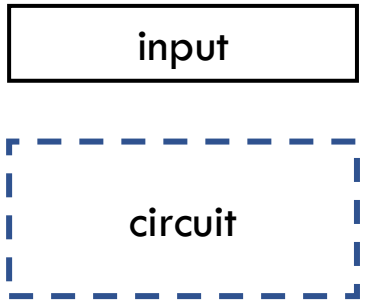

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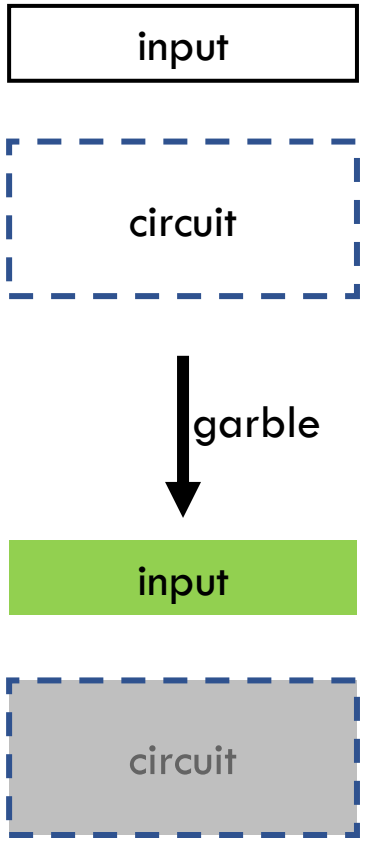

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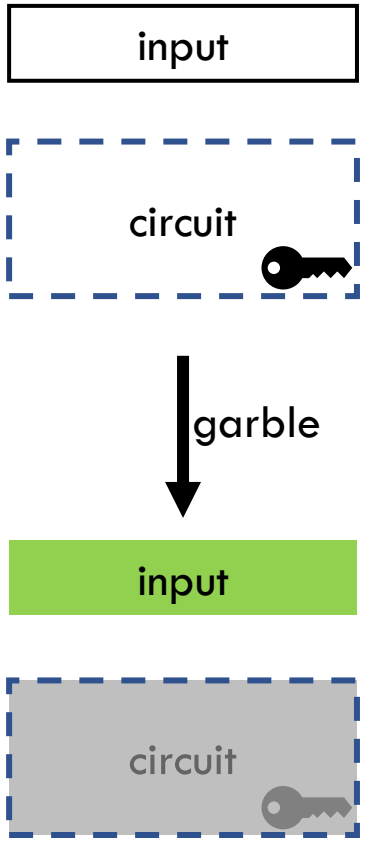
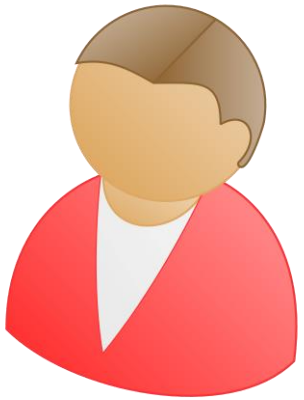


Interactive MCDS

witness

receiver



sender

message

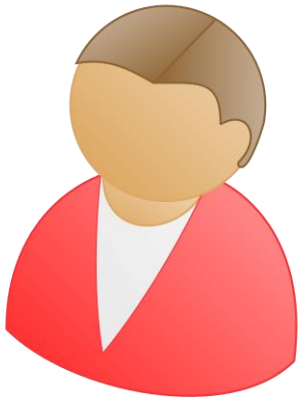
Input: witness

if witness satisfies condition,
output message

Interactive MCDS

witness

receiver



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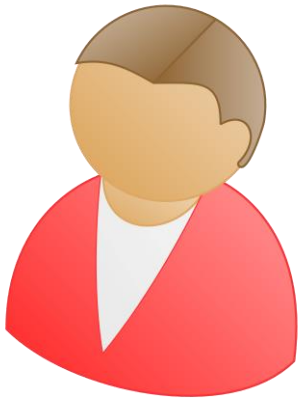

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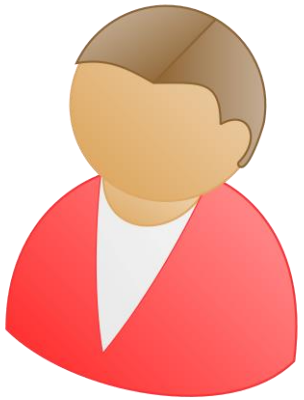
Interactive MCDS

witness



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Interactive MCDS

witness

Input: witness

if witness satisfies condition,
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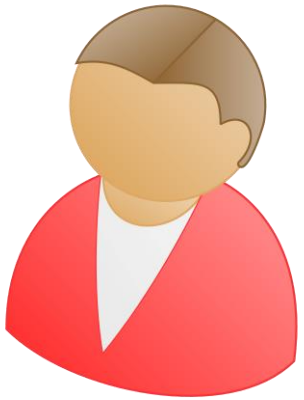

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Interactive MCDS to protect 4^{th} round

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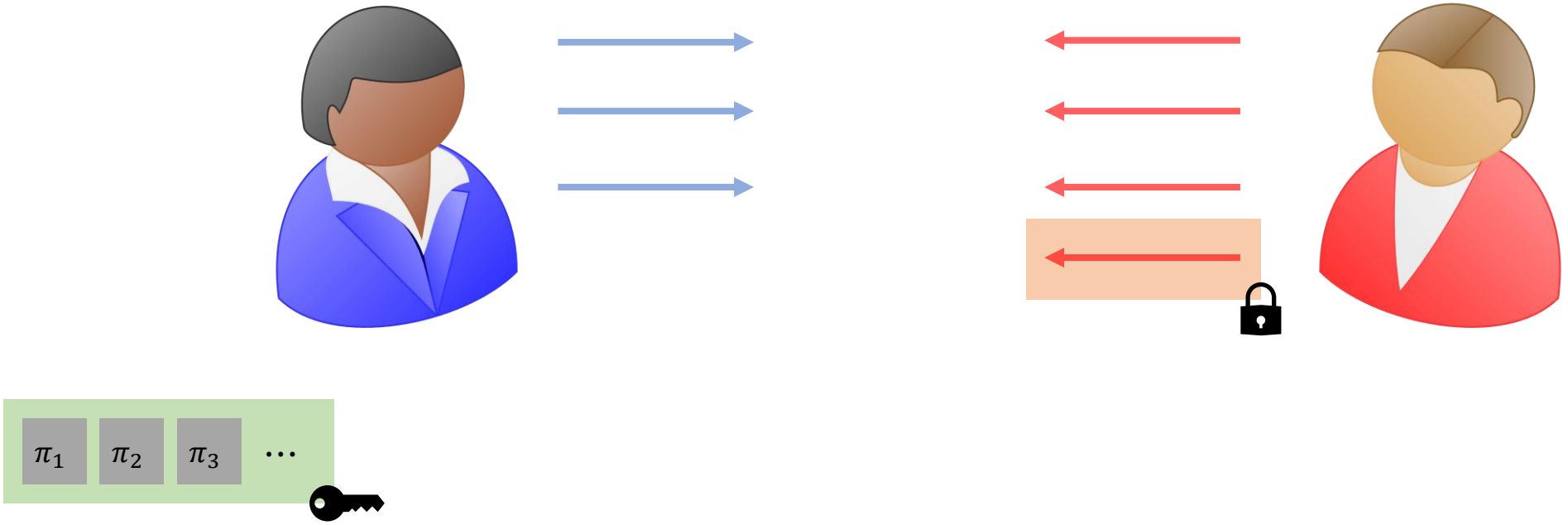

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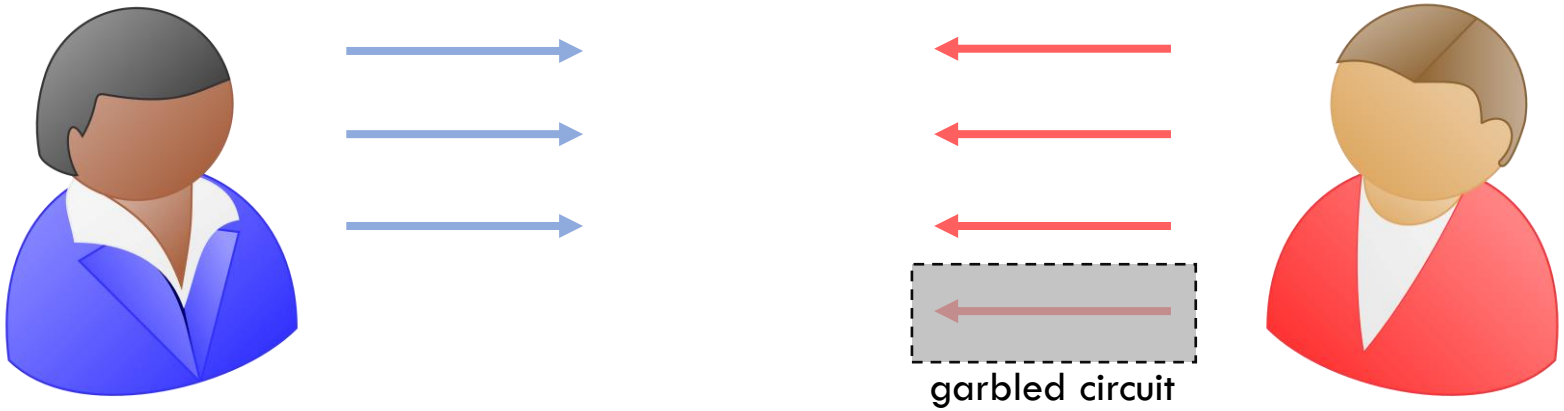
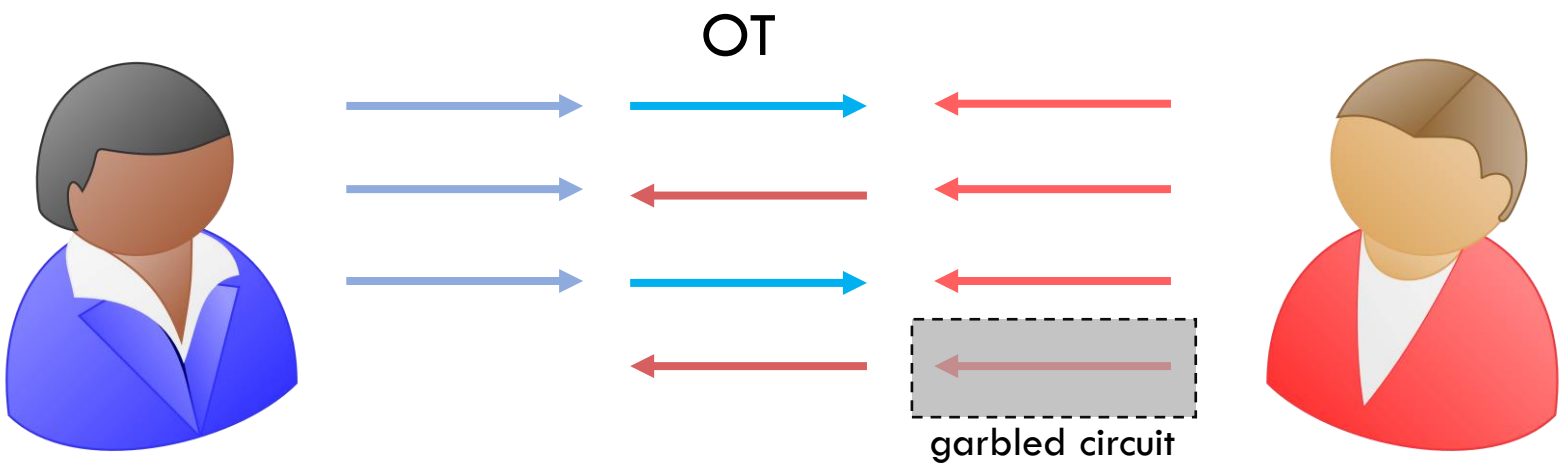


π_1 π_2 π_3 $\cdots$

Interactive MCDS to protect 4^{th} round



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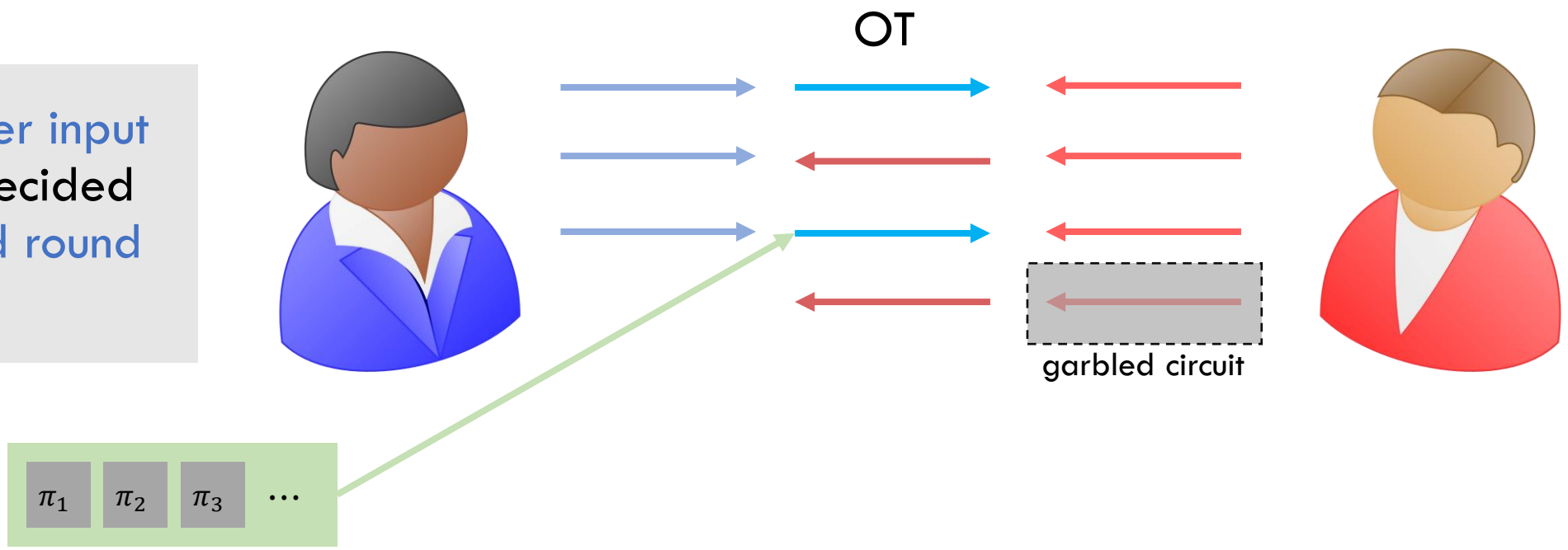
Interactive MCDS to protect 4^{th} round

OT receiver input must be decided by the 3rd round of the OT.



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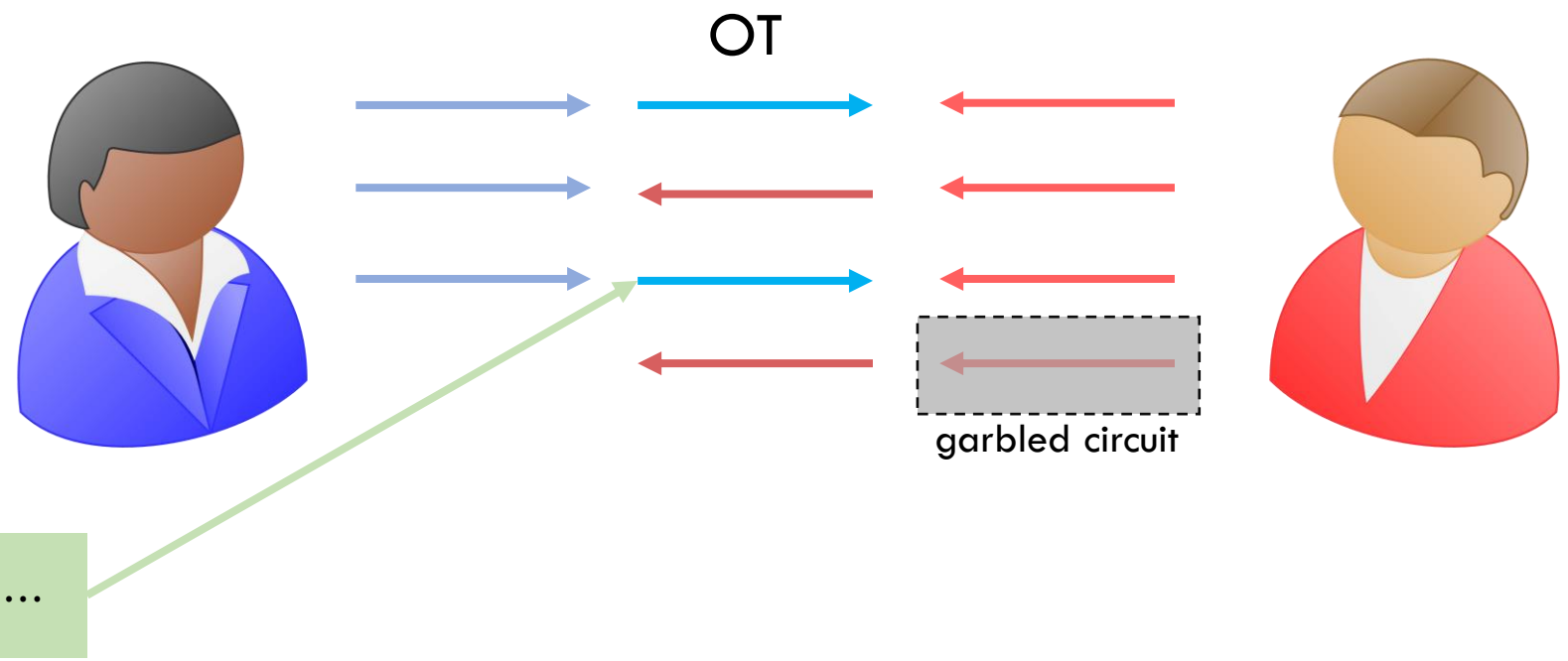
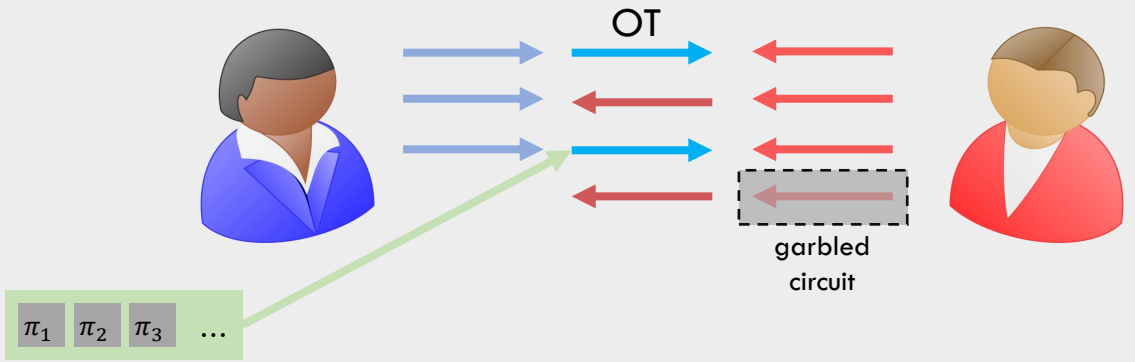


Requires 3 round zero-knowledge proofs!

Weakened Requirement from ZK proof?



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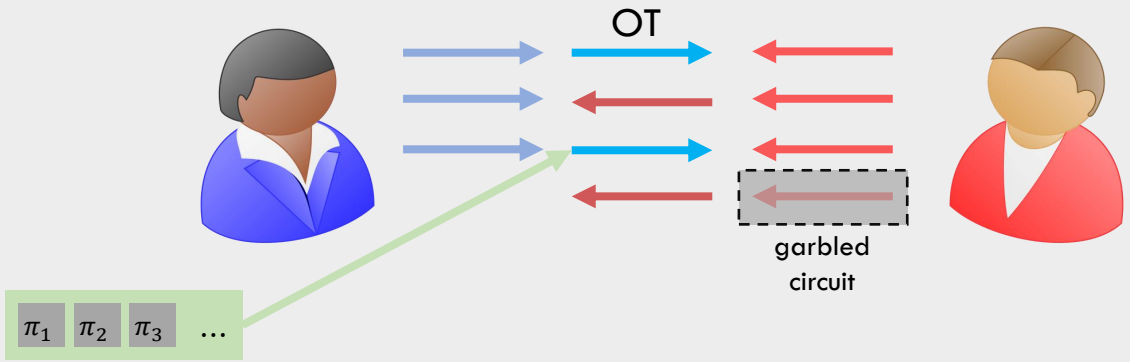

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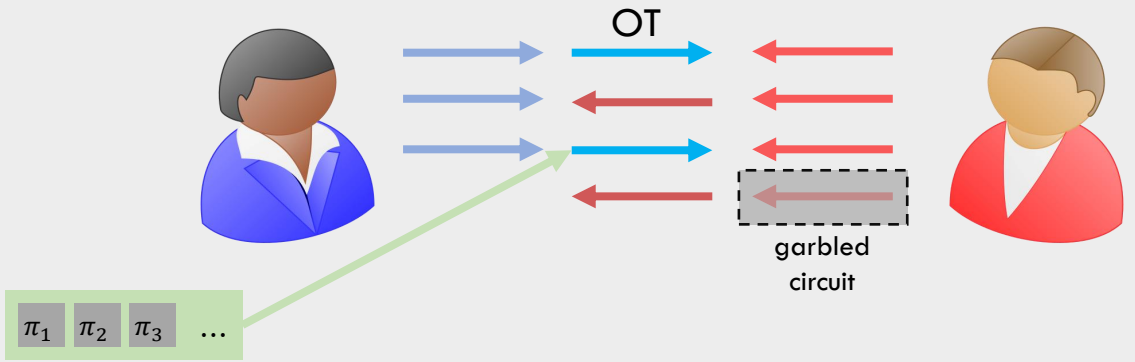
1. ZK in the simultaneous message model.
2. The third round of the ZK proof hidden until the fourth round of MPC.

   Remains hidden if Bob aborts in the third round. Essentially repurposing a three round protocol to work in four rounds.



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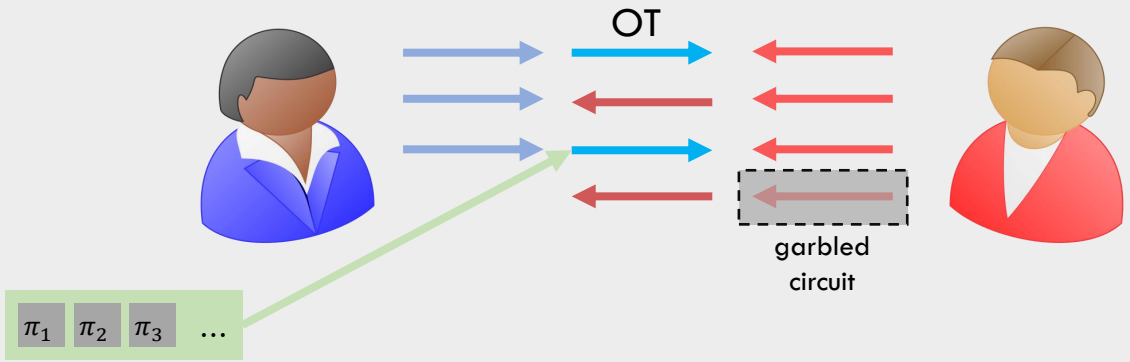

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Promise Zero-Knowledge [Badrinarayanan-Goyal-Jain-Kalai-Khurana-Sahai18]

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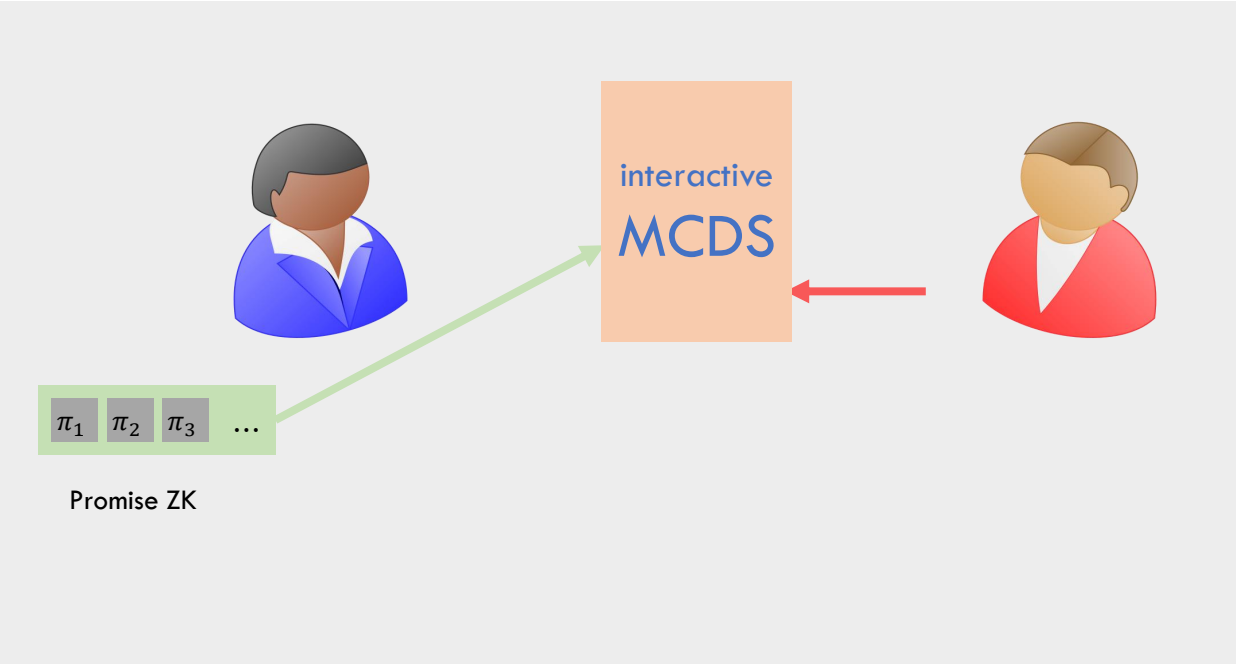

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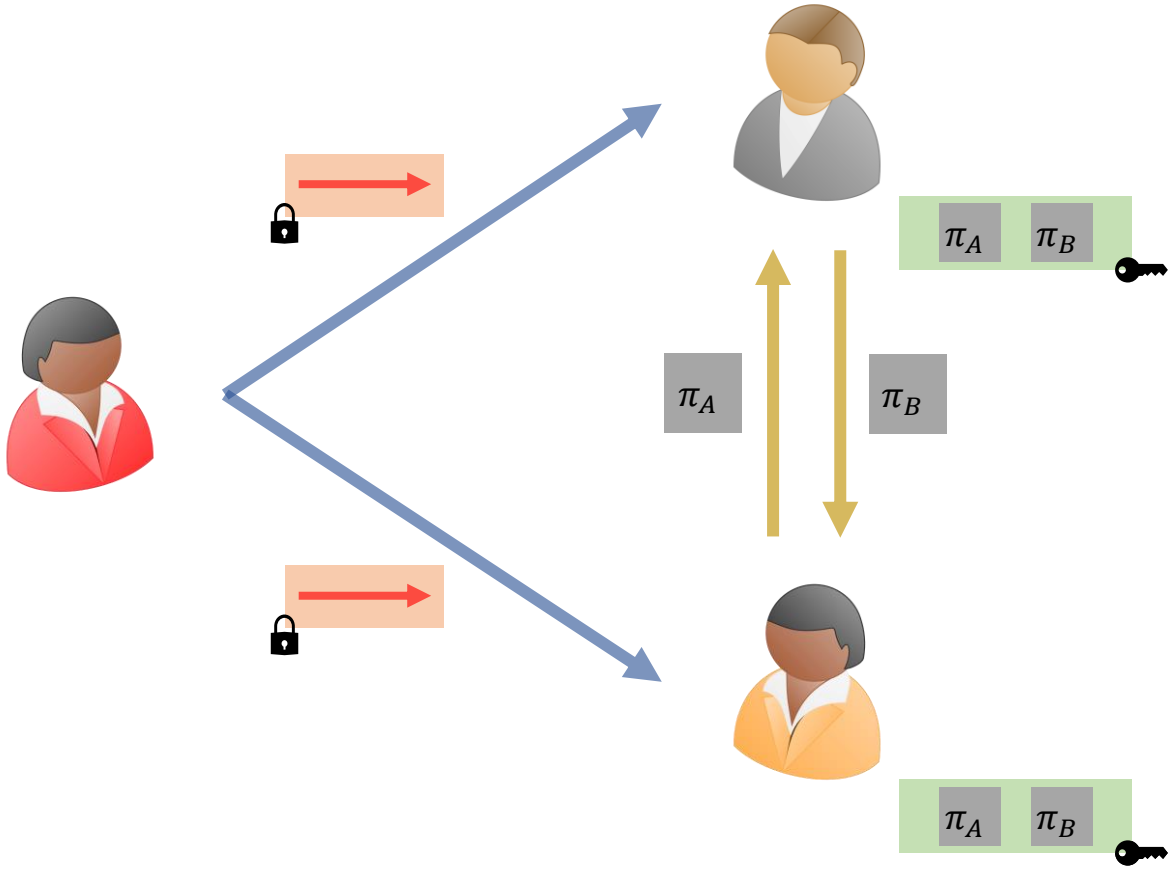

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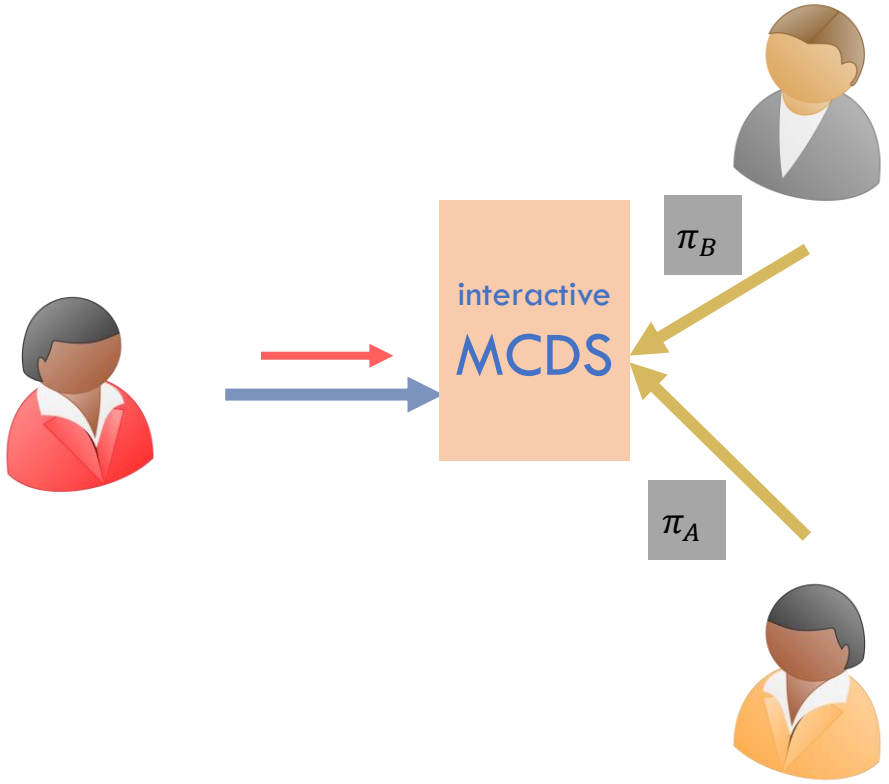

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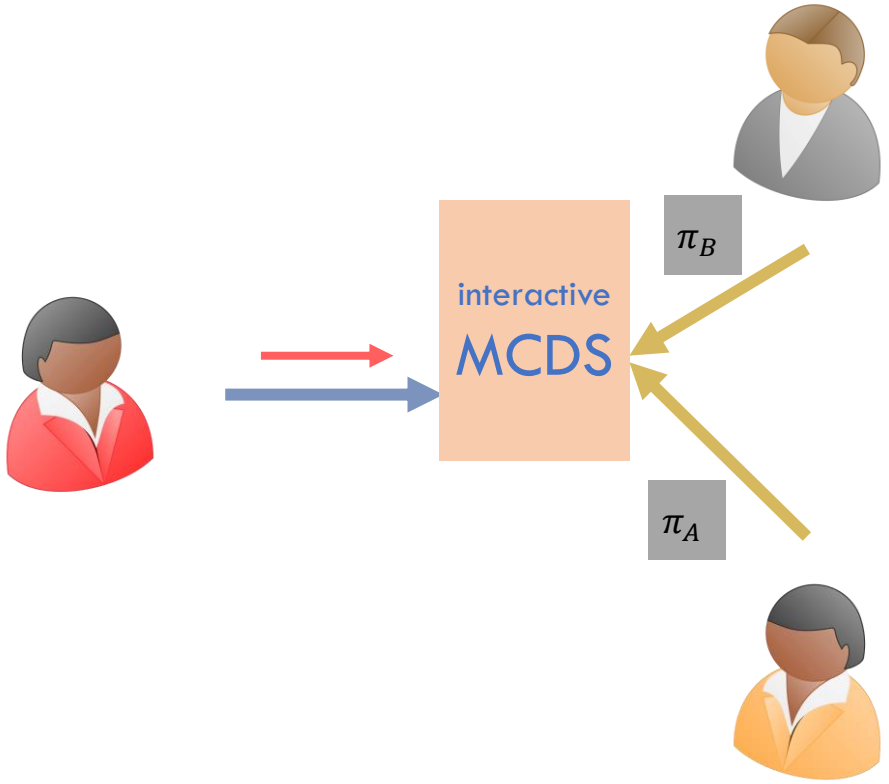

Receive Carol's fourth round message if Promise ZK proofs of Alice and Bob verify.

Nobody receives Carol's message if even one party cheats.

Towards a Full Protocol

Many moving components in the final protocol.

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Non-malleability challenges in limited rounds.

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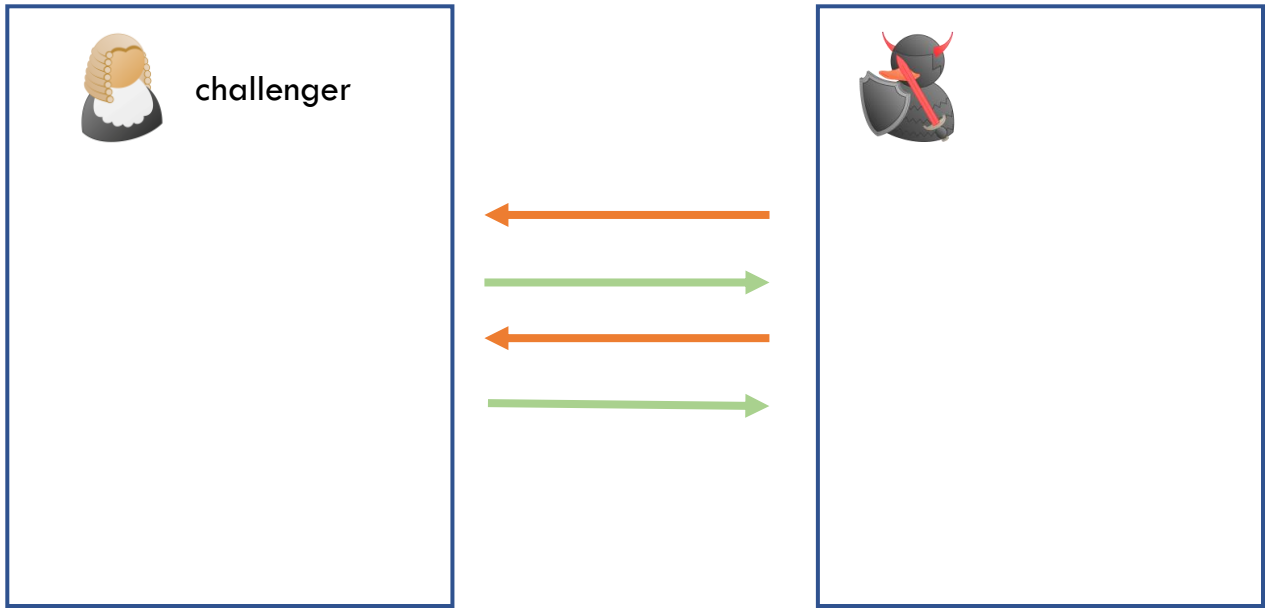
[New!] Assuming regular OT, we construct an OT protocol that retains security guarantees in the presence of a bounded number of rewinds.

Bounded Rewind Secure OT

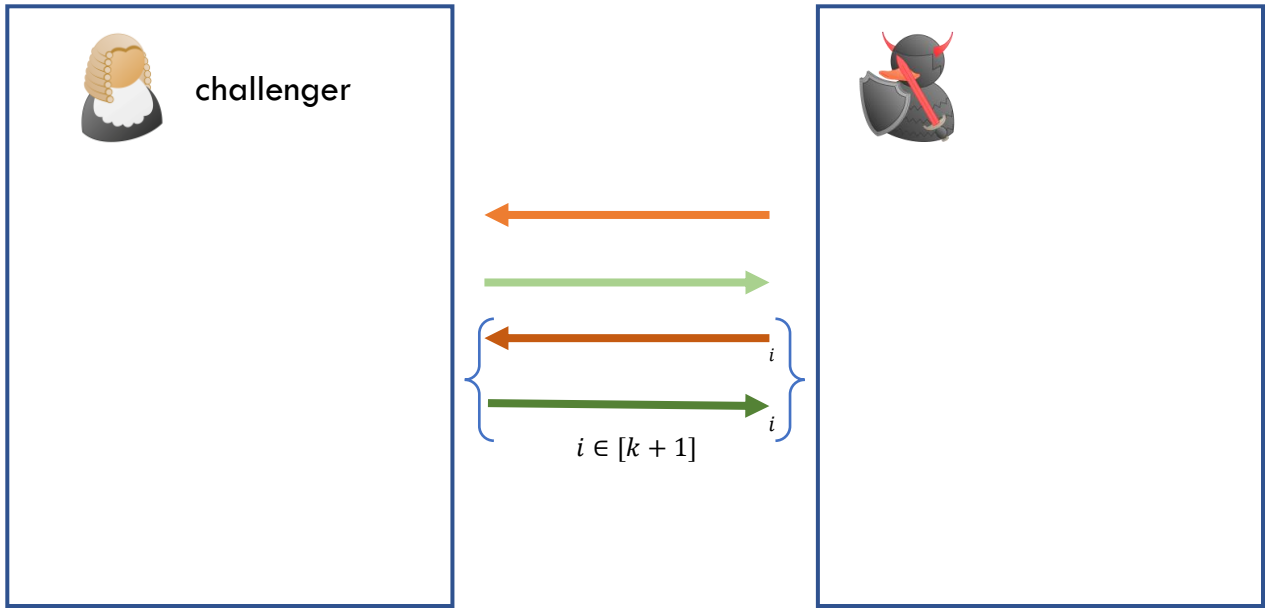
High level idea

k-Bounded Rewind Security



Regular challenger-adversary game

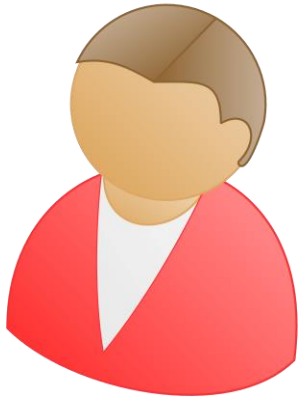
k-Bounded Rewind Security



Bounded rewind challenger-adversary game

4 round 1-Rewind Secure OT

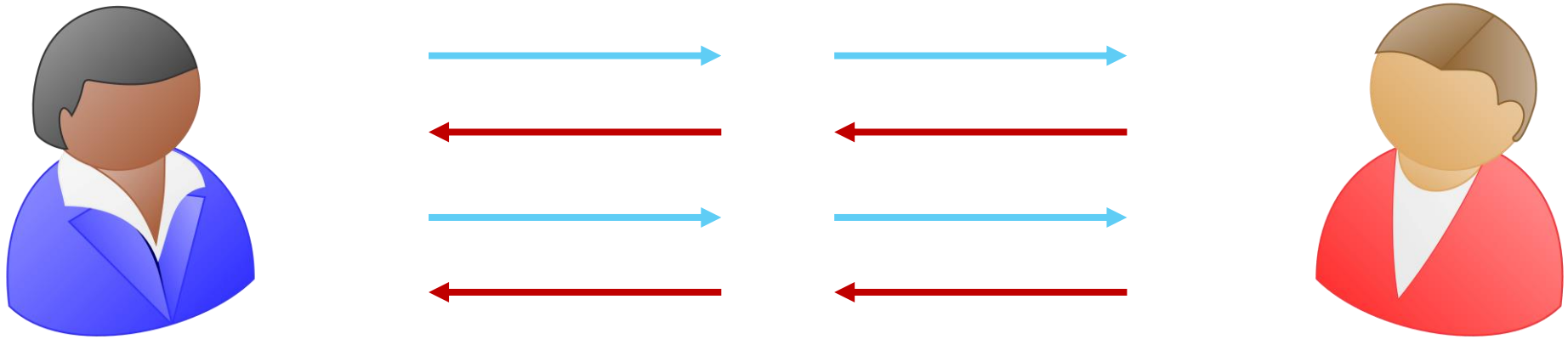
receiver
b



sender
x_0, x_1

Receiver input should be hidden from an adversarial sender that can rewind the receiver once.

4 round 1-Rewind Secure OT

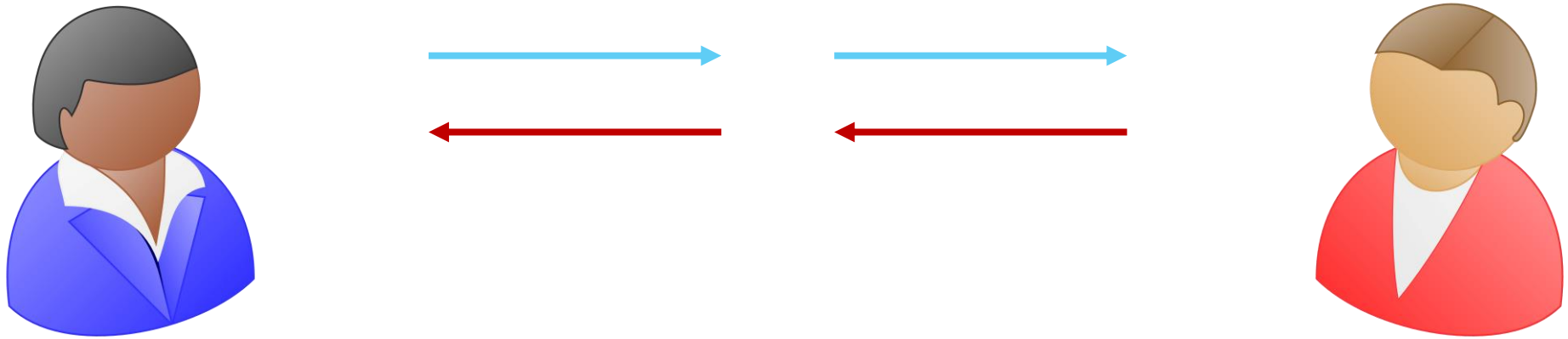


receiver
b

sender
x_0, x_1

Run two parallel copies of the OT. The receiver picks a random OT in the third round to proceed.

4 round 1-Rewind Secure OT



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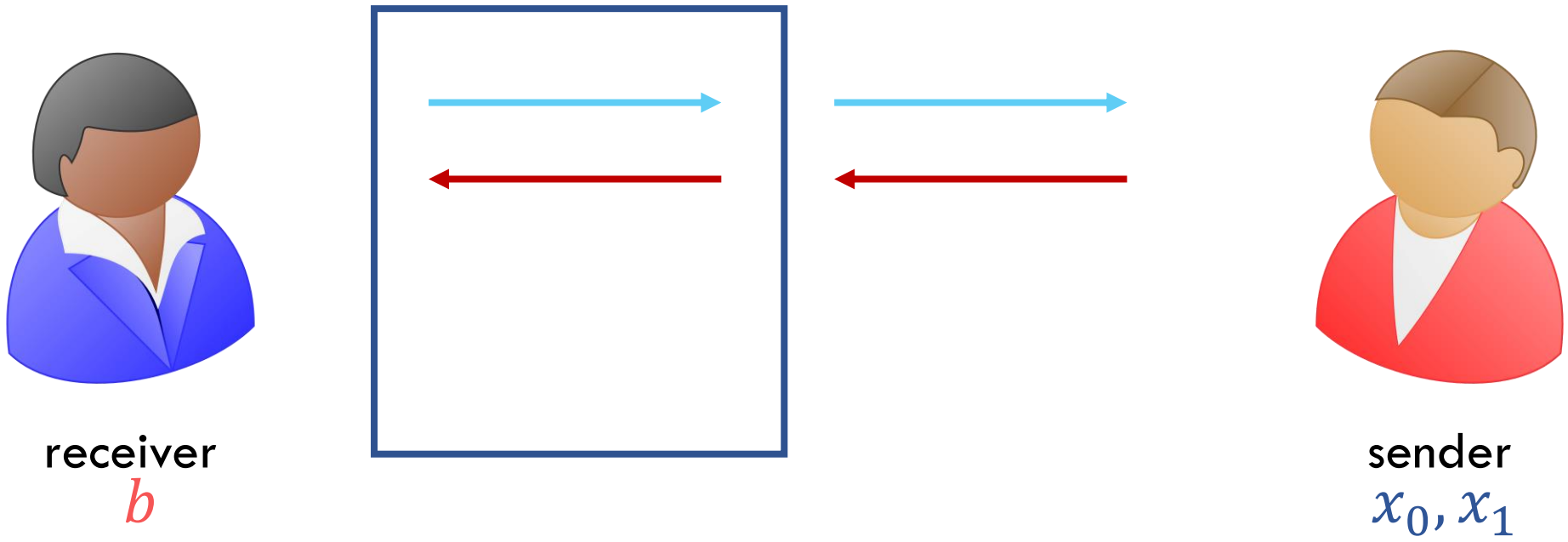
4 round 1-Rewind Secure OT



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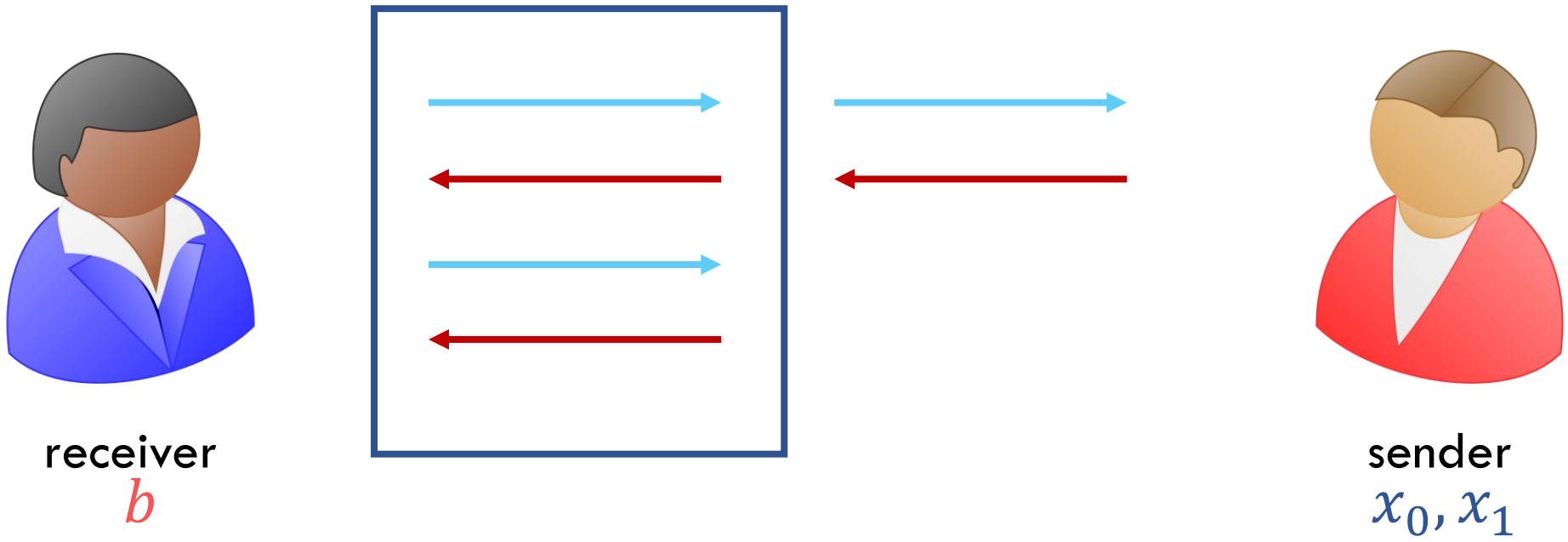

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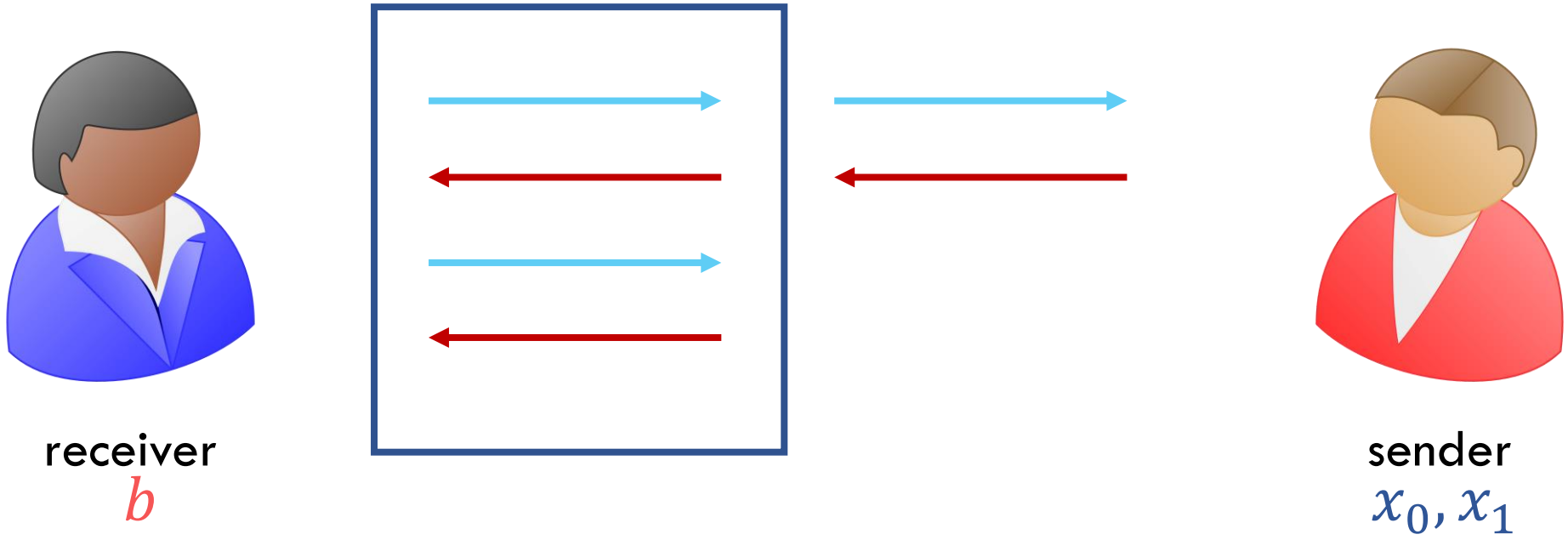
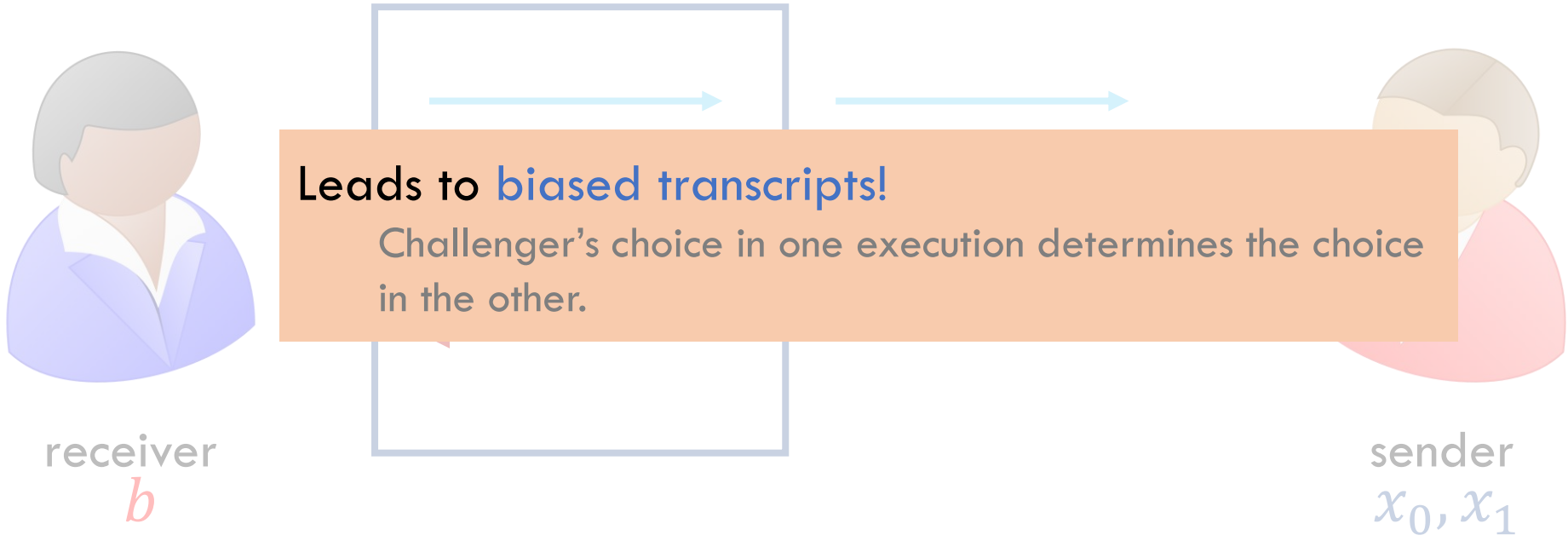


Challenger can use a different instance in the two executions (one rewind).

4 round 1-Rewind Secure OT



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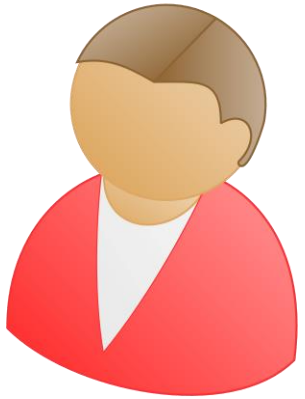
4 round 1-Rewind Secure OT

High level idea: secret share receiver input

receiver

$b = b_1 \oplus b_2$

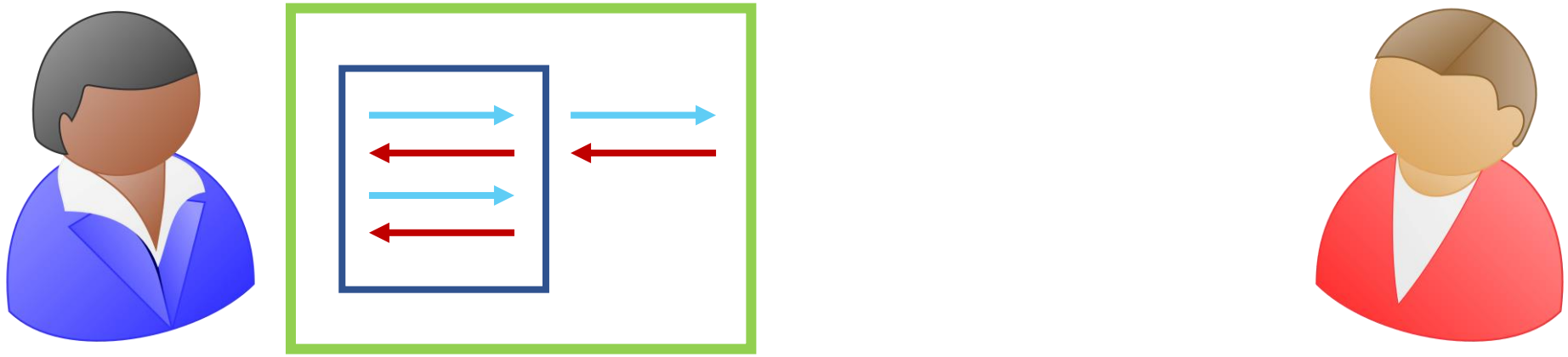


sender

x_0, x_1

4 round 1-Rewind Secure OT

High level idea: secret share receiver input



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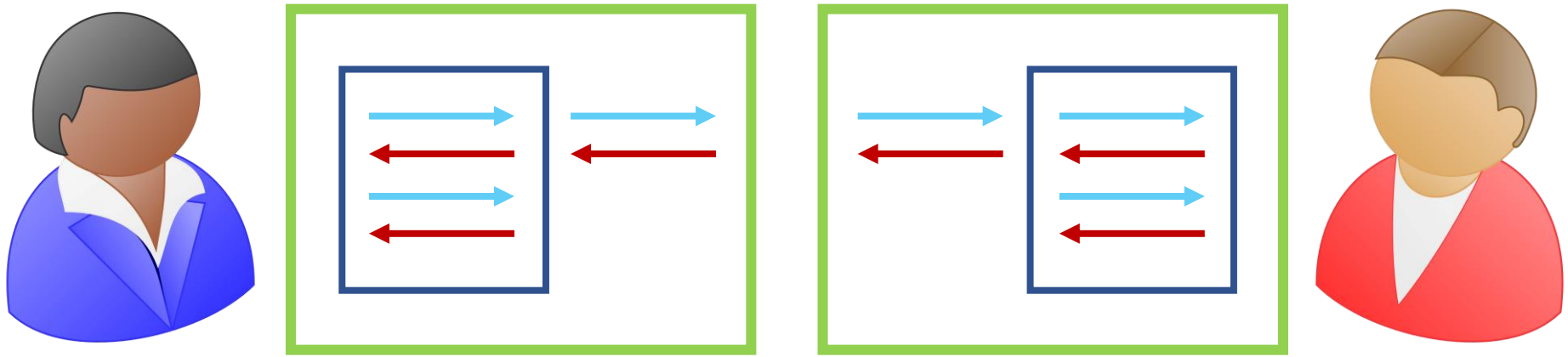
High level idea: secret share receiver input



receiver

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b_1

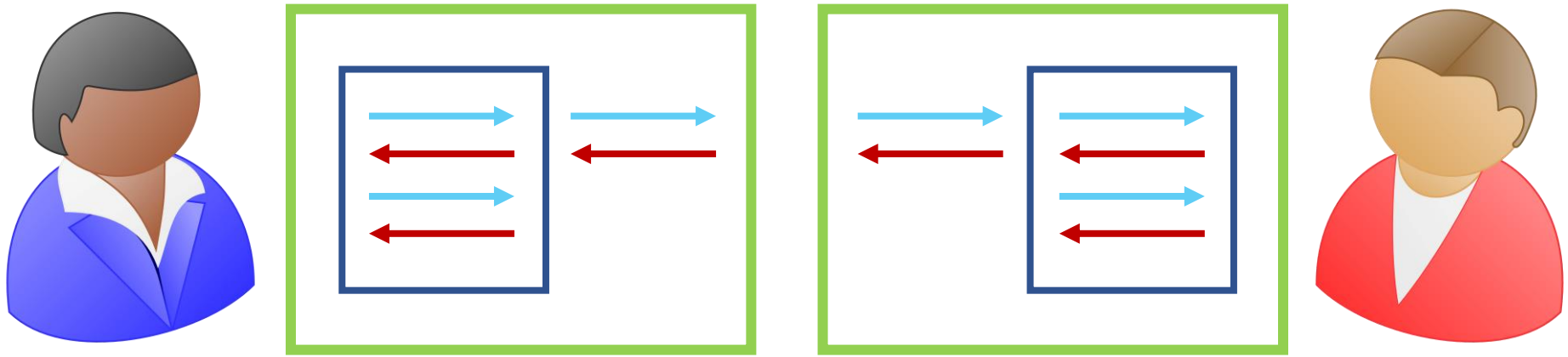
b_2

sender

x_0, x_1

4 round 1-Rewind Secure OT

High level idea: secret share receiver input



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In each execution, the challenger independently samples which instance to use for every index.

Secure if at least one index results in two different executions. Can be amplified.

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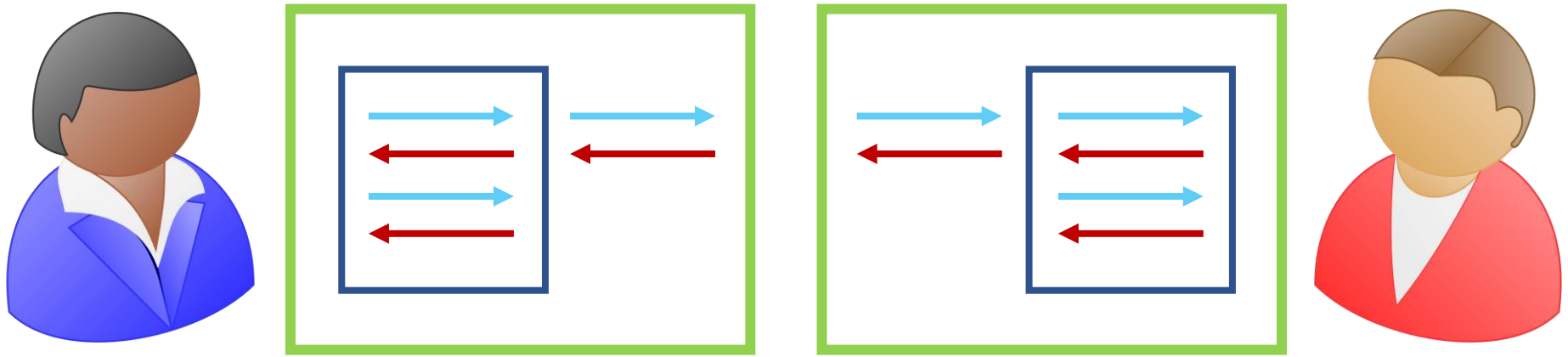
High level idea: secret share receiver input



receiver

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sender

x_0, x_1

High level idea: details missing.

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Assuming 4 round oblivious transfer (OT), there exists a 4 round MPC protocol.

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Thank you. Questions?

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ia.cr/2019/216