Founding Secure Computation on Blockchains

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Johns Hopkins University

Eurocrypt 2019, Darmstadt

Motivation

Blockchain!

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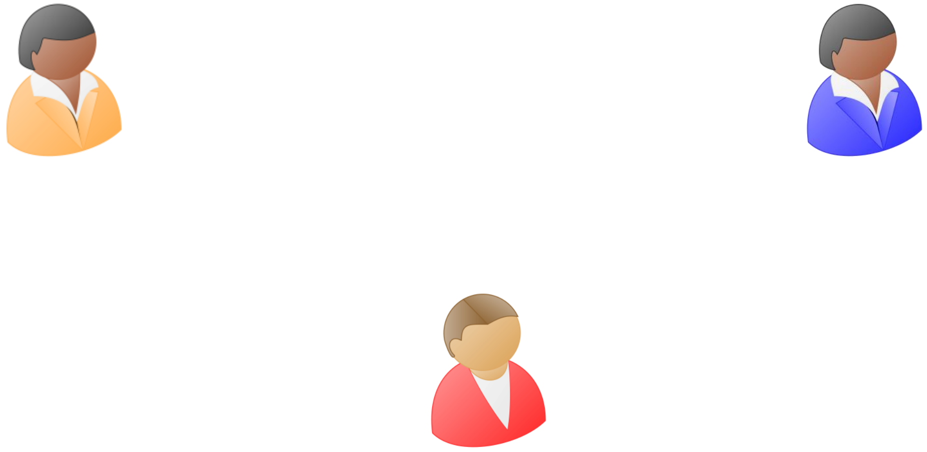
Examine the foundation of secure computation protocols in the context of blockchains.



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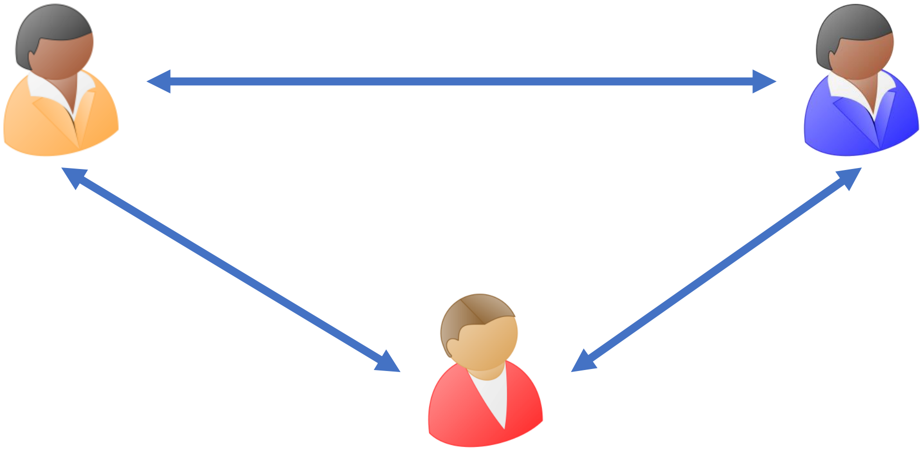

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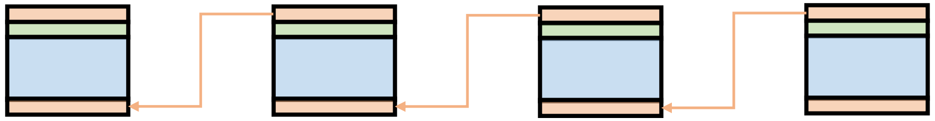

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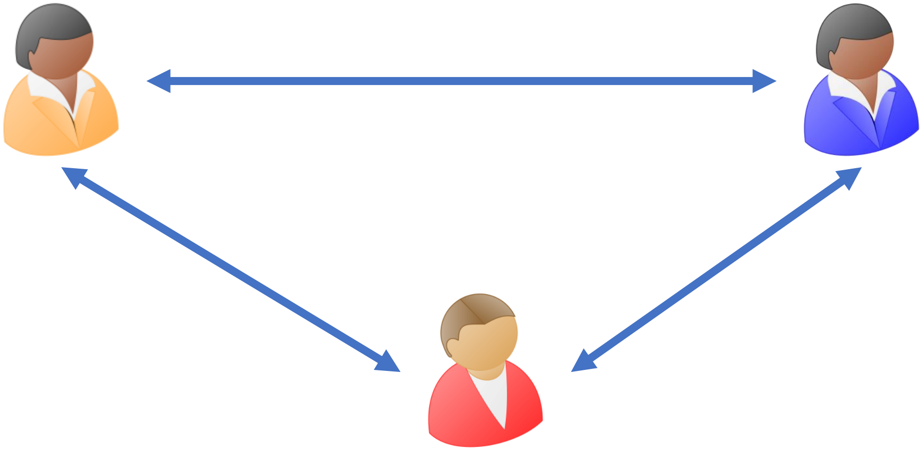

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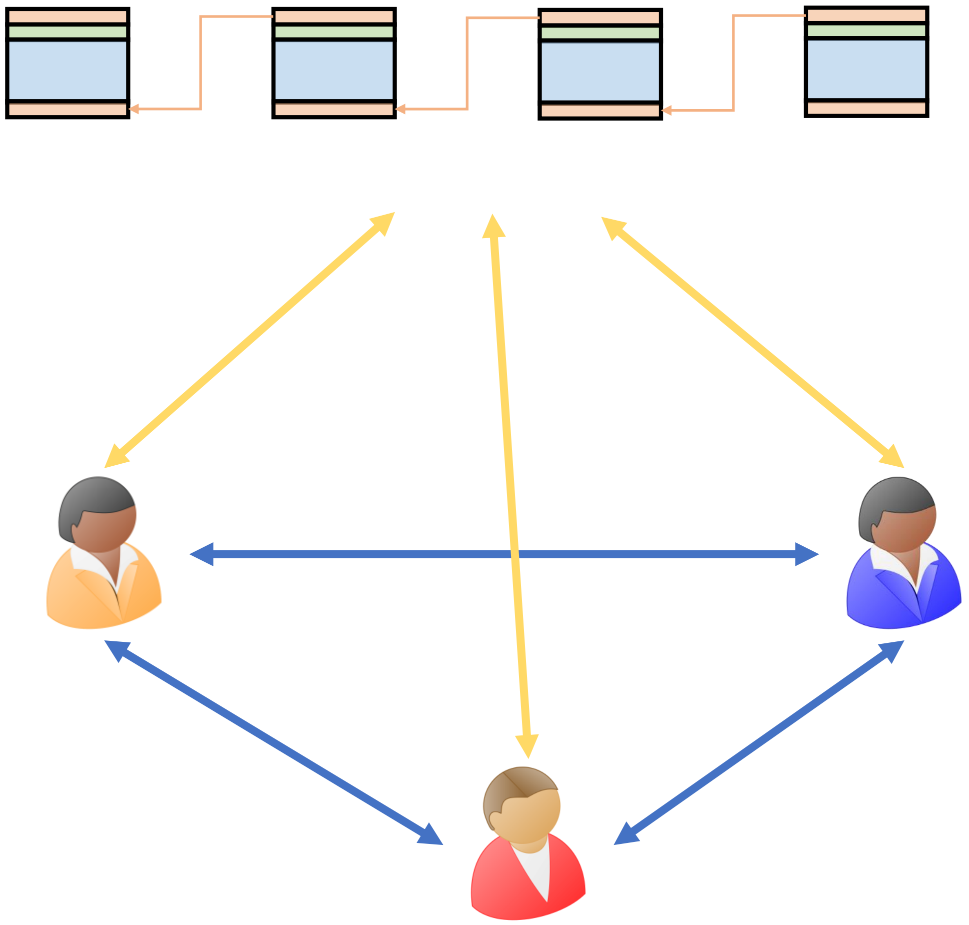

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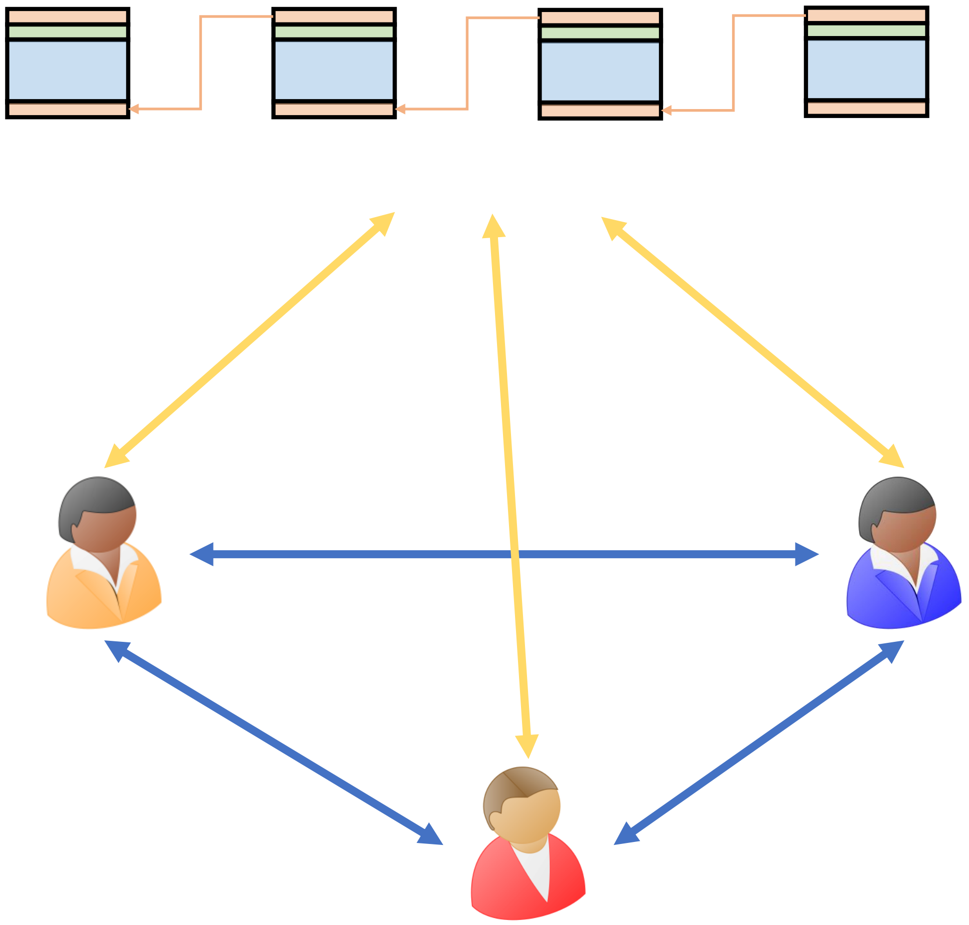

What change does this make to the study of protocols in this setting?

Model

Modeling of the blockchain:

Model

Modeling of the blockchain:

[Kiayis-Zhou-Zikas 16, Badertscher-Maurer-Tschudi-Zikas 17, Badertscher-Gazi-Kiayis-Russell-Zikas 18]

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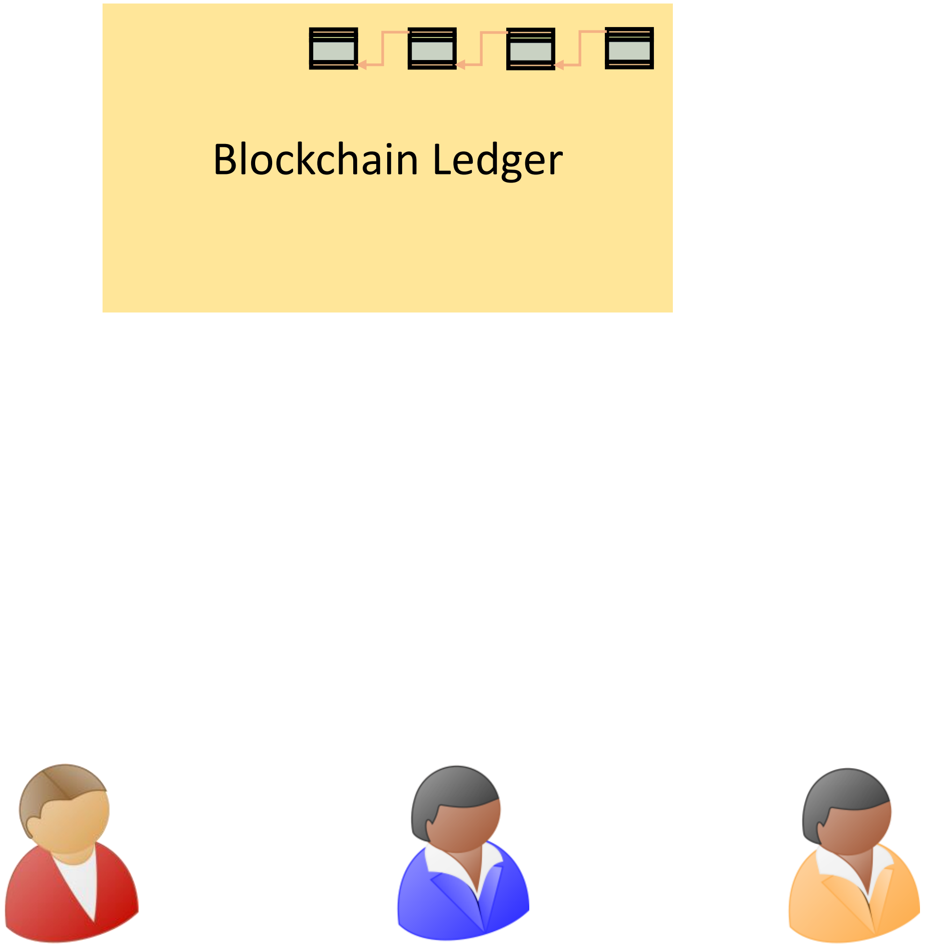
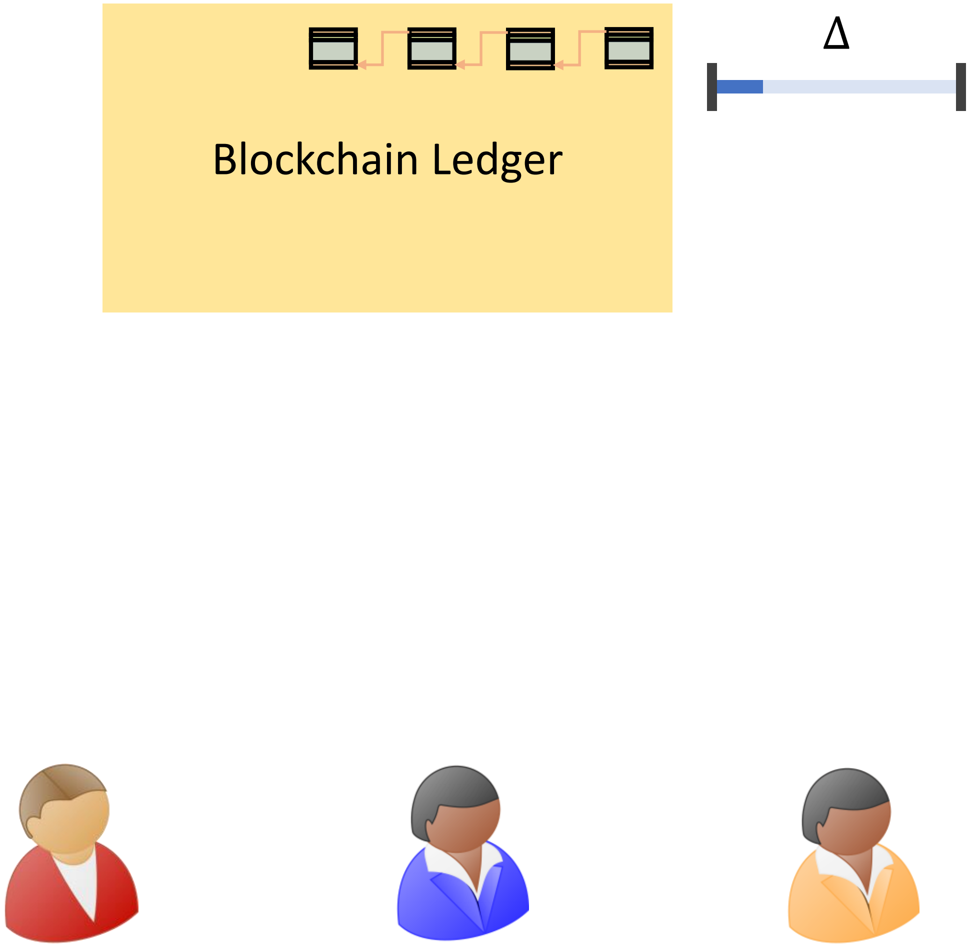
For this talk: simplified model

Simplified Model



Blockchain Ledger

Simplified Model



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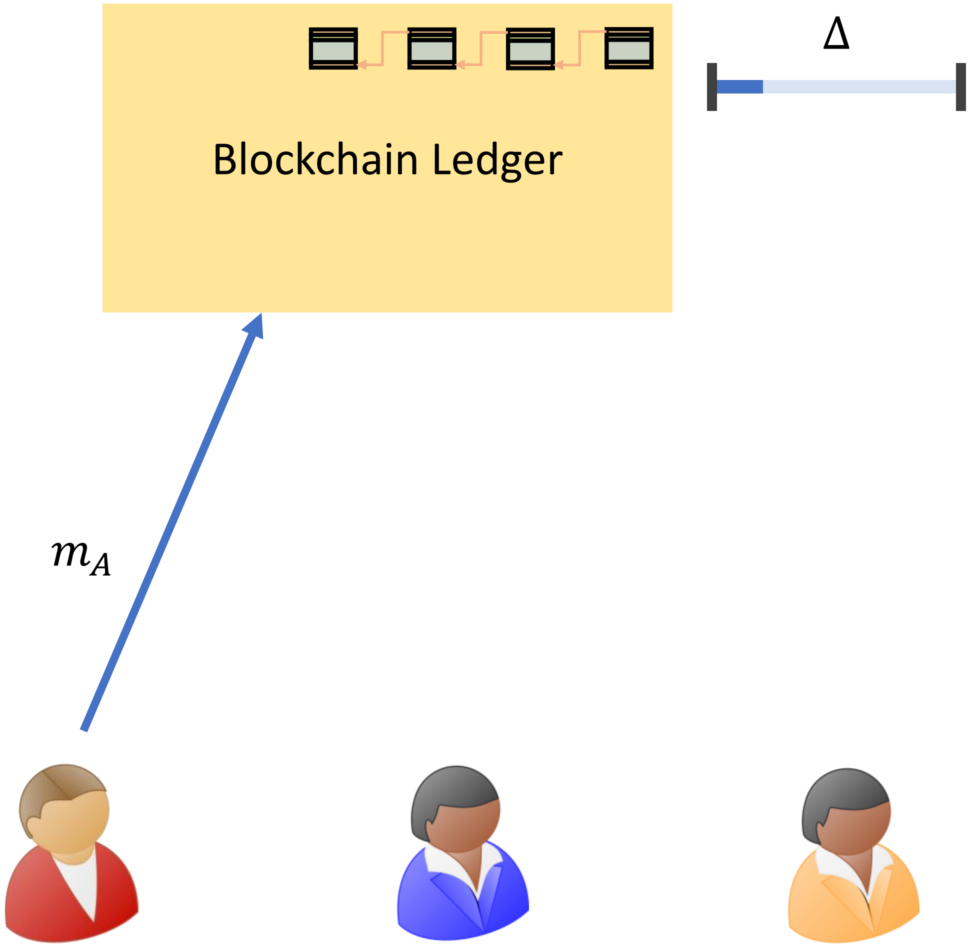

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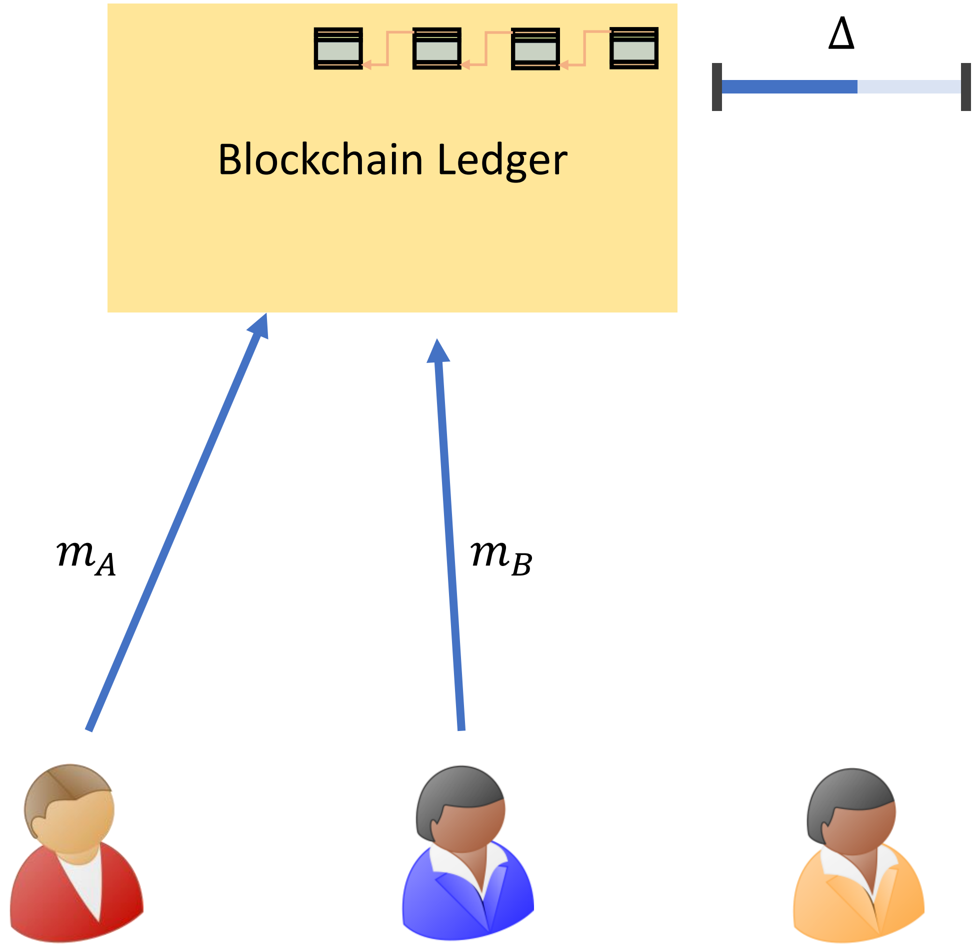

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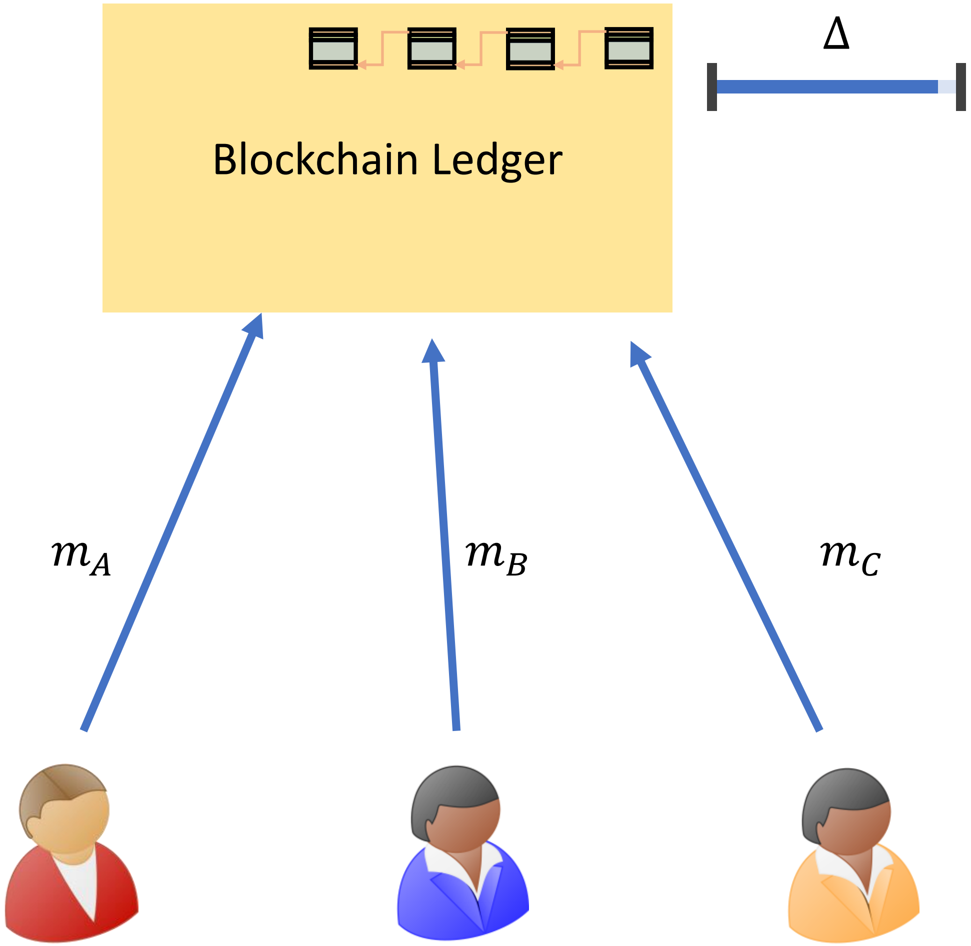

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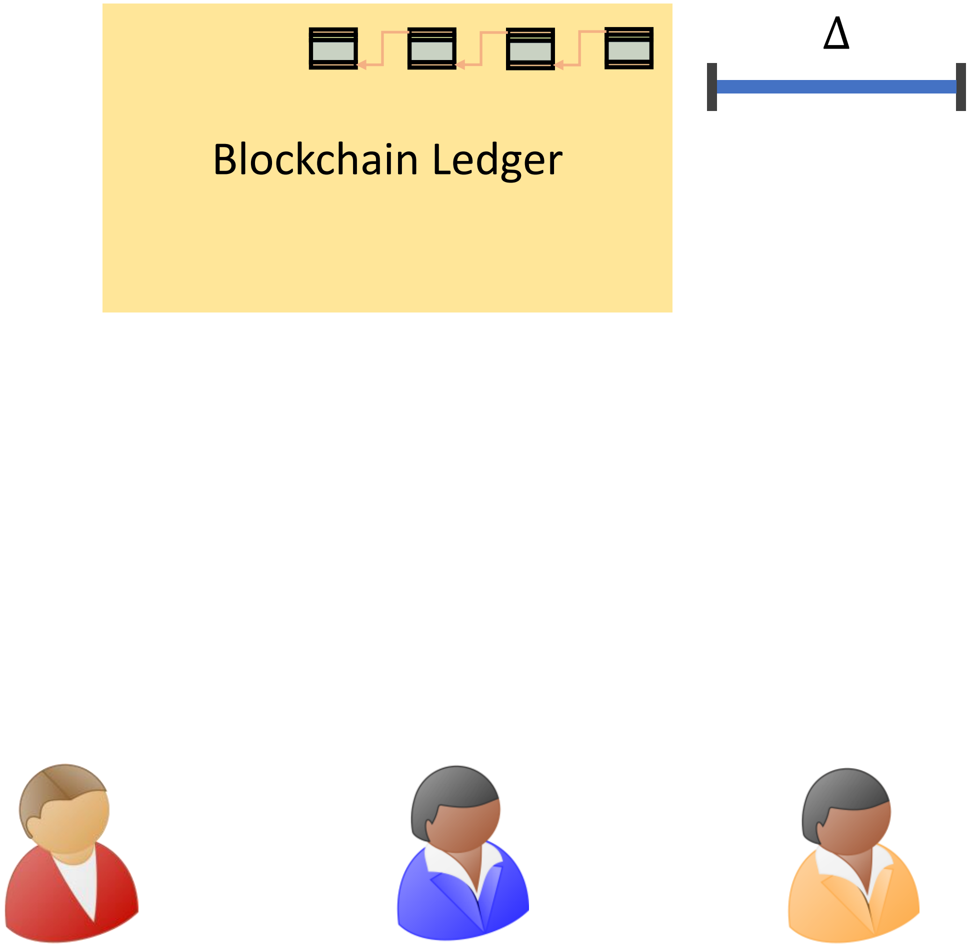

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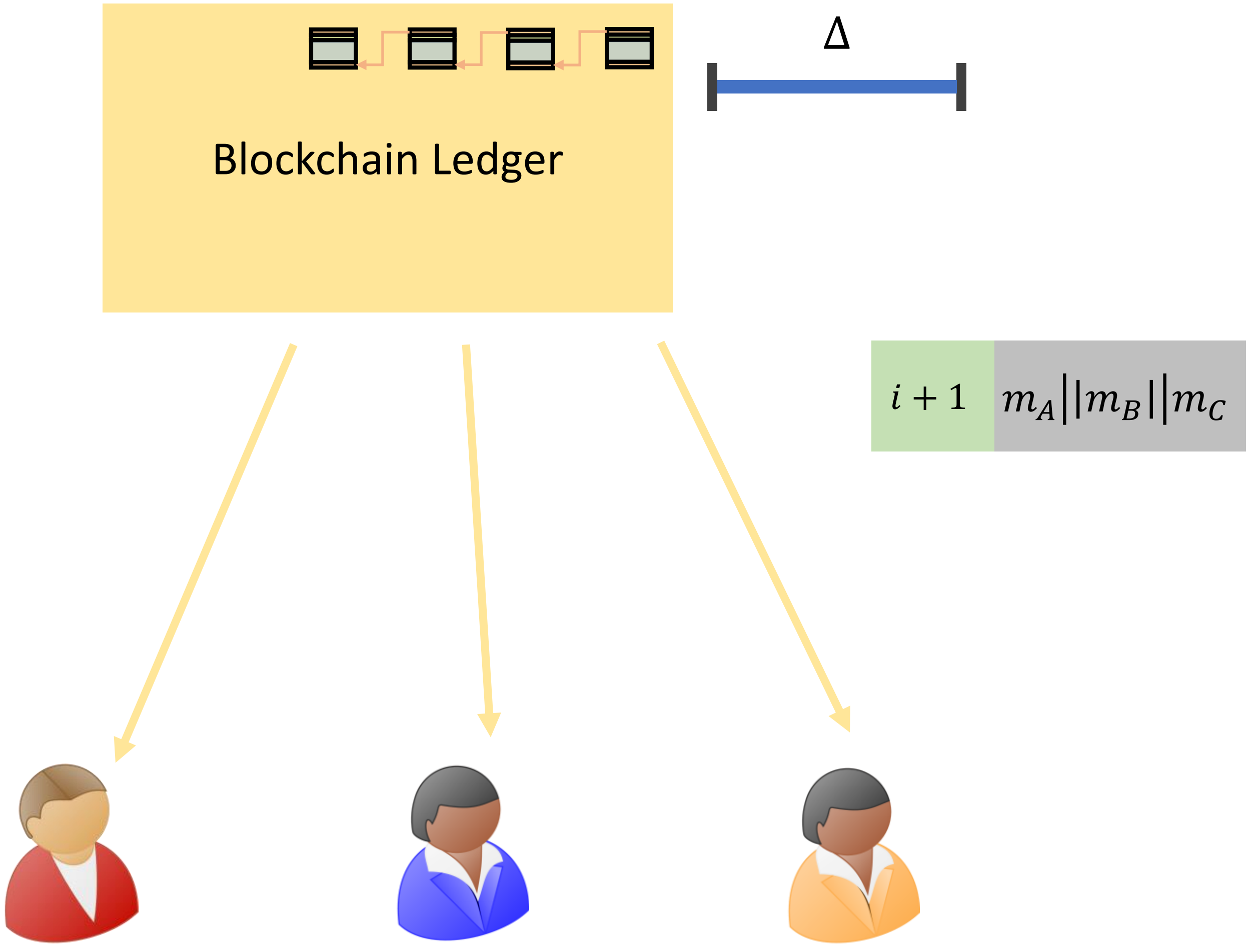


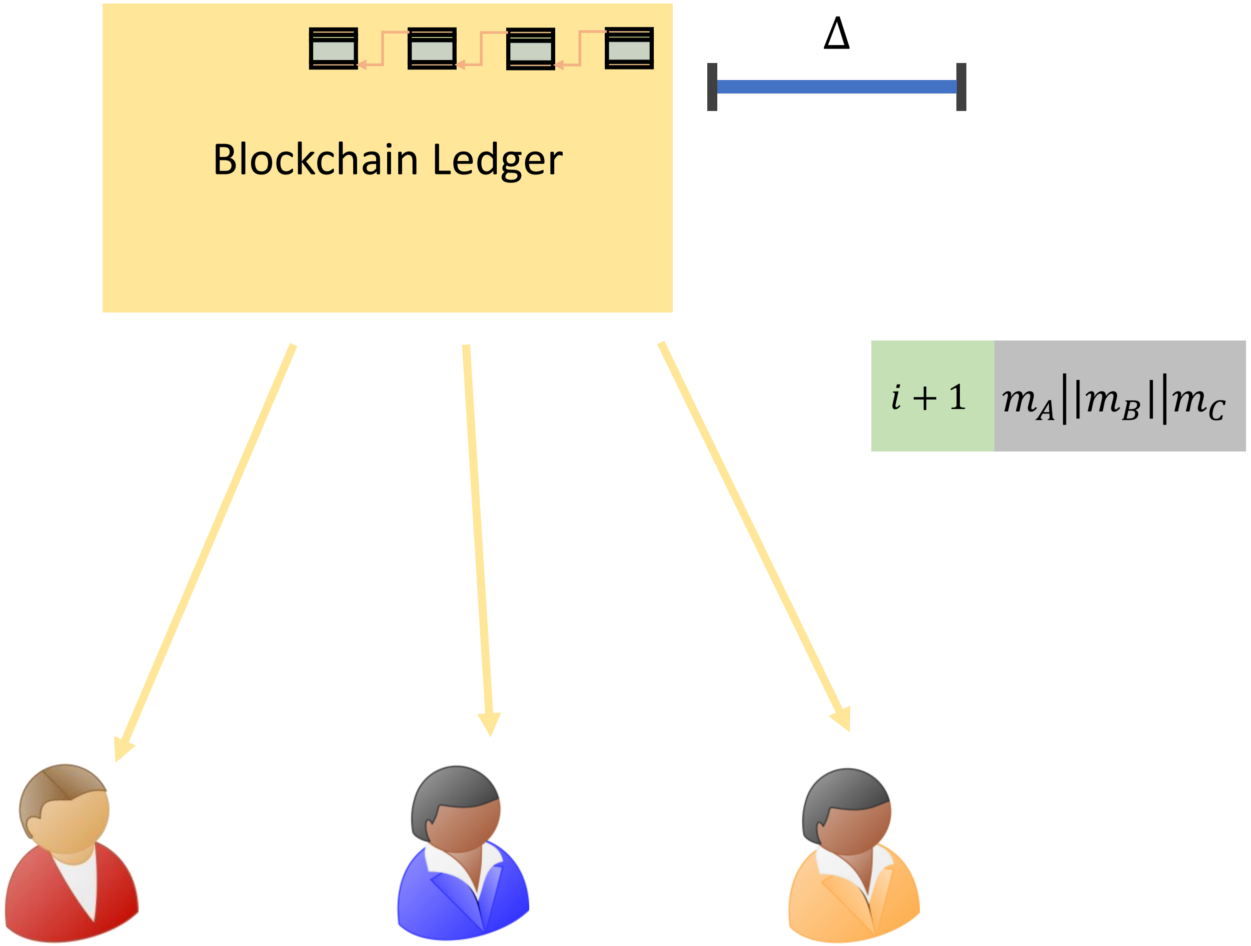
Blockchain Ledger

Δ

$i + 1$ $m_A||m_B||m_C$

Simplified Model

All parties have a consistent view of the blockchain



Simplified Model

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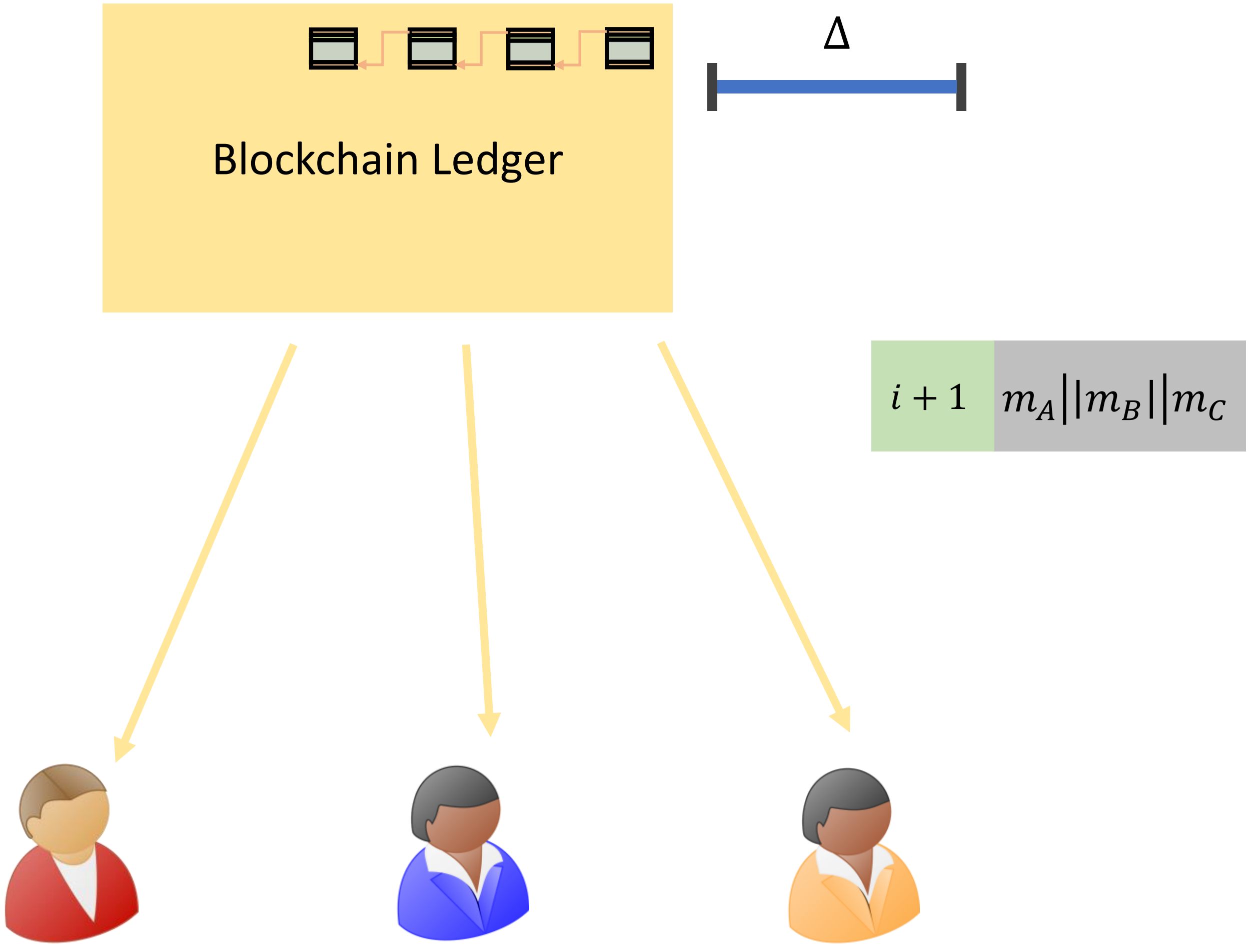
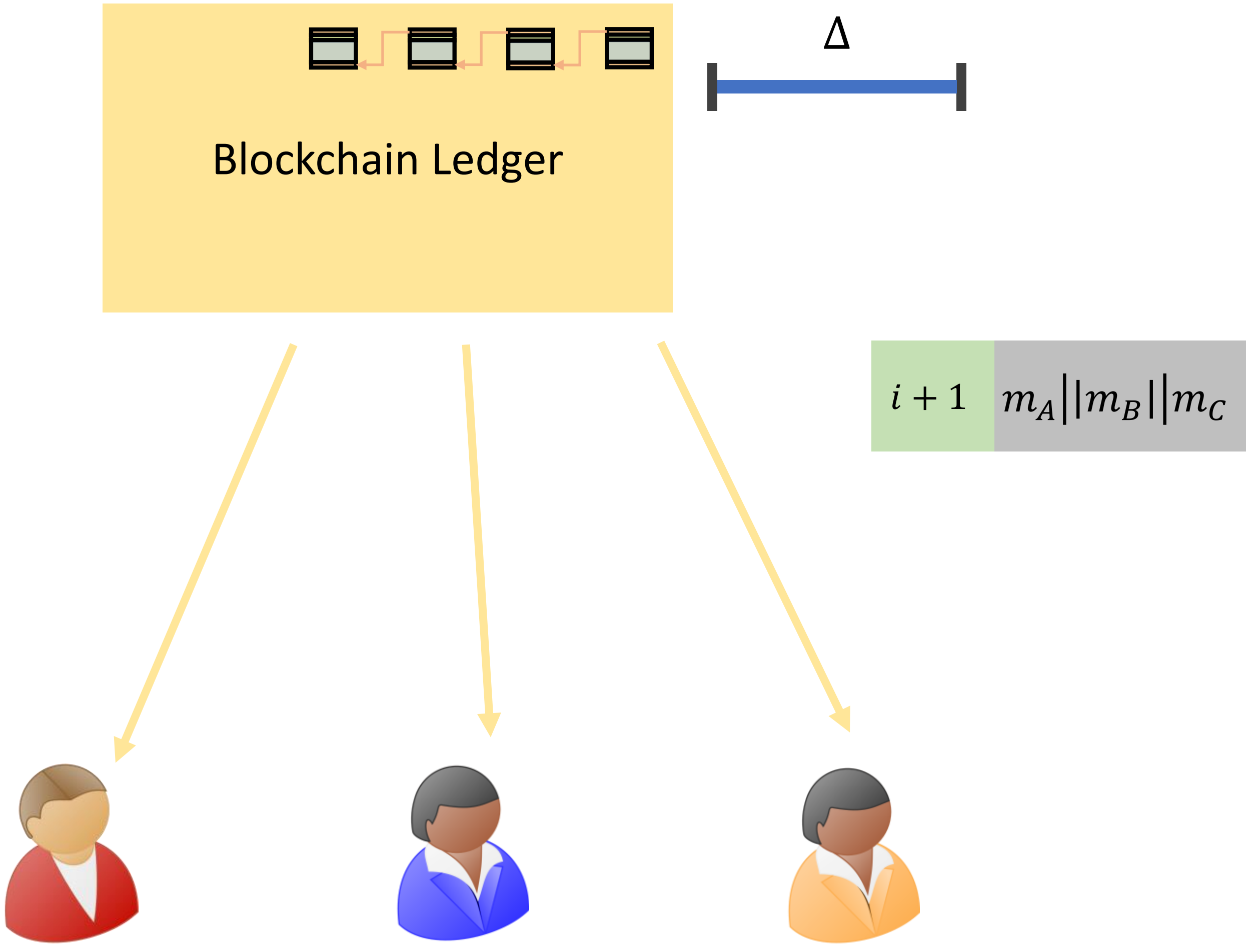


Simplified Model

All parties have a consistent view of the blockchain

A message sent to the oracle is guaranteed to appear on the next block

Only the oracle can create blocks



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Blockchain hybrid model

A party is called blockchain active if it has post and read access to the blockchain

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Simulator has same access to the blockchain

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Local access: [Choudhuri-Green-Jain-Kaptchuk-Miers 17, Goyal-Goyal 17]

Our Results

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Black-box Zero Knowledge Impossible in the presence of blockchain active adversary

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$\omega(1)$ round Black-box Zero Knowledge in the blockchain hybrid model

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Concurrent secure computation possible for all functionalities in the blockchain hybrid model

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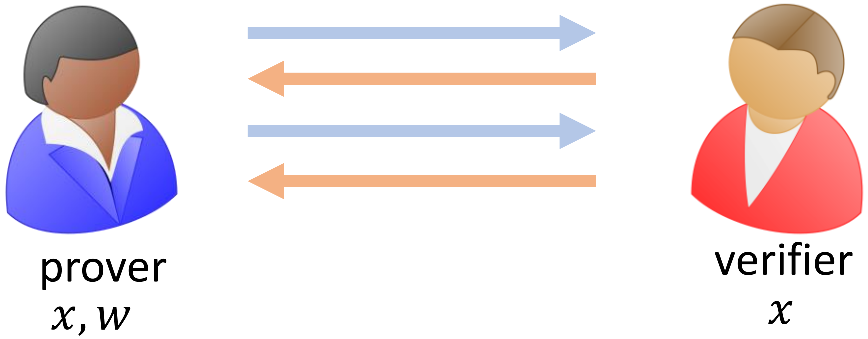
Blockchains have both destructive and constructive uses.

Zero Knowledge

Zero Knowledge (ZK)



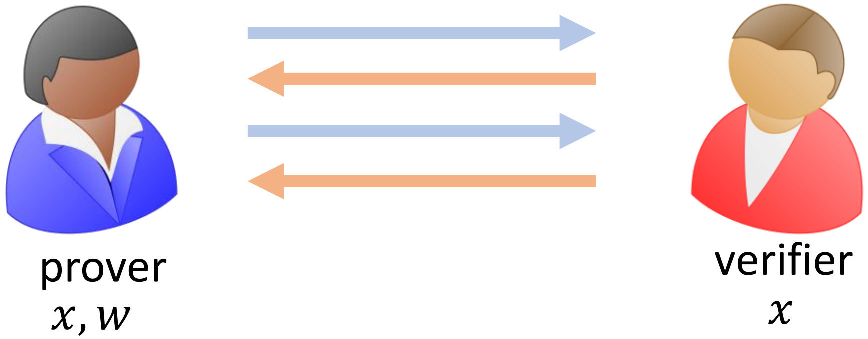
prover

x, w

verifier

x

Zero Knowledge (ZK)



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Completeness

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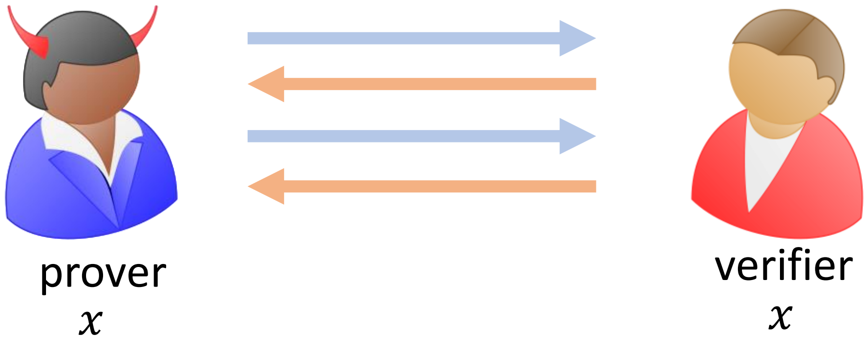
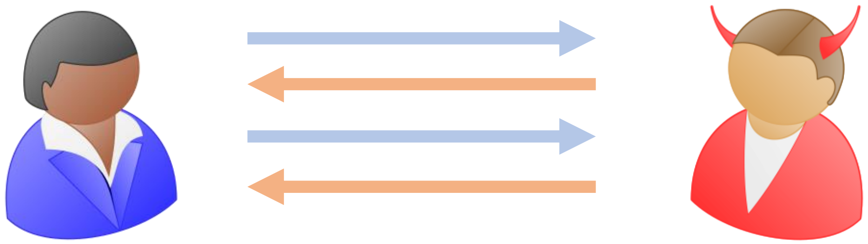


Completeness

Soundness

Zero Knowledge (ZK)



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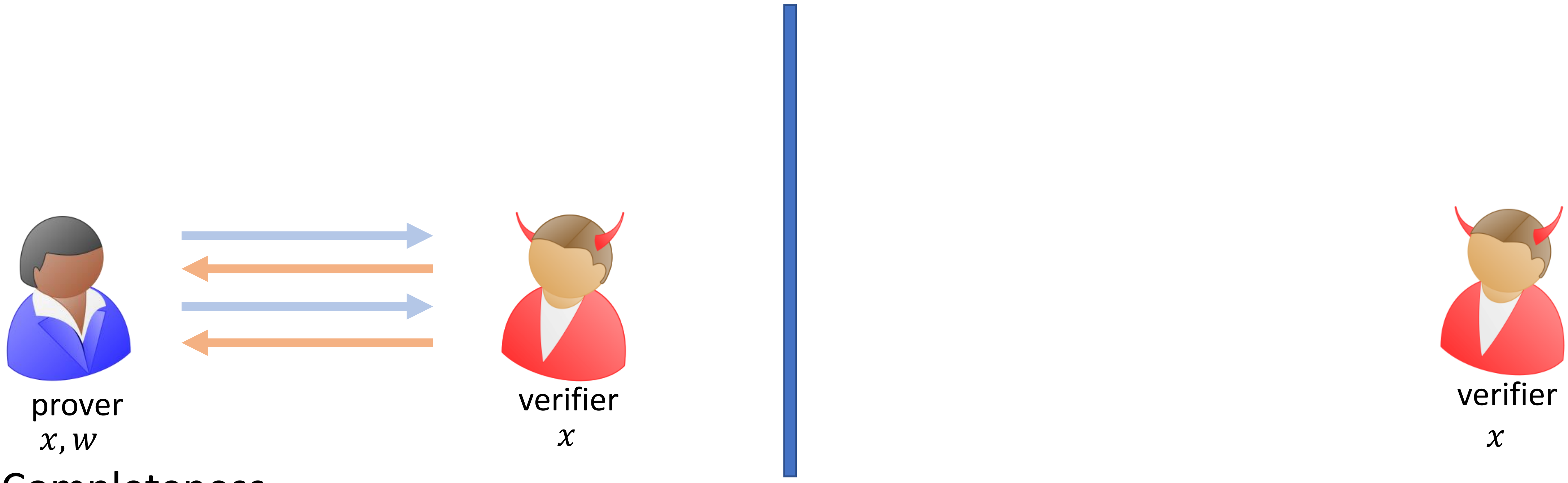

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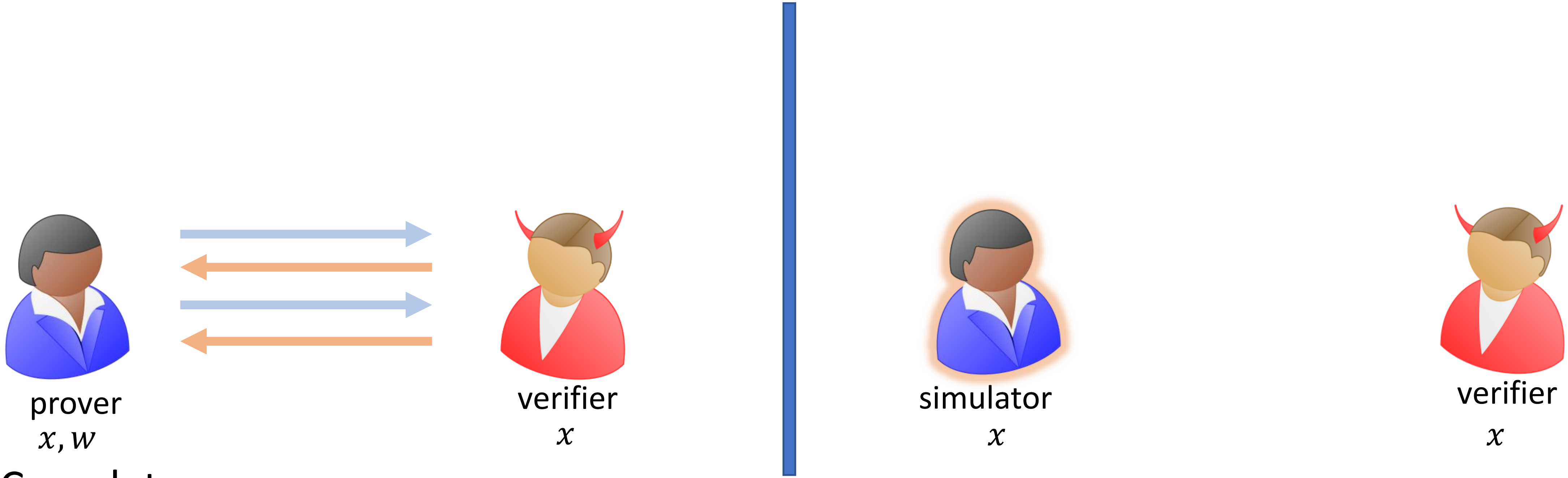

prover

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verifier

x

simulator

x

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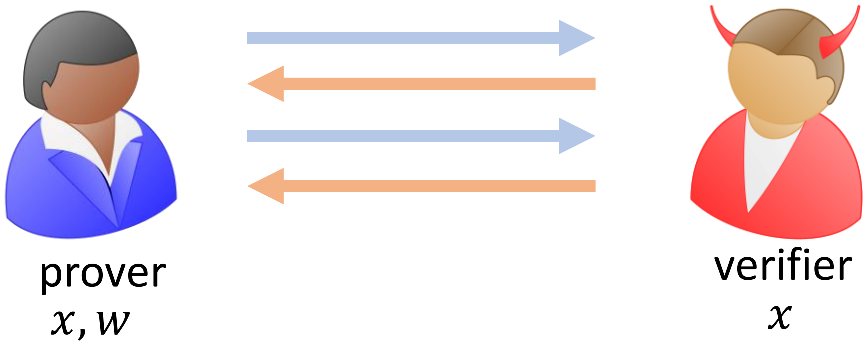

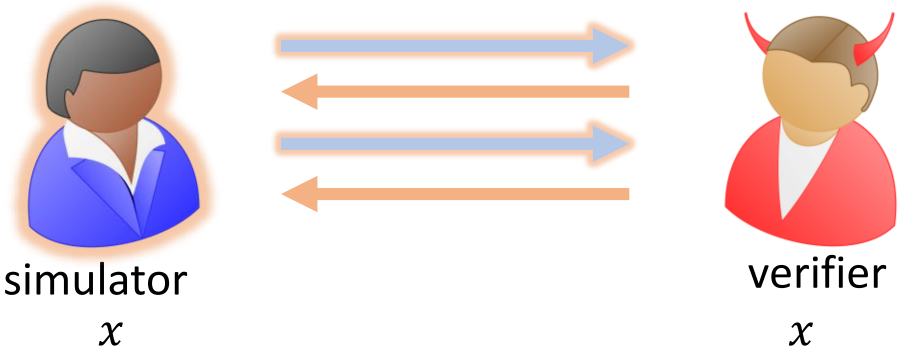

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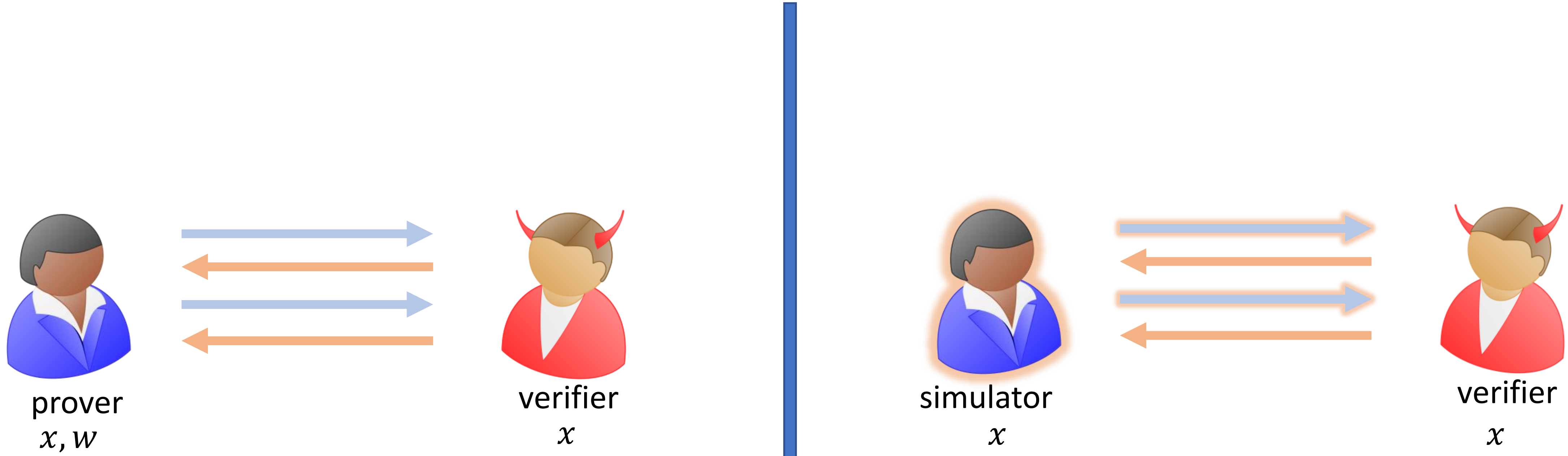

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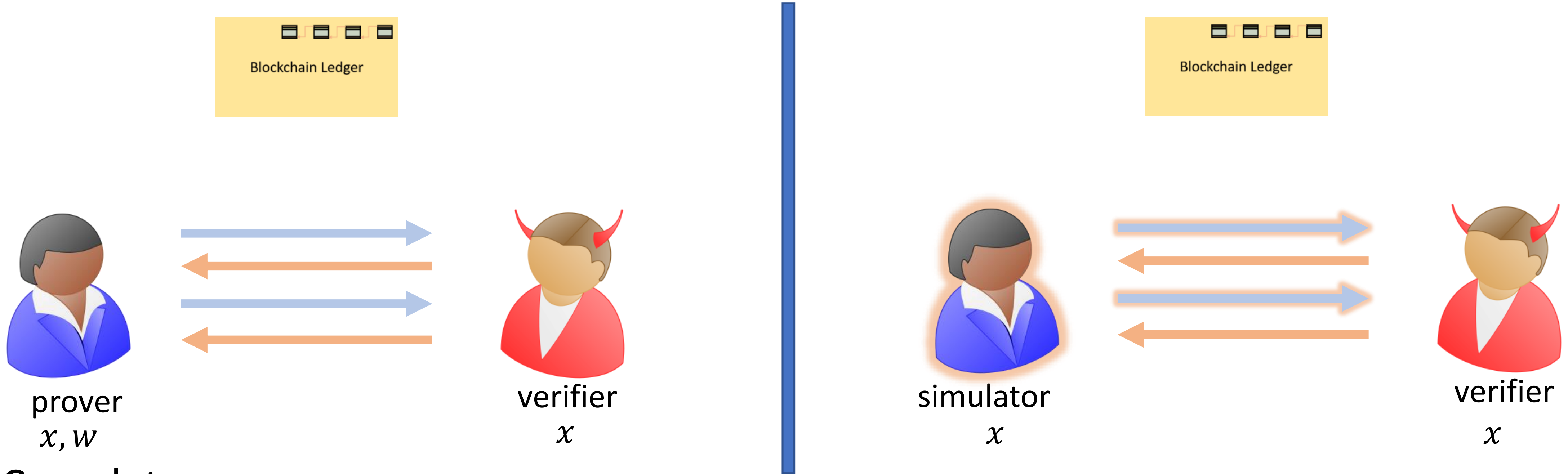

$\approx$

Completeness

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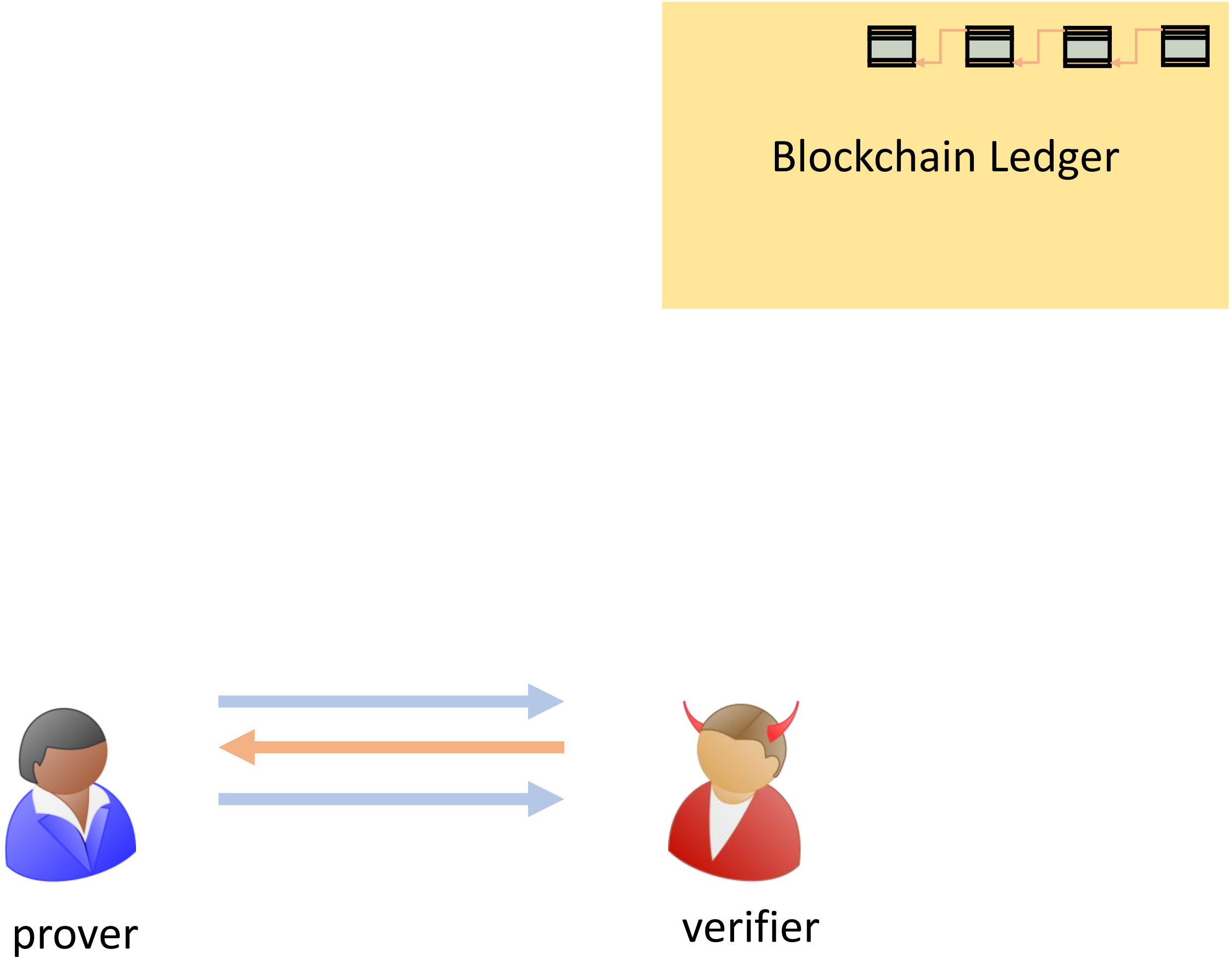
Zero Knowledge

ZK Impossible against Blockchain Active Adversaries



Blockchain Ledger

prover

verifier

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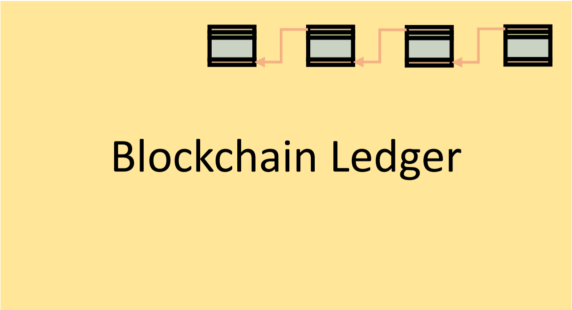
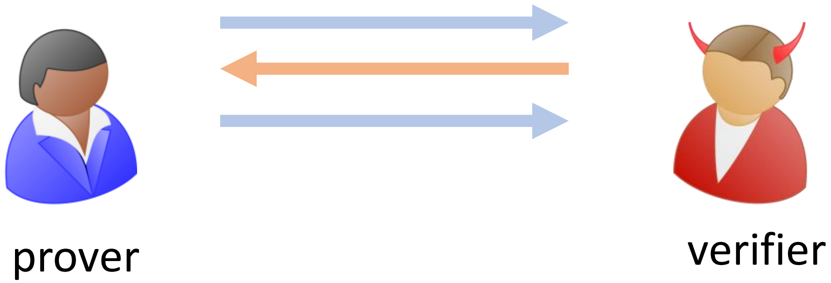


Prevent Simulator from rewinding the verifier.



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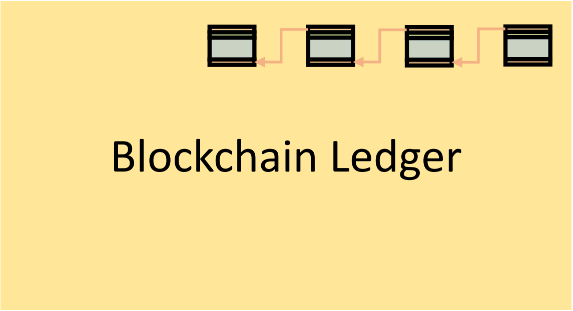

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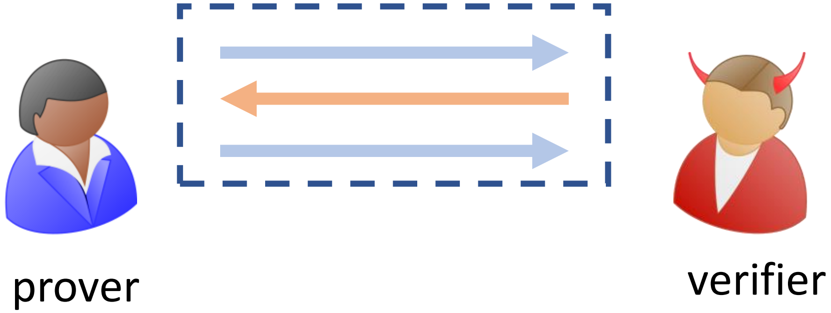

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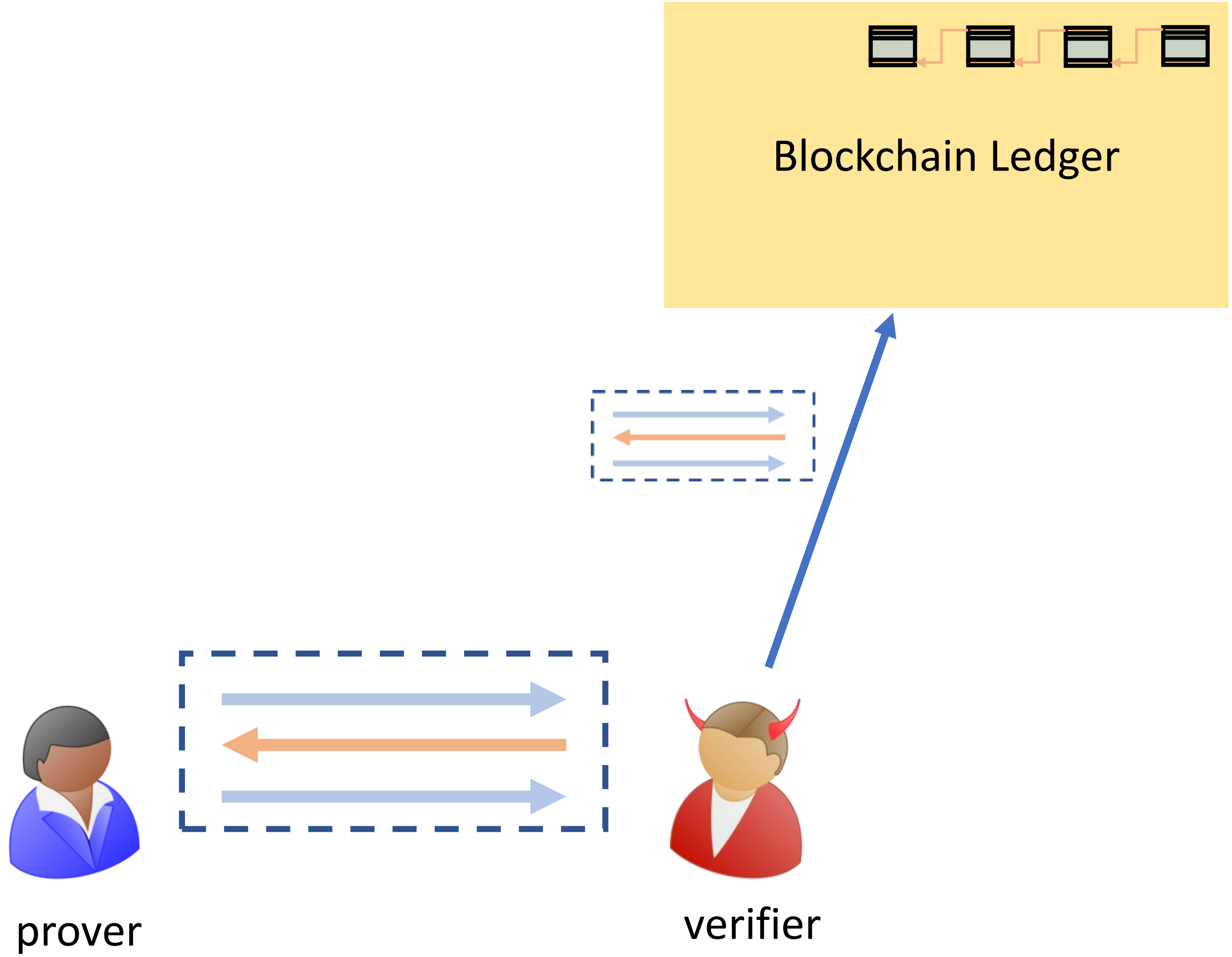

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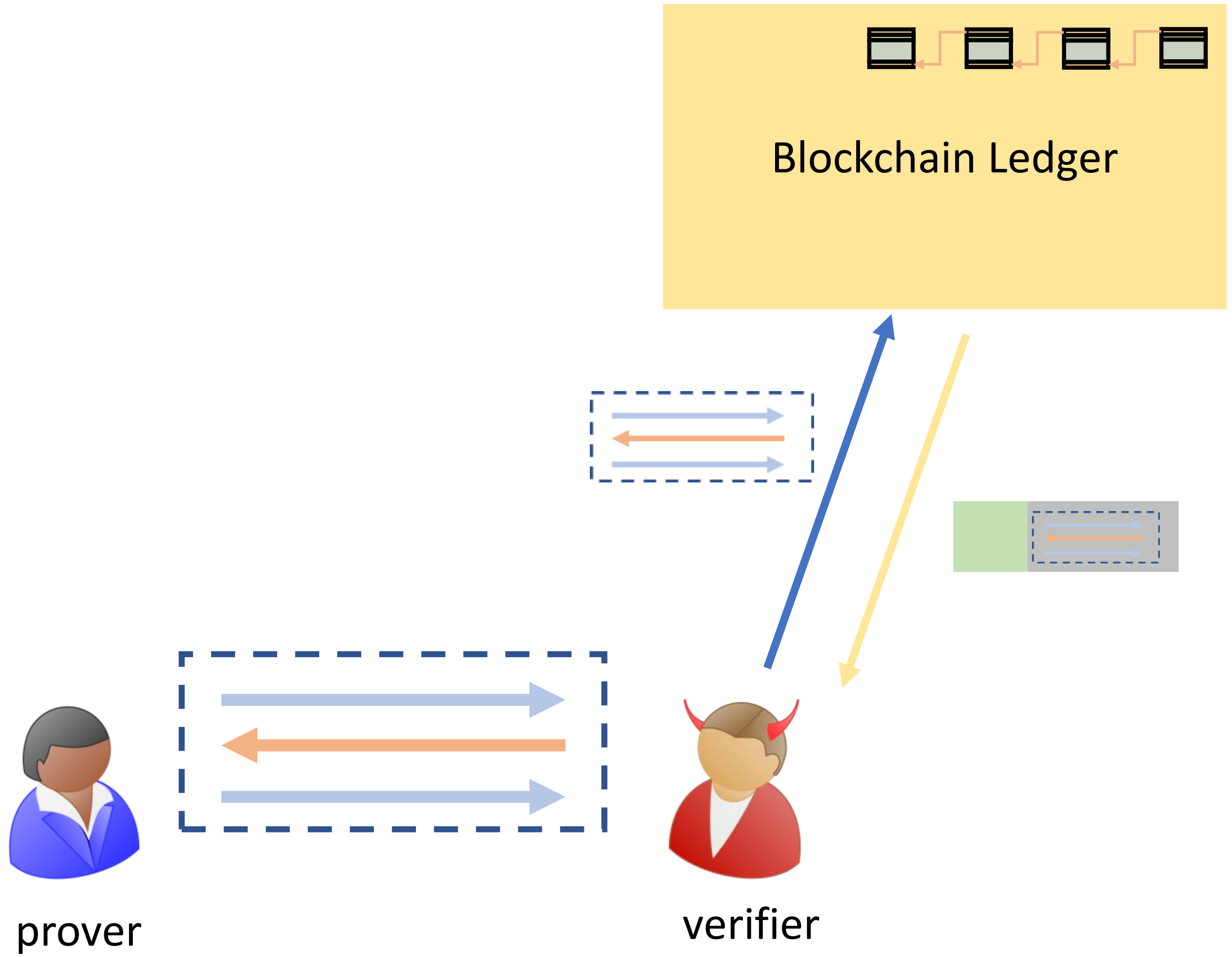

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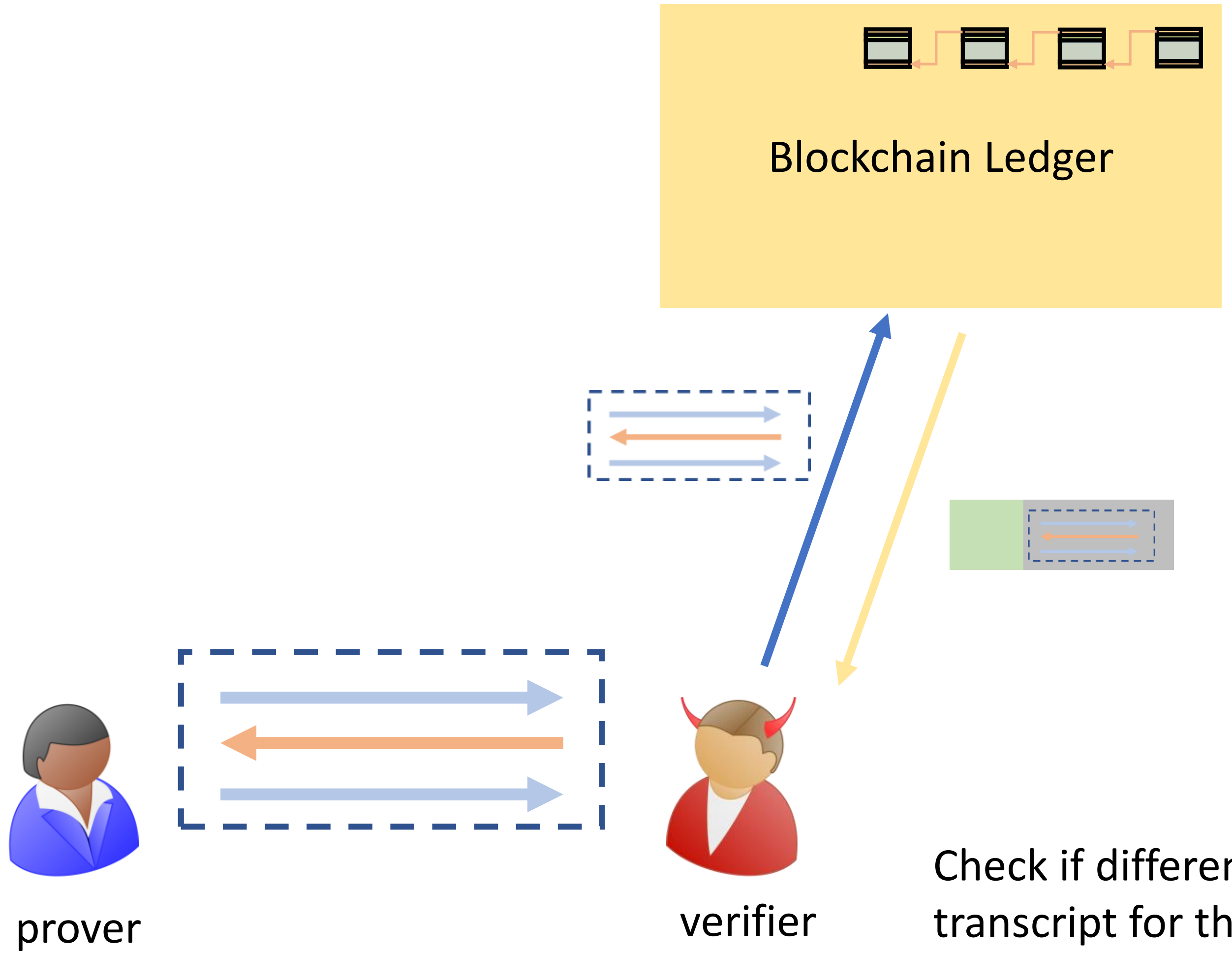

Check if different transcript for the same session.

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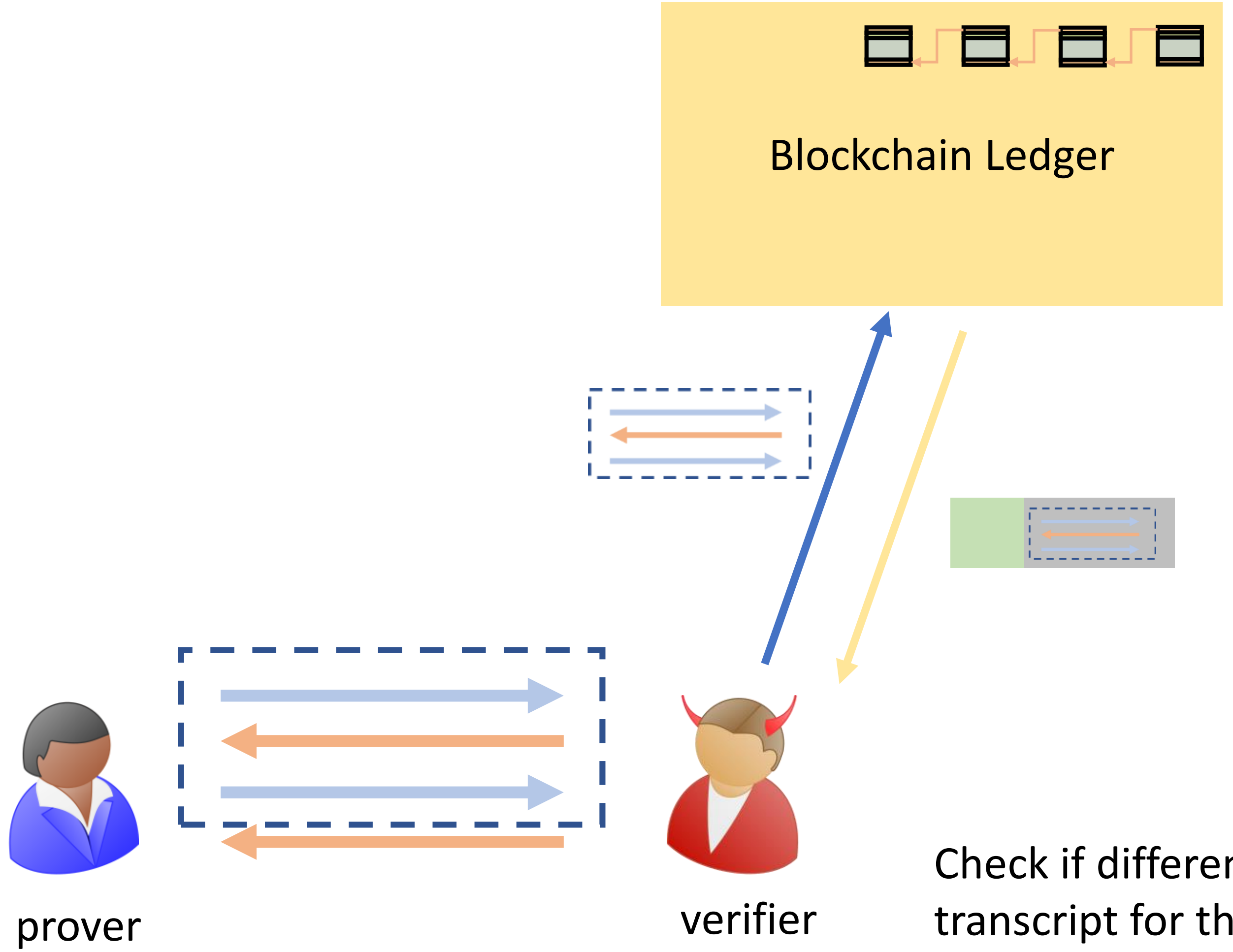

Check if different transcript for the same session.

Achieving ZK in the Blockchain hybrid model

Impossible: Only adversary is blockchain active

Achieving ZK in the Blockchain hybrid model

Impossible: Only adversary is blockchain active

Positive result: All parties are blockchain active

Structure of the Zero Knowledge Protocol

[Prabhakaran-Rosen-Sahai 02]

Structure of the Zero Knowledge Protocol

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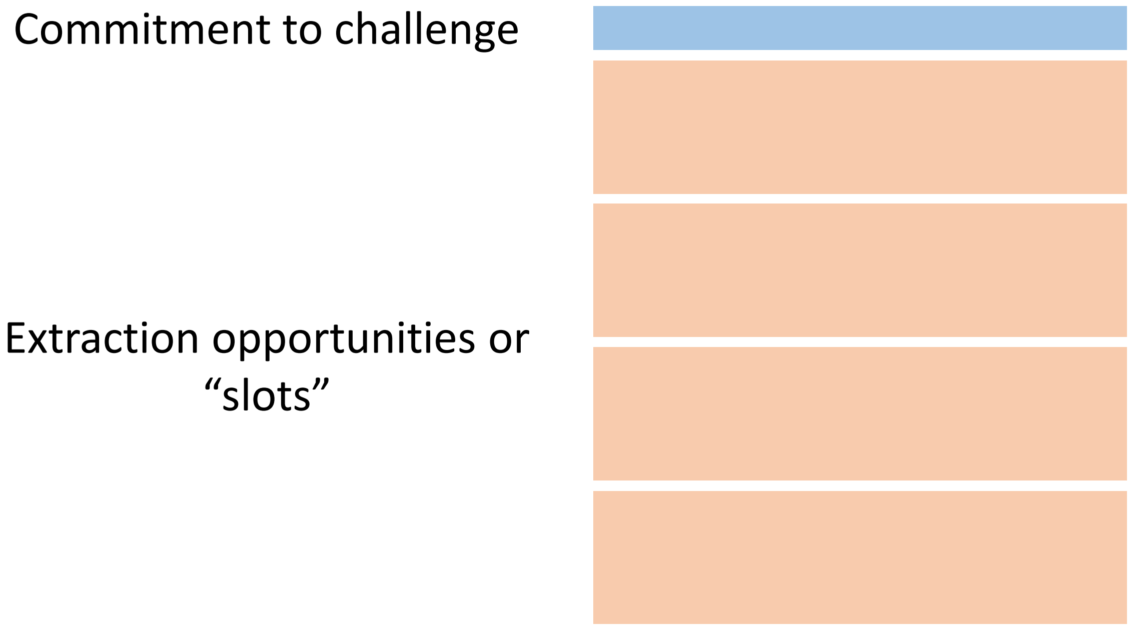
Commitment to challenge

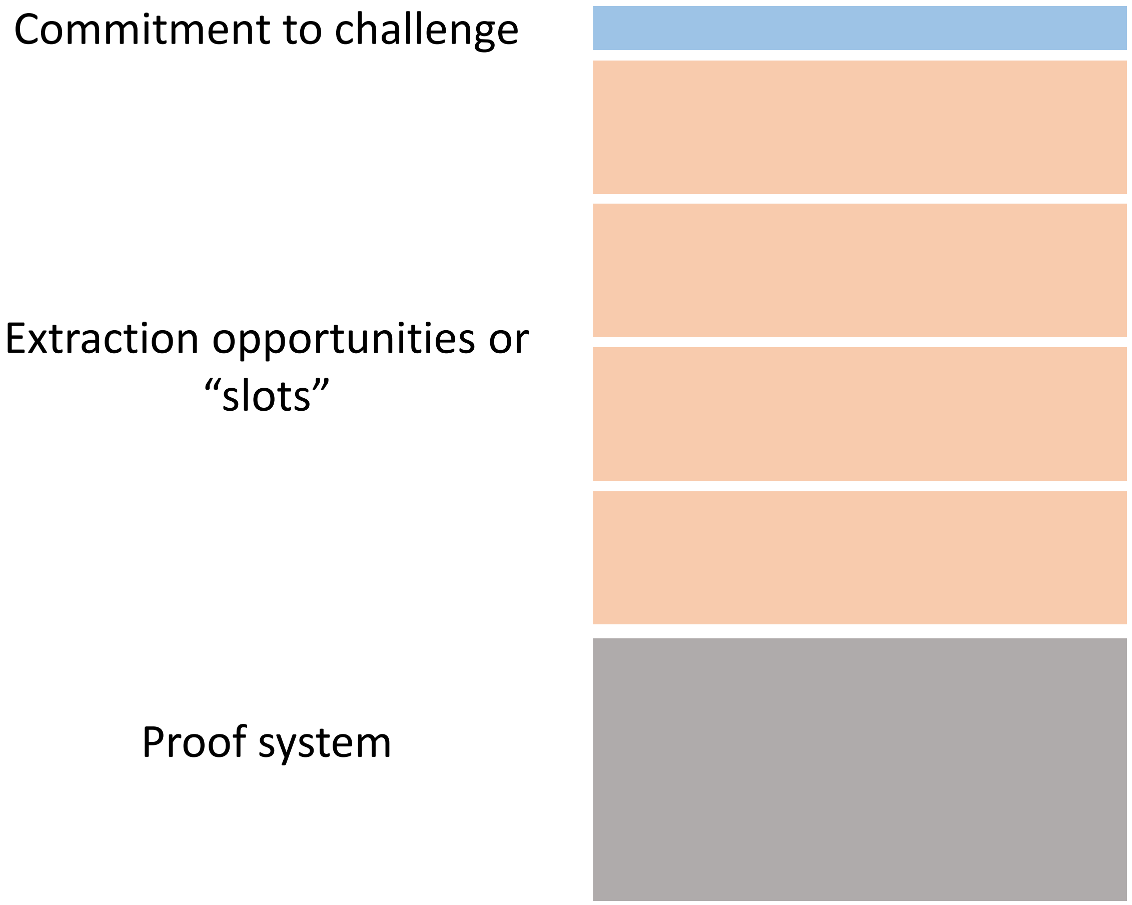
Structure of the Zero Knowledge Protocol

[Prabhakaran-Rosen-Sahai 02]



Structure of the Zero Knowledge Protocol

[Prabhakaran-Rosen-Sahai 02]



Commitment to challenge

Extraction opportunities or “slots”

Proof system

Structure of the Zero Knowledge Protocol

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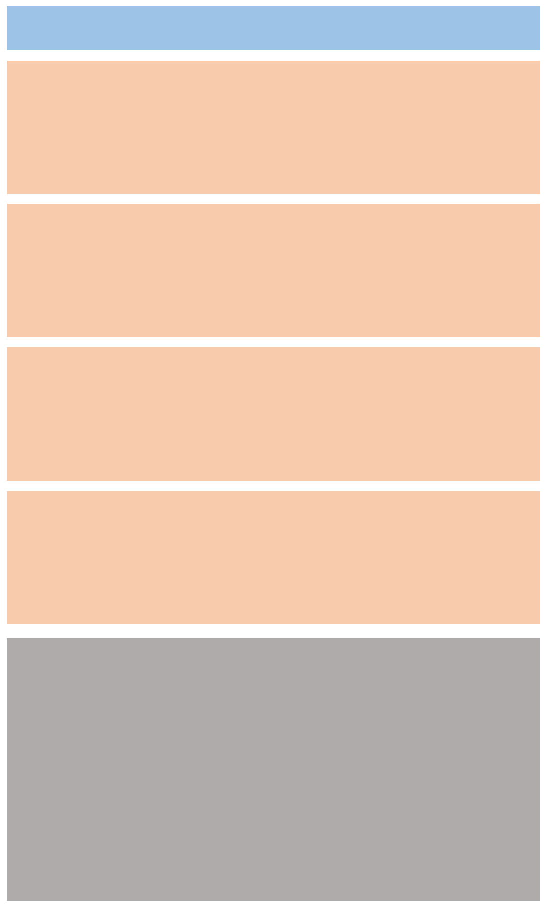

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E.g. Hamiltonicity Proof System

Structure of the Zero Knowledge Protocol

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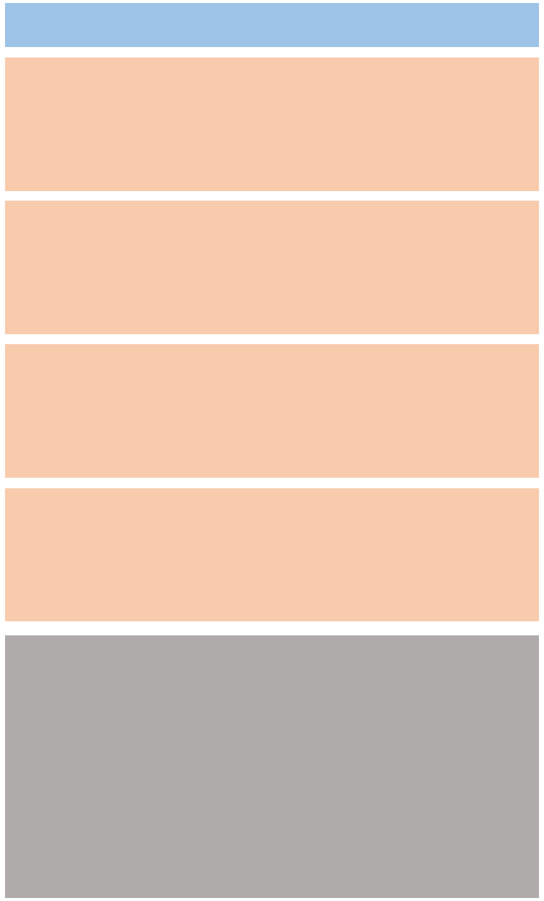


Commitment to challenge

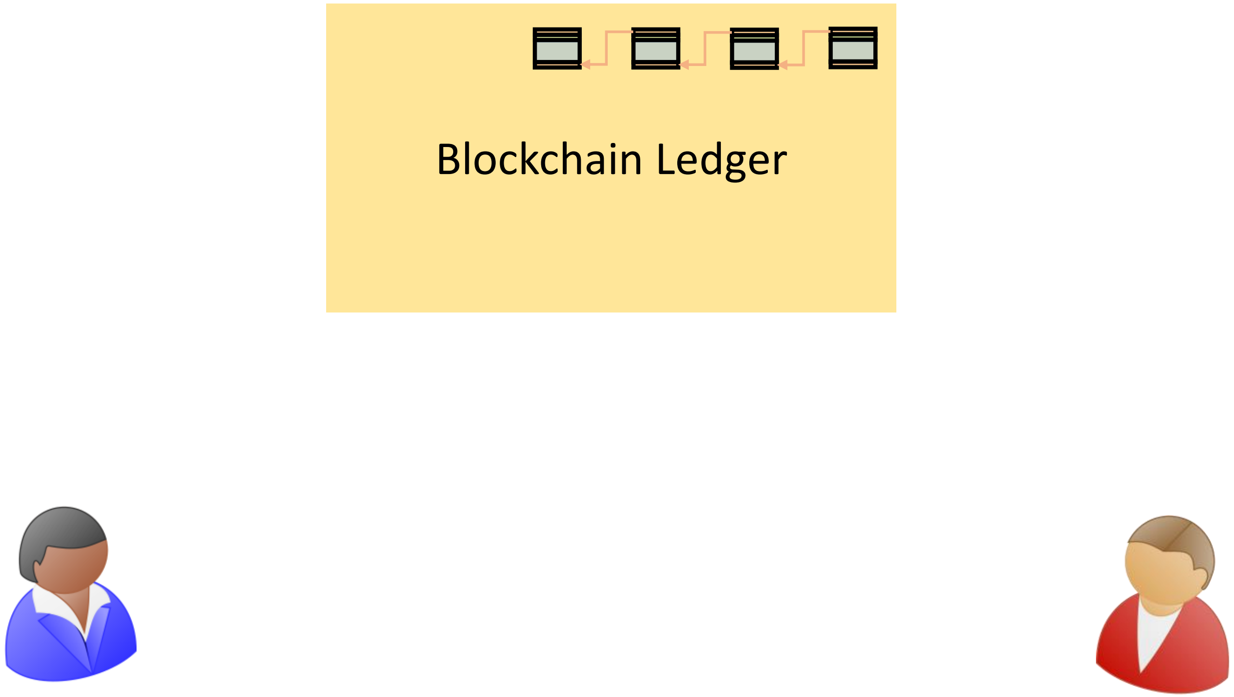
Extraction opportunities or "slots"

Proof system

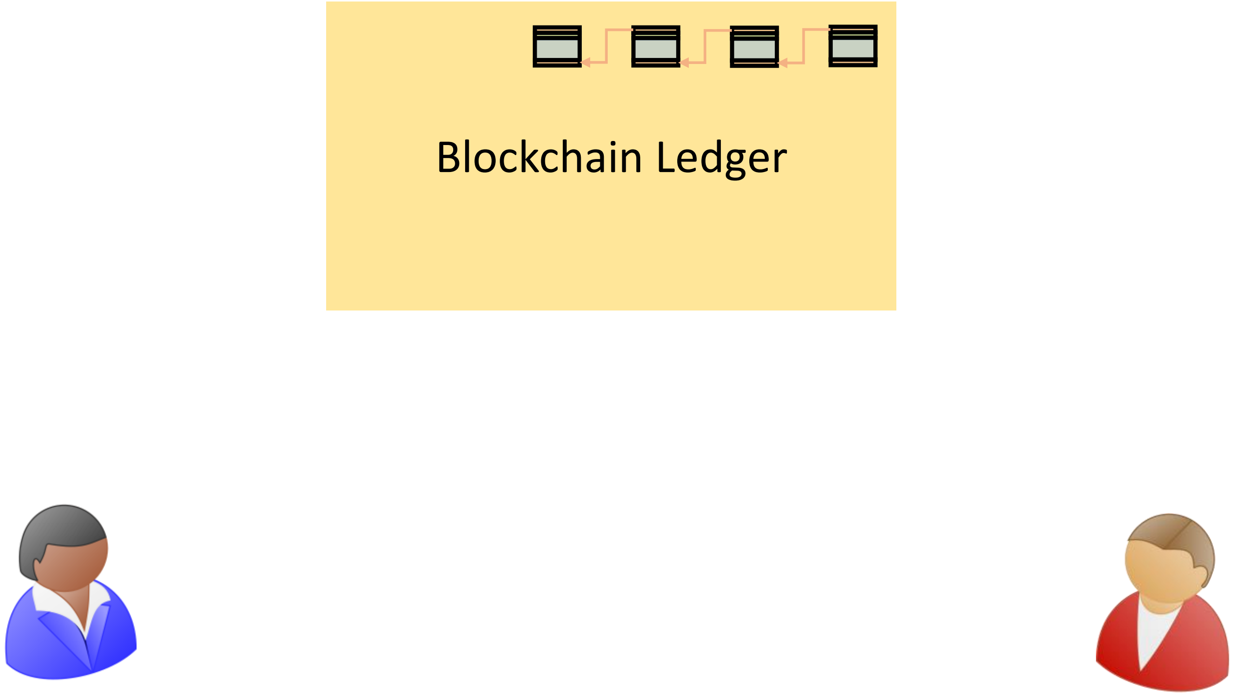
E.g. Hamiltonicity Proof System

Simulation Guarantee:

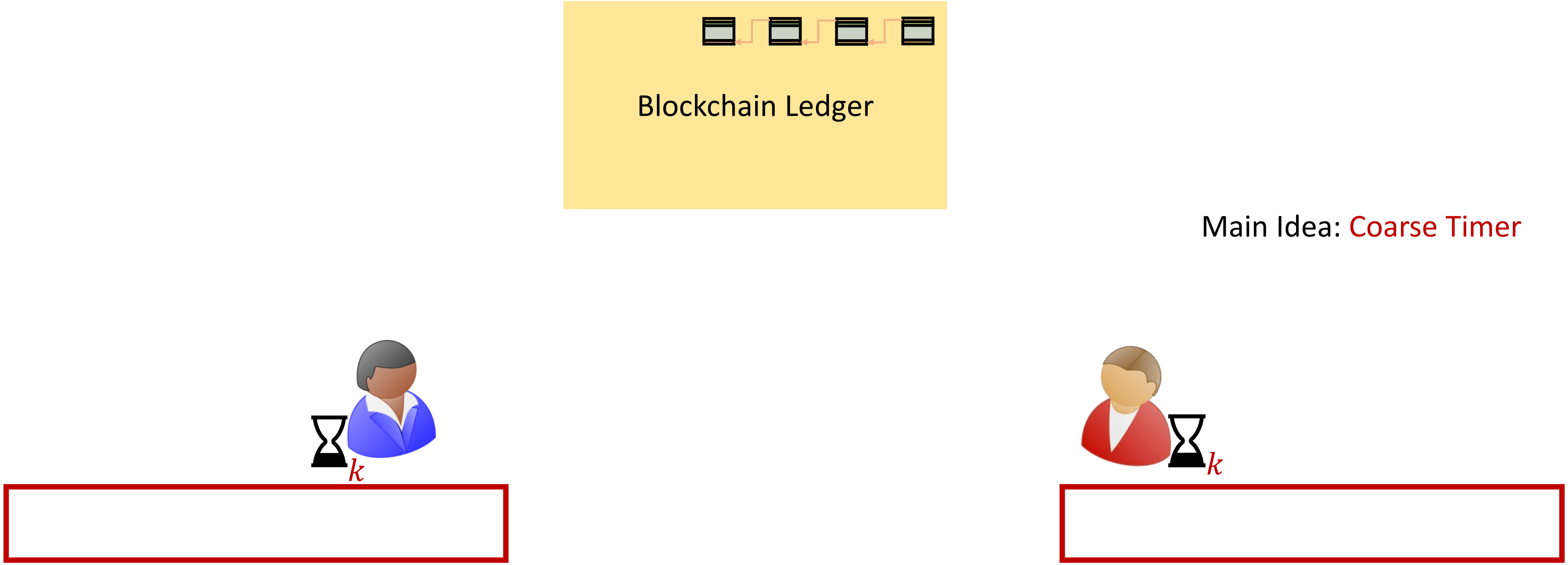
If extraction succeeds in one of the slots, the simulation can be performed in a simple manner without rewinding.



Blockchain Ledger



Main Idea: Coarse Timer



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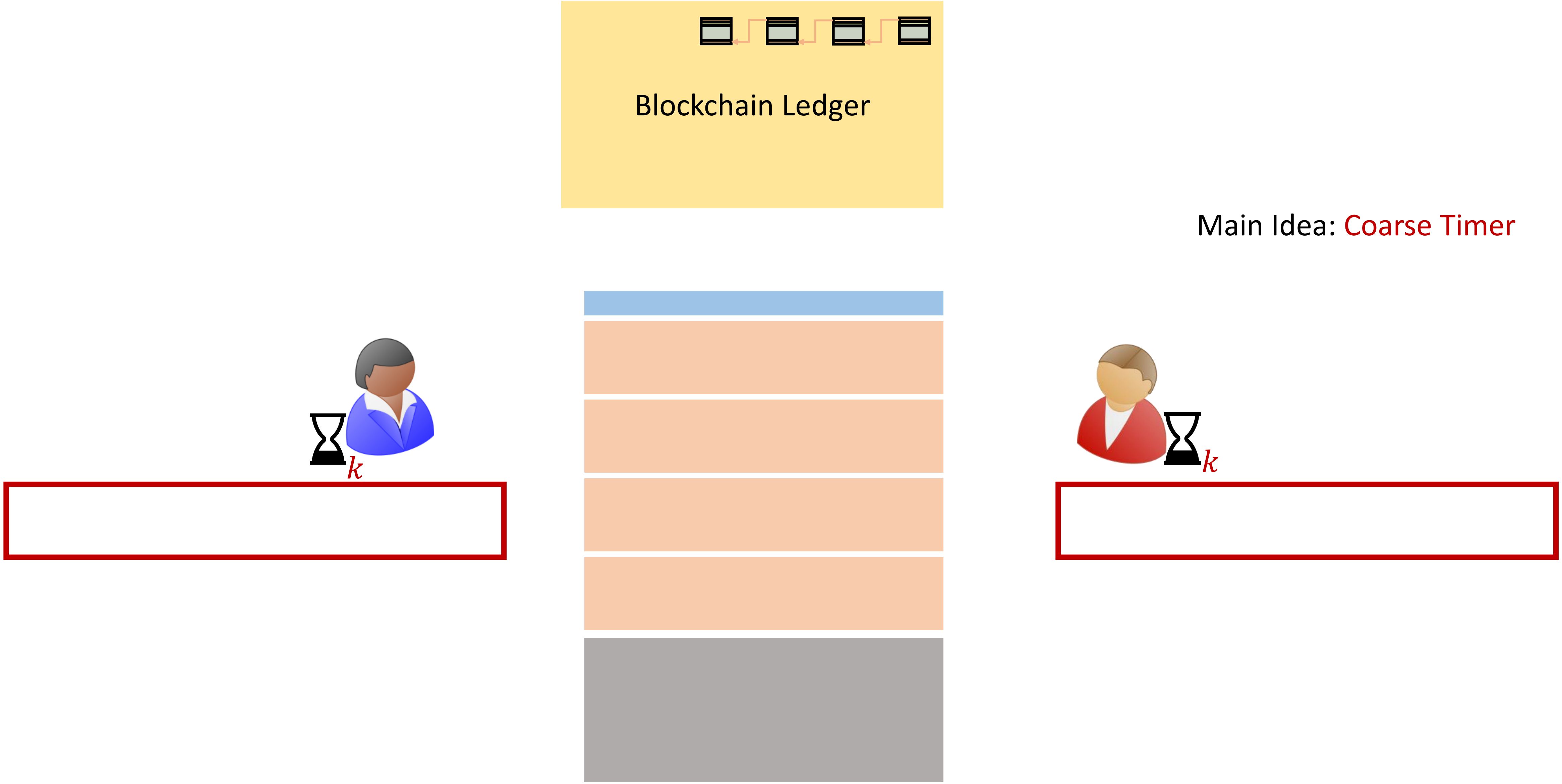

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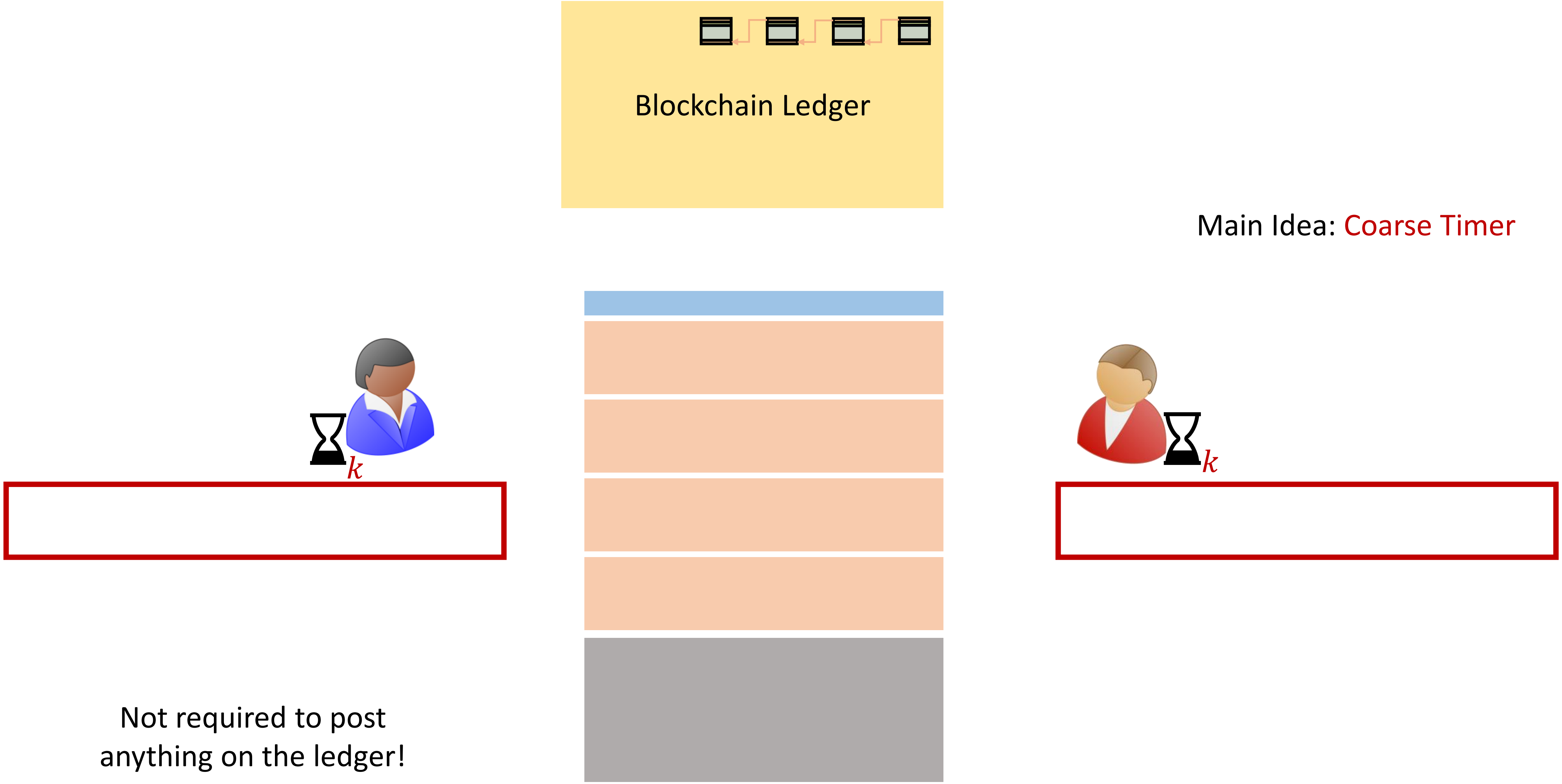
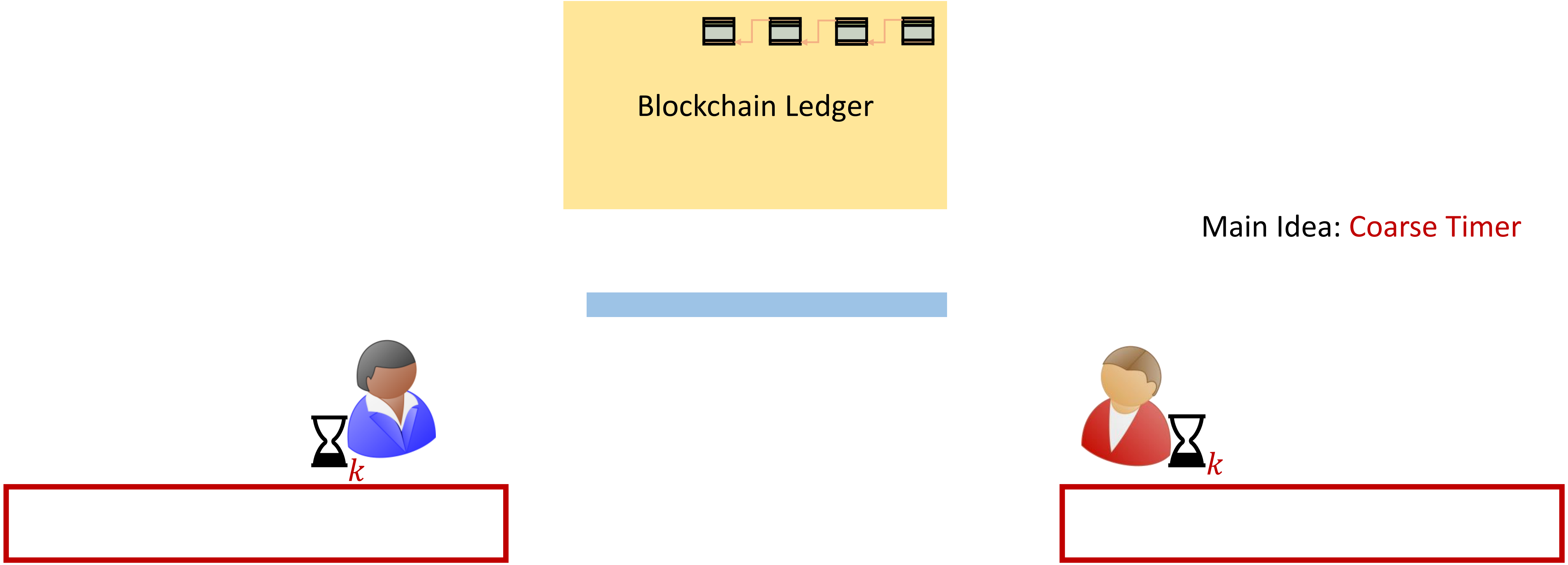


Not required to post
anything on the ledger!



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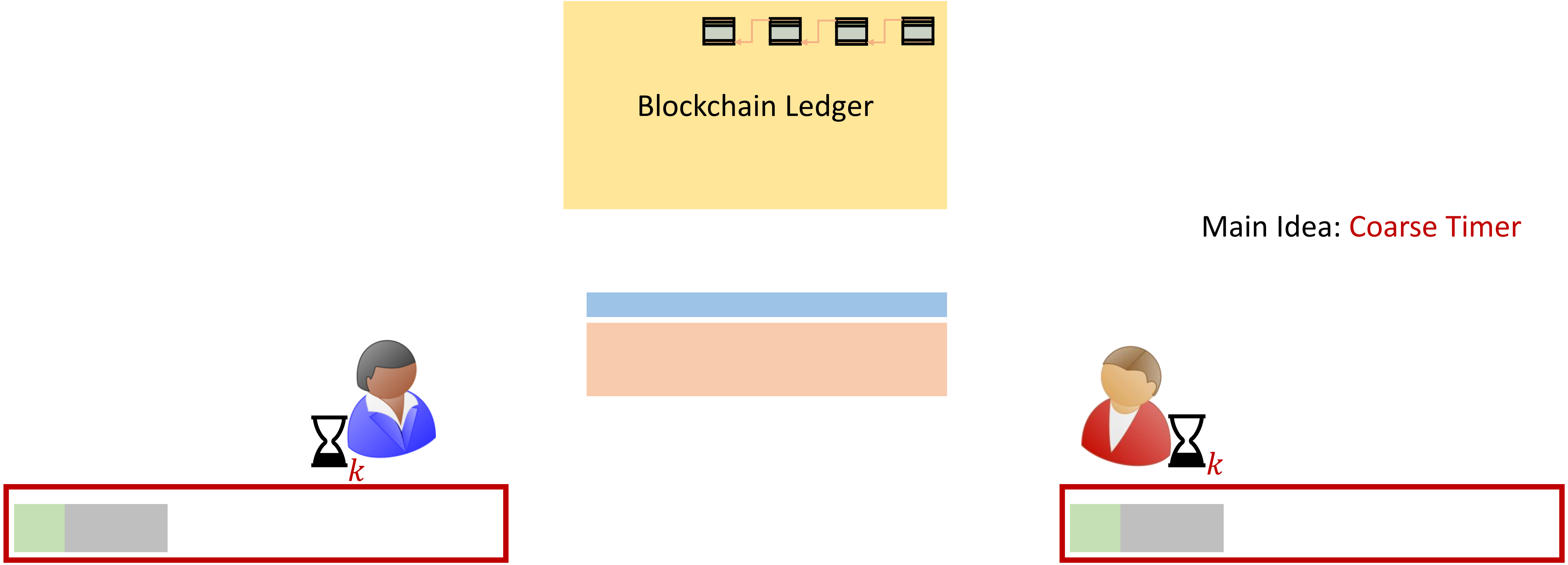

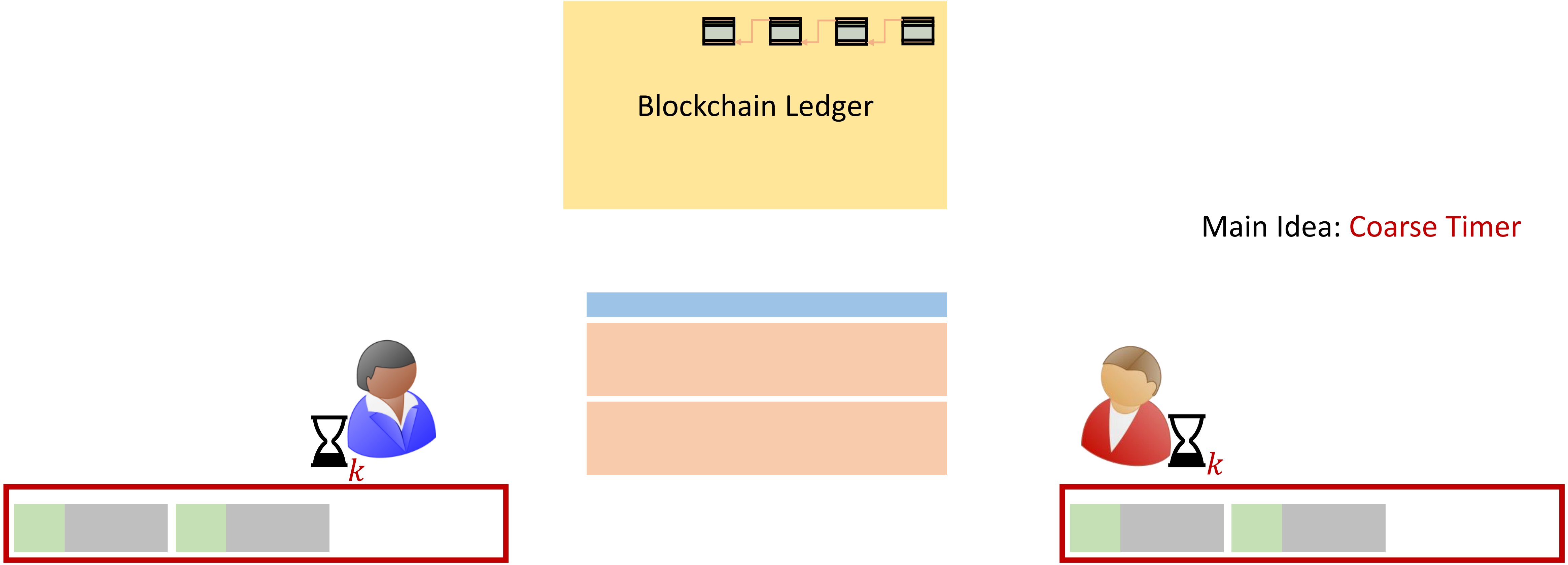

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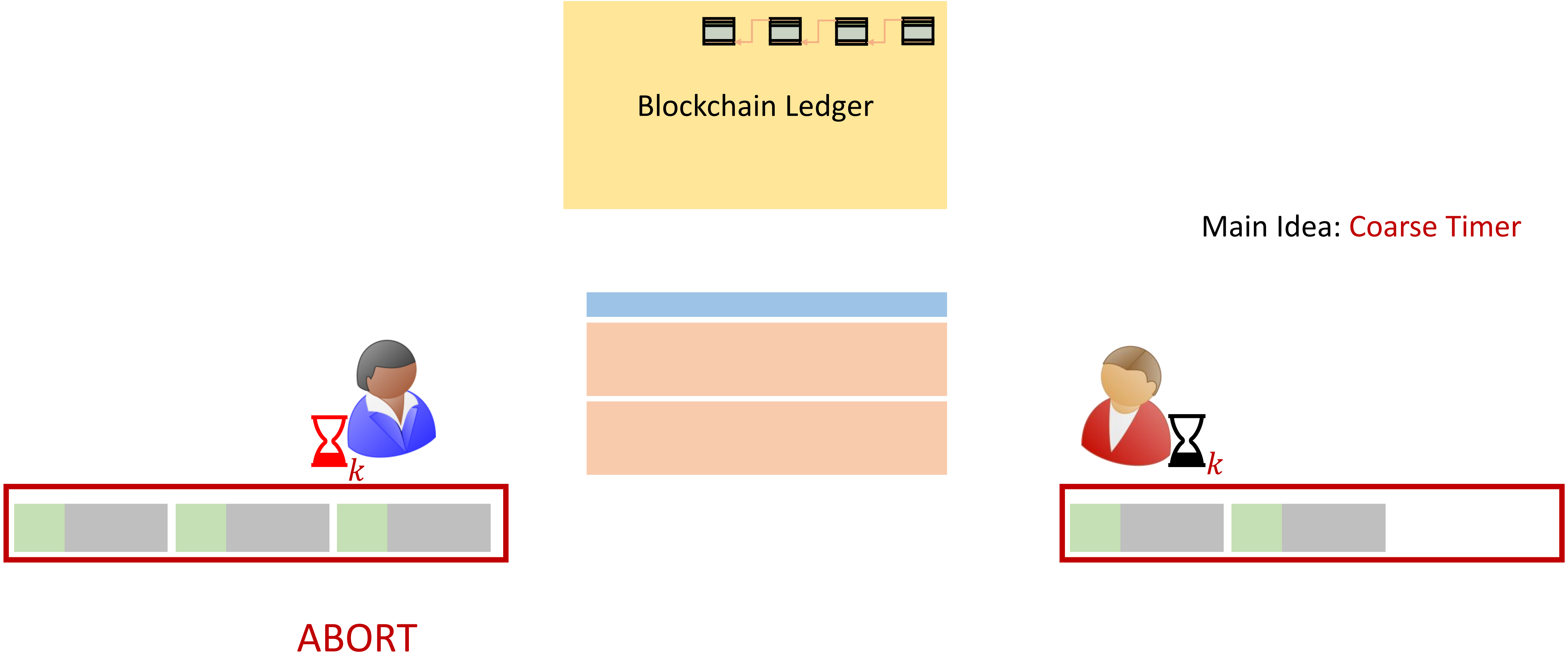

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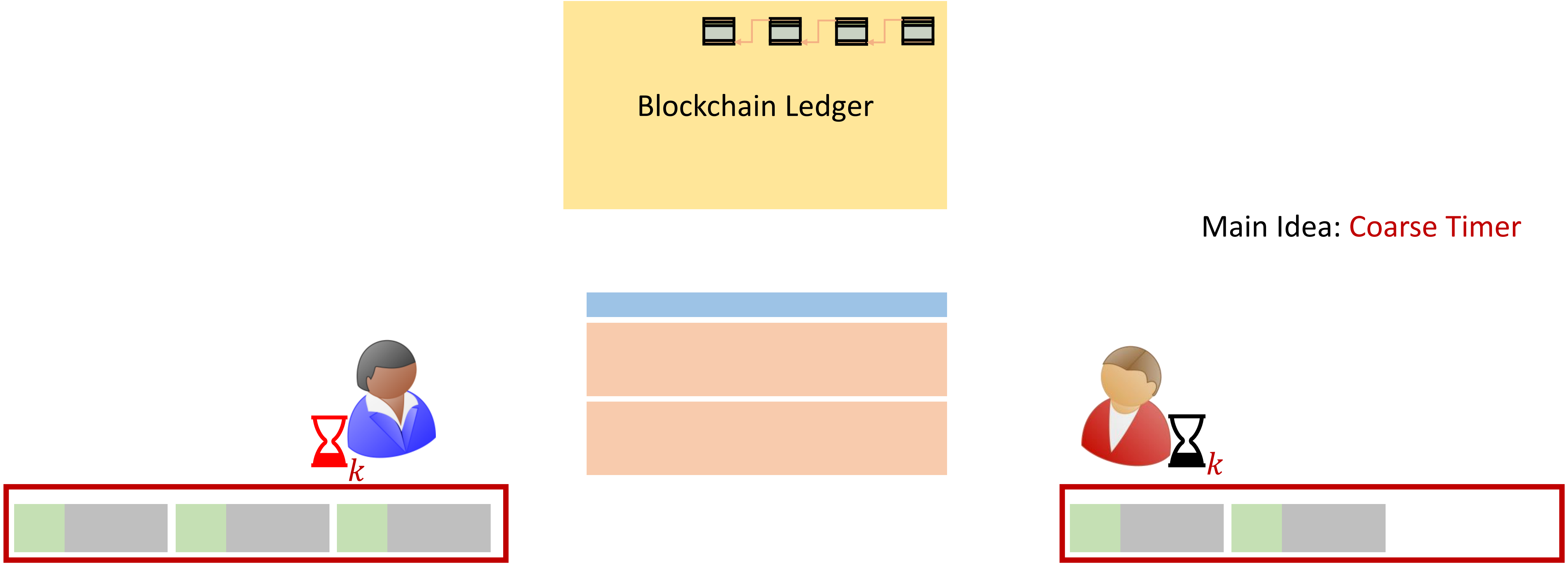
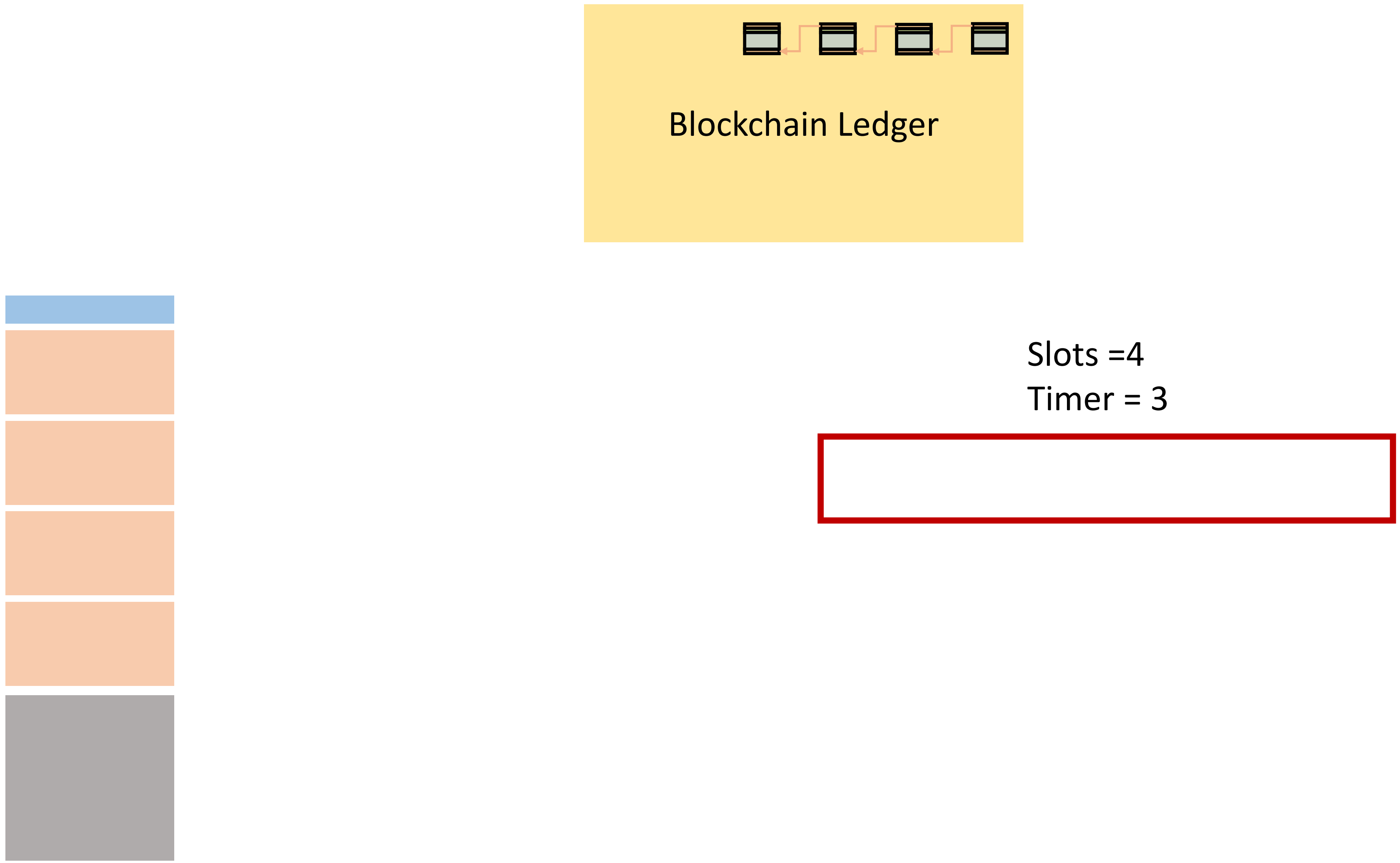


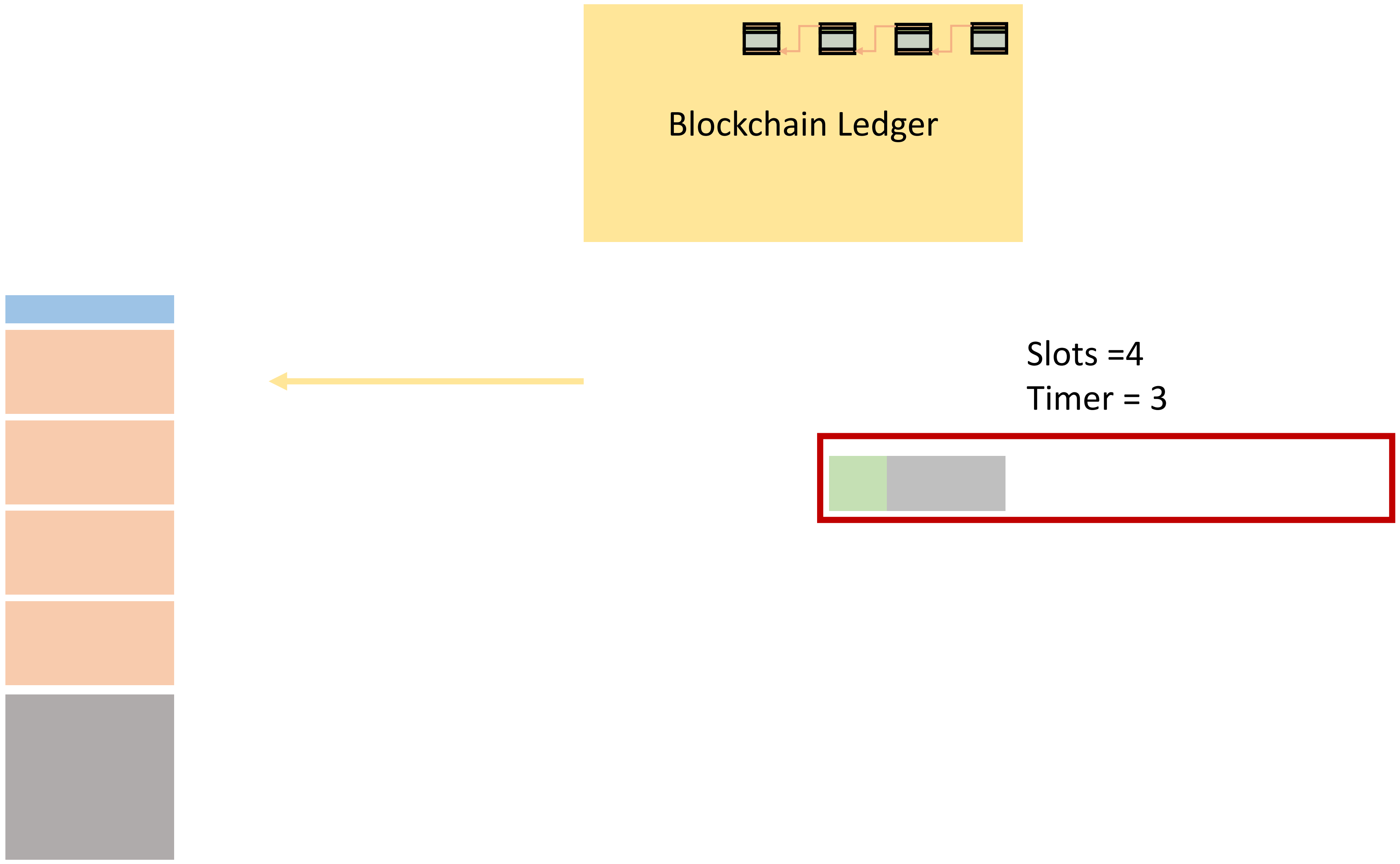
ABORT

Why is this helpful?



Blockchain Ledger

Slots =4
Timer = 3



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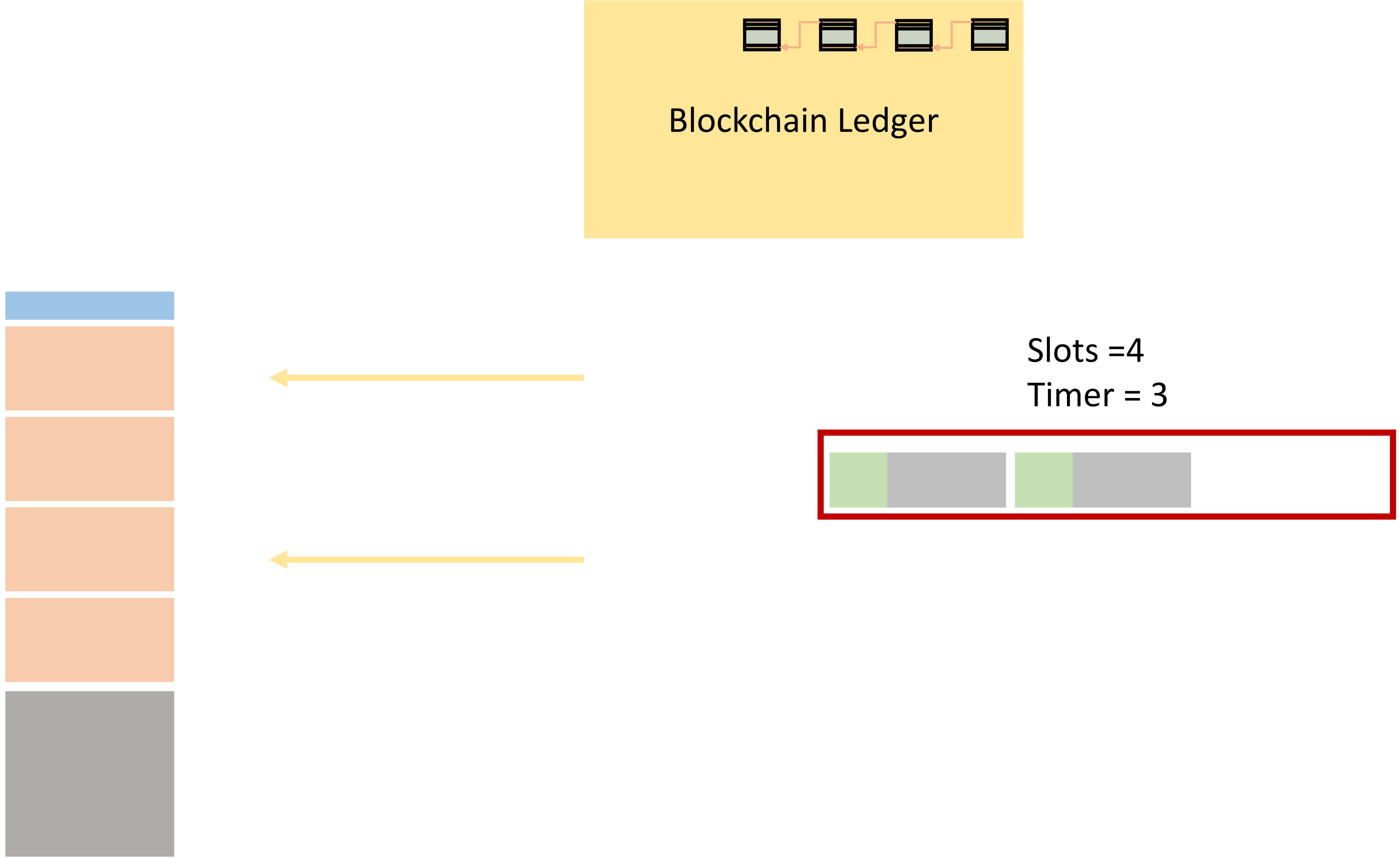

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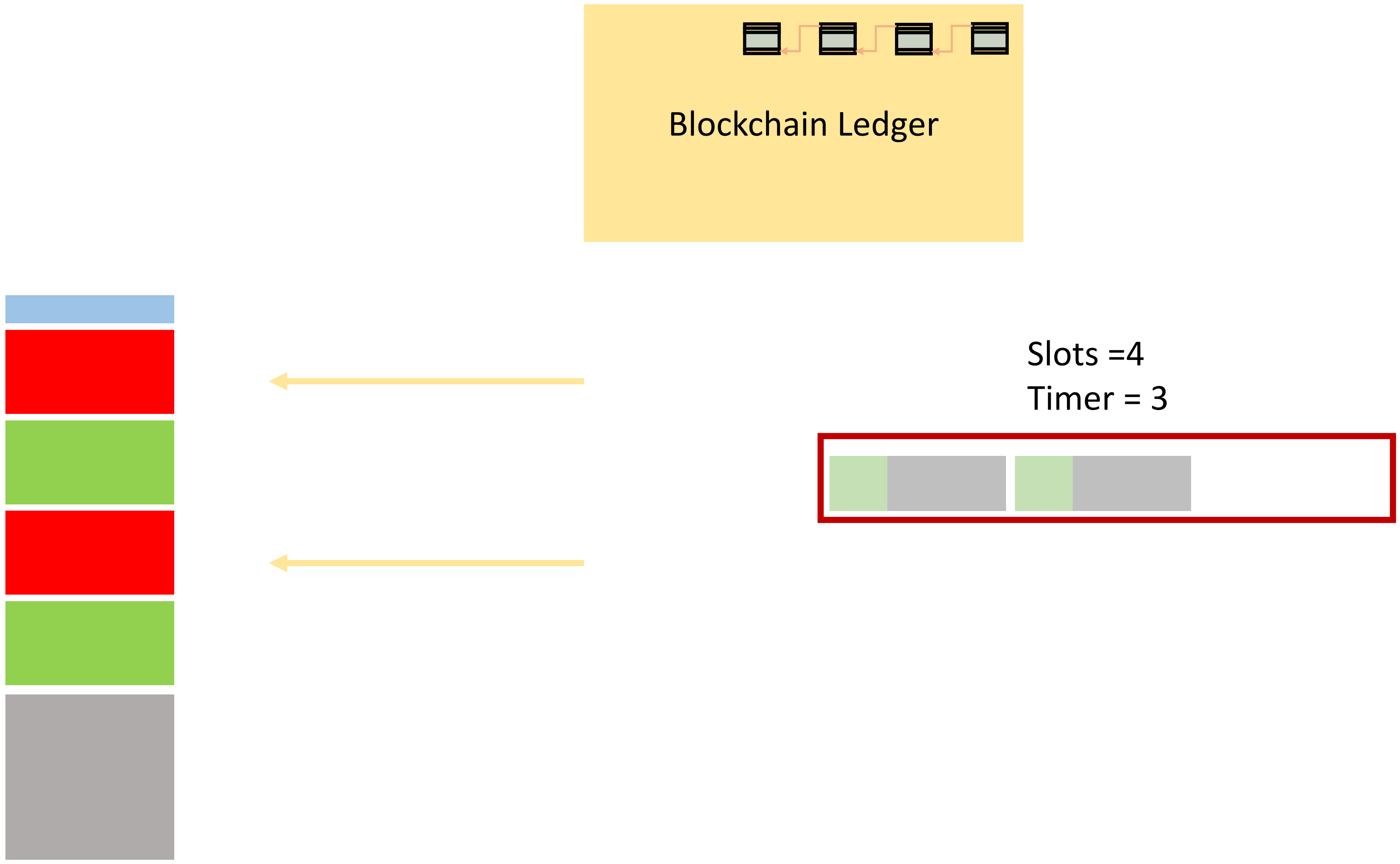

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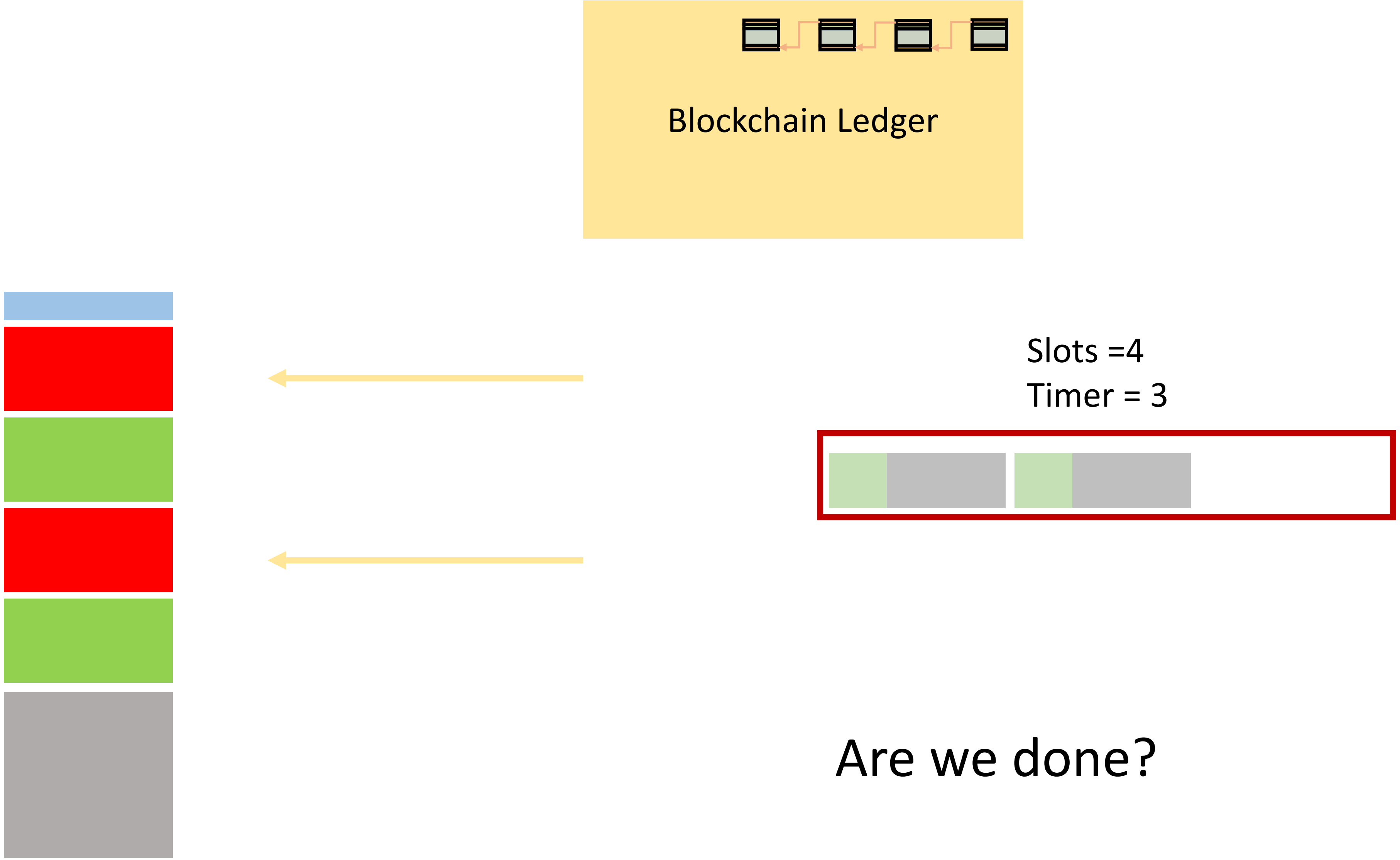

Blockchain Ledger

Slots =4
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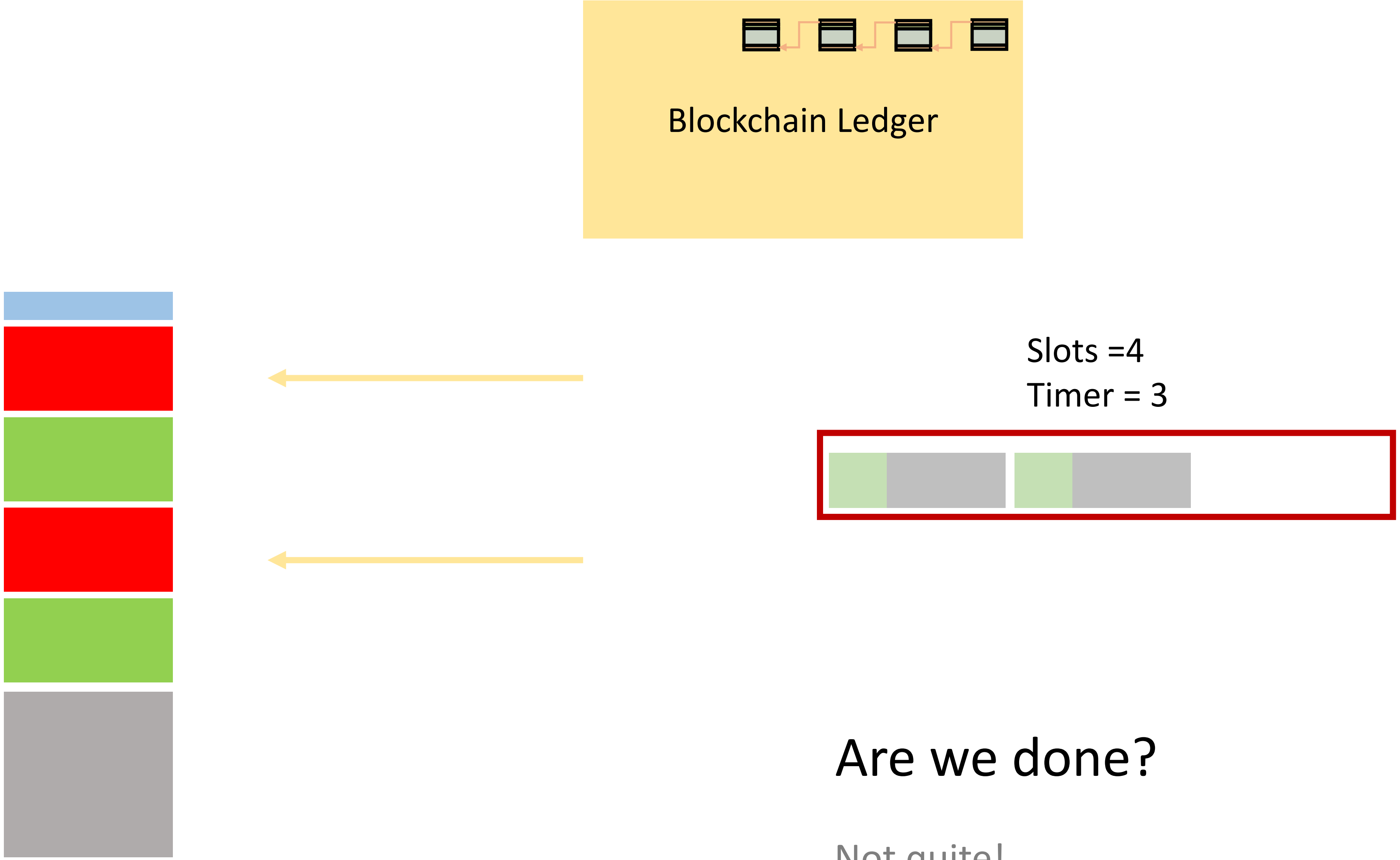
Are we done?



Are we done?

Not quite!

Challenge: Timing Leakage

Running time of the simulator larger than running time of adversary.

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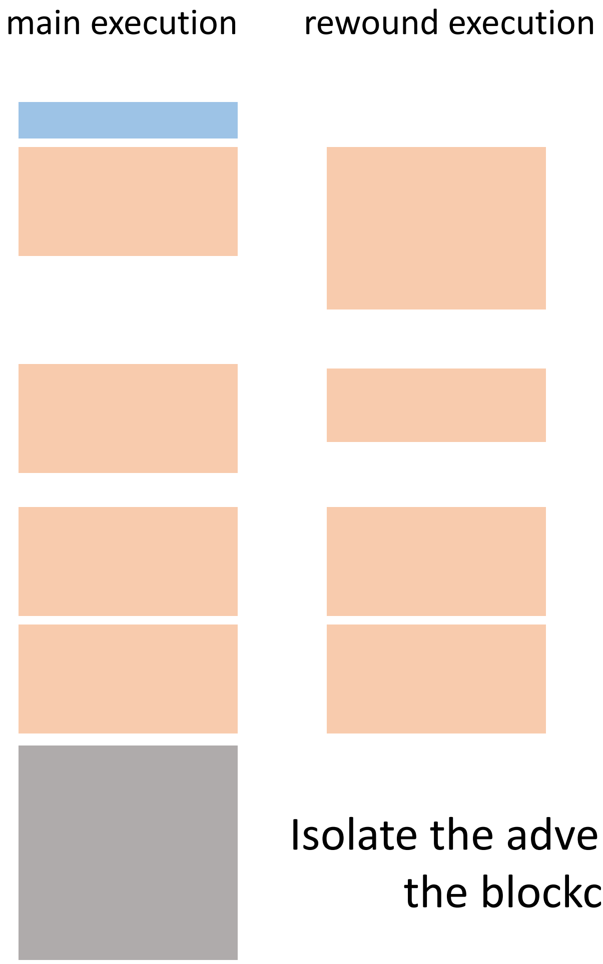
Running time of the simulator larger than running time of adversary.

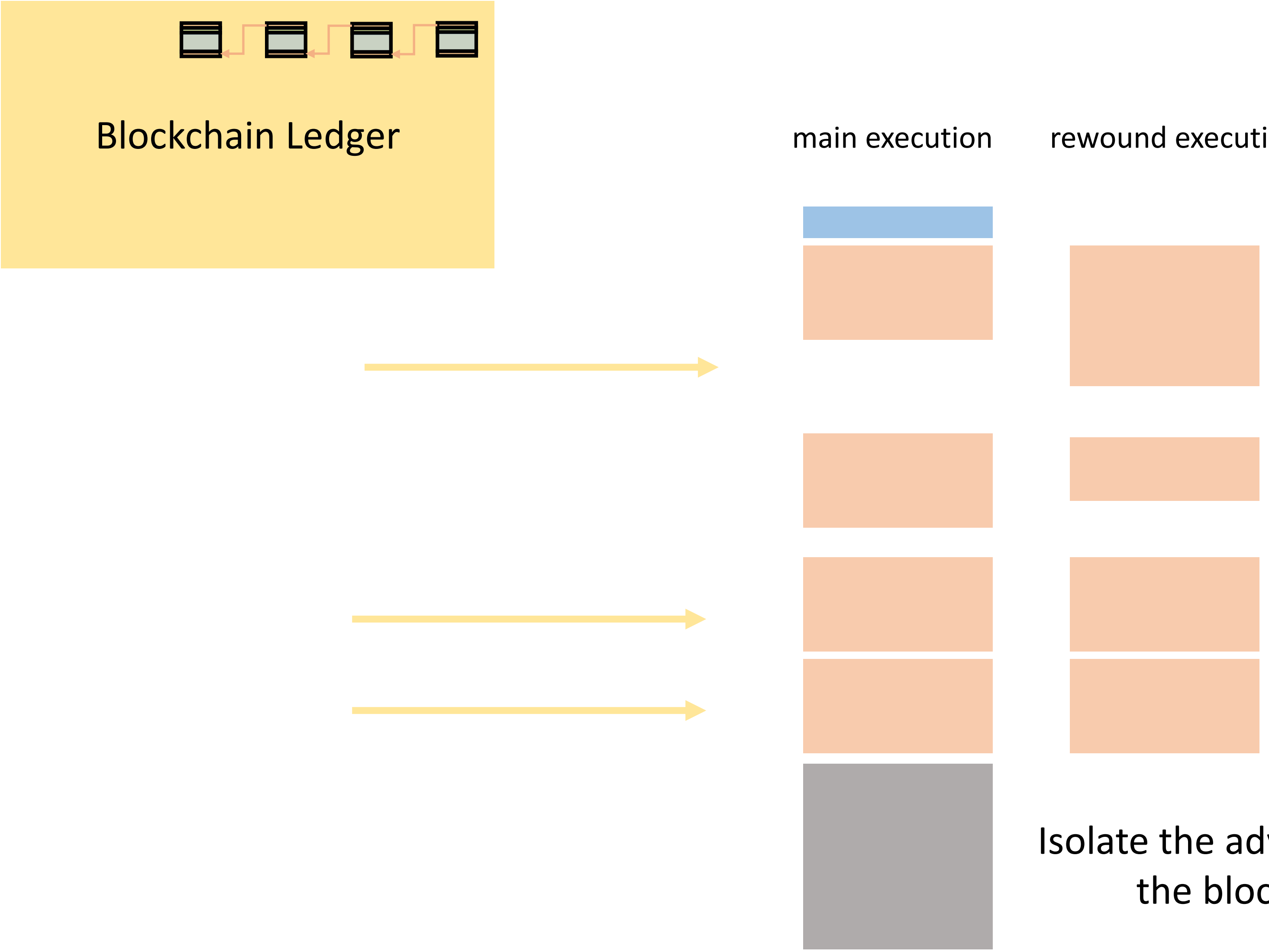
Time that the simulator takes to complete v/s number of computational steps.

Simulate in parallel



Isolate the adversary from the blockchain

Simulate in parallel



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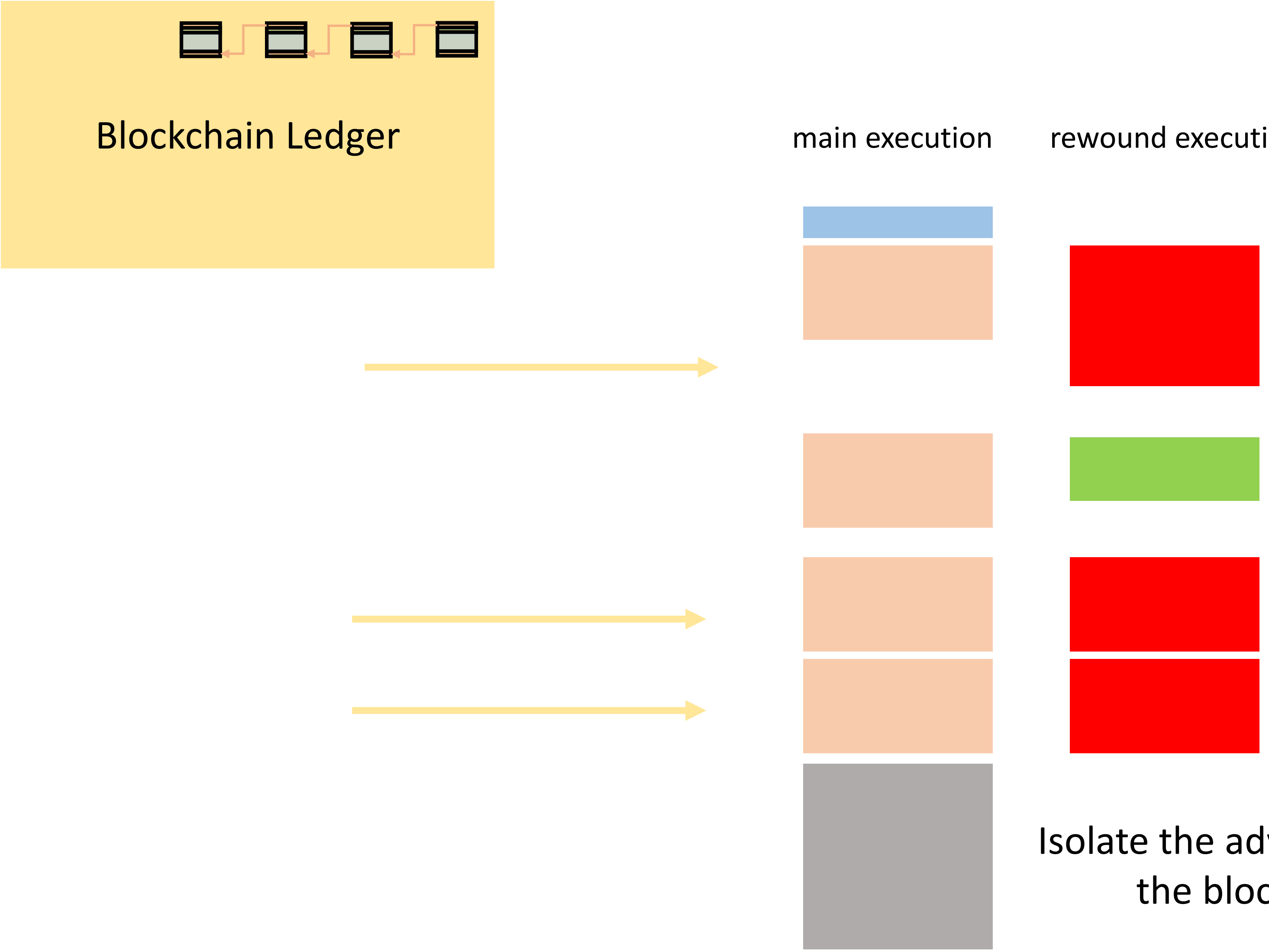
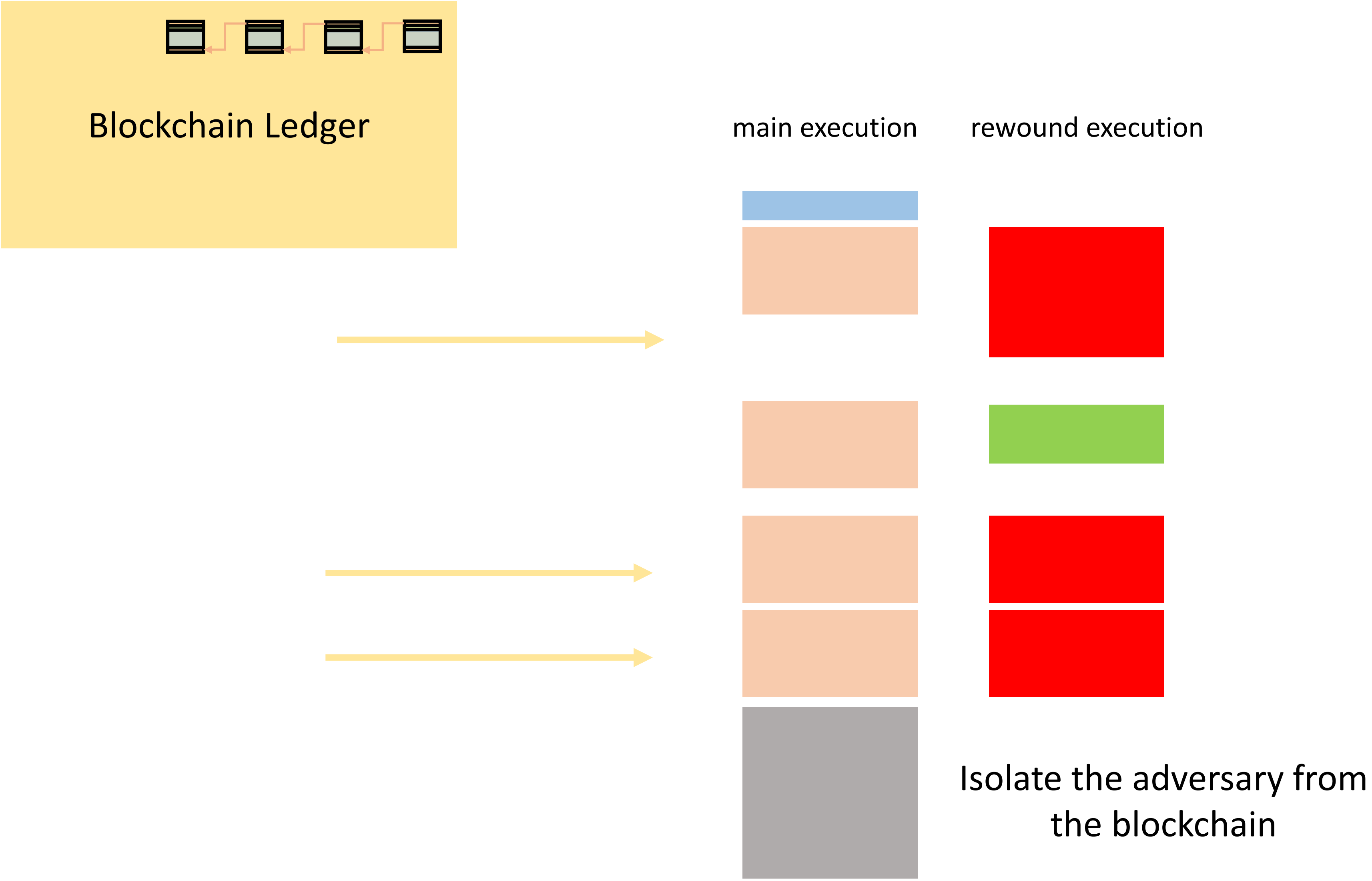


Isolate the adversary from the blockchain

Simulate in parallel



Blockchain Ledger

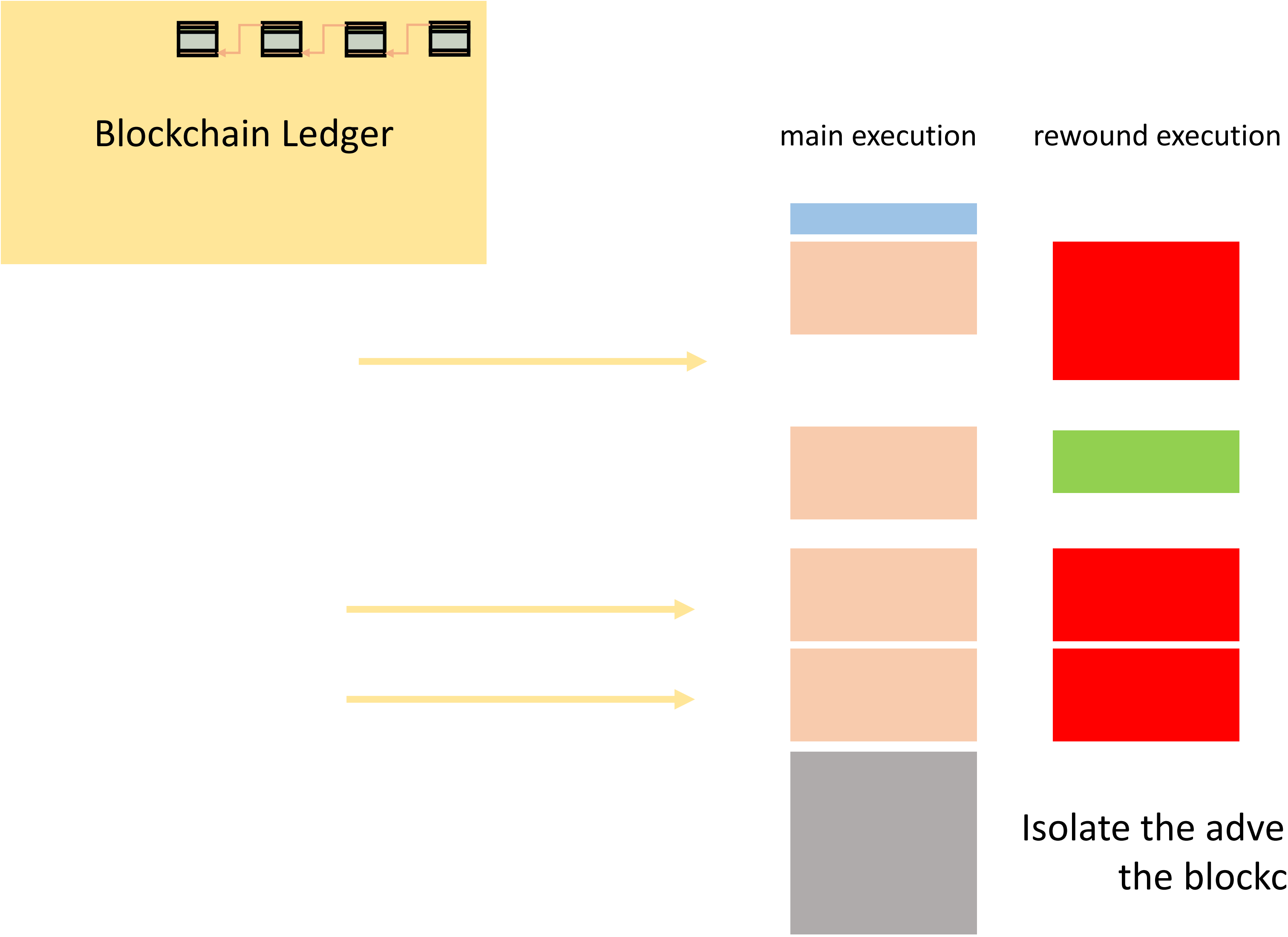
main execution

rewound execution

Isolate the adversary from the blockchain

For extraction to succeed, we need $\omega(1)$ slots.

Simulate in parallel

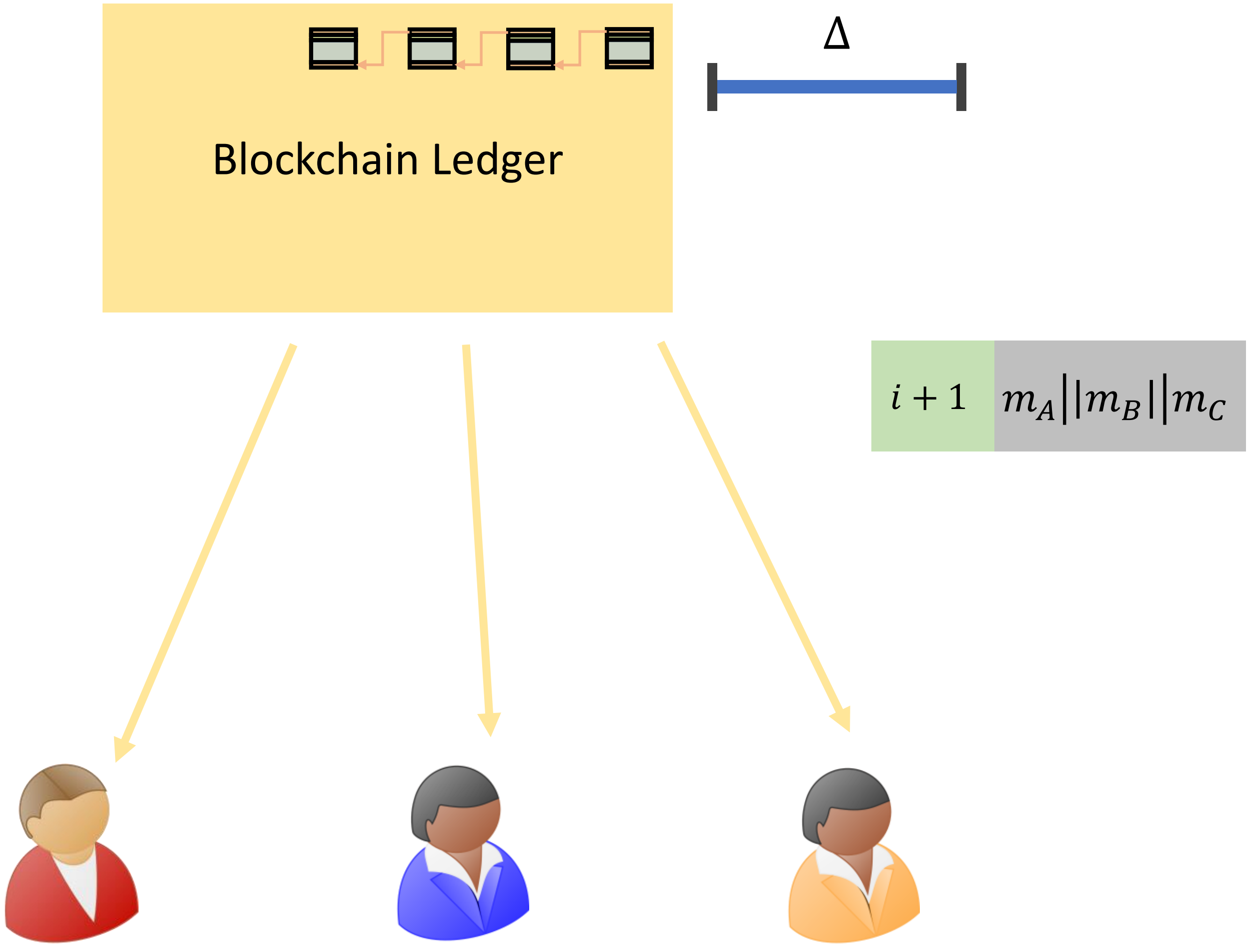


Isolate the adversary from the blockchain

For extraction to succeed, we need $\omega(1)$ slots.

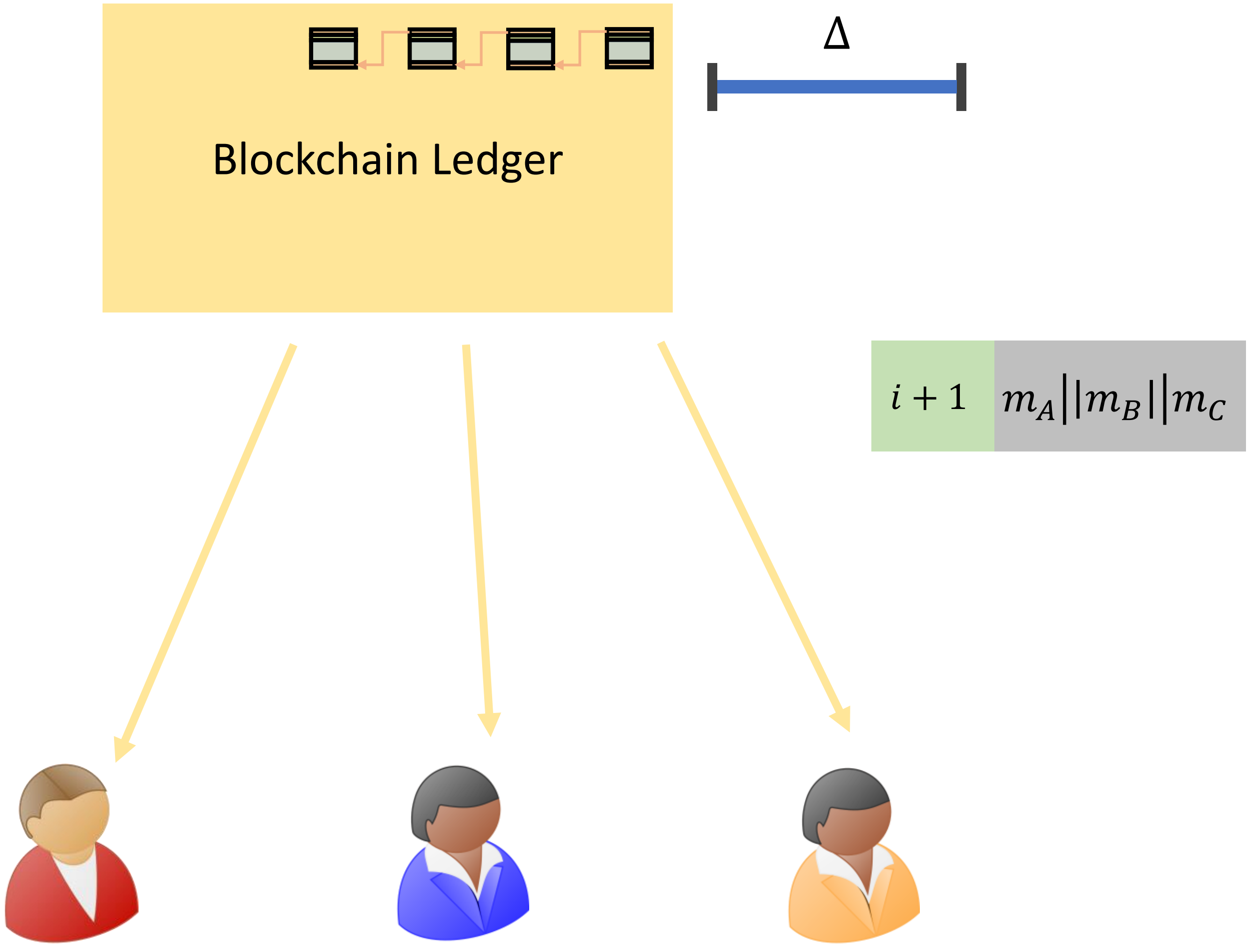
There does not exist an $O(1)$-round ZK argument in the blockchain-hybrid model with black-box simulation.

Simplified Model



Simplified Model

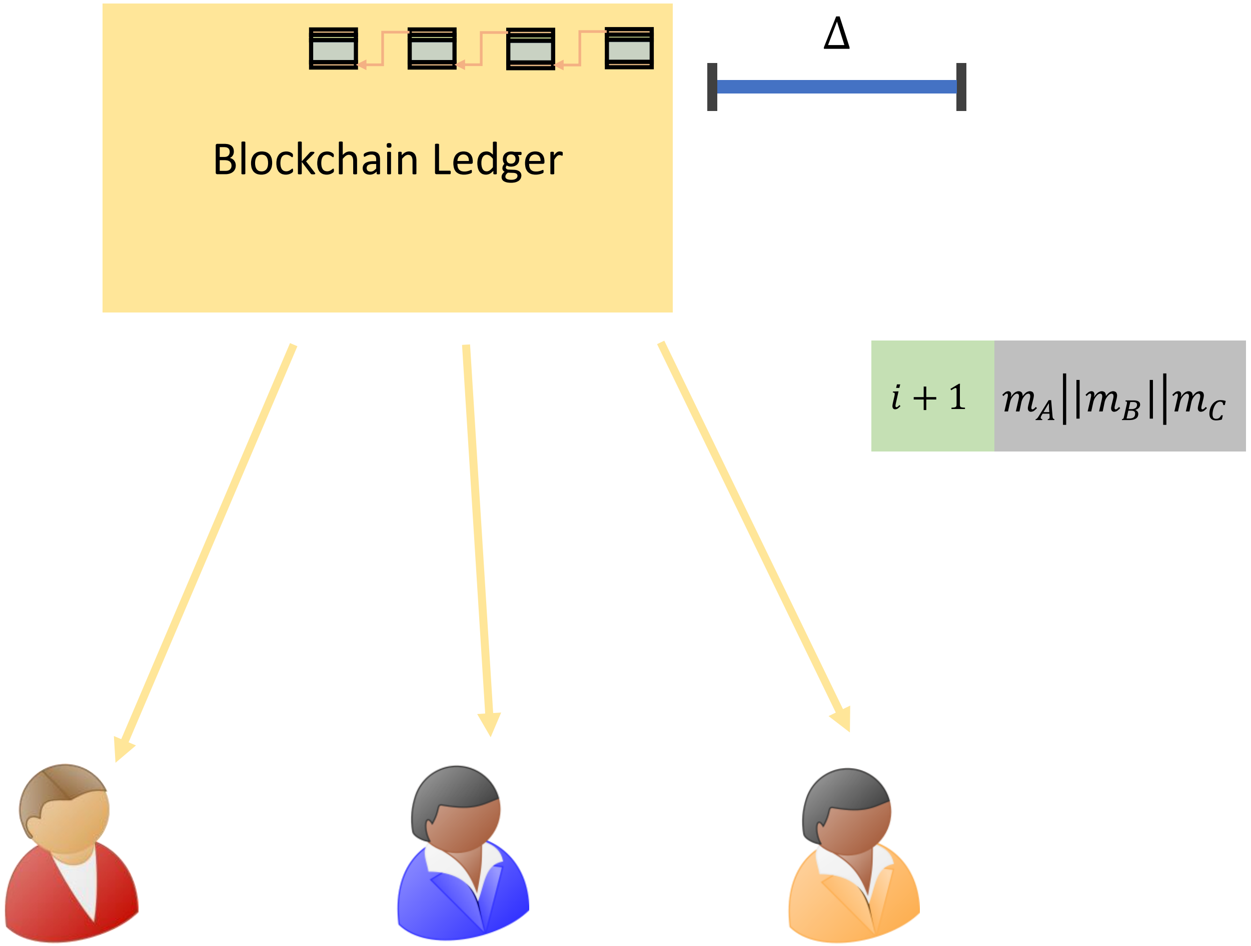
Comparison to Timing Model



Simplified Model

Comparison to Timing Model

Simulator can control the clock.



Blockchain Ledger

Δ

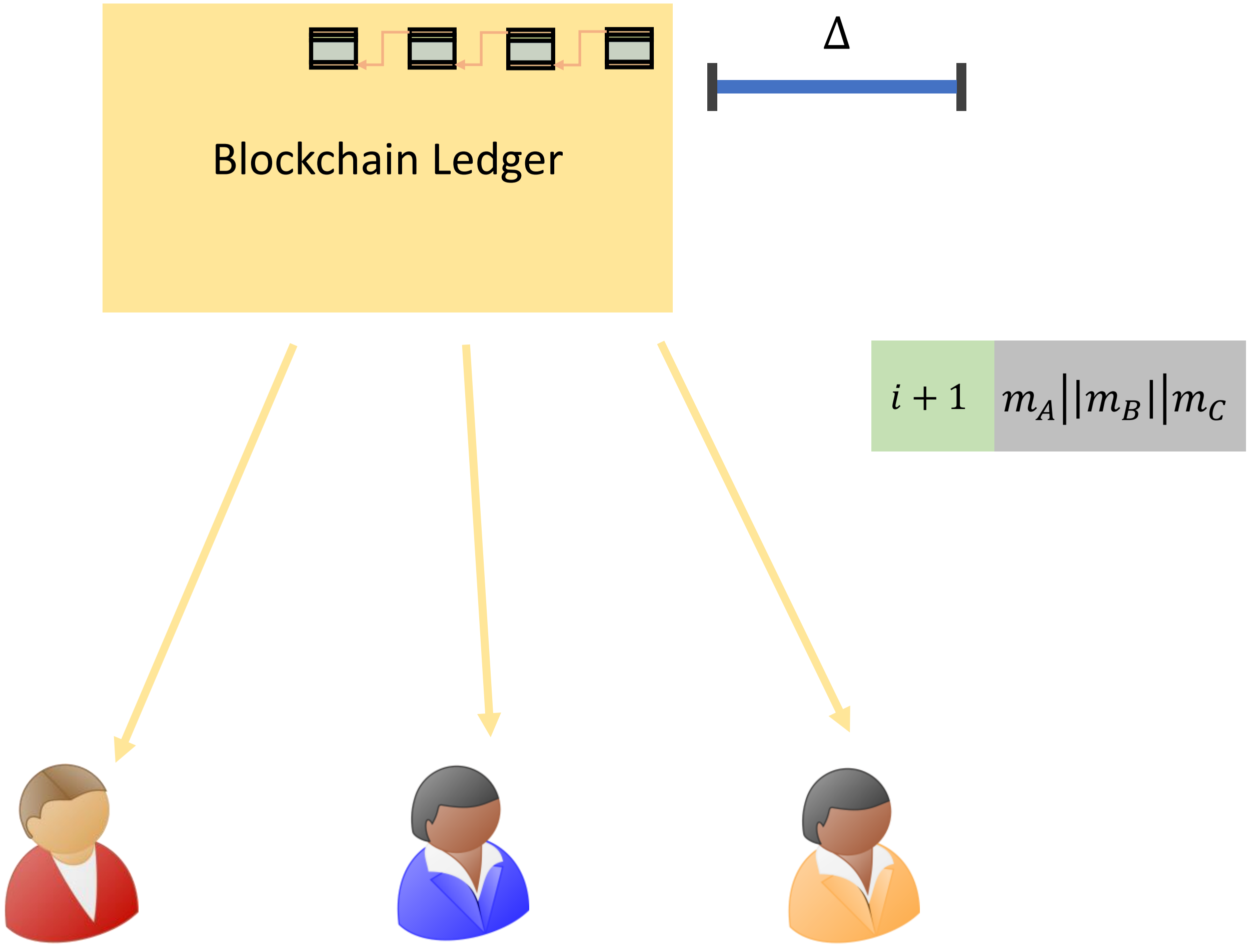
$i+1$ $m_A||m_B||m_C$

Simplified Model

Comparison to Timing Model

Simulator can control the clock.

unforgeable clock



Simplified Model

Comparison to Timing Model

Simulator can control the clock.

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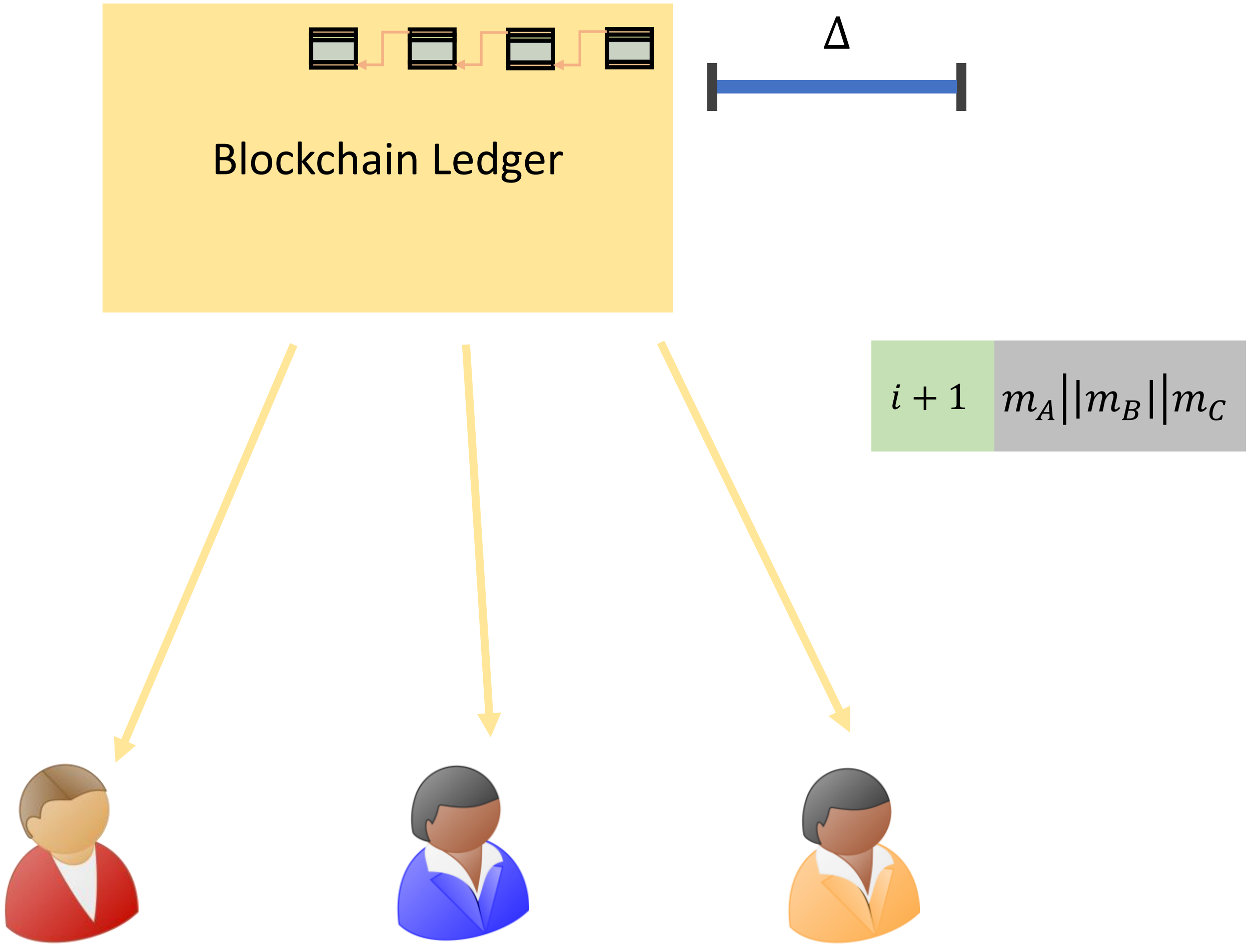
Adversary can be rewound at any point.



Simplified Model

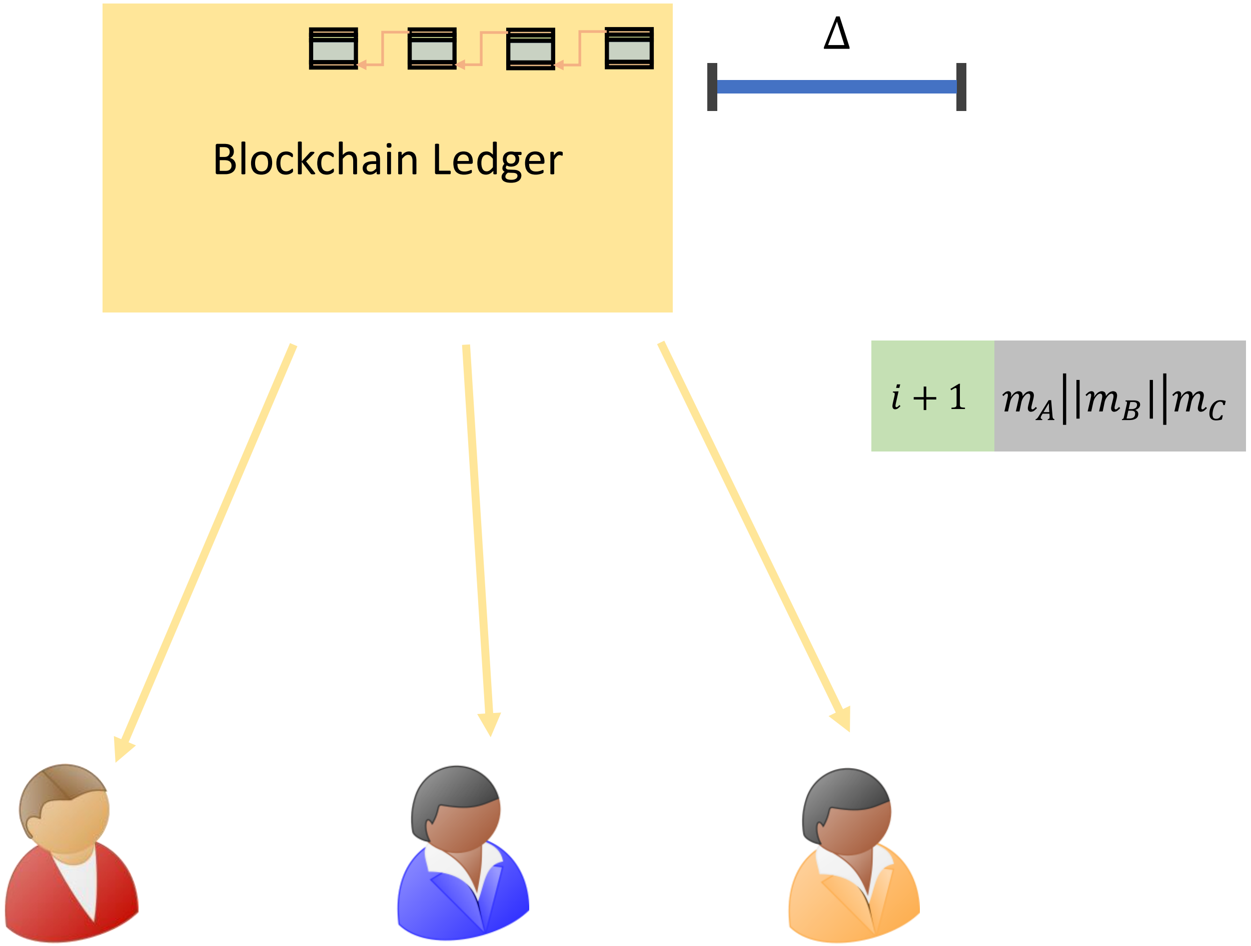
Comparison to Timing Model

Simulator can control the clock.

unforgeable clock

Adversary can be rewound at any point.

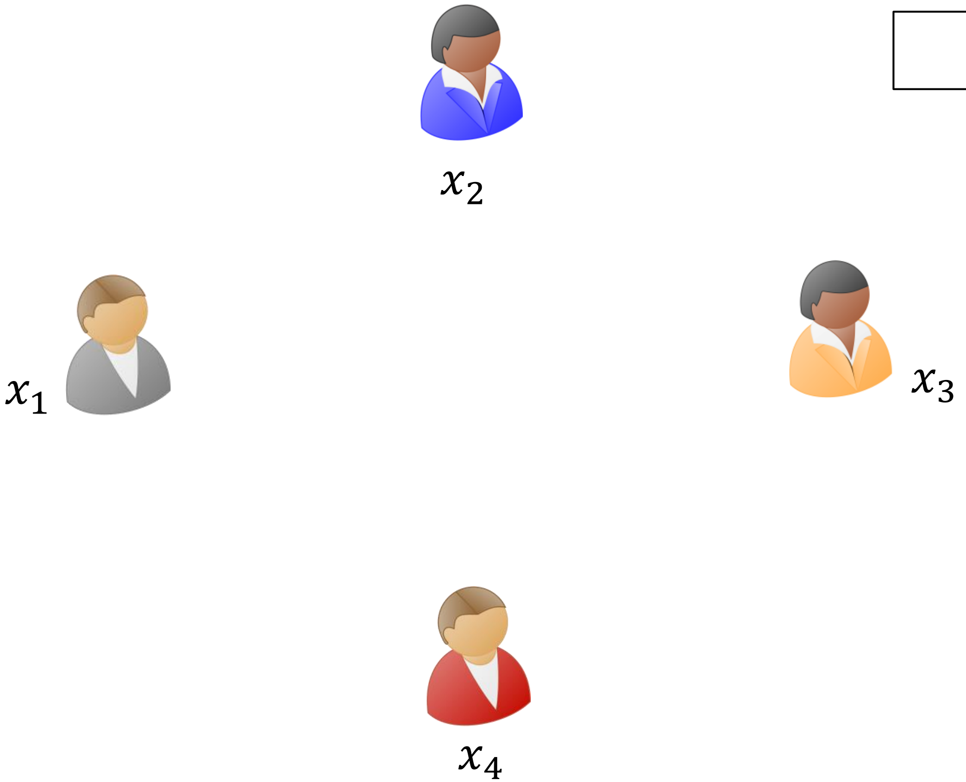
new rewinding techniques



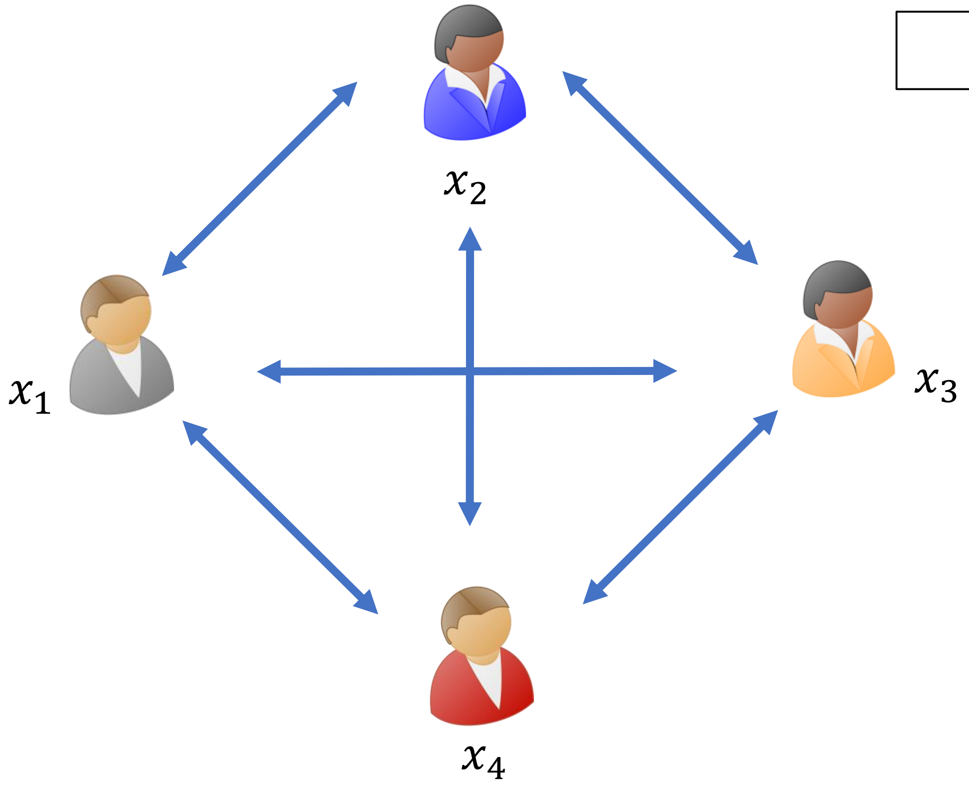
Concurrent Self Composition

Secure Computation

$$\boxed{y = f(x_1, x_2, x_3, x_4)}$$



Secure Computation



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Secure Computation

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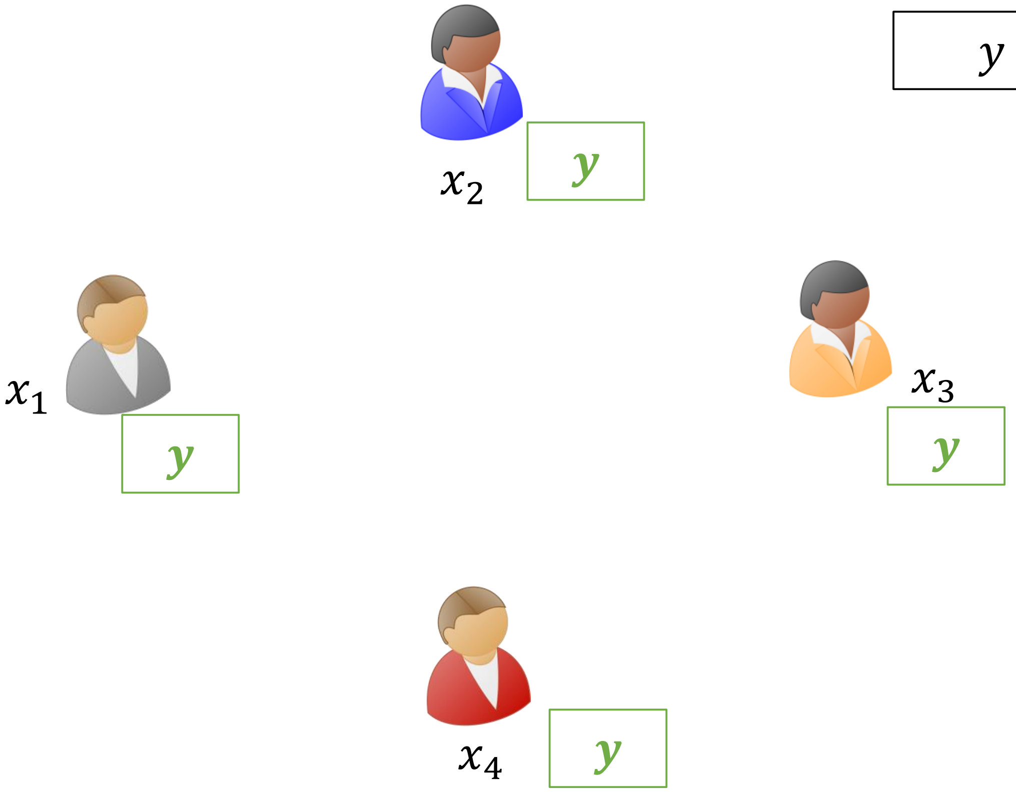
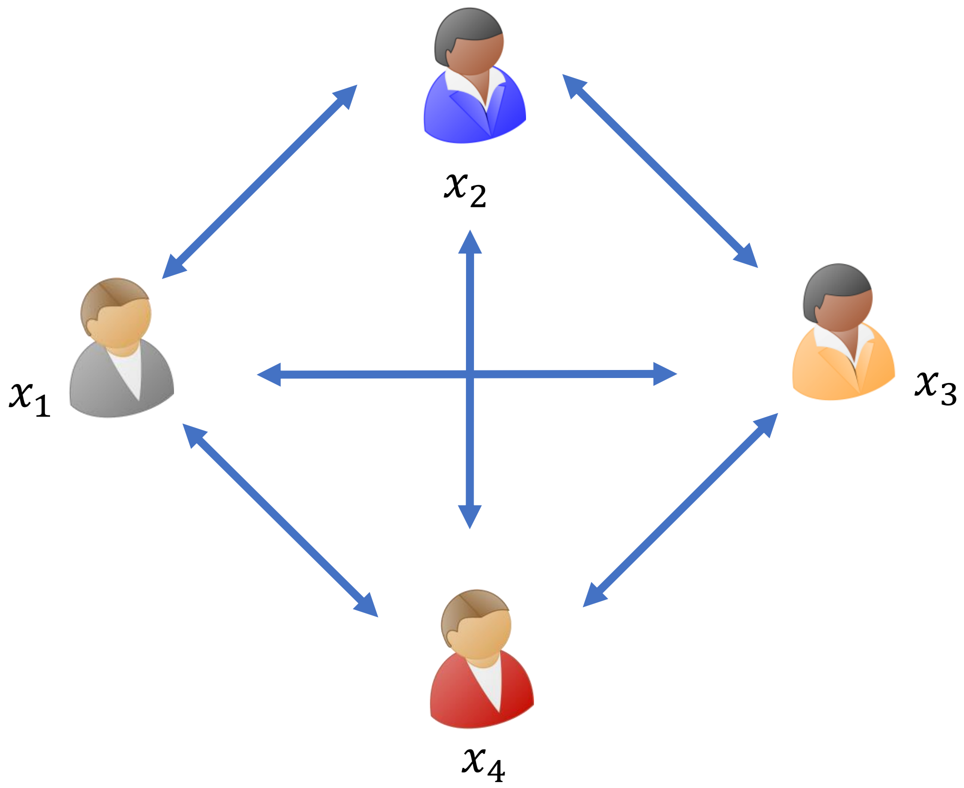


Security



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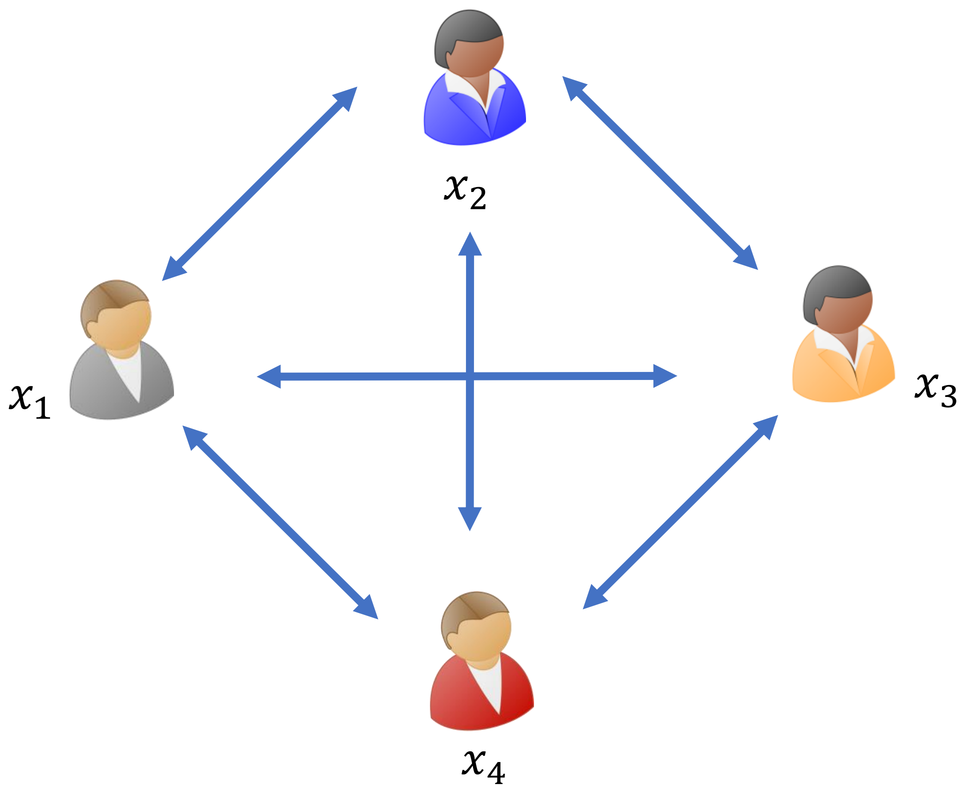

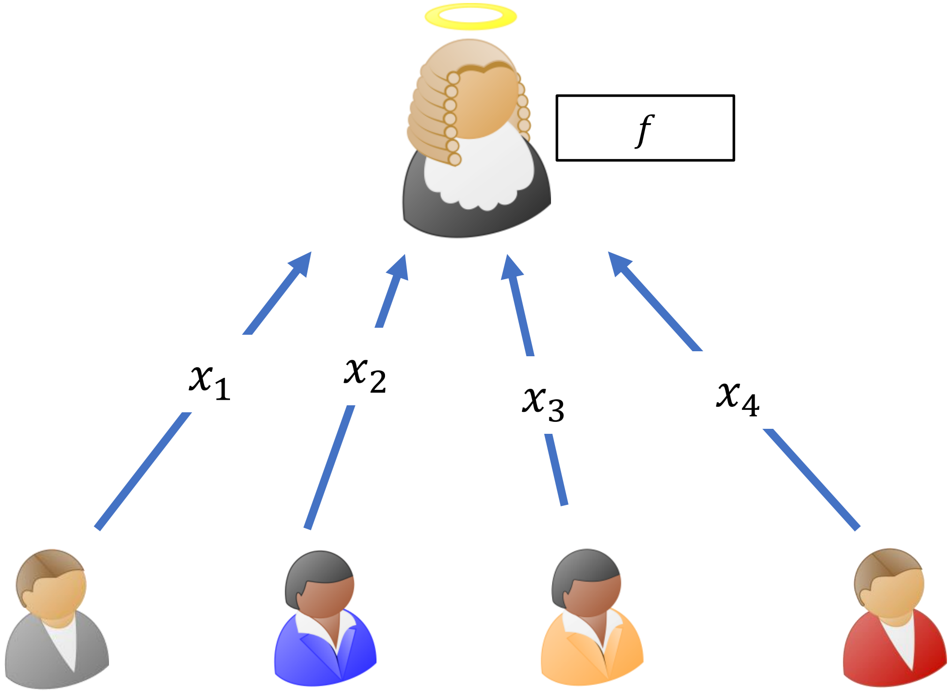

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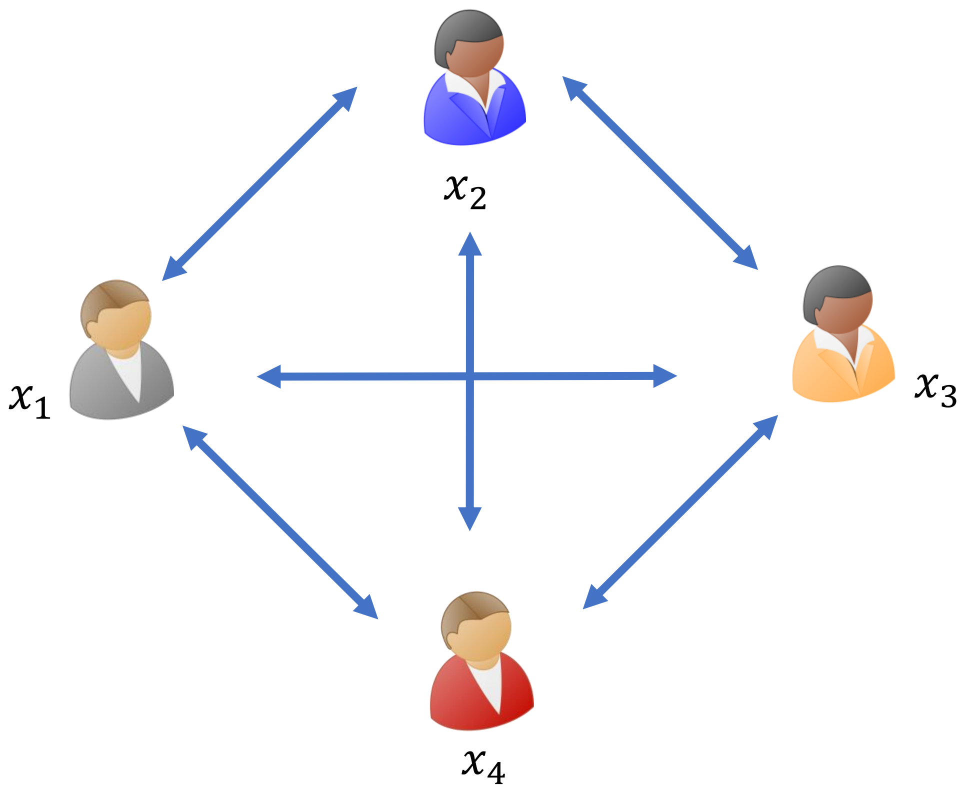

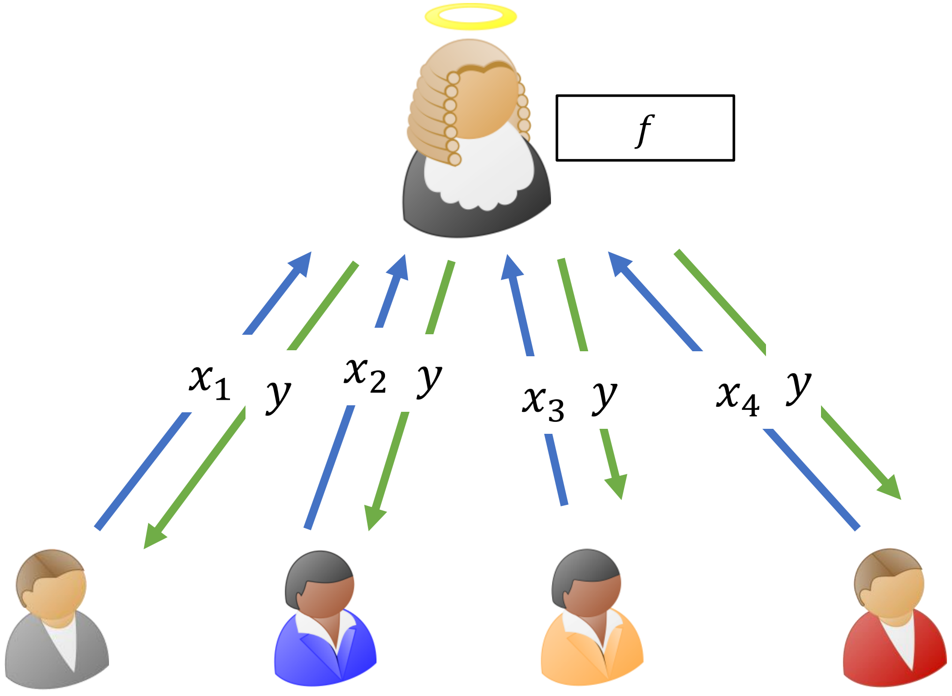

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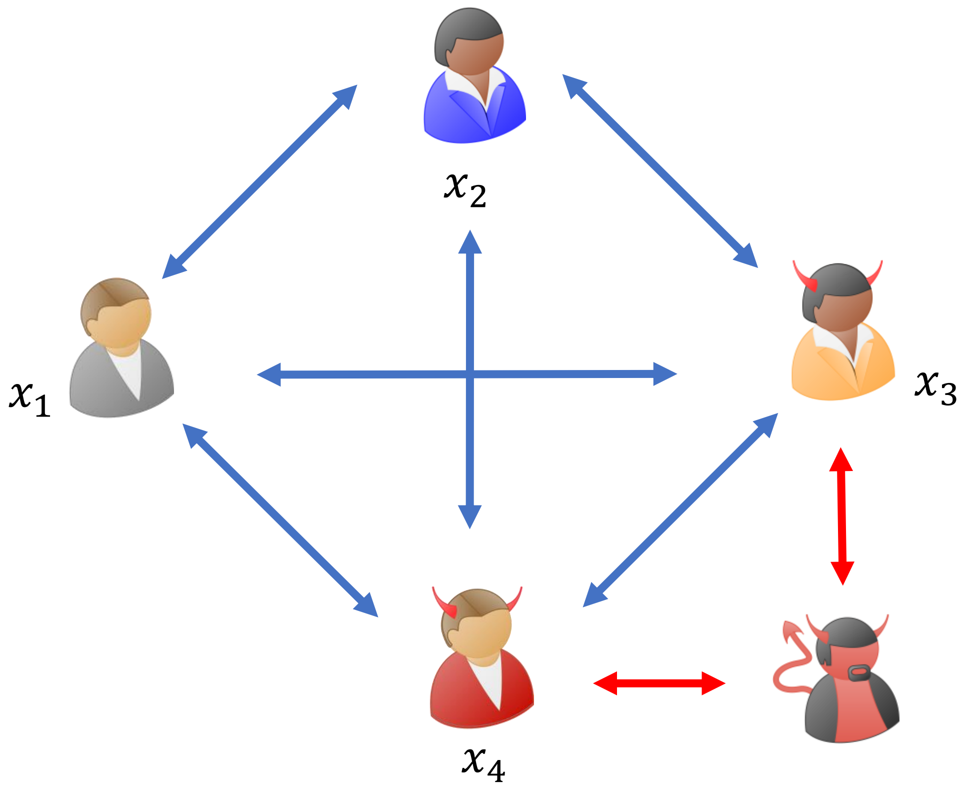
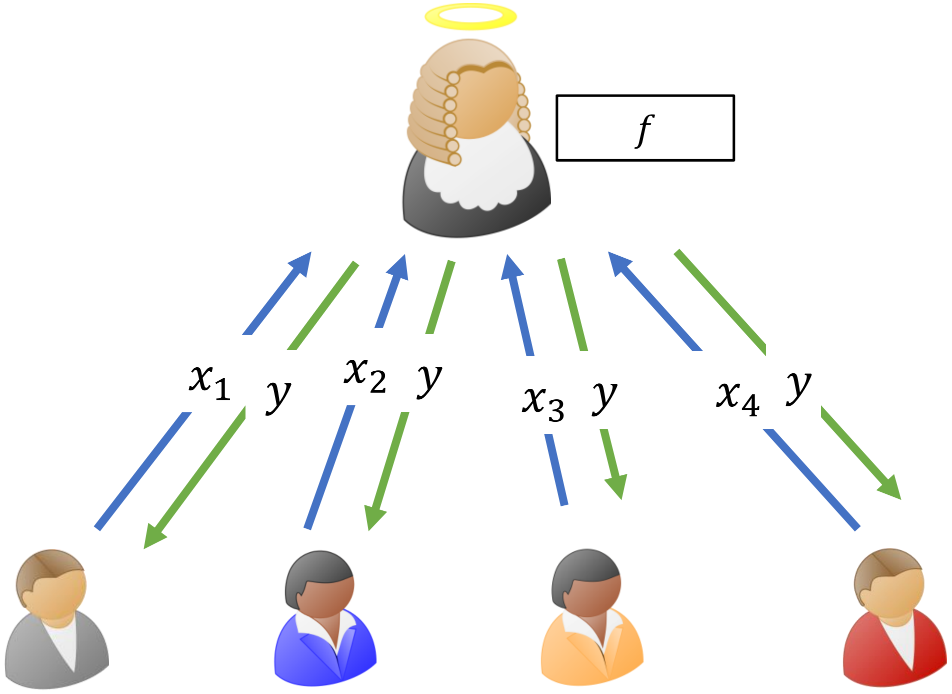


Real World



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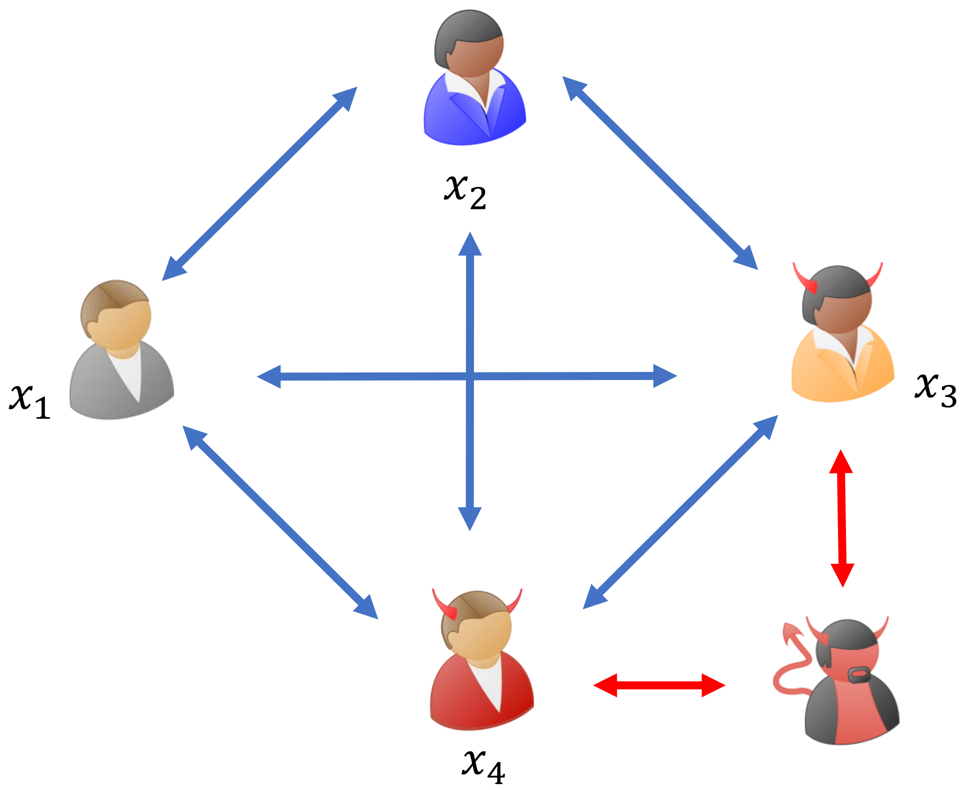
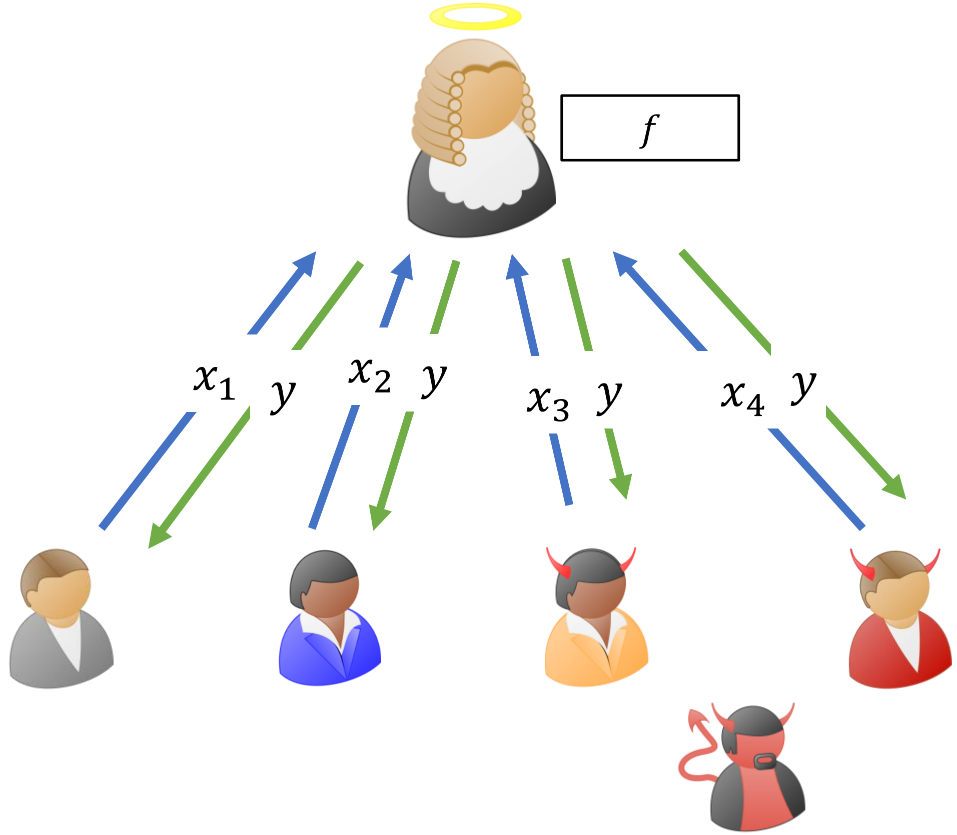
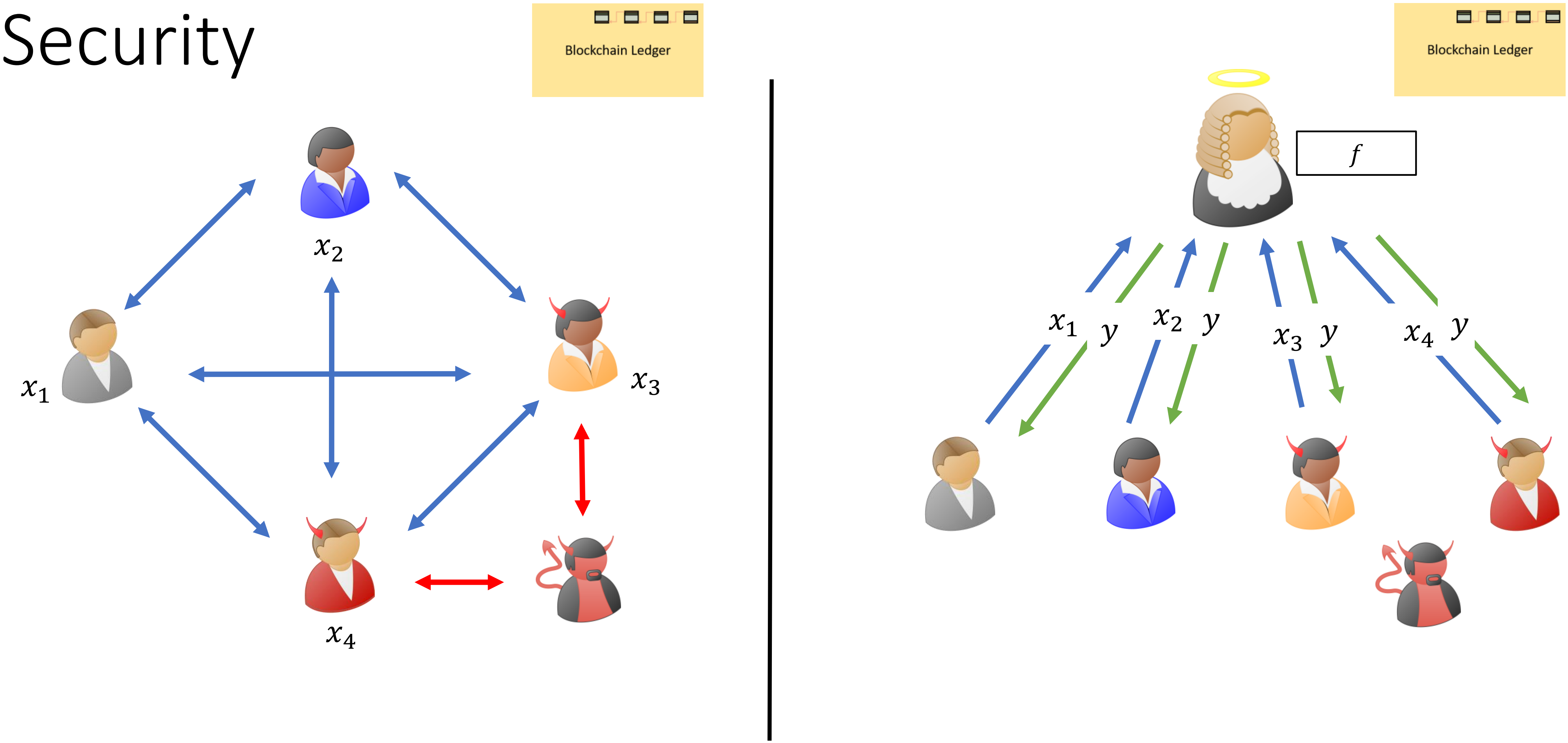




Real World

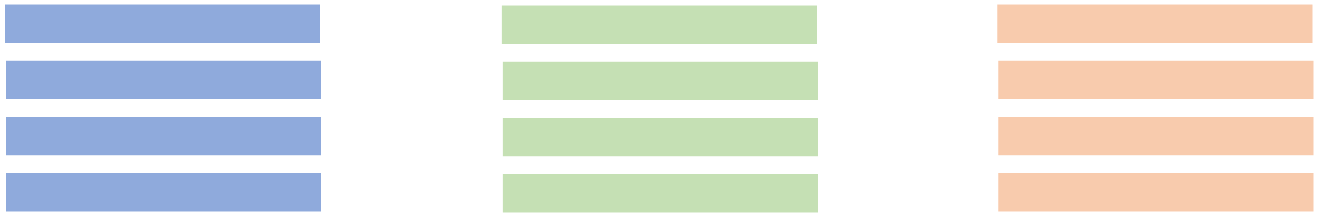
Ideal World

Security



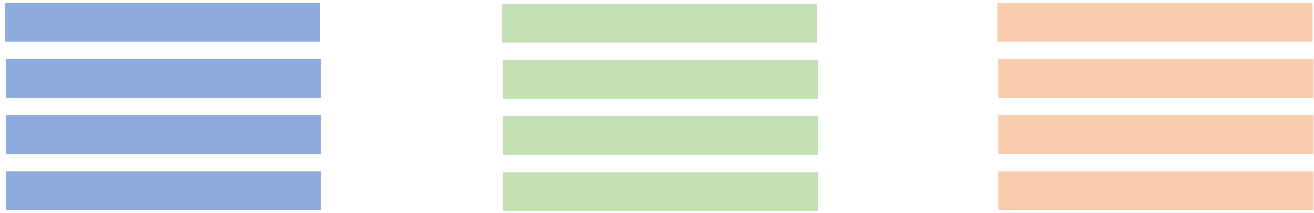
Real World ≈ Ideal World

Concurrent Secure Computation



Protocol transcripts

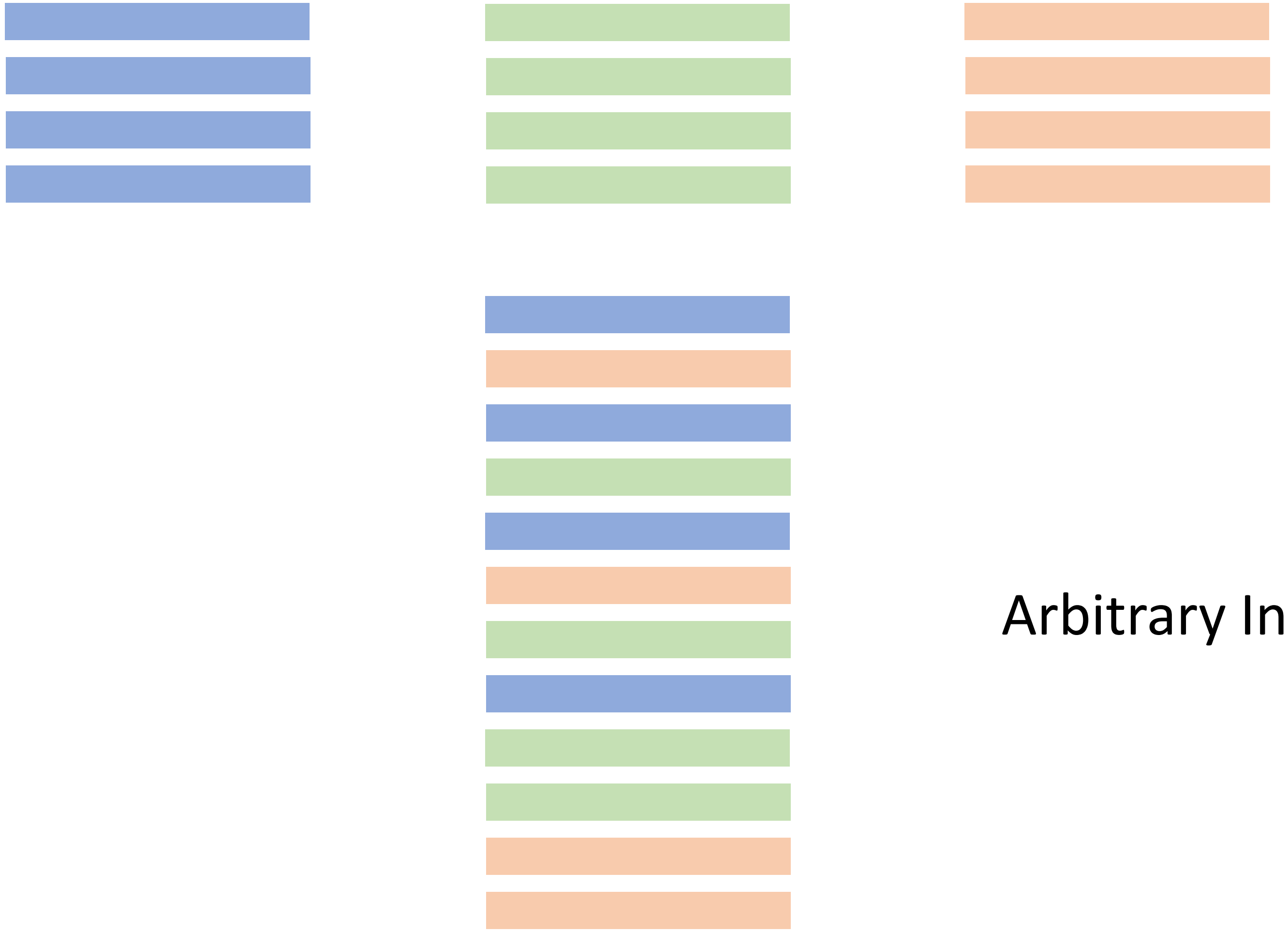
Concurrent Secure Computation



Protocol transcripts

Self Composition

Concurrent Secure Computation

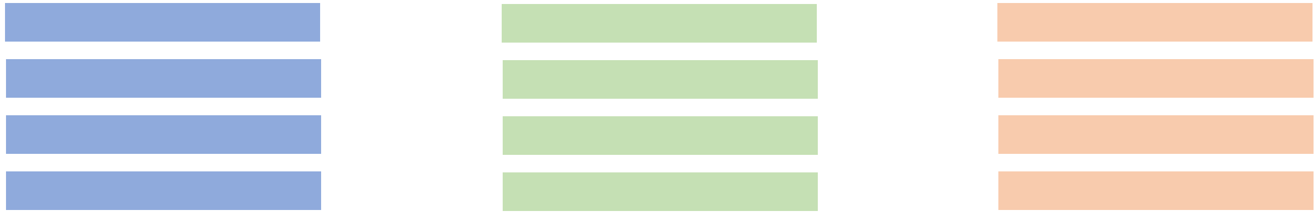


Protocol transcripts

Self Composition

Arbitrary Interleaving

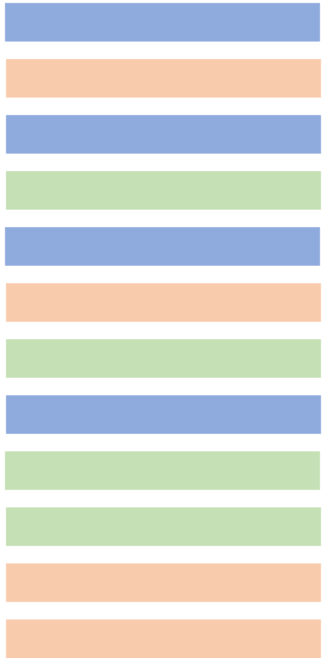
Concurrent Secure Computation



Protocol transcripts

Self Composition

Impossible in the plain model.



Arbitrary Interleaving

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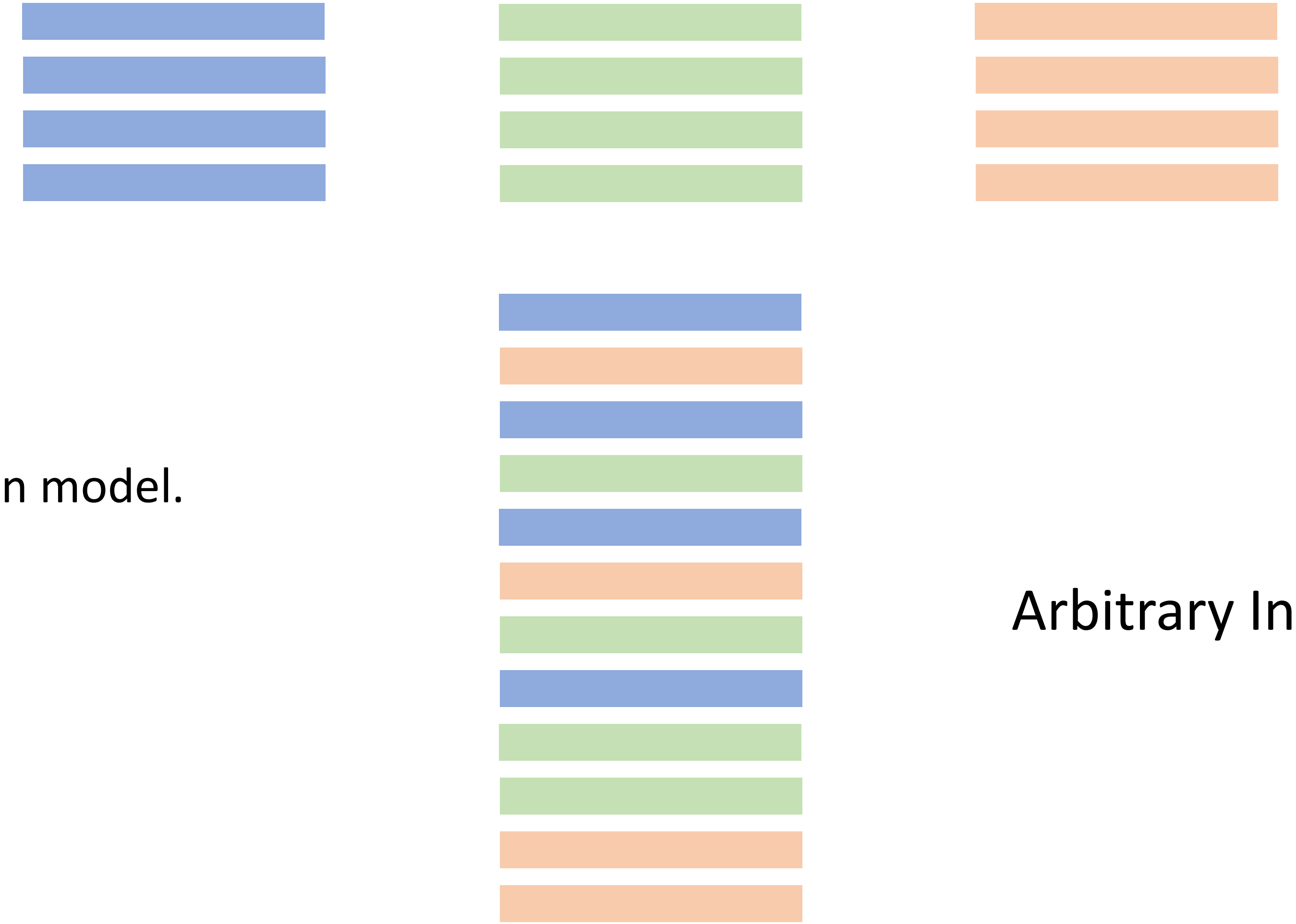

Protocol transcripts

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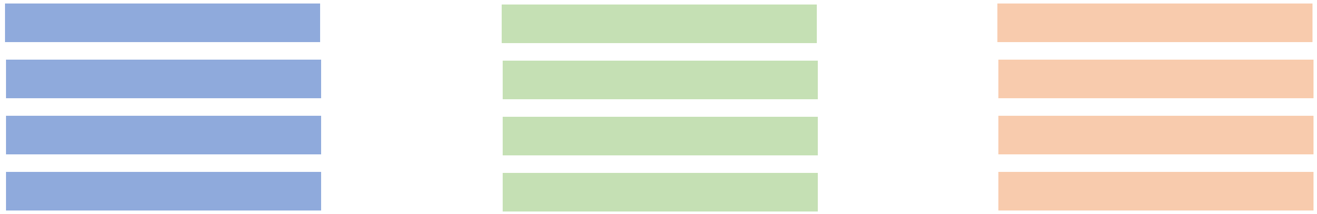
Prior work:

Arbitrary Interleaving

Concurrent Secure Computation



Protocol transcripts

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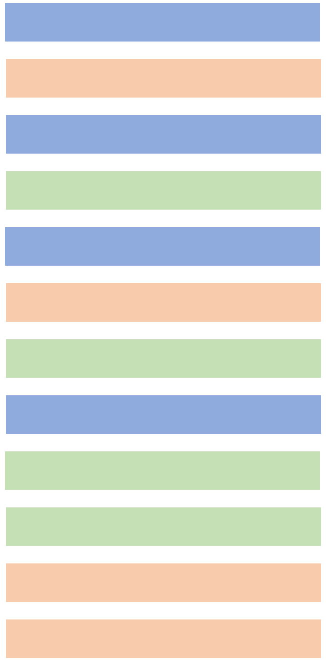


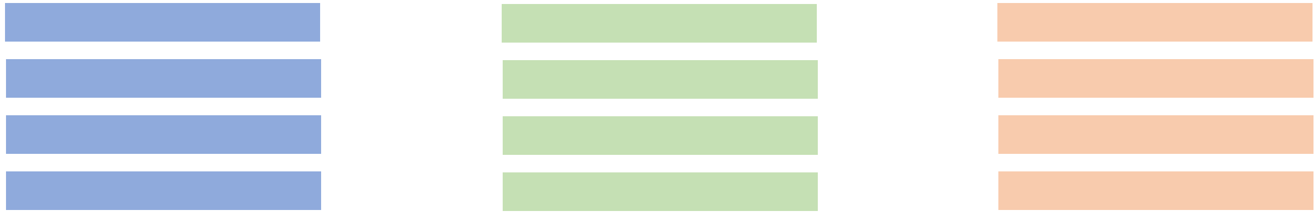
Impossible in the plain model.

Prior work:

Weaker security notion

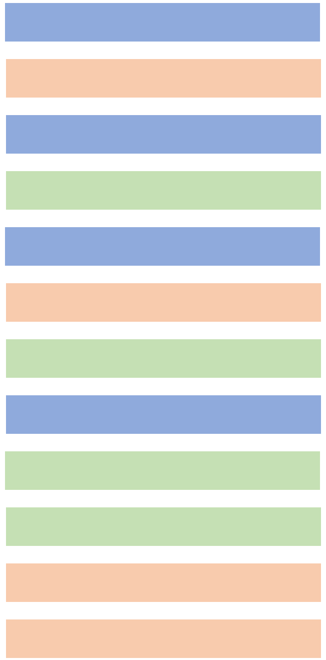
Arbitrary Interleaving

Concurrent Secure Computation



Protocol transcripts

Self Composition



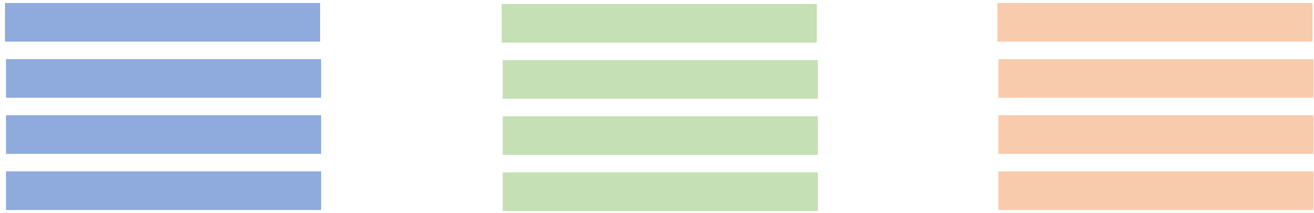
Arbitrary Interleaving

Impossible in the plain model.

Prior work:

- Weaker security notion
- Trust Assumptions

Concurrent Secure Computation



Protocol transcripts

Self Composition

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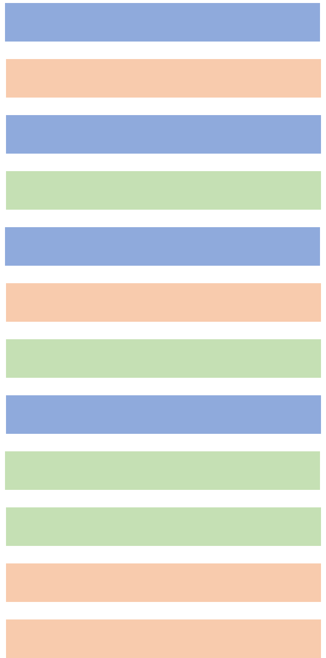


Arbitrary Interleaving

Decentralized trust assumption

Concurrent Secure Computation Impossible

Concurrent Secure Computation Impossible

Black-box impossible

[Lindell 04]

Concurrent Secure Computation Impossible

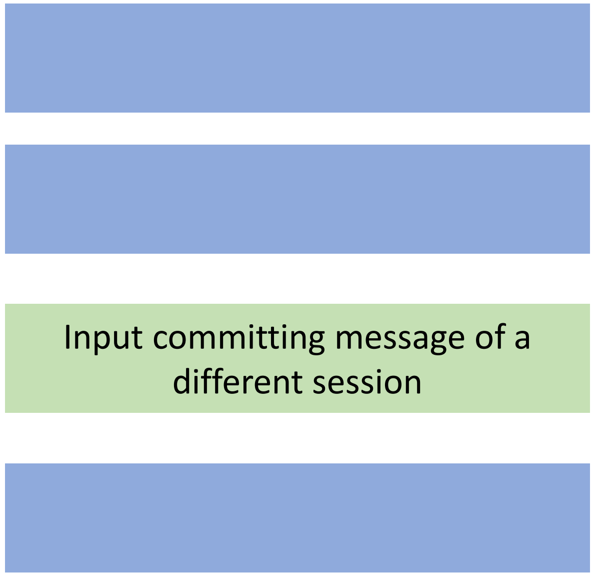
Black-box impossible

[Lindell 04]

Non-black box, and varied settings:

[Barak-Prabhakaran-Sahai 06]
[Goyal 12]
[Agrawal-Goyal-Jain-Prabhakaran-Sahai 12]
[Garg-Kumarasubramanian-Ostrovsky-Visconti 12]

Concurrent Secure Computation Impossible



Input committing message of a different session

Black-box impossible

[Lindell 04]

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Concurrent Secure Computation Impossible

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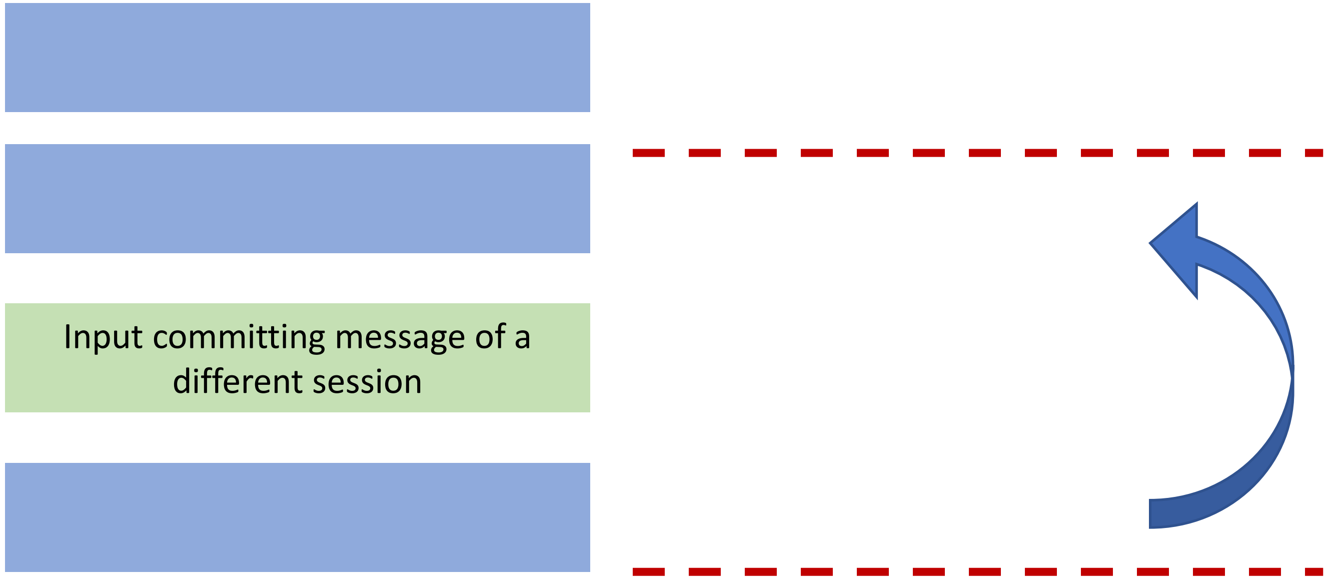


Input committing message of a different session

Structure of Concurrently Secure Computation

Weaker models

[Goyal-Jain-Ostrovsky 10, Goyal-Gupta-Jain 13, Canetti-Goyal-J 15]

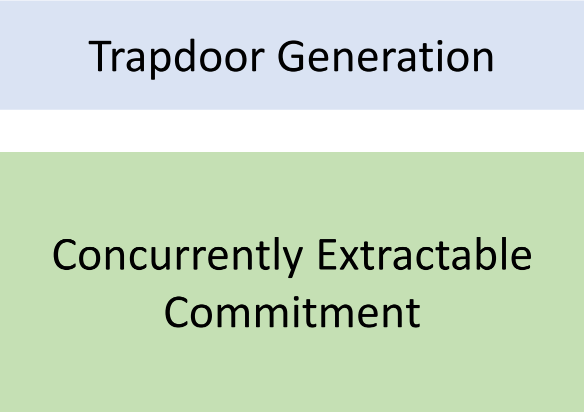
Structure of Concurrently Secure Computation

Trapdoor Generation

Weaker models

[Goyal-Jain-Ostrovsky 10, Goyal-Gupta-Jain 13, Canetti-Goyal-J 15]

Structure of Concurrently Secure Computation



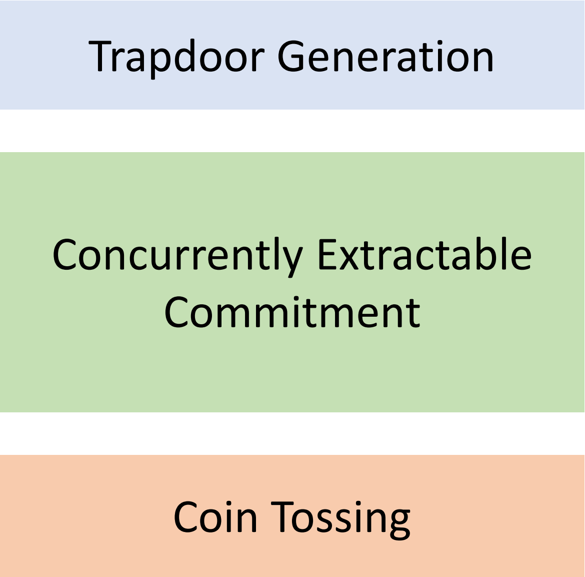
Trapdoor Generation

Concurrently Extractable Commitment

Weaker models

[Goyal-Jain-Ostrovsky 10, Goyal-Gupta-Jain 13, Canetti-Goyal-J 15]

Structure of Concurrently Secure Computation



Trapdoor Generation

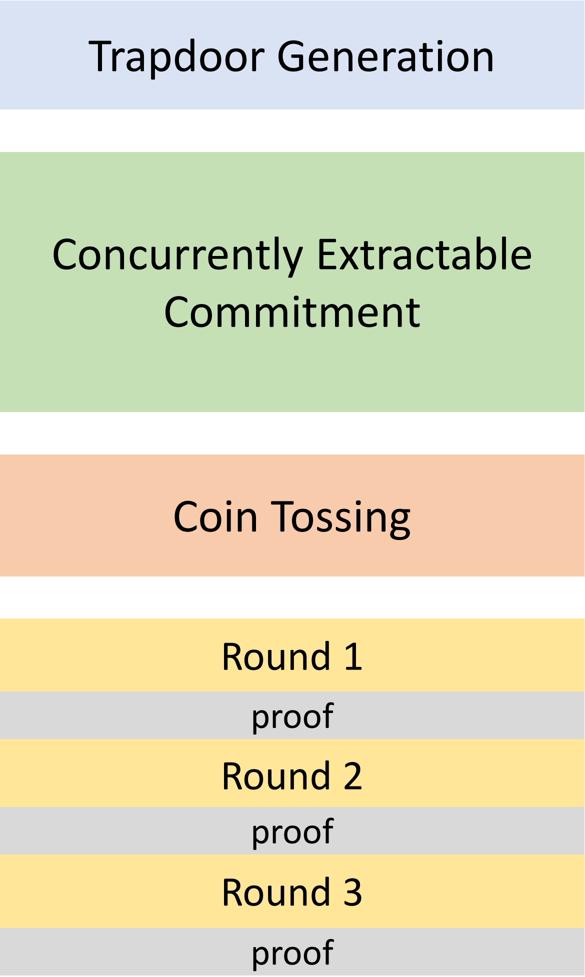
Concurrently Extractable Commitment

Coin Tossing

Weaker models

[Goyal-Jain-Ostrovsky 10, Goyal-Gupta-Jain 13, Canetti-Goyal-J 15]

Structure of Concurrently Secure Computation



Trapdoor Generation

Concurrently Extractable Commitment

Coin Tossing

Round 1

proof

Round 2

proof

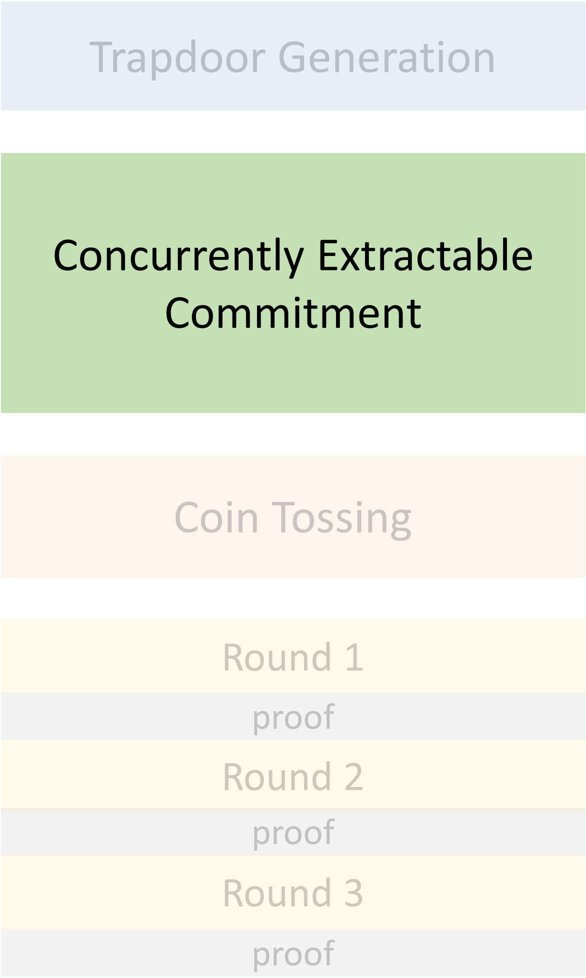
Round 3

proof

Weaker models

[Goyal-Jain-Ostrovsky 10, Goyal-Gupta-Jain 13, Canetti-Goyal-J 15]

Structure of Concurrently Secure Computation



Trapdoor Generation

Concurrently Extractable Commitment

Coin Tossing

Round 1

proof

Round 2

proof

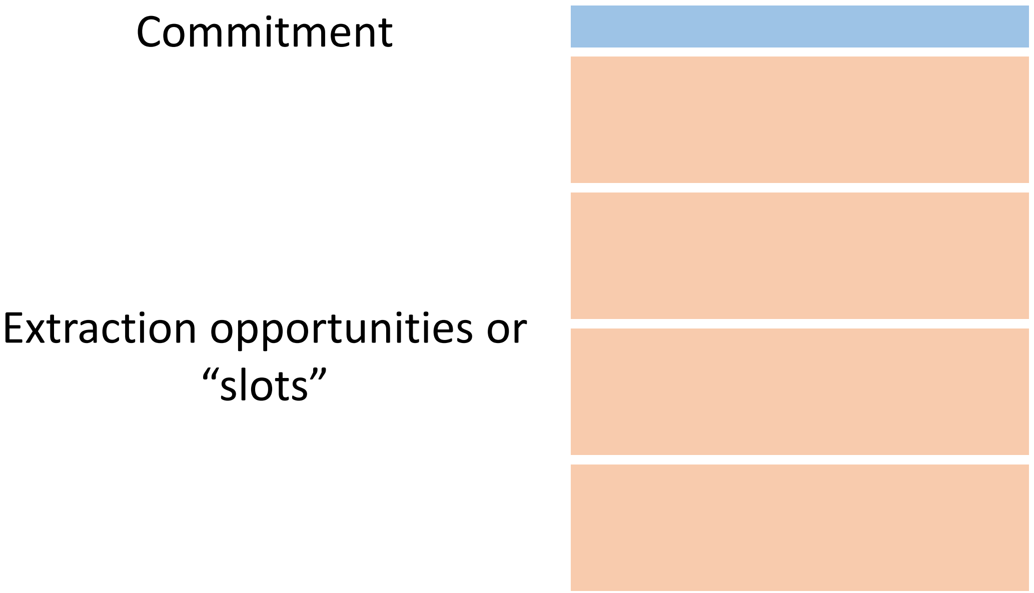
Round 3

proof

Weaker models

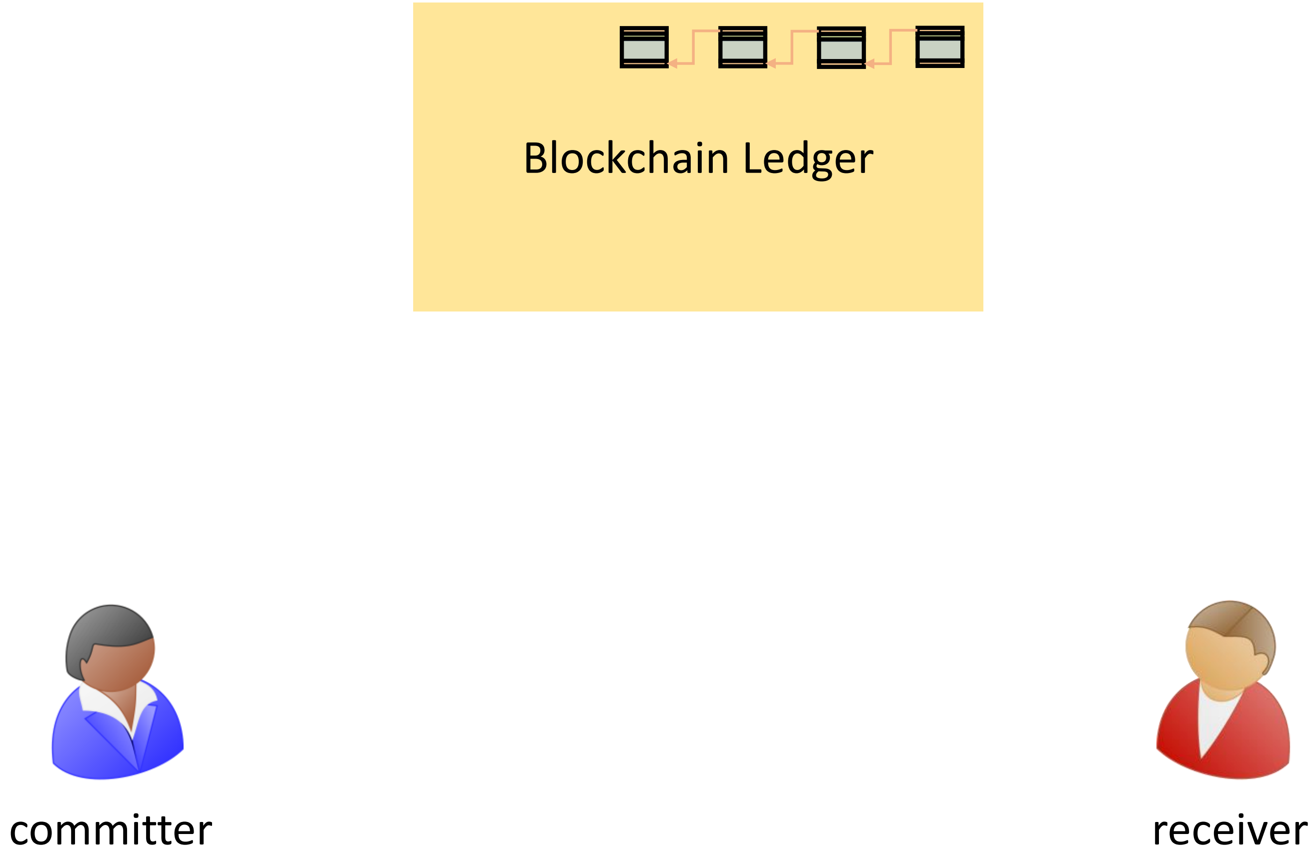
[Goyal-Jain-Ostrovsky 10, Goyal-Gupta-Jain 13, Canetti-Goyal-J 15]

Commitment: Structure



Commitment

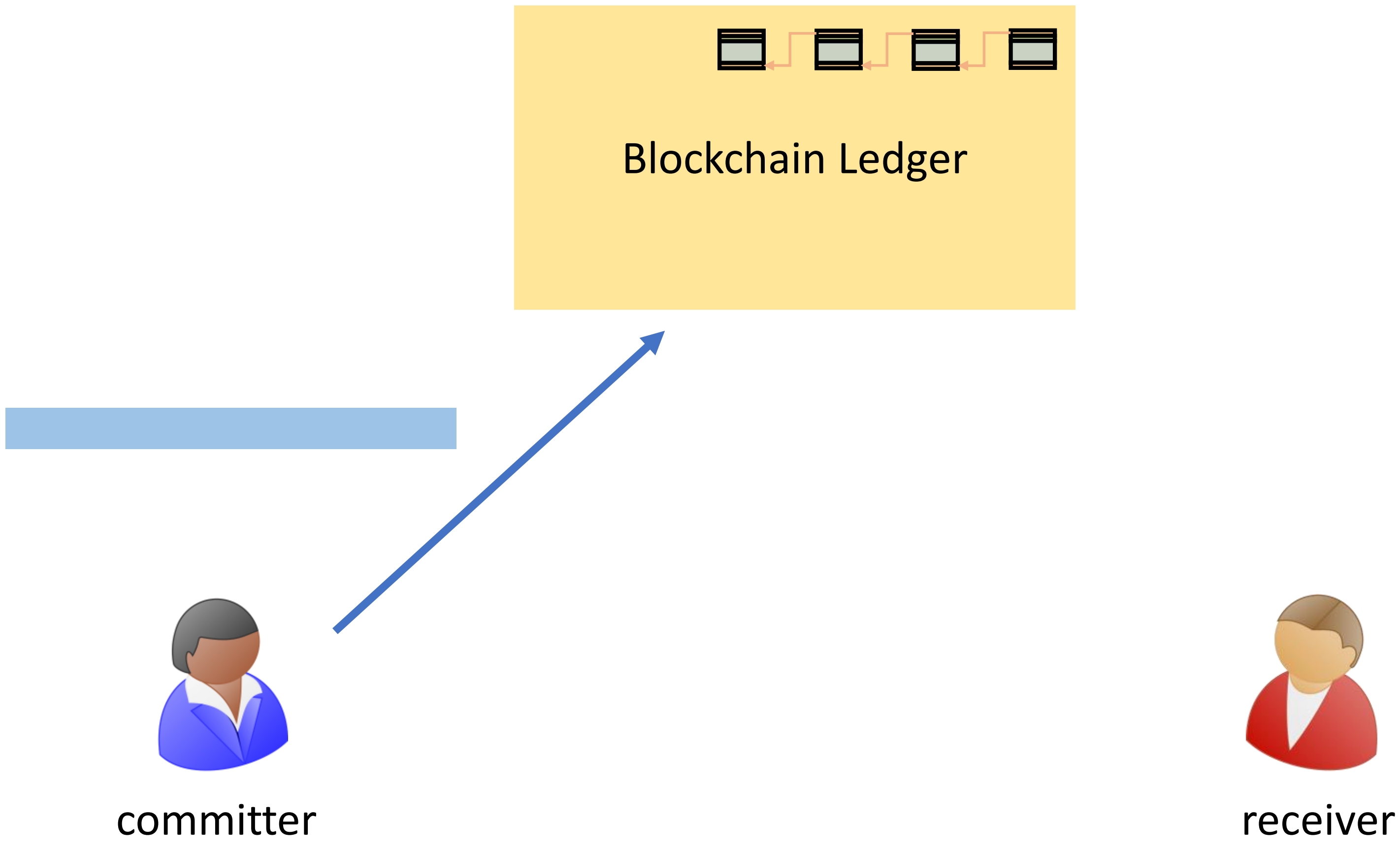
Extraction opportunities or
“slots”



Blockchain Ledger

committer

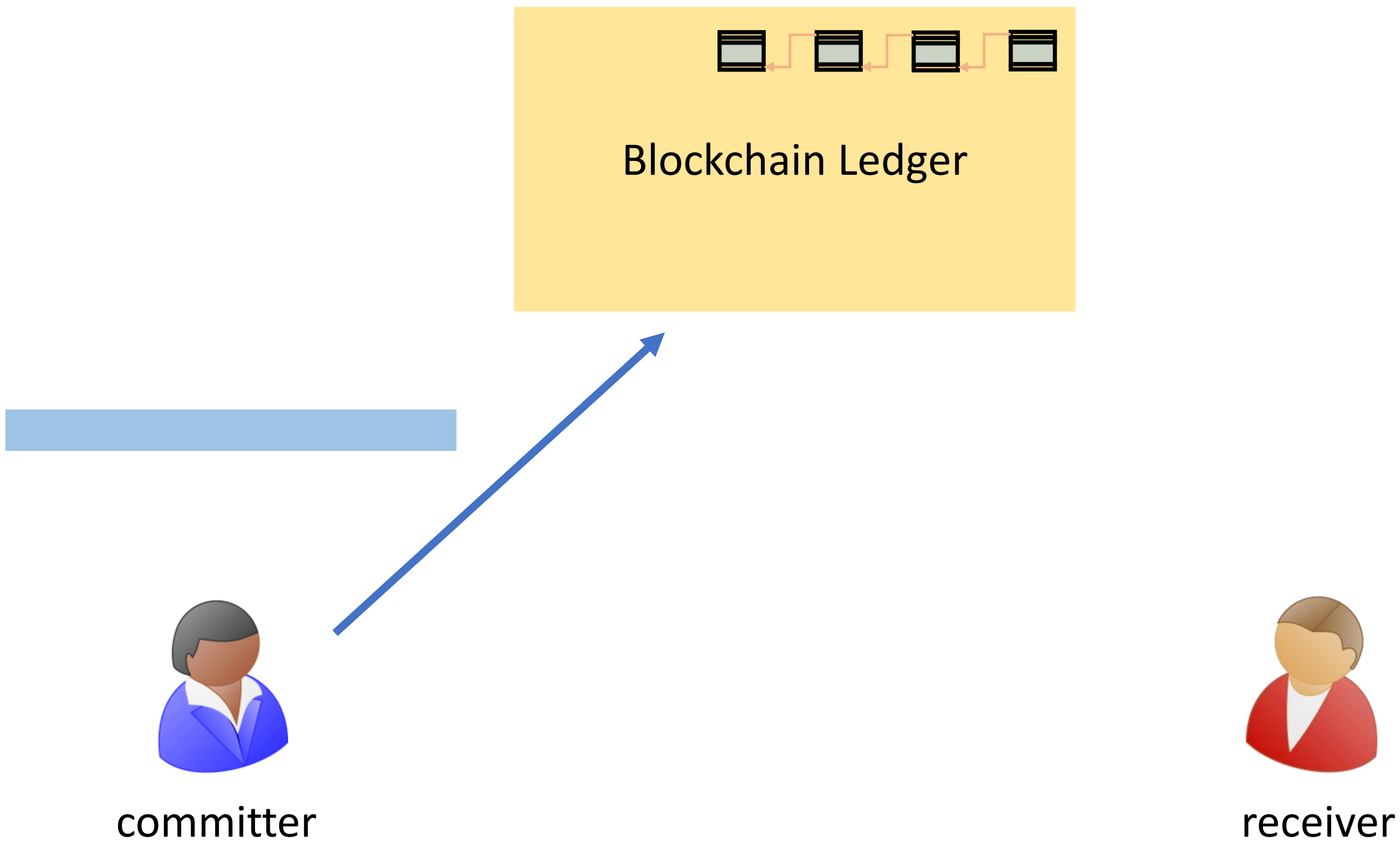
receiver



Blockchain Ledger

committer

receiver

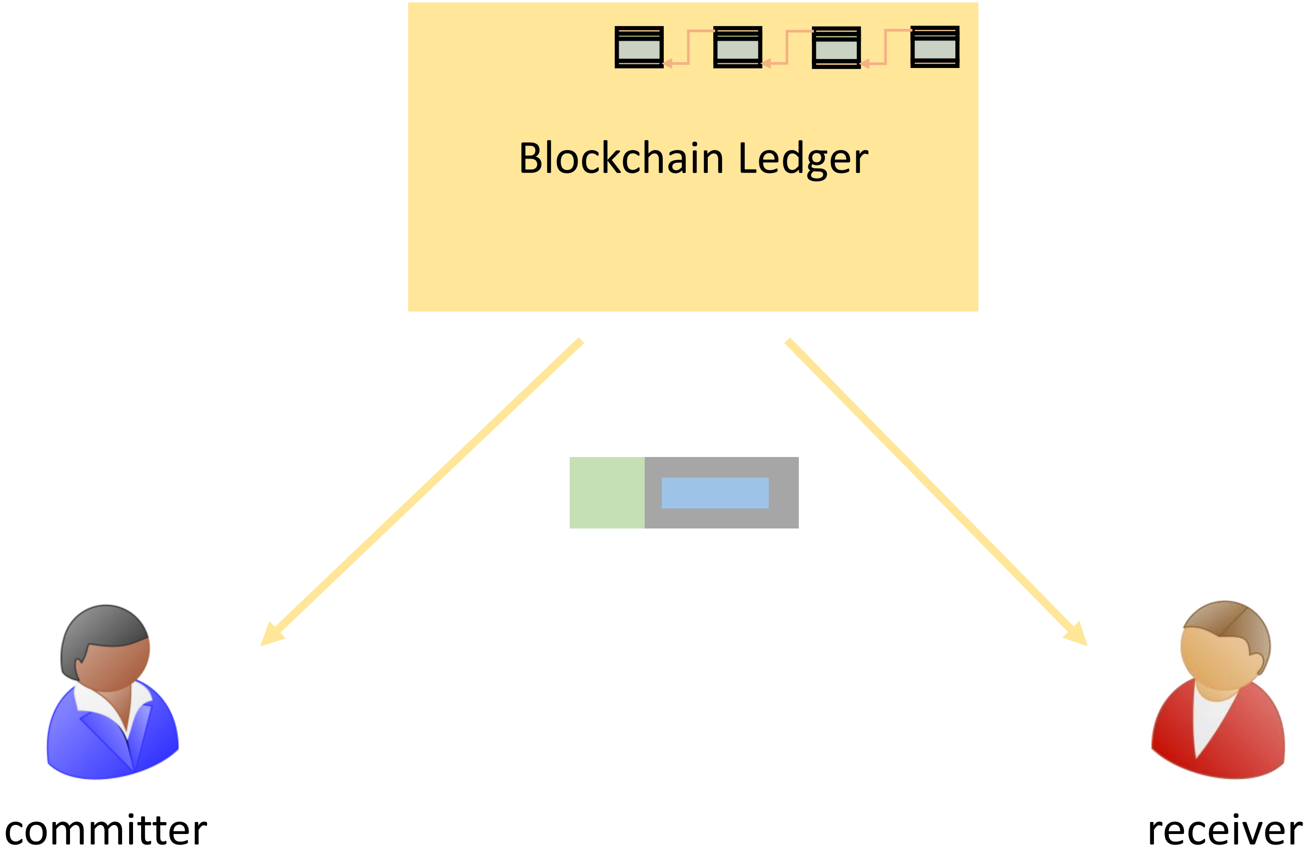


Blockchain Ledger

committer

receiver

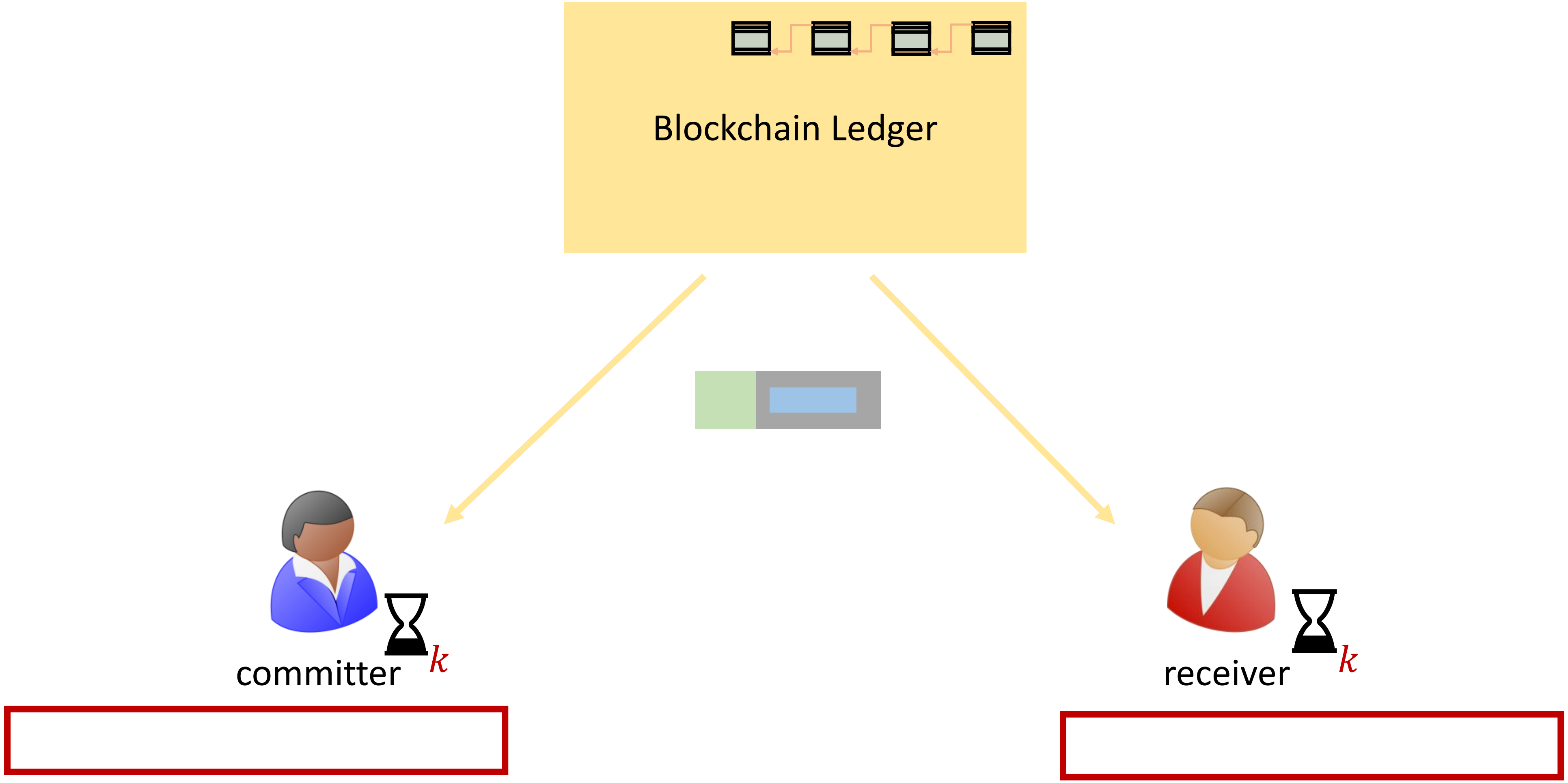
Commit to the blockchain



Blockchain Ledger

committer

receiver



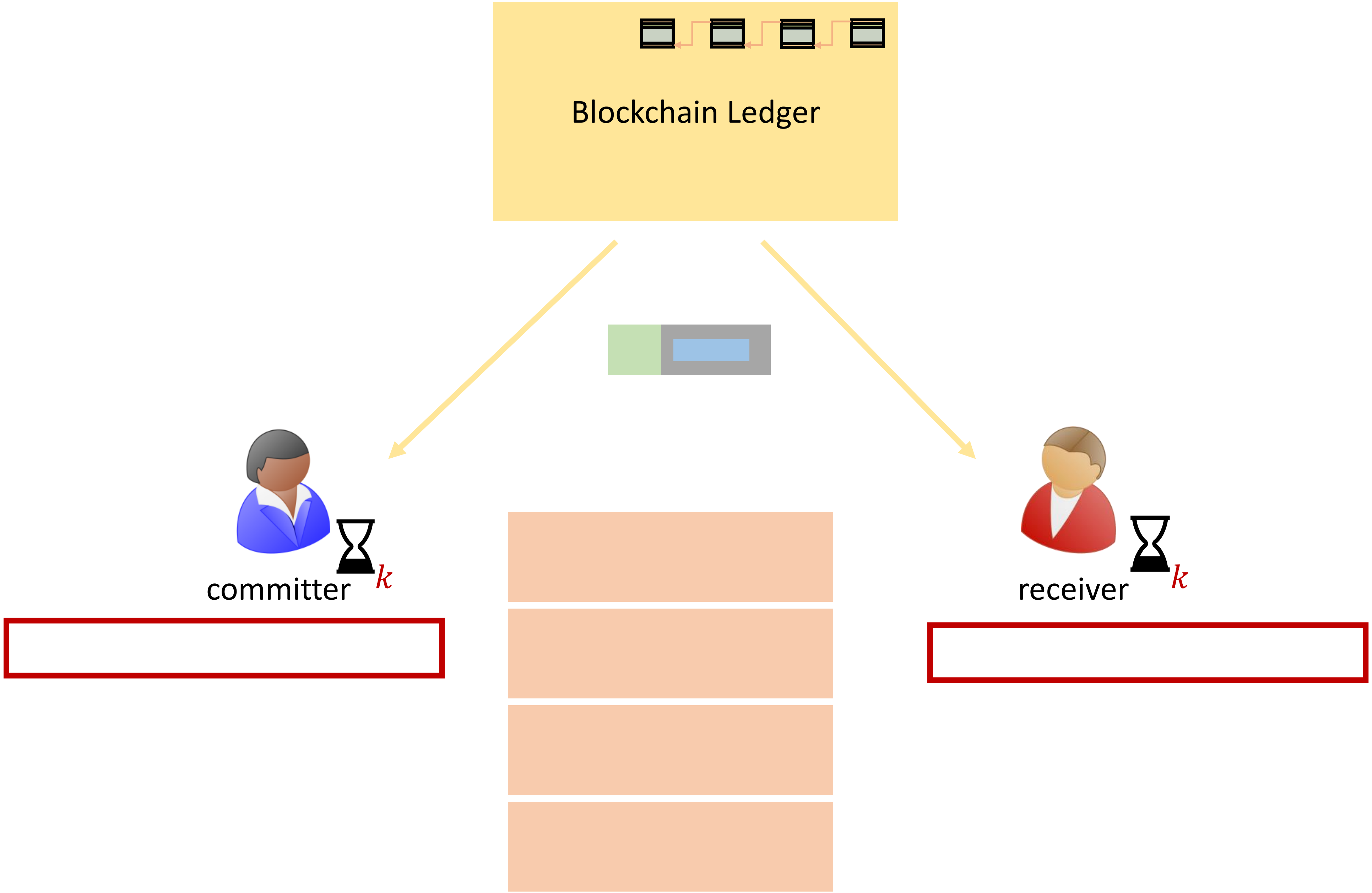
Blockchain Ledger

committer

k

receiver

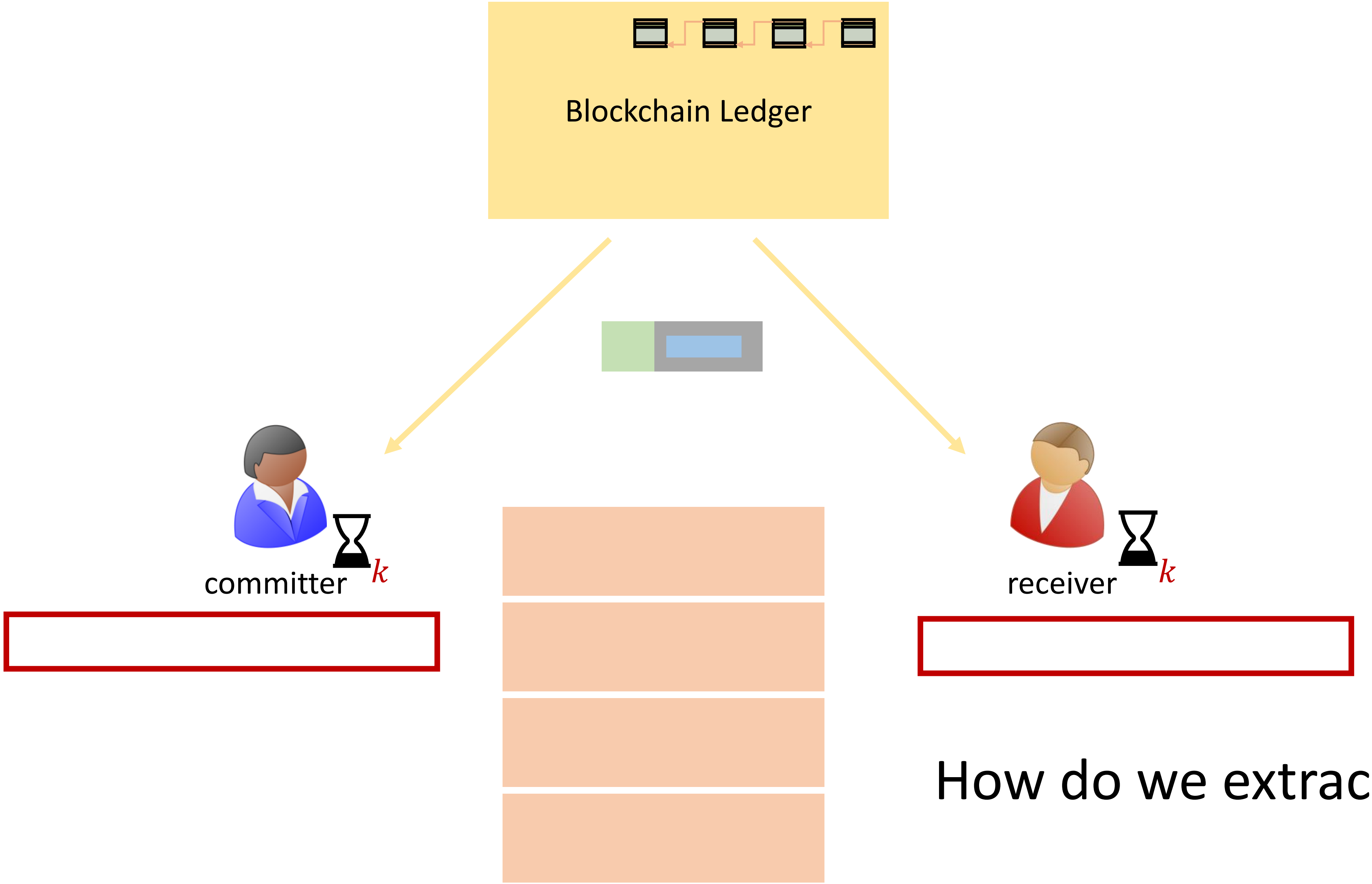
k



Blockchain Ledger

committer k

receiver k



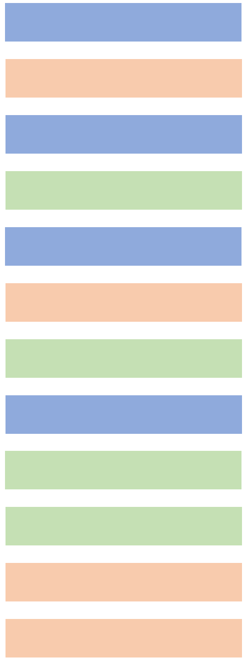
Blockchain Ledger

committer k

receiver k

How do we extract?

Extraction: Idea

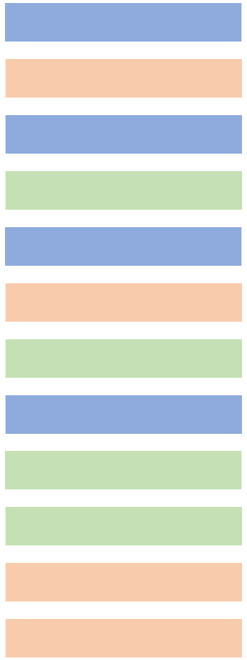


Extraction: Idea

Robust Extraction Lemma

[Goyal-Lin-Pandey-Pass-Sahai15]

Extraction in the presence of constant number of external messages.



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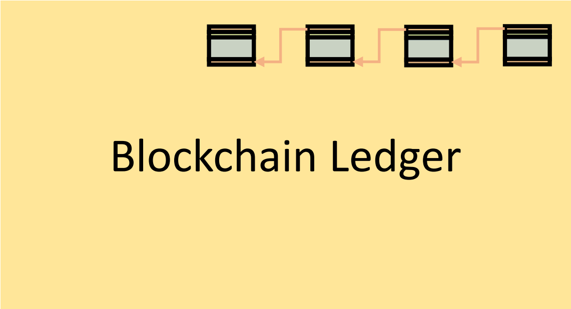

Blockchain Ledger

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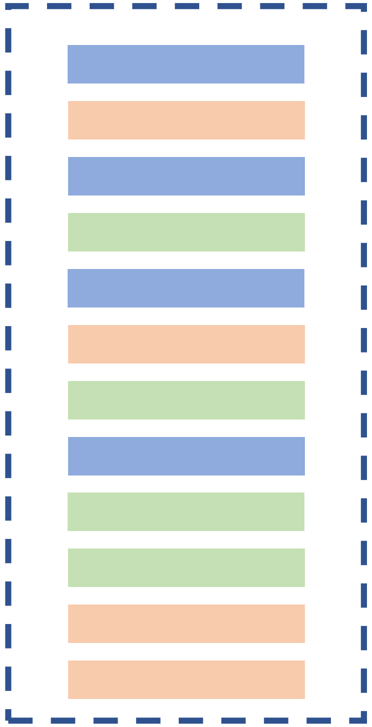

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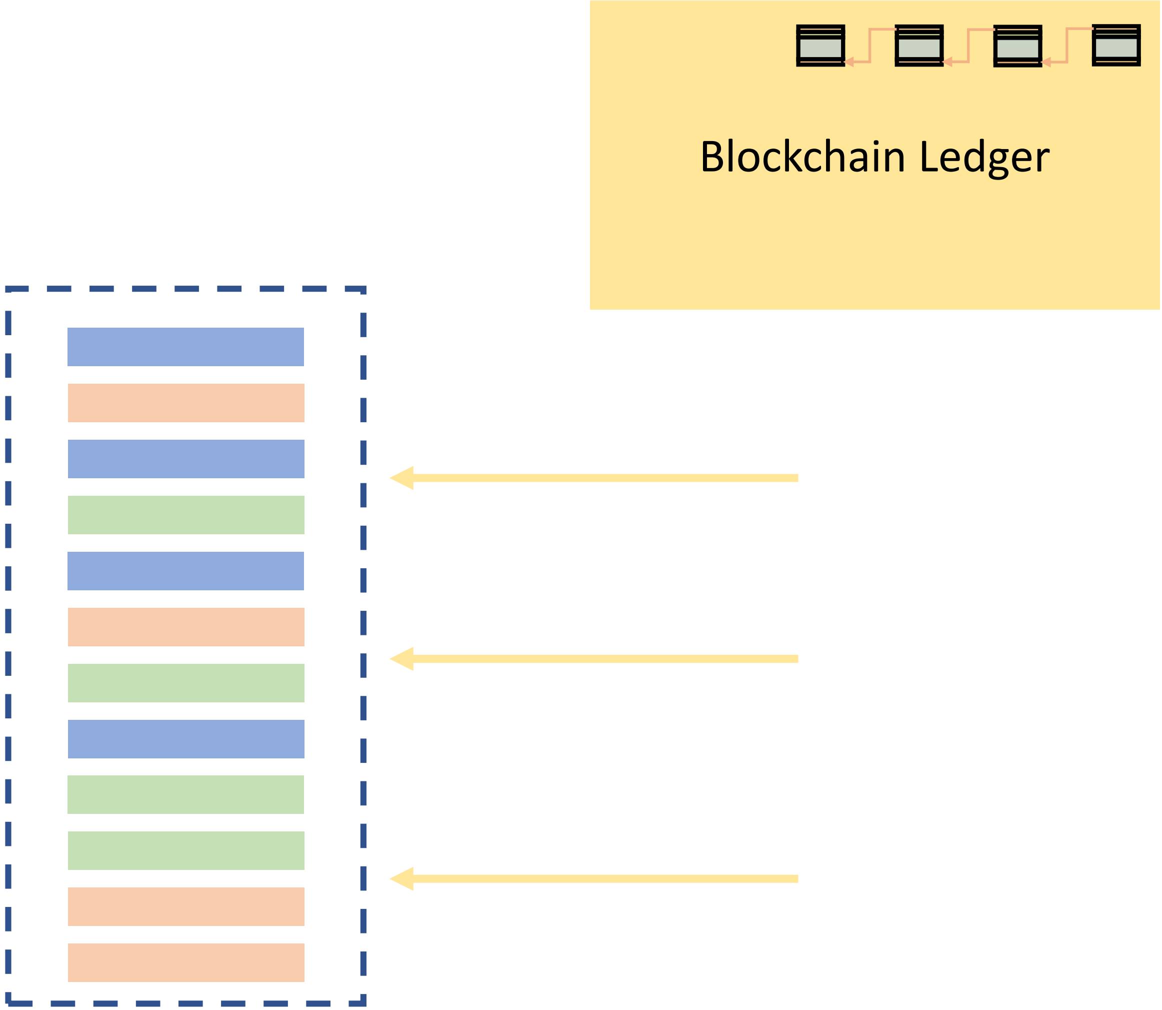

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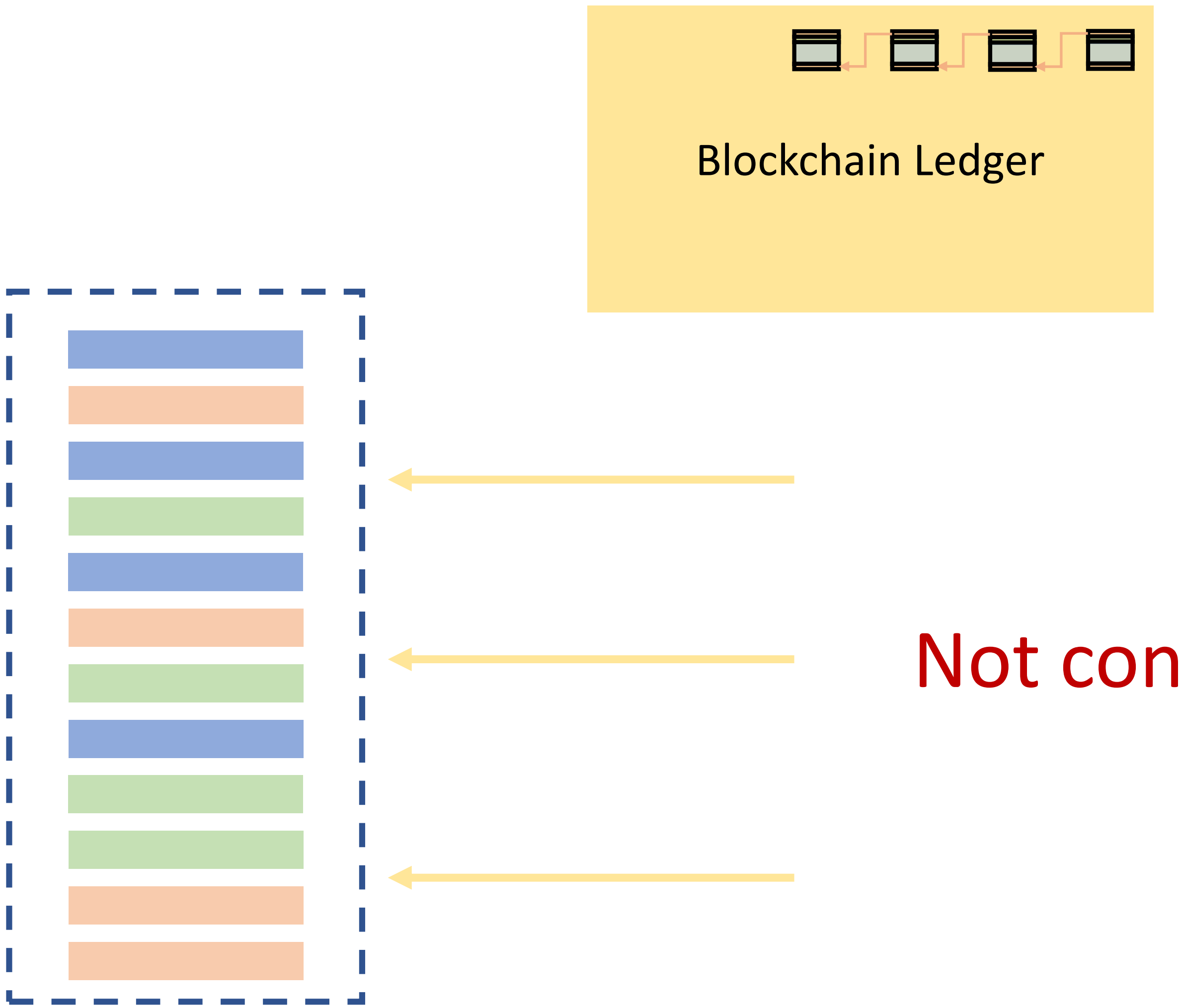

Not constant

Conclusion

Blockchains have both destructive and constructive uses in the context of secure computation.

Thank you. Questions?

https://ia.cr/2019/253
achoud@cs.jhu.edu