Publicly Verifiable Zero-Knowledge from *(Collapsing)* Blockchains

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Publicly Verifiable Zero-Knowledge Proofs

+ **One** proof convinces ***all*** verifiers π

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Soundness: only proof of true statements are accepted by a verifier

Zero-Knowledge: nothing besides truthfulness of the theorem is revealed

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+ **One** proof convinces ***all*** verifiers π

Soundness: only proof of true statements are accepted by a verifier

Zero-Knowledge: nothing besides truthfulness of the theorem is revealed

+ Public verifiability especially desired in blockchain applications

Publicly Verifiable Zero-Knowledge Proofs

requires setup assumptions

PVZK ≈ Non-interactive ZK (NIZK)

- [**trusted*** party] CRS
- [heuristic] Random Oracle

Publicly Verifiable Zero-Knowledge Proofs

blockchain
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Publicly Verifiable Zero-Knowledge Proofs

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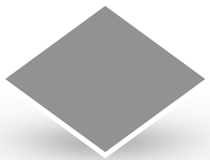
Blockchain protocols
with
their underlying assumption



Blockchain Assumption to Replace Trusted Setups

Public verifiable ZK from Blockchain Assumption?

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[Goyal Goyal TCC 2017]

GG-NIZK: Non-interactive ZK from a Proof-of-Stake Blockchain**

Blockchain Assumption to Replace Trusted Setups

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GG-NIZK: Non-interactive ZK from a Proof-of-Stake Blockchain**

** Additional Limitations on Adversary

** Additional Assumptions on the stakeholder behaviour

Our contribution

1

2

Our contribution

1

Subtleties in using a blockchain as an assumption

a single static adv playing as blockchain user ***invalidates*** *ZK of GG-NIZK*

2

Our contribution

1. Subtleties in using a blockchain as an assumption

   a single static adv playing as blockchain user ***invalidates*** *ZK of GG-NIZK*

2. PVZK from a “generic blockchain assumption”

   it remains zk even if ***all blockchain players*** *are eventually* ***corrupt***
   (collapsing blockchain)

1 Subtleties in using a blockchain as an assumption

a single adv playing as blockchain user ***invalidates*** *ZK of* ***GG-NIZK***

GG-NIZK from Proof-of-Stake Blockchain

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Proof-of-Stake blockchain assumption

at any point in time, if you look at the total current stake, the majority belongs to honest people

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NIZK from Proof-of-Stake [GG17]

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NIZK from Proof-of-Stake [GG17]

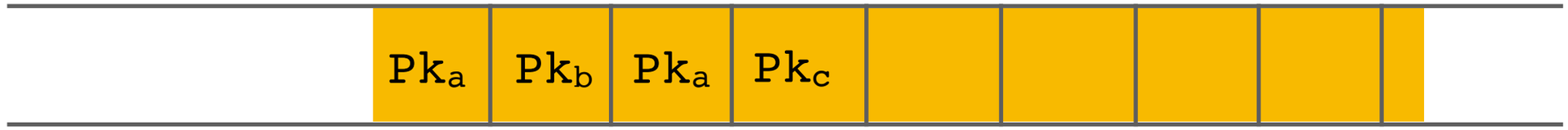
NI Witness Indistinguishability —> NI Zero-Knowledge

trapdoor theorem

“x in L” OR "I computed a fork”

1 GG-NIZK from Proof-of-Stake Blockchain

Proof-of-Stake Blockchain (param K)



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"These are encryptions under stakeholders keys of shares of the witness

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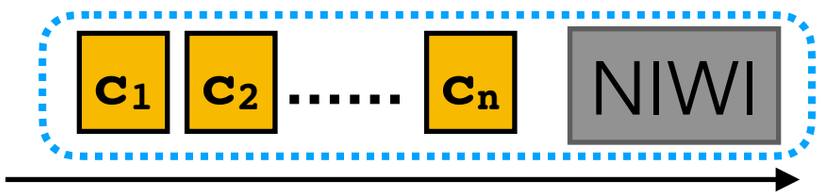
Public Proof



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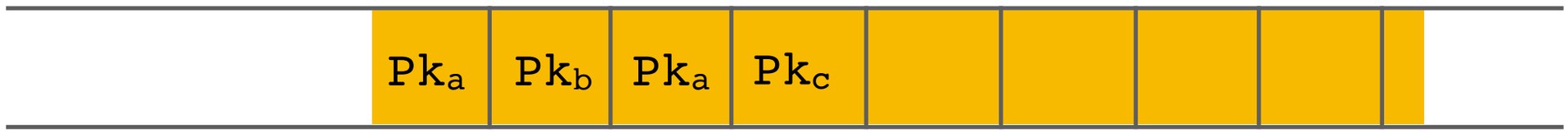
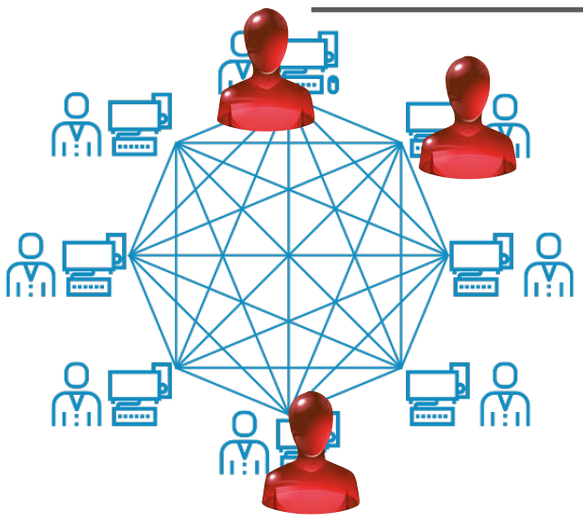
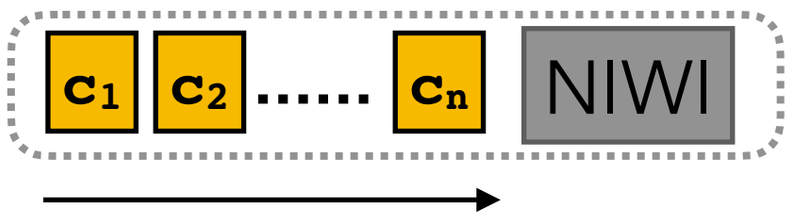
1 Soundness of GG-NIZK







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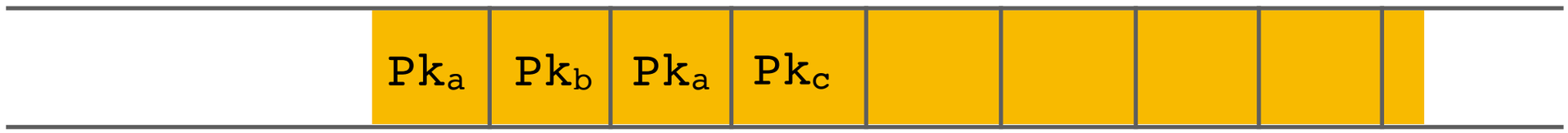

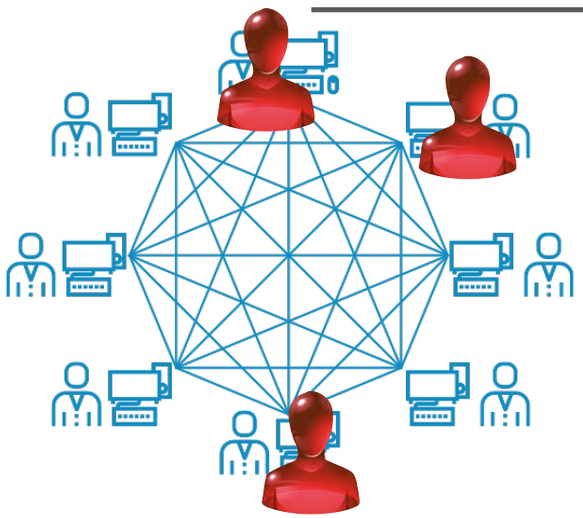

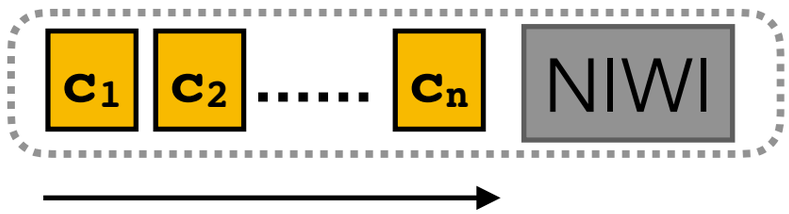

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Assumptions:

Soundness NIWI

+ honest majority of stake

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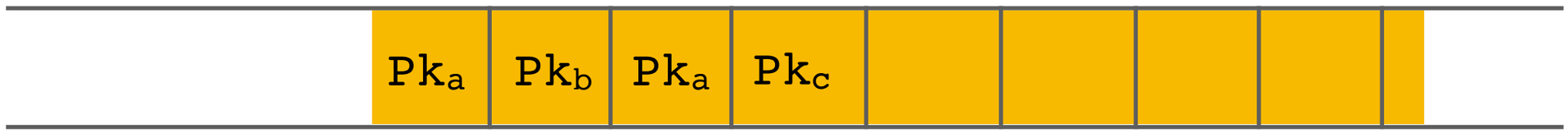

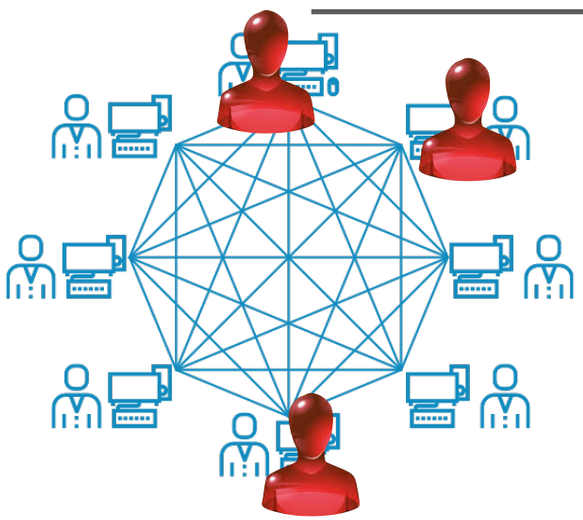

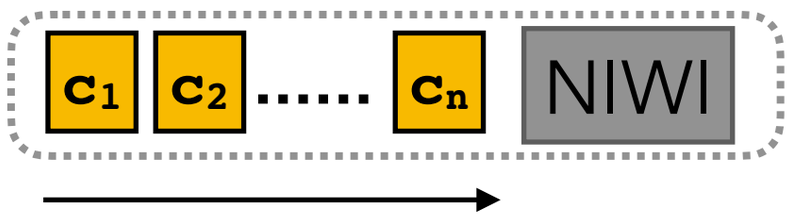

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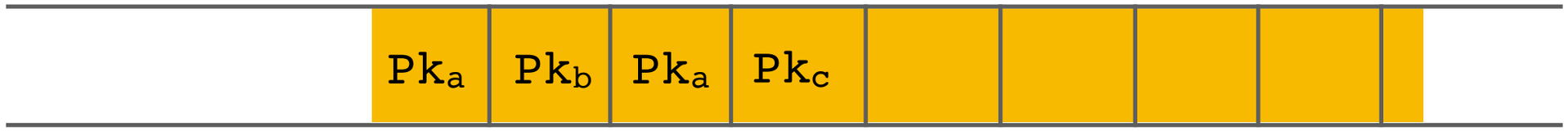

Simulator

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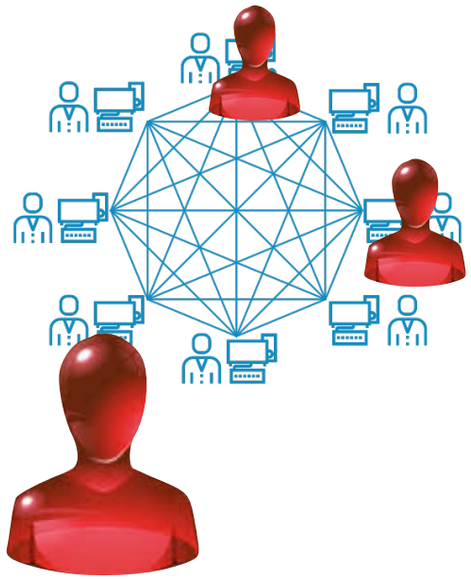

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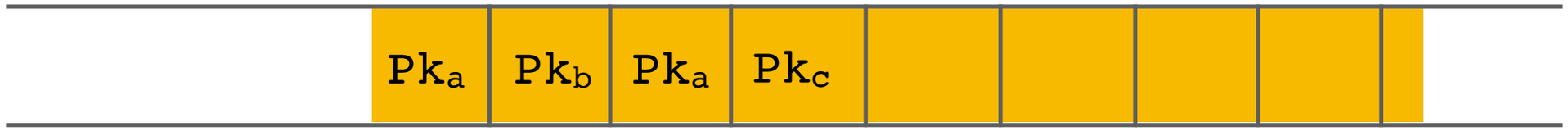

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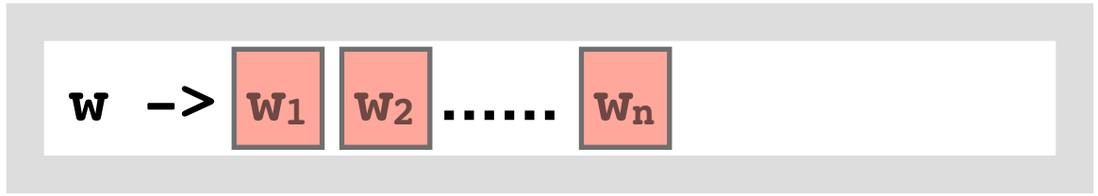

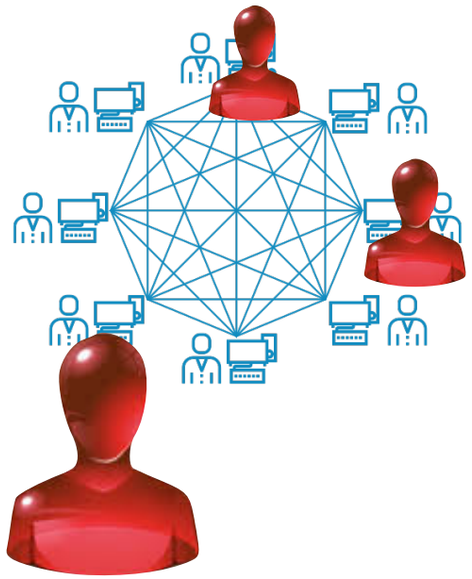

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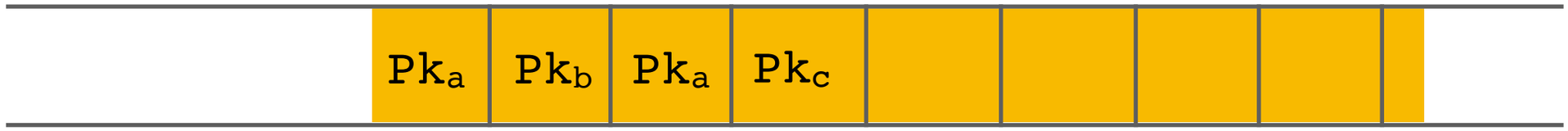

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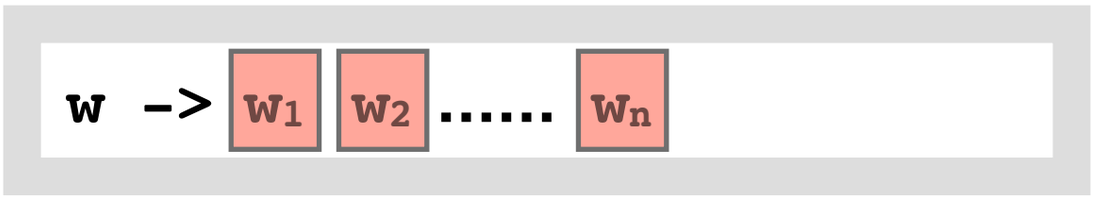

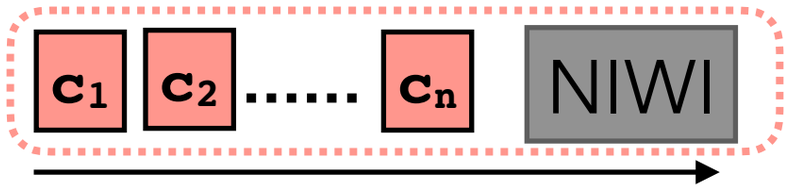

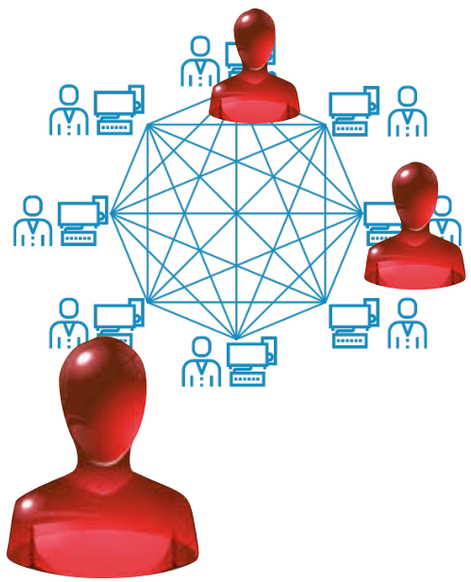

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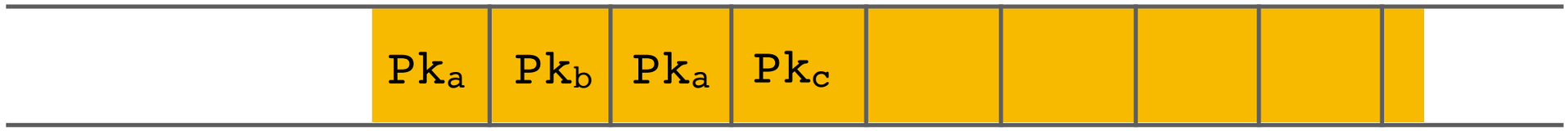

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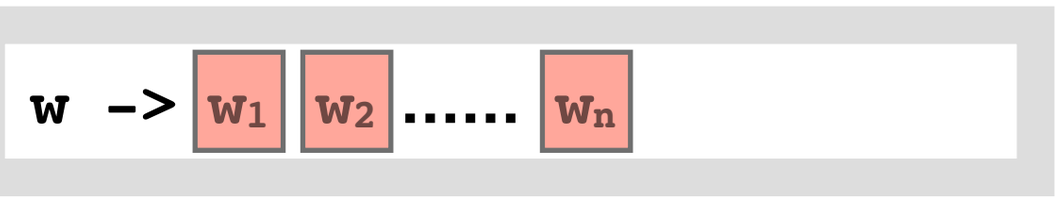

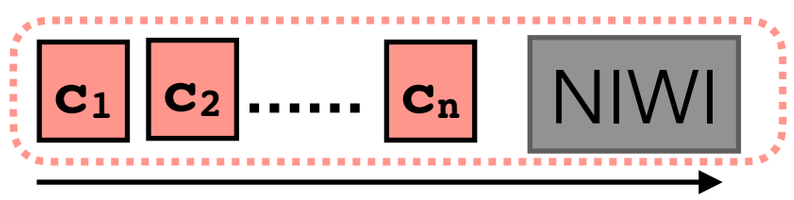

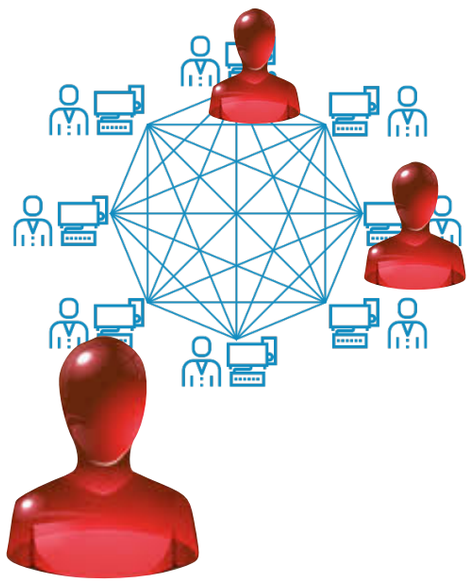

Witness Indistinguishability, CPA security

+ honest majority of stake

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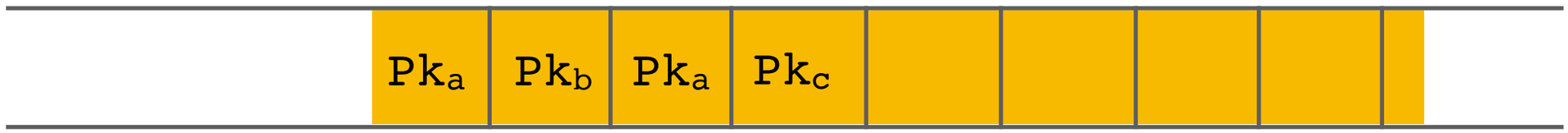

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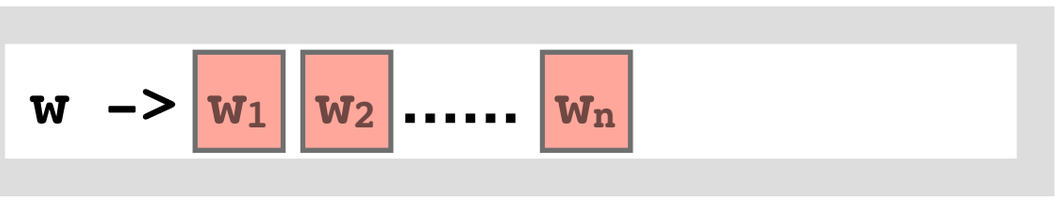

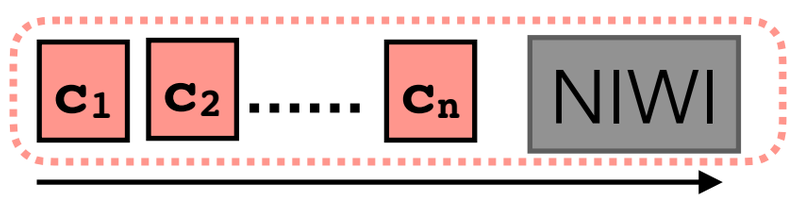

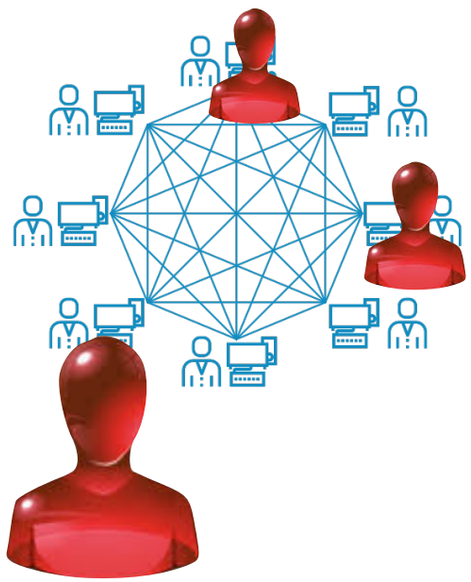

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Additional Assumptions:

❌ No adaptive corruption of blockchain players

❌ Honest stakeholders never reveal their stake key

Our contribution

1 Subtleties in using a blockchain as an assumption

*a single adv playing as blockchain user **invalidates** ZK of GG-NIZK*

1 Invalidating GG-NIZK zero-knowledge property

Assume all the restrictions are satisfied.

❌ No adaptive corruption of blockchain players

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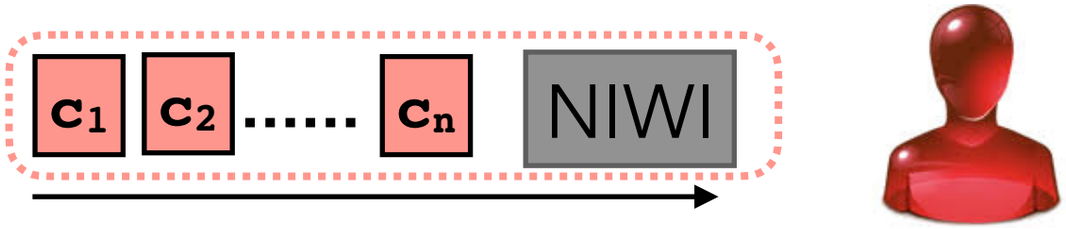

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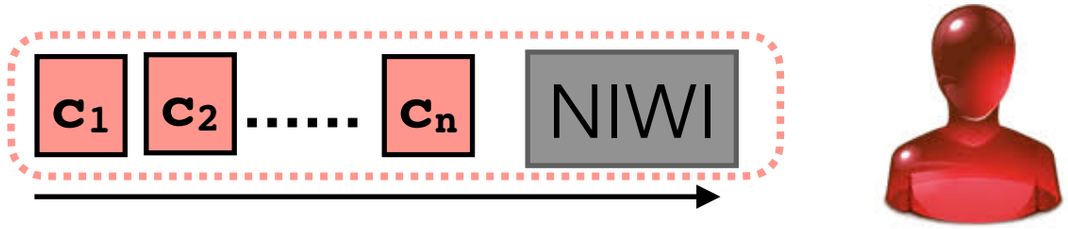

ZK can be violate by playing as a ***user*** of the Blockchain with a legitimate *smart contract*

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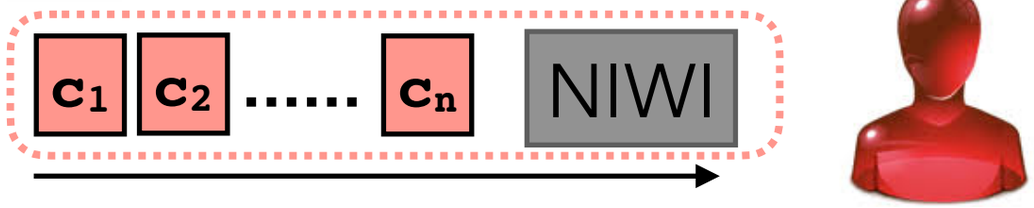

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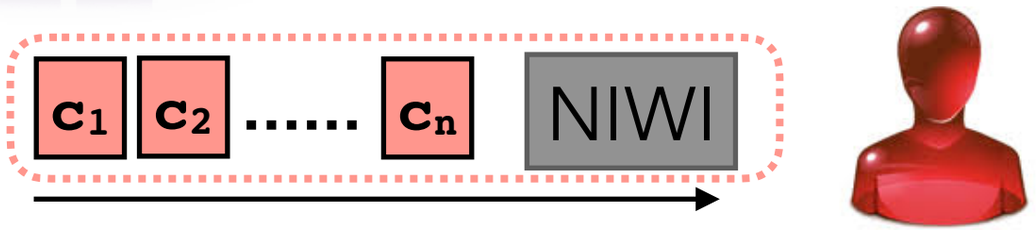

DecryptionForBarbados

1. Init: Upon receiving (init, $reward, ctx, PK_i) from a contractor $\mathcal{C}$:
   - Assert $\mathsf{Ledger}[\mathcal{C}] > \$\mathsf{reward}$.
   - $\mathsf{Ledger}[\mathcal{C}] := \mathsf{Ledger}[\mathcal{C}] - \$\mathsf{reward}$.
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2. Claim: On input (claim, v) from a player Pt_i:
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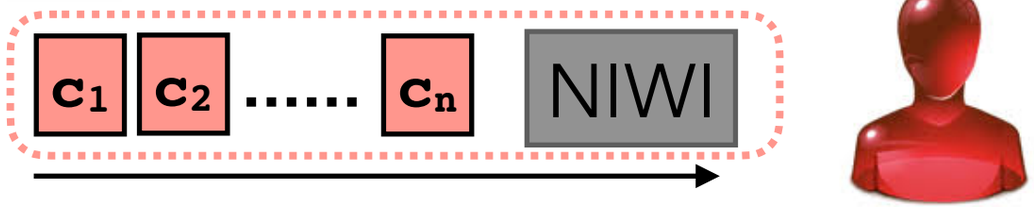

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Observations **Honest Stakeholder** **Adversary**

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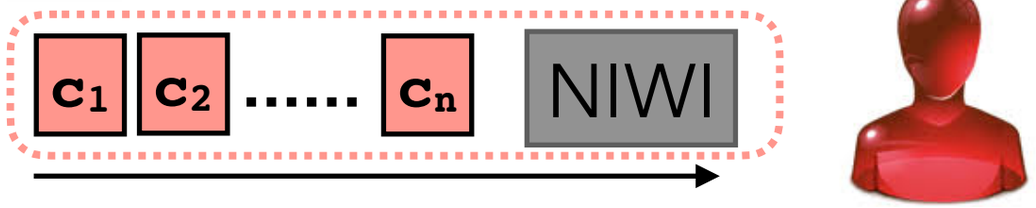

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Honest Stakeholder

- not reveling key

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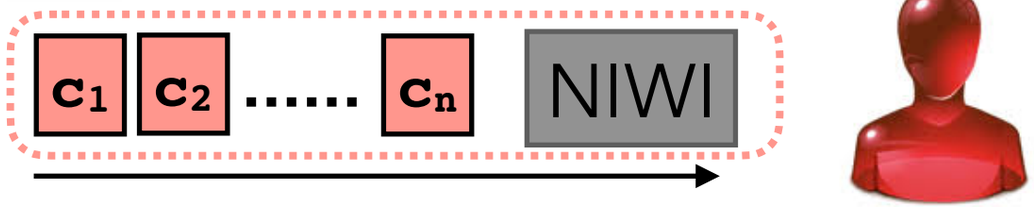

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- unaware that this ctx is part of zk

Adversary

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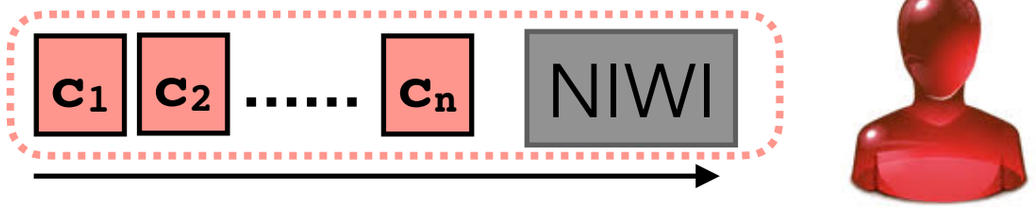

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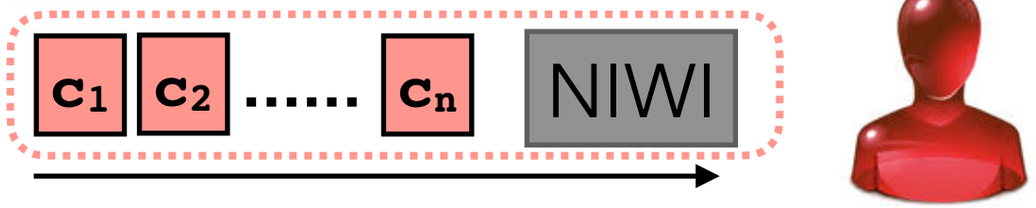
Adversary

- no corruption

1 Invalidating GG-NIZK zero-knowledge property



DecryptionForBarbados

1. Init: Upon receiving (init, $reward, ctx, PK_i) from a contractor $\mathcal{C}$:
   - Assert Ledger$[\mathcal{C}] >$ $reward.
   - Ledger$[\mathcal{C}]$:= Ledger$[\mathcal{C}]$ − $reward.
   - Set state := INIT.

2. Claim: On input (claim, v) from a player Pt_i:
   - Parse $v = (m, r)$.
   - If ctx $= \mathsf{Enc}_{\mathsf{PK}_i}(m, r)$ then set rewards Ledger[Pt] := Ledger[Pt] + $reward.
   - Set state := CLAIMED.

Observations

Honest Stakeholder

- not reveling key
- unaware that this ctx is part of zk

Adversary

- no corruption
- no bribing

1 Observations from our attack

A

B

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A The long-term security of the **external protocol, should not depend on permanent secrets of blockchain players.**

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1 Observations from our attack

A The long-term security of the **external protocol, should not depend on permanent secrets of blockchain players.**

B **No PVZK** is known from a blockchain assumption

Our contribution

1 Subtleties in using blockchain assumption without marrying the threat model

a single adv playing as blockchain user **invalidates** ZK of GG-NIZK

2 PVZK from a “generic blockchain assumption”

*it remains zk even if **all blockchain players** are eventually **corrupt** **(collapsing blockchain)***

2 Property of a Generic Blockchain

Chain-Quality

Any sequence of **N** consecutive blocks contains **K** blocks generated by honest players (where **N**, **K** are parameters that depend on adversarial resources).

2 Our Blockchain Assumption

Chain-Quality

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Our **Chain-Quality assumption**

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Chain-Quality

Any sequence of **N** consecutive blocks contains **K** blocks generated by honest players (where **N**, **K** are parameters that depend on adversarial resources).

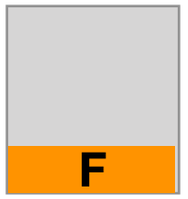
Our **Chain-Quality assumption**

Any sequence of **N** consecutive blocks contains at least **K** blocks generated by honest players and contain an *high-min entropy* string

2 A bit more concretely

Block

A block contains a distinguished field **F** (eg. `coinbase` transaction)



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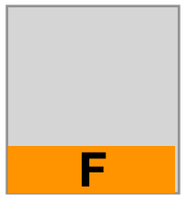

Our **Assumption:**

Any sequence of **N** consecutive blocks contains **K** blocks with *fresh* F and > 1/2 of them are generated by honest players and set to an high-min entropy string.

=> adv cannot predict too many **F** fields at *posting* time.

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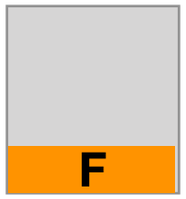

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Example Bitcoin:

Any sequence of **100** blocks contains **50 blocks with** fresh coinbase addresses. And at least 26 of them were created by honest miners.

2 Our PVZK protocol

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- Any Blockchain satisfying our assumption
- Statistically Binding Commitment (OWP)
- Publicly Verifiable Witness Indistinguishable [SSV19] (OWP)
  - ☑ Witness Indistinguishable even if the **Blockchain Collapse**
  - ☑ It can be based on any blockchain that satisfies our assumption

2 Our PVZK protocol

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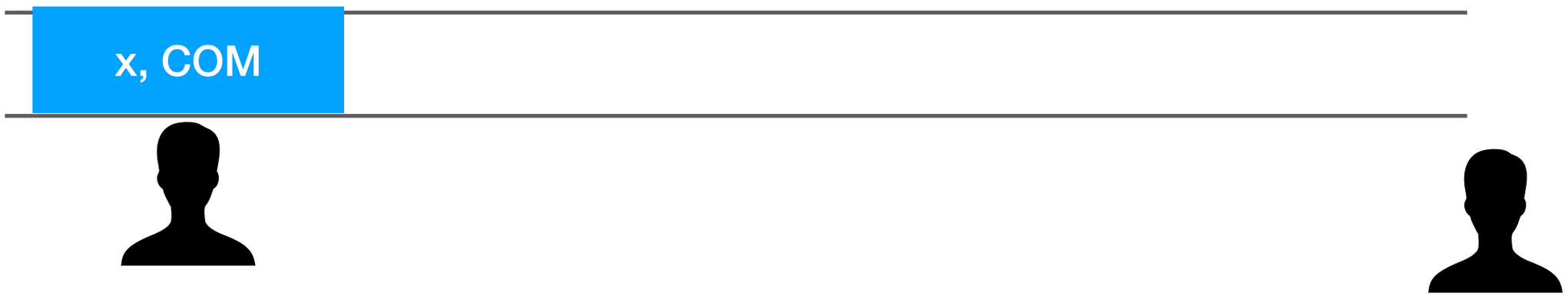

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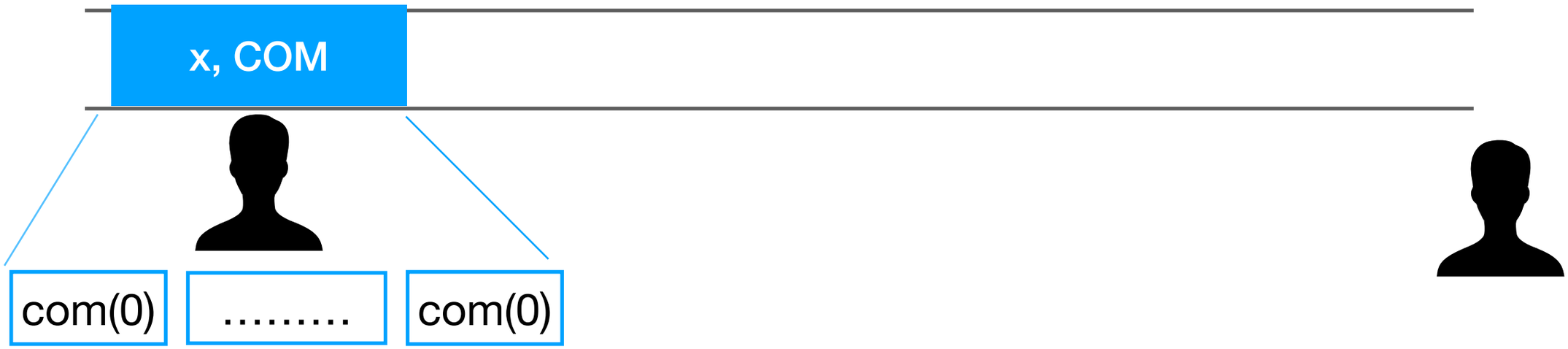

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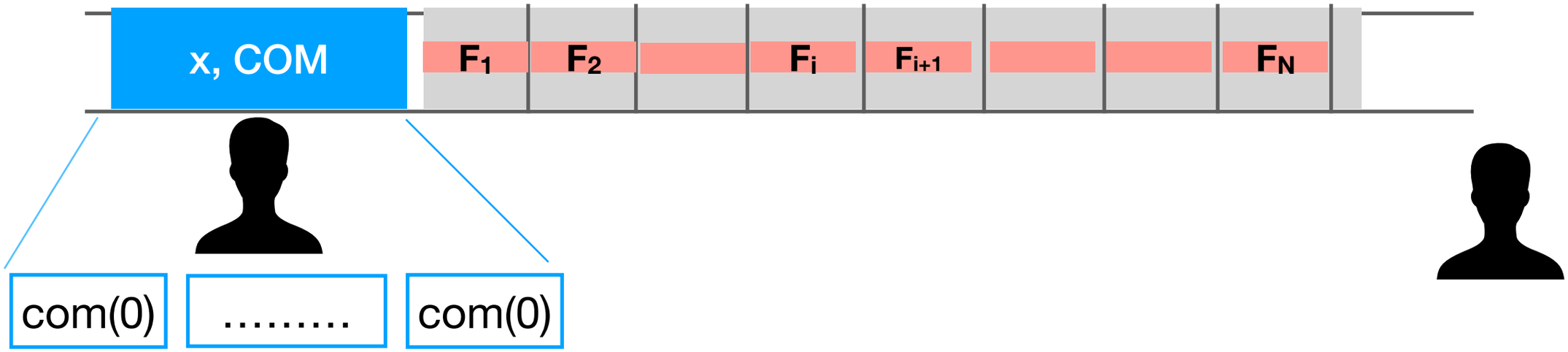

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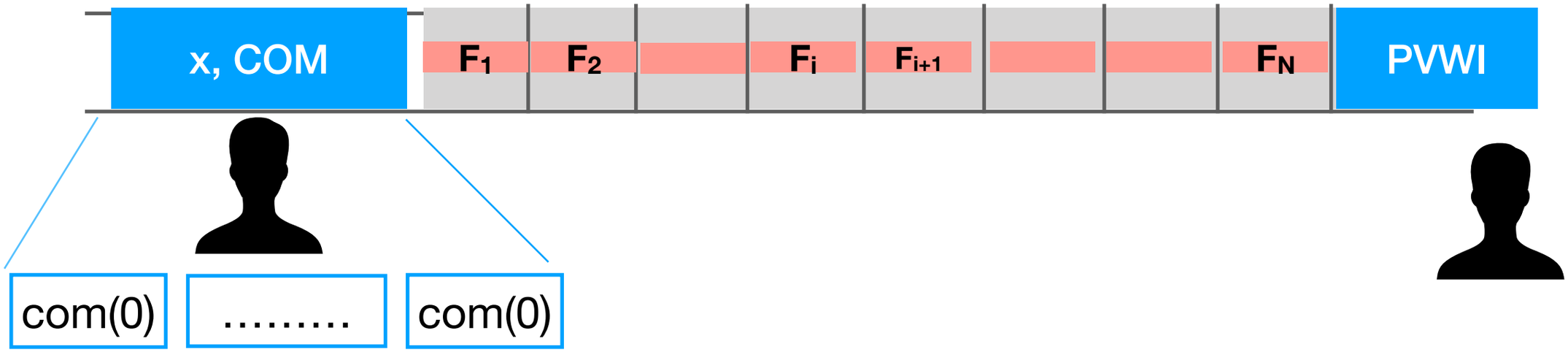

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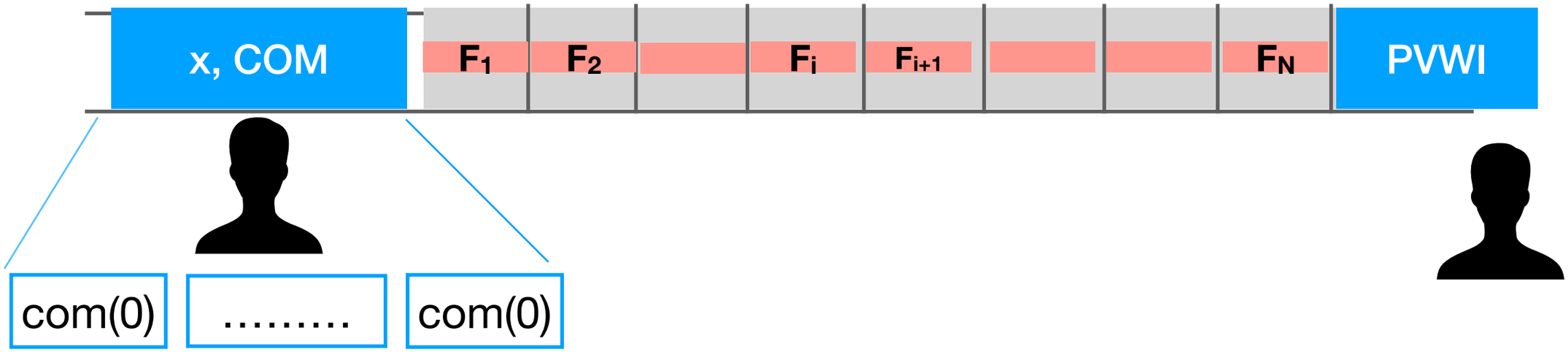

trapdoor theorem

TH: “x in L” OR “I will predict the next K/2+1 field in the BC”

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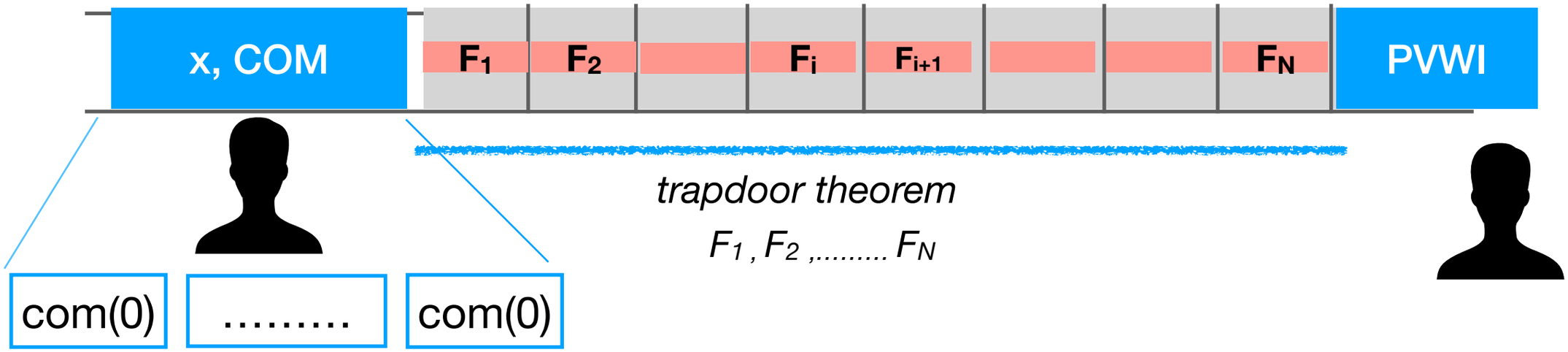

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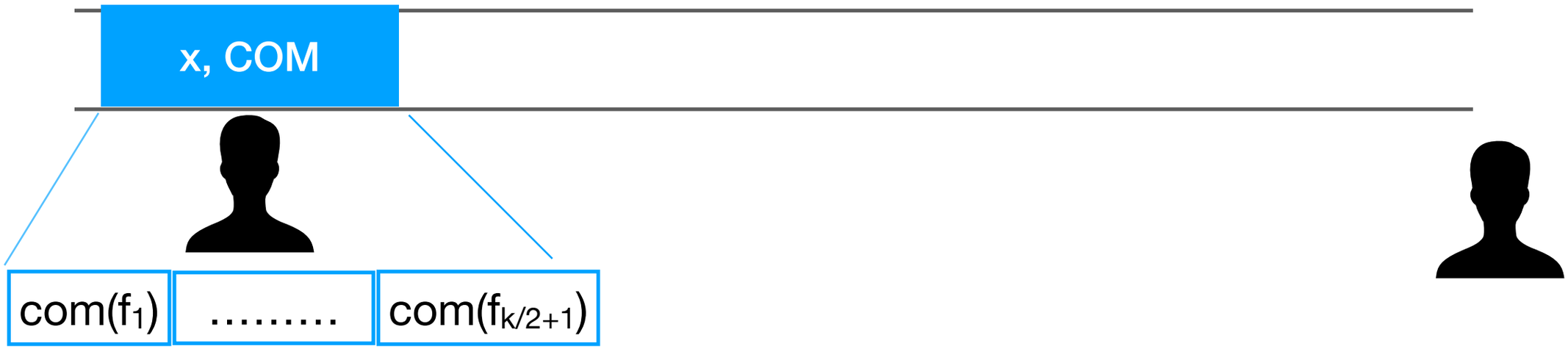

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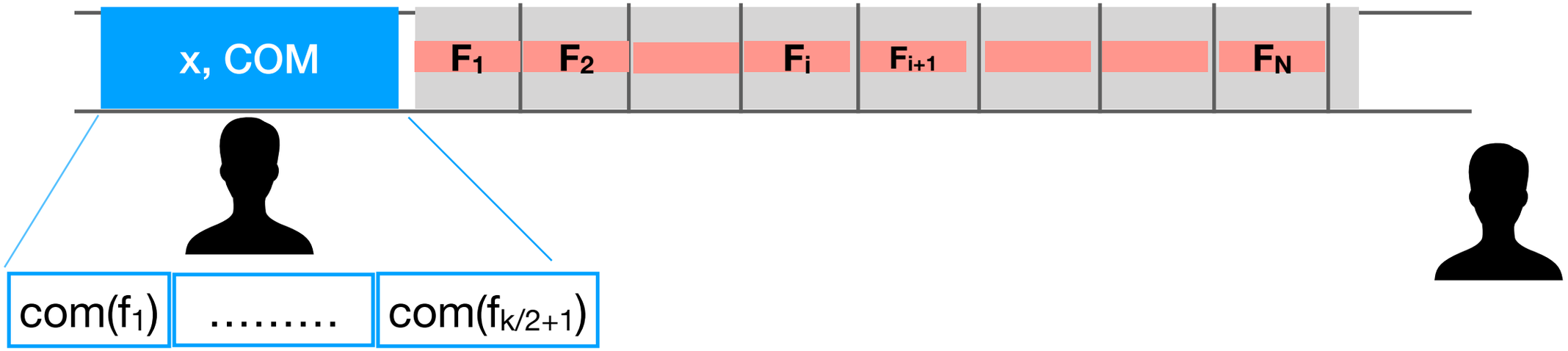

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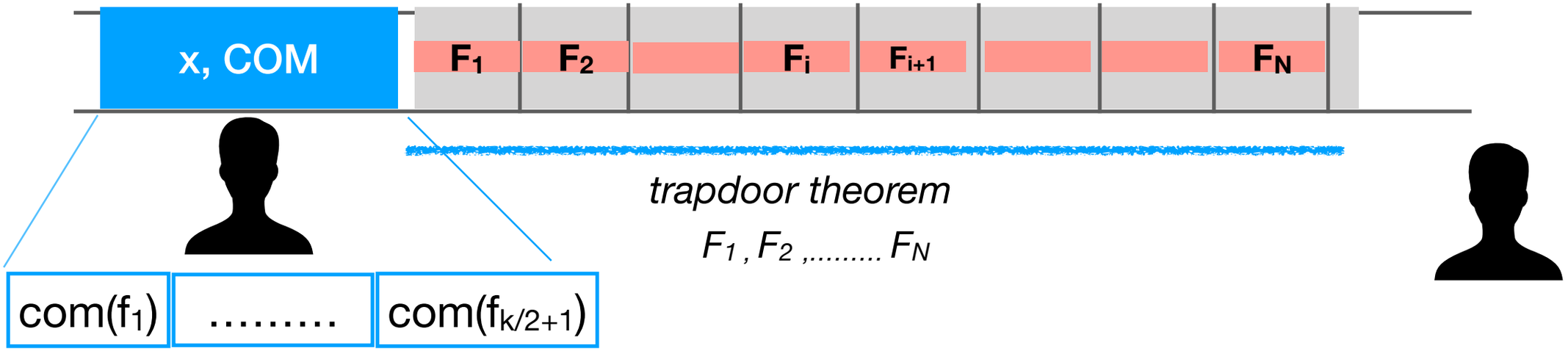

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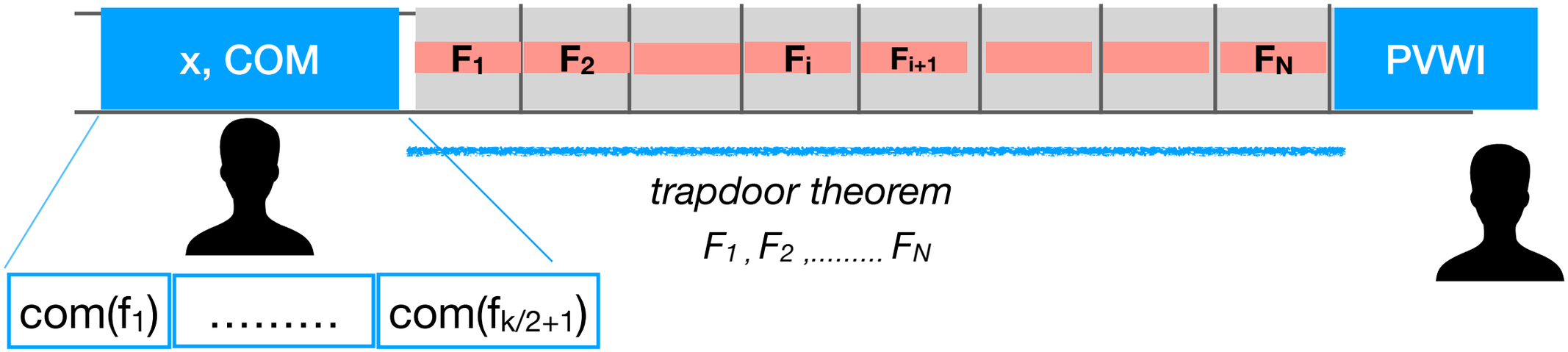

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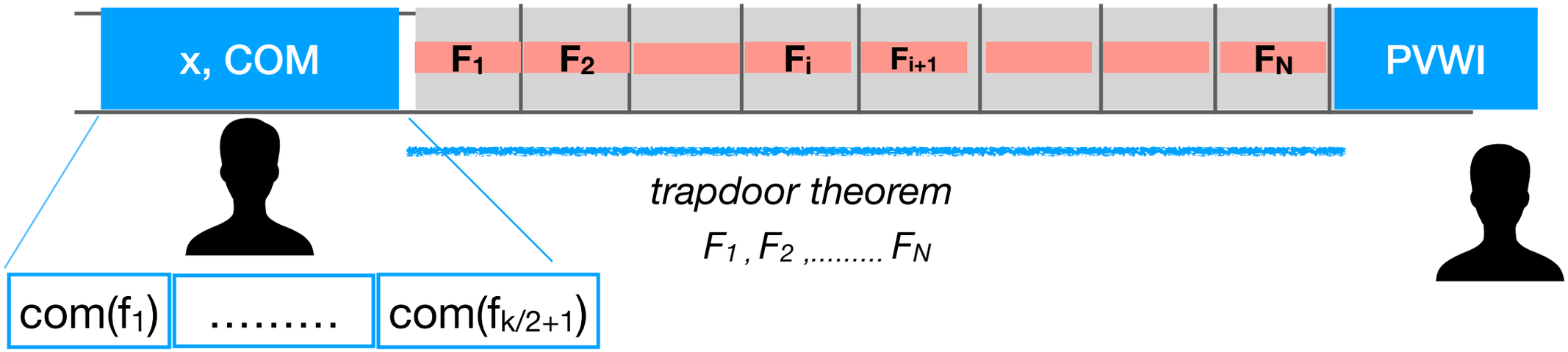

Zero-Knowledge: Simulator

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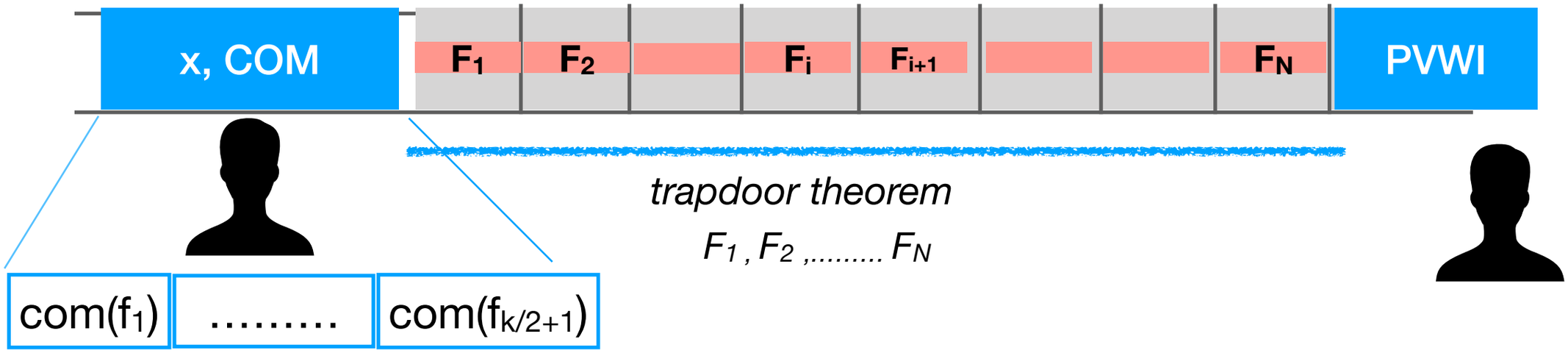

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it controls honest parties

=> *Sets the majority of the random fields F*

=> *Uses WI with the trapdoor witness*

=> *Indistinguishable due to Com (and WI)*

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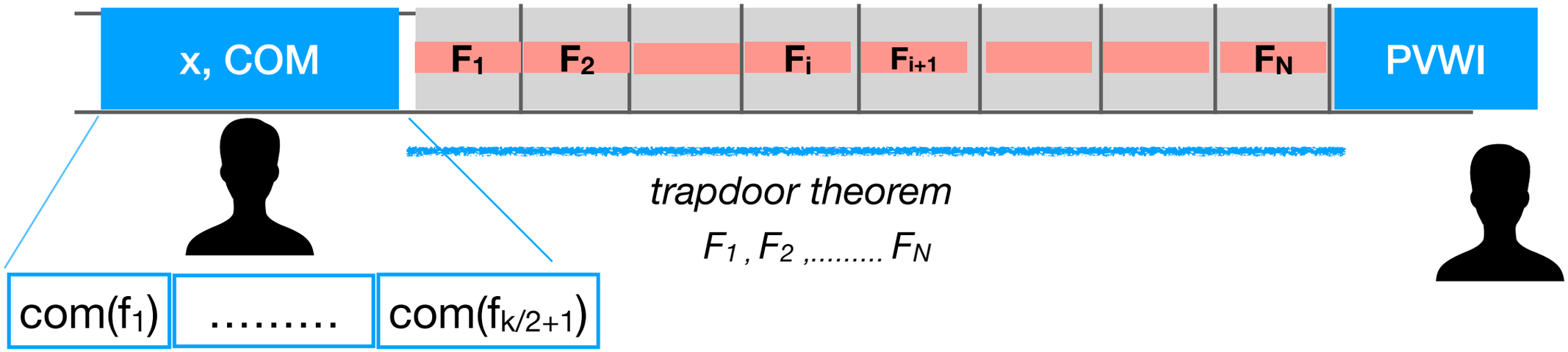

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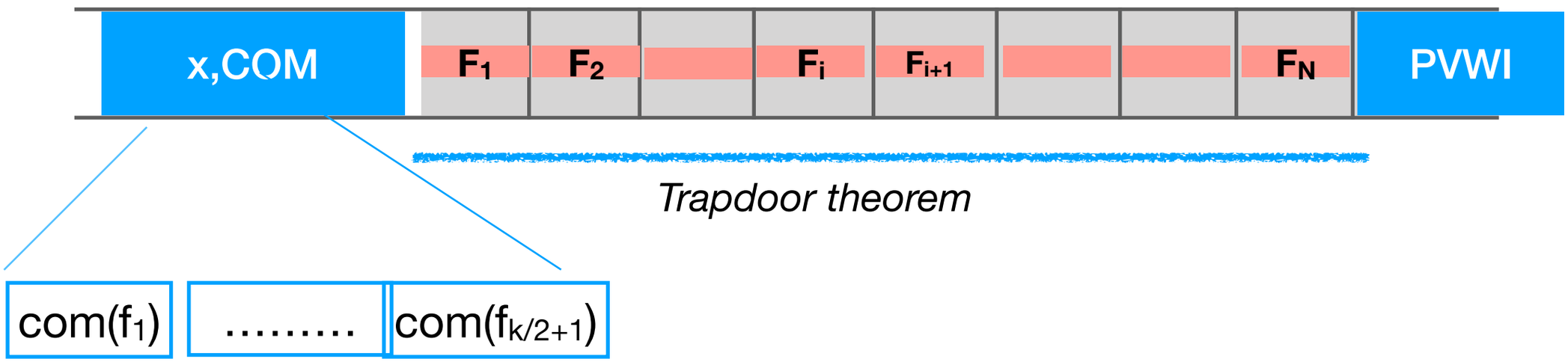
Soundness

follow from our assumption

+

Statistical Soundness of WI

2 ZK even if blockchain Collapses!



Zero-Knowledge in Presence of Blockchain Collapse!

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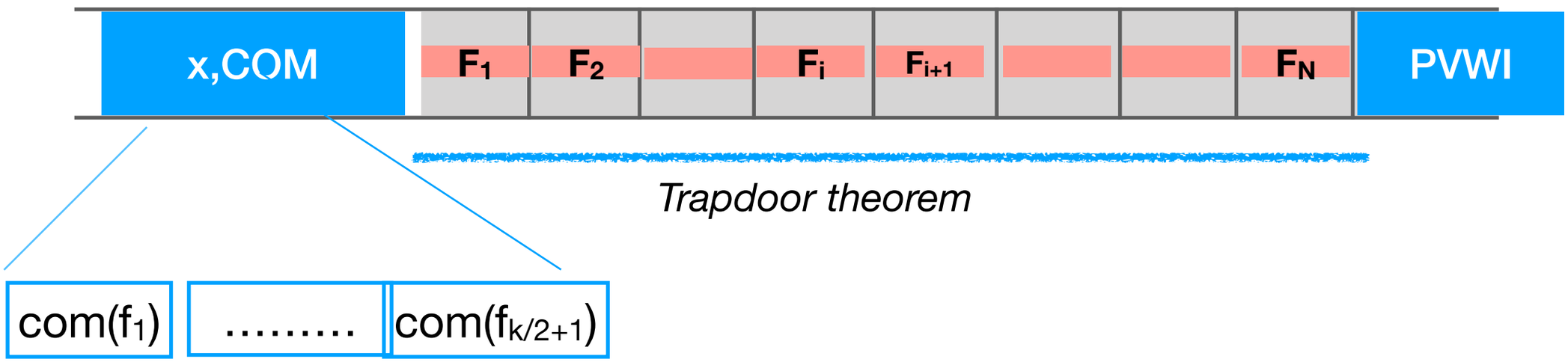

Zero-Knowledge in Presence of Blockchain Collapse!

knowing private states and *keys of all the blockchain players*
does not help breaking commitments neither forward WI.

Conclusion: We show

Our PVZK vs GG-NIZK

	Completely non-interactive	**Type of Blockchain**	**Complexity Assumptions**	**Further restrictions on a) consensus protocol, b) stake transfer protocol, c) smart contracts**
[GG17]	Yes	PoS blockchain	NIWI	The honest stakeholders should not: -reveal their secrets even with 0 stake -participate in other applications
PVZK	No - P writes messages in the blockchain	Any blockchain satisfying some assumption	OWPs	None

Thanks