What does the SHARK say?

Mariana Raykova
Eran Tromer
Madars Virza

Zero-knowledge on the blockchain

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Privacy-preserving cryptocurrencies

Privacy-preserving smart contracts

Proof of regulatory compliance

Blockchain-based sovereign identity

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see [ZKProof Standardization – Applications Track]

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Need zero-knowledge non-interactive arguments of knowledge, ideally succinct ones: zk-SNARK.

Which zk-SNARK?

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- QAP-based [GGPR13][PGHR13][BCGTV13][DFGK14][Groth16][GM17][BG18]…

  Fastest verification. Widely used.

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  ZKProof Standardization

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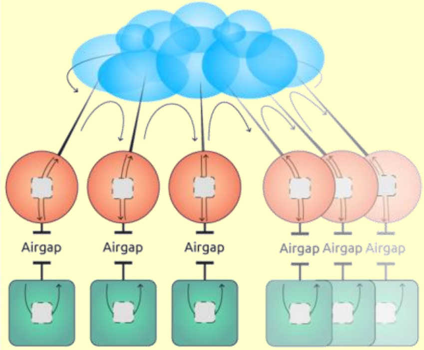

- Trusted setup
- MPC + destruction [BCGTV15][BGG17]
- Updatable SRS [GKMMM18, MBKM19]
- Scalable SRS generation ("Powers of Tau") [BGM18]

Avoiding a Structured Reference String

Other zk-SNARKs

- PCP-based (e.g., *libSTARK*)

[Micali94][BCGT13][BCS16][BBCGGHPRSTV17][BBHR18]

Asymptotically succinct but large constants.

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Non-succinct ZK:

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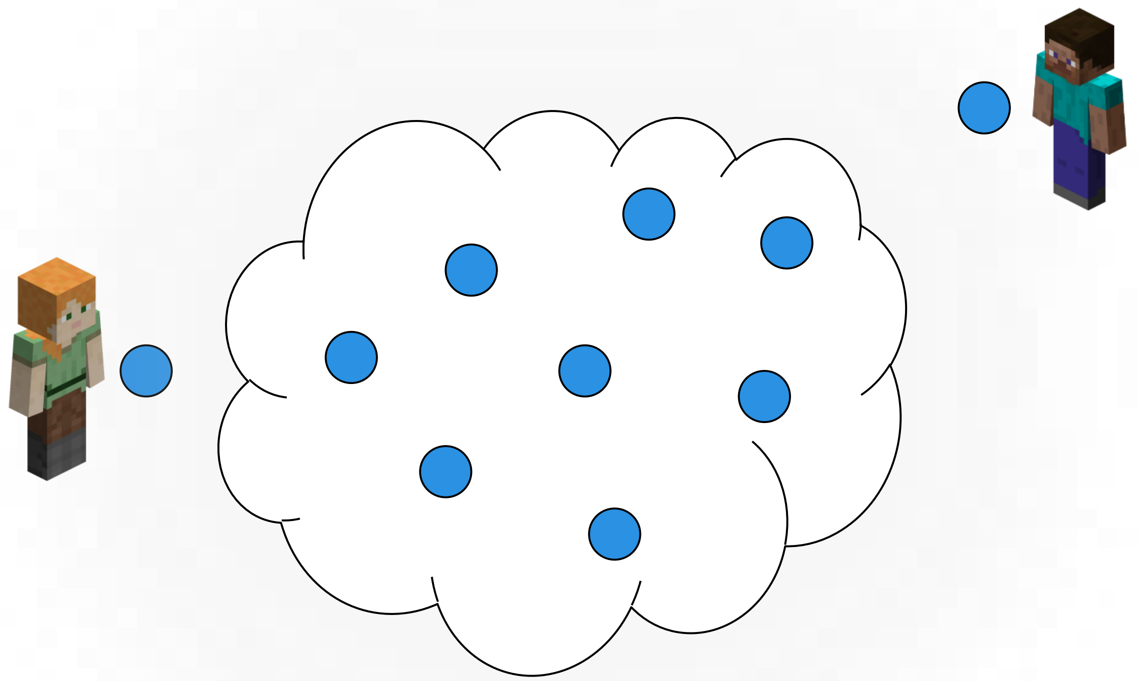
Non-succinct ZK:

- Aurora [BCRSVW19]
- Bulletproofs [BCCGP16][BBBPWM17]
- Hyrax [WTSTW17]
- Ligero [AHIV17]
- ZKBoo(++) [GMO16][CDGORRSZ17]

Slow verification and/or large proofs (as statement grows).

Proof transmission & verification speed



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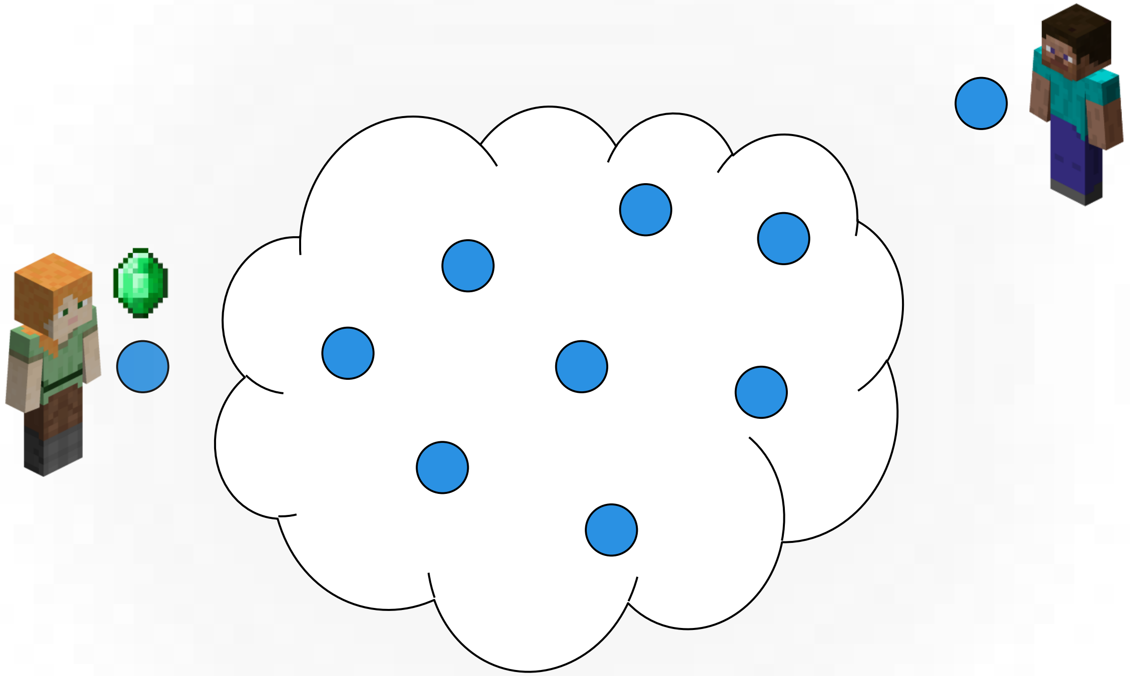

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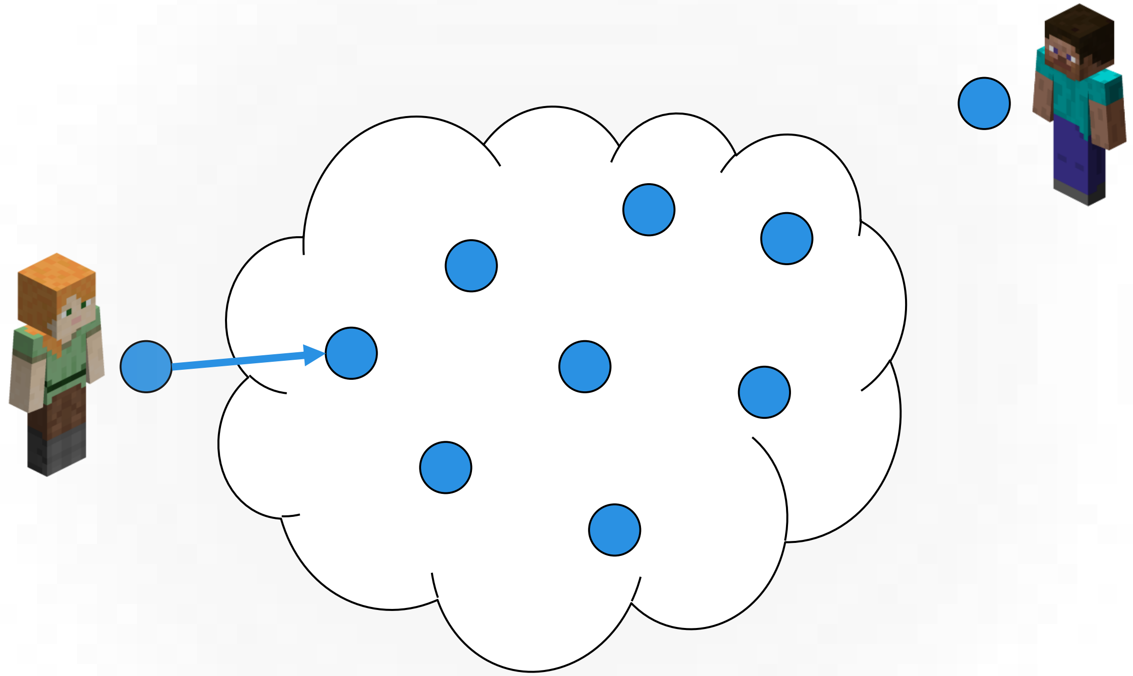

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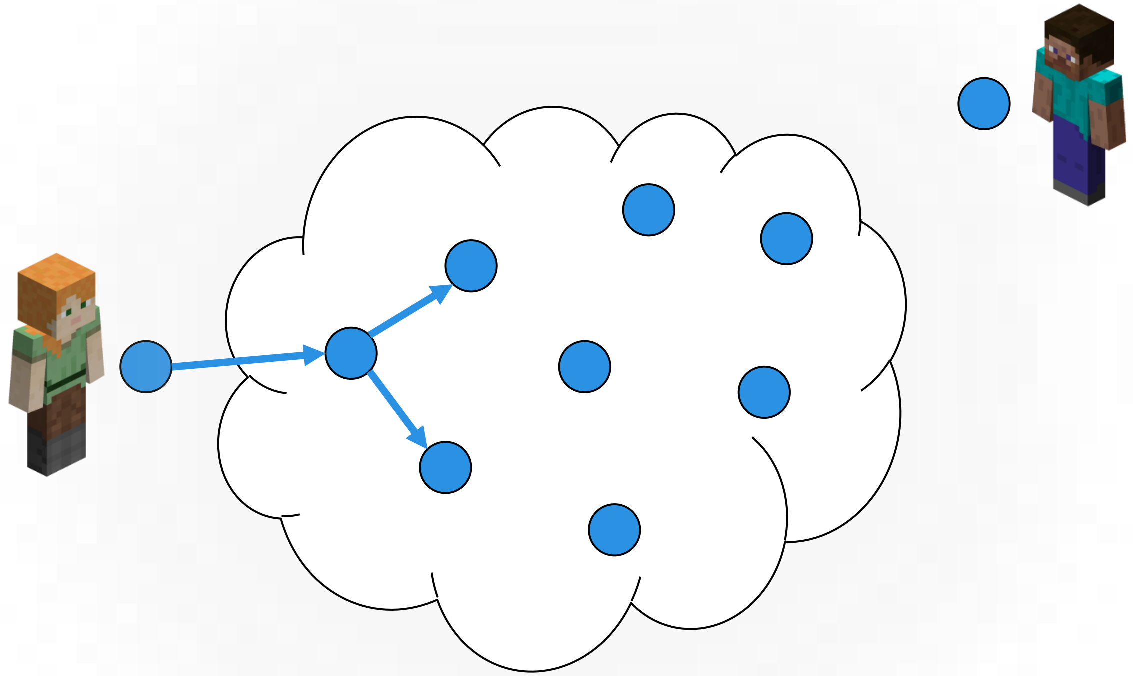

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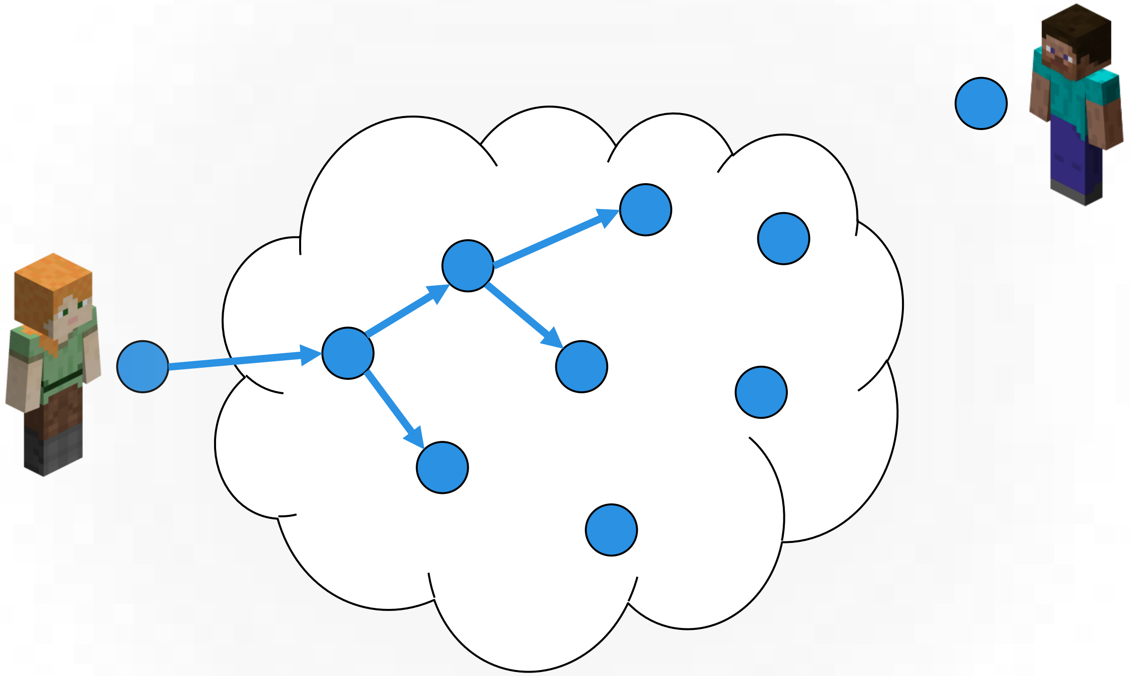

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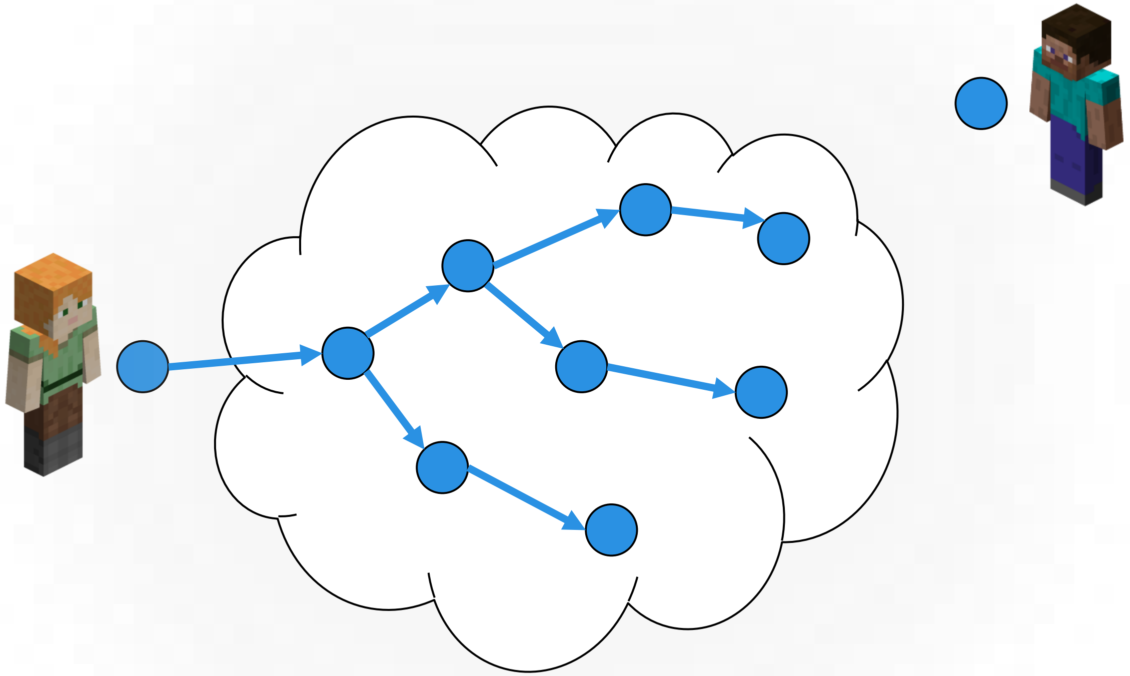

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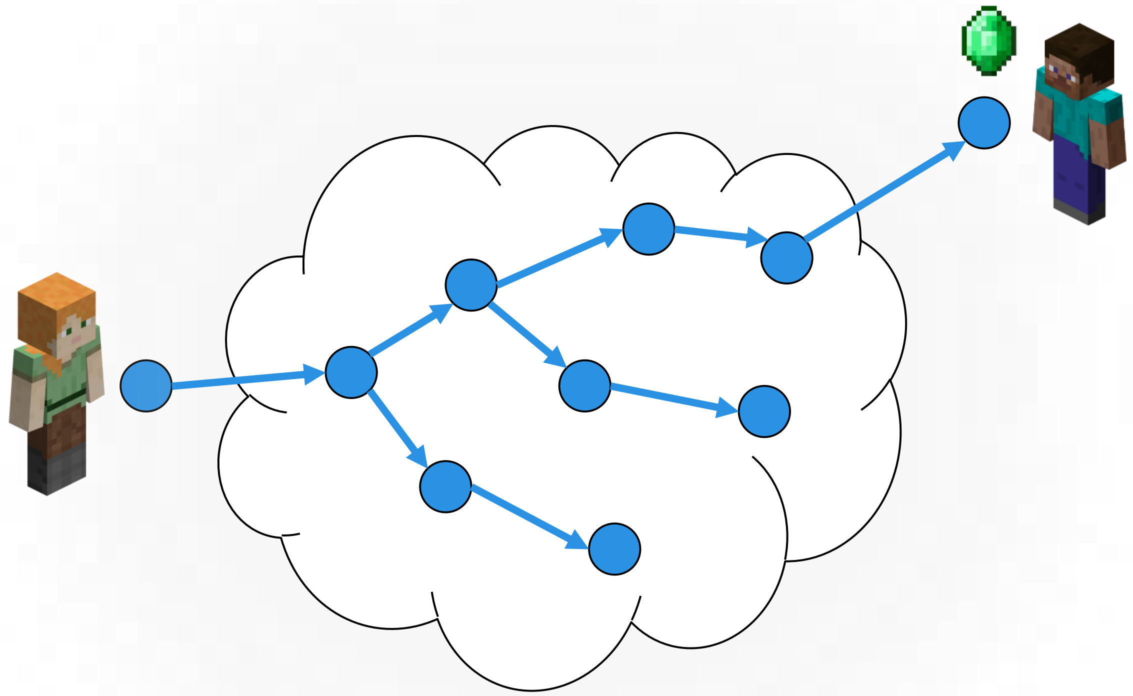

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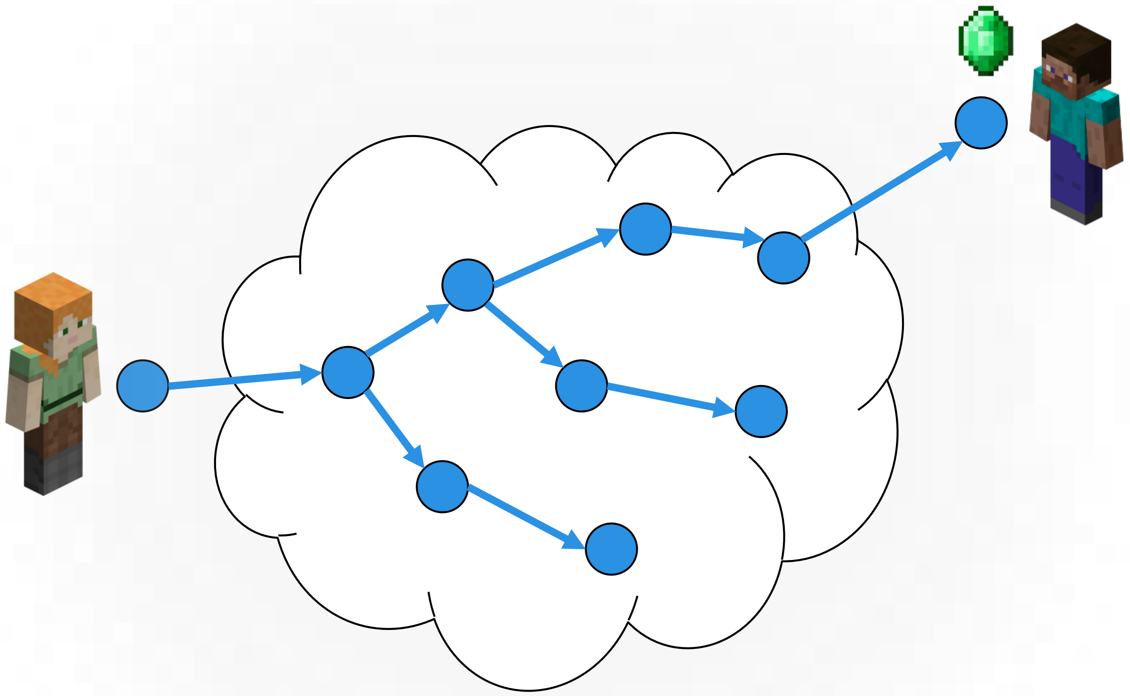
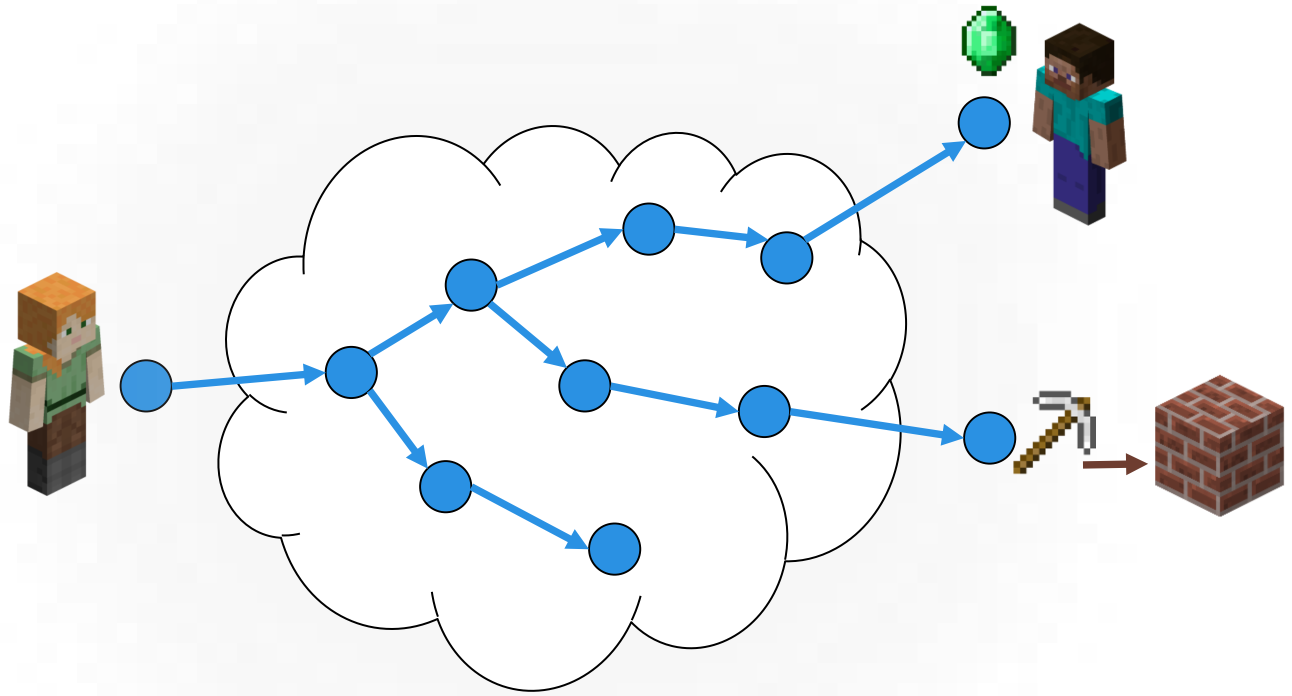


Seeing
transactions

Proof transmission & verification speed



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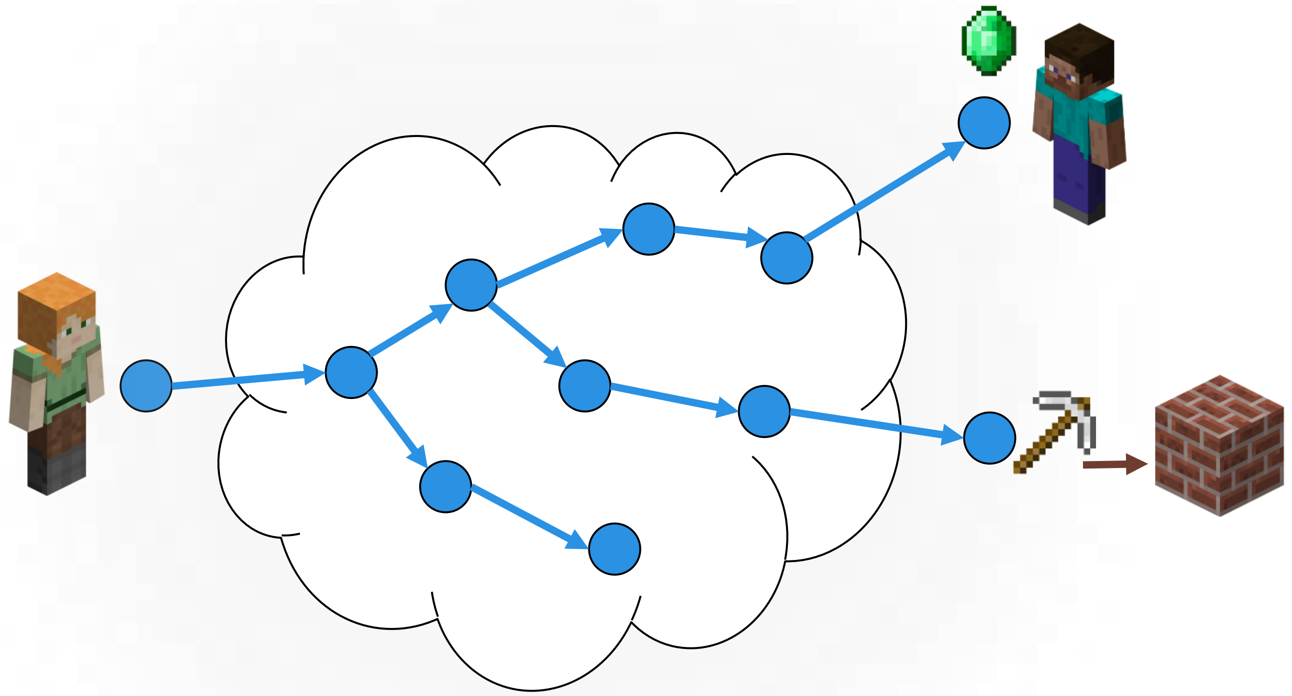

Seeing transactions

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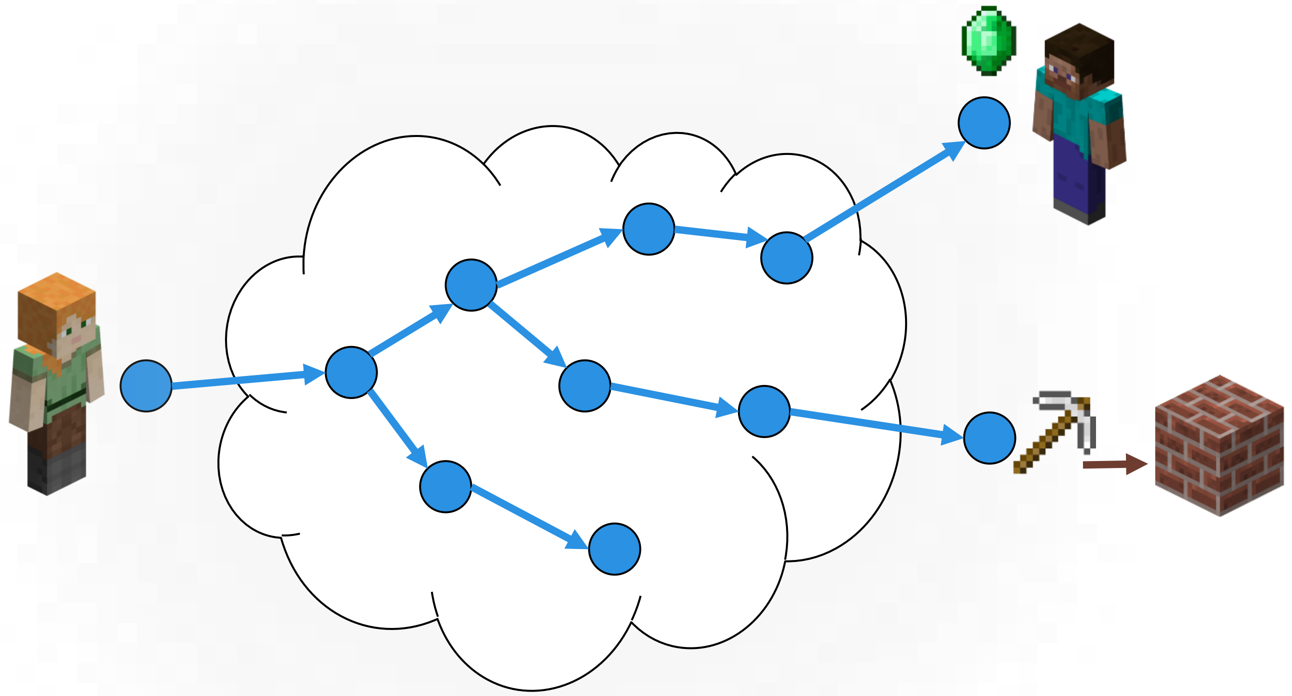

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Slow verification
→ miners get a head start by not validating
→ double-spends and chain splits [July 2015 Bitcoin fork]

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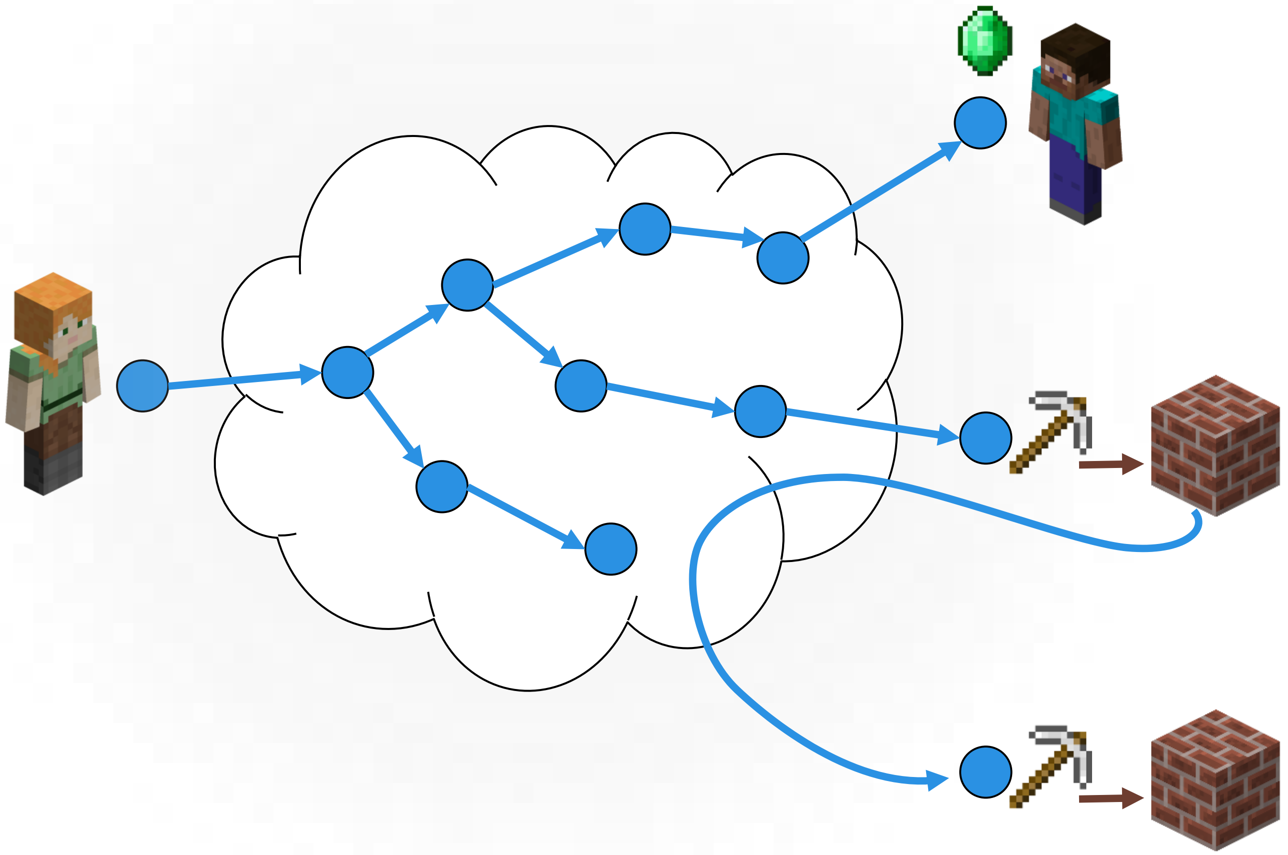

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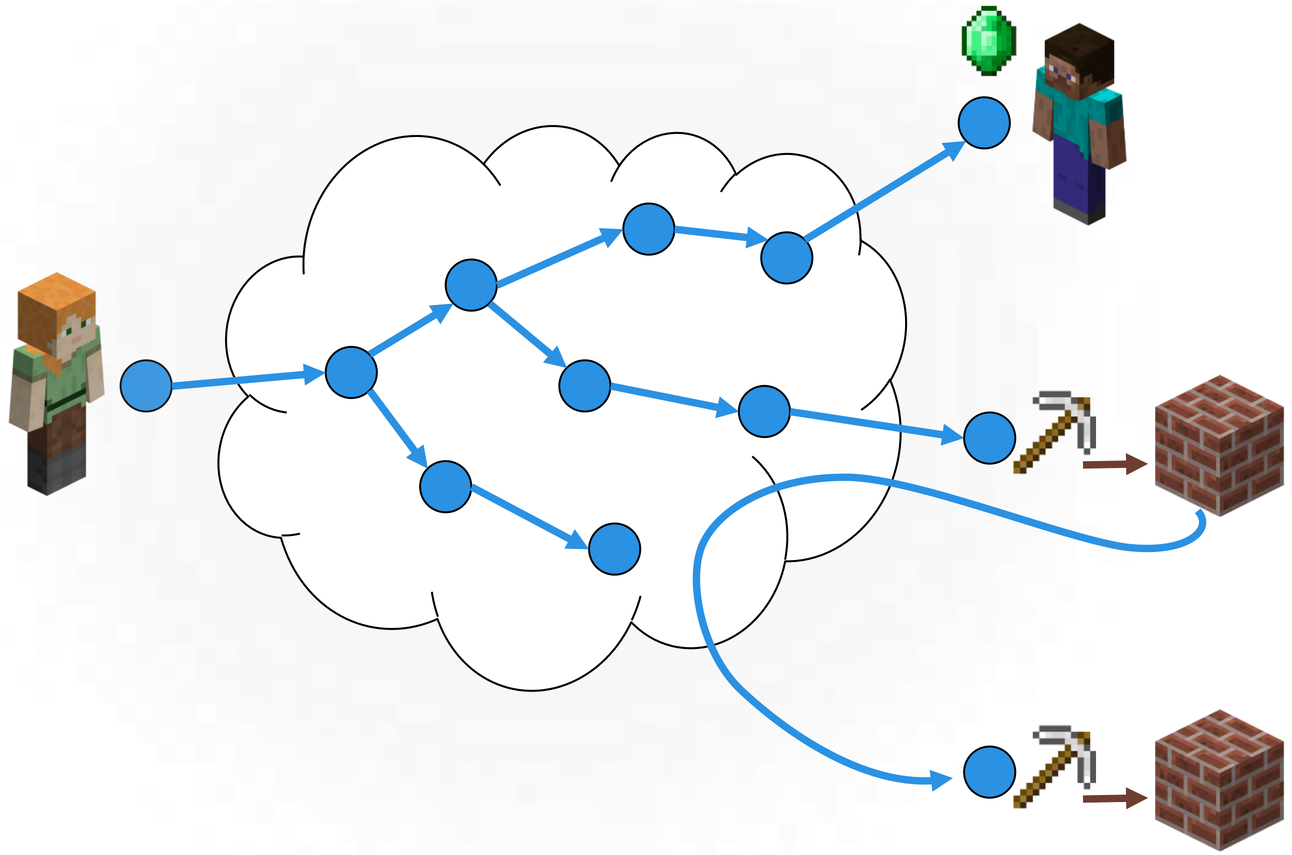

Seeing transactions

Including new transactions in a block

Verifying the previous block

Slow verification

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zk-SHARK

zero-knowledge
succinct hybrid argument of knowledge

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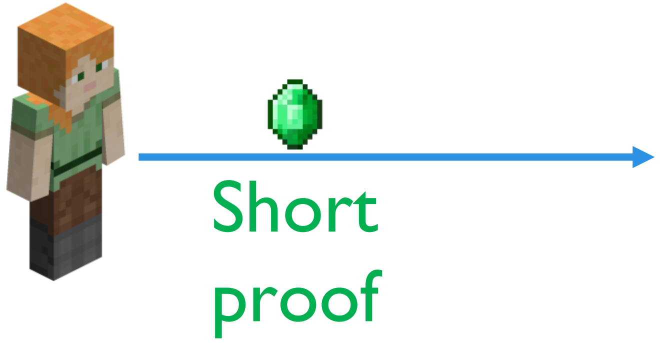

zk-SHARK

zero-knowledge
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Short
proof

Prudent verification

Slow (comparable to Bulletproofs)

No SRS

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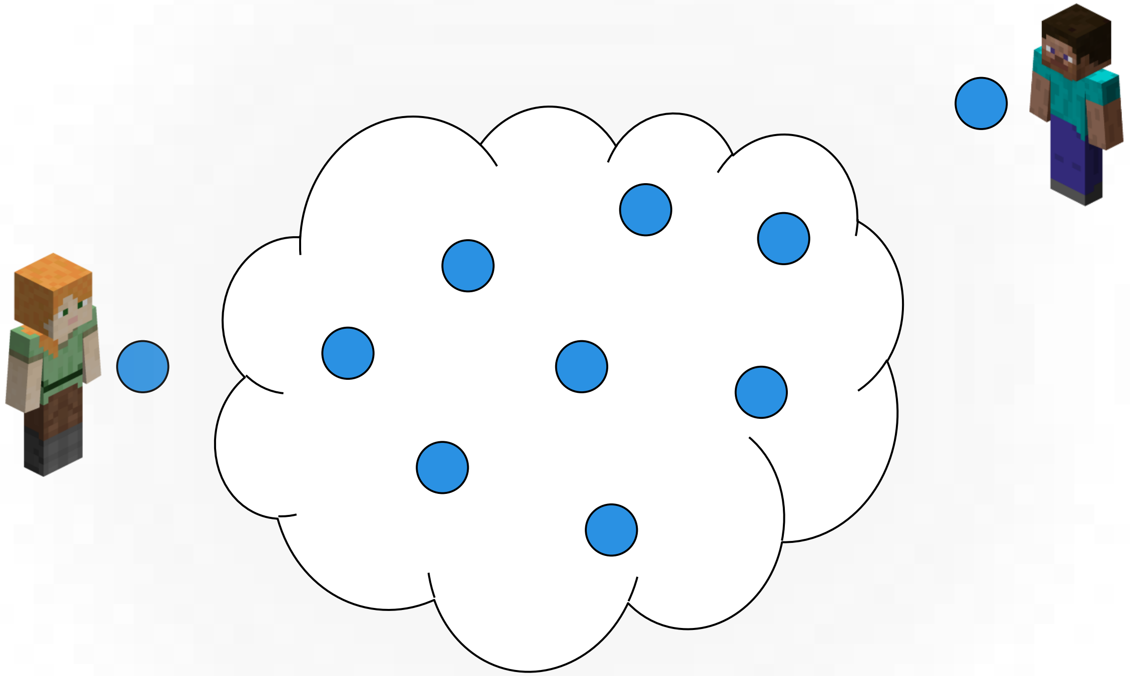
Optimistic verification

Fast (comparable to QAP-based SNARK)

Relies on SRS

Proof transmission & verification speed



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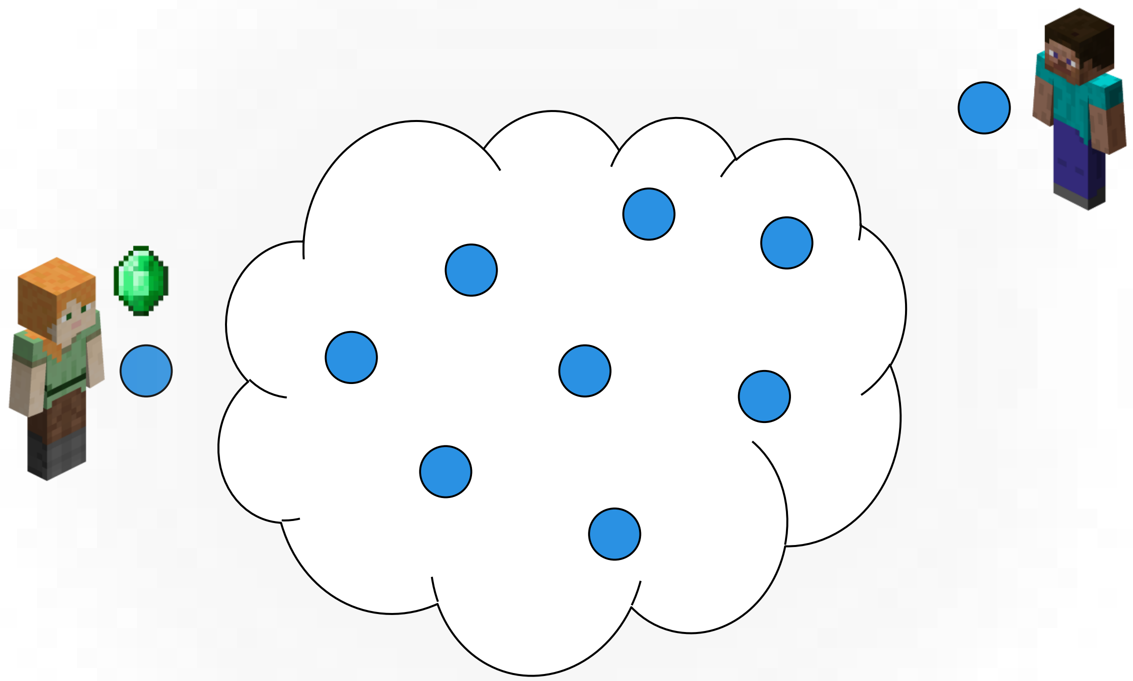

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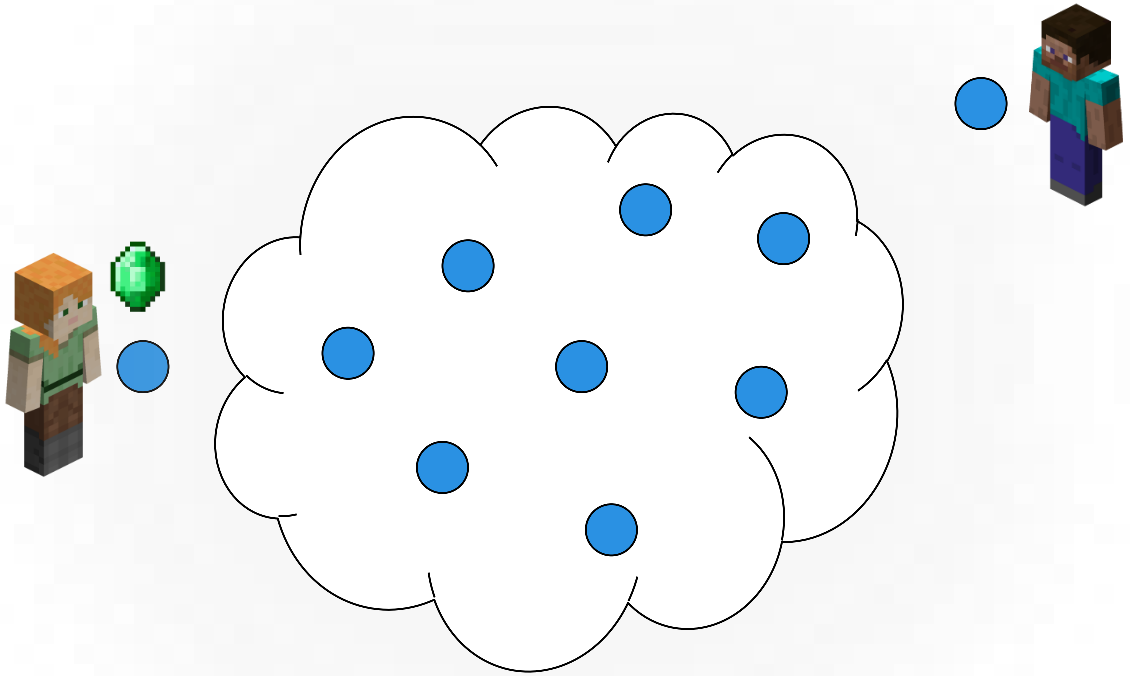

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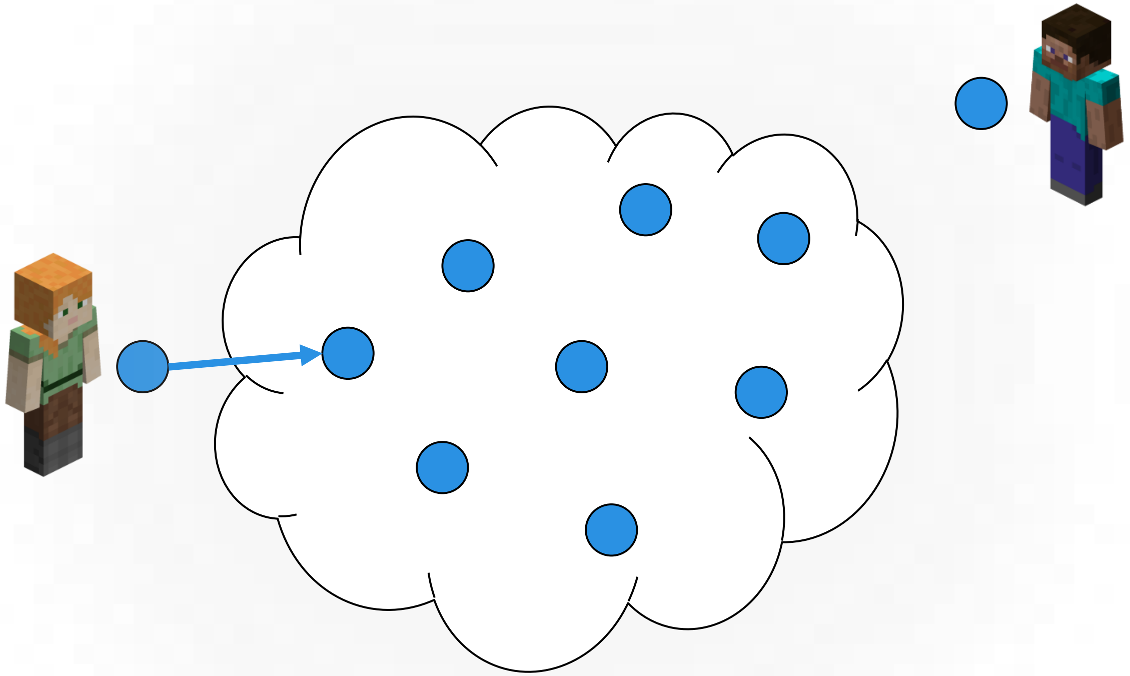

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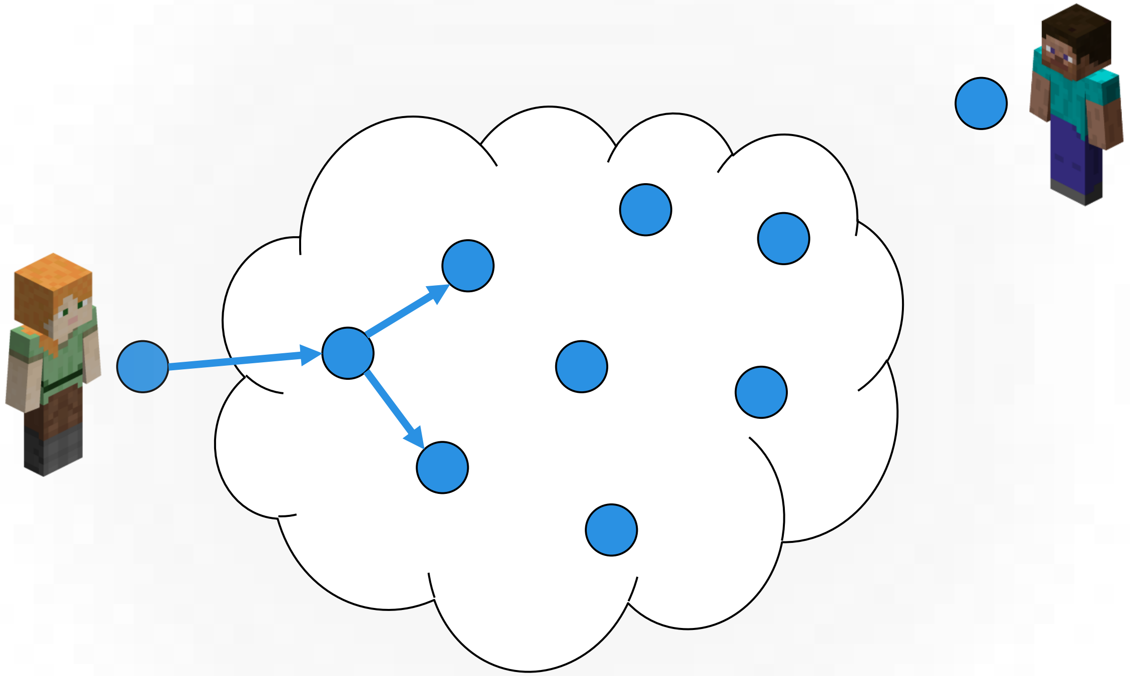

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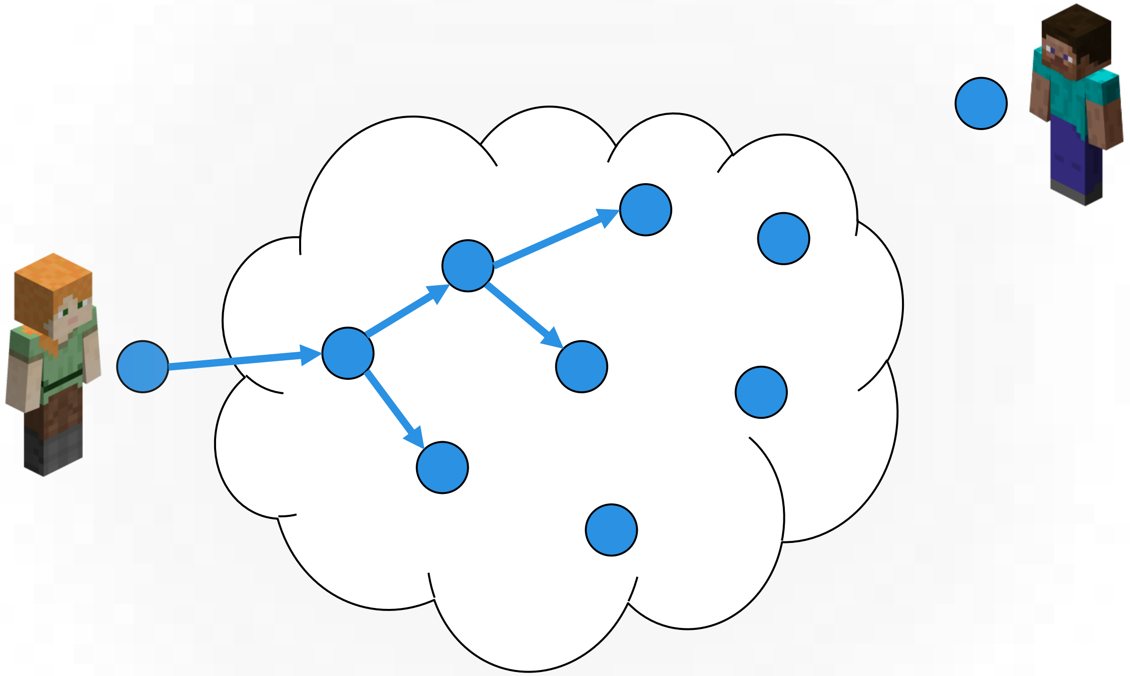

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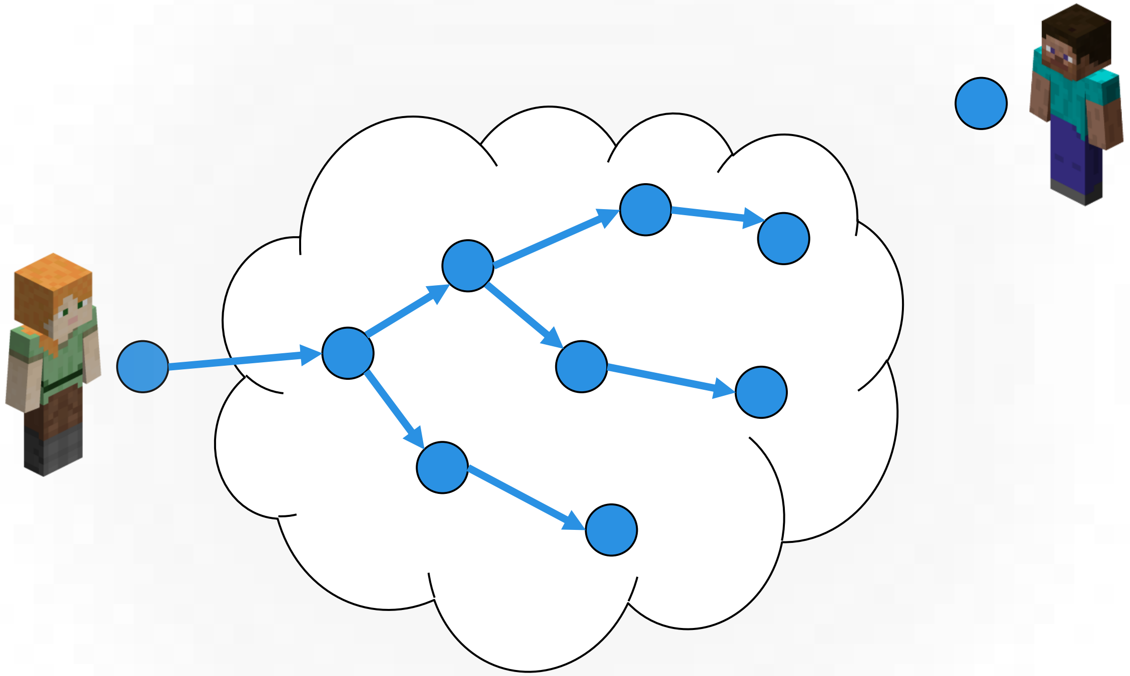

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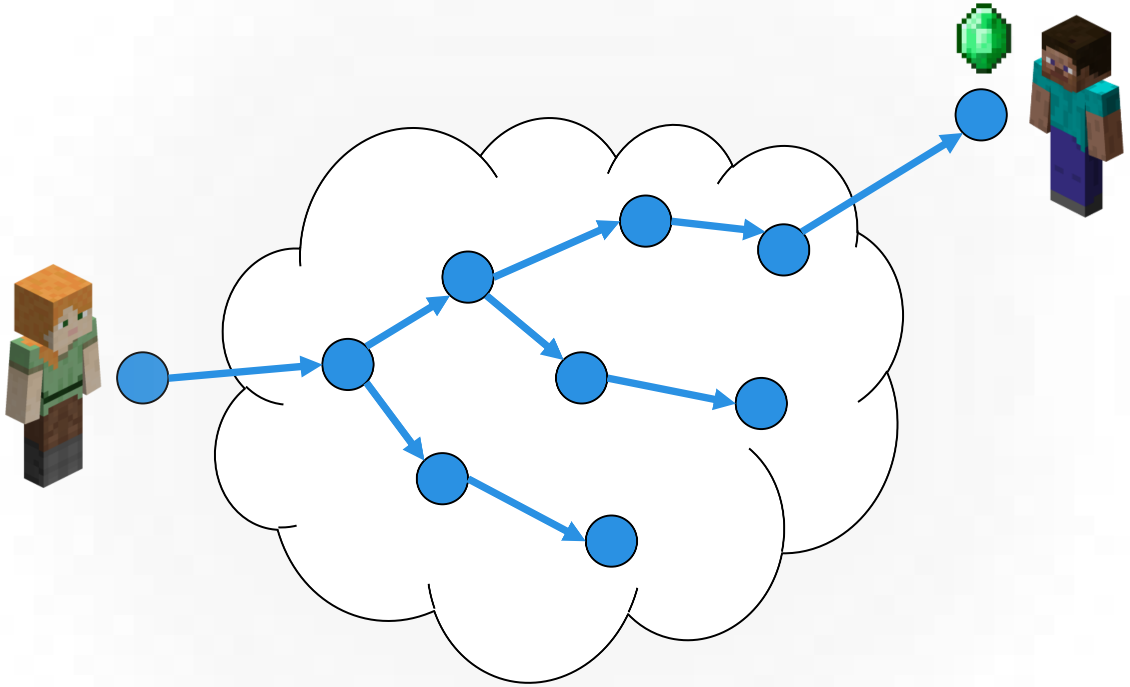

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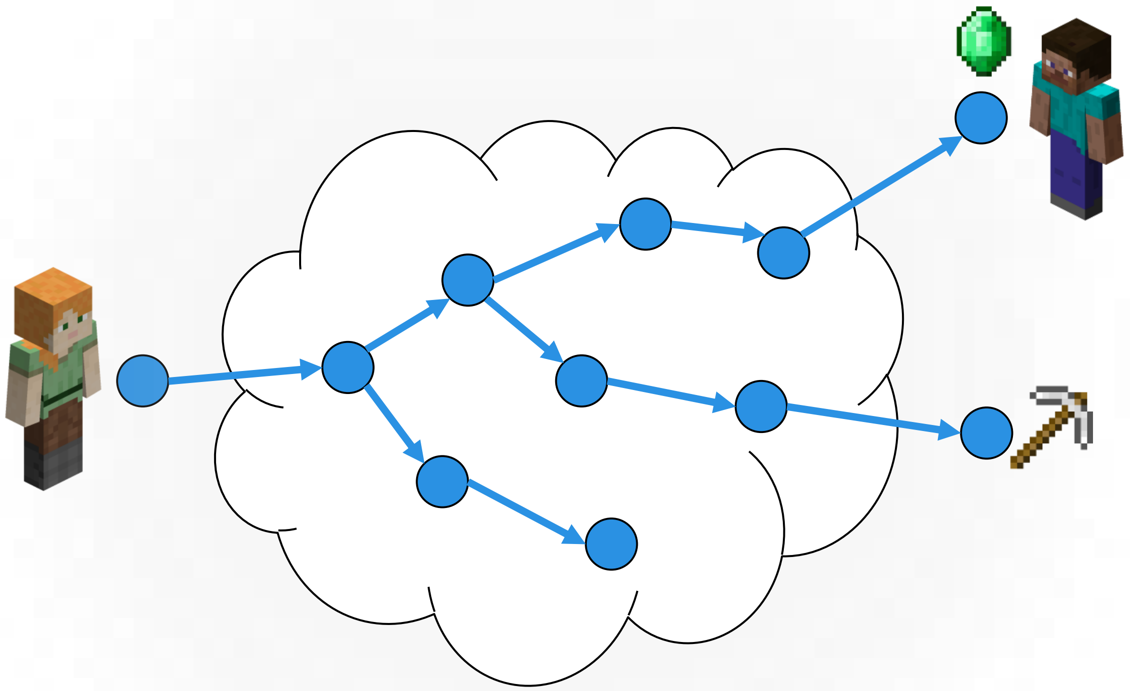

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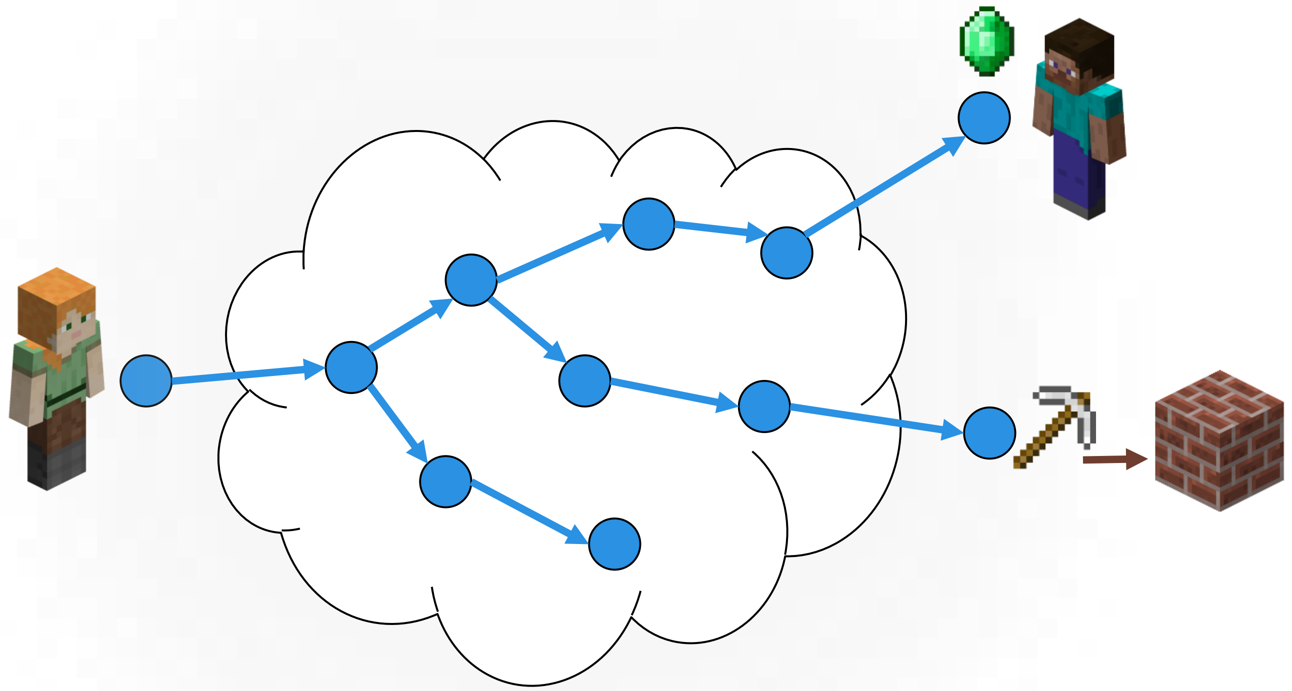

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Optimistically verify tx for inclusion in block template.

Prudently verify later, during PoW.

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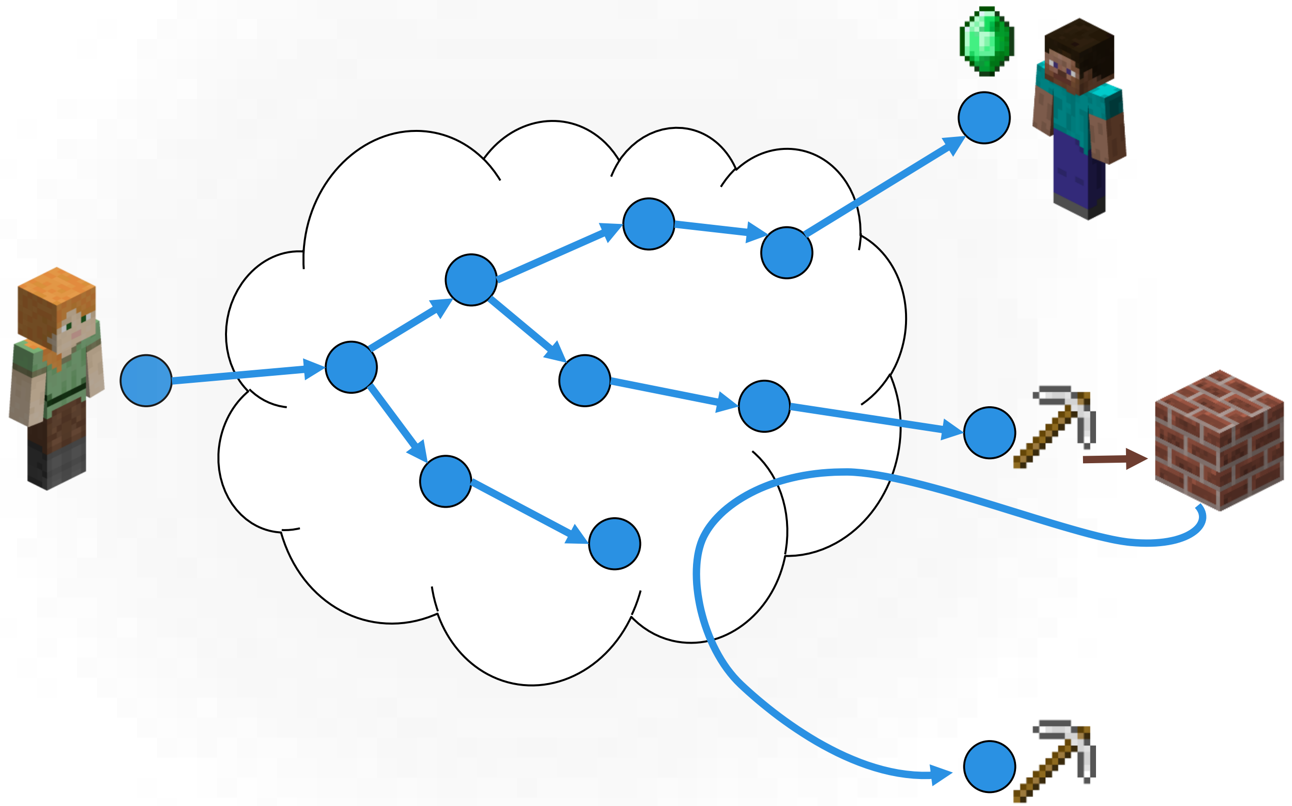

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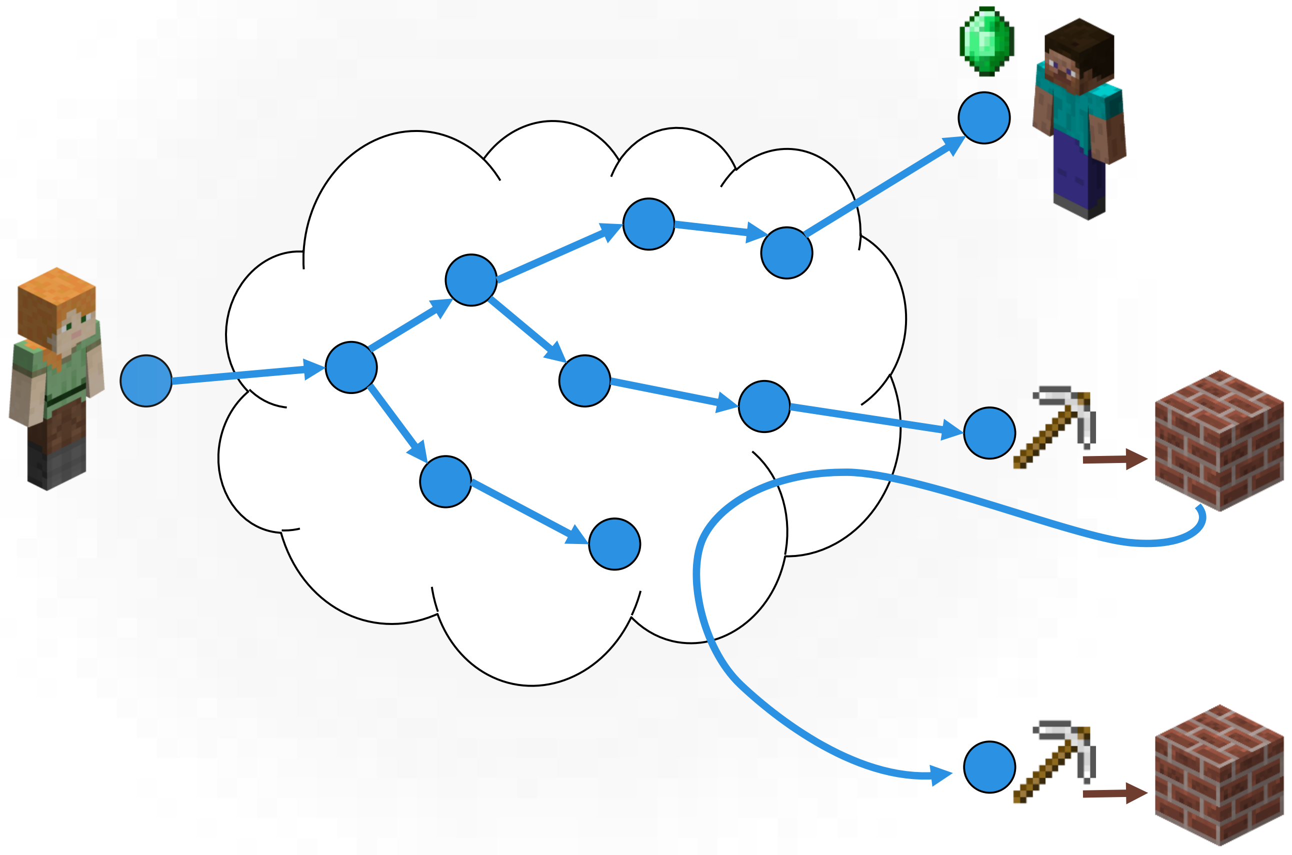

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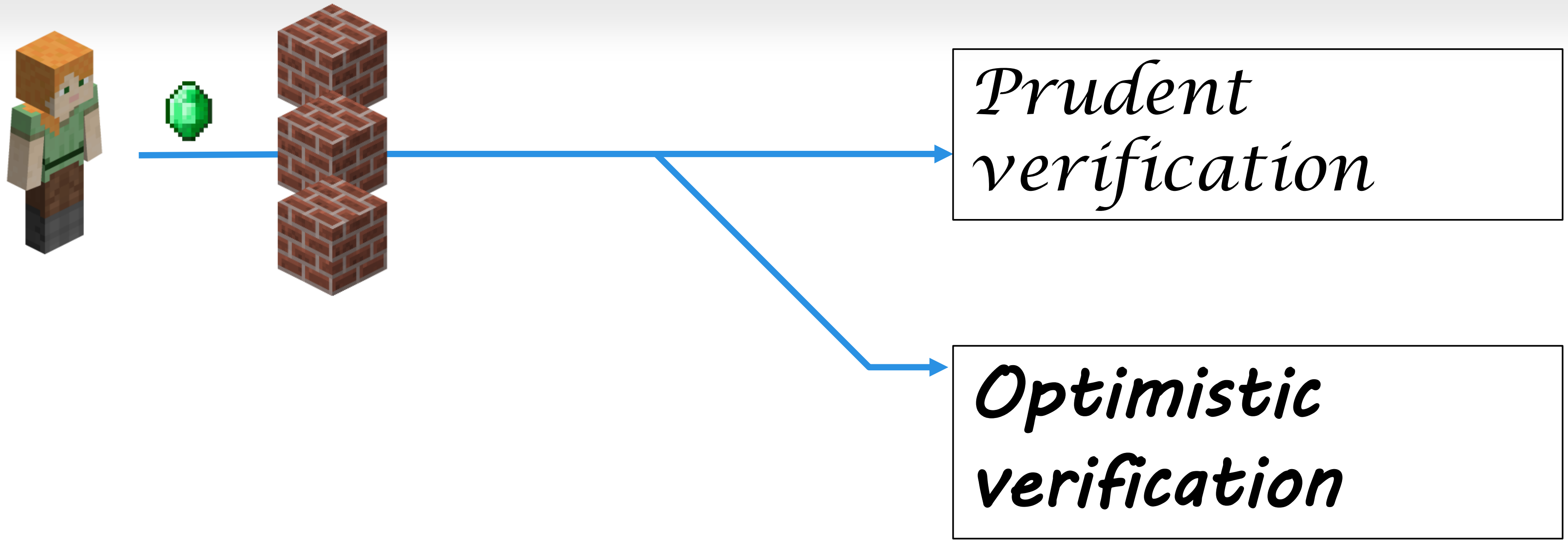

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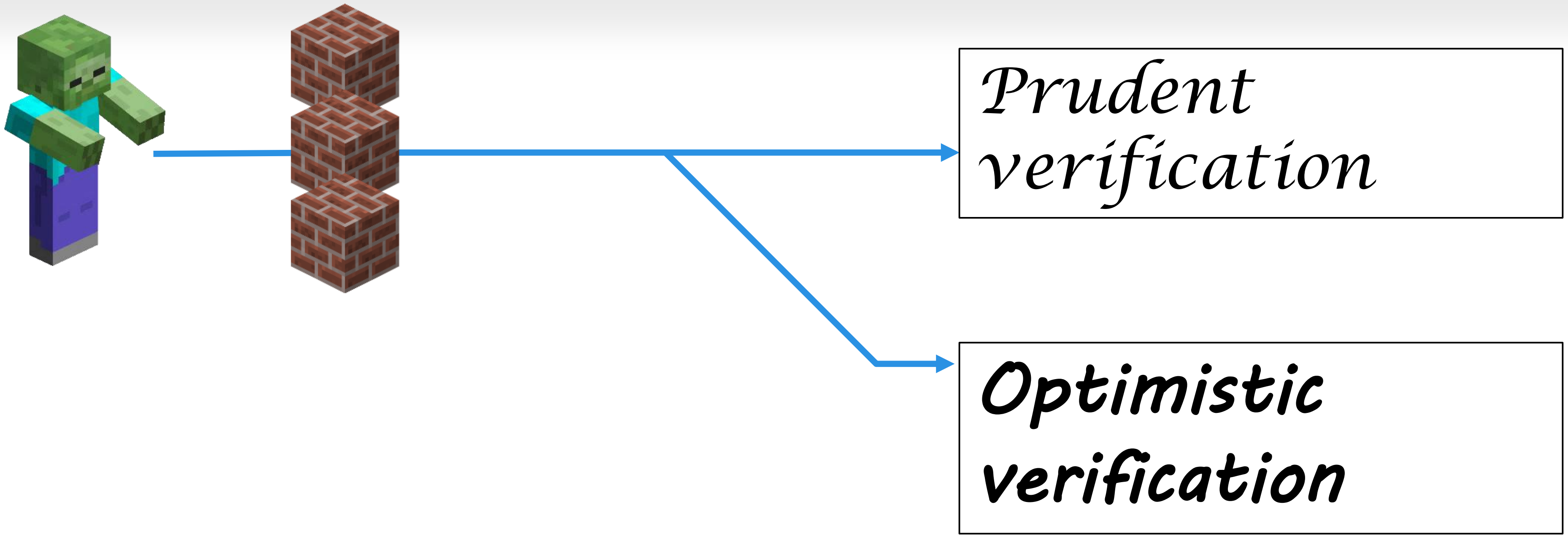

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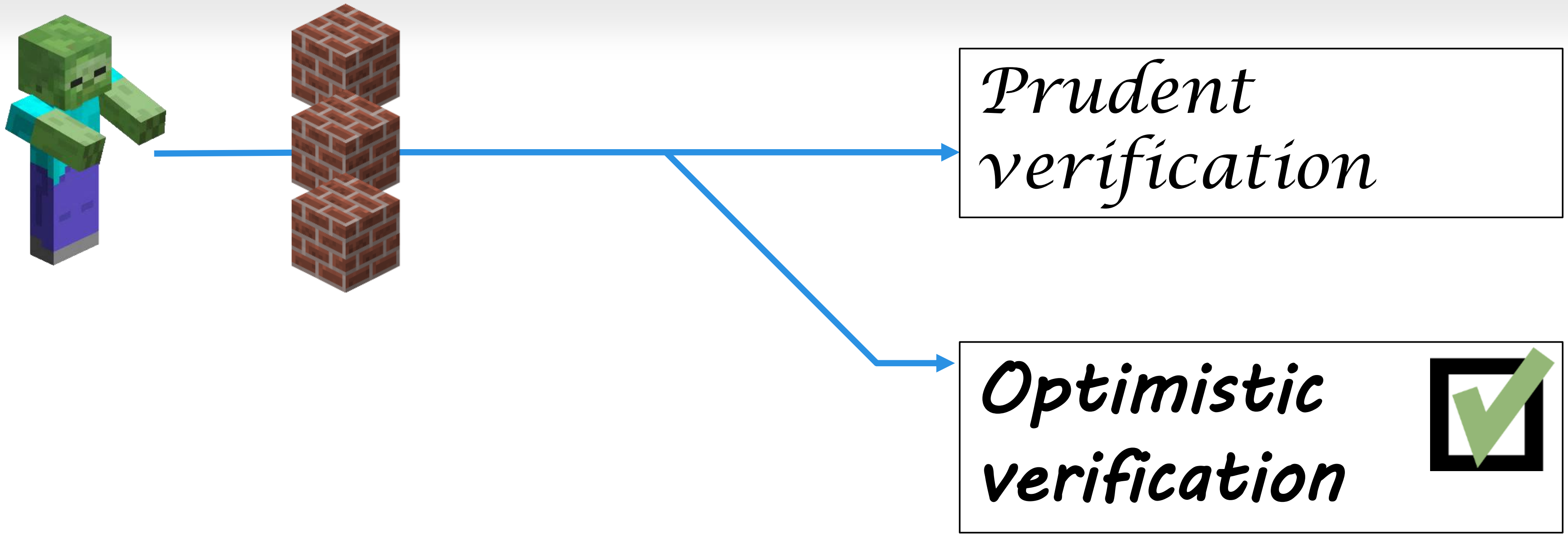

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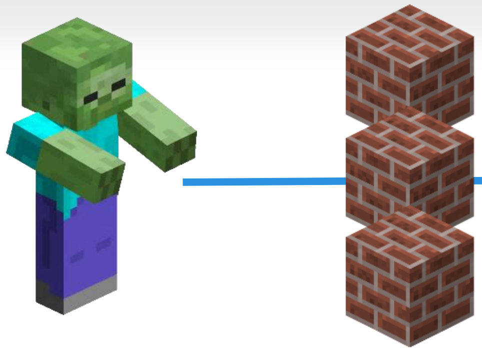

Prudent verification

Optimistic verification

- Detection
  - Real-time

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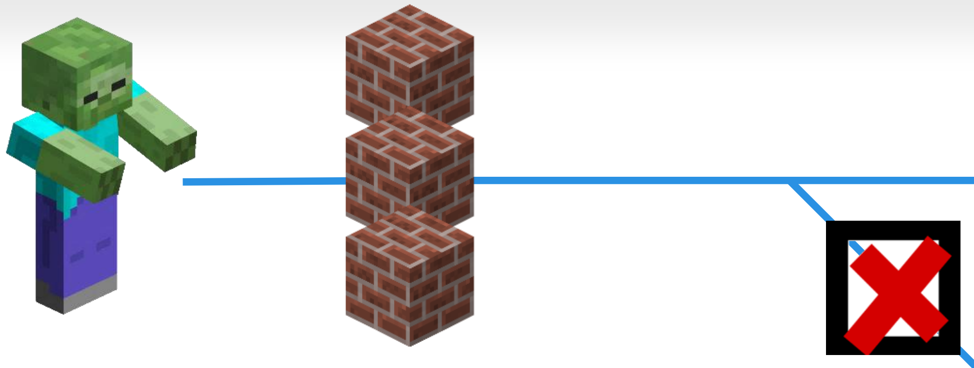

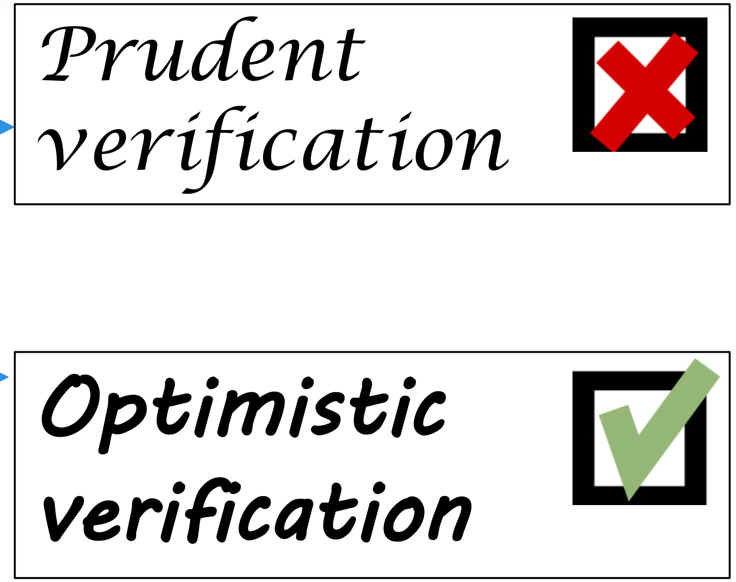

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  - Revoke SRS
  - Such pair of proofs is a *fraud proof* for compromised SRS!

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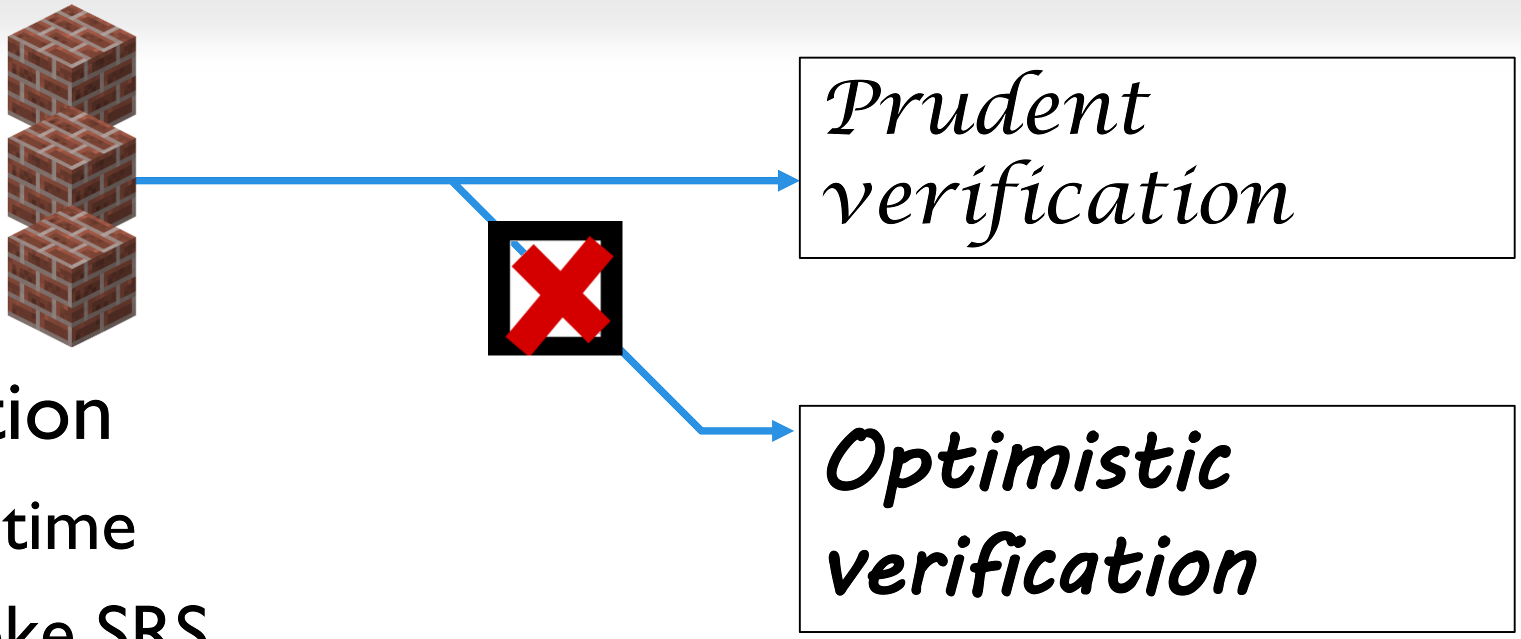

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- Recovery

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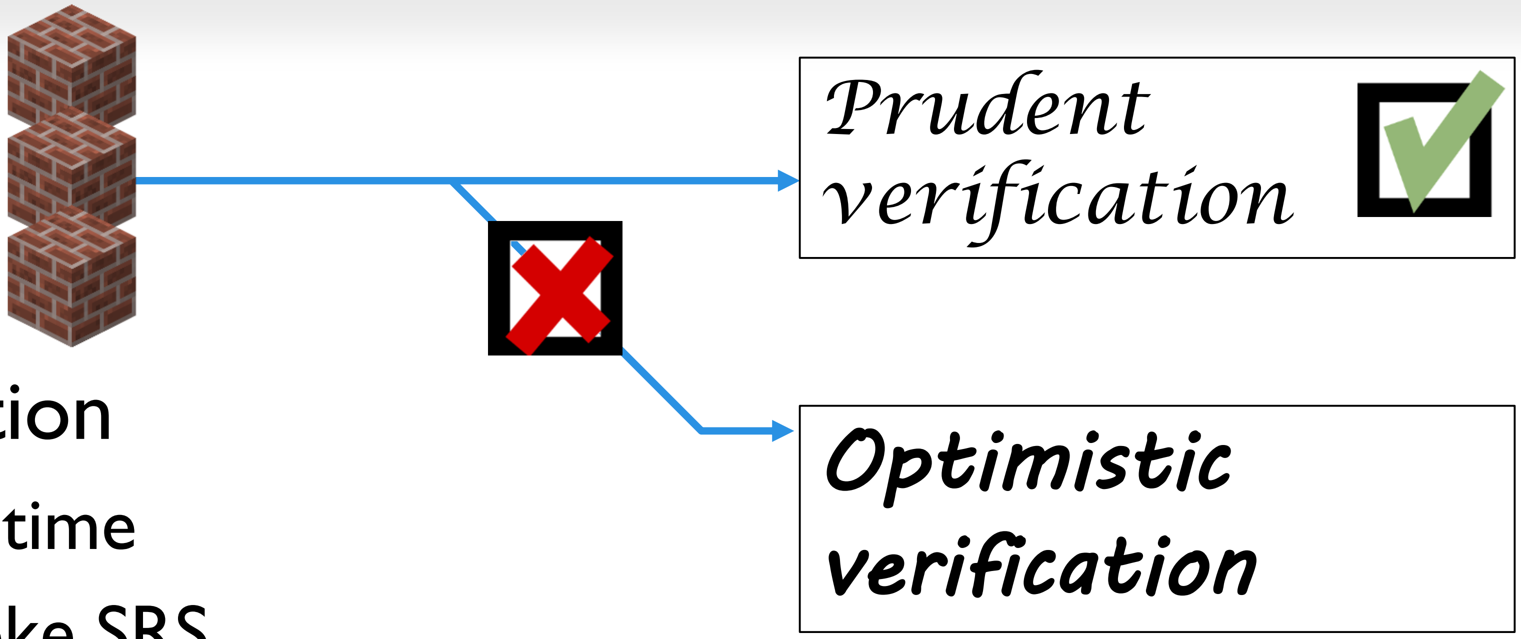

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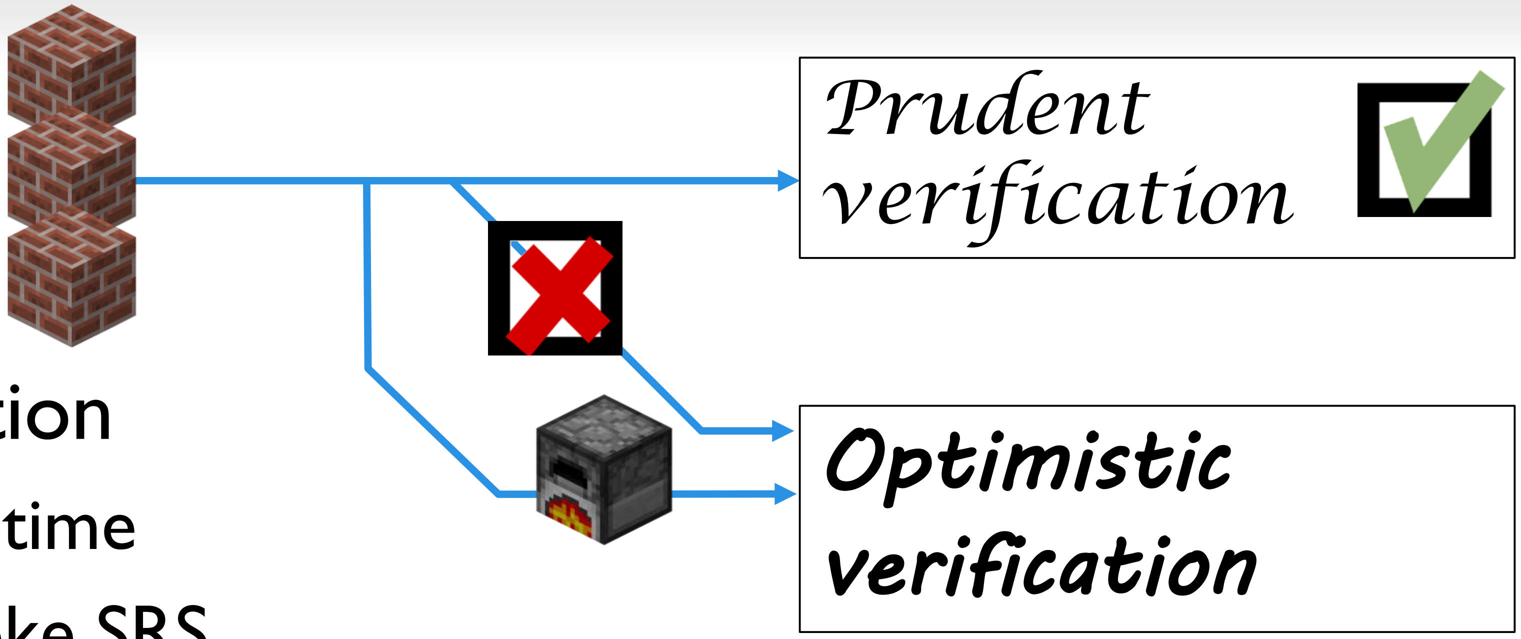

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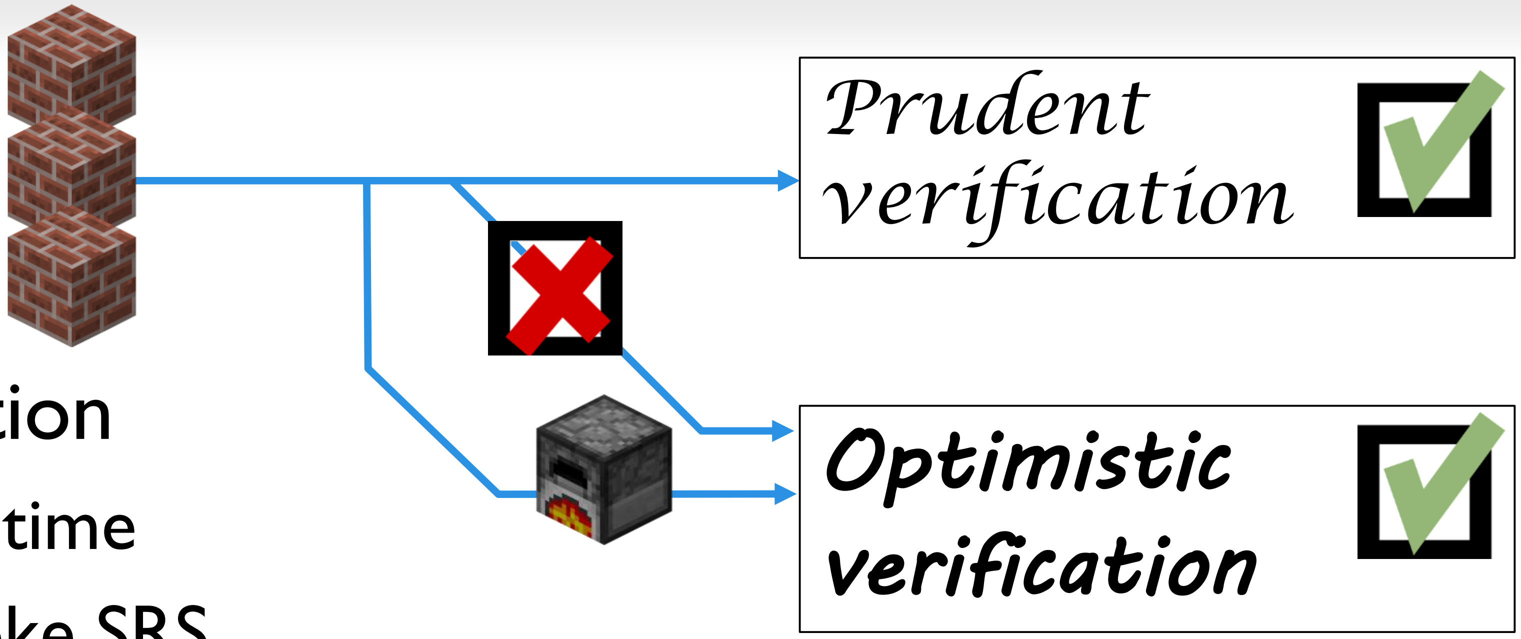

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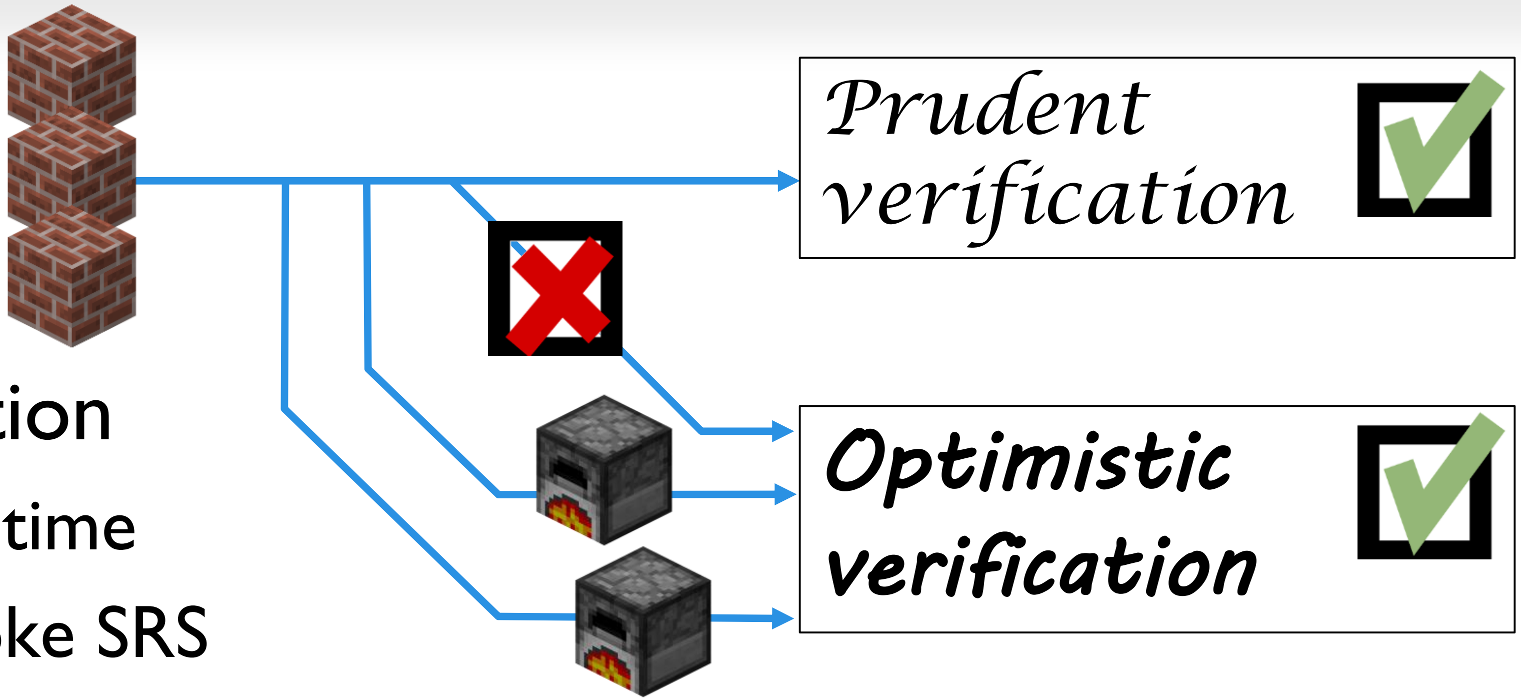

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SHARK requirement: ***anyone can refresh***, without original sender.

A generic SHARK construction

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Attempt – parallel composition:

A generic SHARK construction

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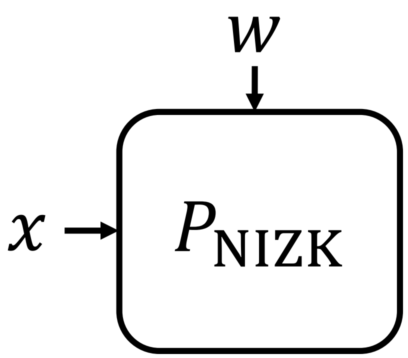

Not pictured: G_{NIZK}

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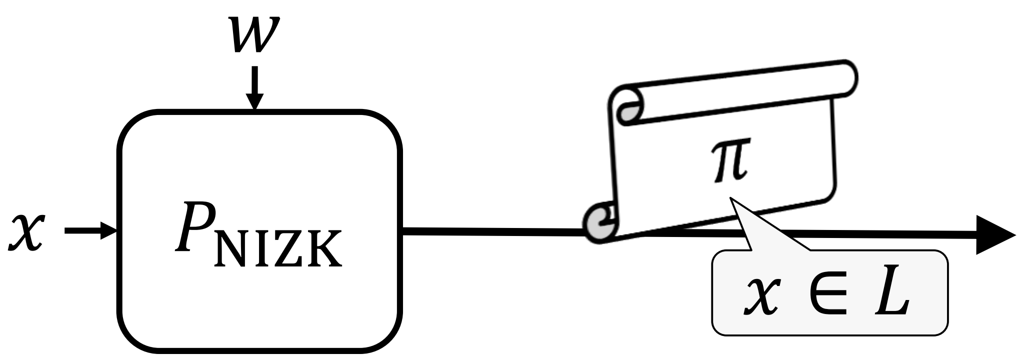

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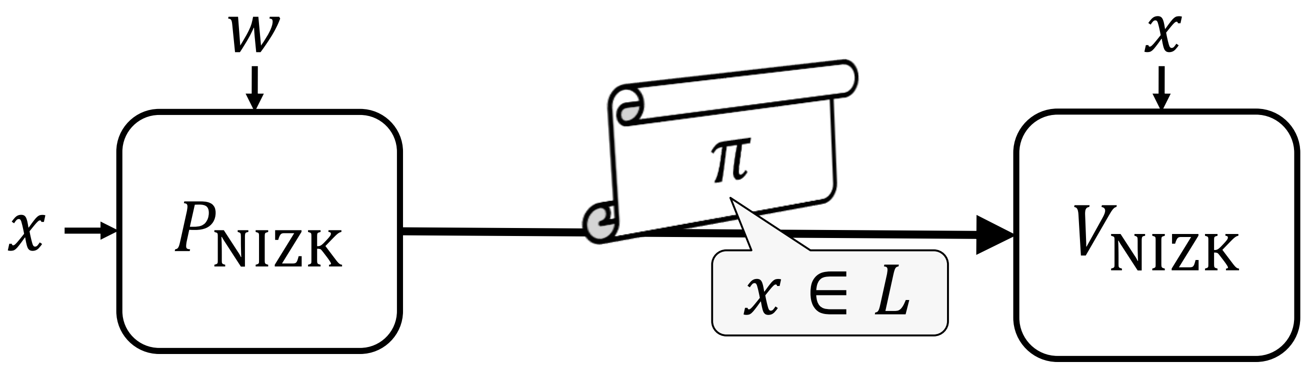

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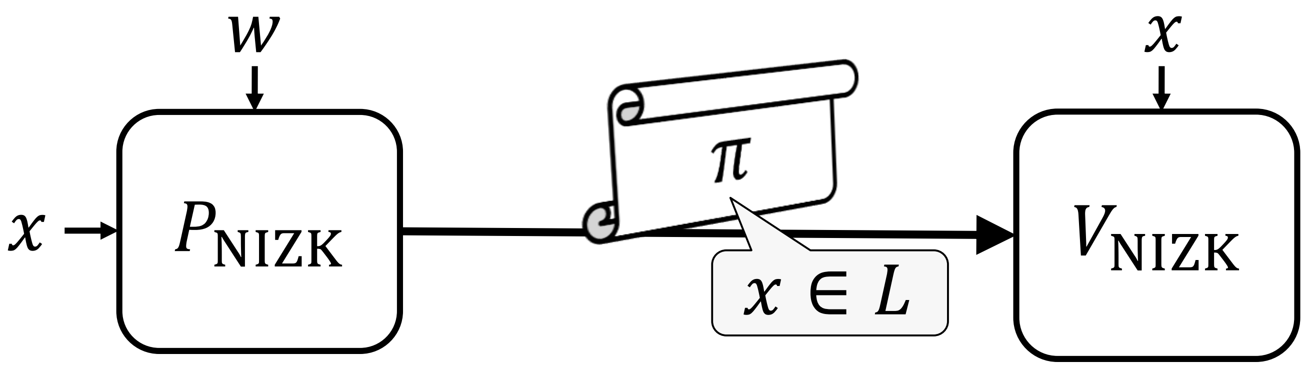

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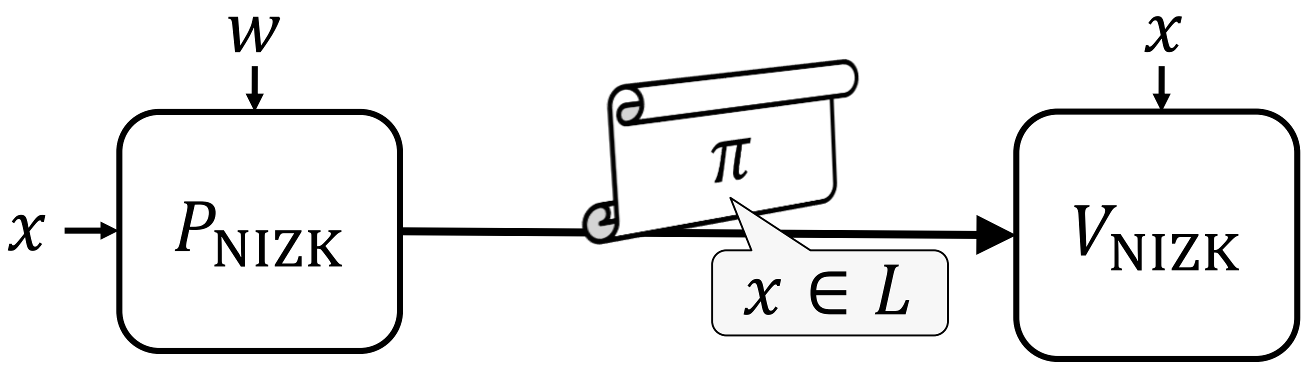

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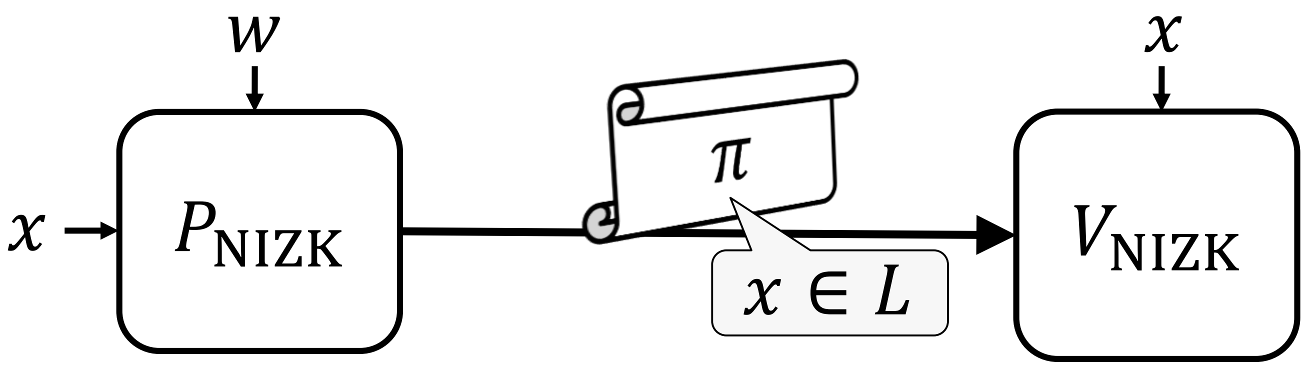

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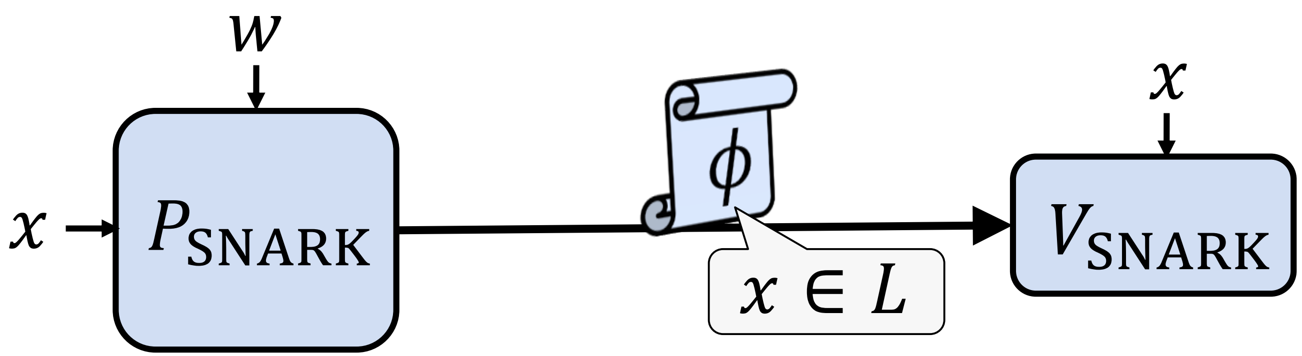

Not pictured: $G_{\mathrm{NIZK}}, G_{\mathrm{SNARK}}$

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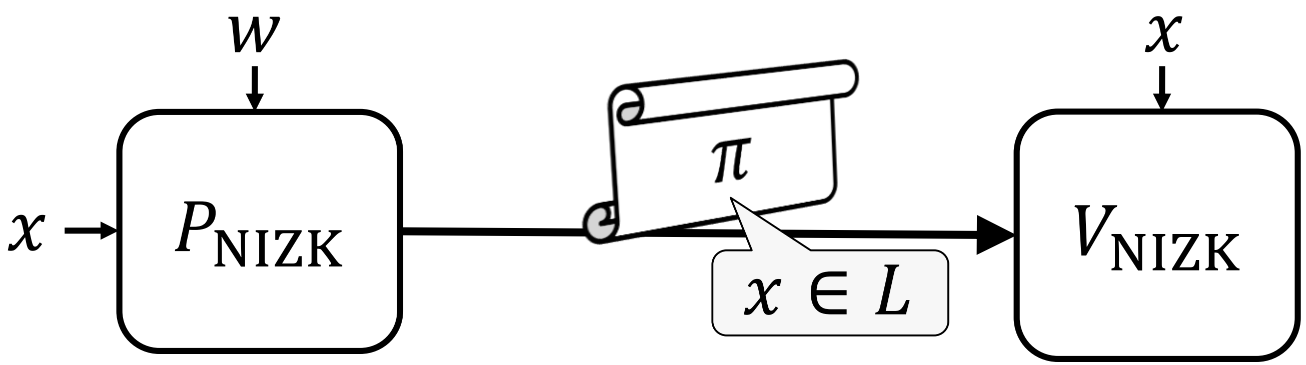

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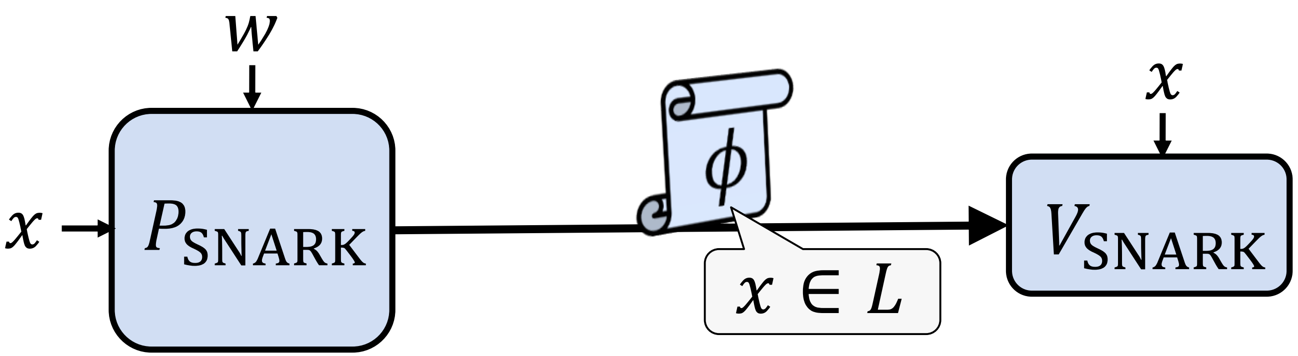

Optimistic proofs should be refreshable without w

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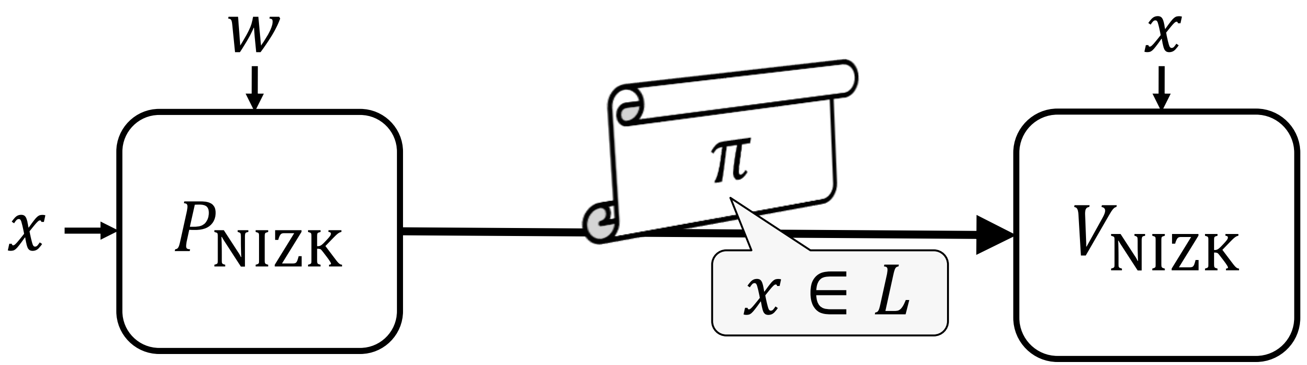

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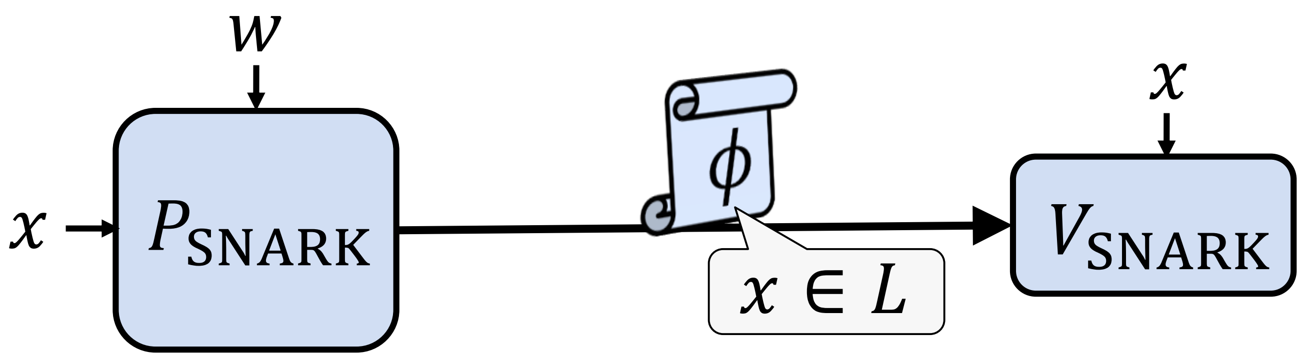

Optimistic proofs should be refreshable without w

$\Rightarrow$ ϕ is **not** a SHARK optimistic proof

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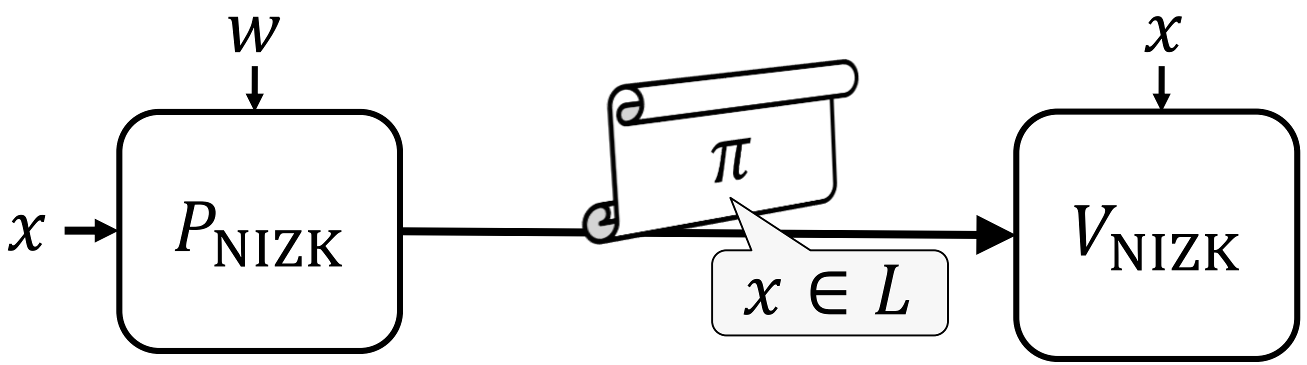

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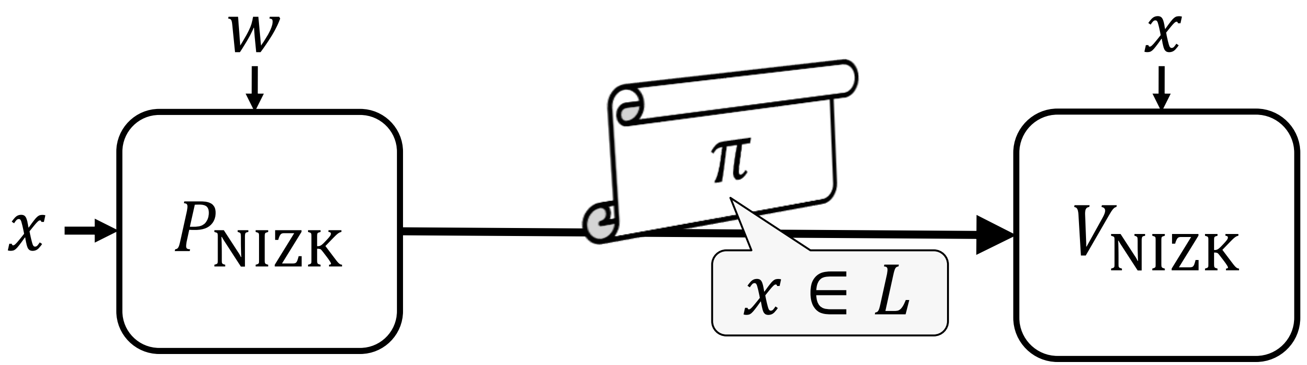

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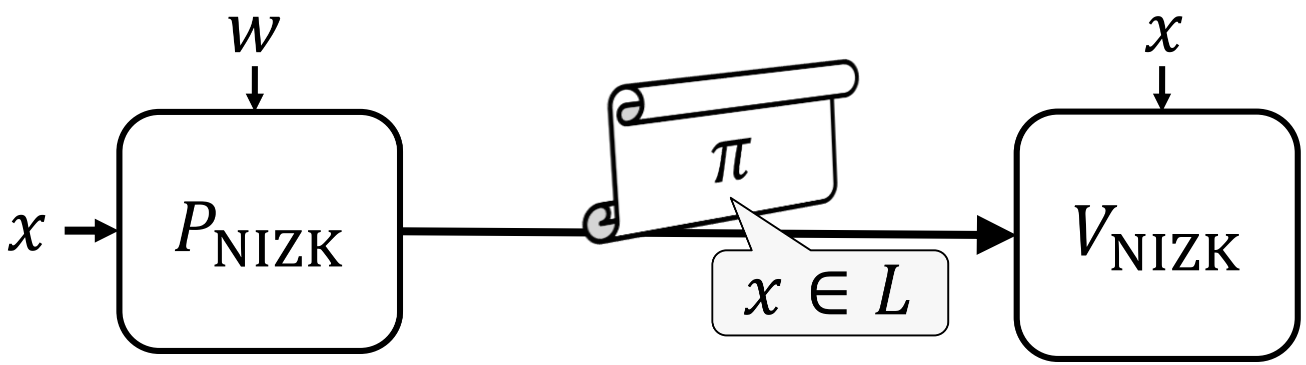

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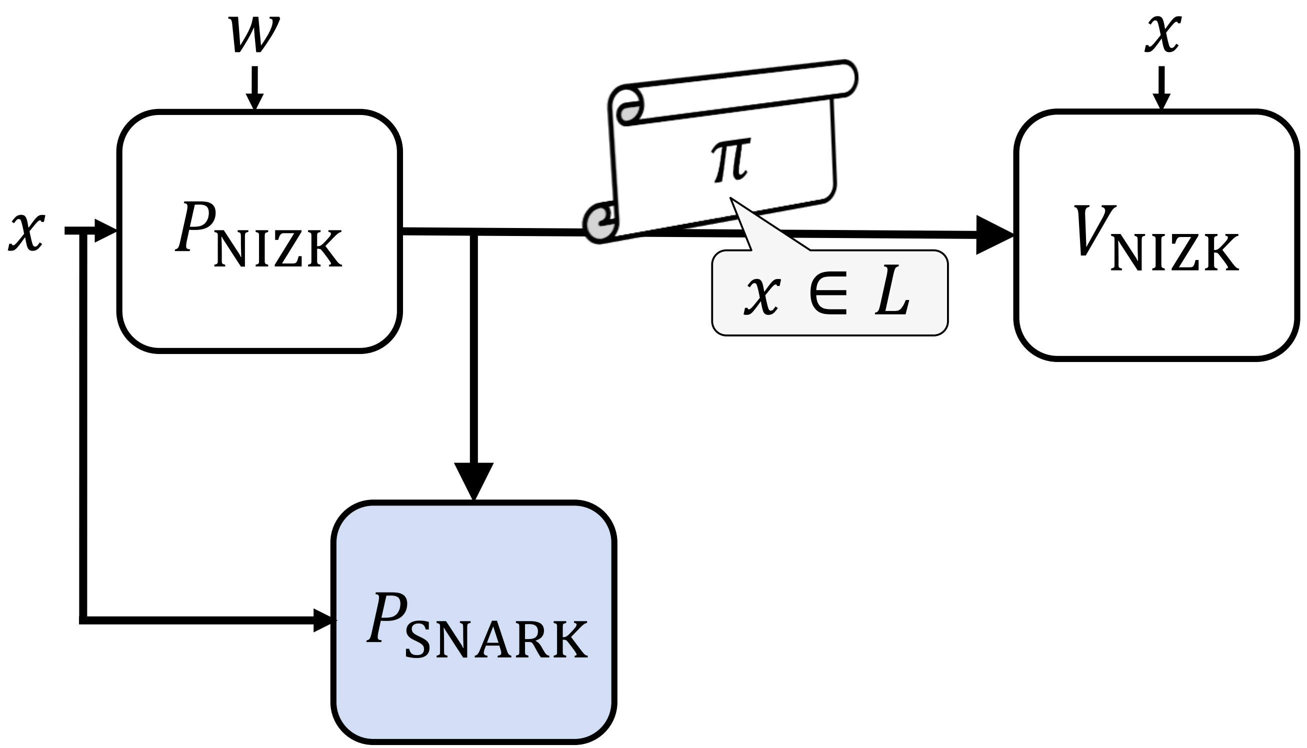

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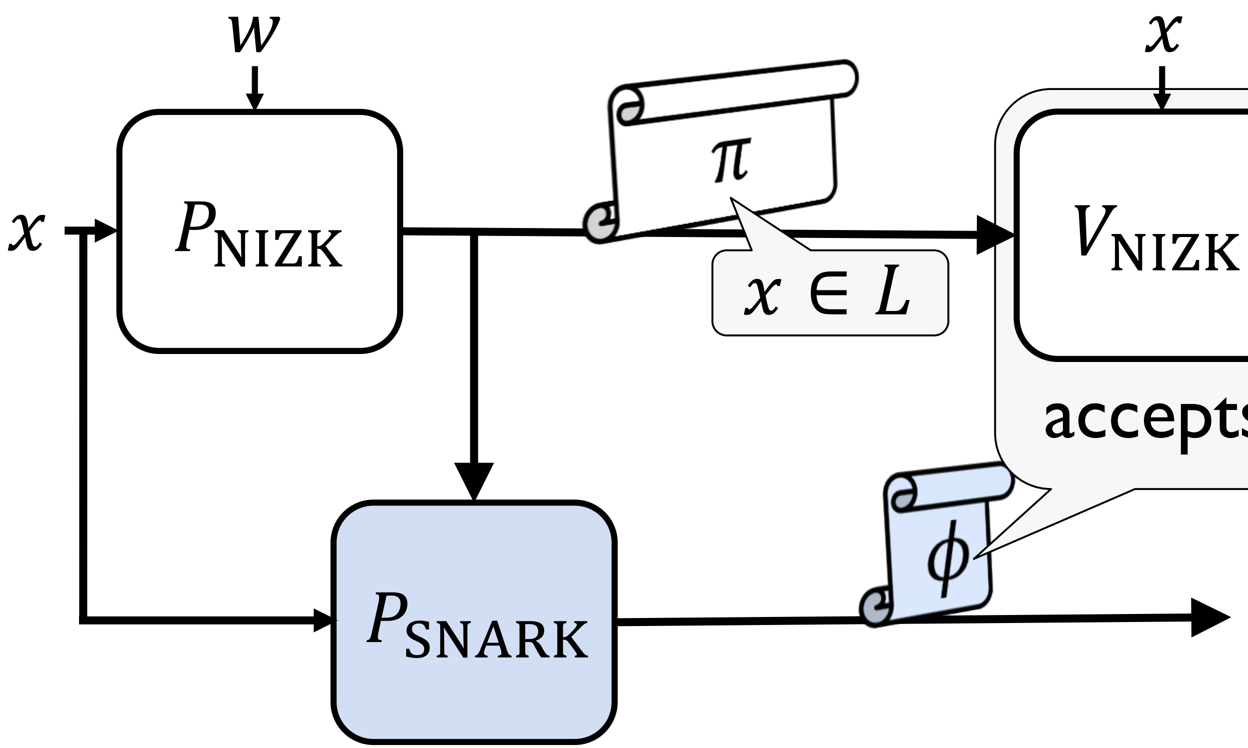

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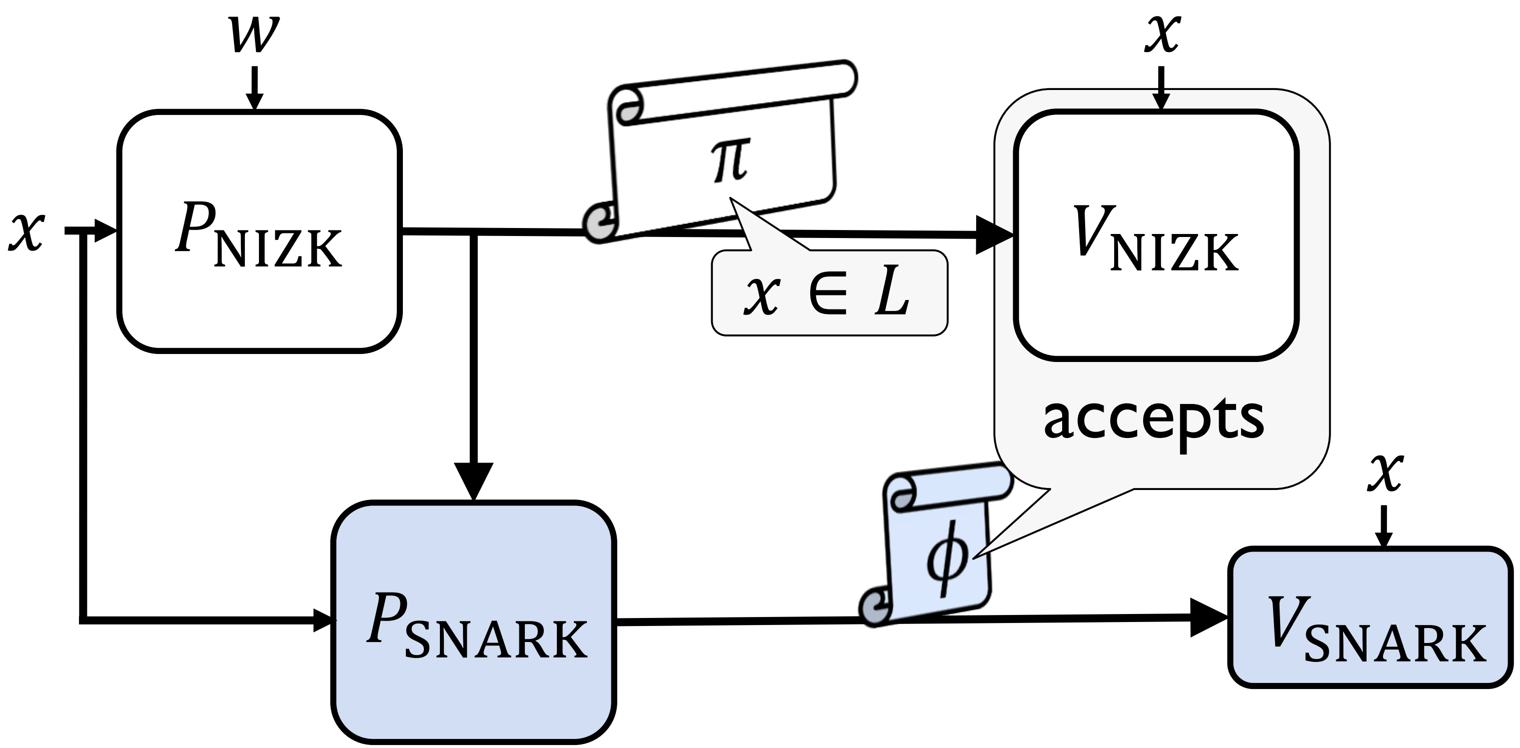

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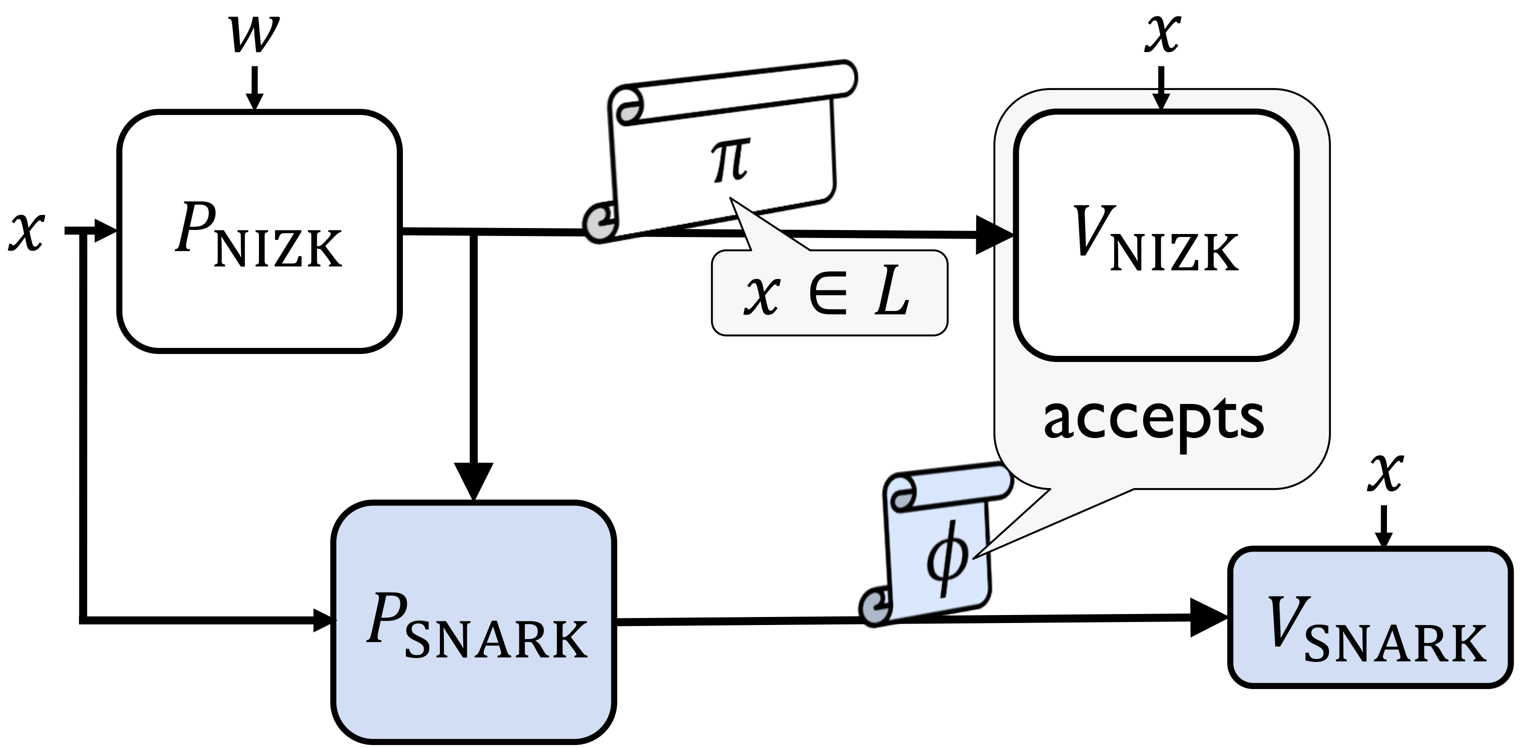

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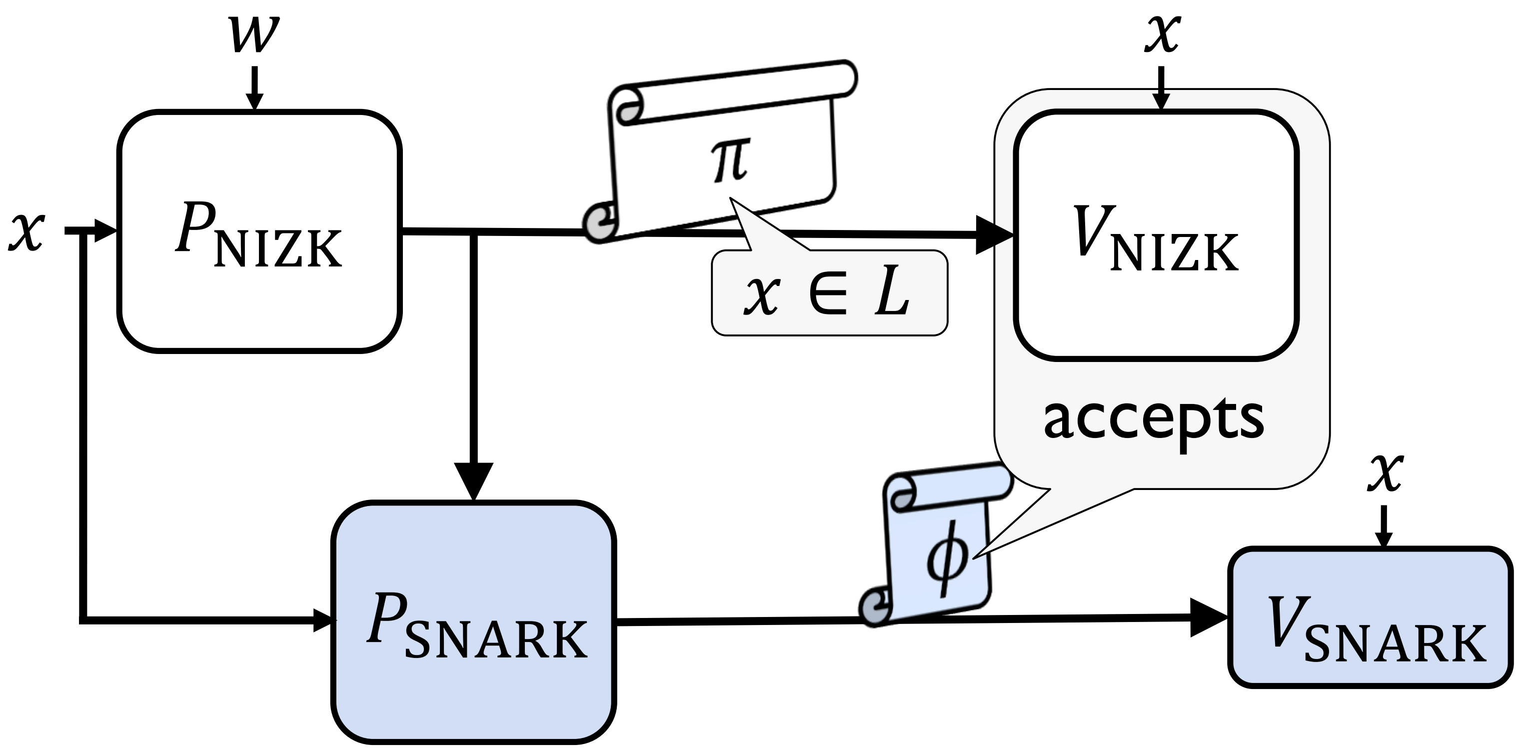

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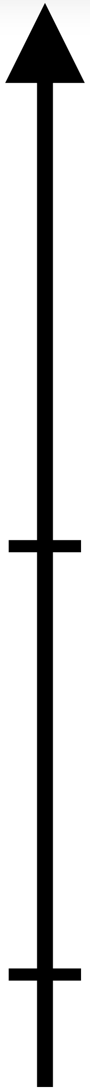

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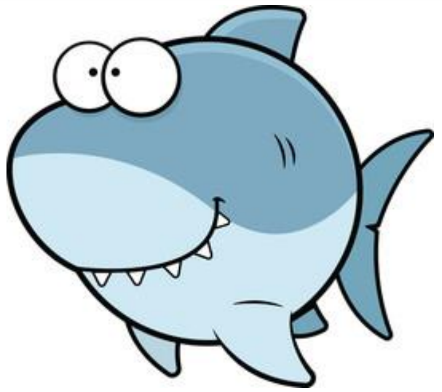

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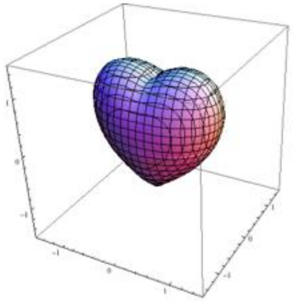

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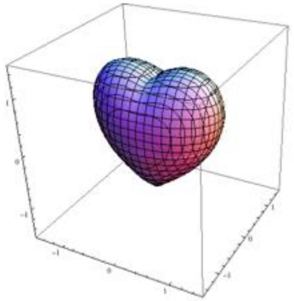

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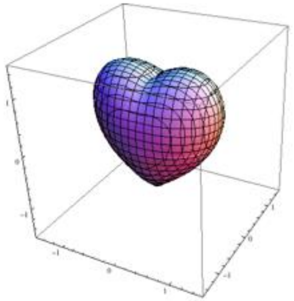

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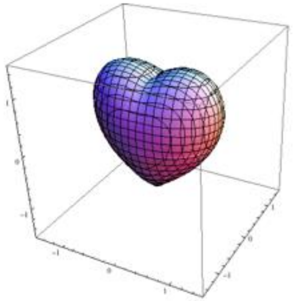

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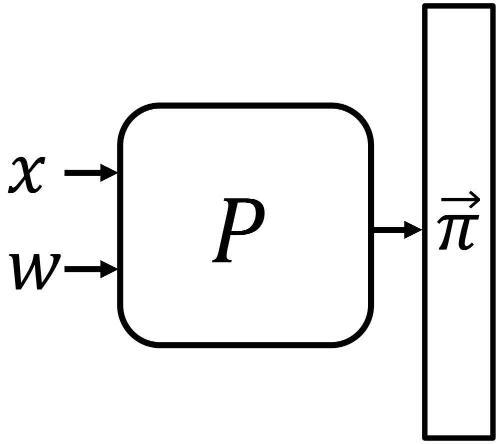

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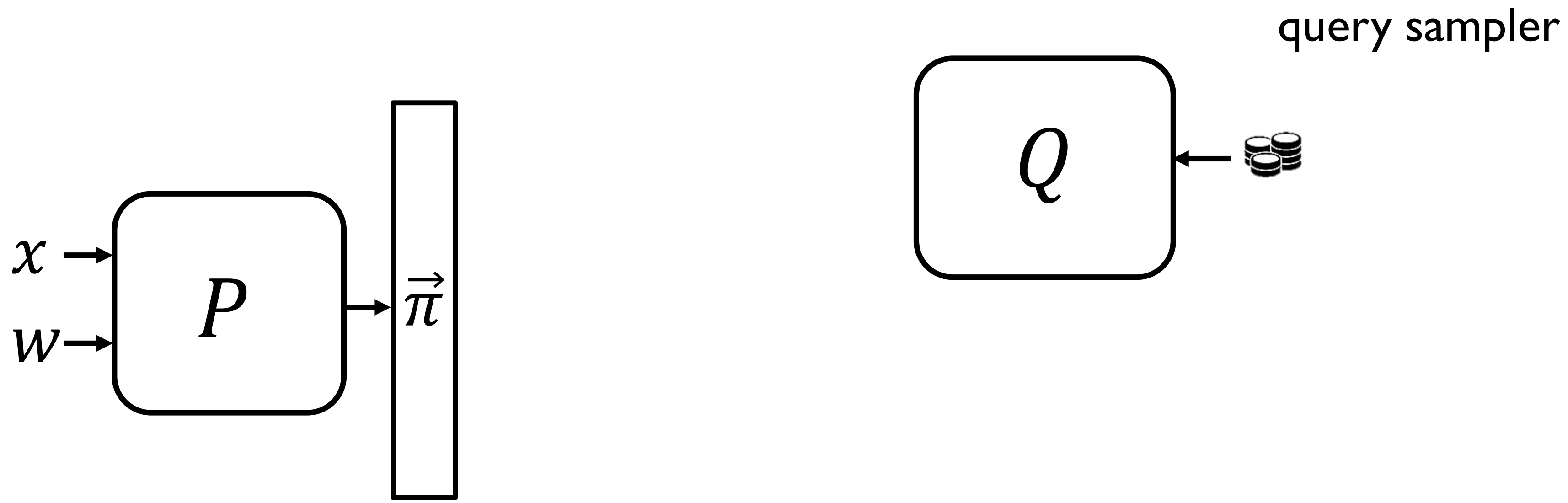

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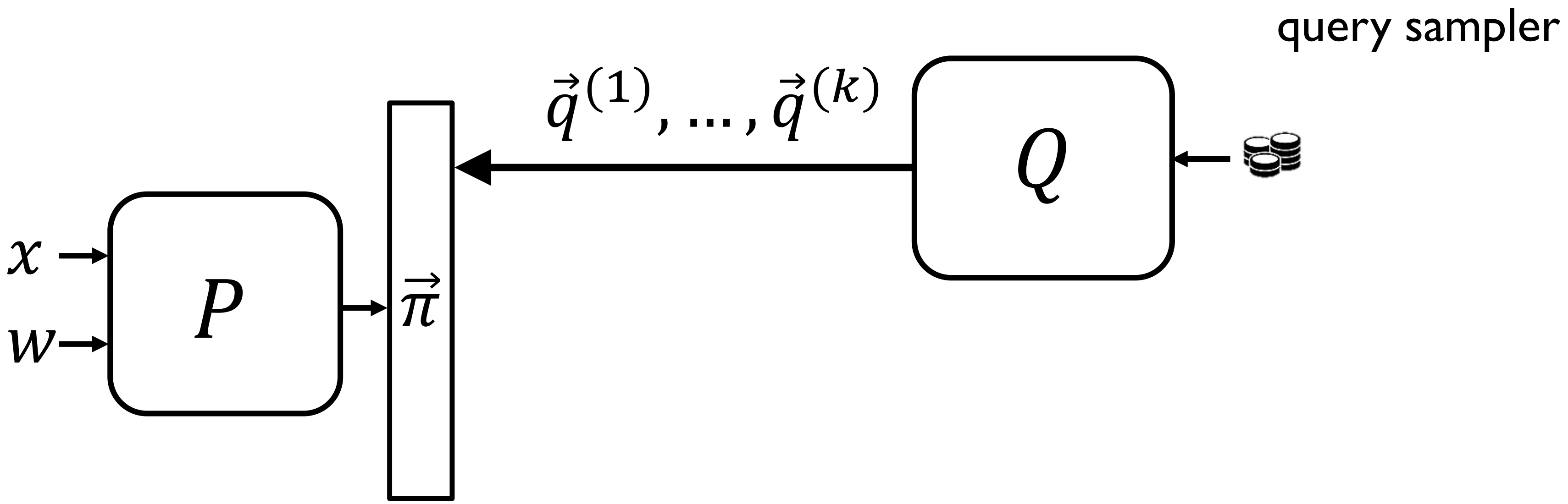

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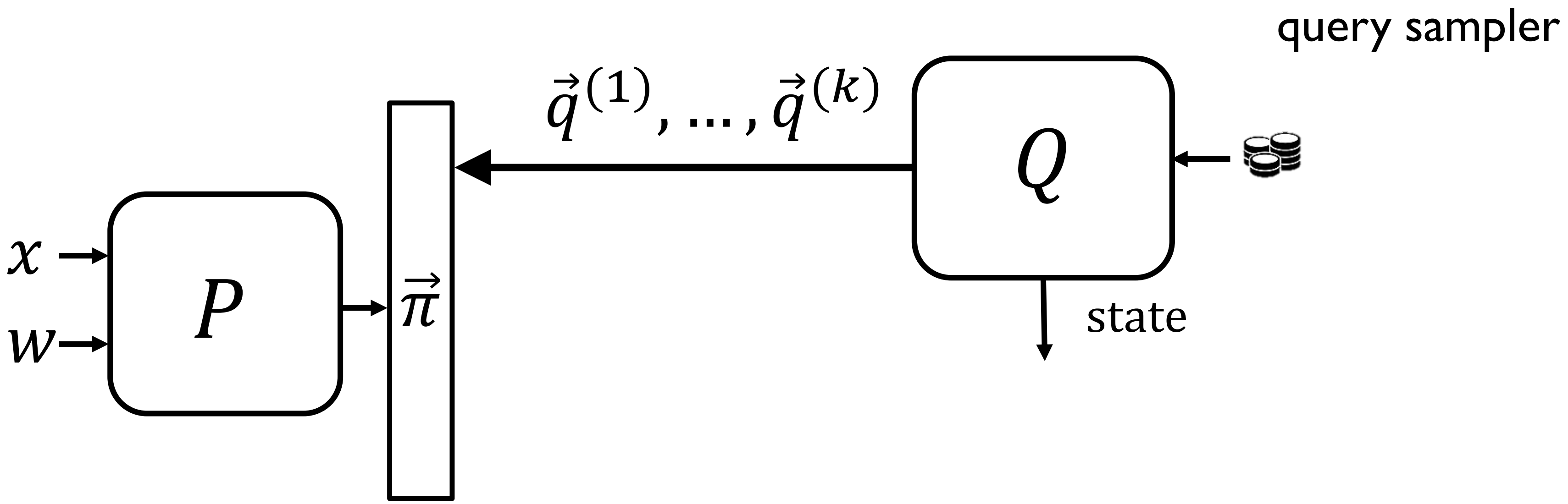

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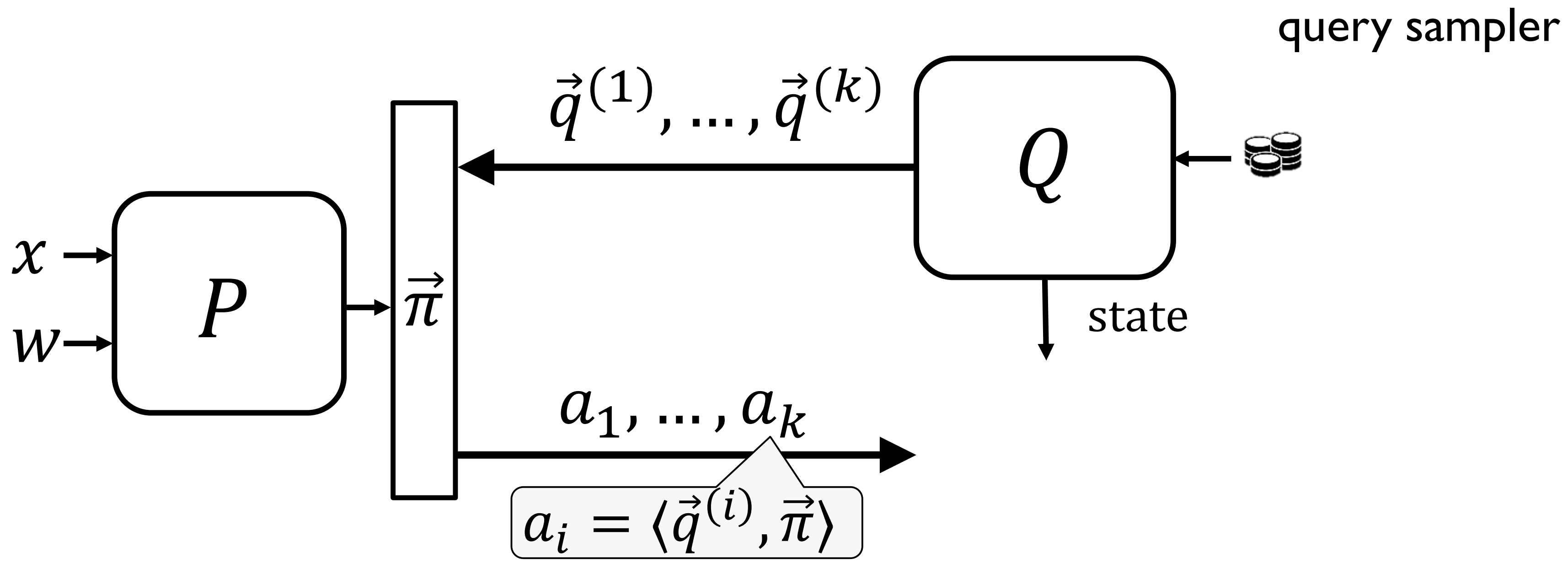

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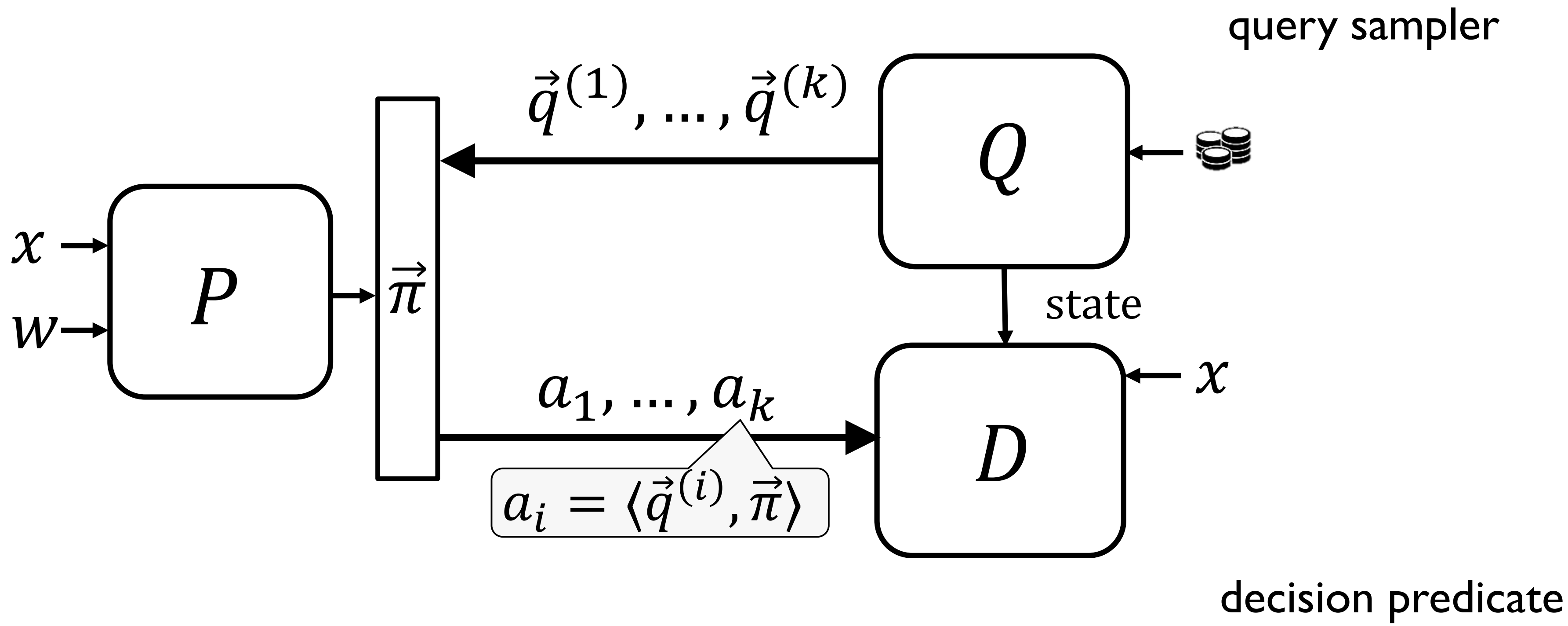

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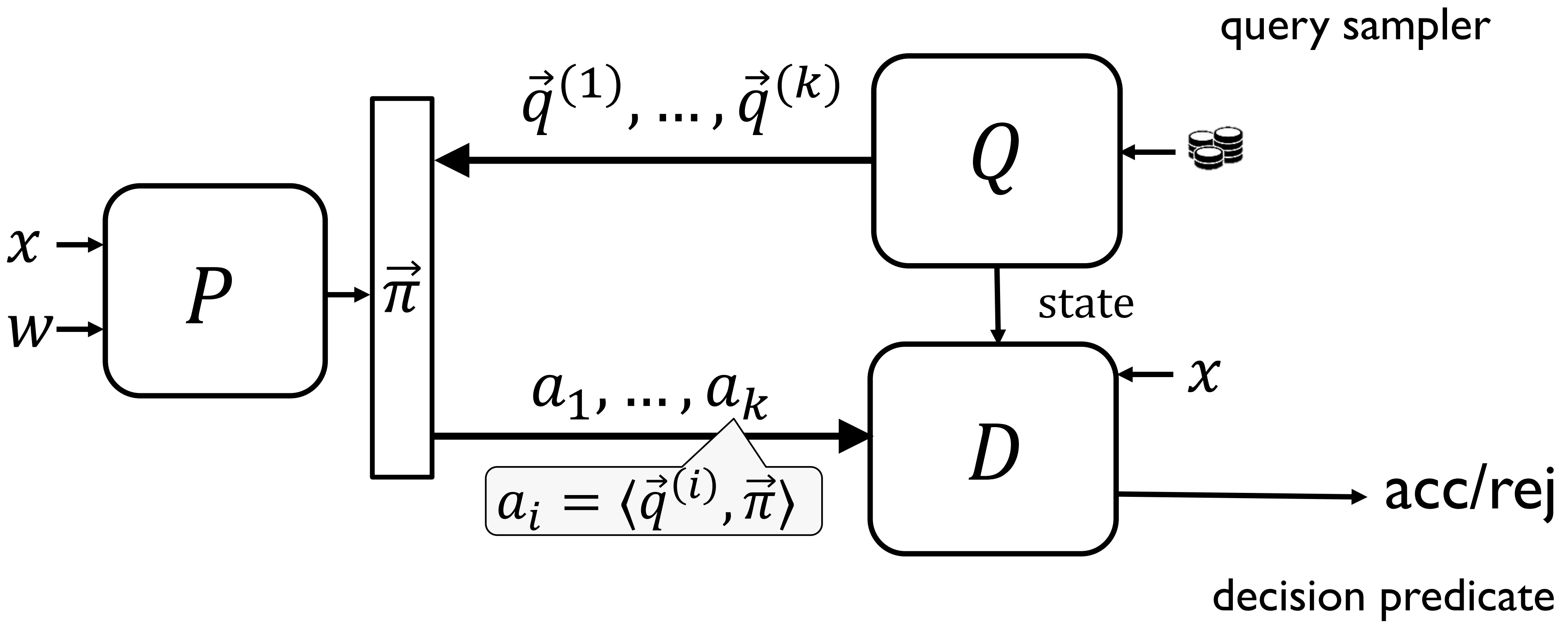

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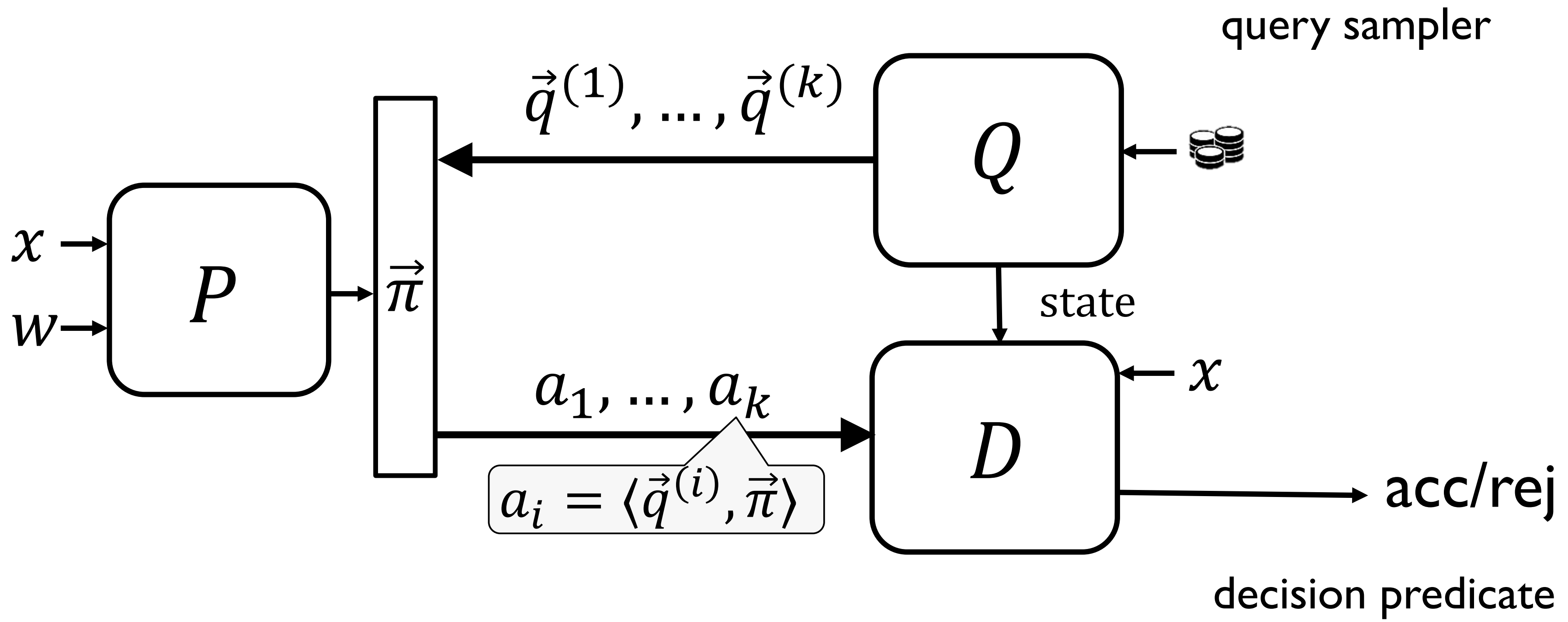

Can define natural notions of completeness, PoK, ZK.

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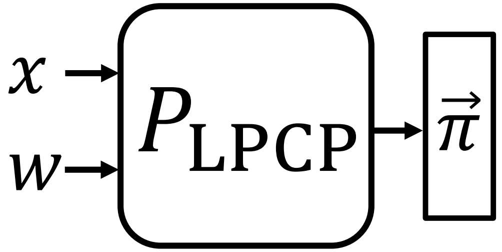

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$$\xrightarrow{\mathbf{cm}_{\vec{\pi}} := \mathrm{Commit}(\vec{\pi})}$$

1 Run:

$x, w \rightarrow \boxed{P_{\mathrm{LPCP}}} \rightarrow \boxed{\vec{\pi}}$

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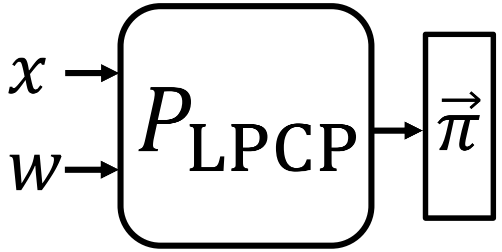

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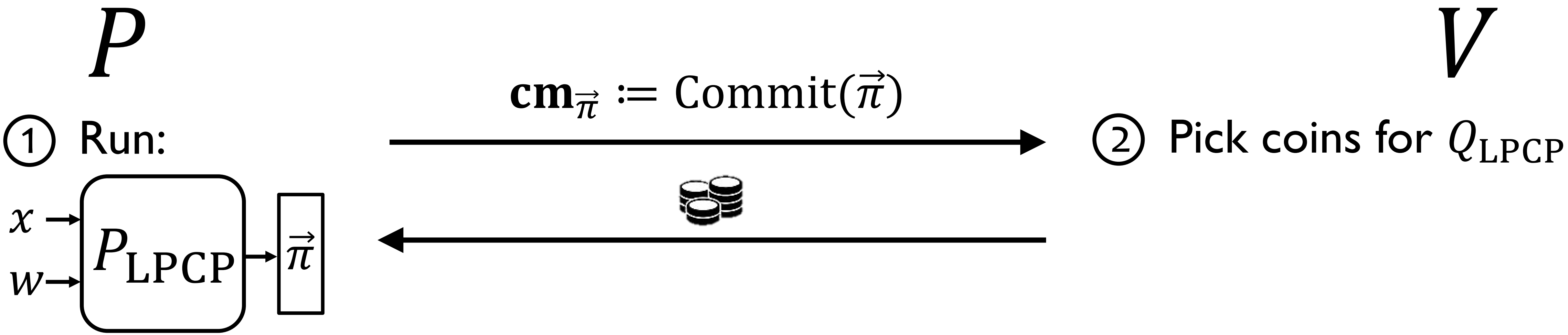

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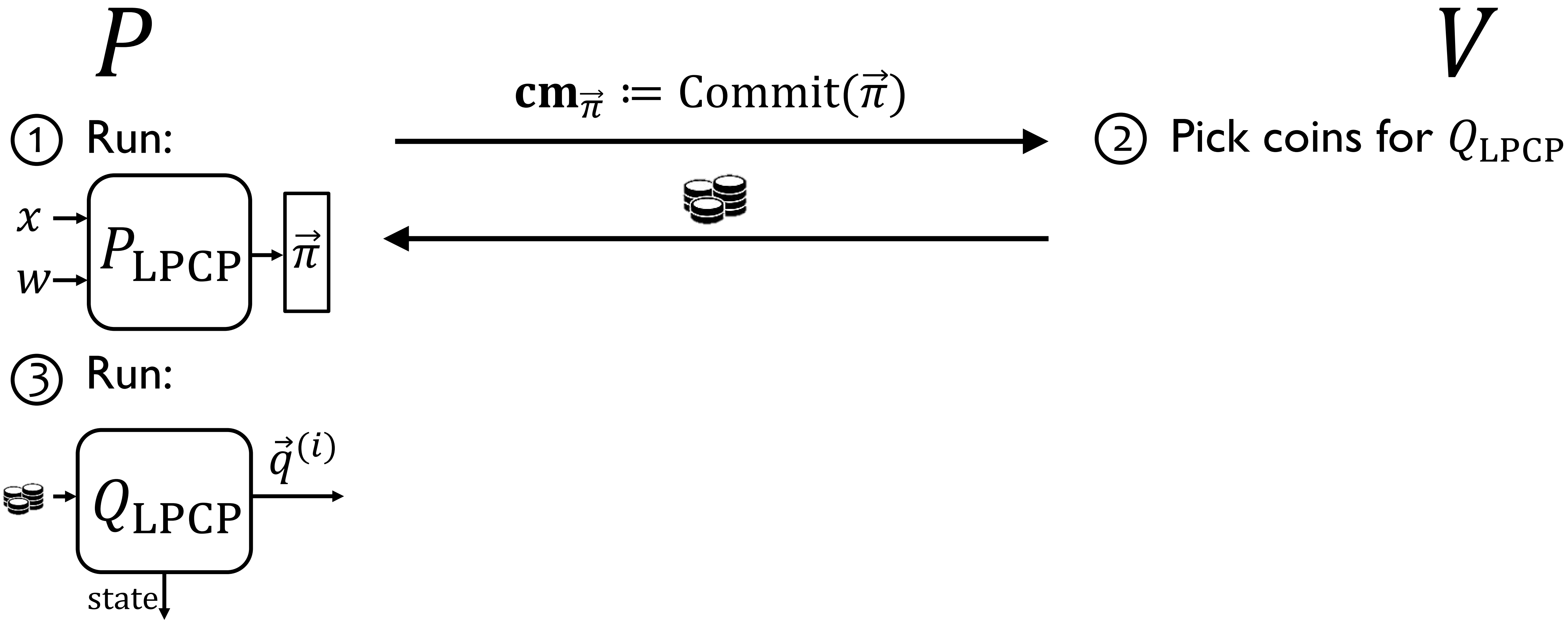

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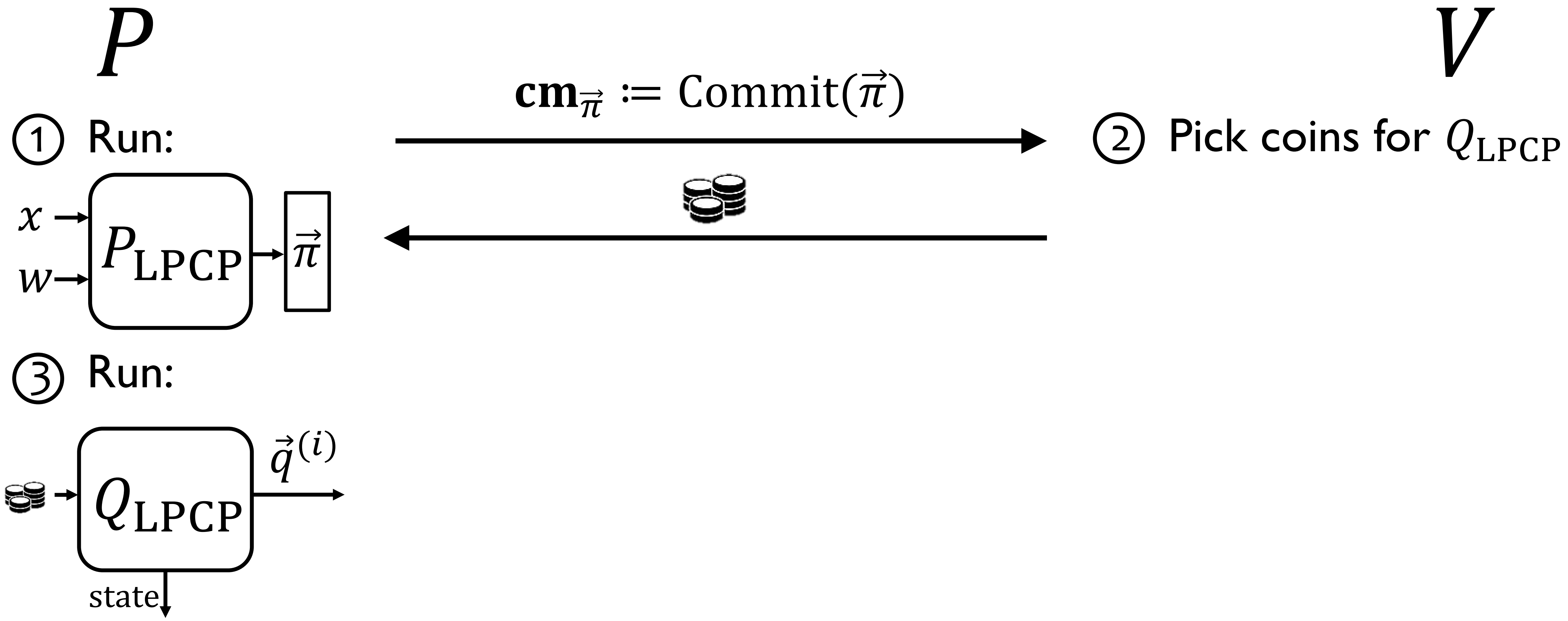

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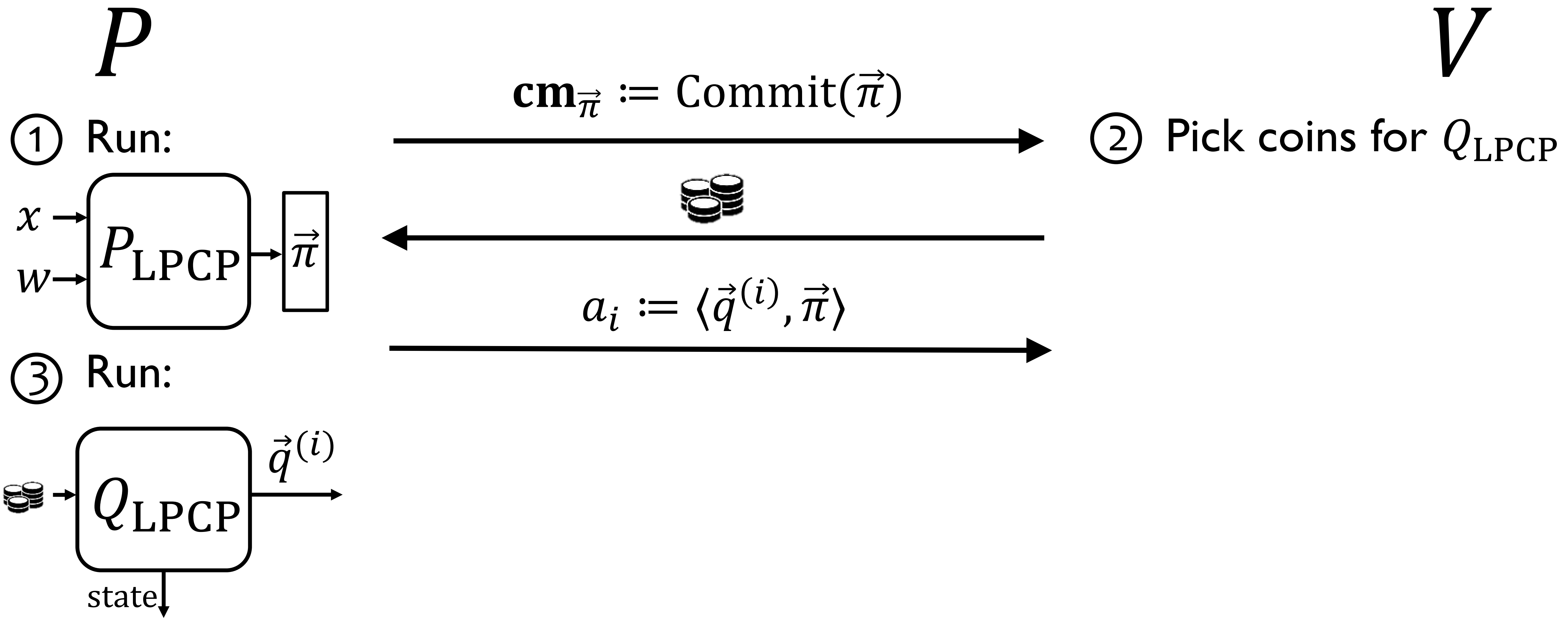

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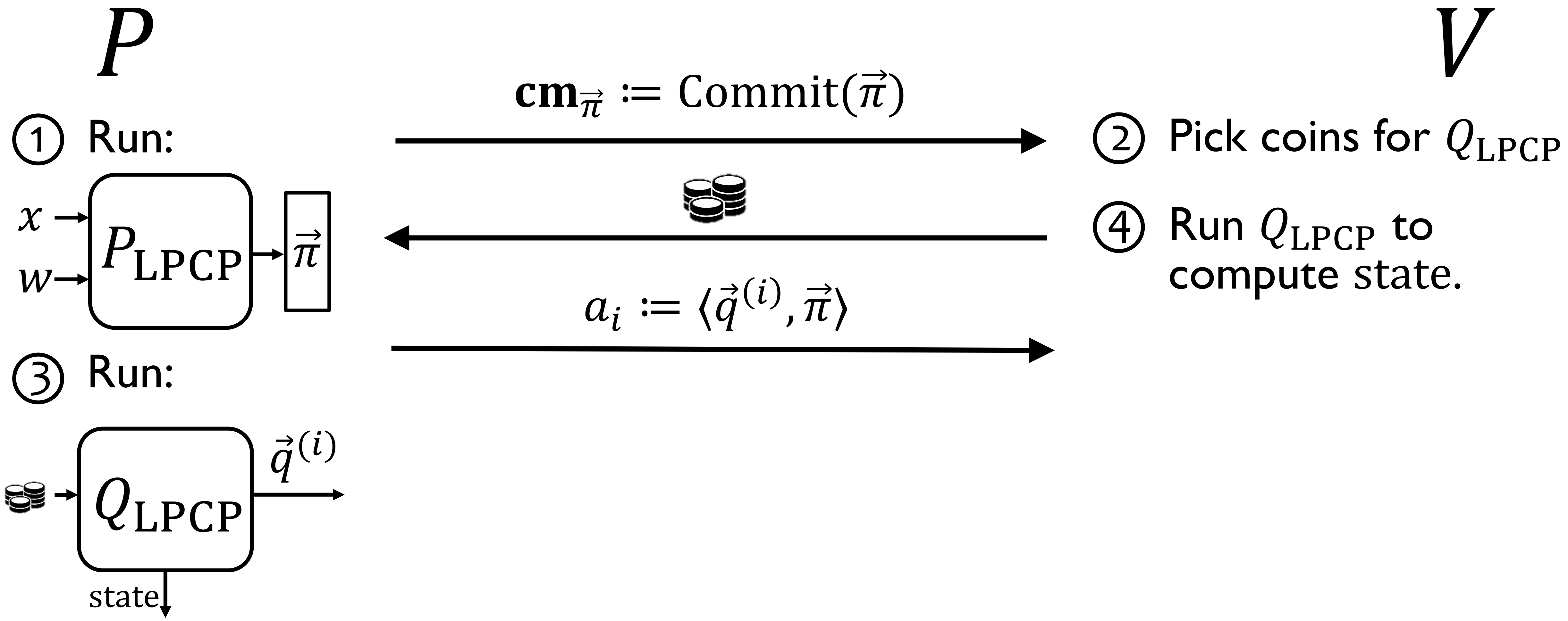

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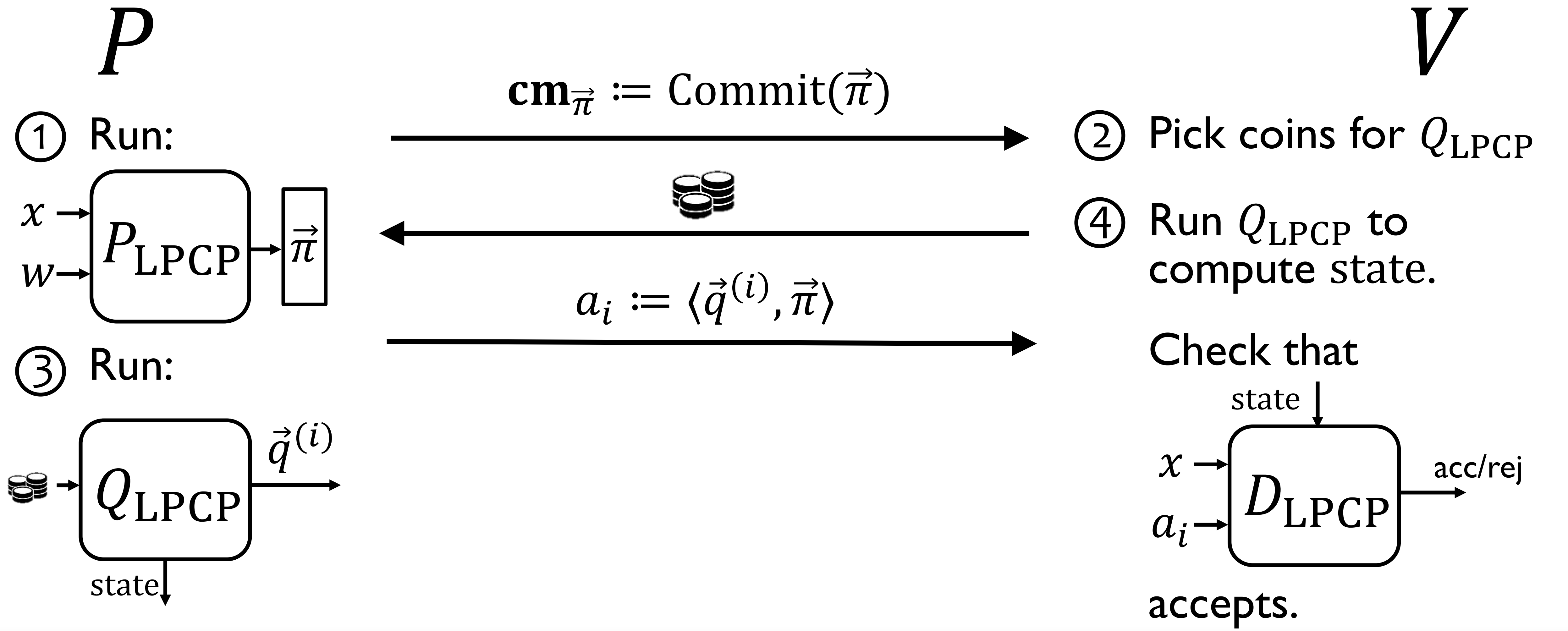

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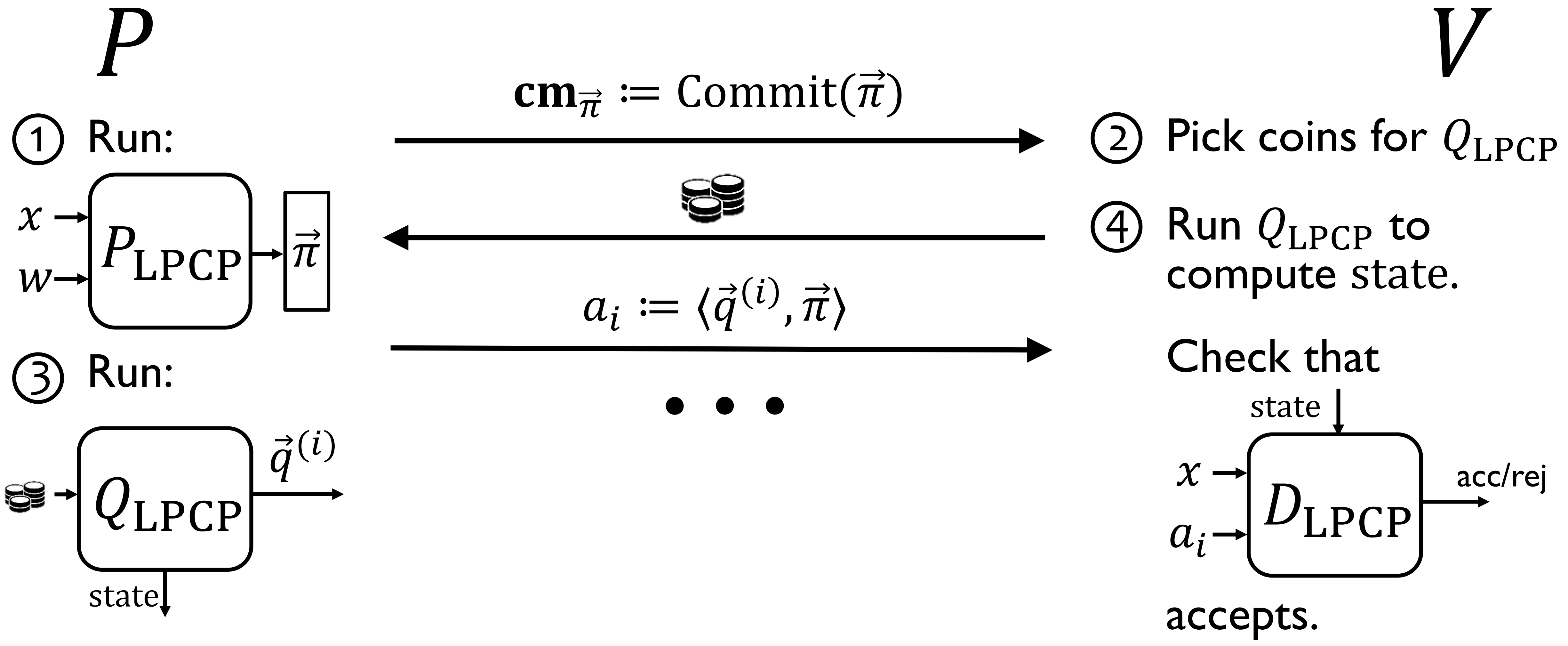

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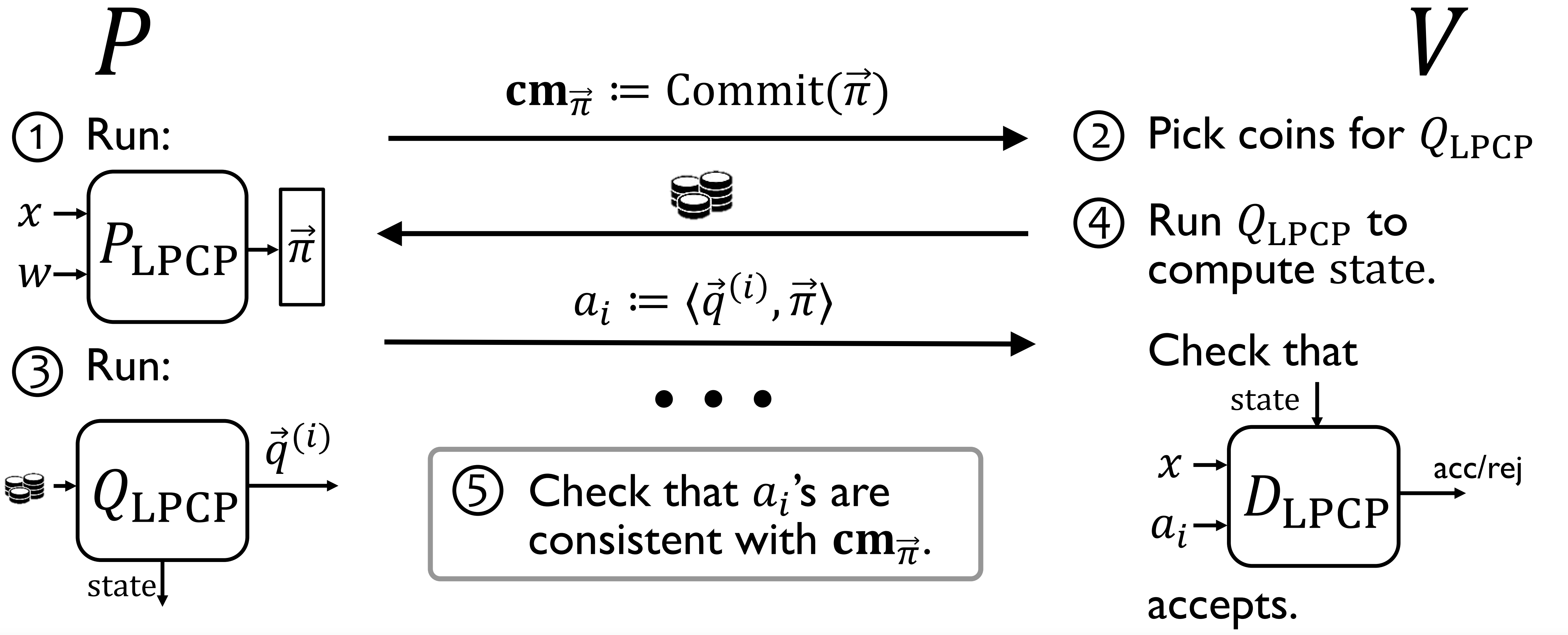

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A new building block:
"encoded polynomial delegation"

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Outsourcing vector commitment computation

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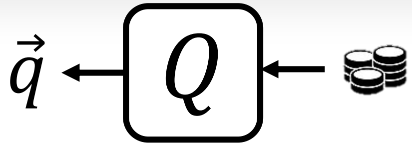

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Most efficient linear PCP: quadratic arithmetic programs of [GGPR12]

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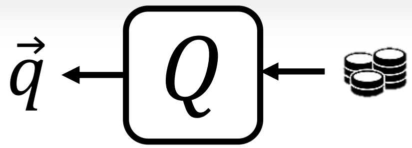

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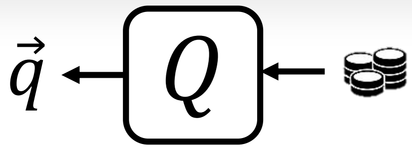

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New building block: SNARK for encoded polynomial delegation in pairing groups

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☑ SHARK optimistic proofs

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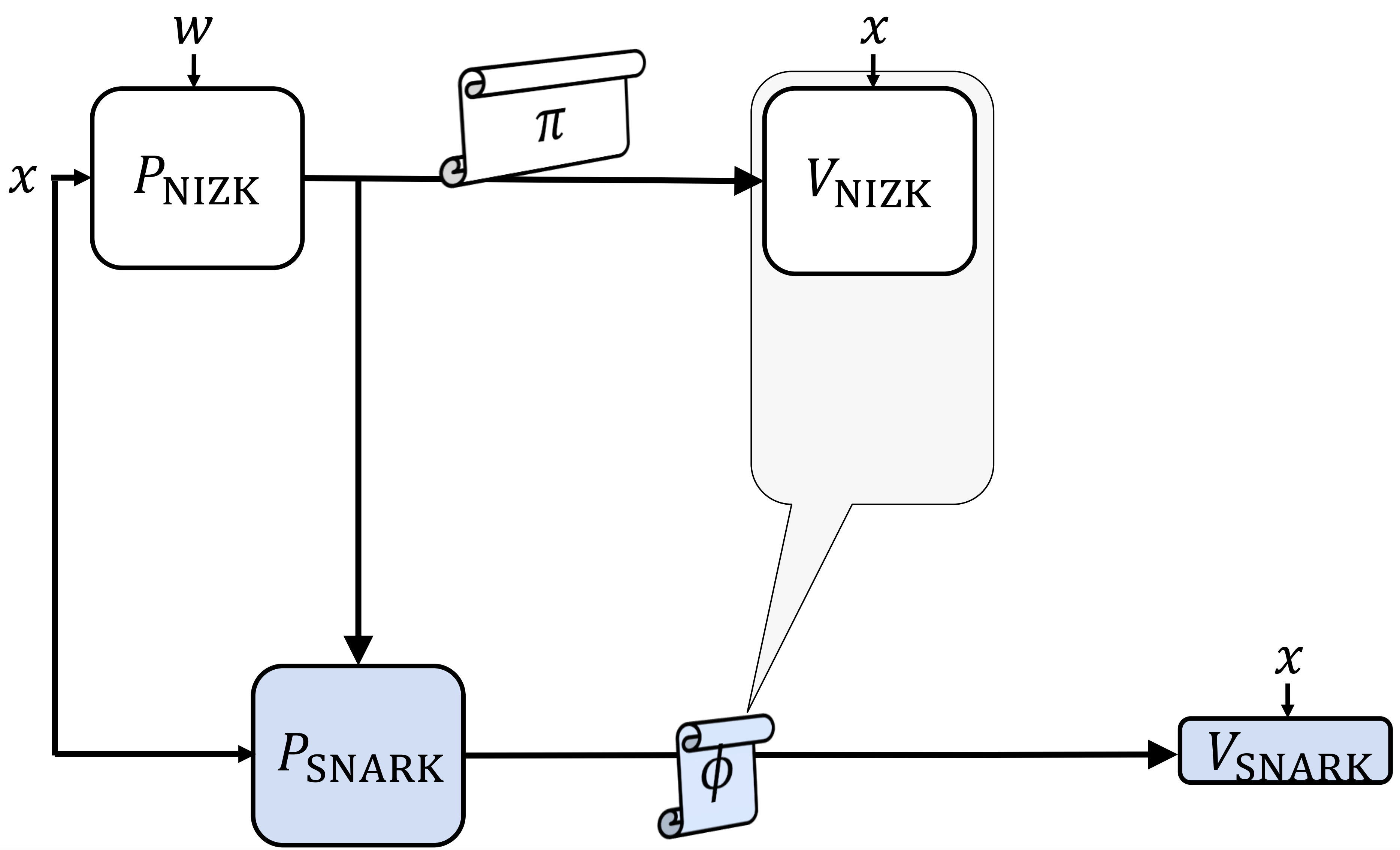

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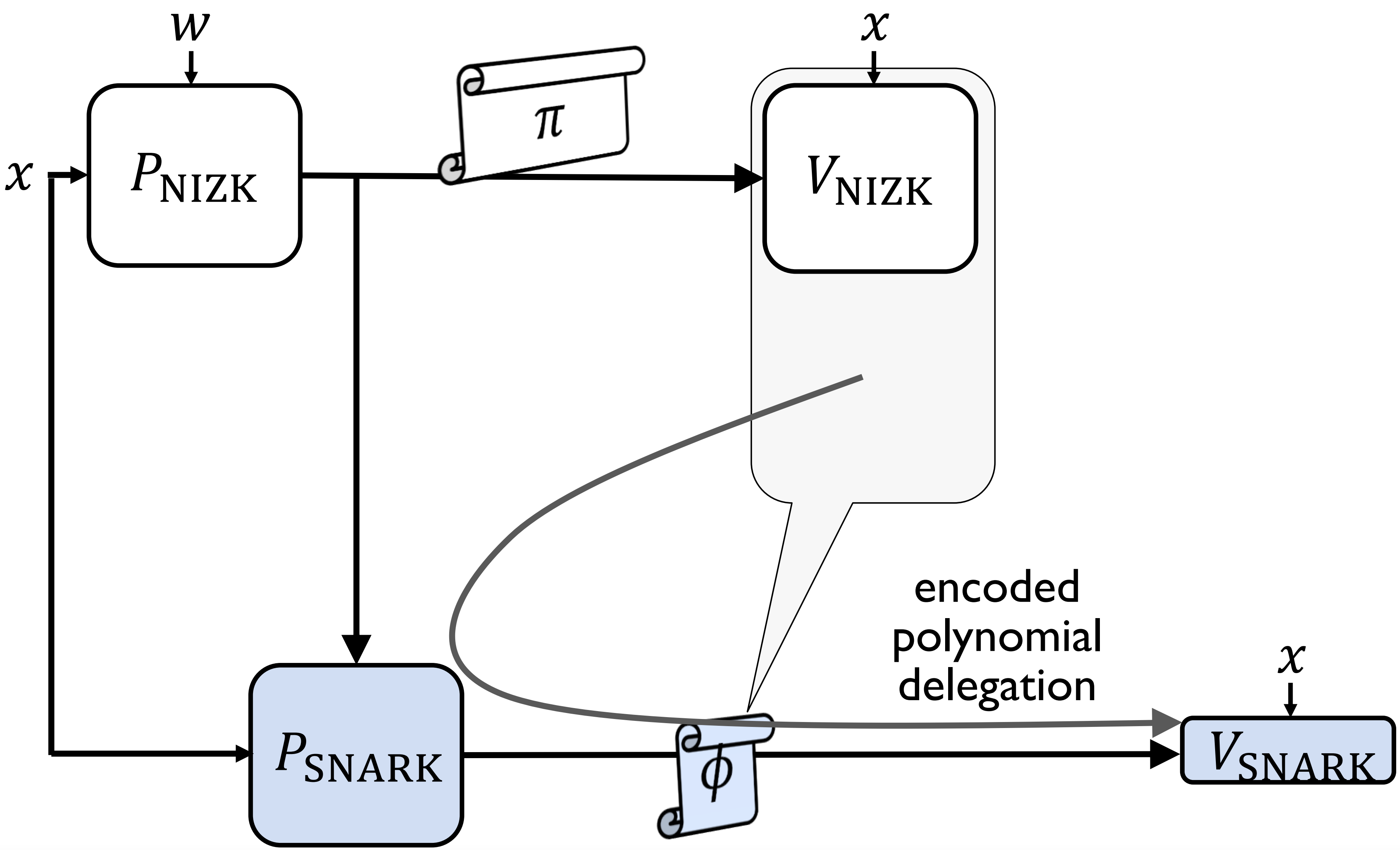

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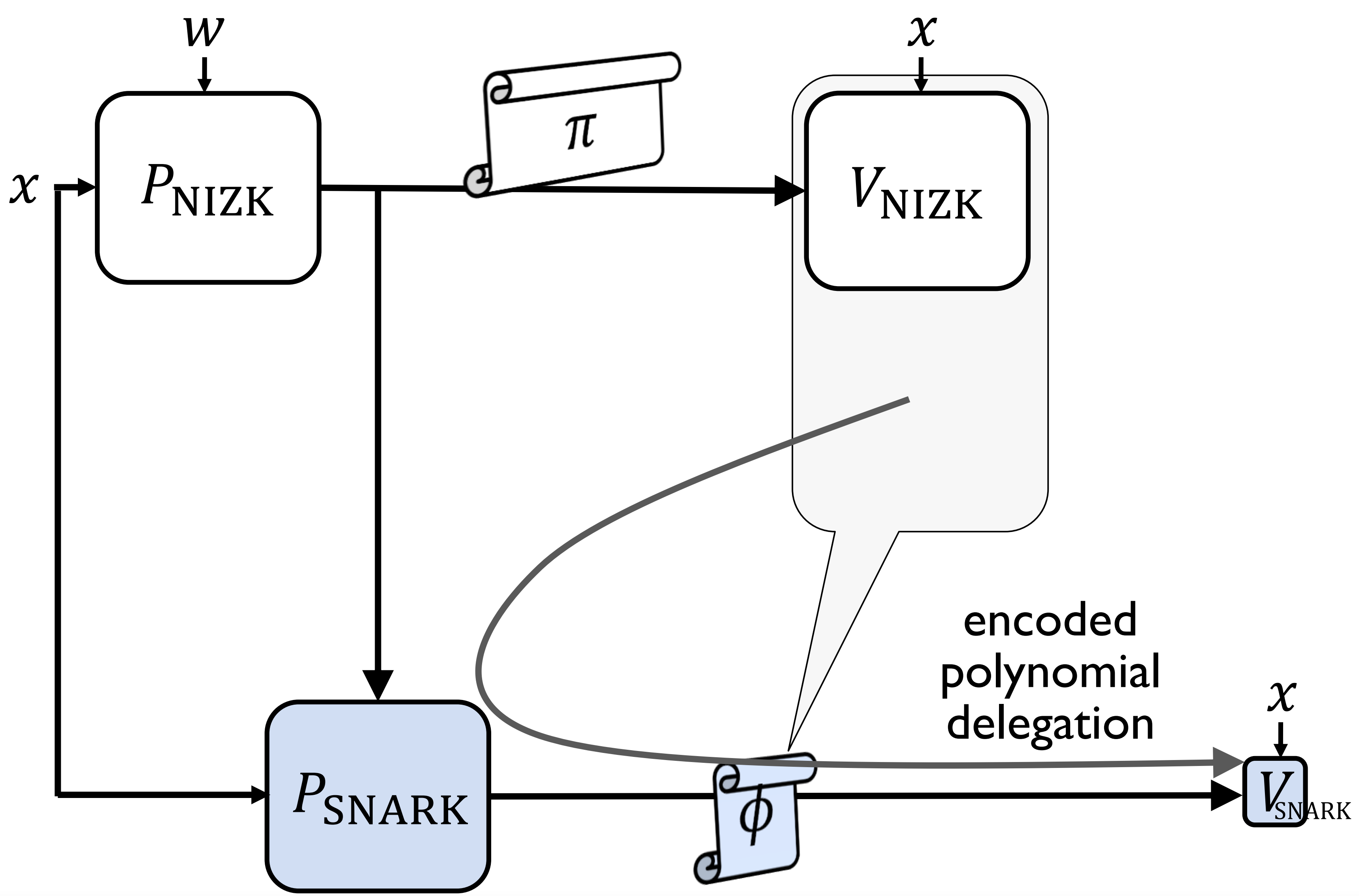

Comparison with generic instantiation

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$O(\lambda^2|C|)$ group ops in P_{SNARK}

$O(\lambda|C|)$ group ops in V_{NIZK}

$O(|C|)$-size circuit

Generic instantiation

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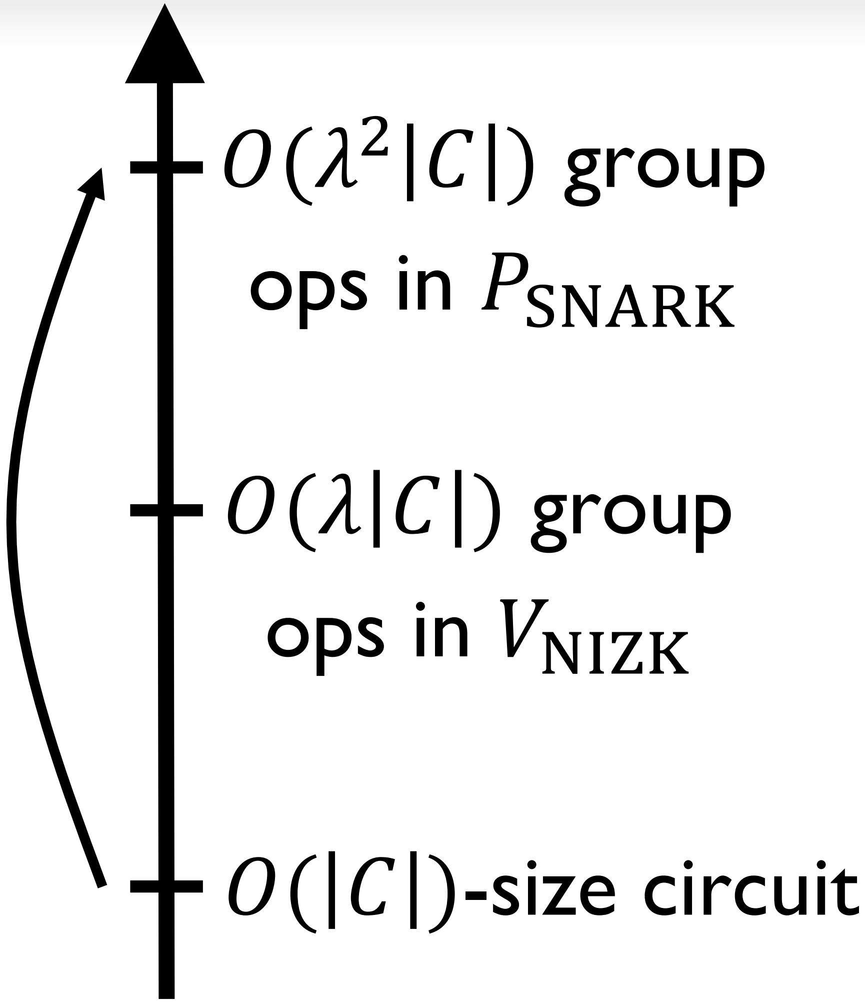

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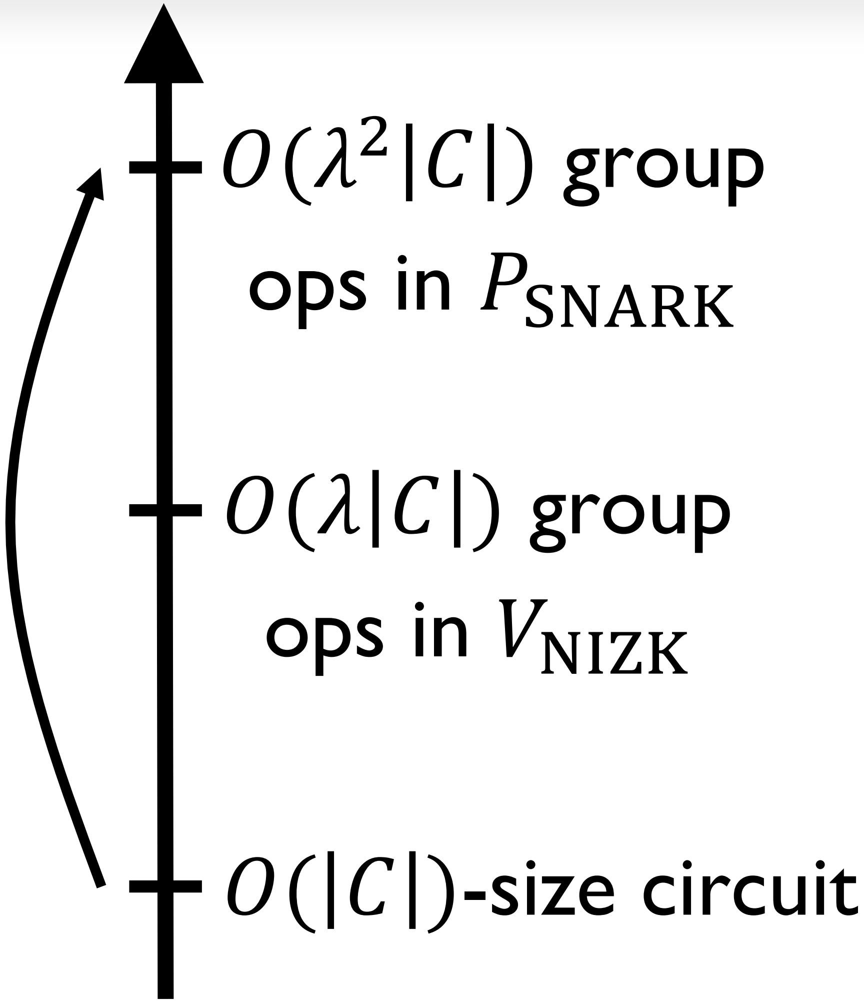

Generic instantiation

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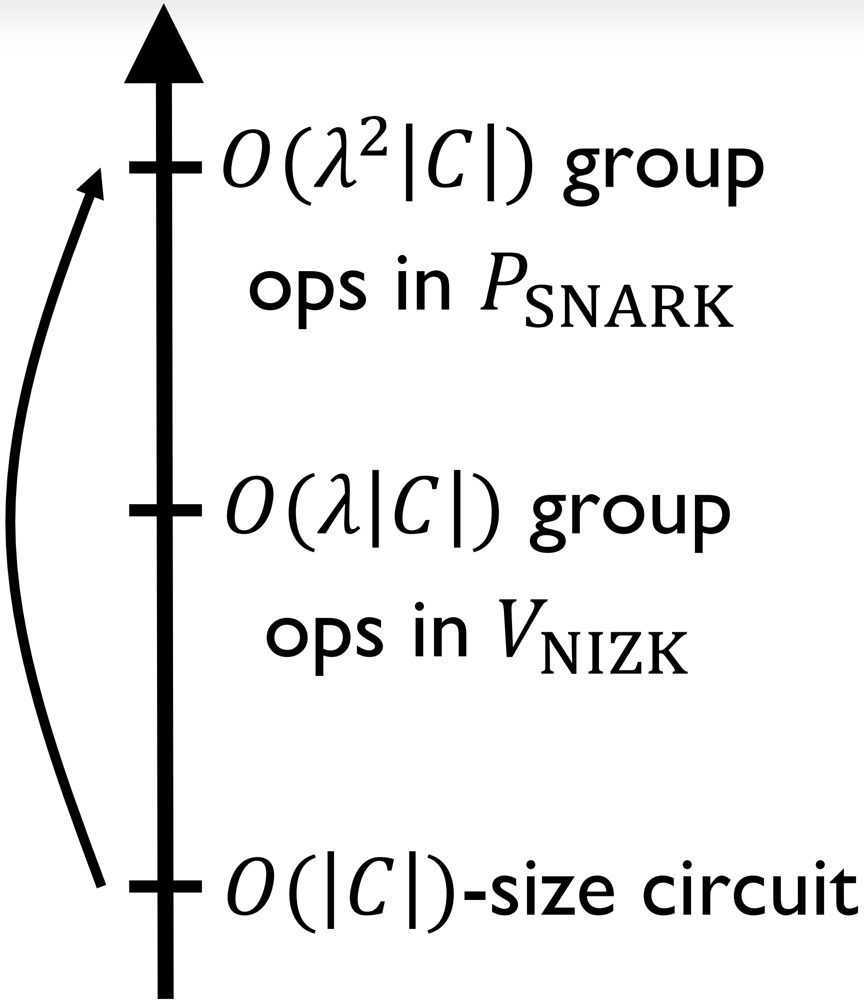

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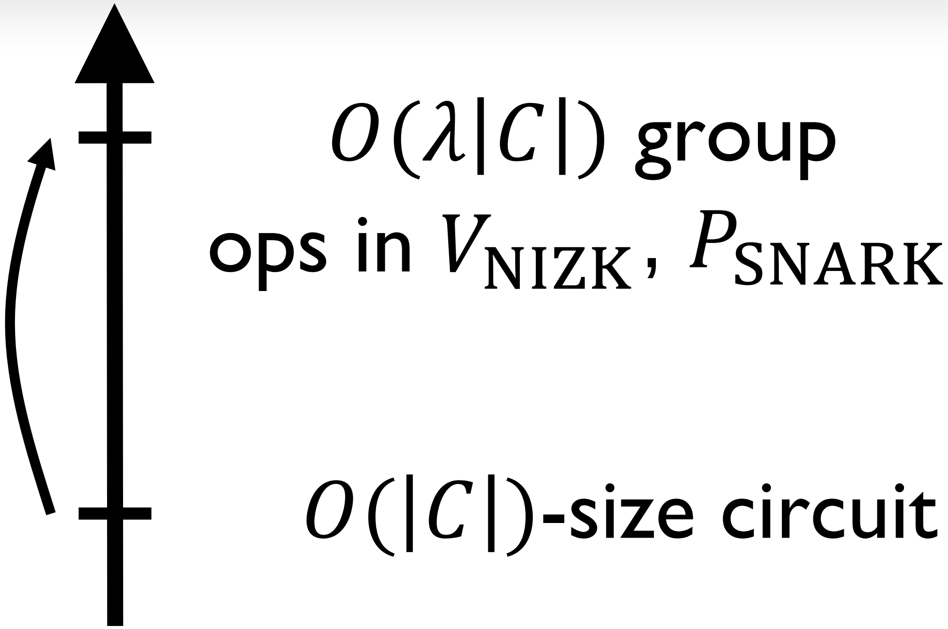

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$+$ competitive proof size and verification time

This work

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e.g. 5 batchable pairings and
$6 \times \mathbb{G}_1$ for an optimistic proof

This work

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- New building blocks along the way:
    - Optimized inner product argument
    - SNARK for encoded polynomial delegation