But Why Does it Work?

A Rational Protocol Design Treatment of Bitcoin

Christian Badertscher ETH Zurich
Juan Garay Texas A&M
Ueli Maurer ETH Zurich
Daniel Tschudi ETH Zurich

Vassilis Zikas
University of Edinburgh & IOHK

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The Evolution of Bitcoin: A Partial View

Time

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2008/09 White Paper & Genesis

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Rational analysis and attacks

- Selfish Mining: Bitcoin is **not an equilibrium** strategy [ES14]
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2018 — Bitcoin still works and no attack on its "backbone" has been observed!

Why Does it Work?

Why don’t the predicted attacks occur and entirely break it?

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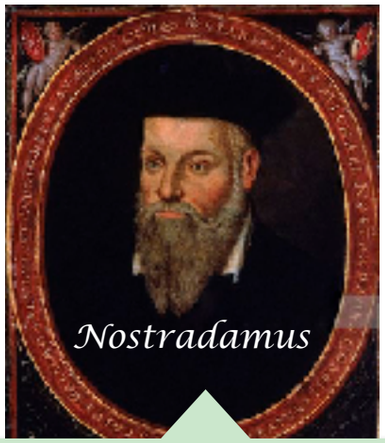

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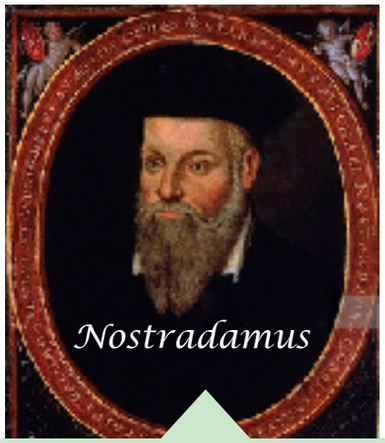

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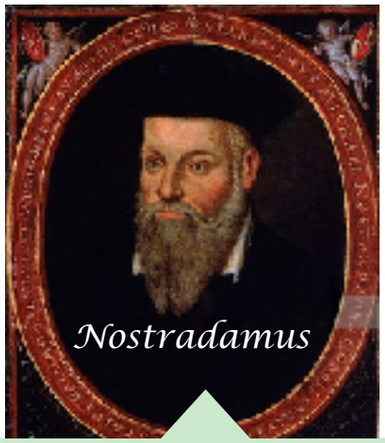

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- Utilities = assumptions to explain/predict players behavior
- If predictions ≠ observable then utilities (and game?) can (should?) be rethought.

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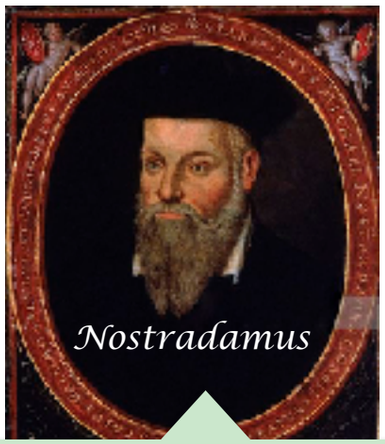

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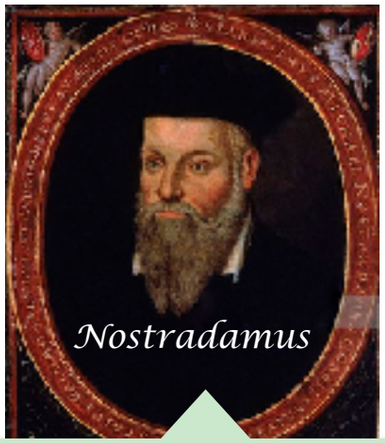

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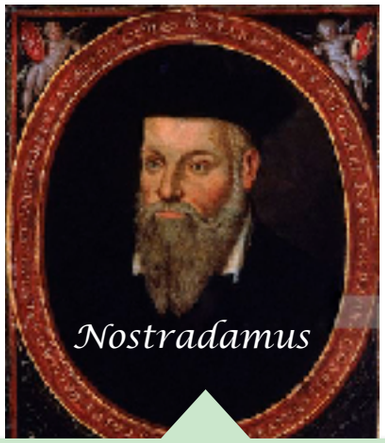

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Calls for an alternative rational treatment

Our Contributions

- A new model for rational analysis of Bitcoin
- Applying the framework to analyze the Bitcoin backbone
  - A class of utilities reflecting “minimal” assumptions about the Bitcoin miners’ incentives.
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Securely implementing a task against
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The Attack Game

Protocol Designer

(n-party) task as an ideal functionality $\mathcal{F}$

Protocol Attacker

u_D

u_A

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Rational Protocol Design (RPD) [GKMTZ13]

Flavors of Protocol Quality (security / stability)

- π is *(u_D, u_A, Π)-attack-payoff optimal* for $\mathcal{F}$ if any other protocol in Π allows for more rewarding attacks
  - π is a best-response strategy among protocols in Π
- π is *$(u_D, u_A, \mathbb{A})$-attack-payoff secure* for $\mathcal{F}$ if the best the attacker can do is play an adversary in $\mathbb{A}$
  - an $\mathbb{A}$-adversary is best response to π

In [GKMTZ13]**:**

✳ Π = The class of all poly-time protocols

✳ $\mathbb{A}$ = The class of all adversaries that honestly execute the protocol

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Bitcoin in RPD++

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For Bitcoin

✳ Π = The class of protocols that use the Bitcoin infrastructure (circulate blocks and transactions of the right format)

✳ $\mathbb{A}$ = The class of semi-honest network-rushing adversaries

➡ *strongly (u_D, u_A)-attack-payoff secure*

Bitcoin in RPD++

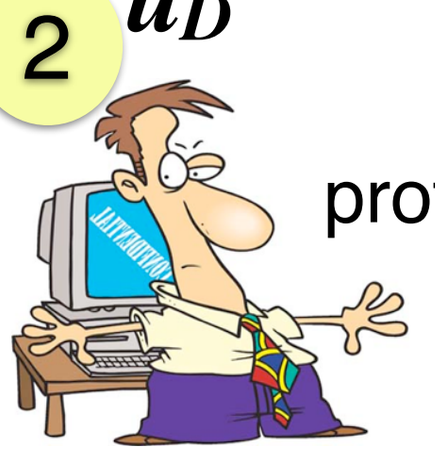
The Bitcoin Attack Game

(n-party) task as an ideal functionality $\mathcal{F}$

1

Protocol Designer

2 u_D



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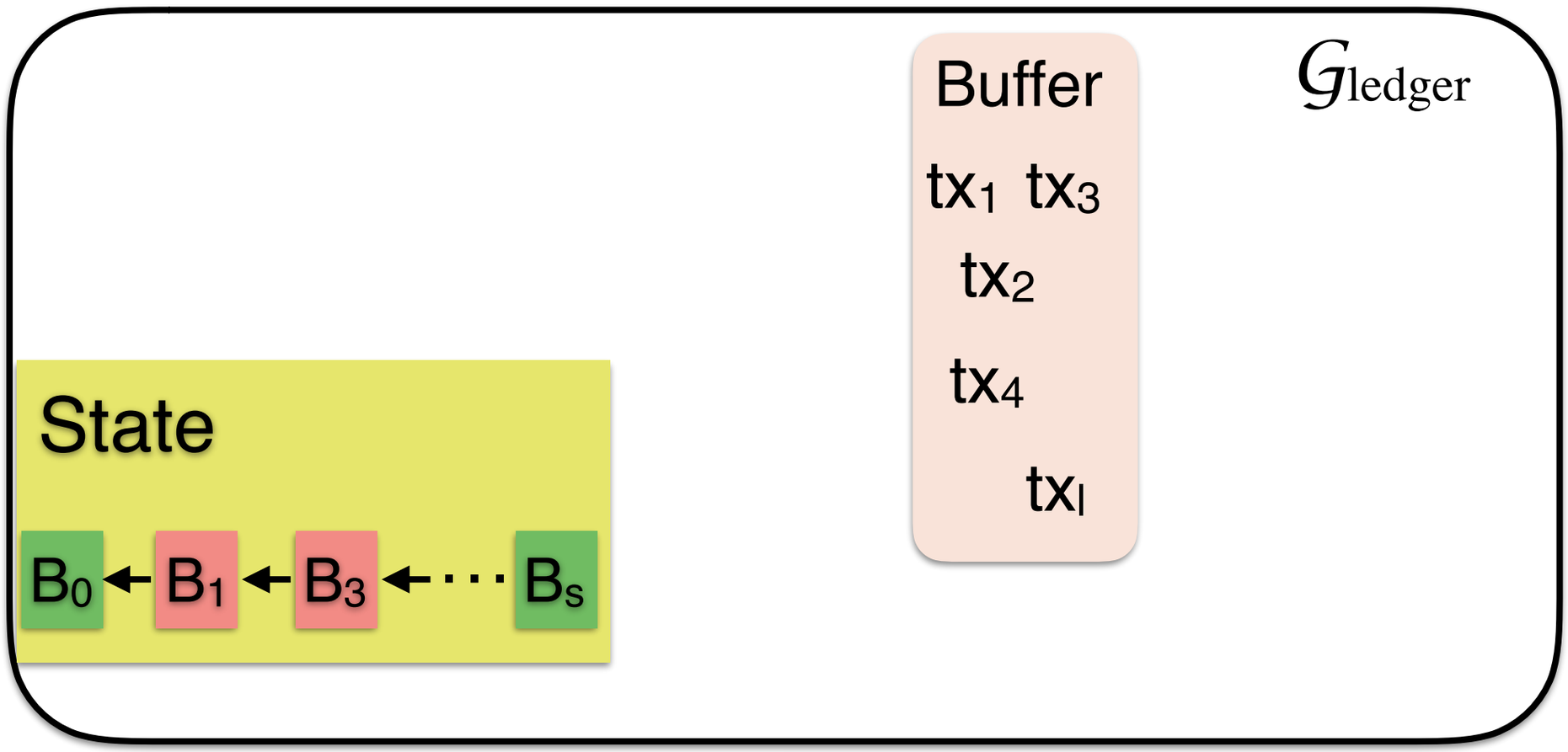

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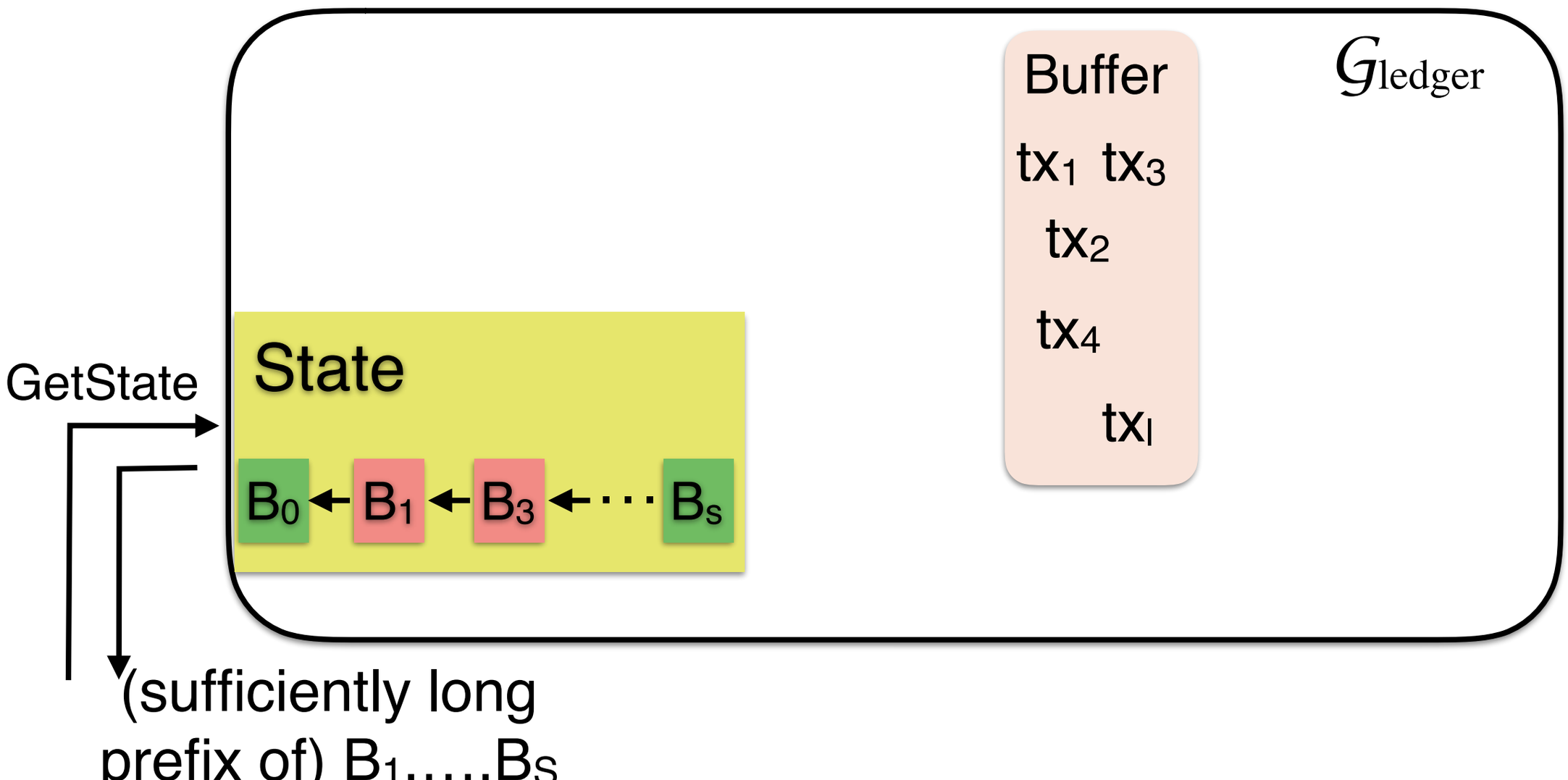

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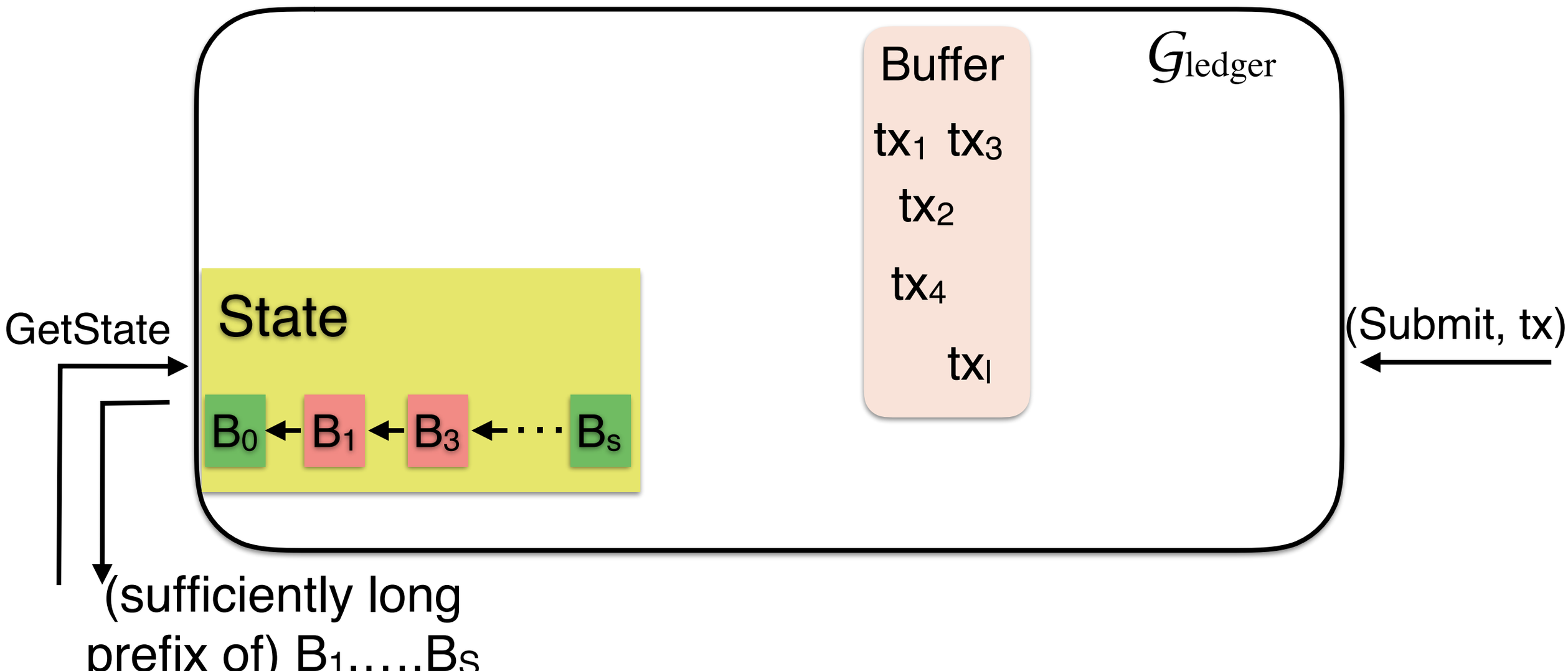

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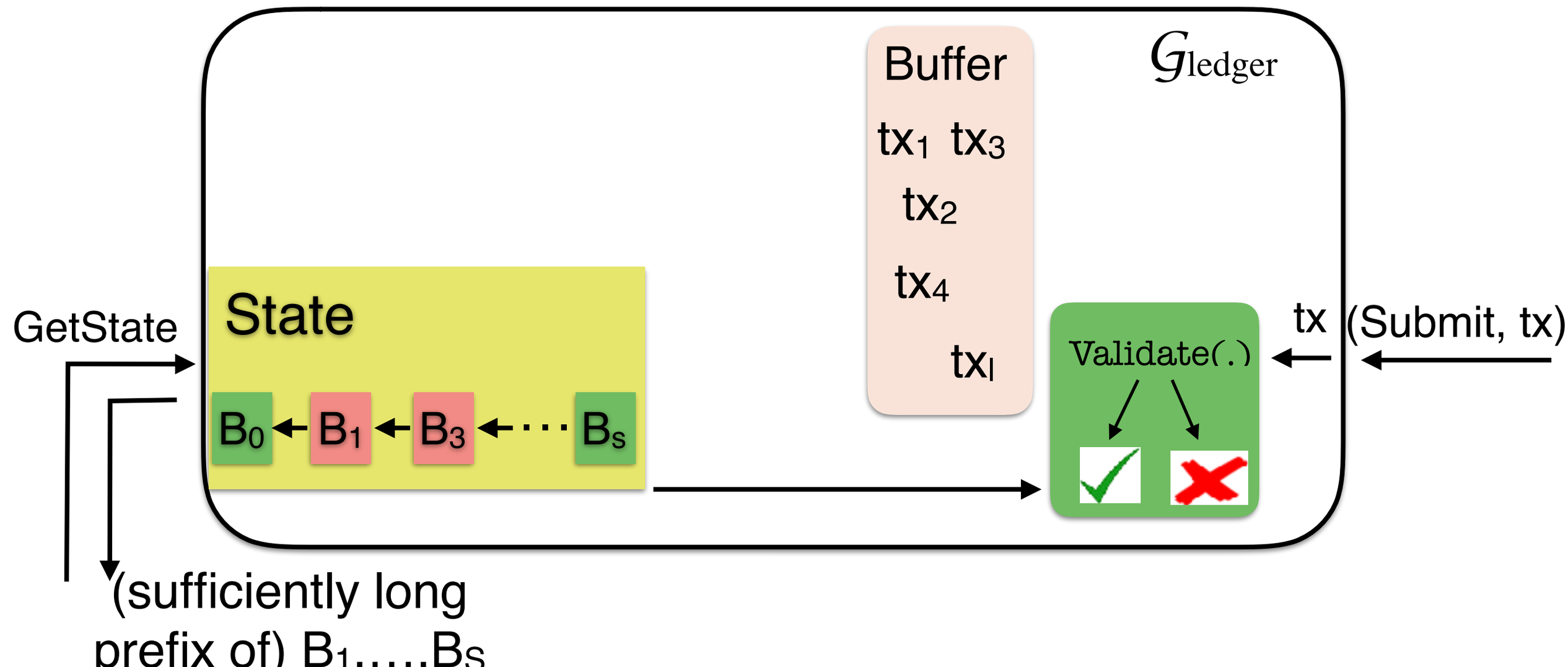

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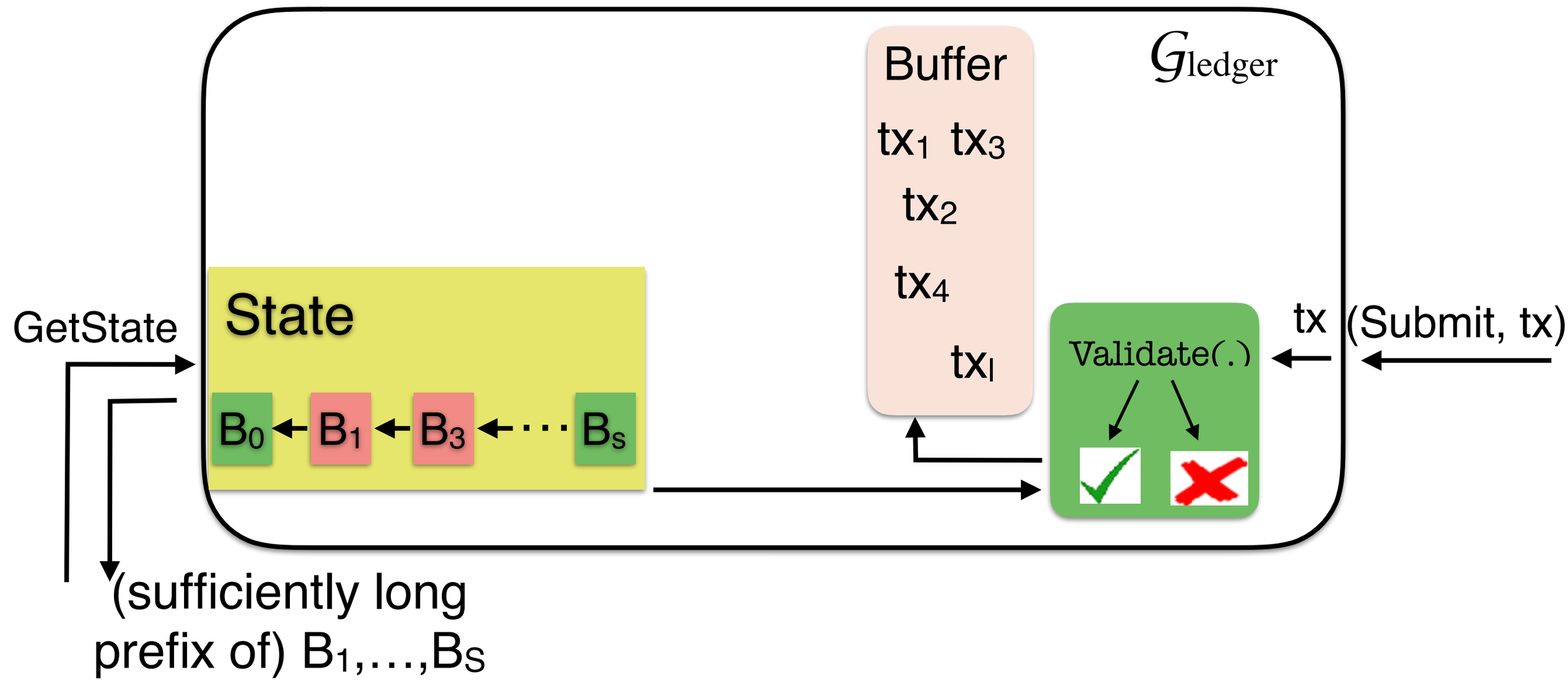

Bitcoin an a Transaction Ledger [BMTZ17]

tx

Buffer

tx_1 tx_3

tx_2

tx_4

tx tx_l

$\mathcal{G}_{\text{ledger}}$

Validate(.)

tx (Submit, tx)

GetState

State

$B_0 \leftarrow B_1 \leftarrow B_3 \leftarrow \cdots B_s$

(sufficiently long prefix of) $B_1,\ldots,B_S$

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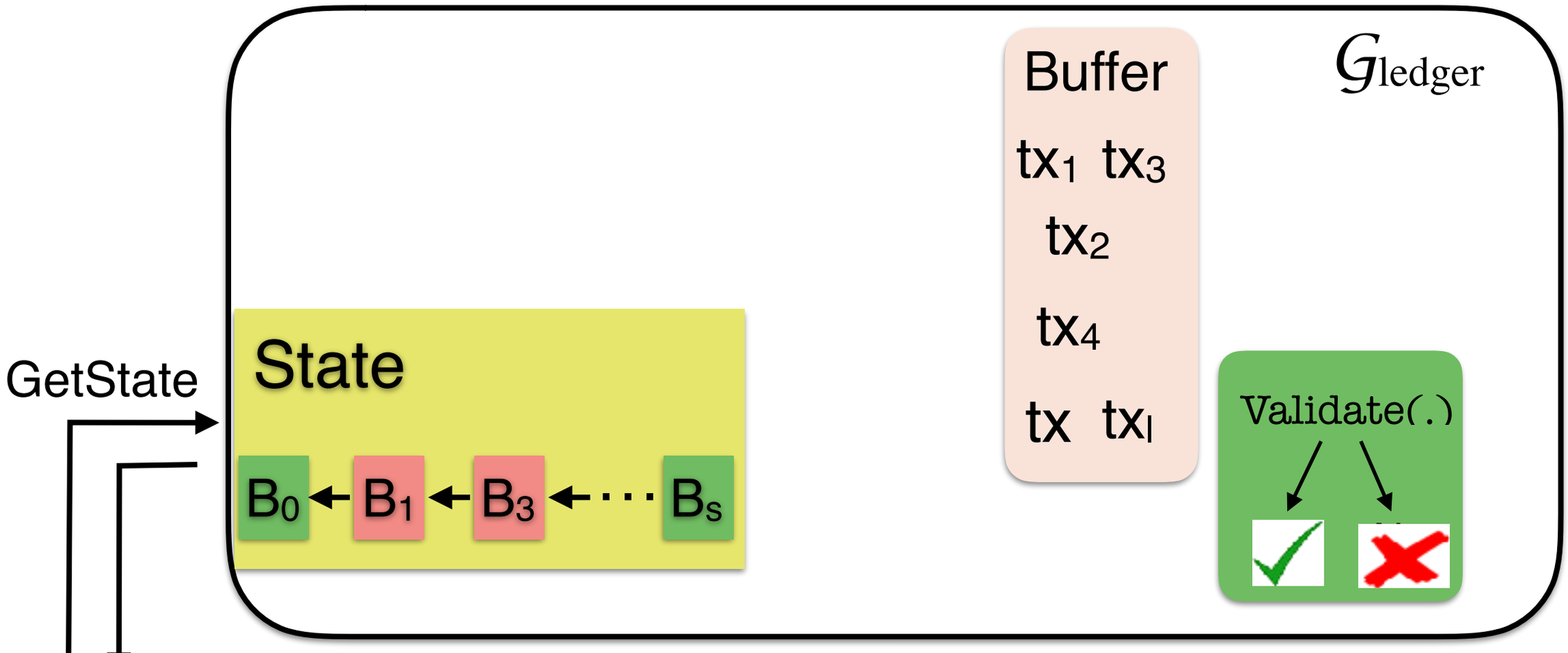

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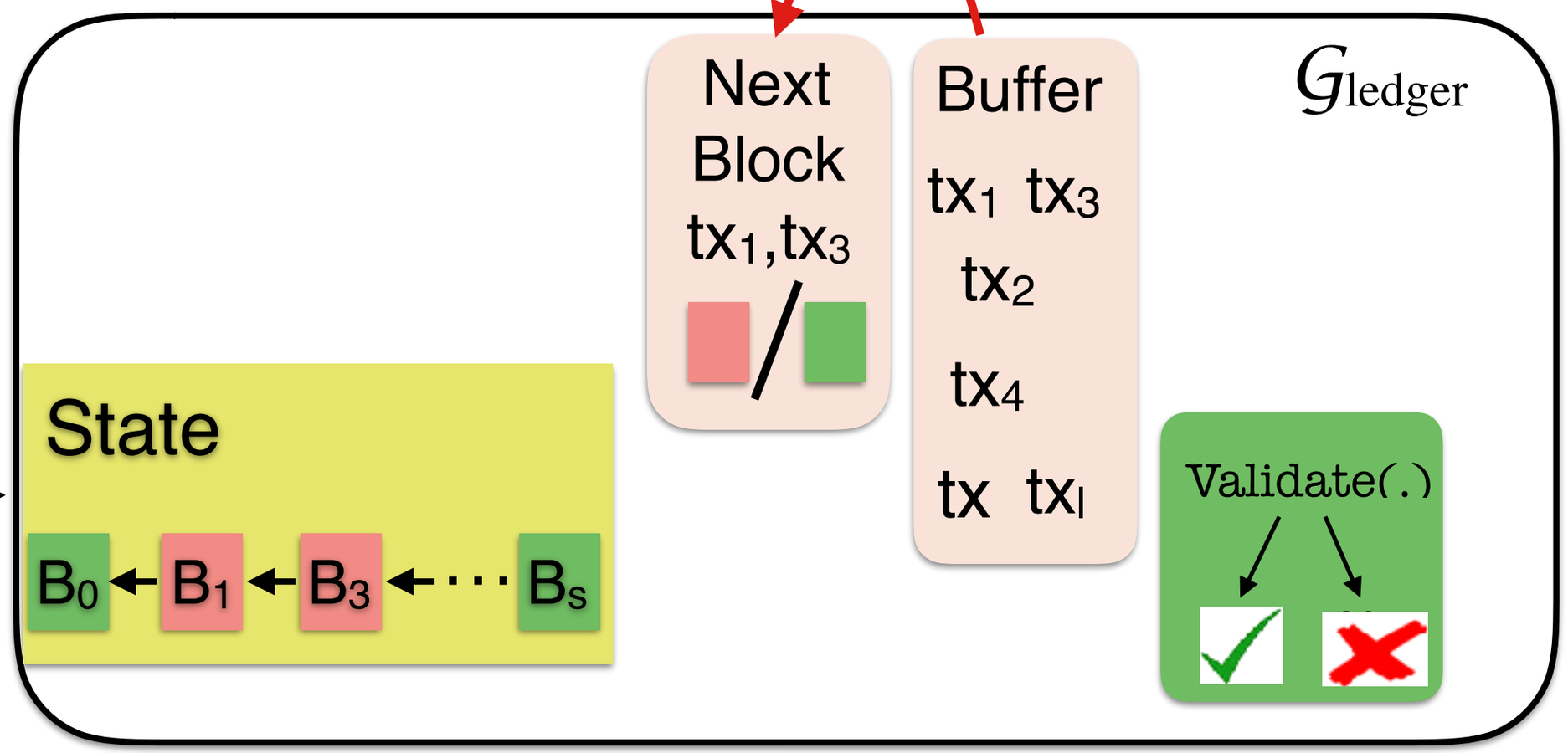

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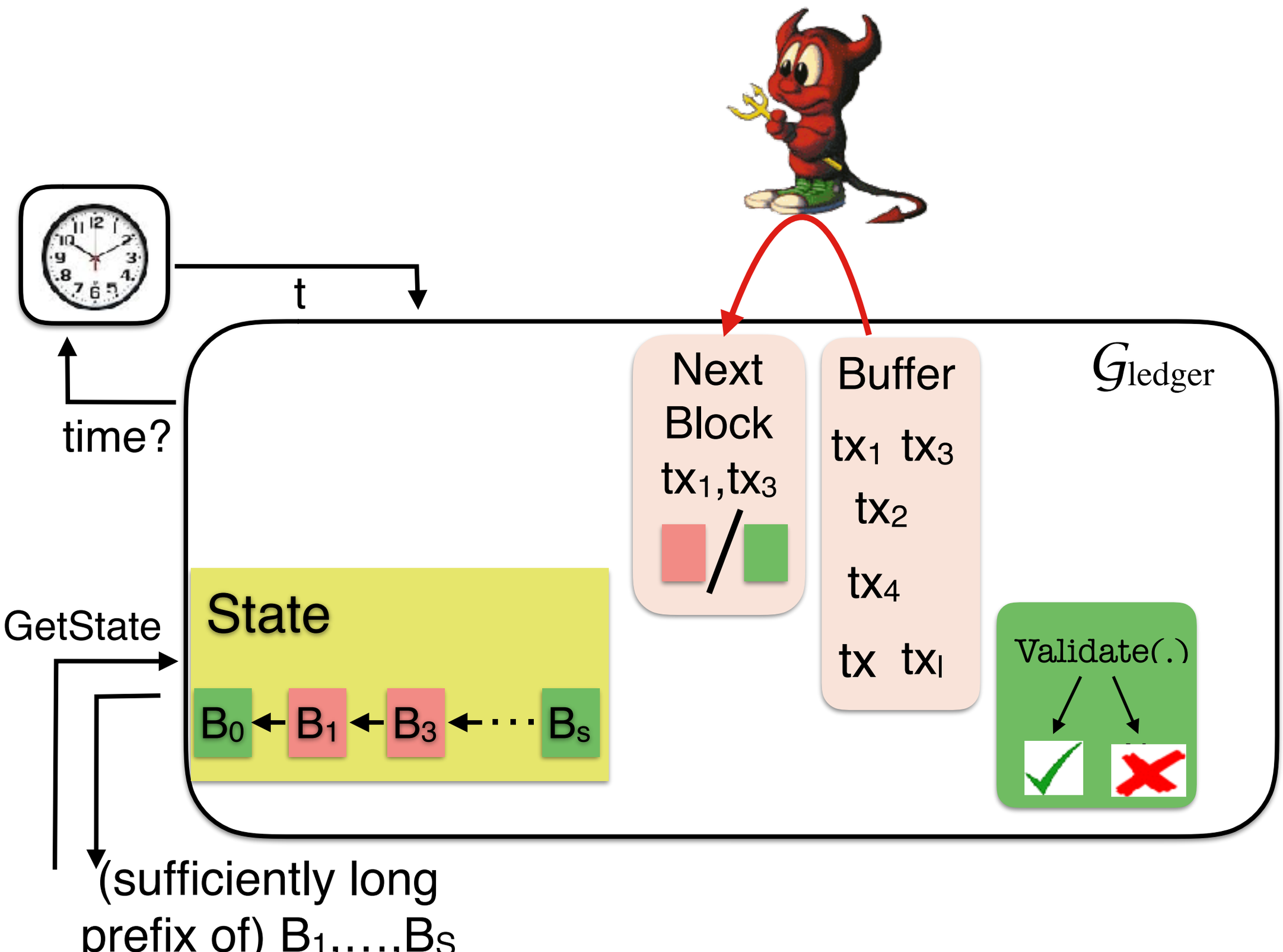

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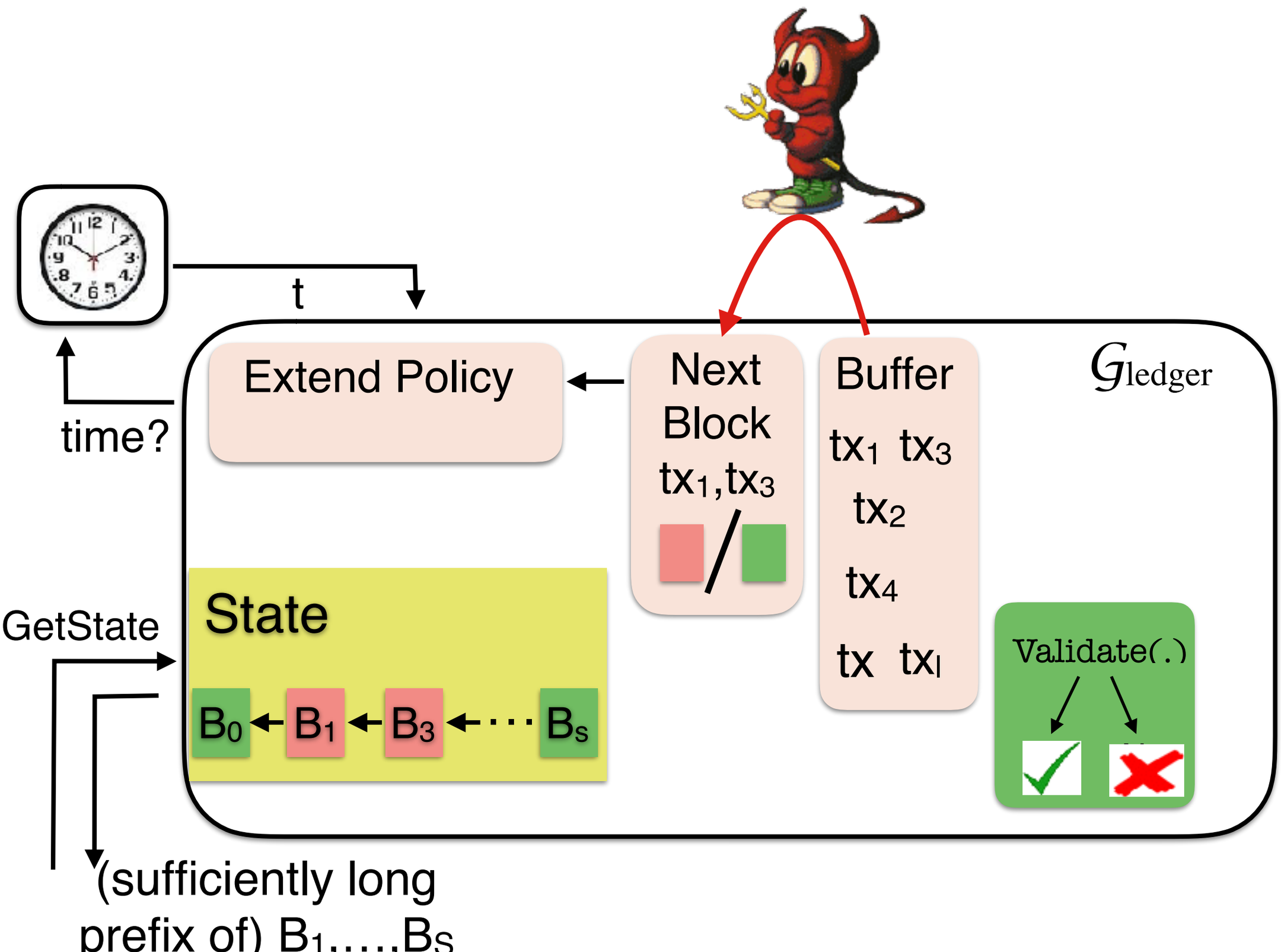

Bitcoin an a Transaction Ledger [BMTZ17]

- chain growth, chain quality,… [GKL15,PSS17]

t

time?

$\mathcal{G}_{\text{ledger}}$

Extend Policy

Next Block

tx_1,tx_3

Buffer

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tx_2

tx_4

tx tx_l

Validate(.)

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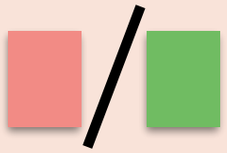

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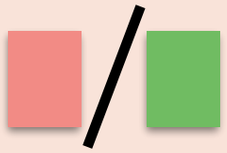
Extend Policy

Blockify

Next Block

Block

tx_1, tx_3



Buffer

tx_1 tx_3

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t

time?

$\mathcal{G}_{\text{ledger}}$

Extend Policy ✓

Next Block

Block tx_1, tx_3

Buffer

tx_1 tx_3

tx_2

tx_4

tx tx_l

Blockify → B_{s+1}

State

$B_0 \leftarrow B_1 \leftarrow B_3 \leftarrow \cdots B_s$

Validate(.)

✓ ✗

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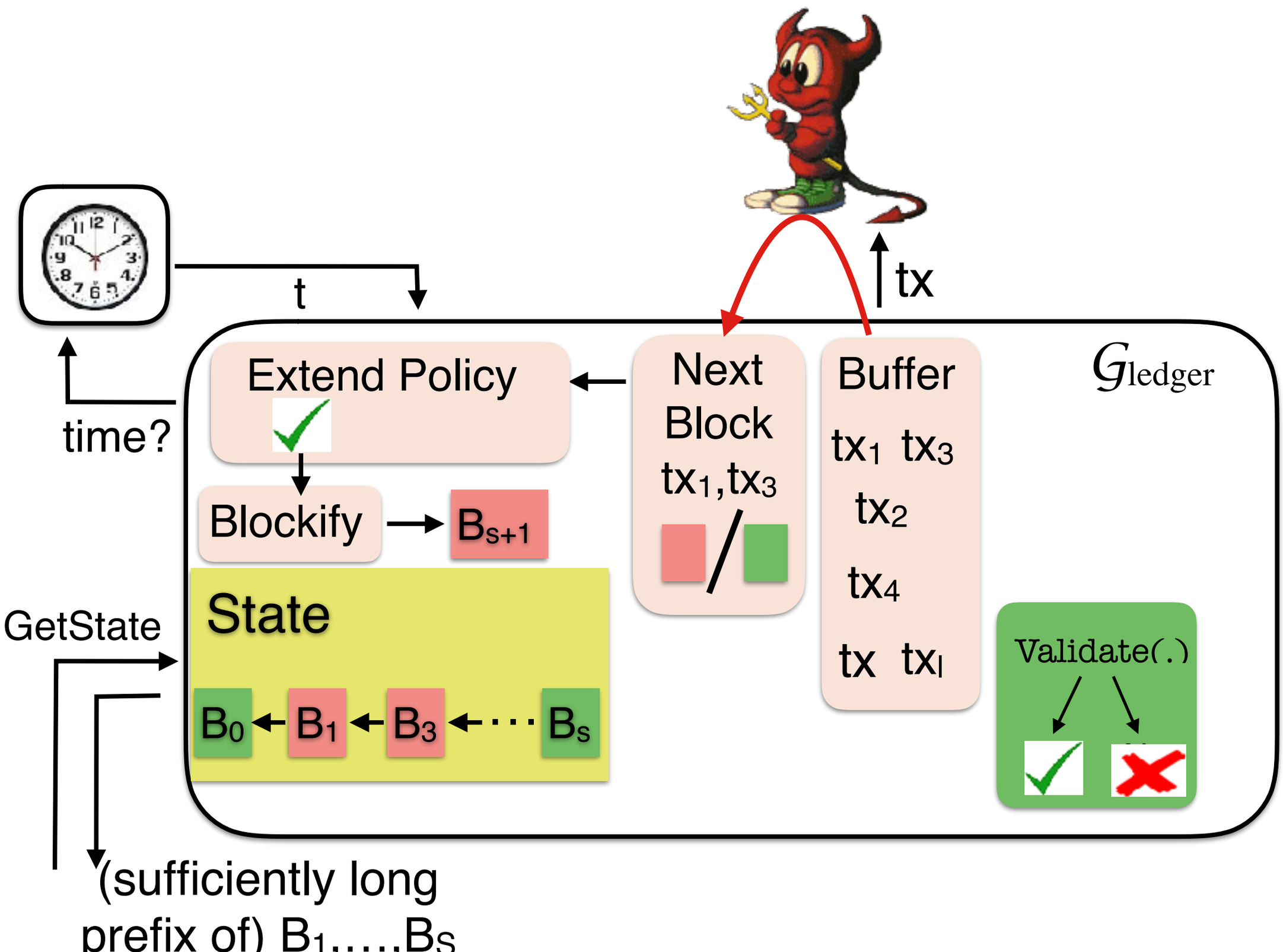

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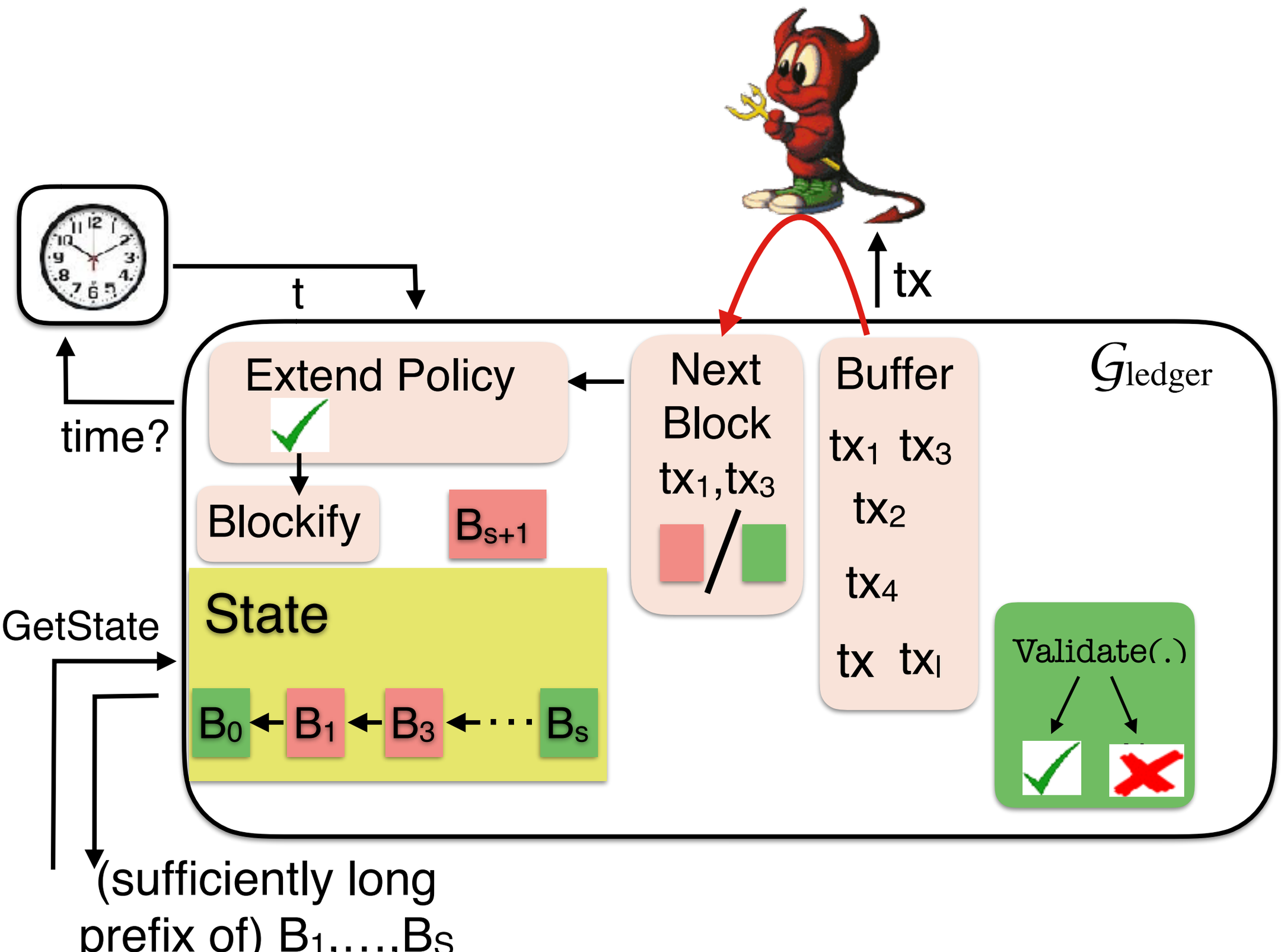

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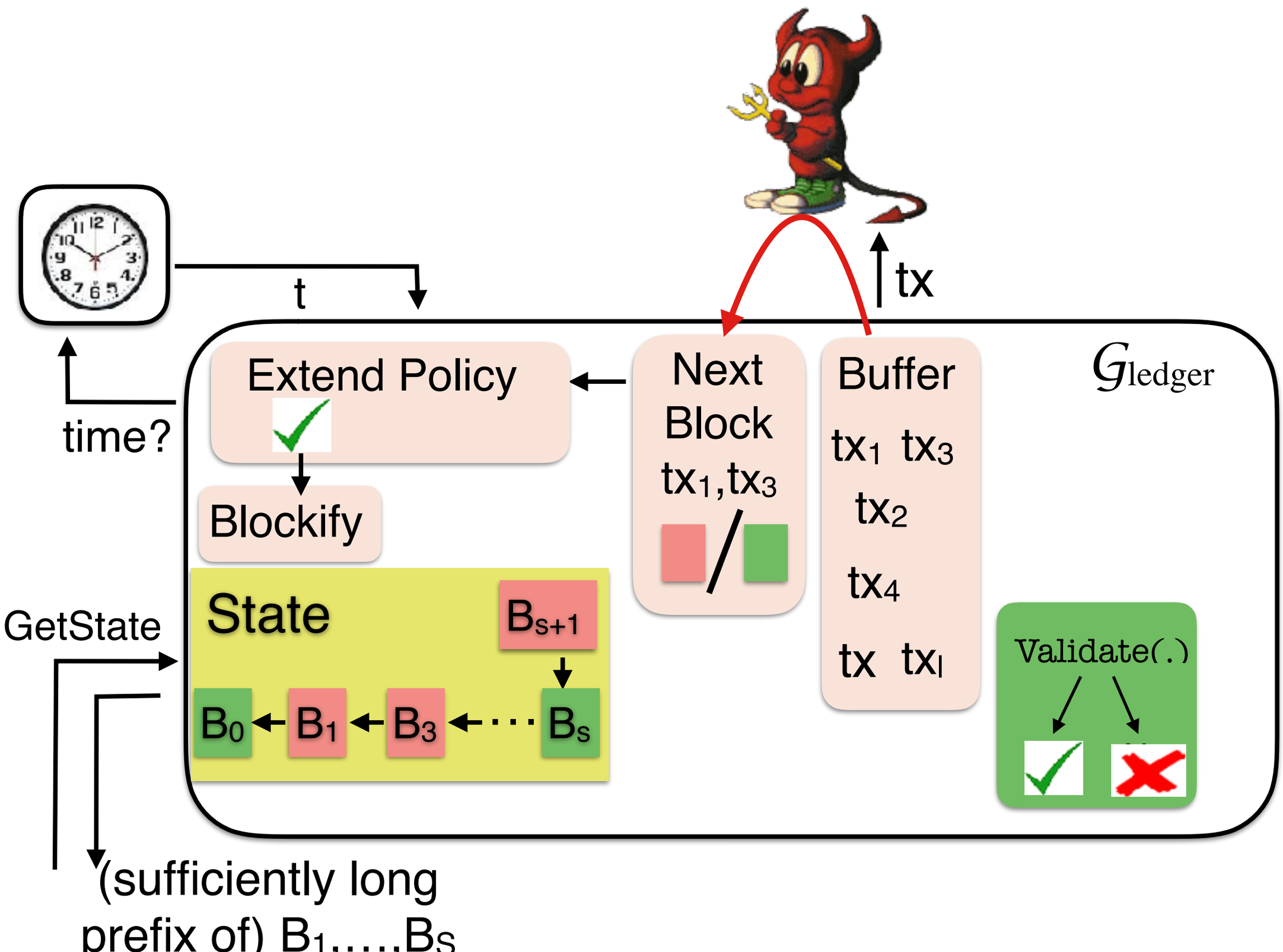

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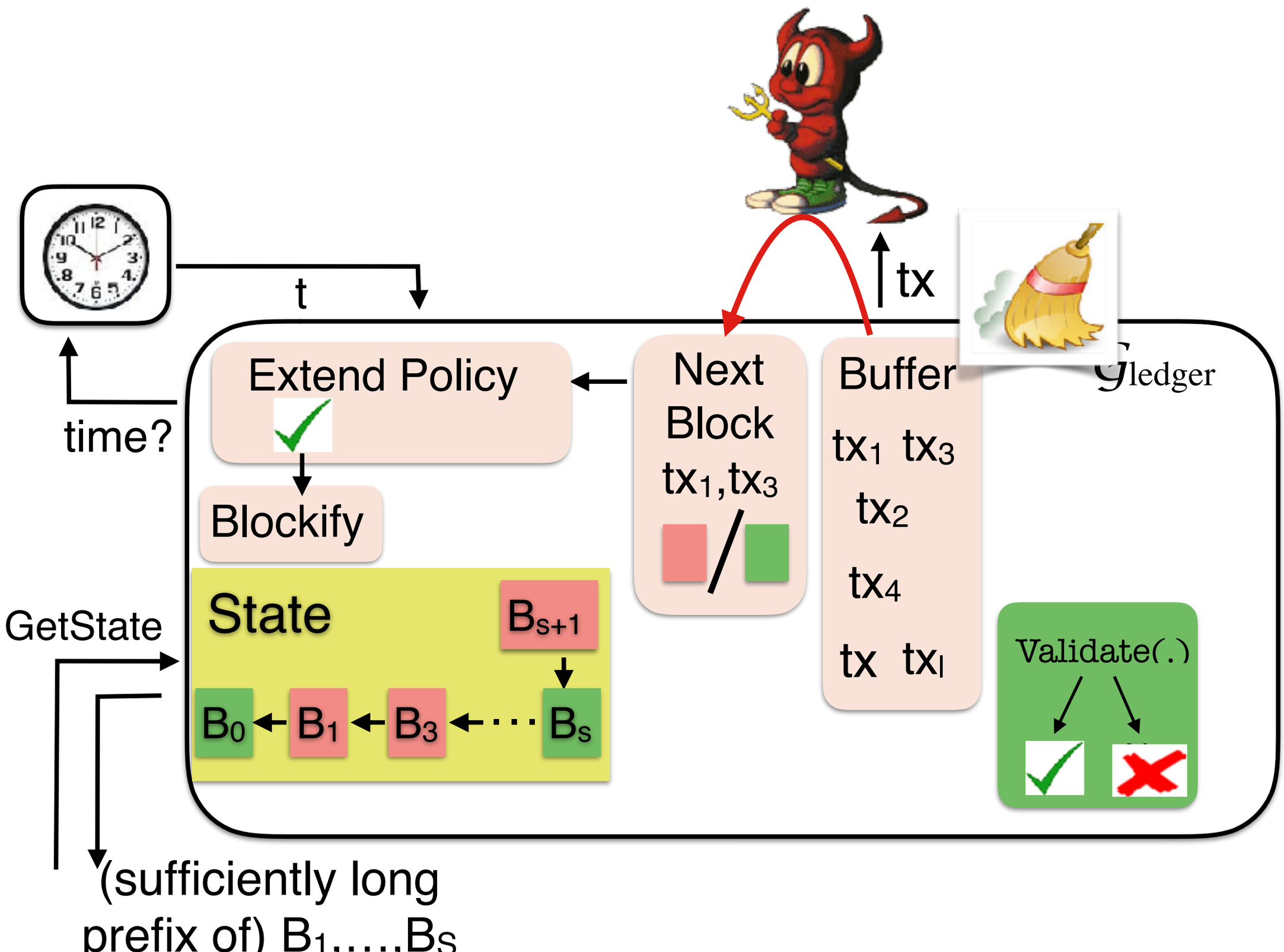

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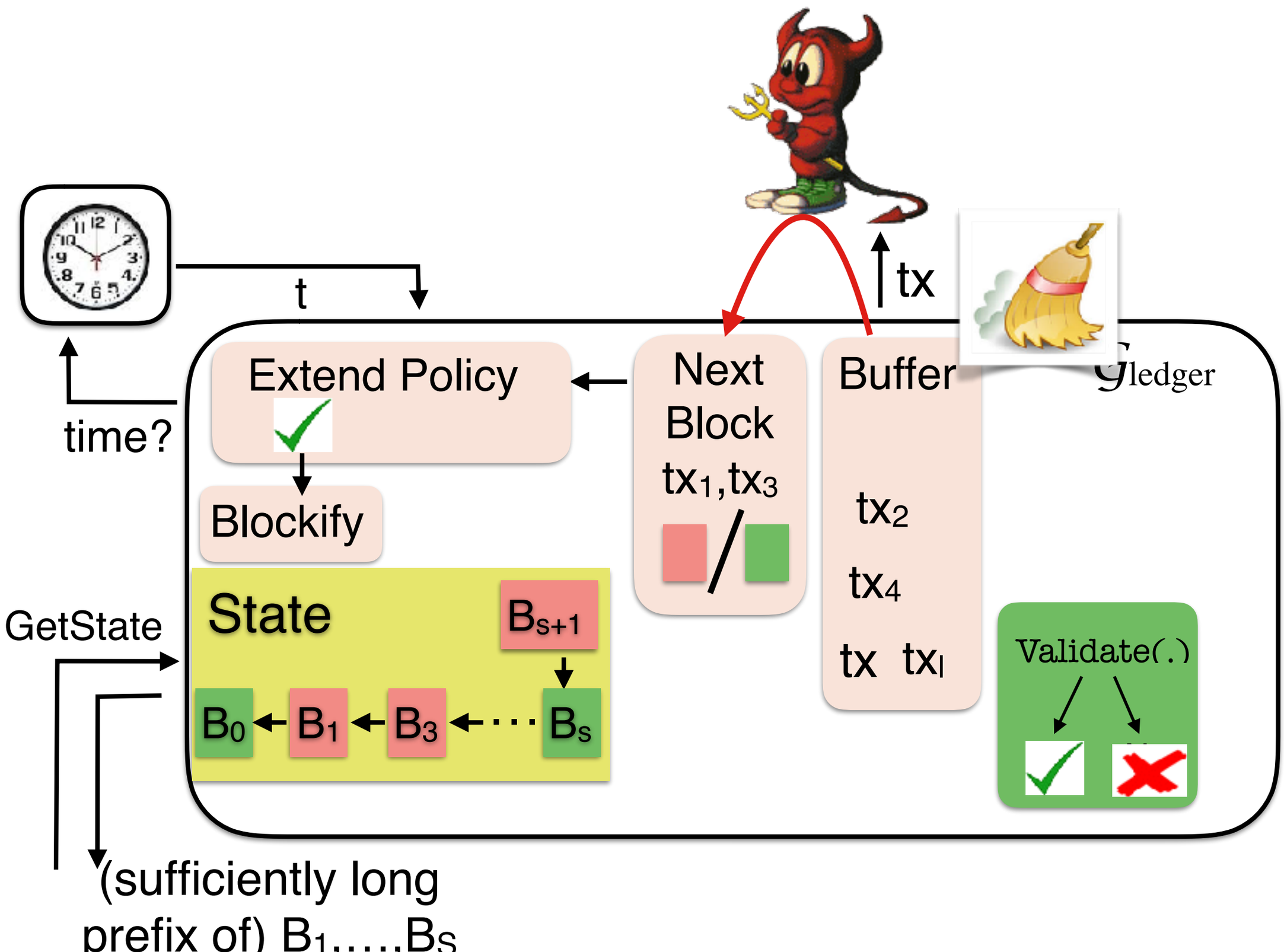
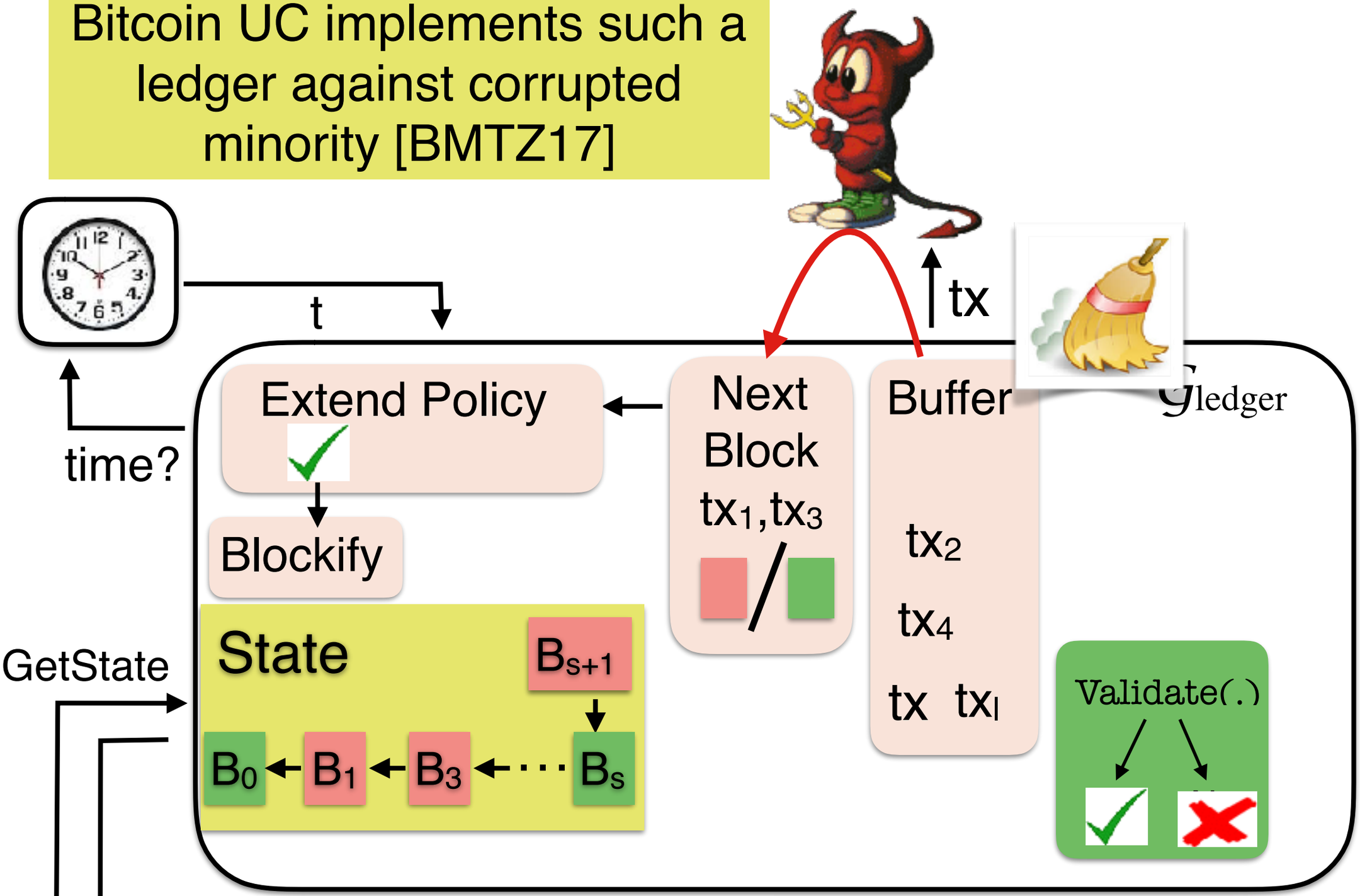


Bitcoin an a Transaction Ledger [BMTZ17]

Bitcoin UC implements such a ledger against corrupted minority [BMTZ17]



Bitcoin in RPD++

The Bitcoin Attack Game

Protocol Designer

(n-party) task as an ideal functionality ~~$\mathcal{F}$~~ $\mathcal{F}_{\text{Ledger}}$ 1

Protocol Attacker

u_D 2

(n-party) protocol π for $\mathcal{F}$

u_A 2

Adversary $\mathcal{A}$ *for attacking* π

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Parameters

(+)	**(+)**	**(-)**
Block Reward	Transaction Fees	Hashing Cost
$\boldsymbol{BR}$ (Unit : BTC)	$\boldsymbol{TF}$ (Unit : BTC)	$\boldsymbol{HC}$ (Unit : KWh)

Utility = expected rewards - expected costs

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1KWh = $\boldsymbol{CR}$ BTC

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1KWh = CR BTC

The attacker's (expected) utility $u_A^{\ddot{\mathbb{B}}}$: Wants to make profit

- For each block a corrupted inserts into the state: $(BR + TF)$ BTCs
- For each hash query a corrupted makes: $-(HC \times CR)$ BTCs

The Utilities

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Can be defined in the ideal experiment
(explicit in the functionality)

The Utilities

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The designer's (expected) utility $u_D^{\ddot{\mathbb{B}}}$: Wants to preserve consensus *and* make profit while doing so

- For each block an honest inserts into the state: $(BR + TF)$ BTCs
- For each hash query an honest makes: **-** $(HC \times CR)$ BTCs
- If the state (permanent part) of the ledger forks then **- exp** BTCs

Bitcoin in RPD++

Advantages over standard rational analysis

- **Simpler (Stackelberg) game to analyze**
  - 2-party 2-move metagame among unbounded agents
- **Most Bitcoin miners will not cheat and will follow the protocol if it is profitable for them**
- **Utilities are defined in the cleaner ideal world**
  - Can define them based on the fixed ledger state rather than local views of parties
- **Automatic composition with crypto** [GKMTZ13]
- **Easily captures adaptive corruption**
  - Example: bribery attacks [Bon16]

Our Contributions

- A new model for rational analysis of Bitcoin

Blockchains

- Applying the framework to analyze the Bitcoin backbone
  - A class of utilities reflecting “minimal” assumptions about the Bitcoin miners’ incentives.
  - Deriving predictions that match the observable.

Stability/Security: No Transaction Fees (TF=0)

Bitcoin is strongly $(u_D^{\ddot{\mathbb{B}}}, u_A^{\ddot{\mathbb{B}}})$-attack-payoff secure for $\mathcal{F}_{\text{Ledger}}$

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Proof Idea:

- The adversary controls the network

- Any non-network related attack involves hashing
  - If the finds a solution to the puzzle he is better off pushing it to the network
  - Otherwise, the hash is useless (and costly)

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Fixed difficulty

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$$\boldsymbol{BR} \cdot \boldsymbol{CR} < \frac{\boldsymbol{HC}}{p}$$

$$\boldsymbol{BR} \cdot \boldsymbol{CR} > \boldsymbol{HC} \cdot \frac{1}{p \cdot (1-p)^{n-1}}$$

* p = Probability of finding a valid block in 1 hash query

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$$\boldsymbol{BR} \cdot \boldsymbol{CR} > \boldsymbol{HC} \cdot \frac{1}{p \cdot (1-p)^{n-1}}$$

Proof Idea:
On expectation, the cost of mining till you find a block is more than the profit (even if the block would make it)

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Proof Idea:
On expectation, the cost of mining till you are the only one that finds a block is less than the profit.

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Stability/Security: With Transaction Fees

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- there is an upper bound on total fees
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Proposal for when rewards approach zero

- no incentive to circulate high-fee transactions to the network

Conclusions

Our Results

- Simple and Crypto-compatible rational model for blockchains
- Rational treatment of the **Bitcoin backbone** with **fixed difficulty** under natural minimal utilities
- The effect of exchange on stability/security
- Proposal for coping with diminishing rewards
- *Also in the paper:* Rationality as a fallback to honest majority

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Future Directions

- Variable difficulty
- Utilities capturing other factors might affect the decision:
    - Detection of a 50% attack might be a deterrence
    - Mining pools' incentives
- A rational analysis of Bitcoin **as cryptocurrency**
    - The contents of transactions might affect the utilities…

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Thank you!