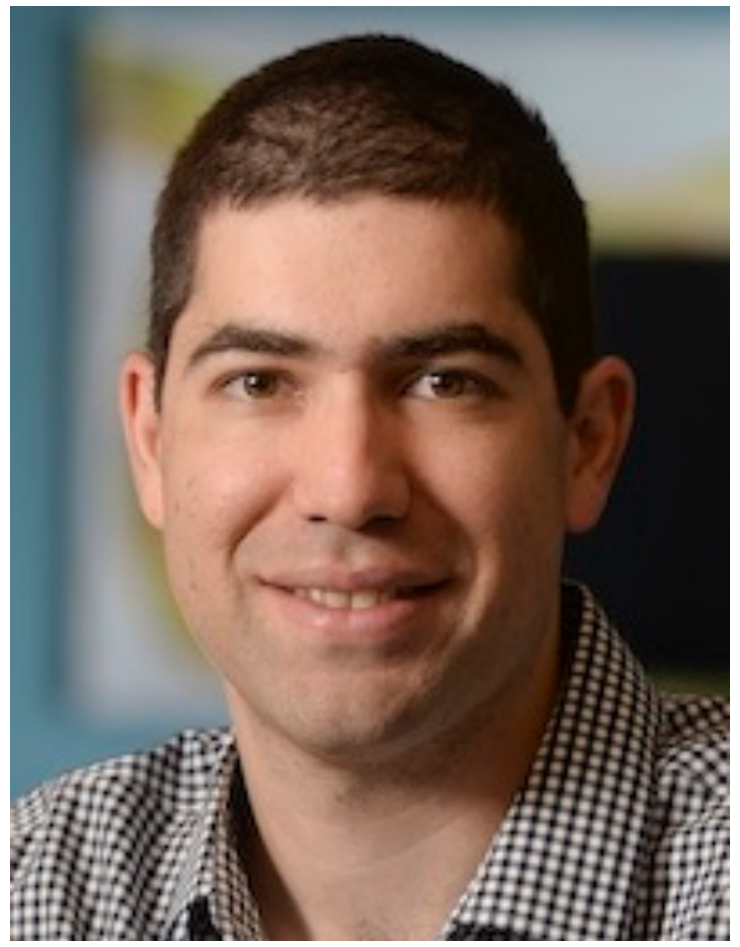
The Complexity of Memory Checking with Covert Security

Neekon Vafa (MIT)

Eurocrypt 2025
May 5, 2025

Based on joint work with:



Elette Boyle
Reichman University
& NTT Research

Ilan Komargodski
Hebrew University
& NTT Research

Remote Cloud Storage

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- **Common solution**: Run computation using **remote cloud** as storage.

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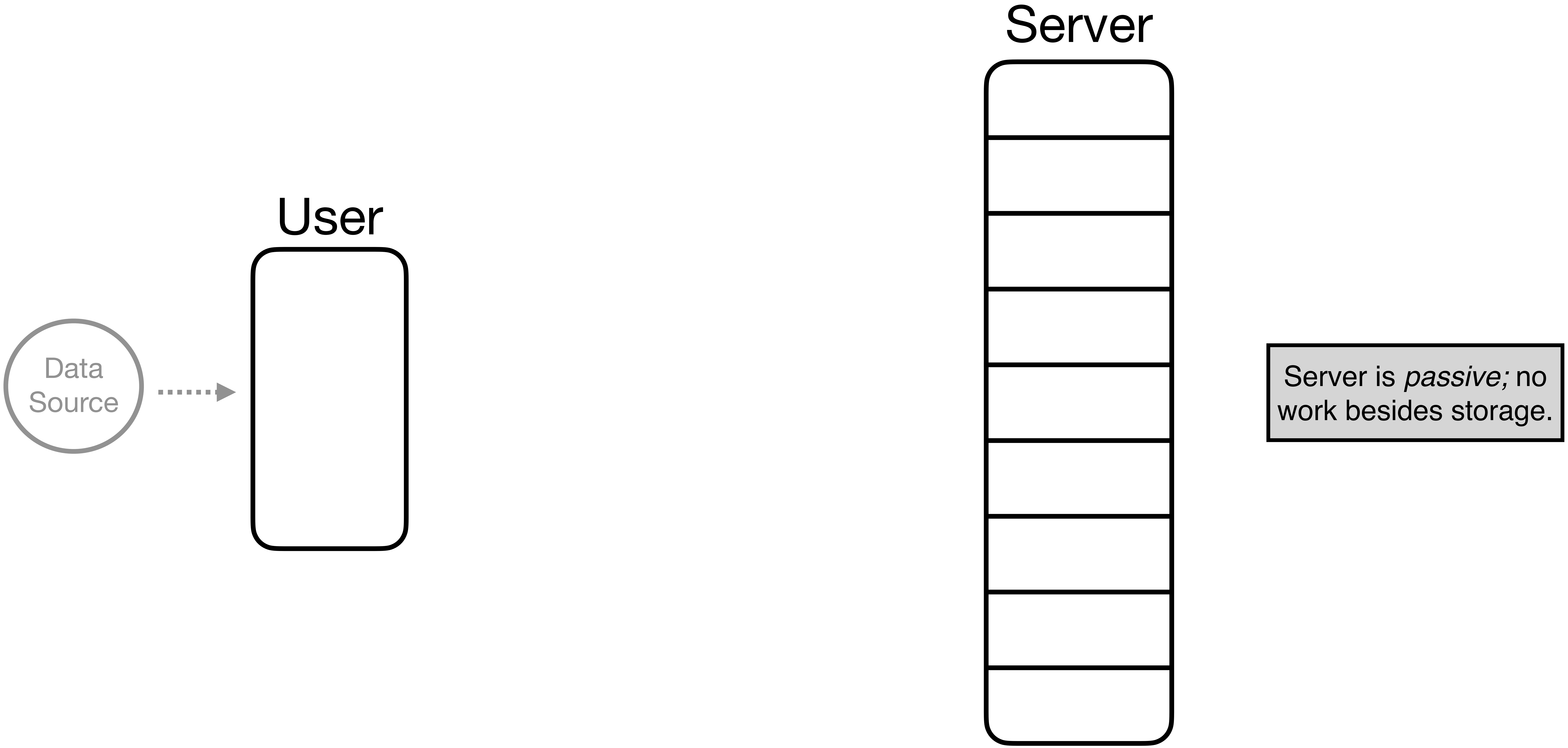
Server
User
Data
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Server is *passive;* no
work besides storage.

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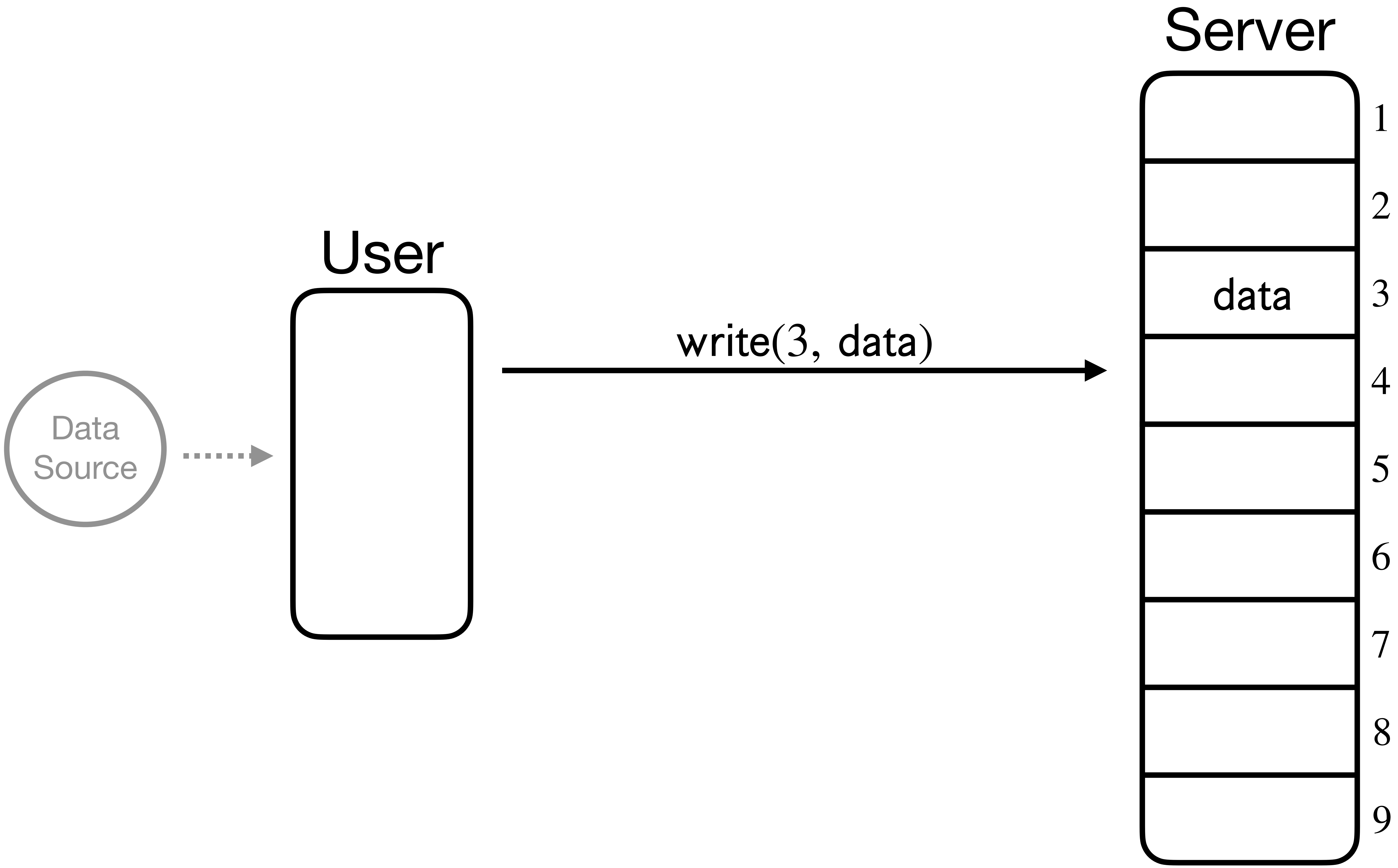

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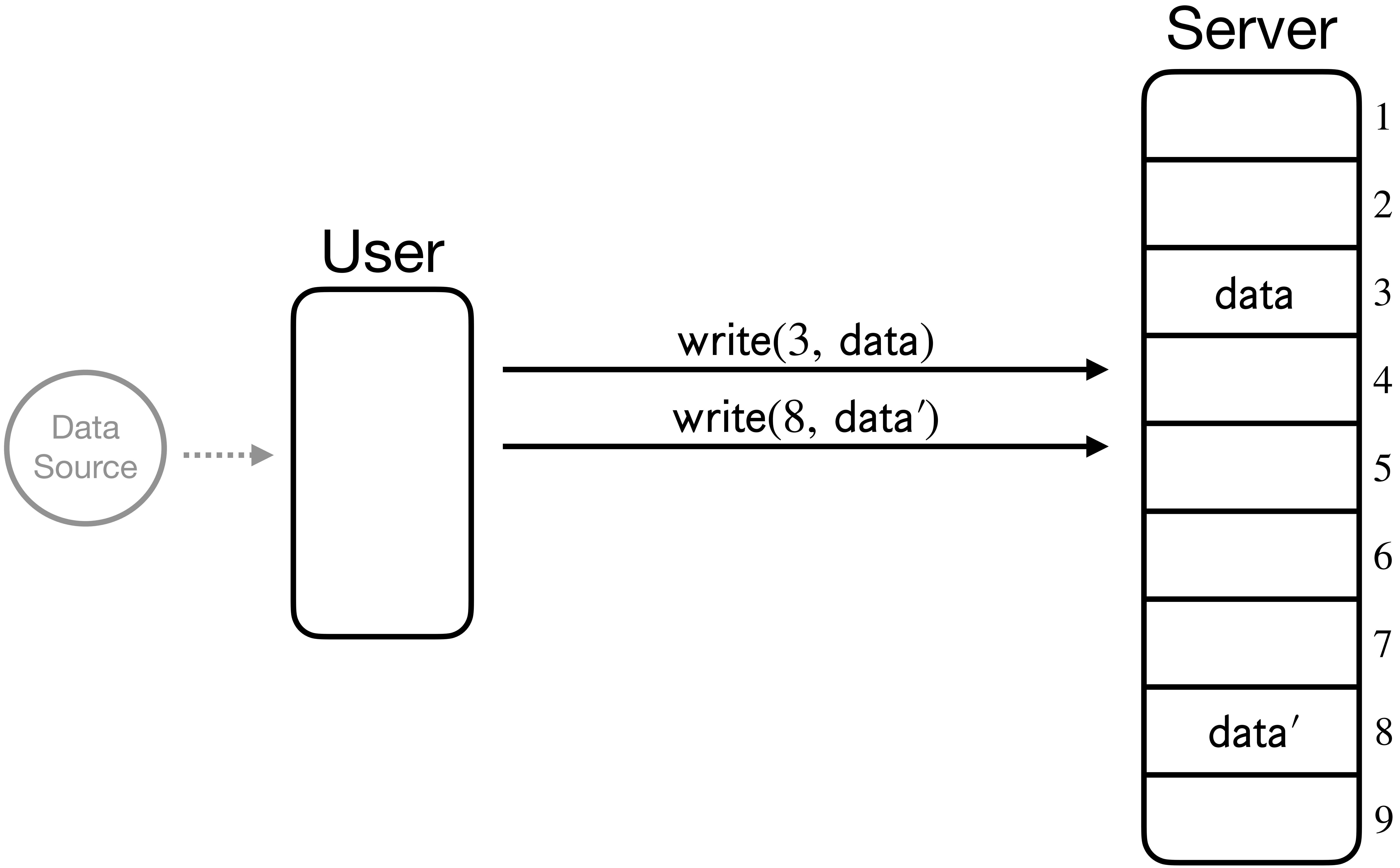

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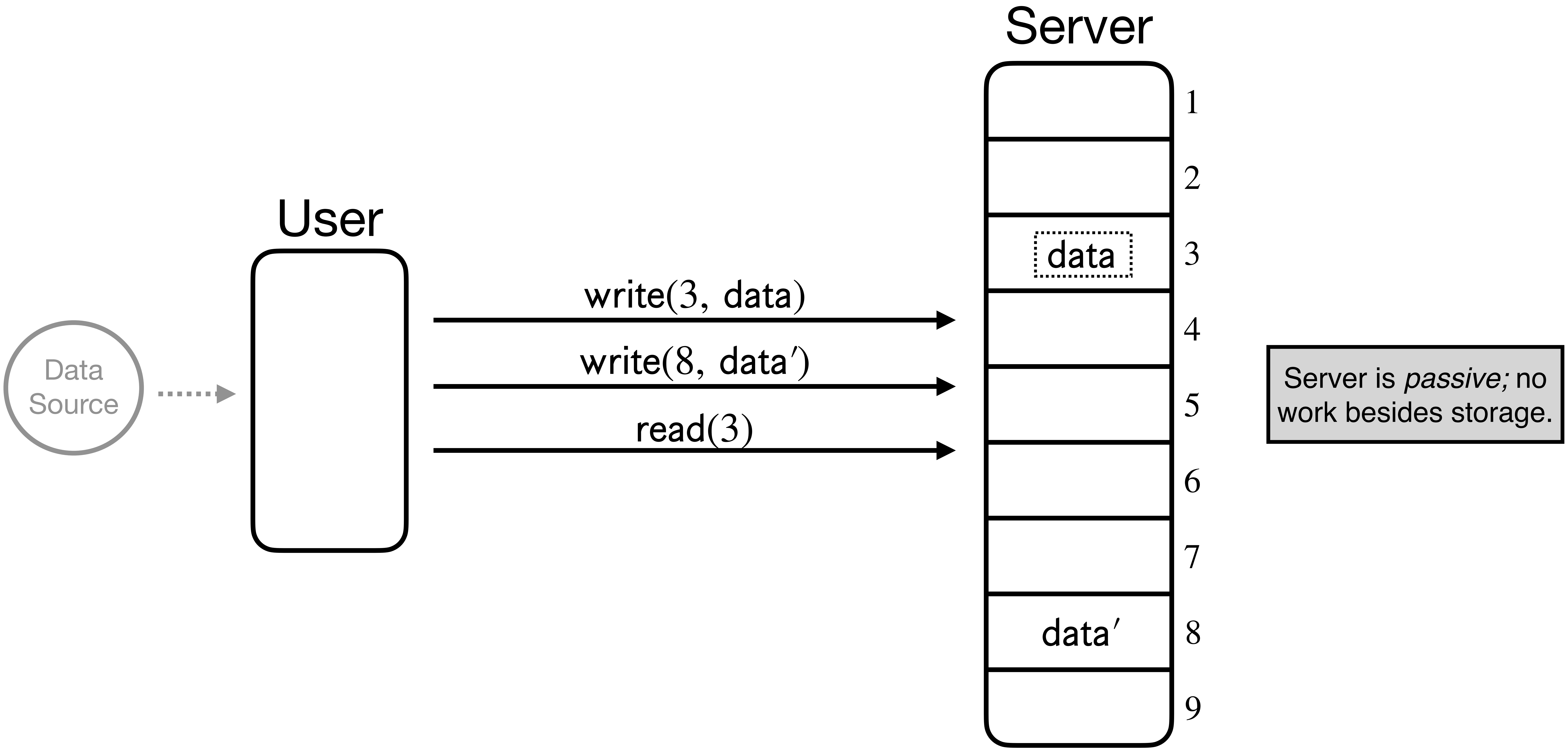
Server
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Data Source
write(3, data)
write(8, data′)
read(3)
data
data′
1
2
3
4
5
6
7
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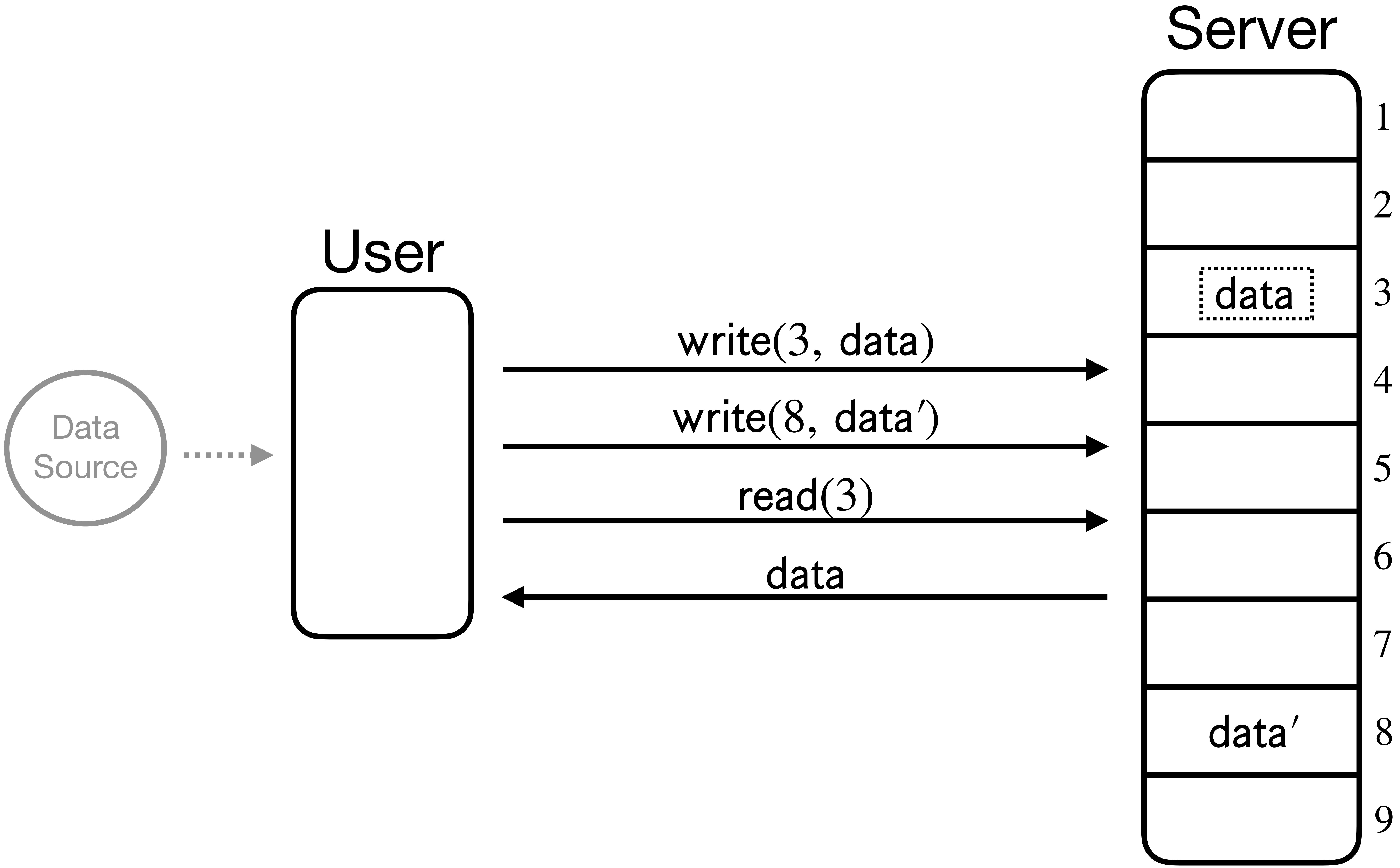

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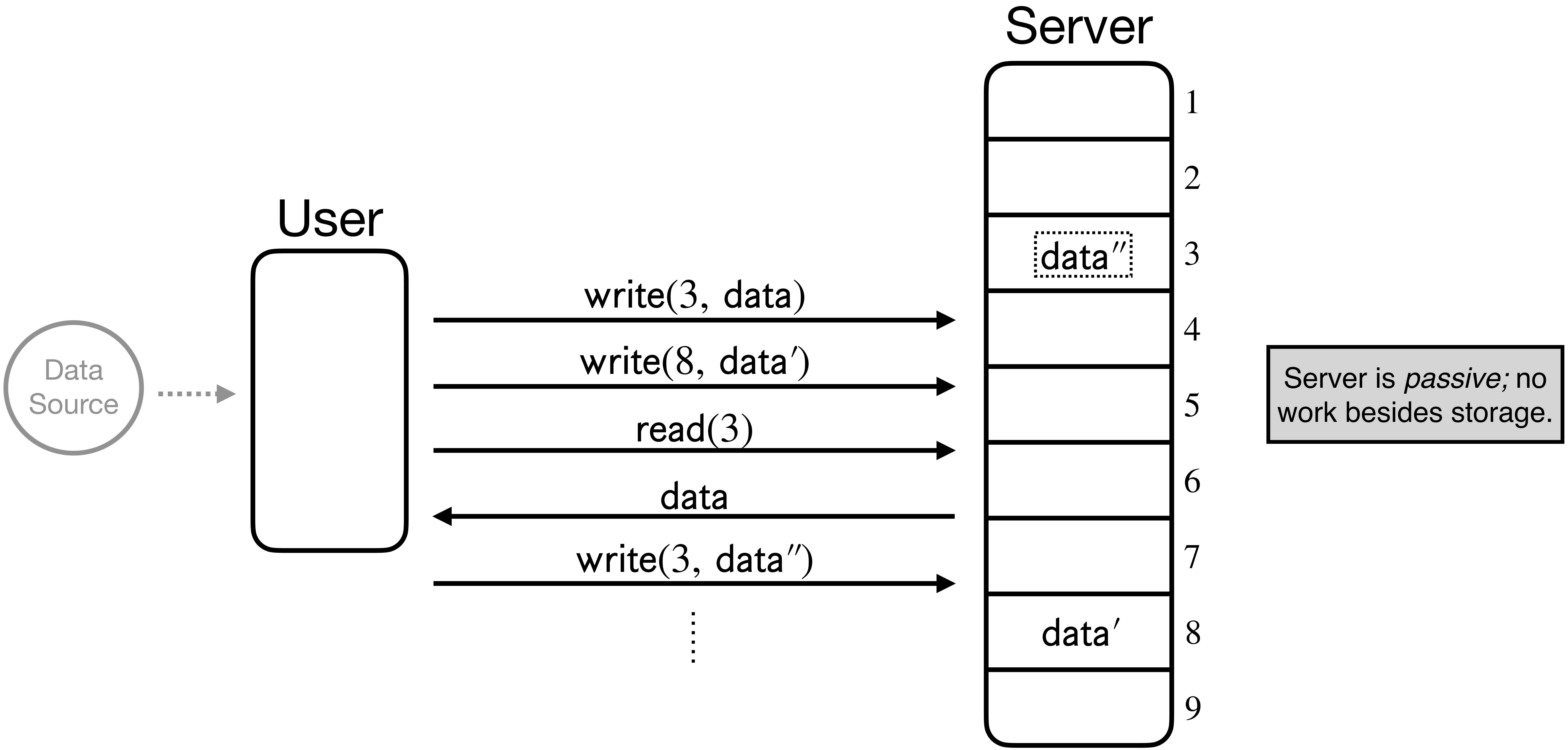
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- (**Privacy + Integrity**: All simultaneously!)

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- Name for this: **memory checker**

Memory Checking

A **memory checker** (MC) is a protocol that prevents adversaries from **undetectably** modifying cloud data.

[FOCS '91, Blum, Evans, Gemmell, Kannan, Naor]

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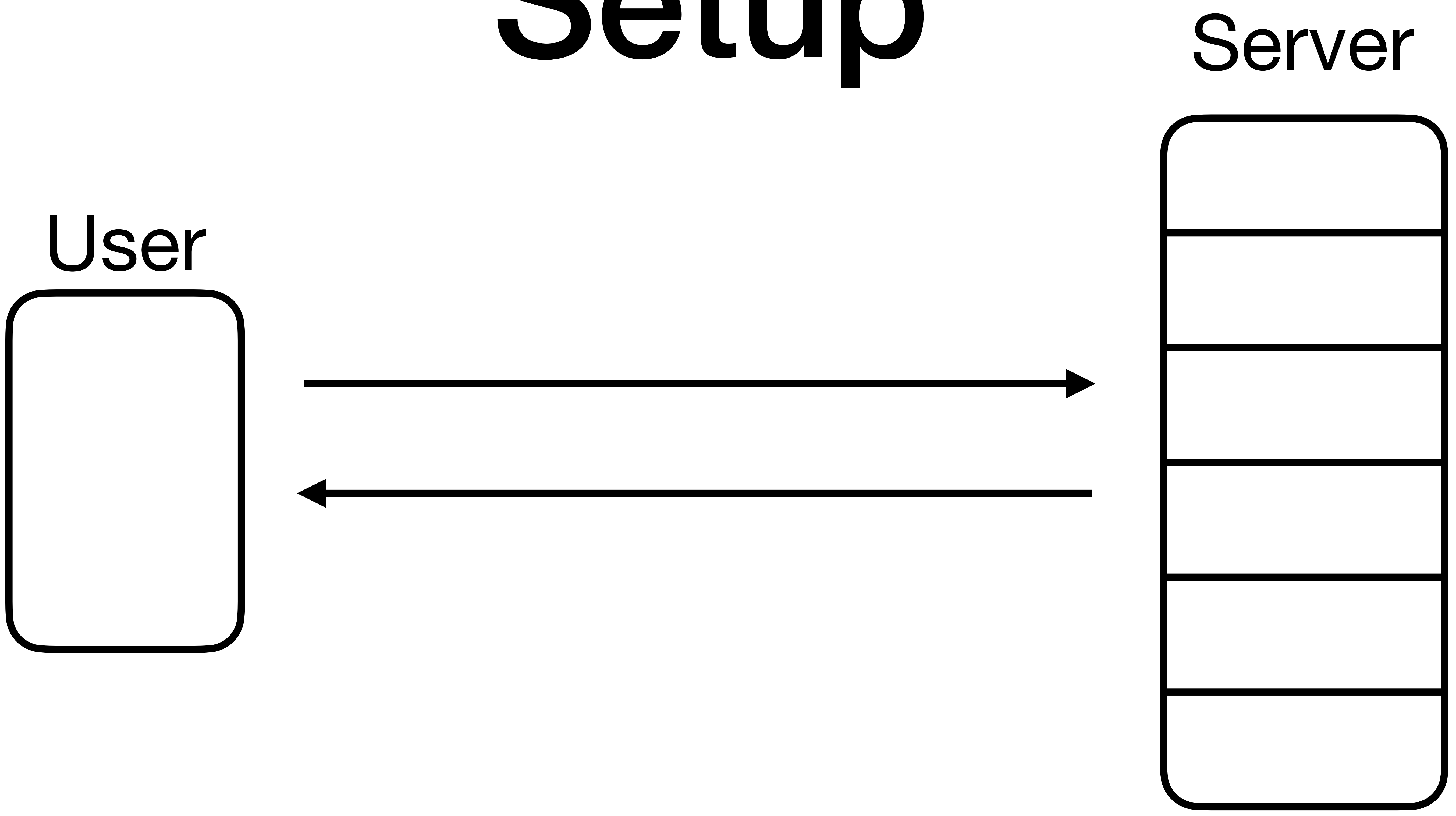

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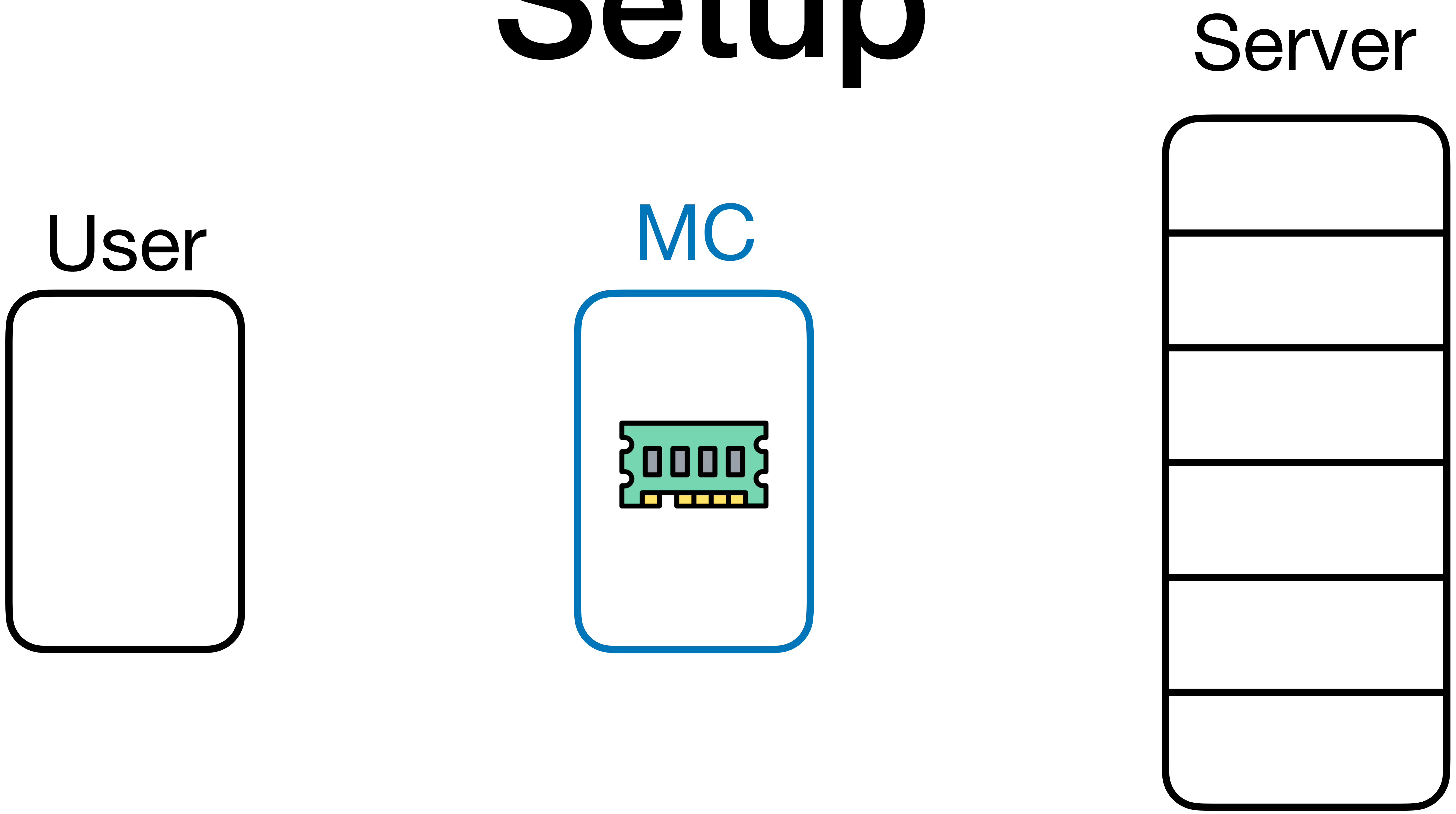

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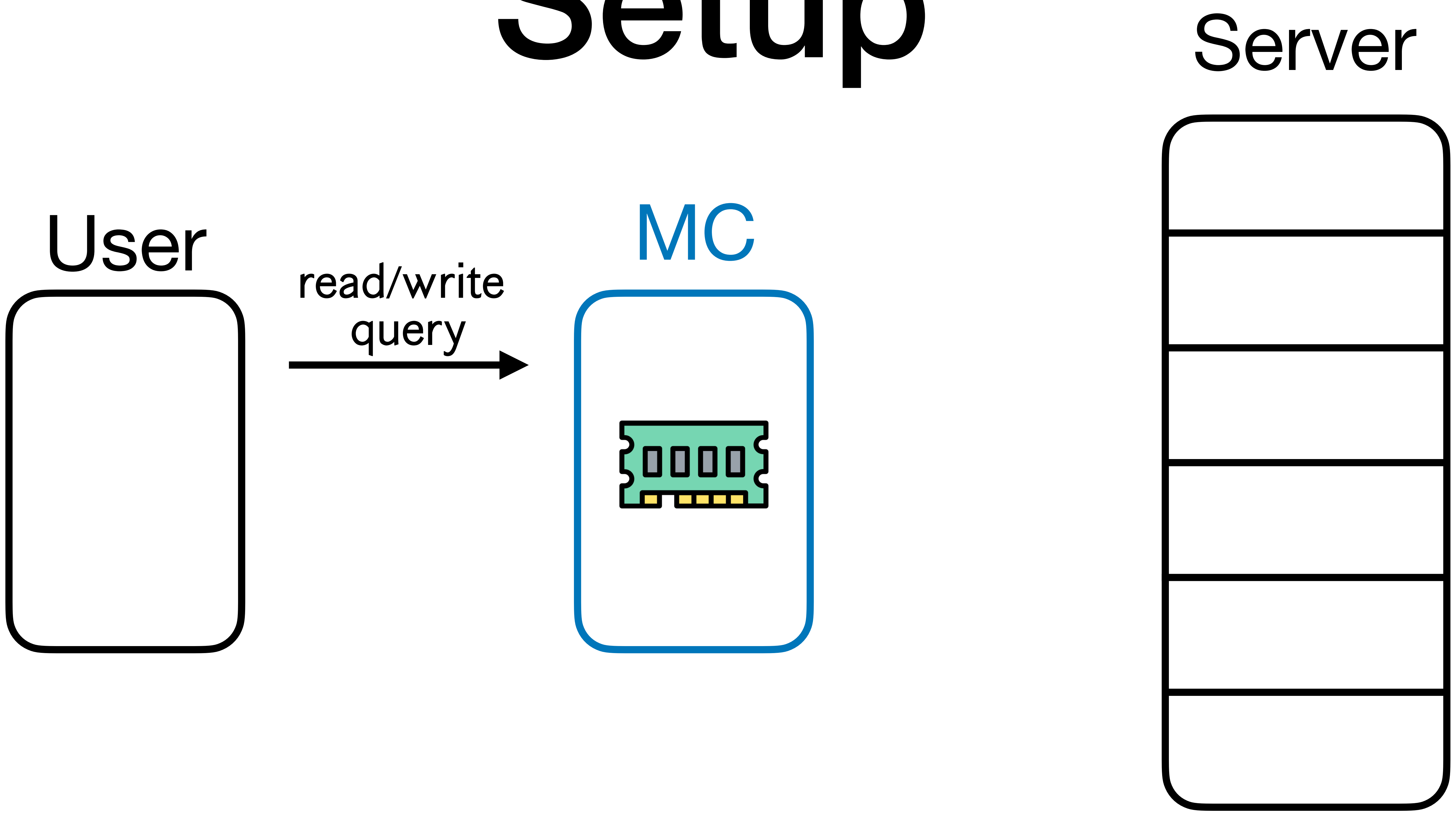

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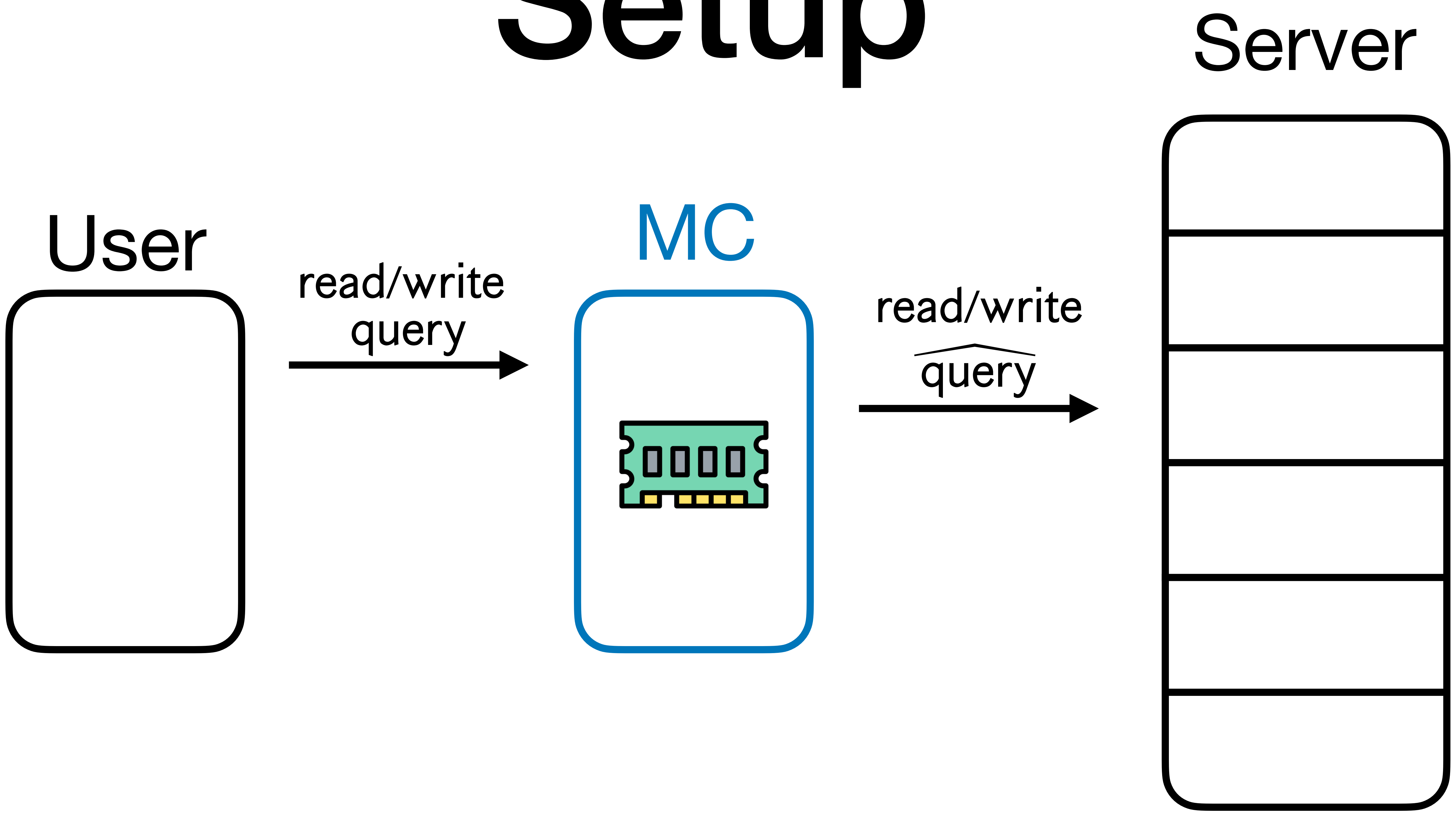
Server
User
read/write
query
MC
read/write
$\widehat{\text{query}}$

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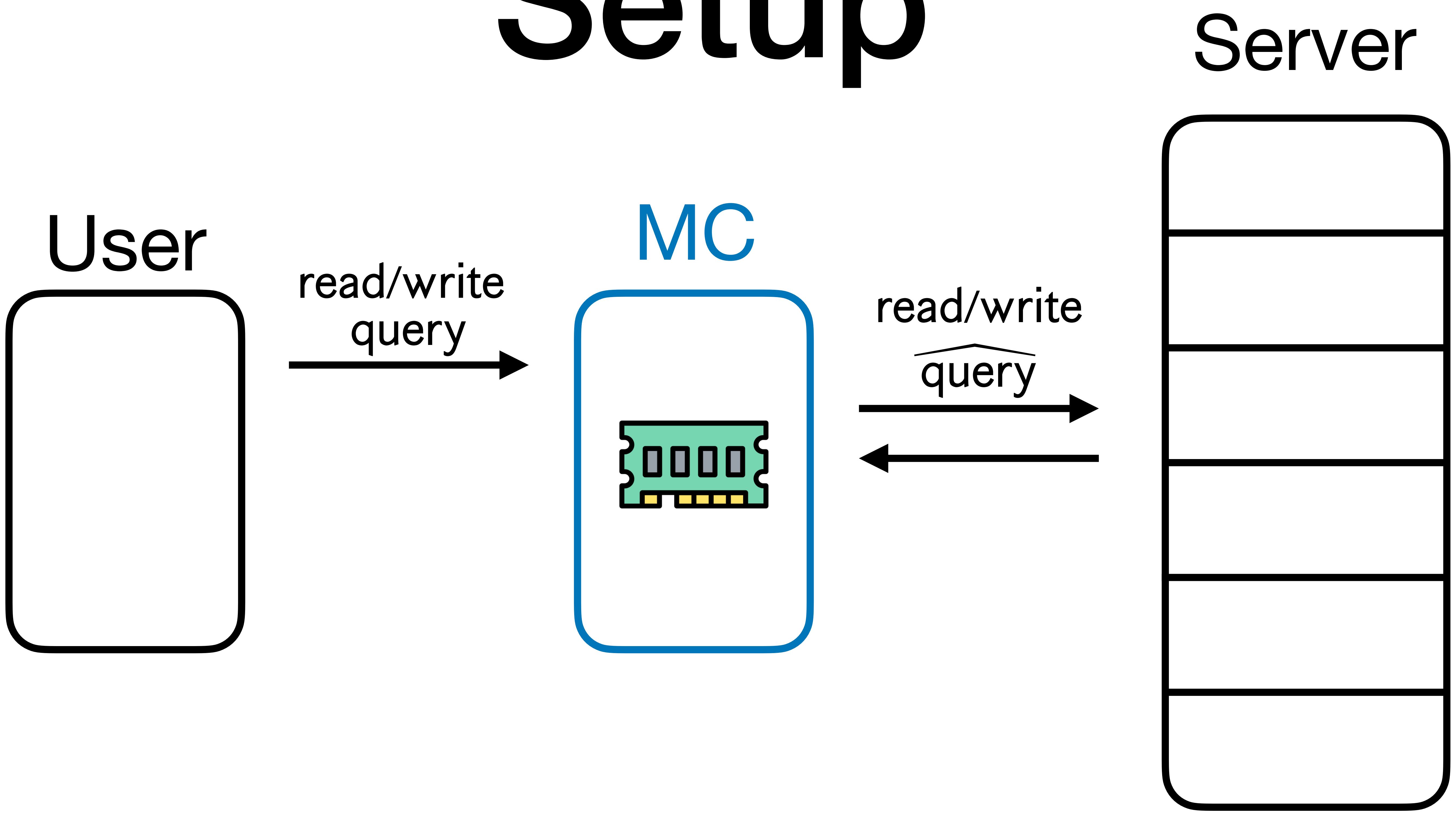
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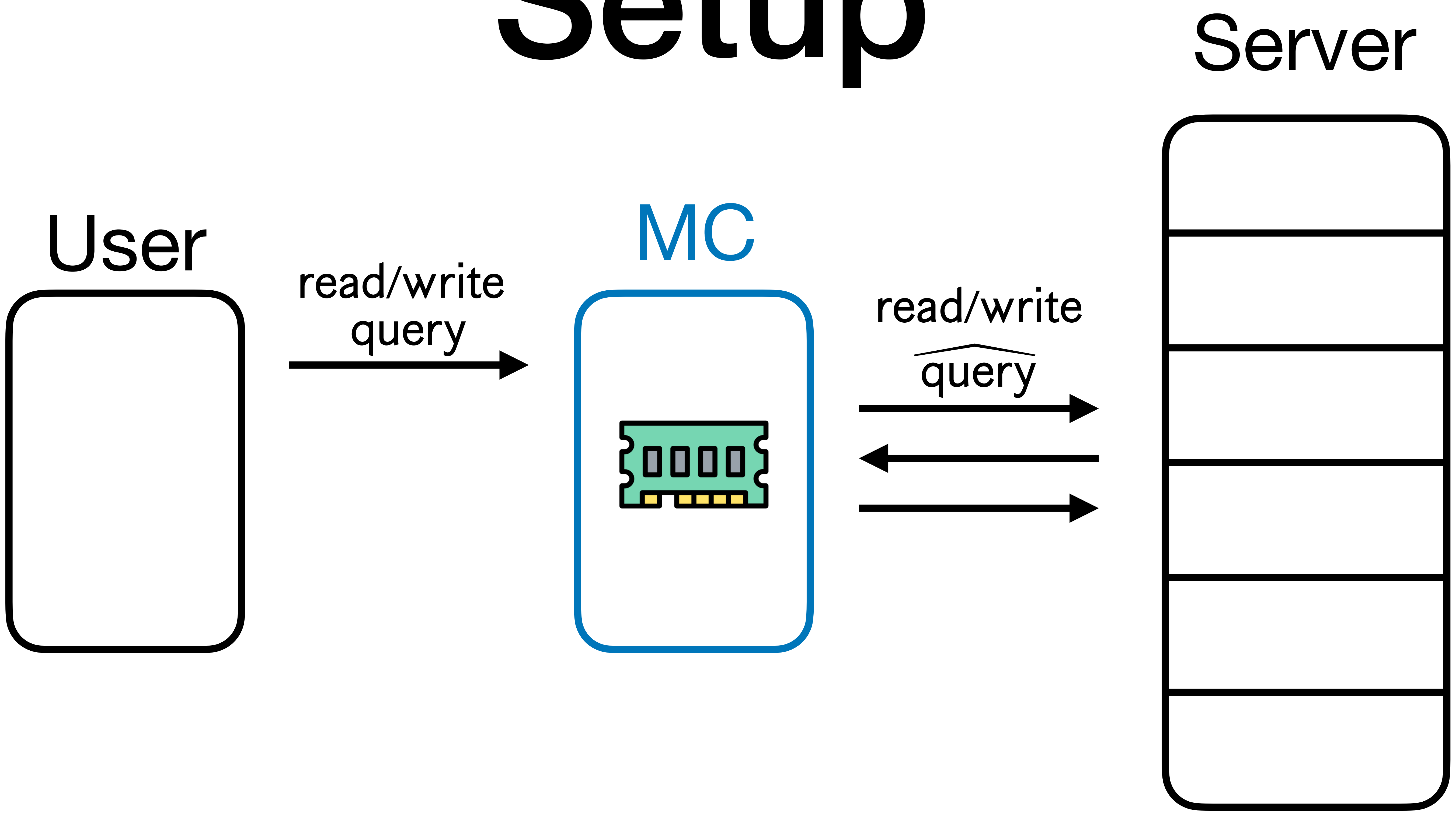

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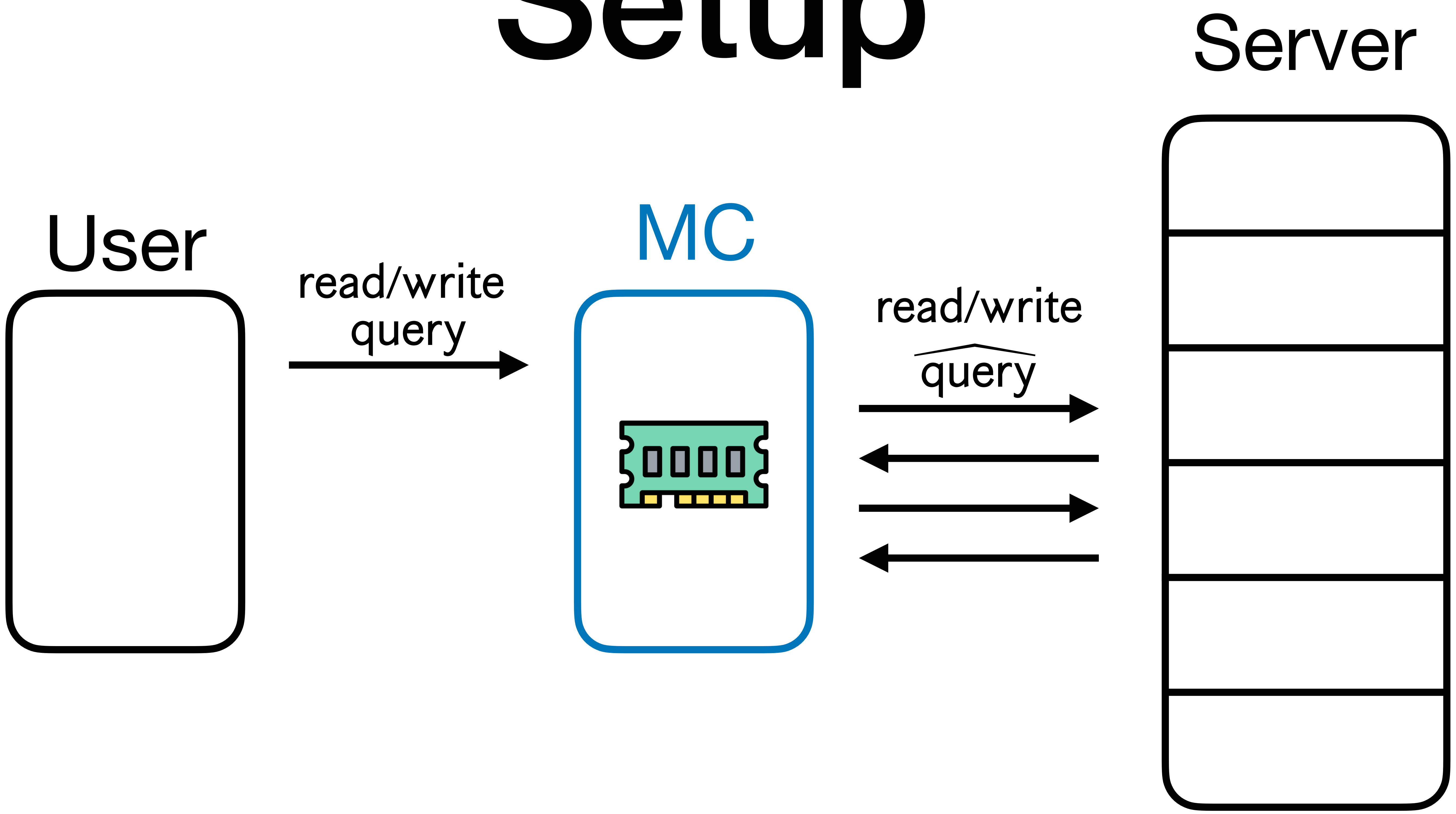

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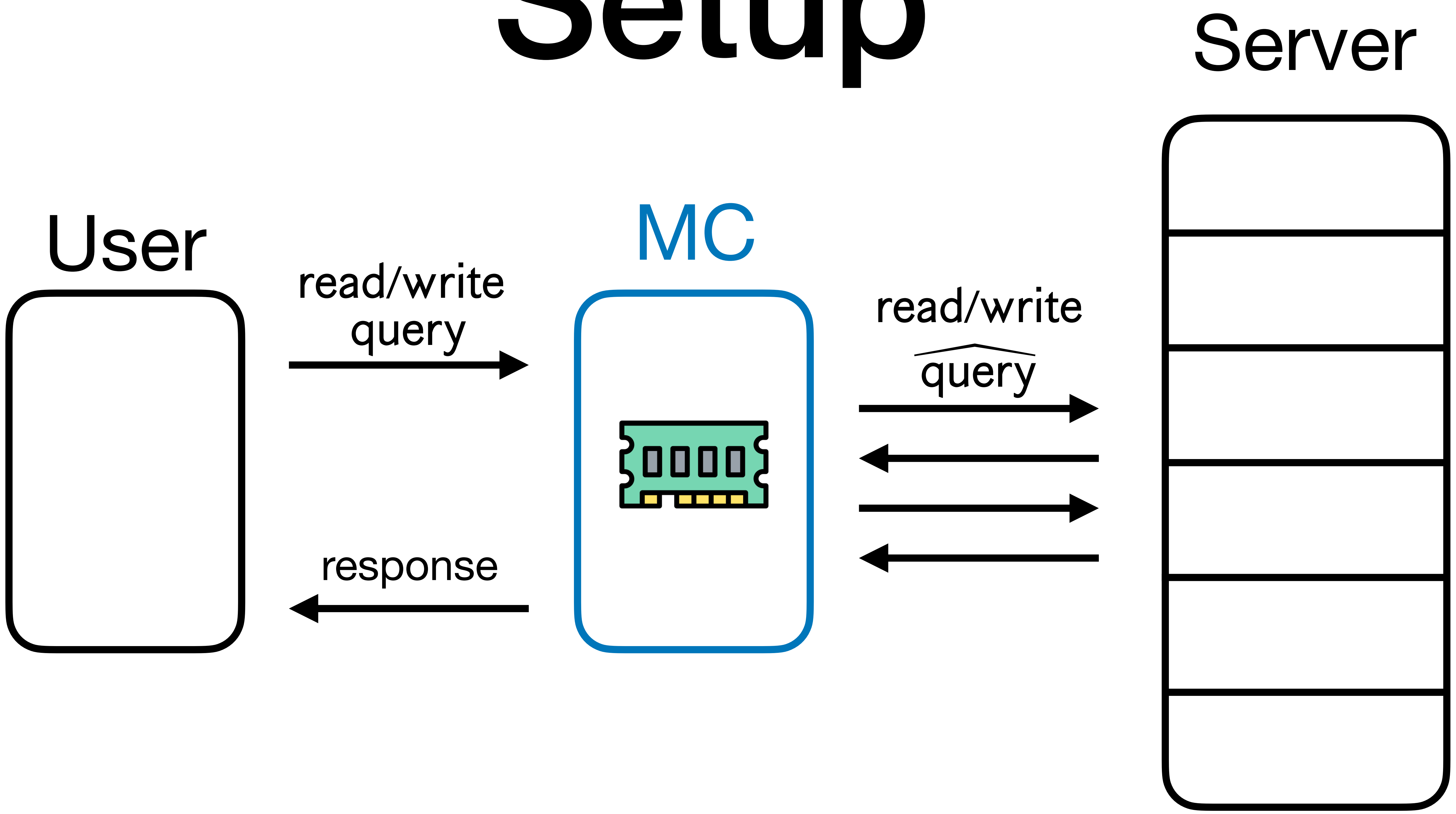

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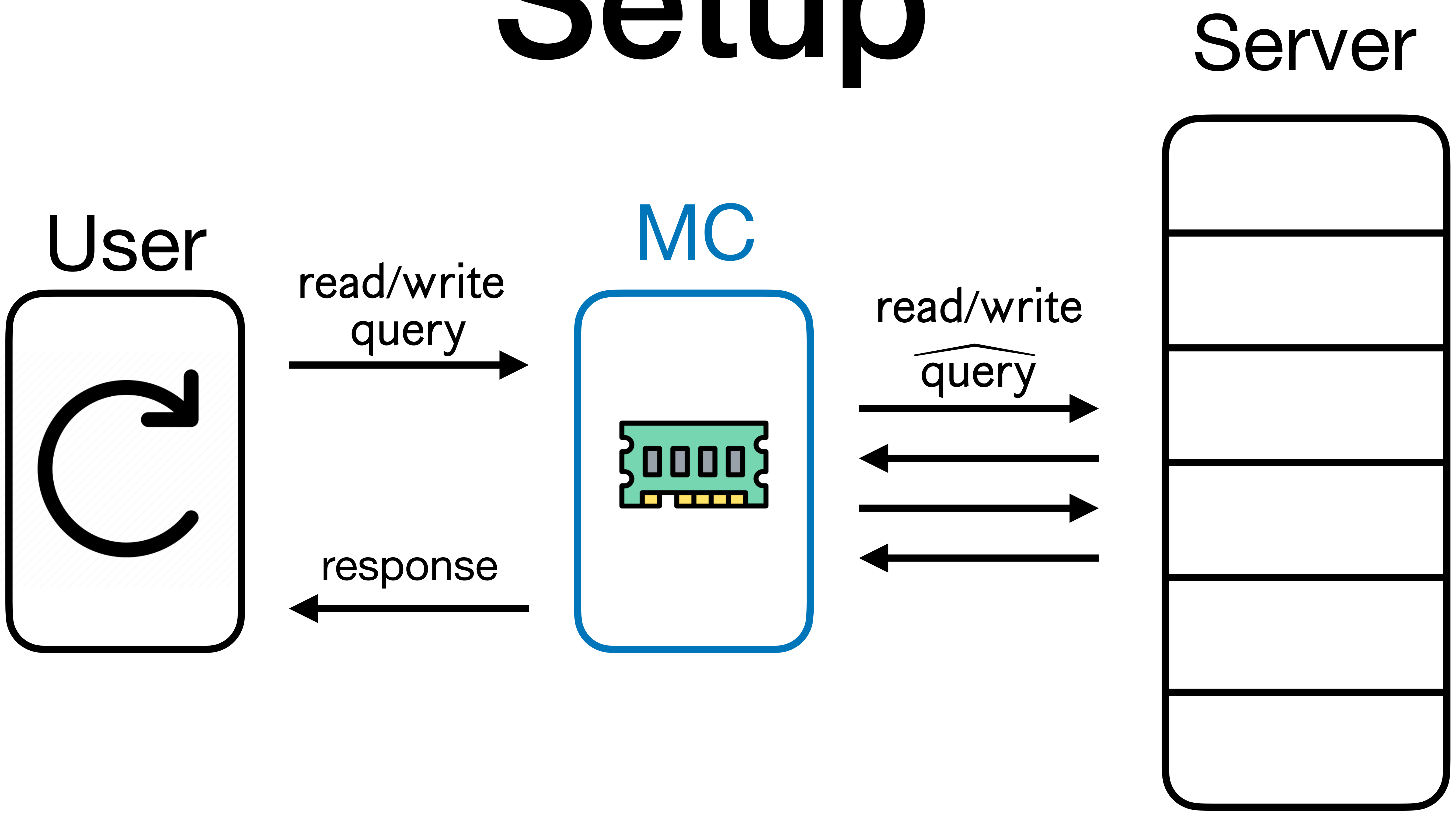

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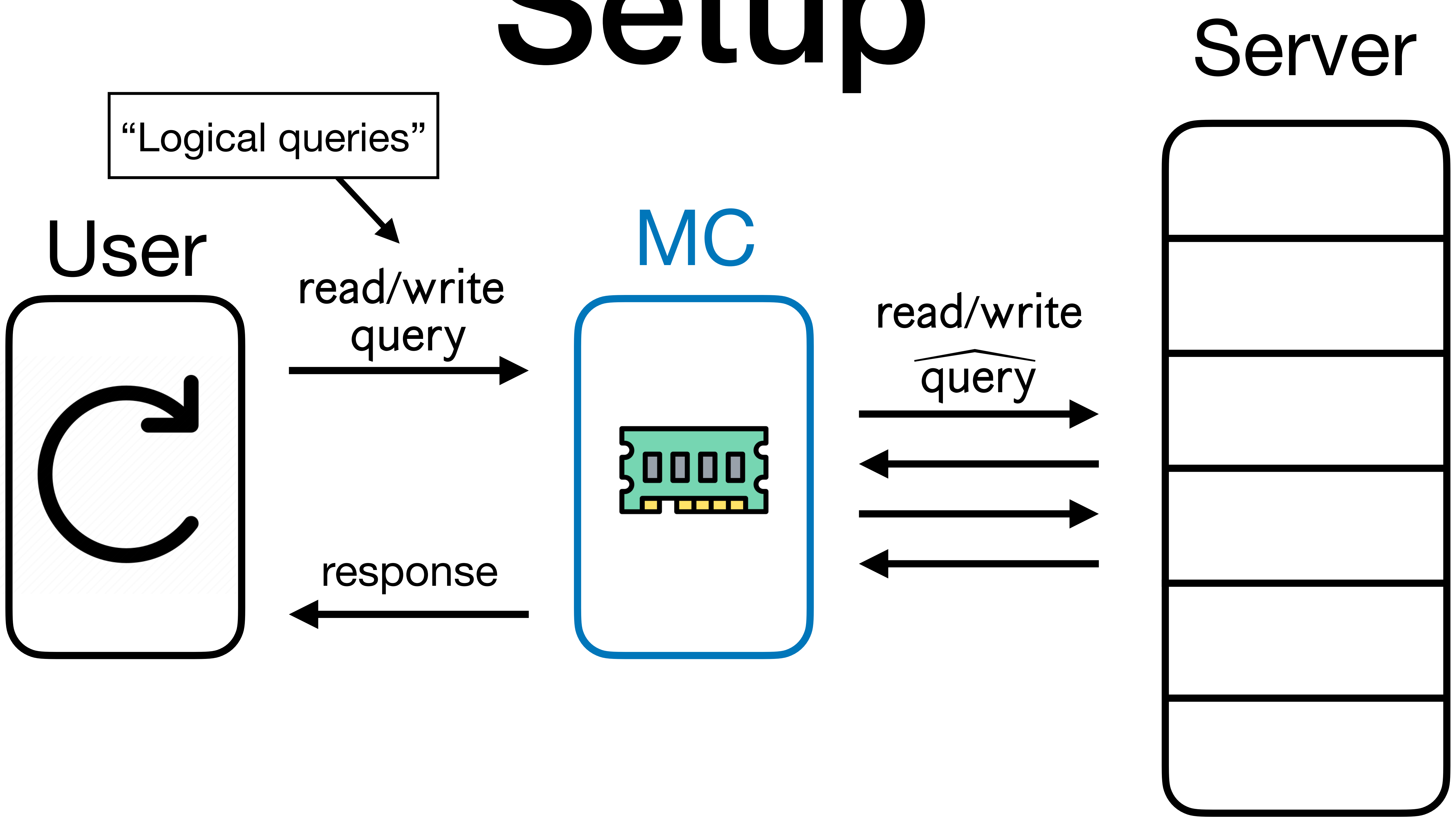
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“Logical queries”
User
read/write
query
MC
read/write
query
response

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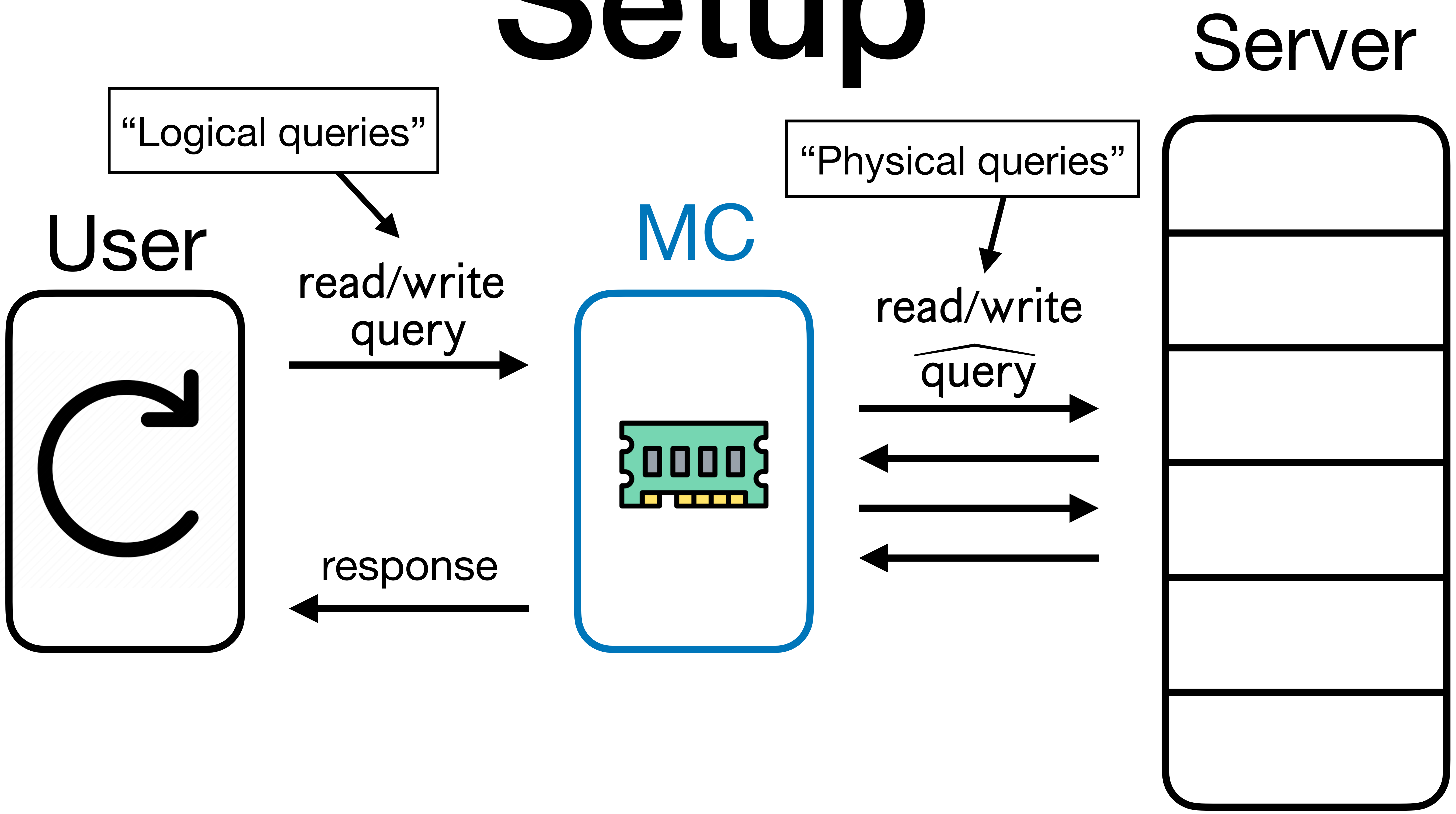
Server
"Logical queries"
"Physical queries"
User
read/write query
MC
read/write
$\widehat{\text{query}}$
response

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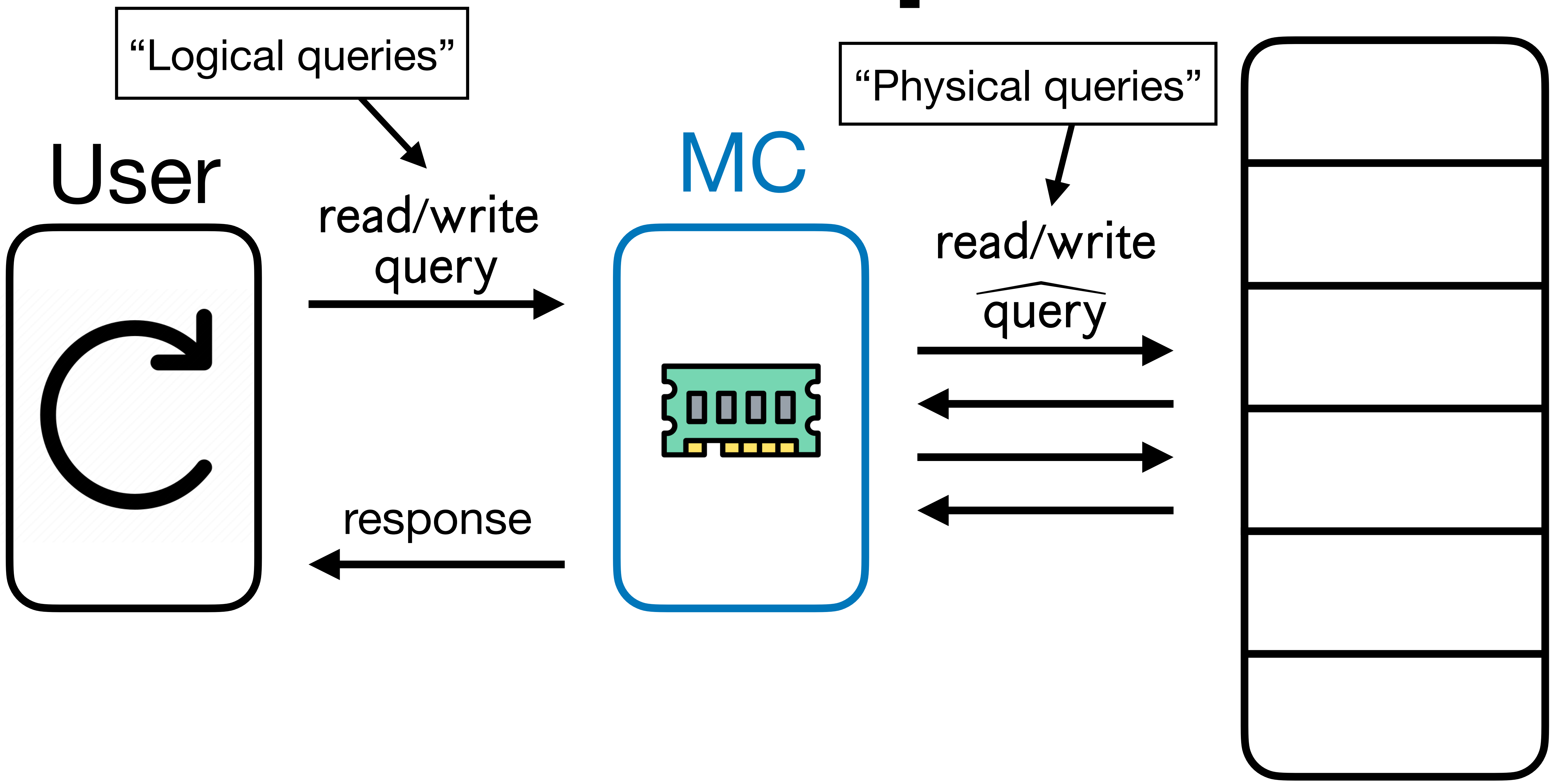

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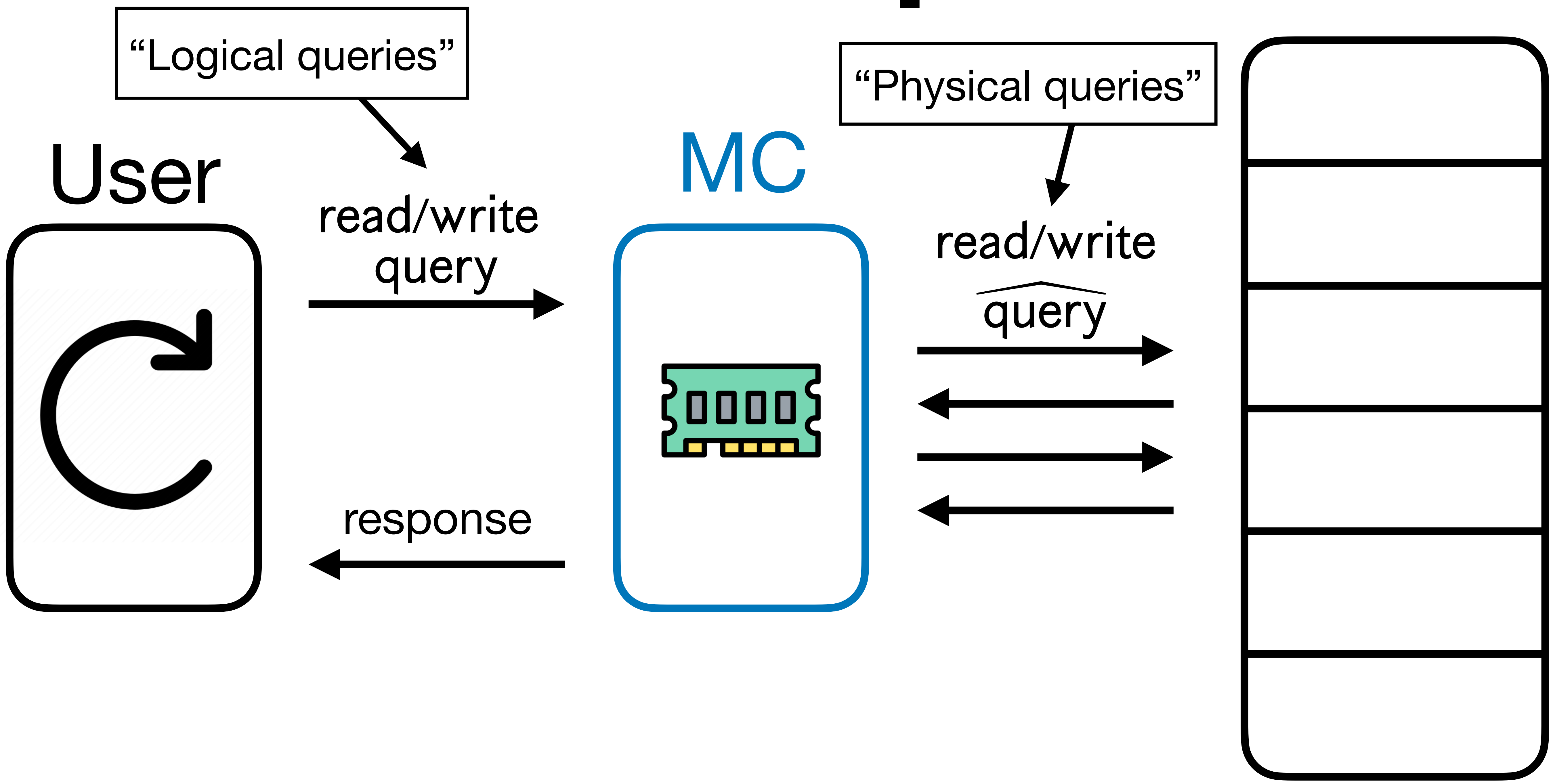

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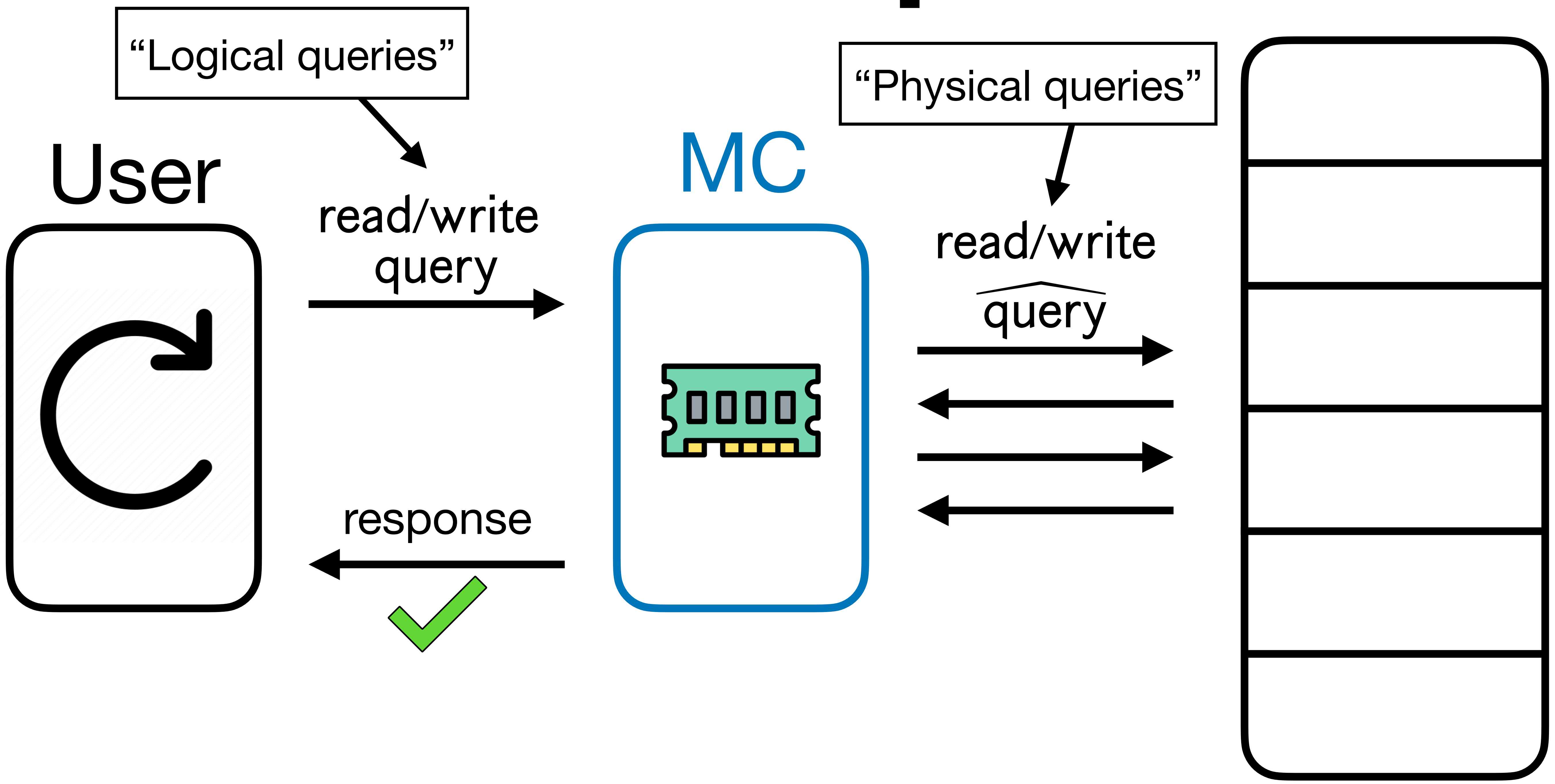

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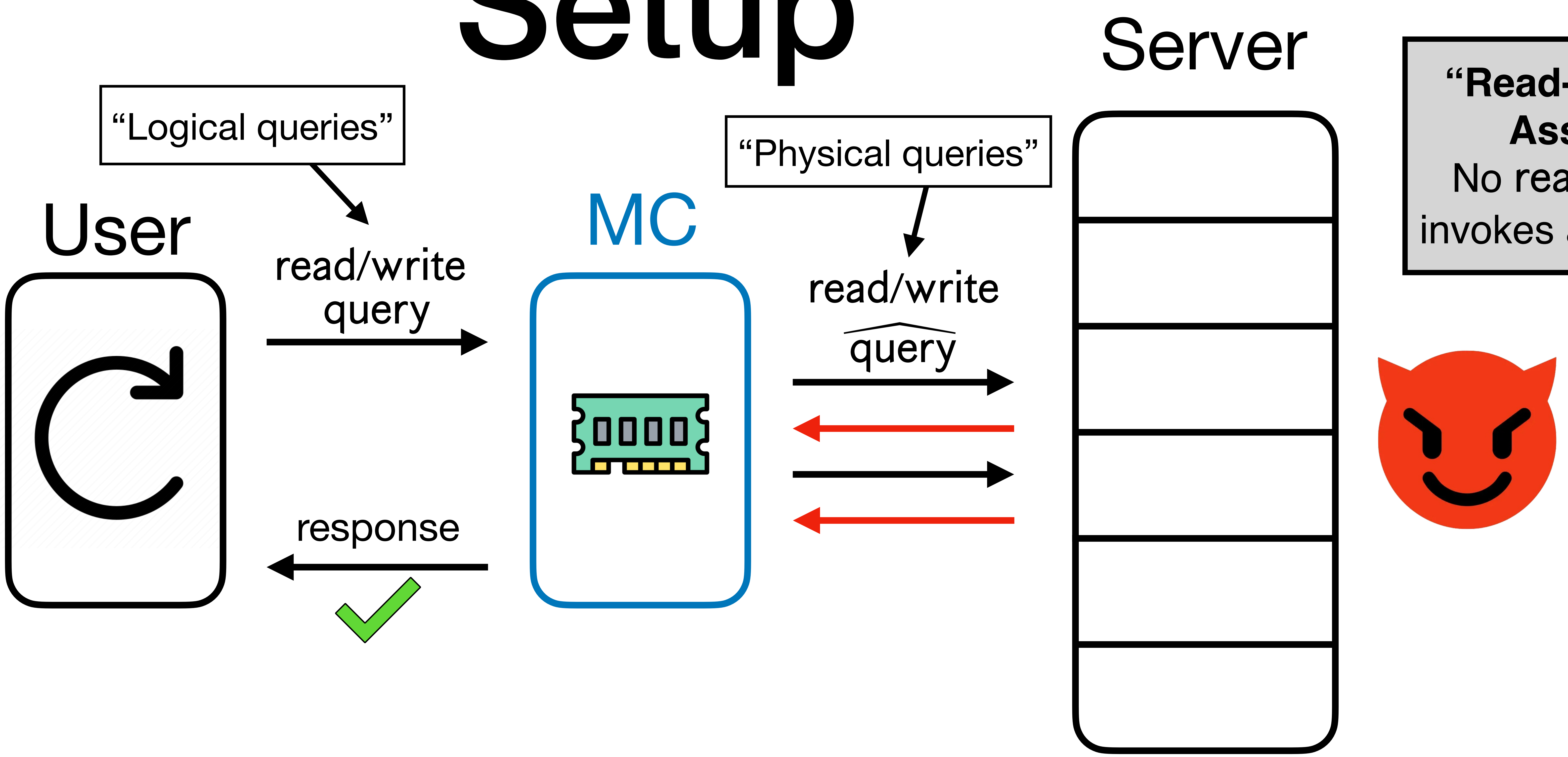

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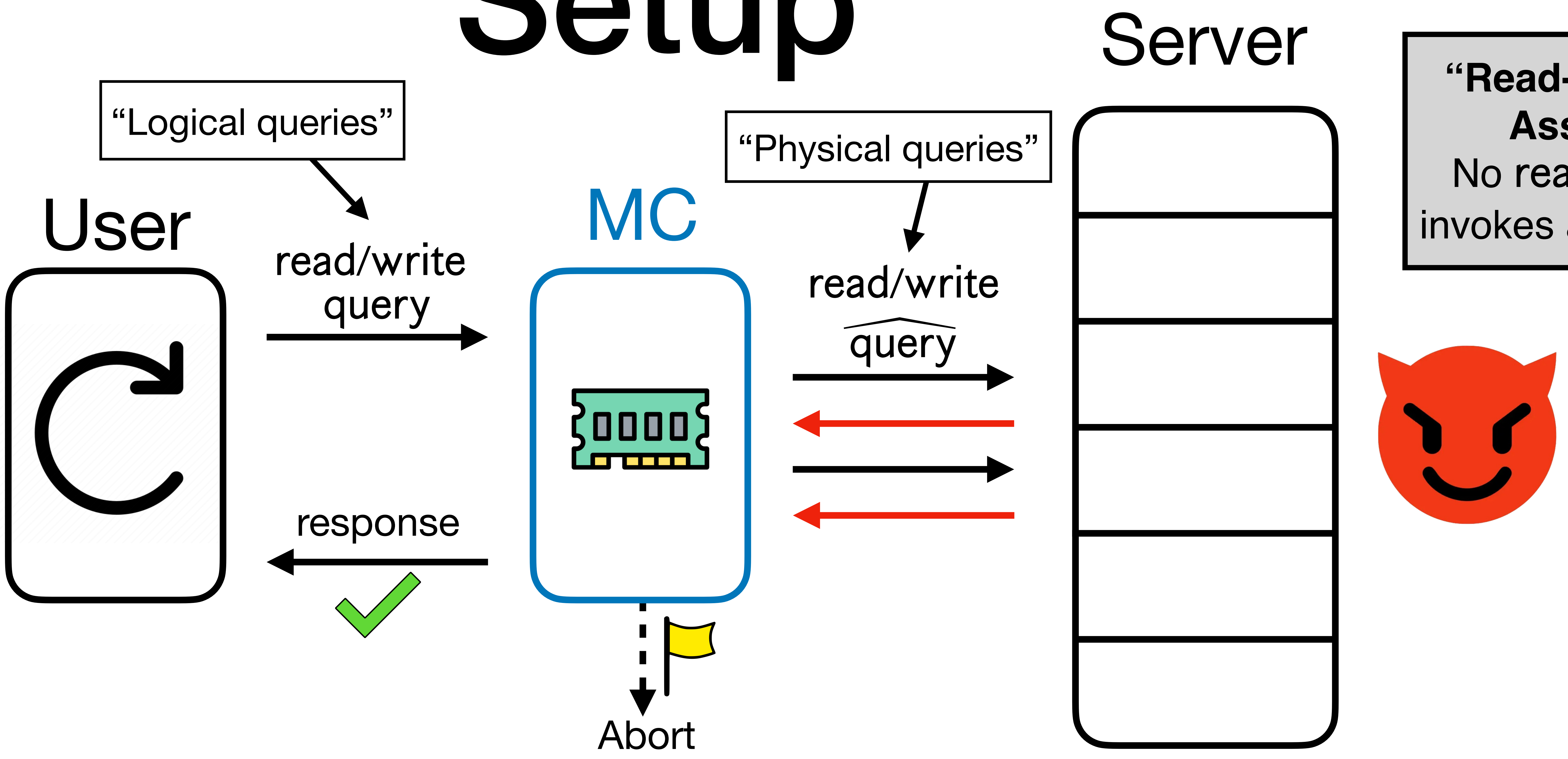

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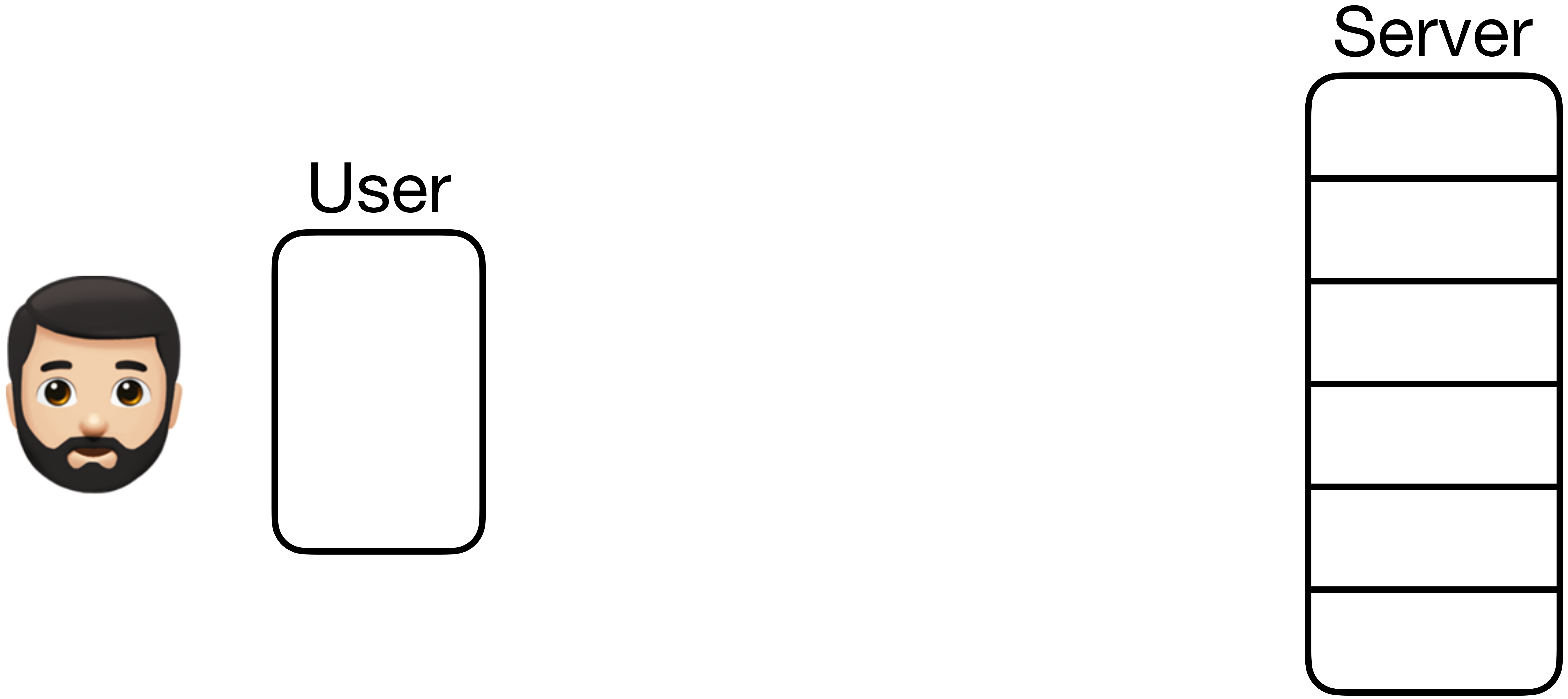

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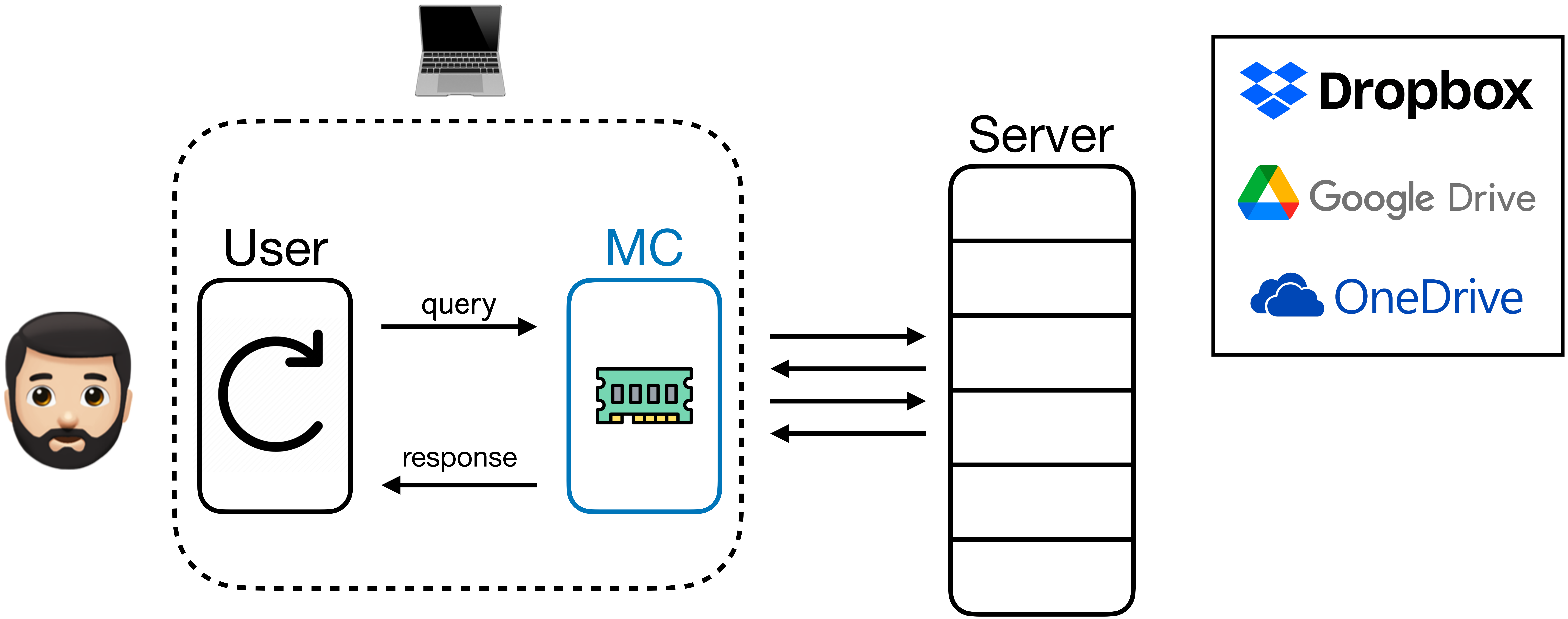

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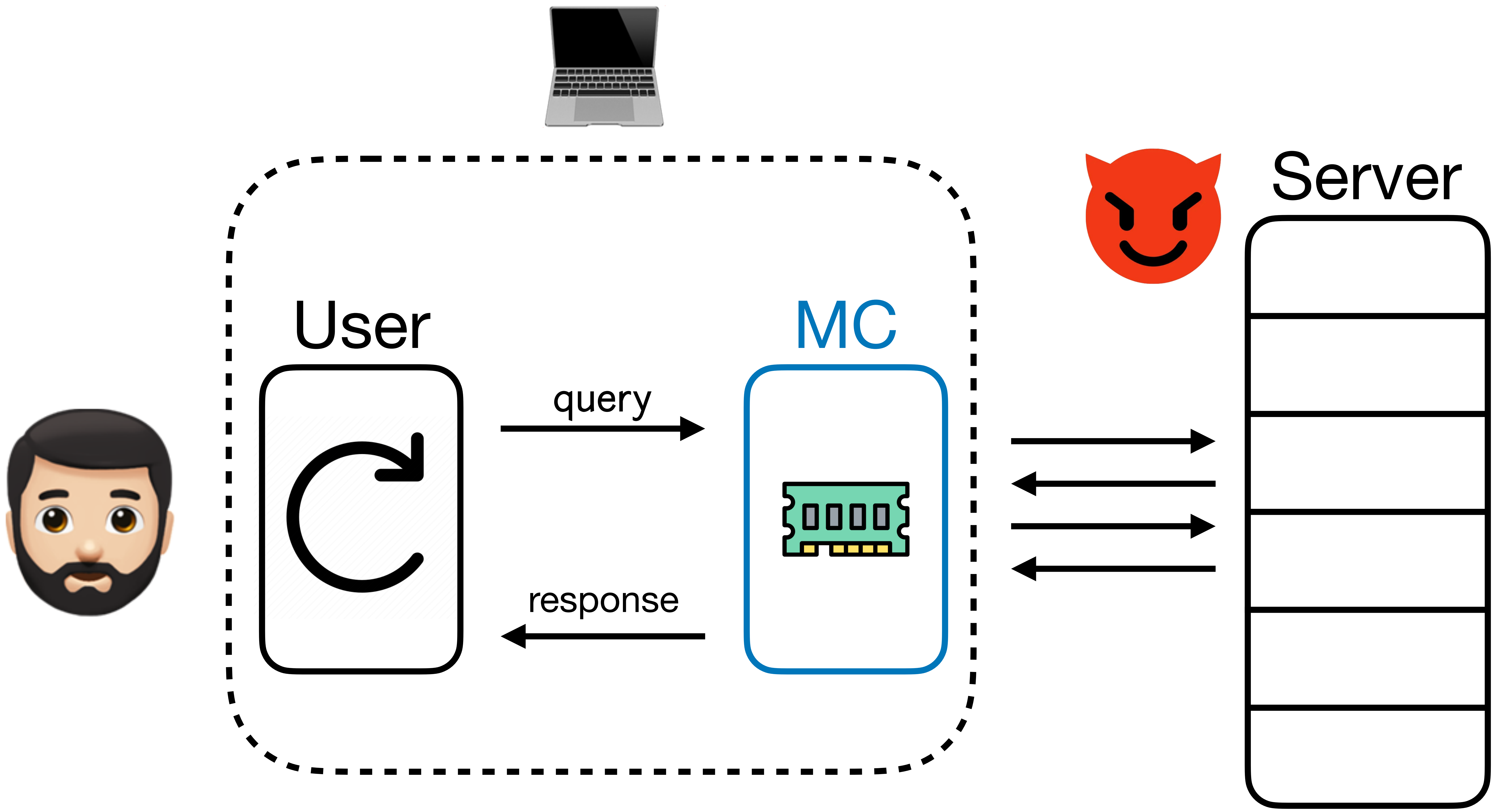

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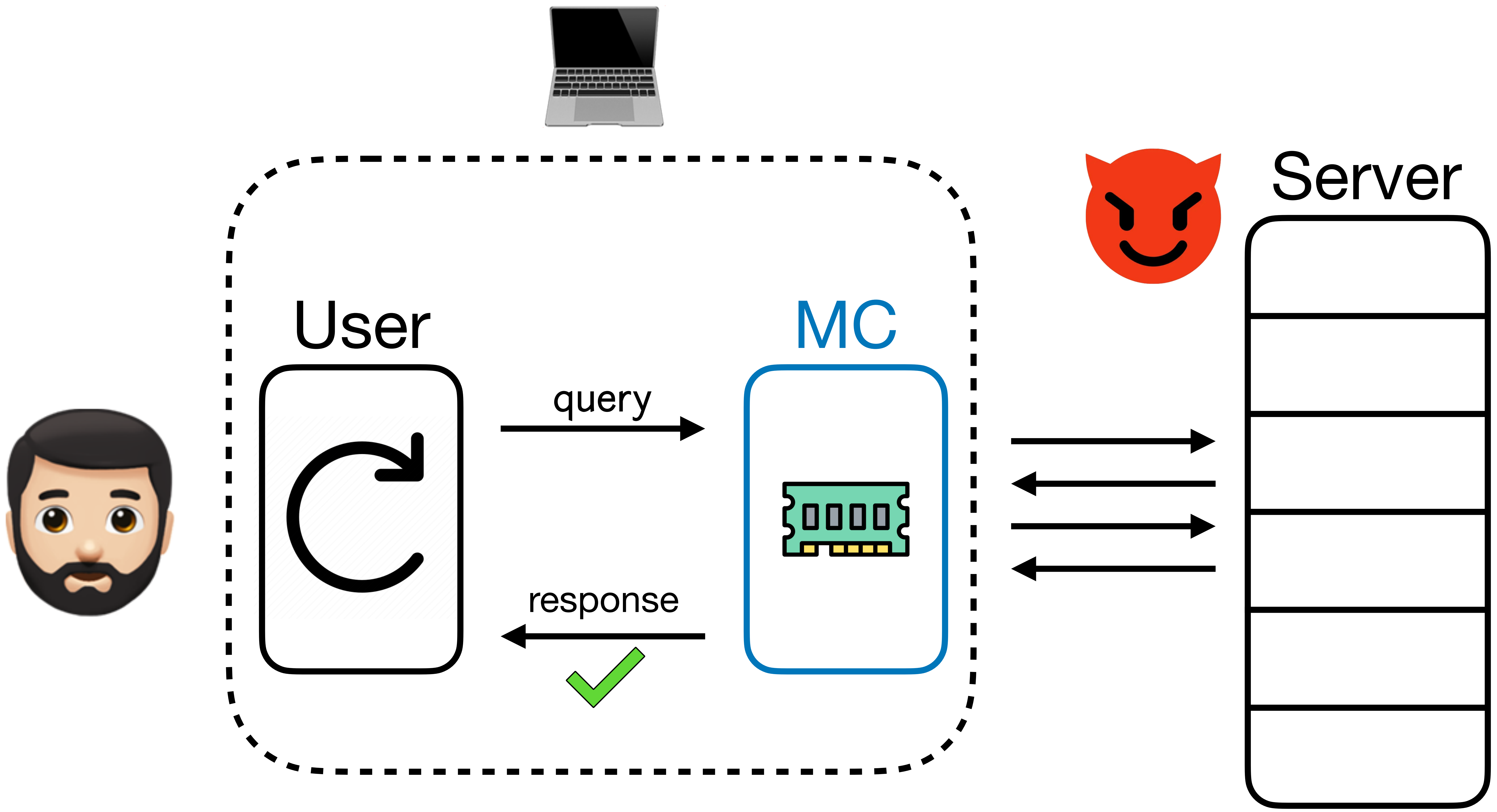

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  - Accumulation schemes [BC24, …]

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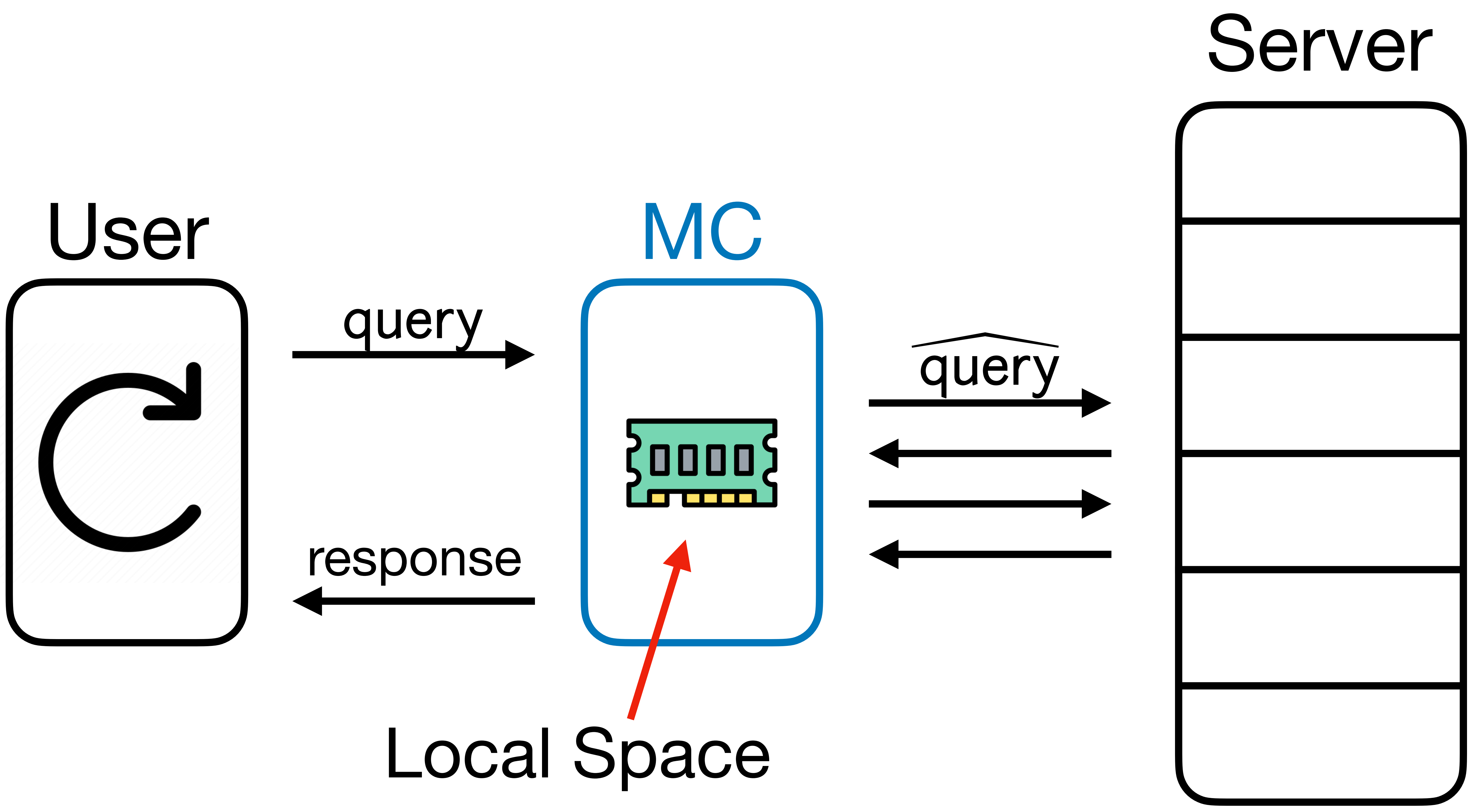
   - For the rest of the talk, assume space at most $n^{1-\varepsilon}$ for some $\varepsilon > 0$.

Efficiency



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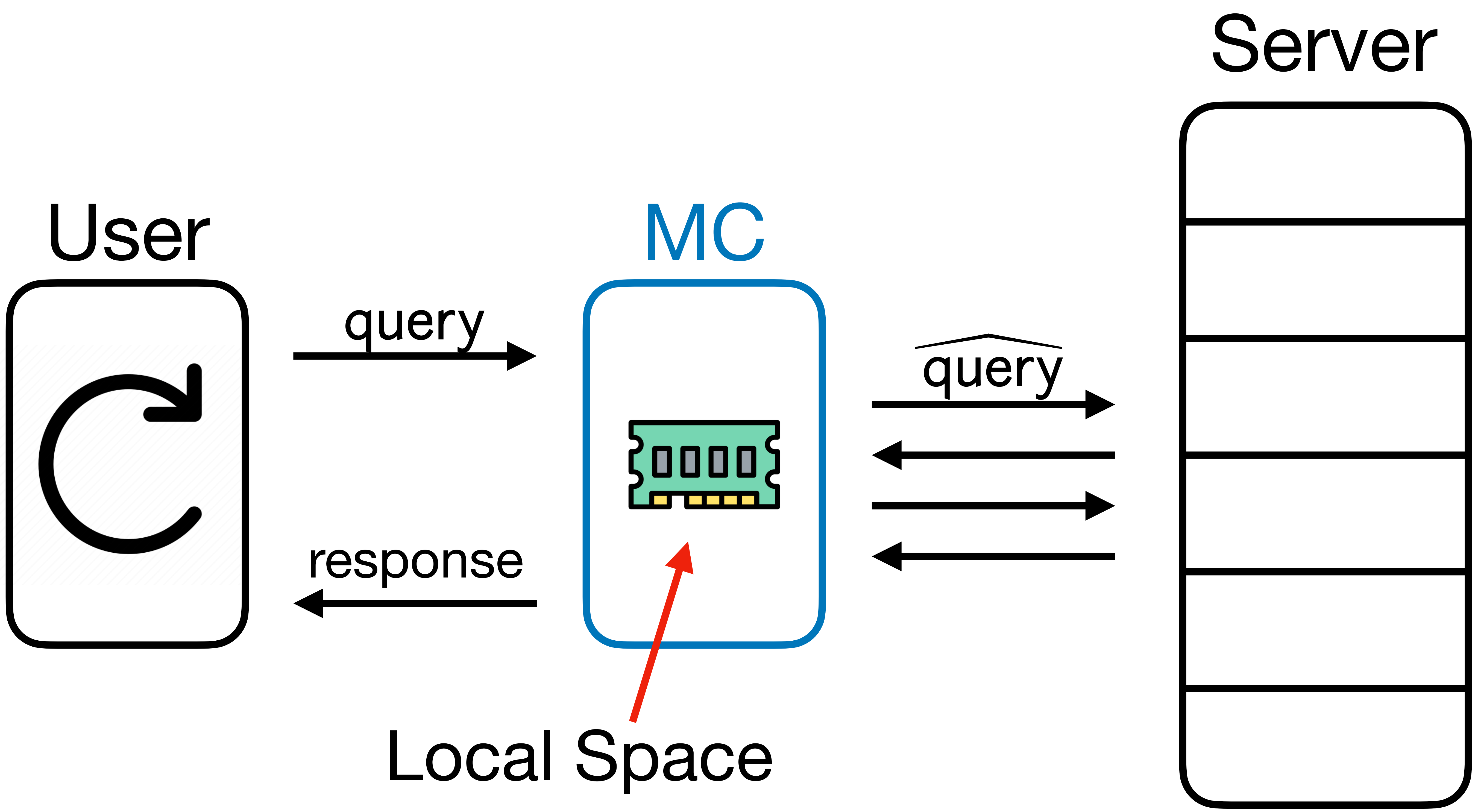

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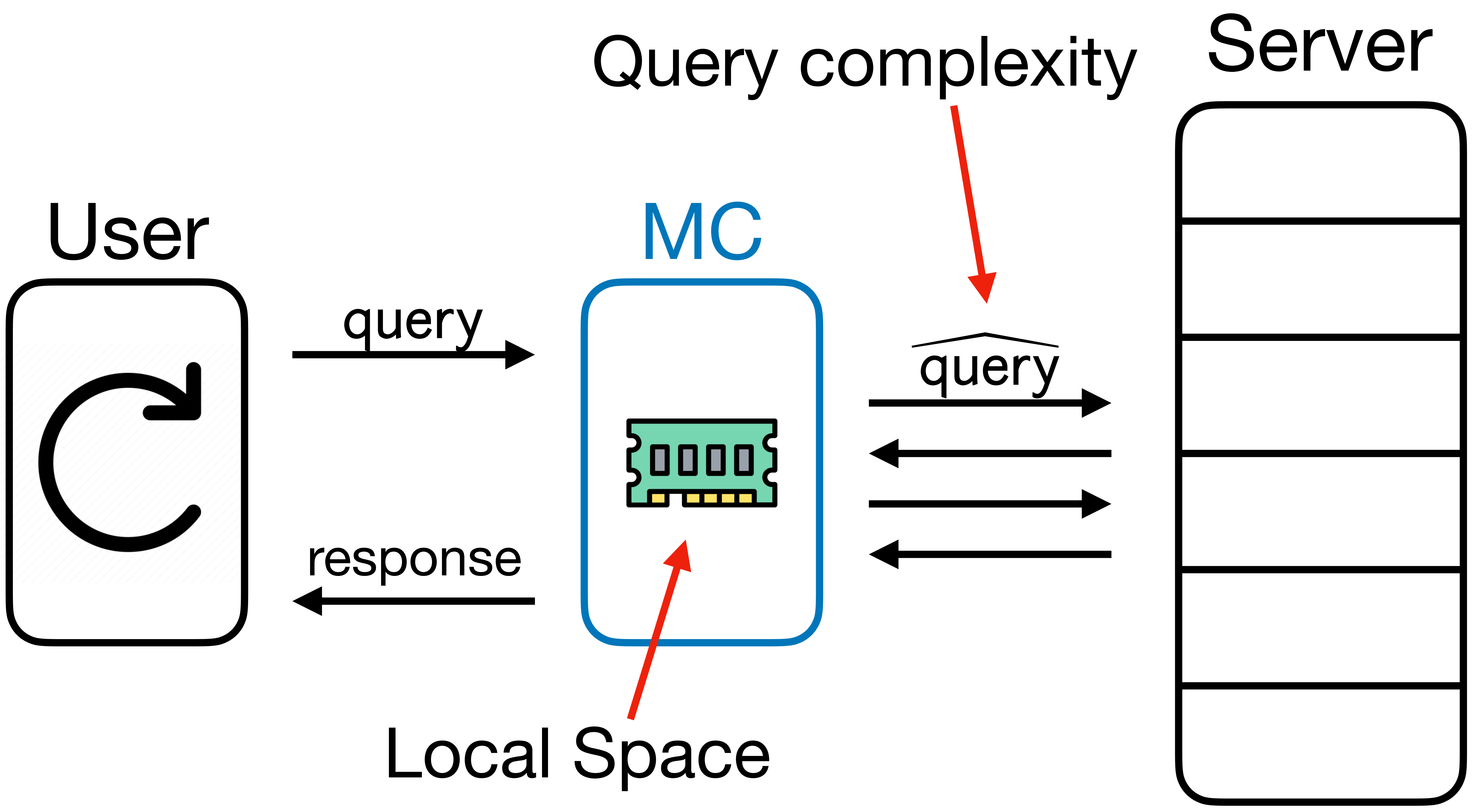

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Database of size n, word size polylog(n), local space $n^{1-\varepsilon}$

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More generally, local space $\times$ queries $= \Theta(n)$

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Limitations of the Computational Lower Bounds

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- Only rules out memory checkers with **inverse polynomial soundness error**, roughly $p \approx 1/n$.
- Doesn’t rule out super-efficient MCs with **larger soundness error**.

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- Naturally fits into memory checking setting: file storage cloud server doesn’t want to harm their reputation!

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Concrete Example: Is there a MC with 5% soundness error and $q = 2$?

Main Result

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- We show:

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<u>Theorem</u>: Every memory checker*, even with $\Omega(1)$ soundness error, must have $q = \Omega(\log n / \log \log n)$.

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- **Tight** up to constant factors. [Papamanthou-Tamassia ’11]
- **Unconditional**. Holds regardless of any computational assumptions.
- Handles **randomized** and **adaptive** memory checkers.
- **An Interpretation**: Unlike many other MPC functionalities, covert security **does not** enable efficiency gains for memory checking.

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Technical Overview

Our Approach

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- Will use following style of compression lemma:
  - Transmitting uniformly random $S \subseteq [n]$ from Alice to Bob where $|S| = k$ requires $\log \binom{n}{k}$ bits, even with shared indep. randomness.

Protocol

Knows $S \subseteq [n]$

Wants to recover S

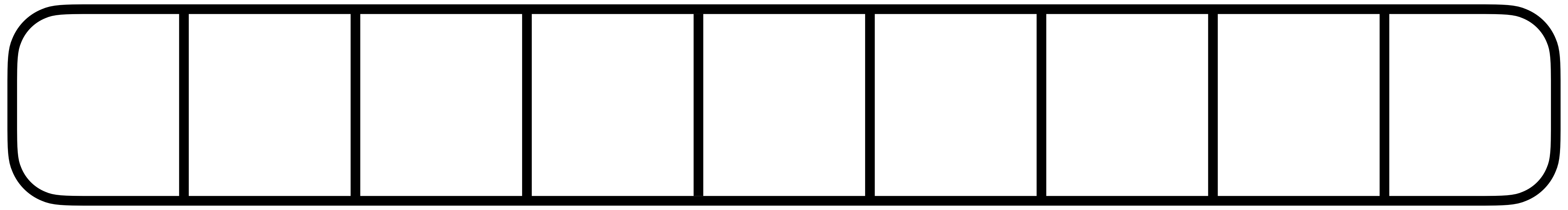
Publicly initialize MC:

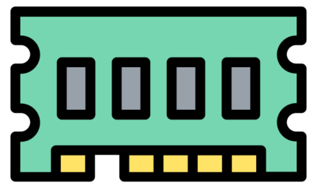
(by performing write$(i, 0)$ for all $i \in [n]$)

Knows $S \subseteq [n]$

Protocol

DB_0



st_0 

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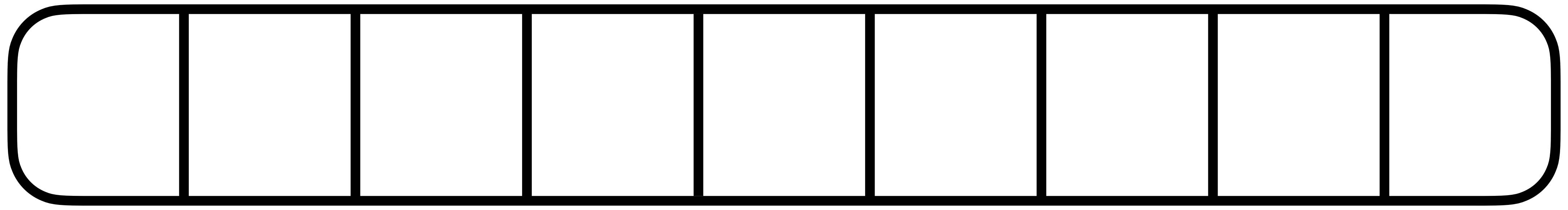

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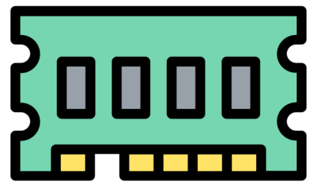
st_0 

For each $i \in S$:

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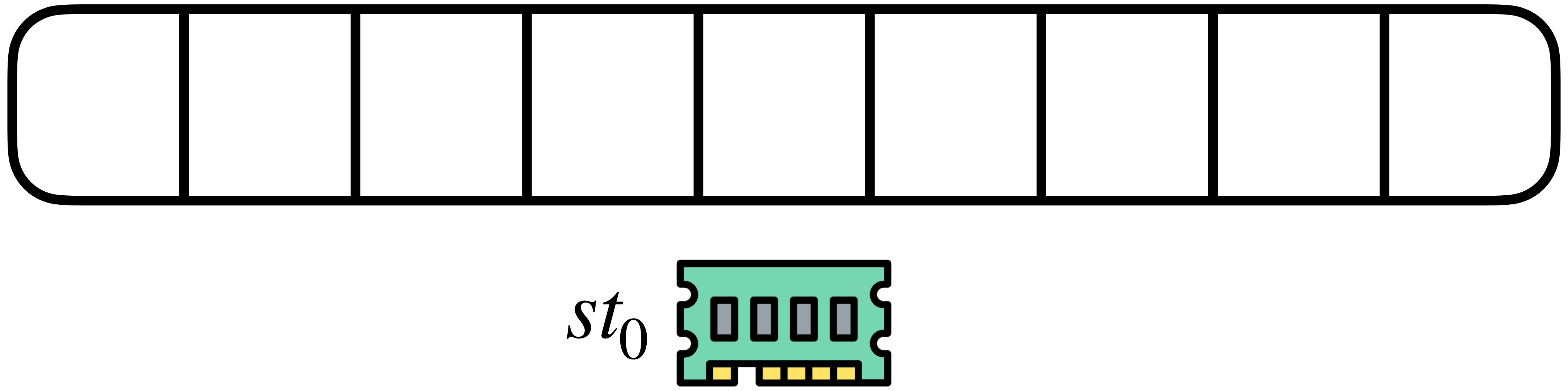

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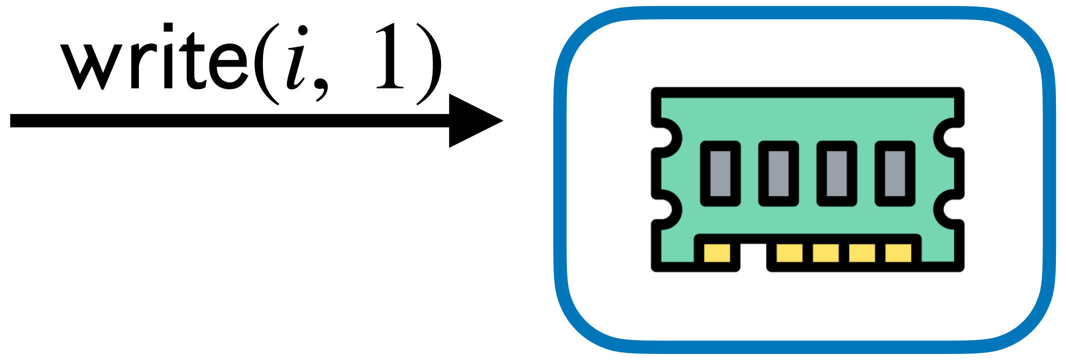

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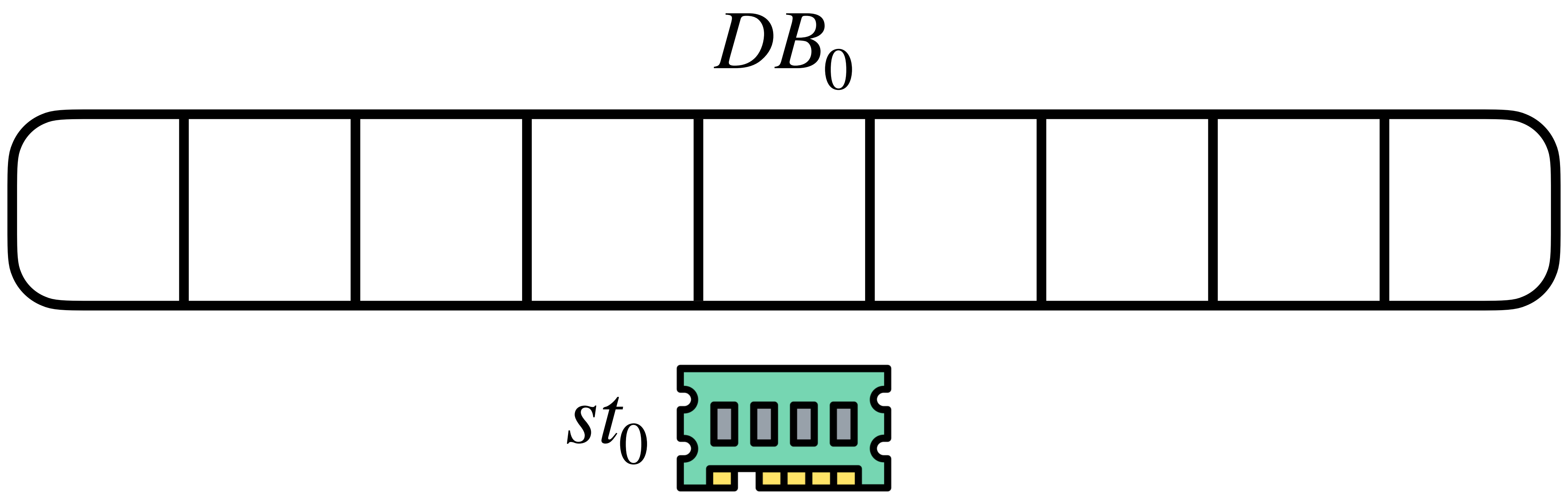

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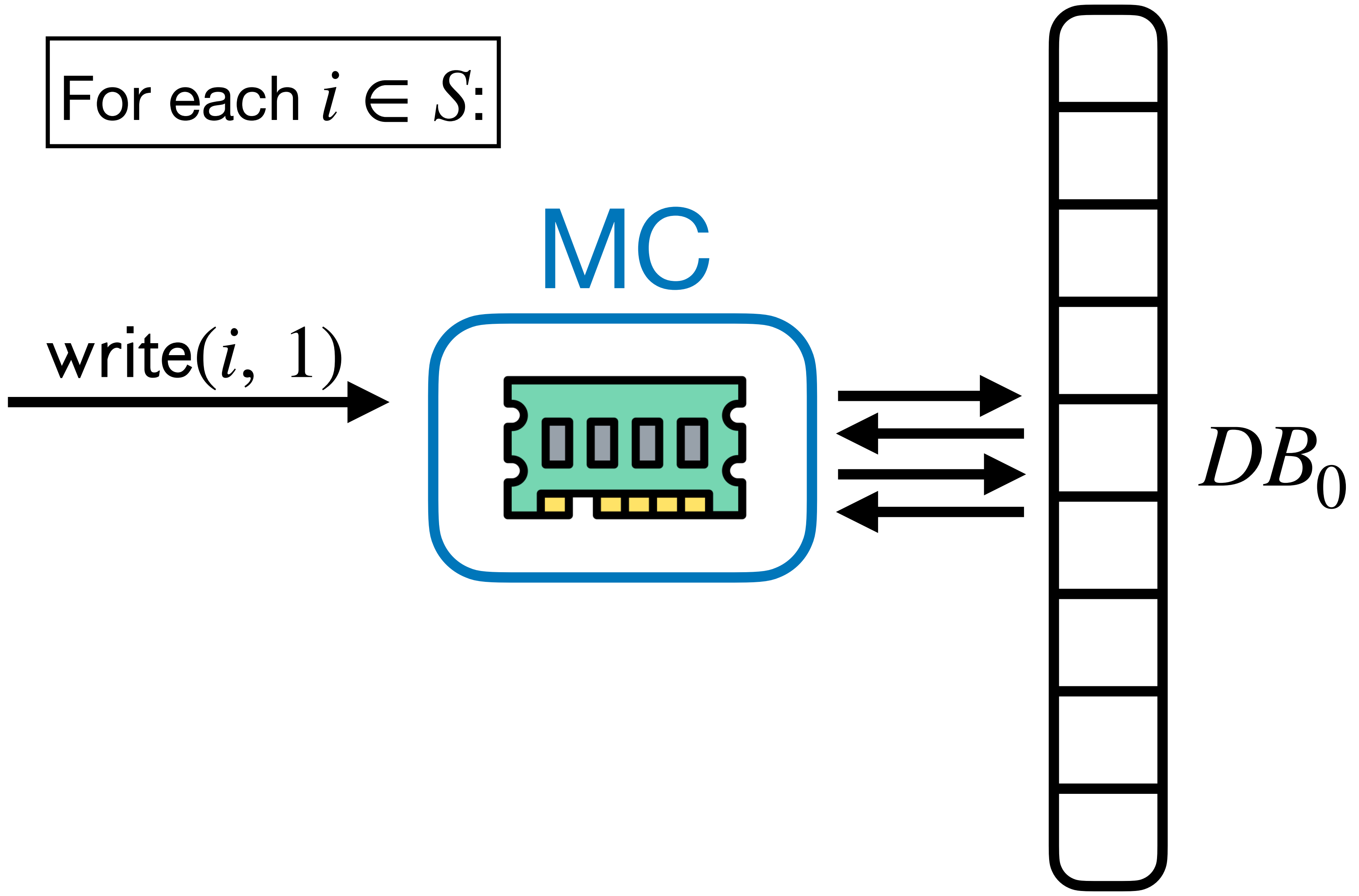

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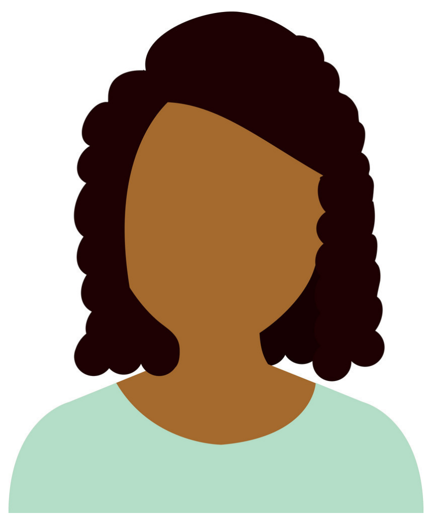

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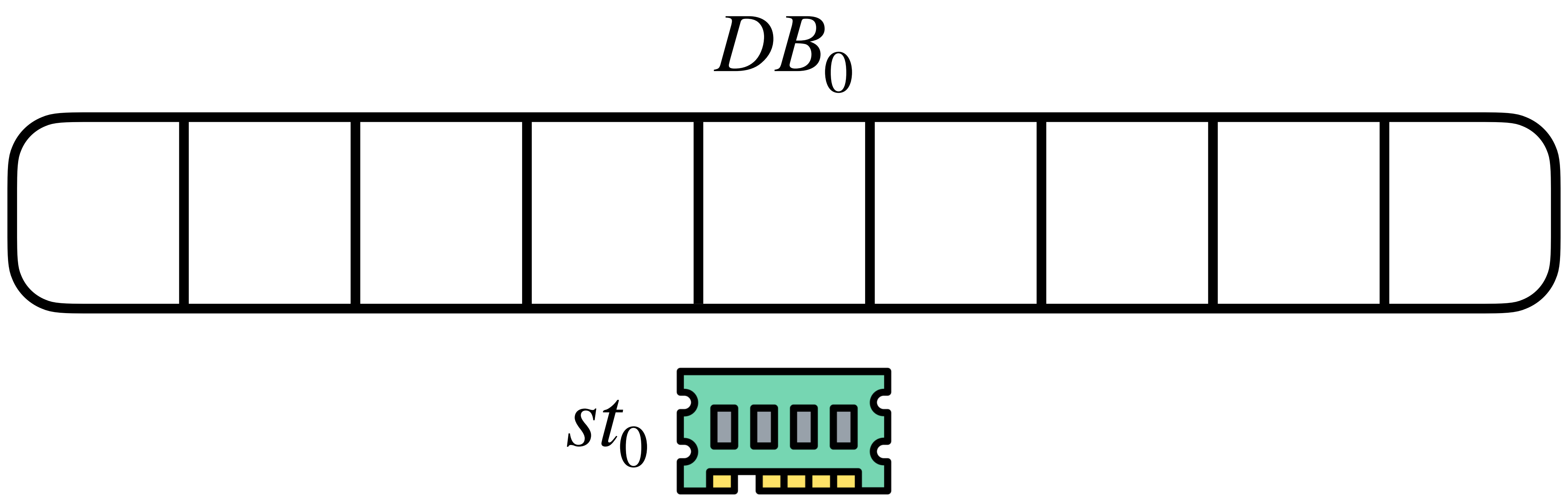

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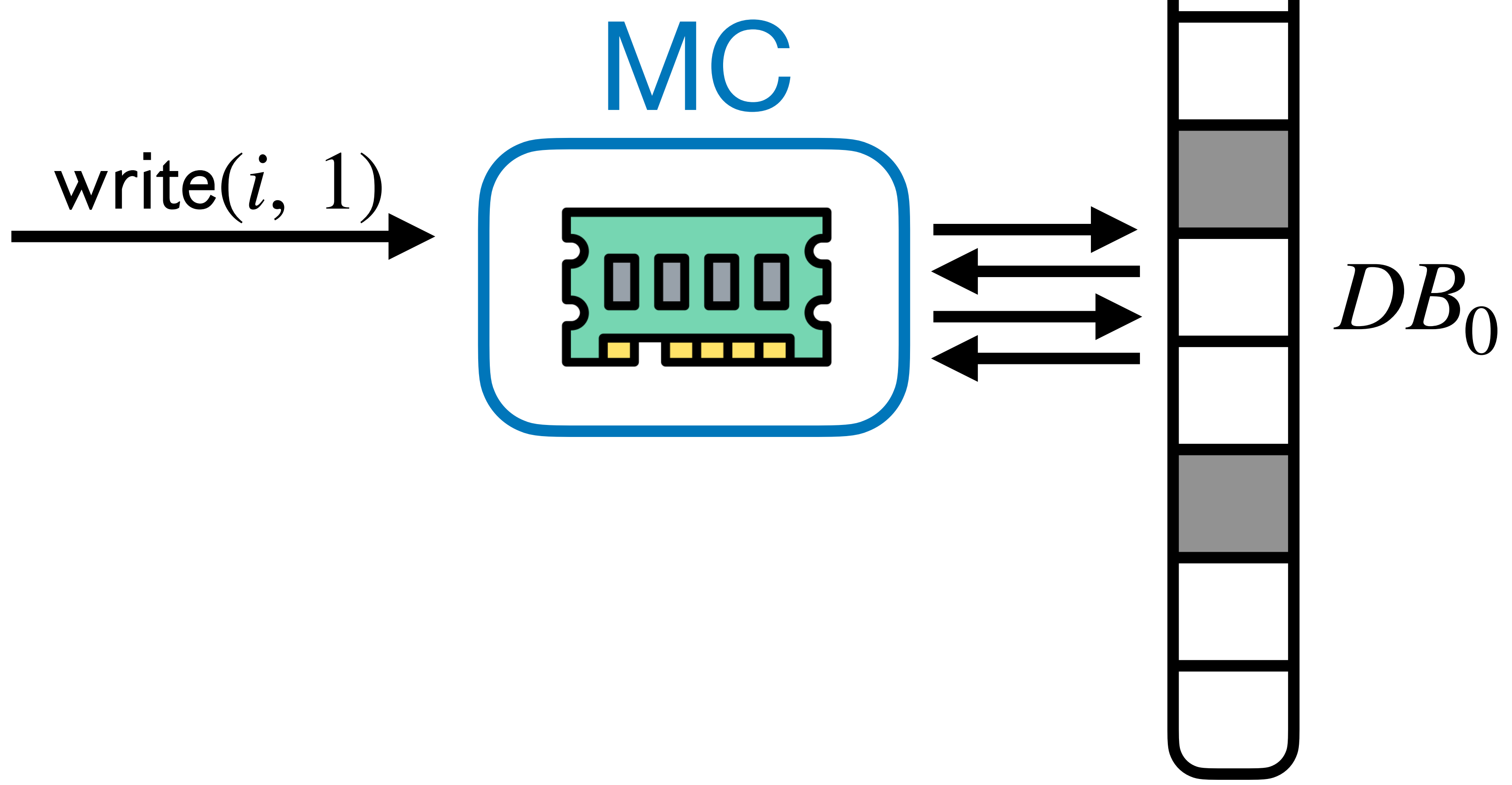

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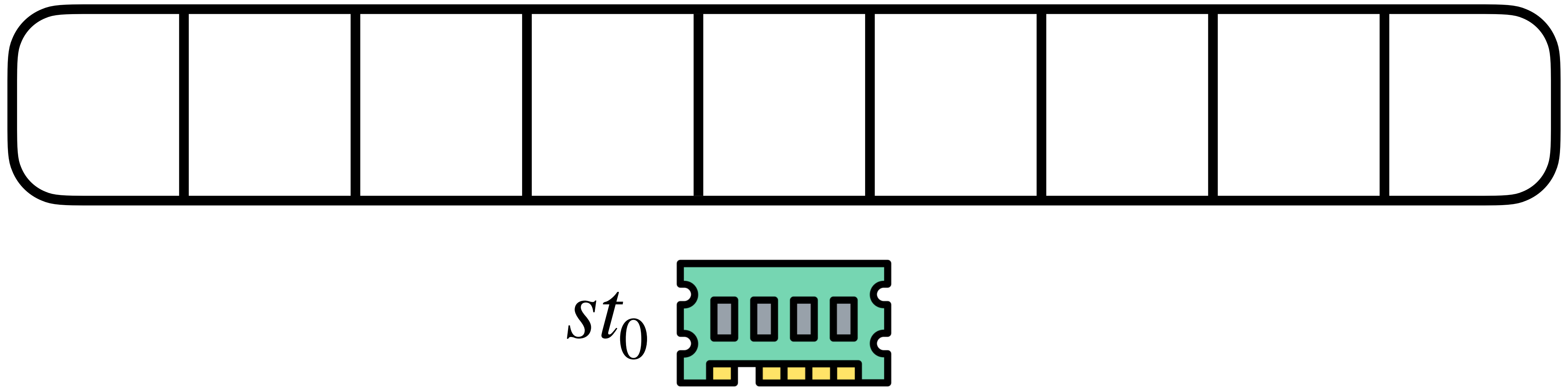

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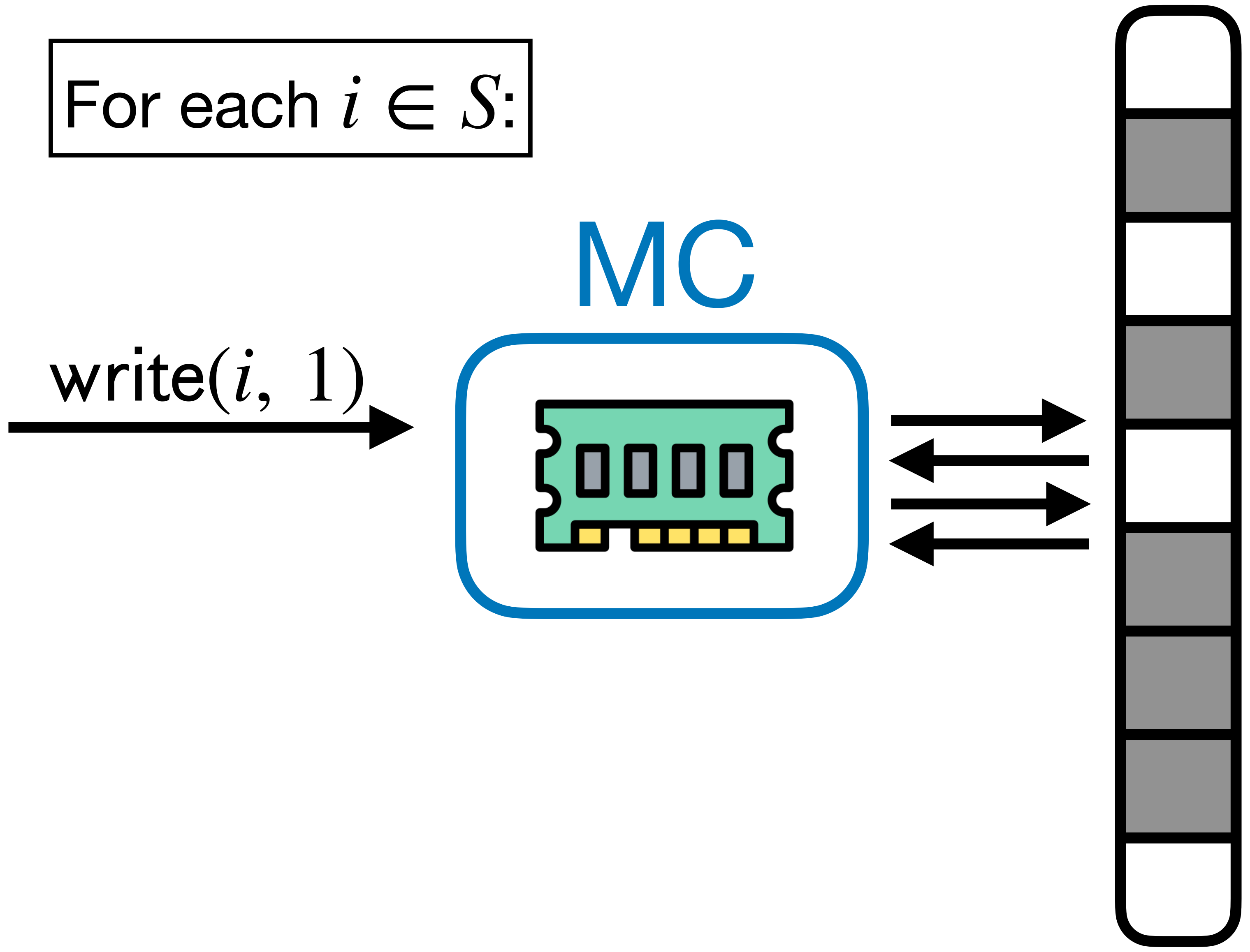

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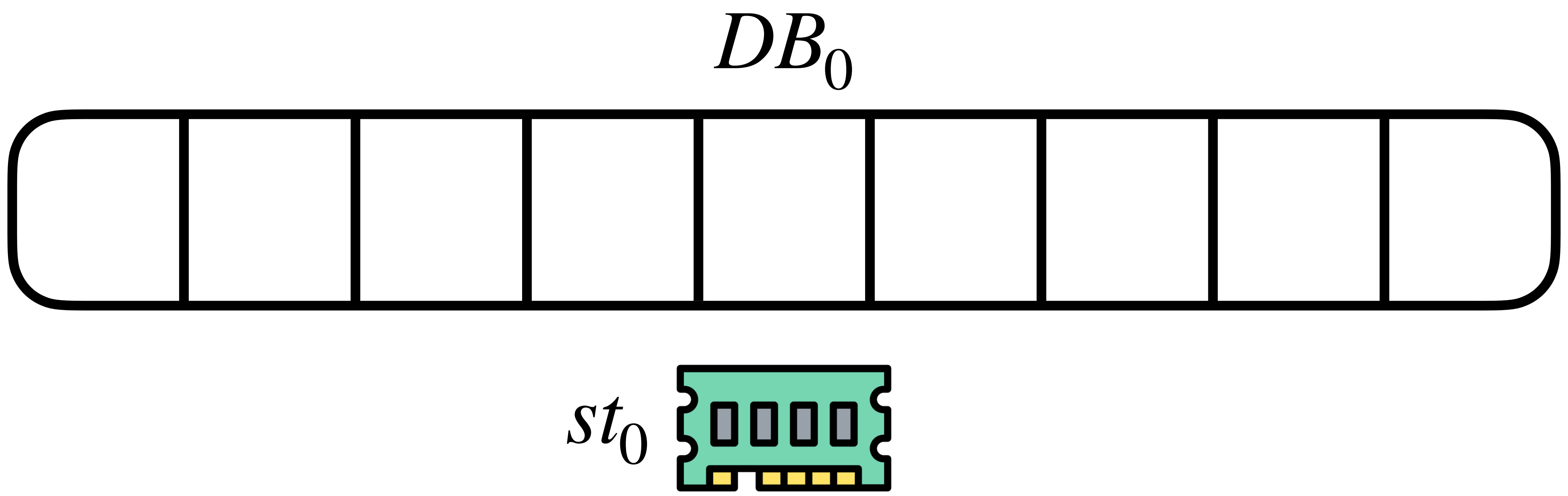

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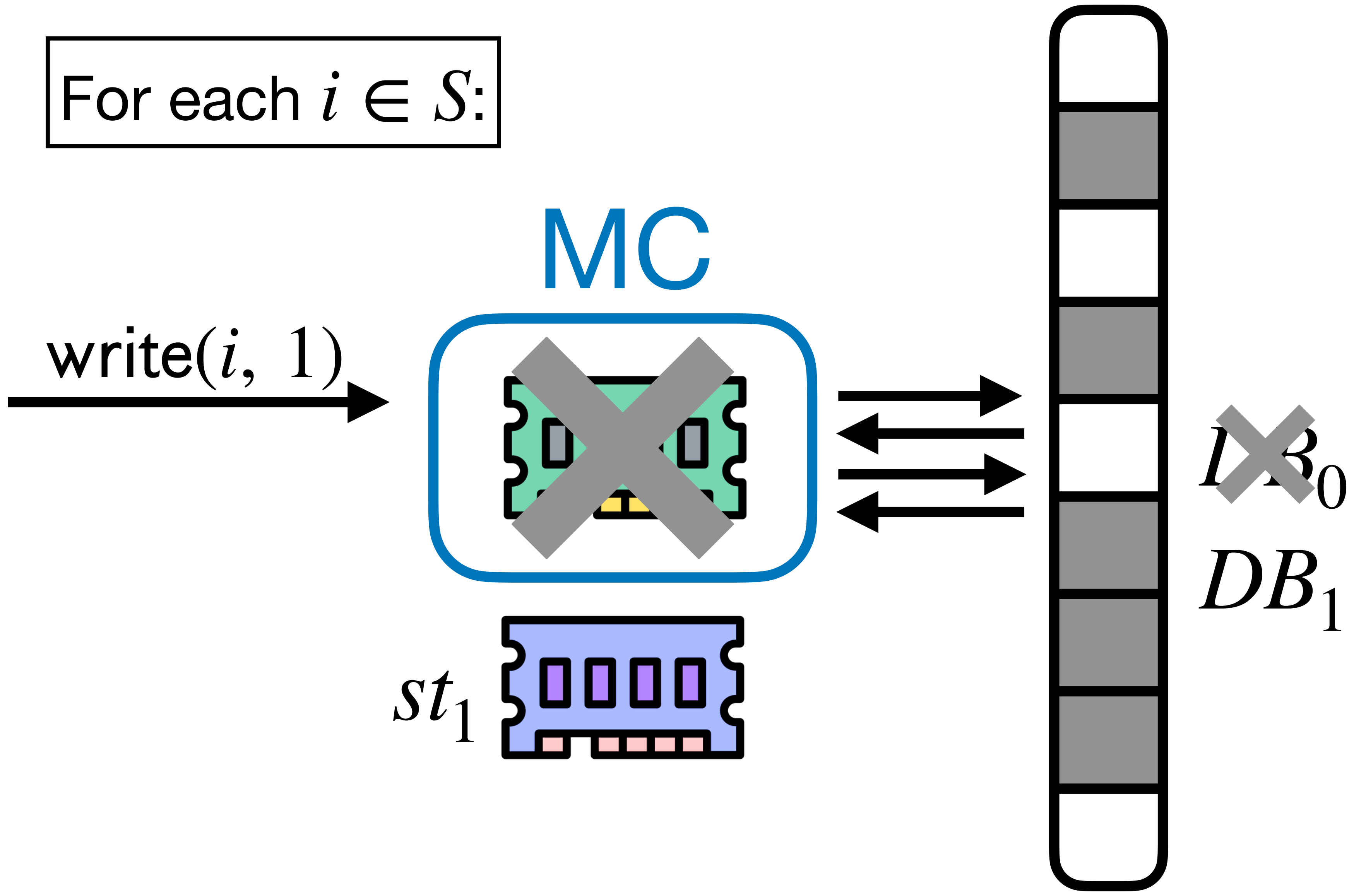


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DB_1
st_1
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$r_i = 1 \iff i \in S$
by **soundness** of MC.
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- Analyze the query distribution of read(i) (where $i \leftarrow [n]$):
  - **Heavy** set H: Small set, all have high probability mass.
  - **Medium** set M: "Total" guarantee of low mass.
  - **Light** set L: "Point-wise" guarantee of low mass.

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Now, will usually prevent this!

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  - H could depend on **private, internal randomness** of the MC.
  - H could **adaptively** change as queries are sent to the MC.

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- Analysis follows from multiplicative and additive Chernoff bounds.

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- We prove **tight, unconditional** lower bounds for MCs, showing that Merkle-style constructions are optimal **even when relaxing to covert security.**

  - Previously known only for **deterministic and non-adaptive** MCs or for MCs with inverse-polynomial soundness.

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Thanks!