# Ensō

## A Streaming Interface for NIC-Application Communication

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Carnegie Mellon University
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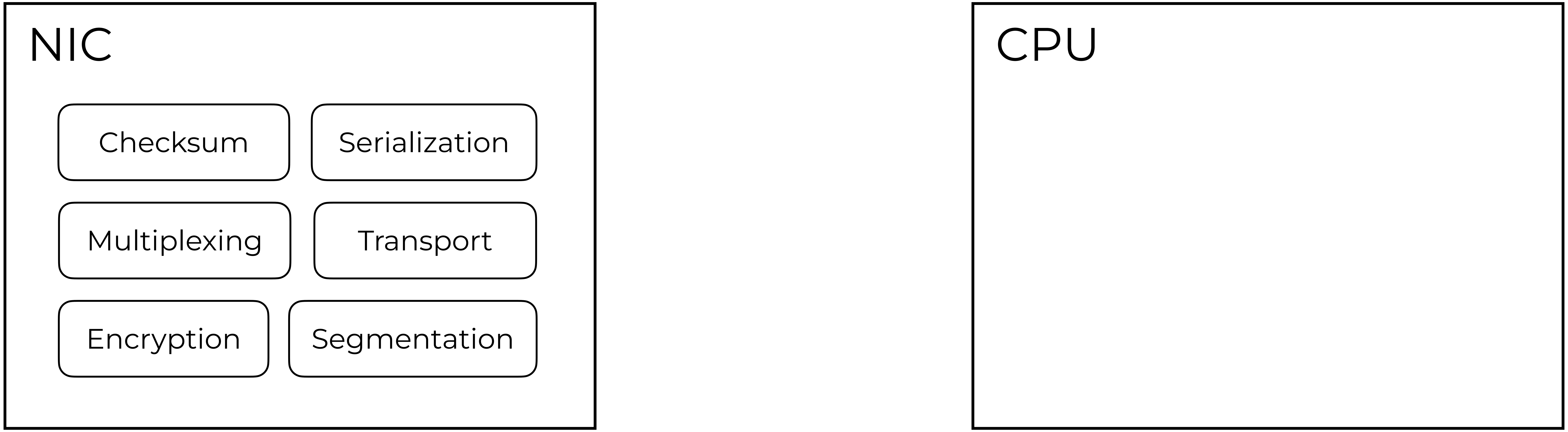
intel

# Two trends in high-performance networking

NIC

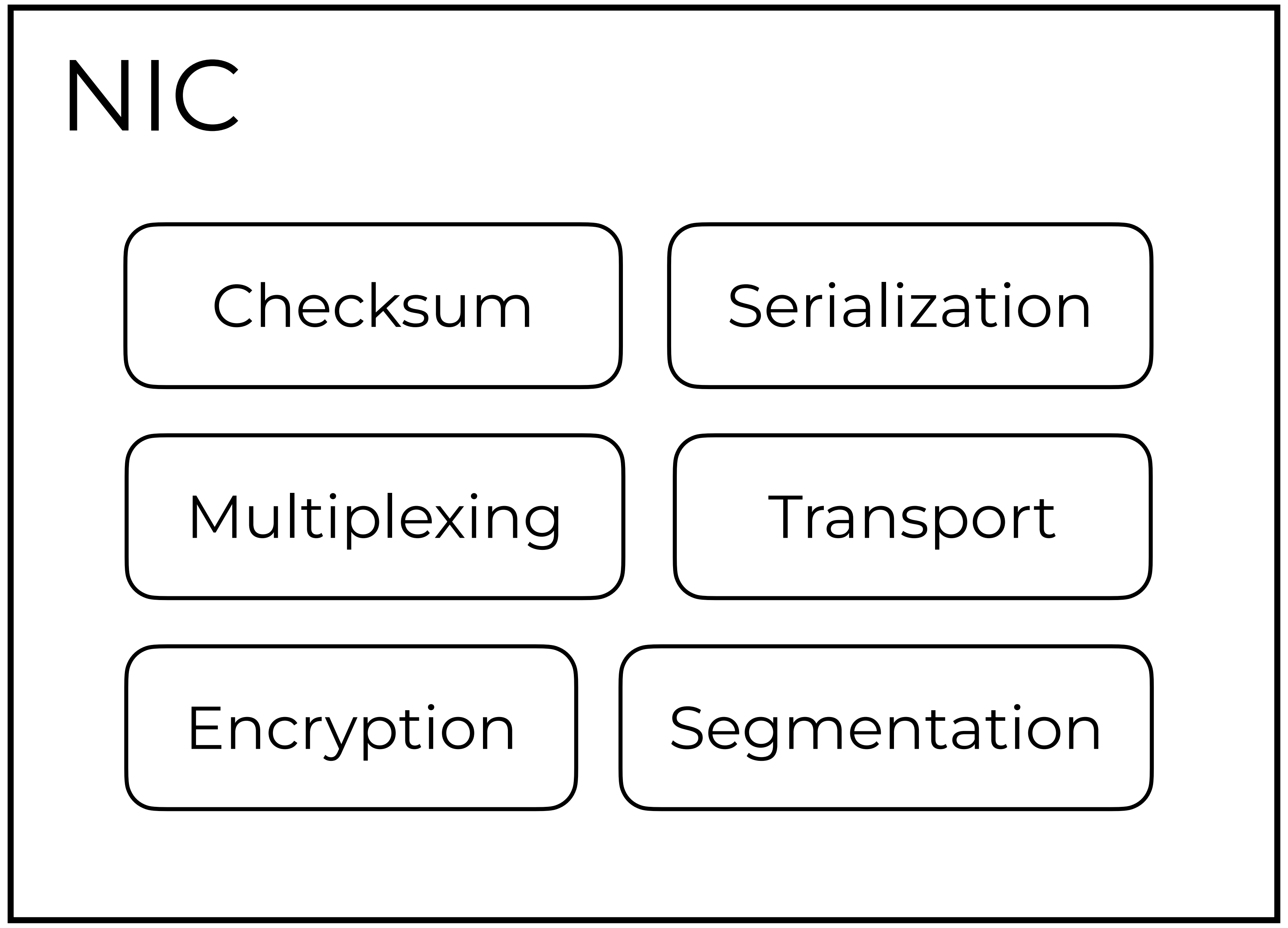
CPU

# Two trends in high-performance networking



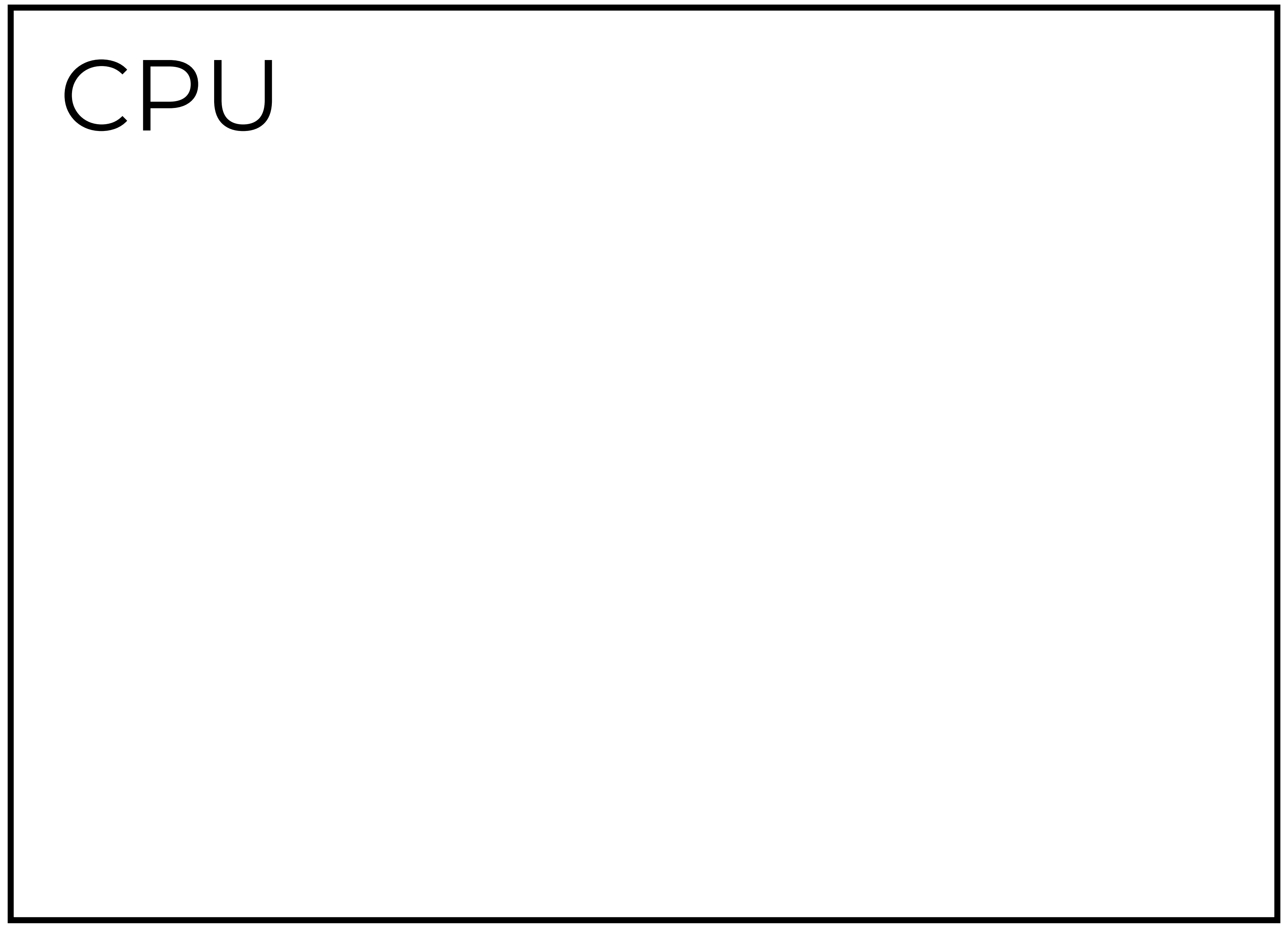

NIC offloads

# Two trends in high-performance networking




NIC offloads

Offloads operate at
higher network layers



# Two trends in high-performance networking

**NIC**

- Checksum
- Serialization
- Multiplexing
- Transport
- Encryption
- Segmentation

NIC offloads

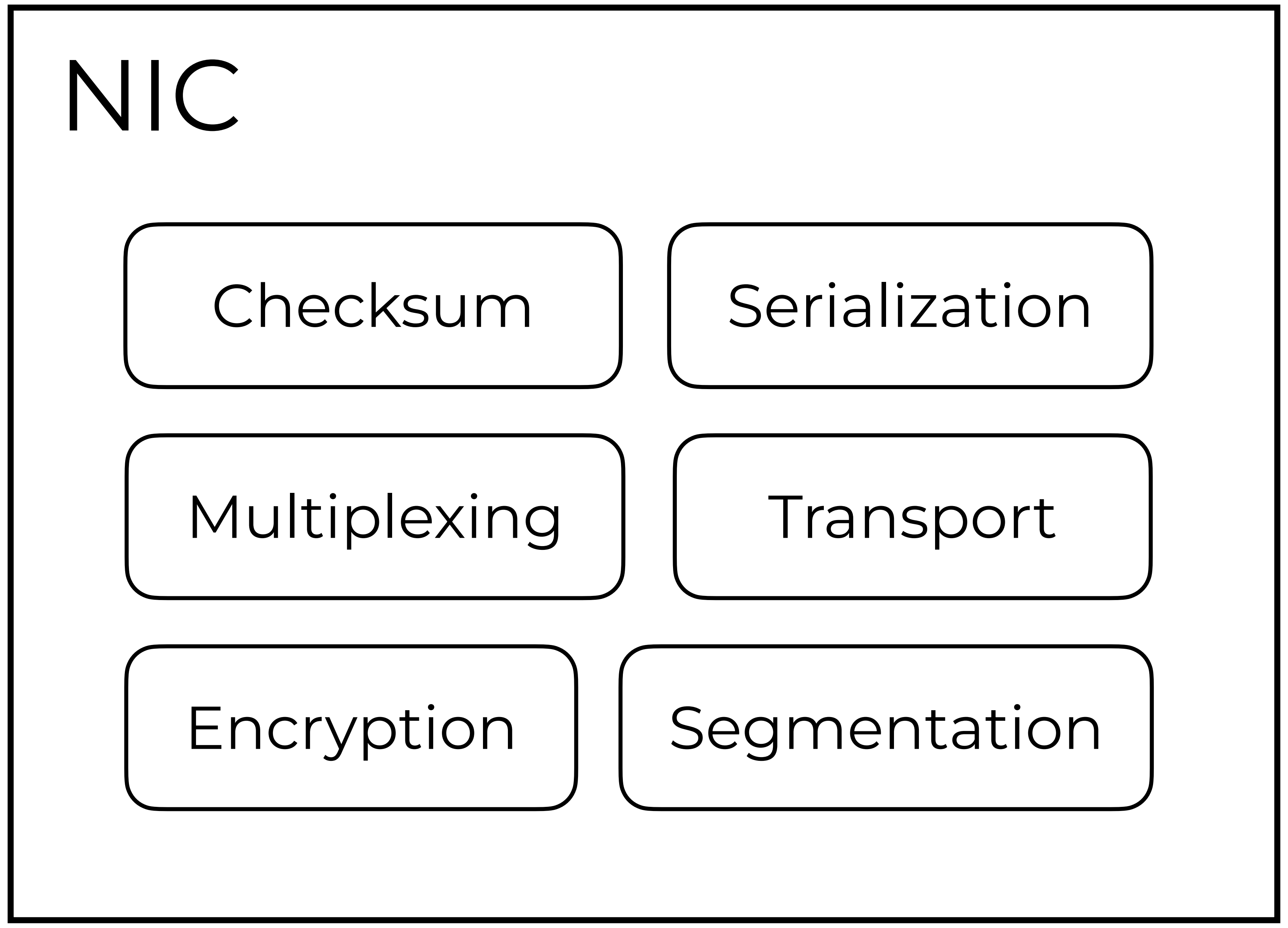
**CPU**

- DPDK
- netmap
- io_uring
- Arrakis
- mTCP
- TAS
- IX

Efficient network stacks

Offloads operate at
higher network layers

# Two trends in high-performance networking

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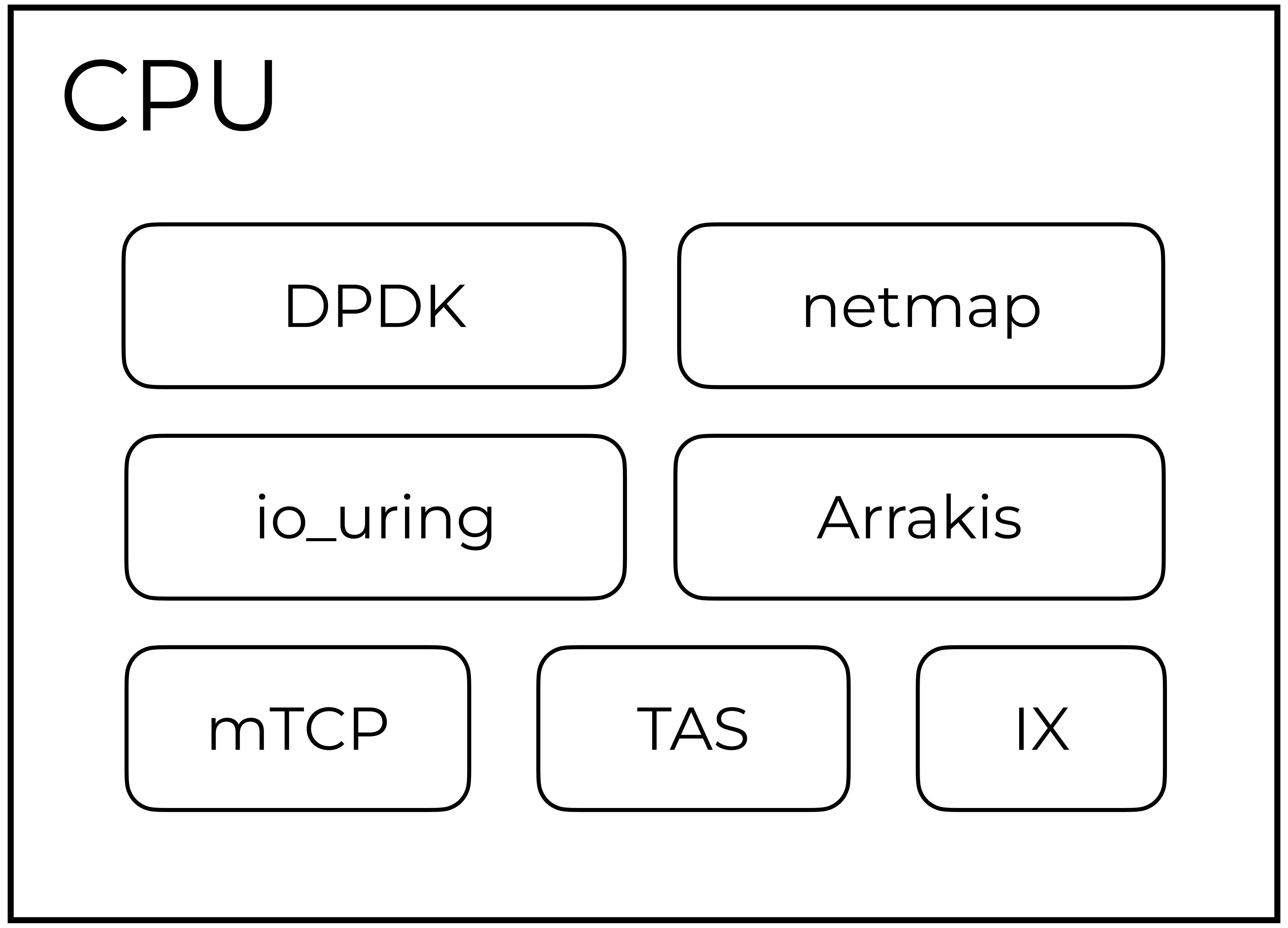


Efficient network stacks

Often bypass the kernel
and rely on batching

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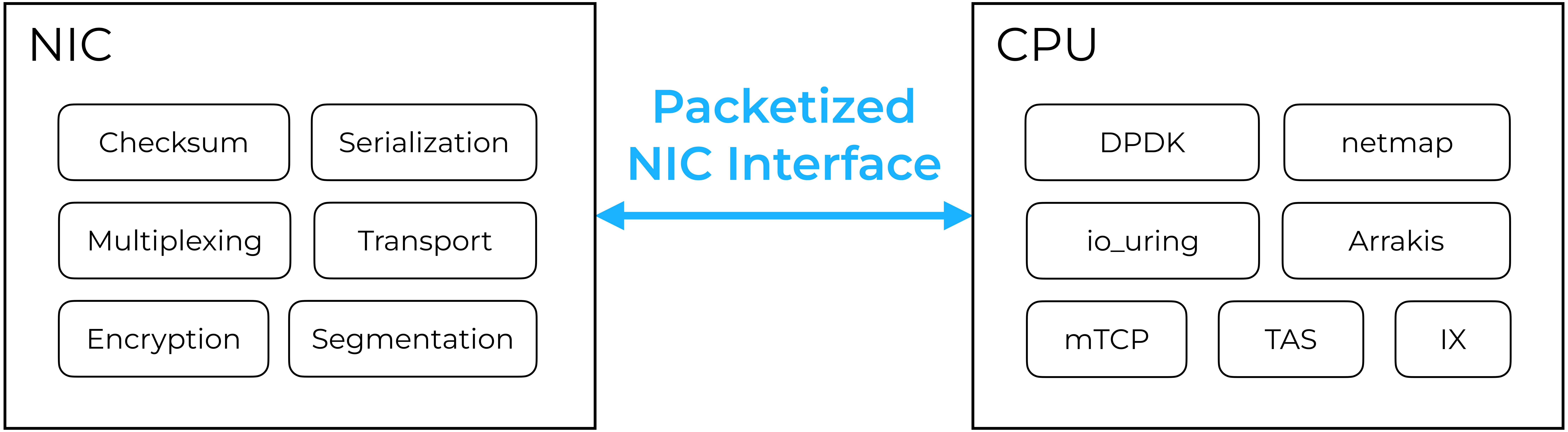



NIC offloads

Efficient network stacks

Offloads operate at higher network layers

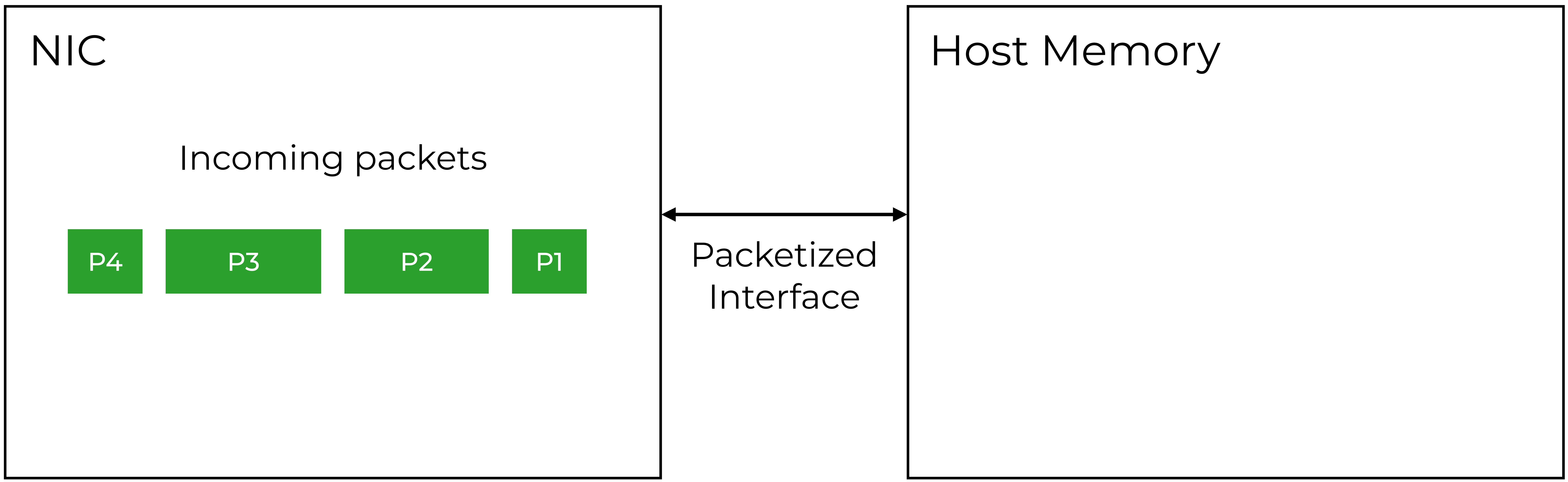
Often bypass the kernel and rely on batching

# This Talk:

① **Mismatch** between how NICs are **used** and the **interface** that they provide

② Fixing this mismatch can significantly **improve performance** while paving the way for **higher-level offloads**

# Existing NICs provide a packetized interface



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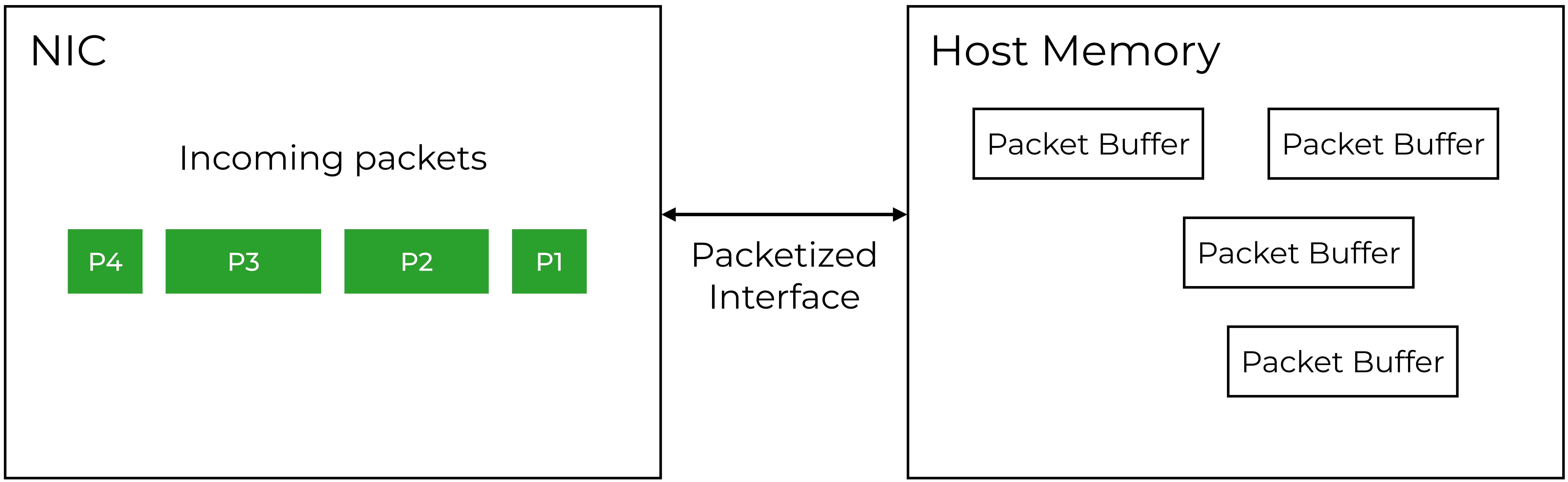

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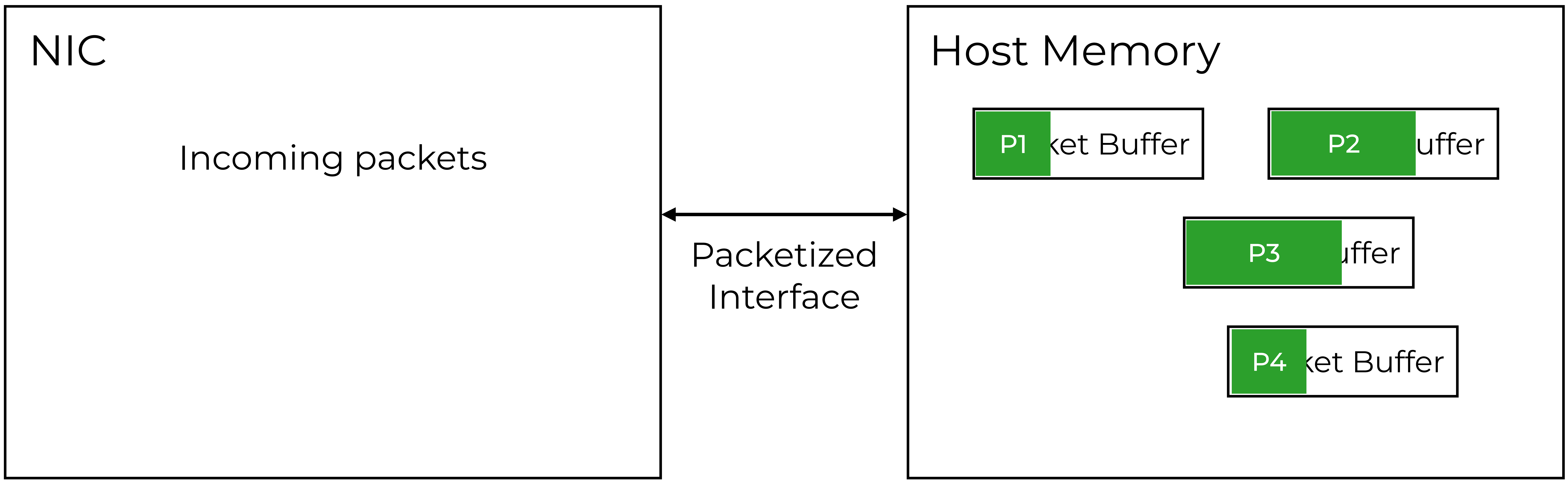
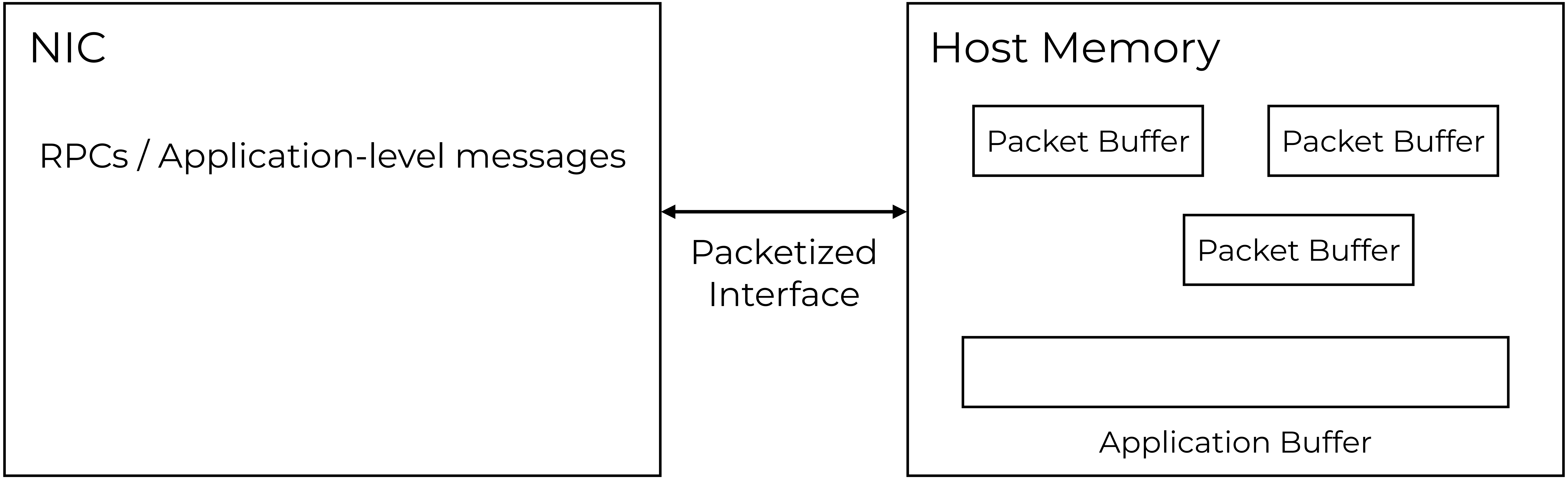


# Problem #1 Packetized Abstraction

Packetized abstraction is unsuitable for higher-level offloads



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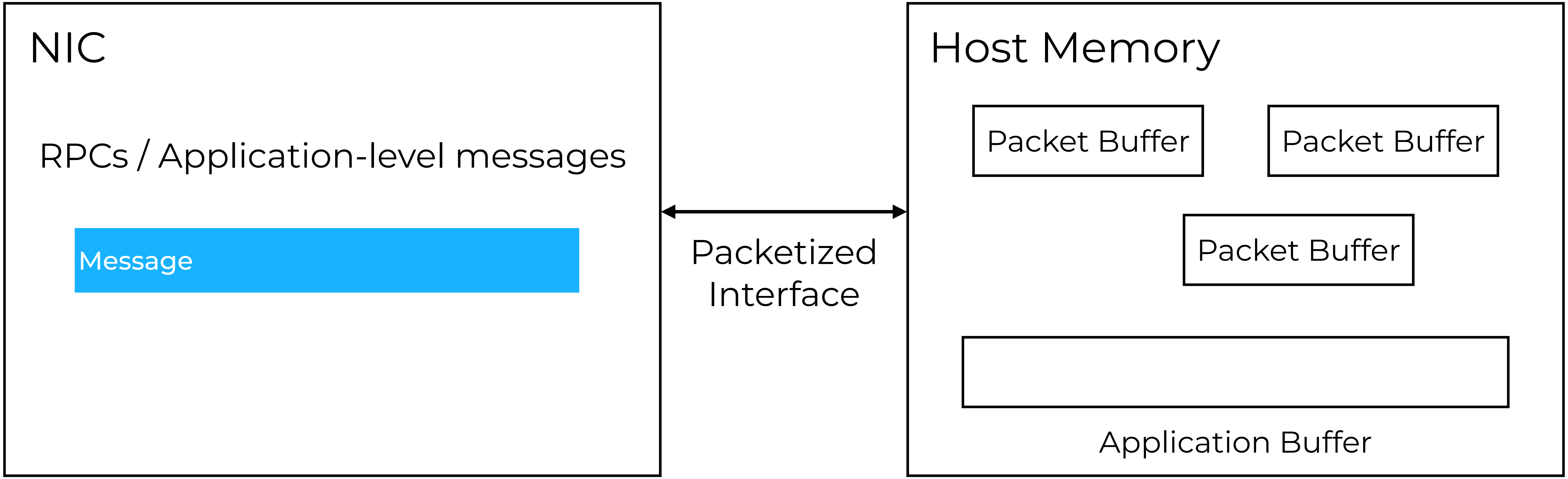

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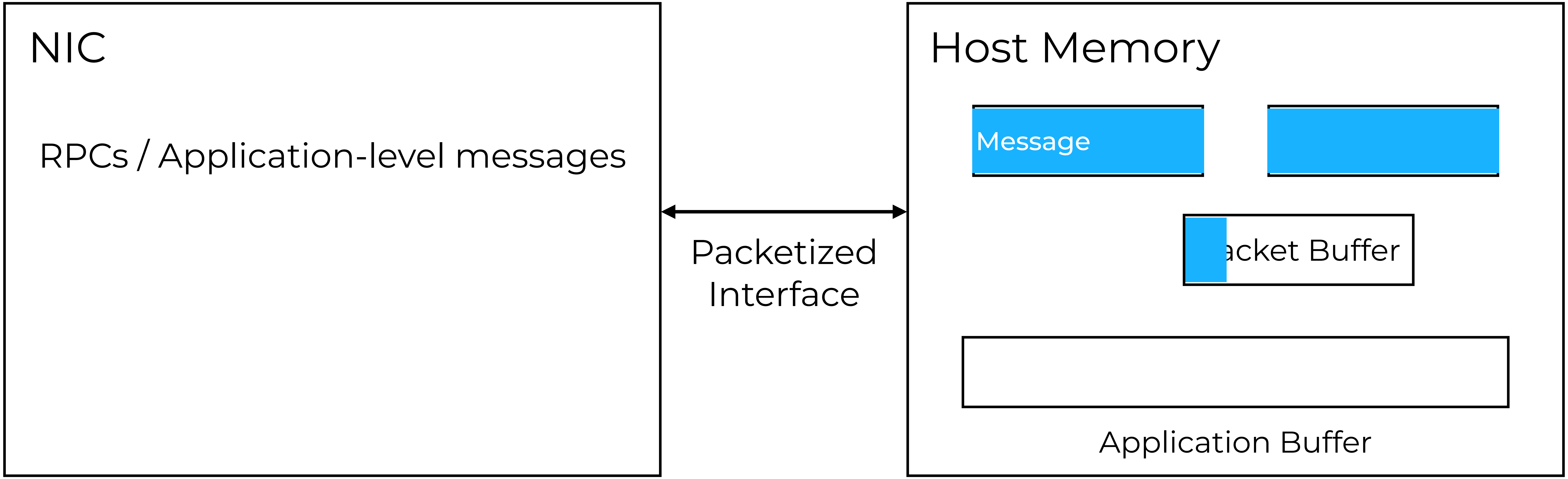

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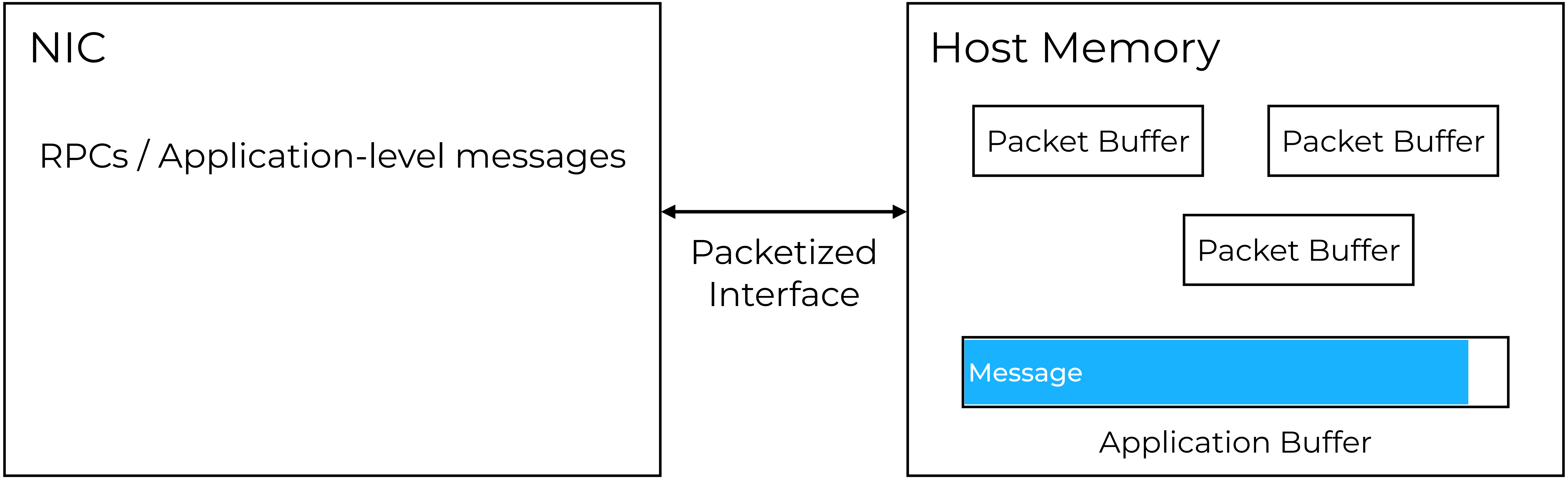

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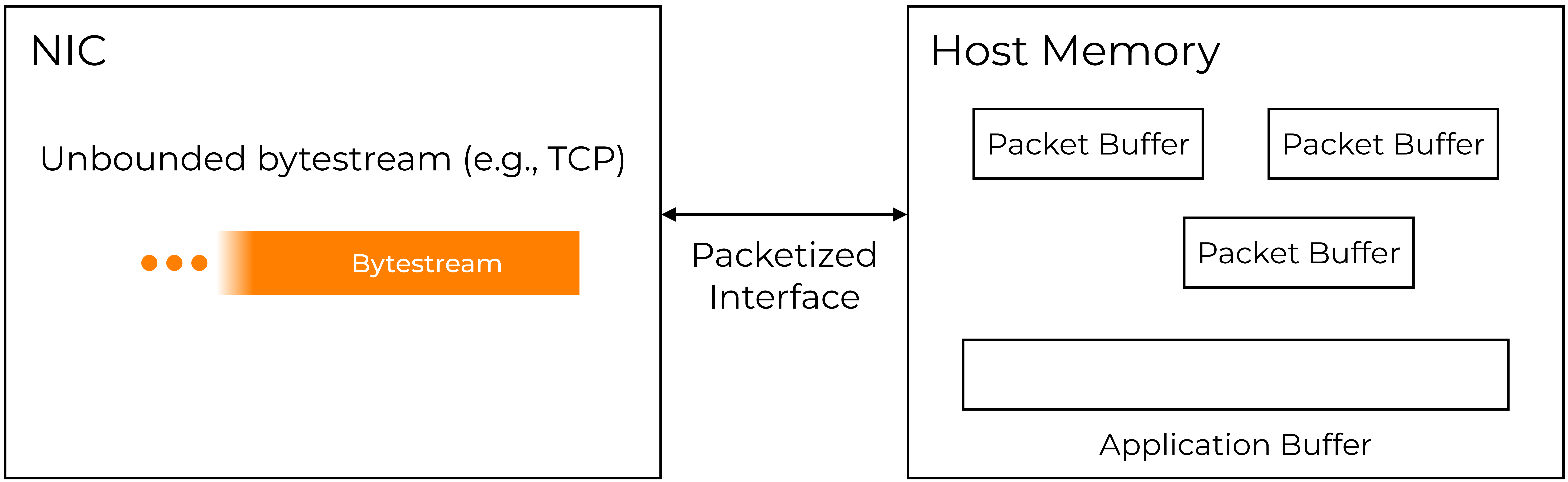

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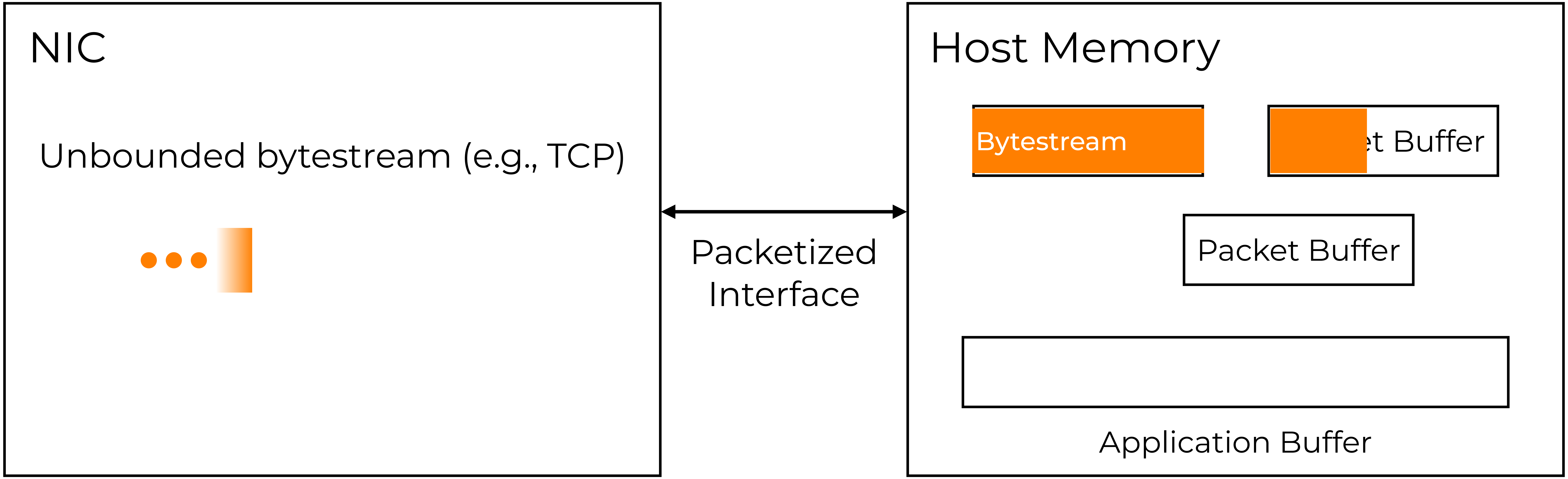

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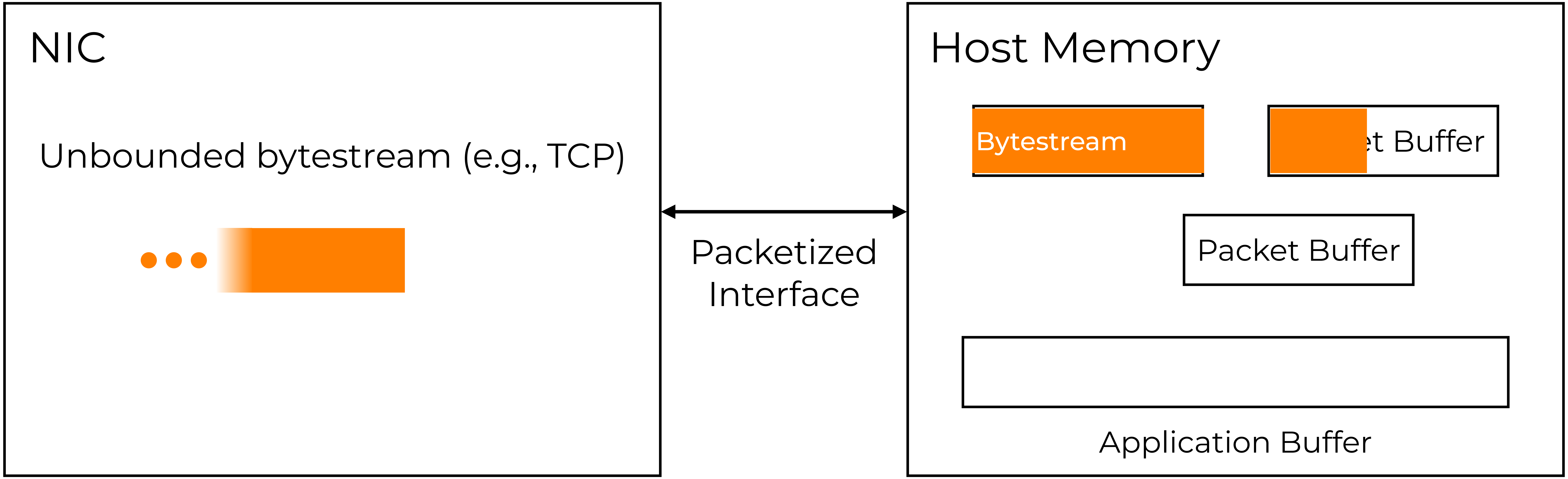

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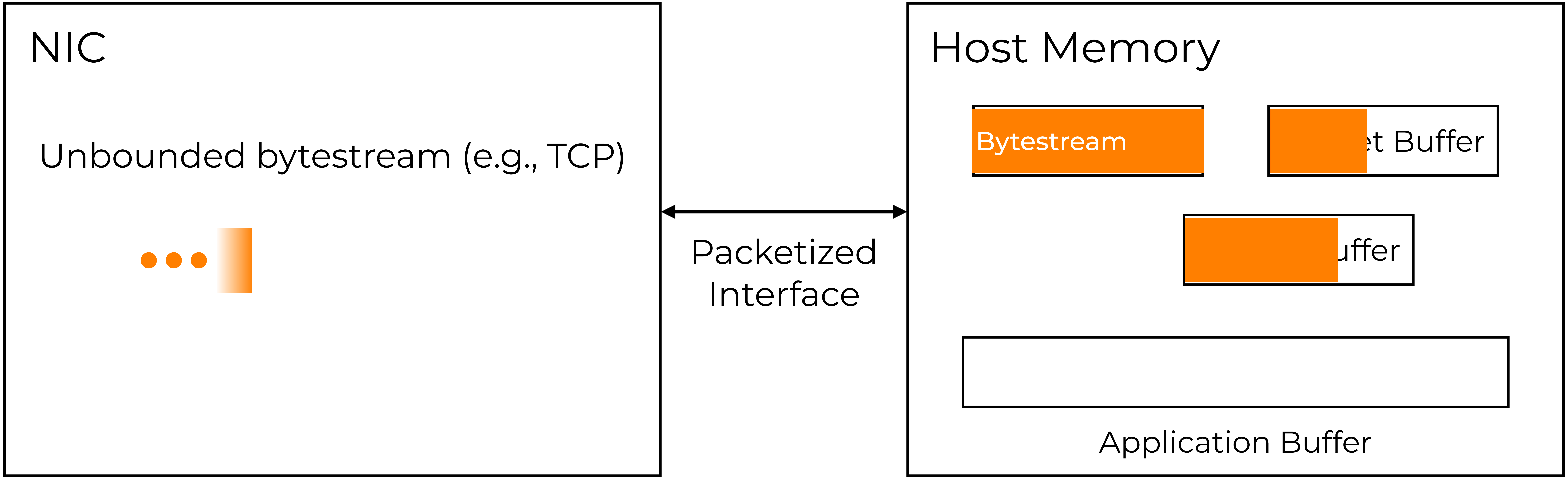

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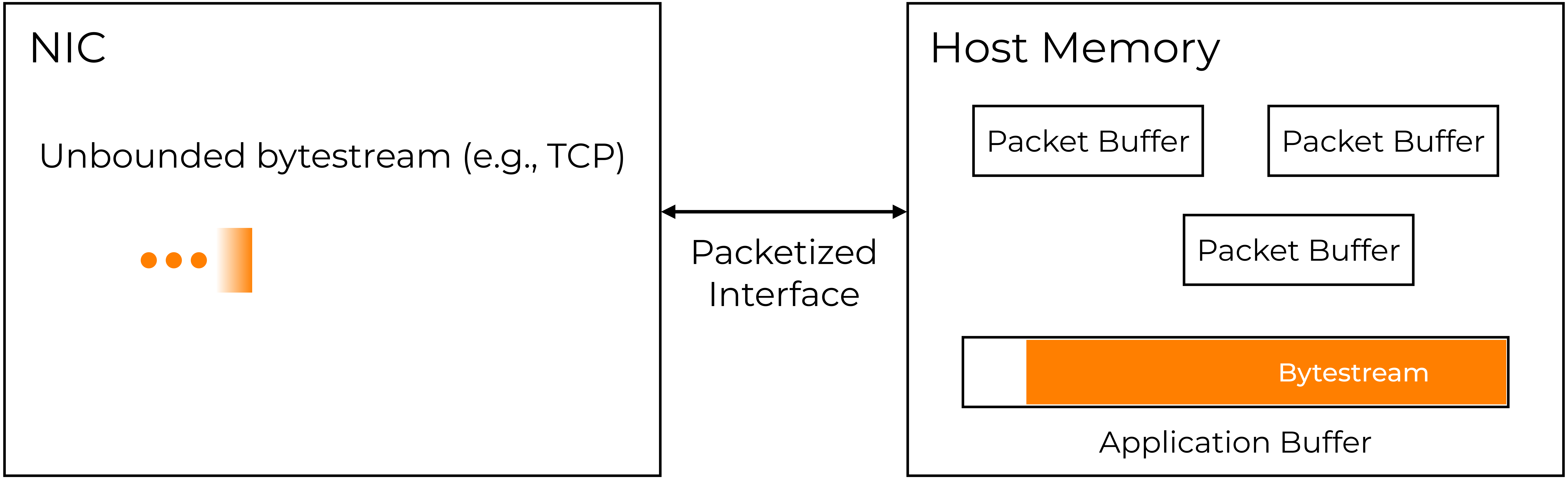
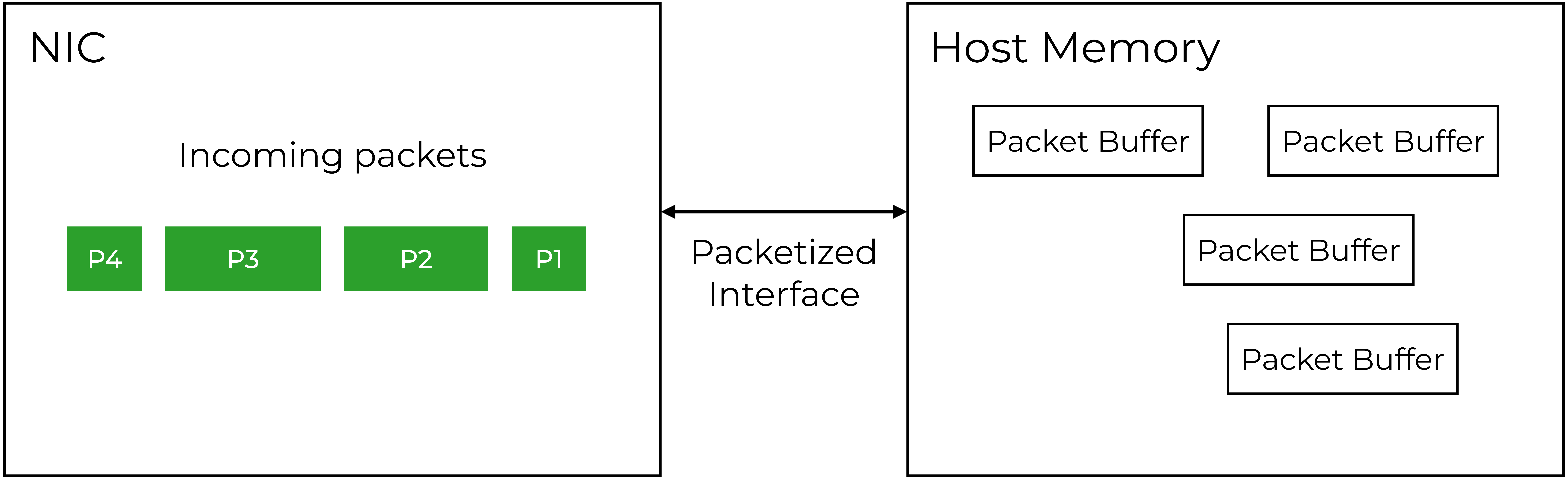


# Problem #2 Poor Cache Interaction

Poor cache interaction due to chaotic memory access



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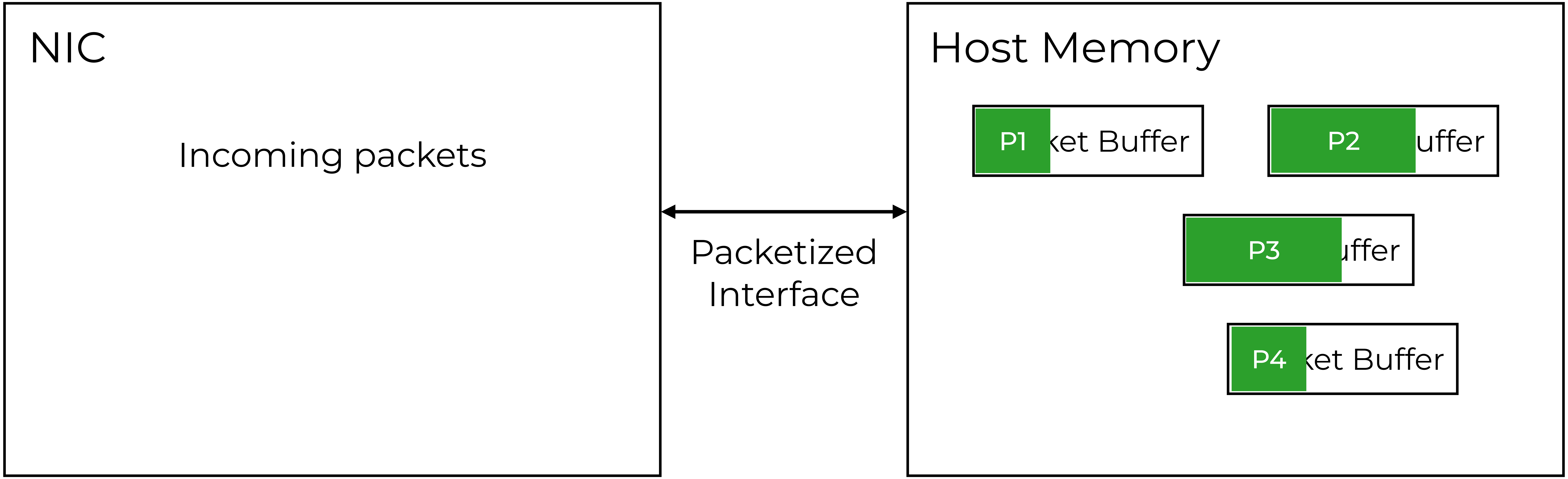

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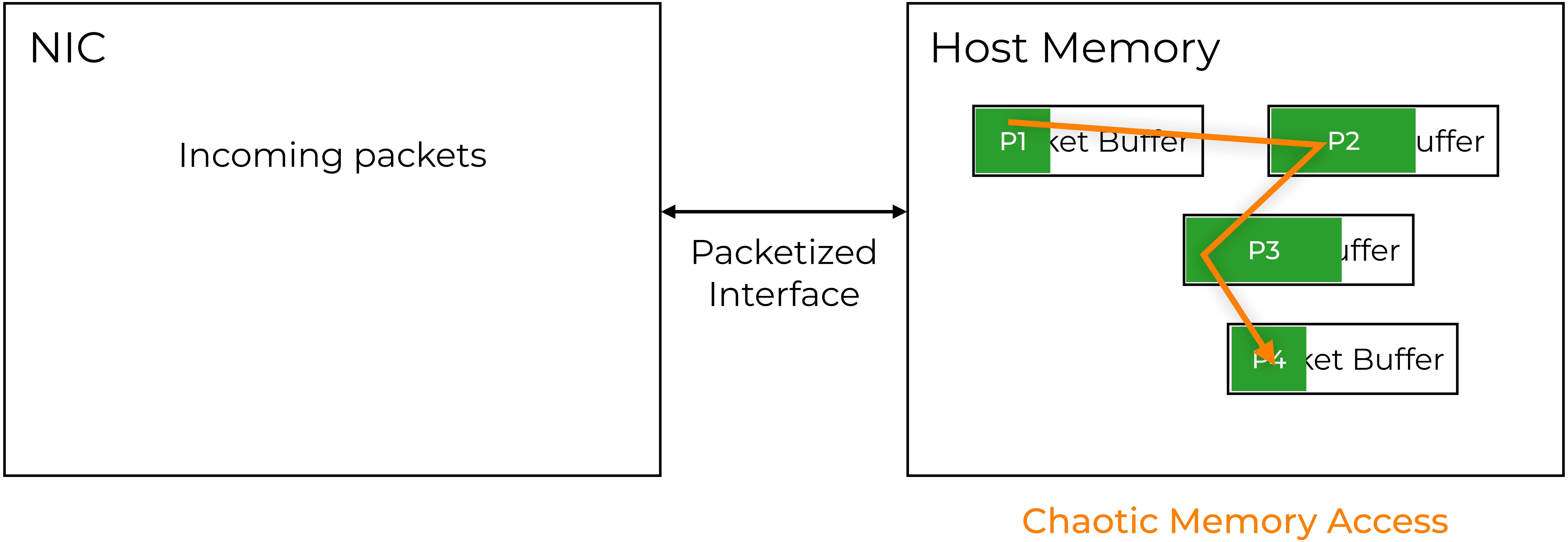

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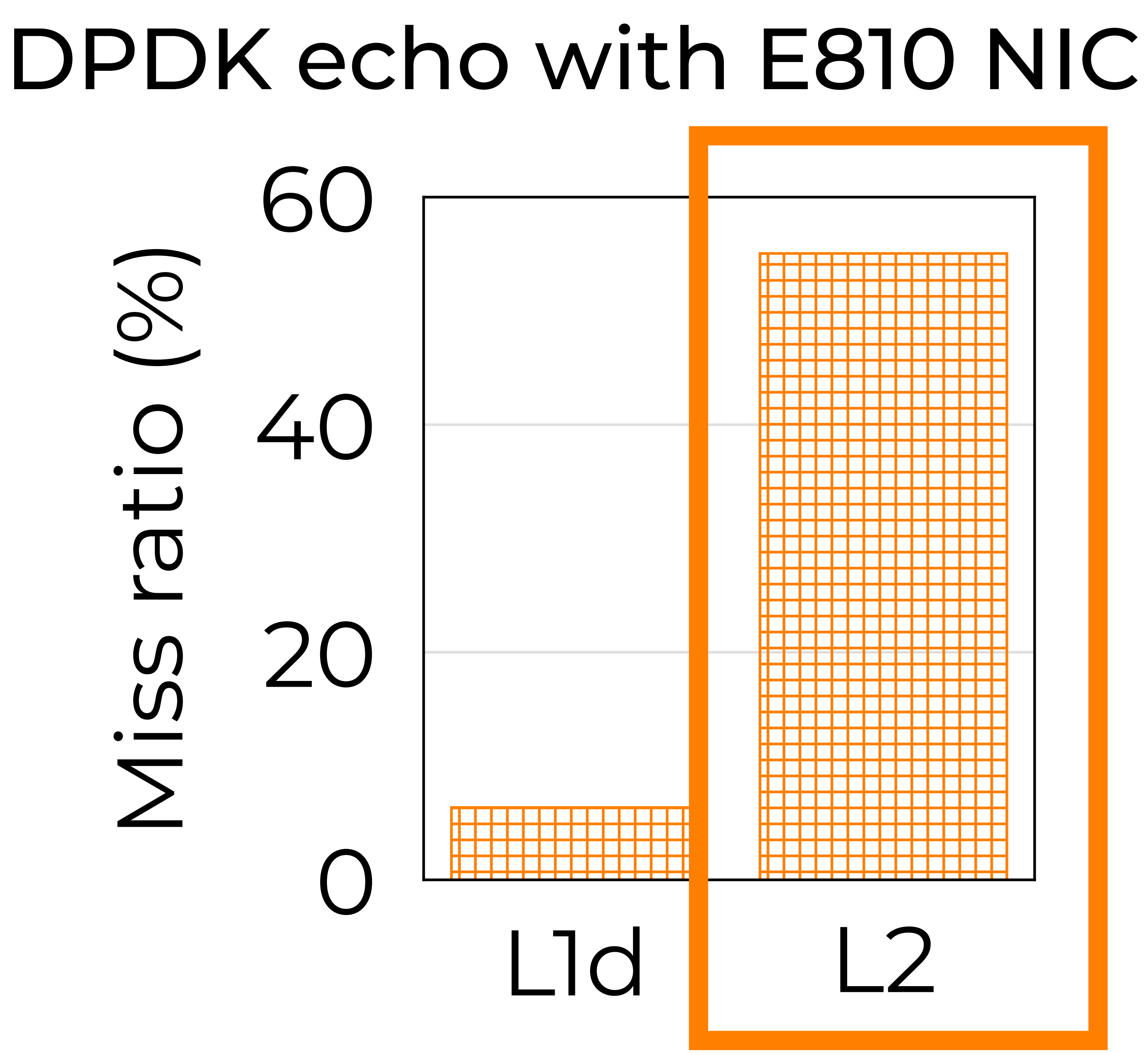
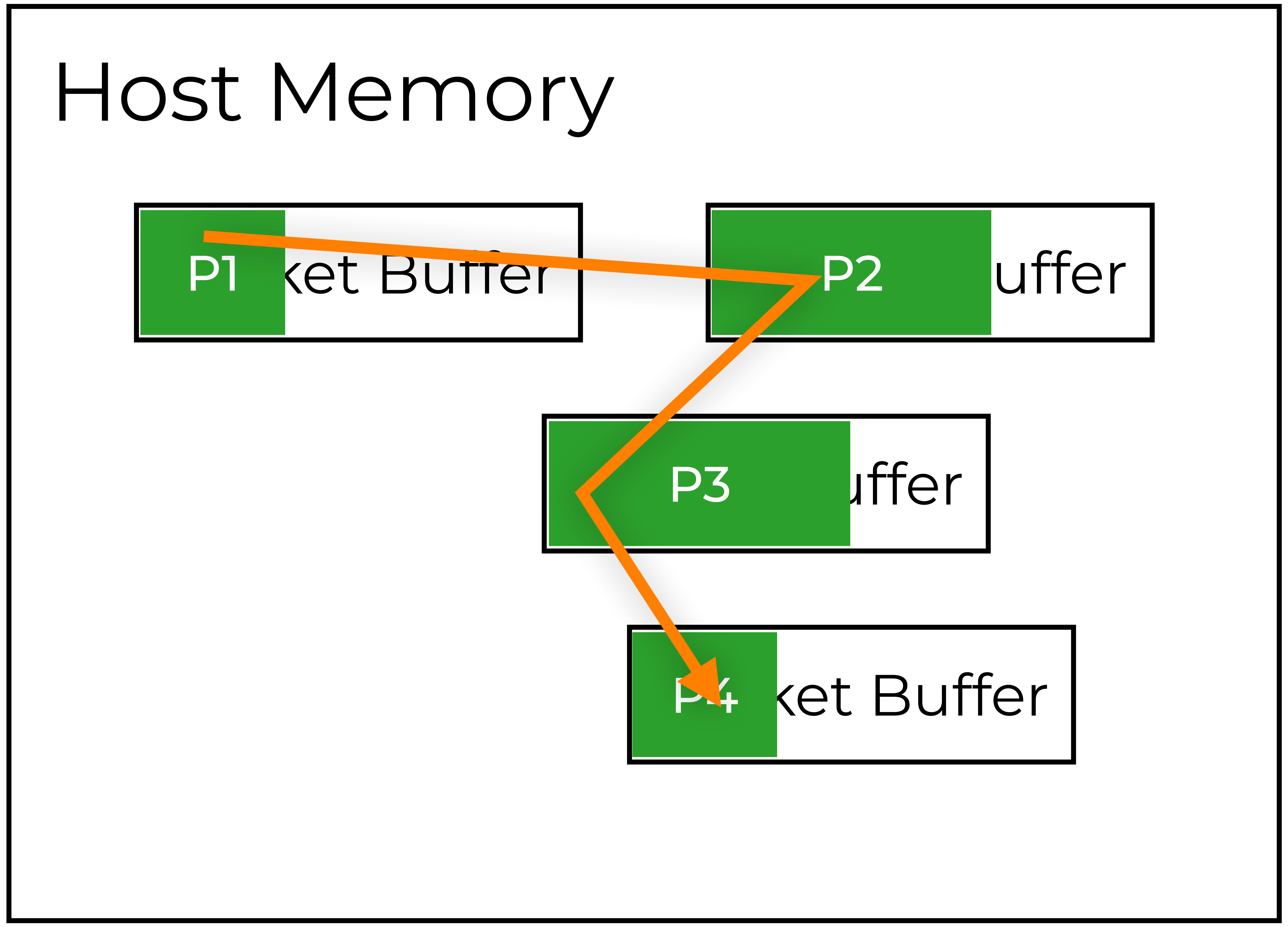


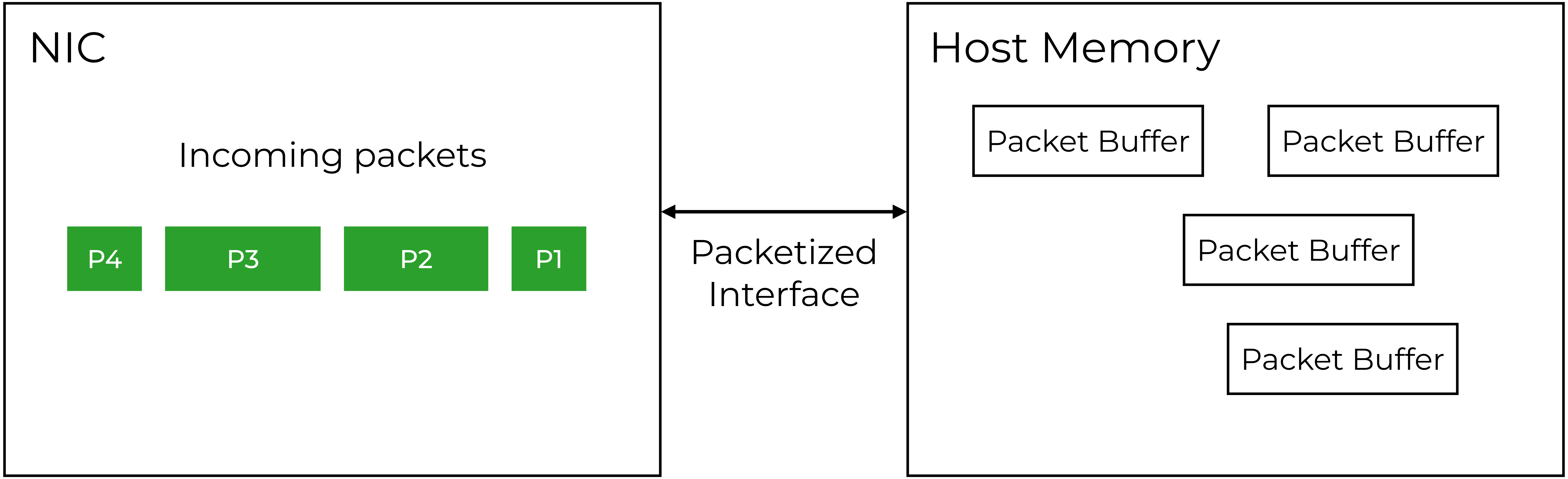




55% Miss Ratio for the L2 Cache

Chaotic Memory Access

# Problem #3 Metadata Overhead

Overhead (PCIe bandwidth and CPU cycles) due to per-packet metadata



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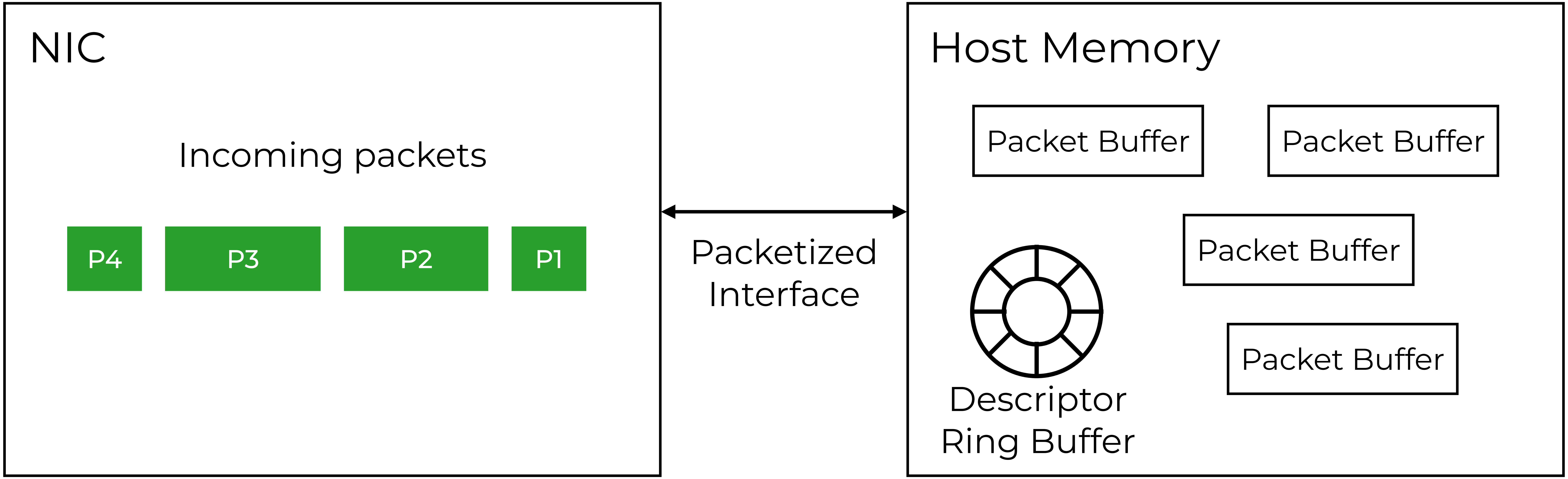

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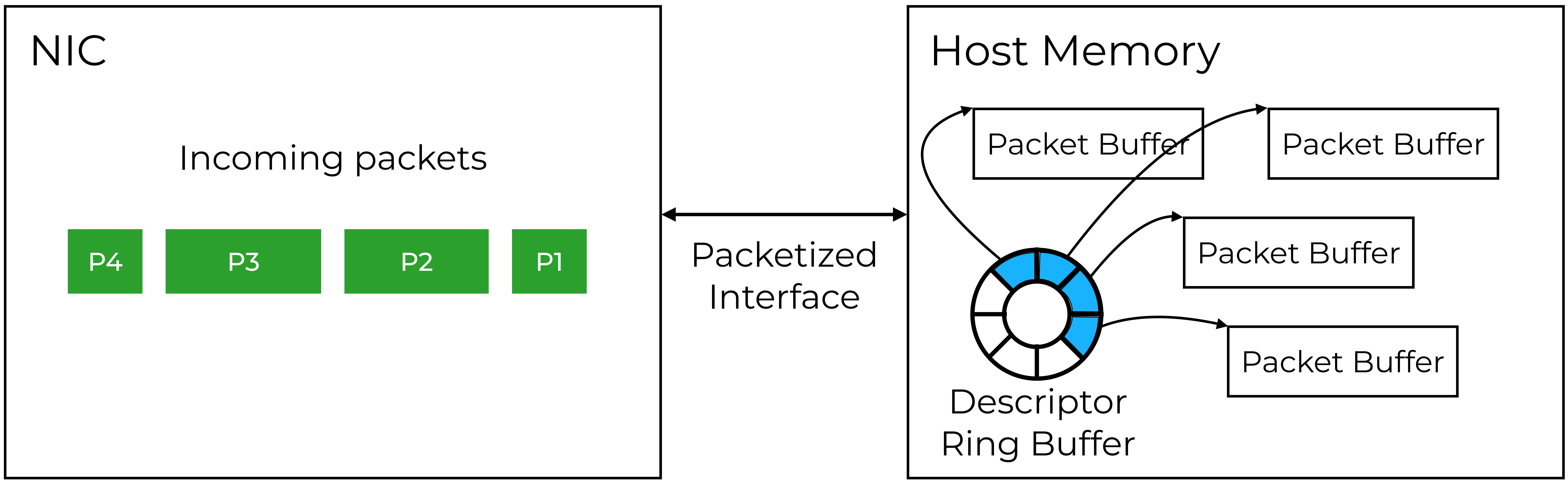

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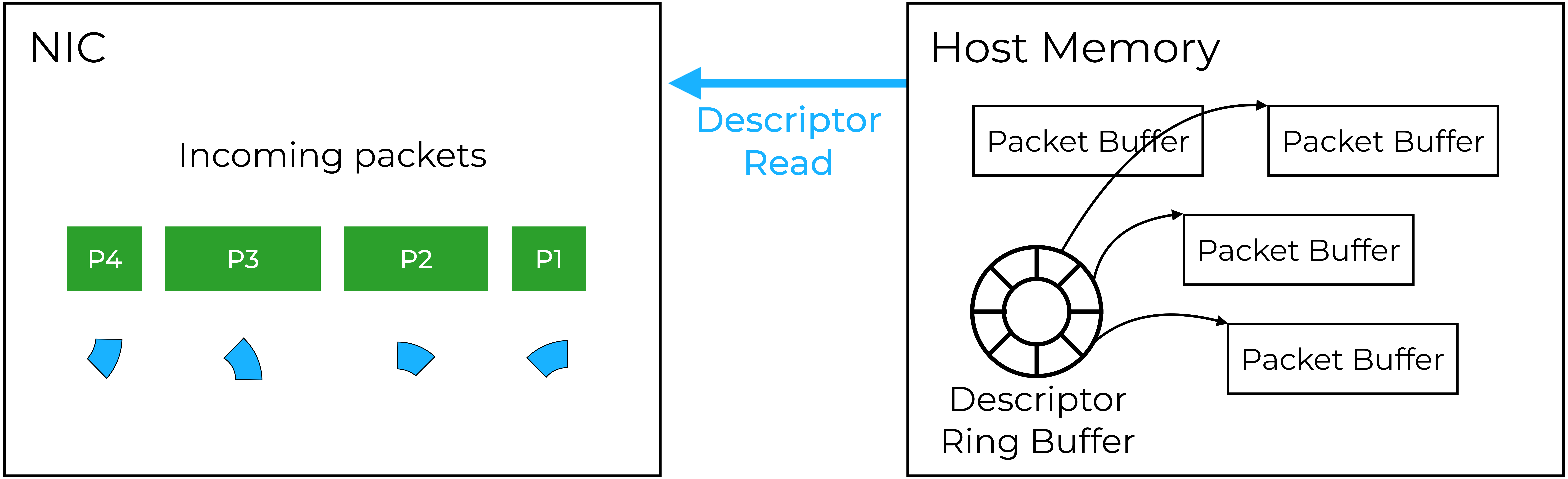

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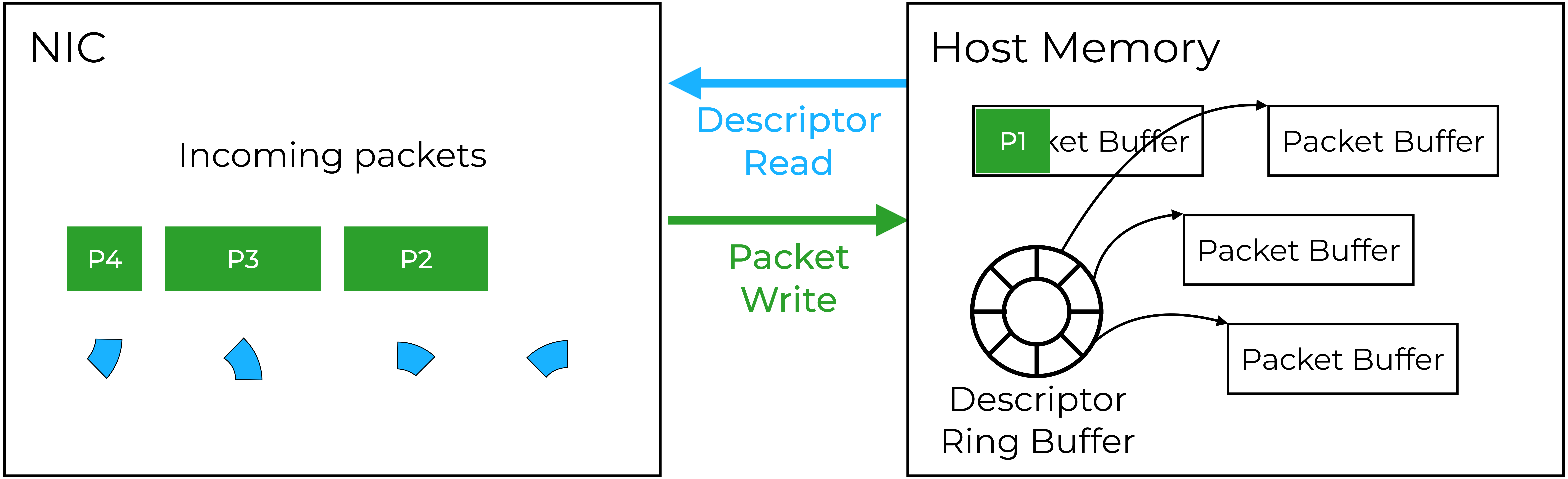

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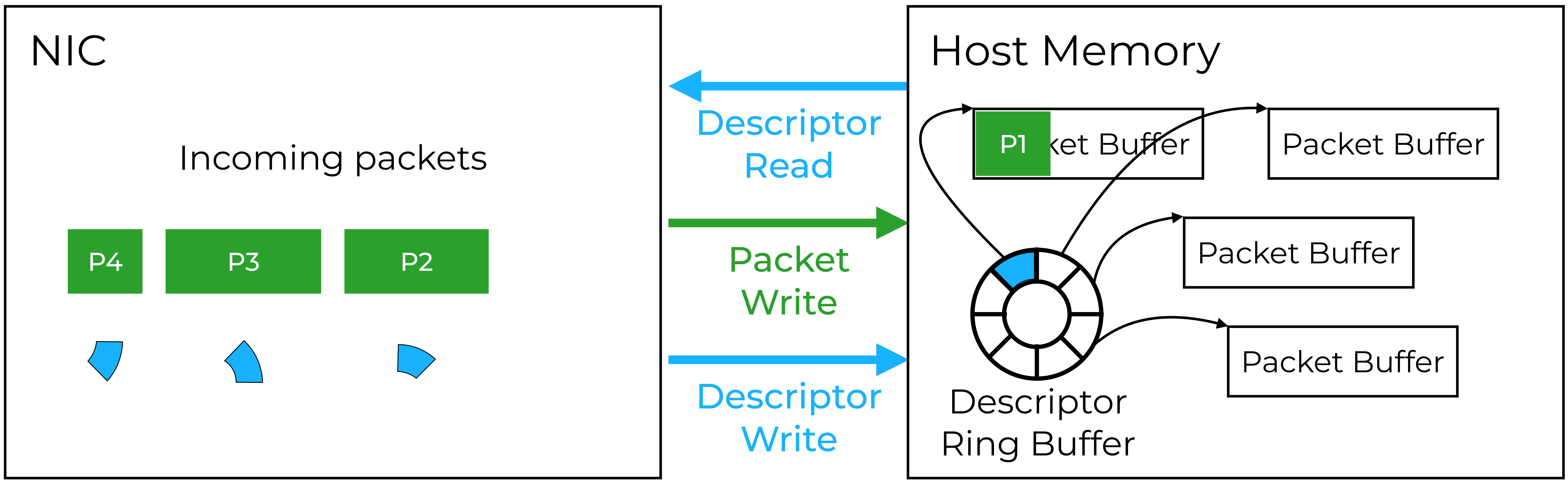

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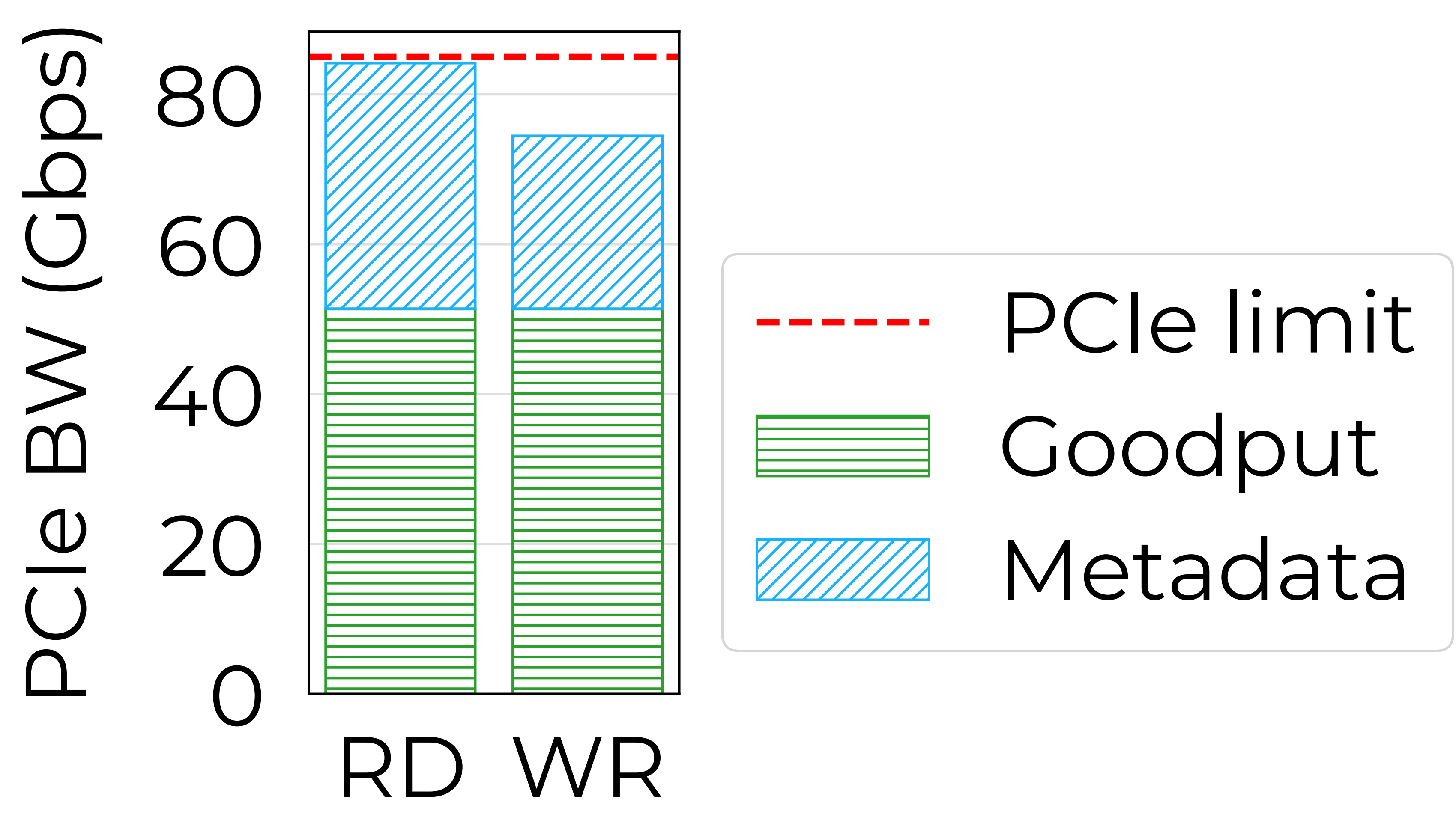
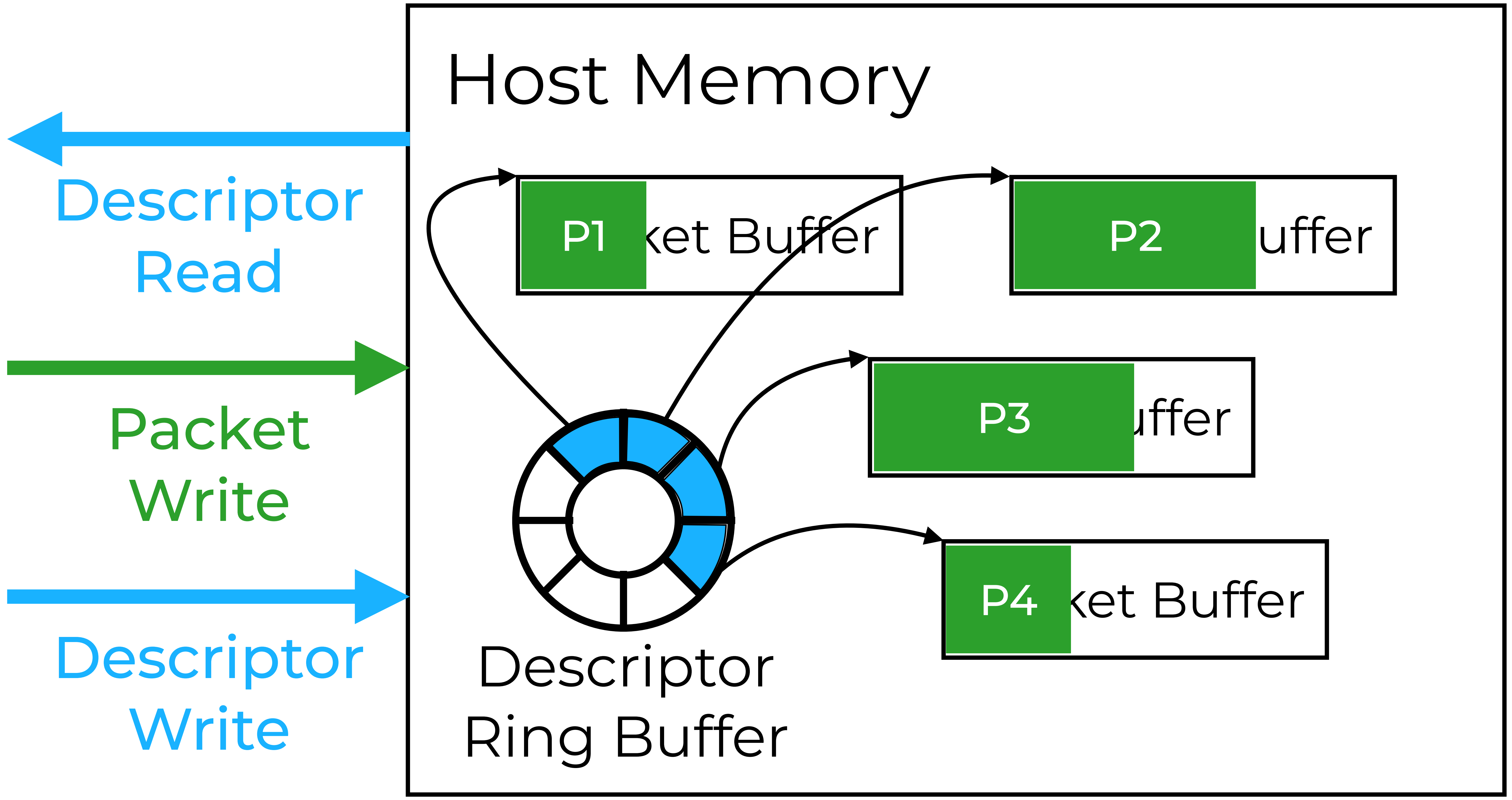
DPDK echo with E810 NIC




Up to 39% of PCIe bandwidth consumed with metadata



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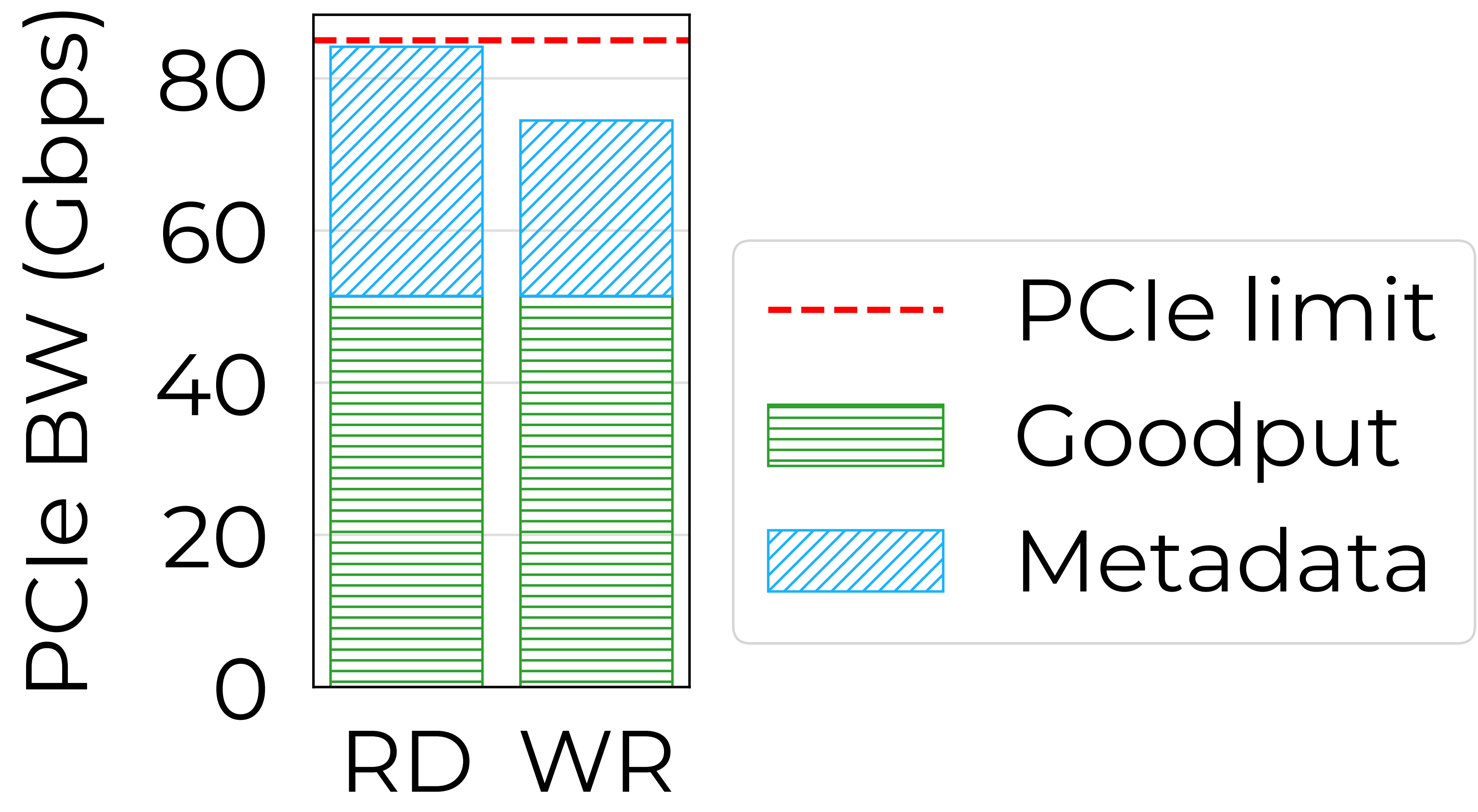


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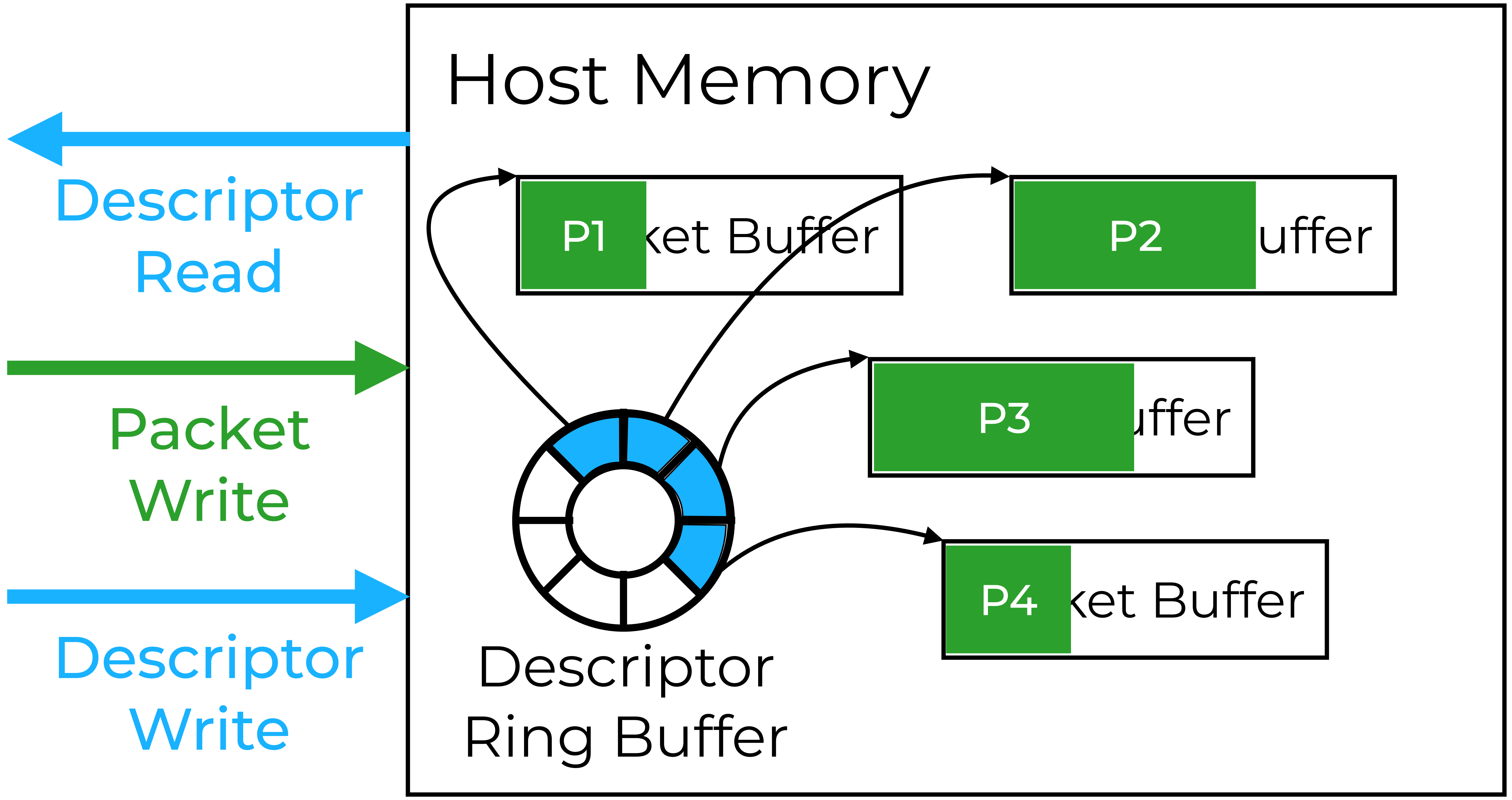
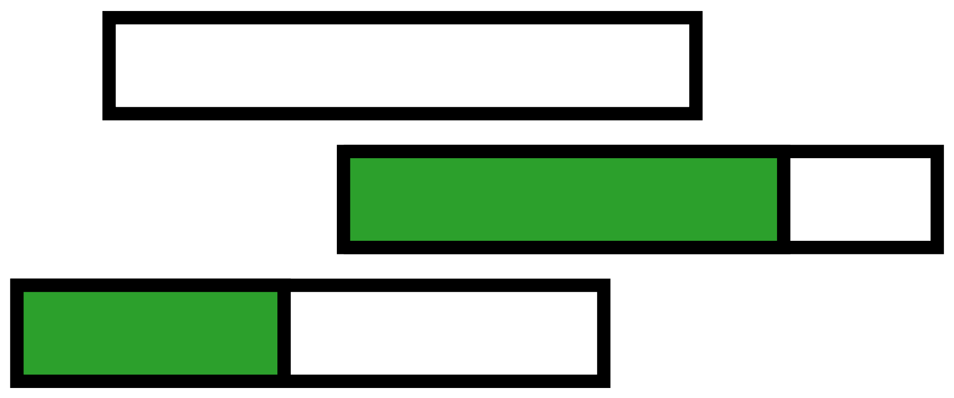



*Similar process to transmit packets*

# Mismatch between how NICs are used and their interface



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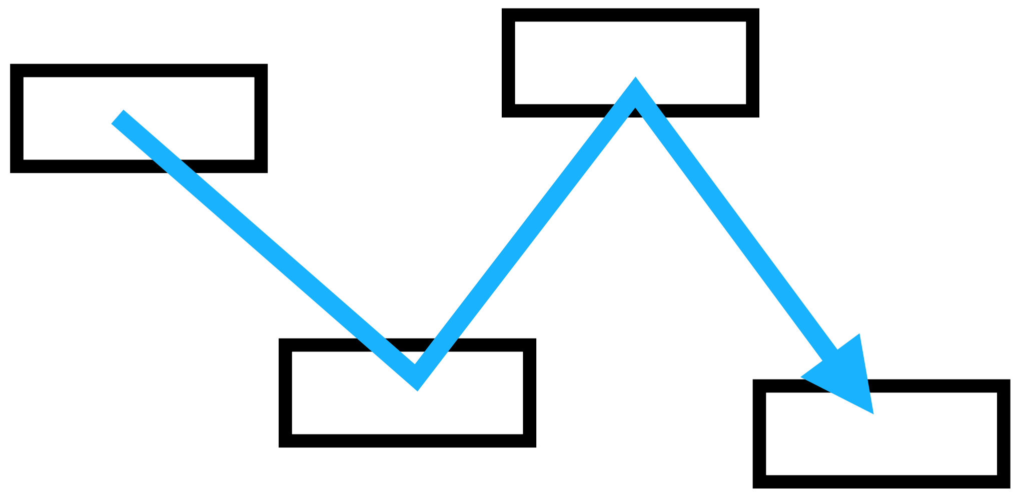
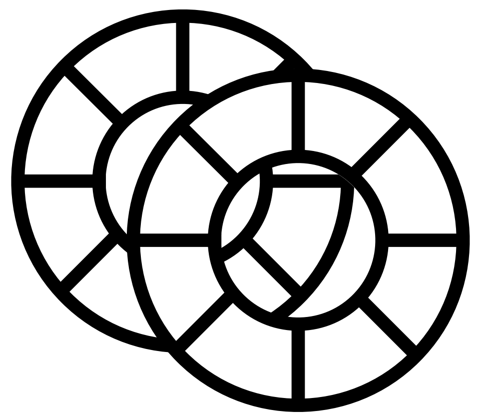


**#2** Poor Cache Interaction



**#3** Metadata Overhead

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## New interface for NIC-Application Communication

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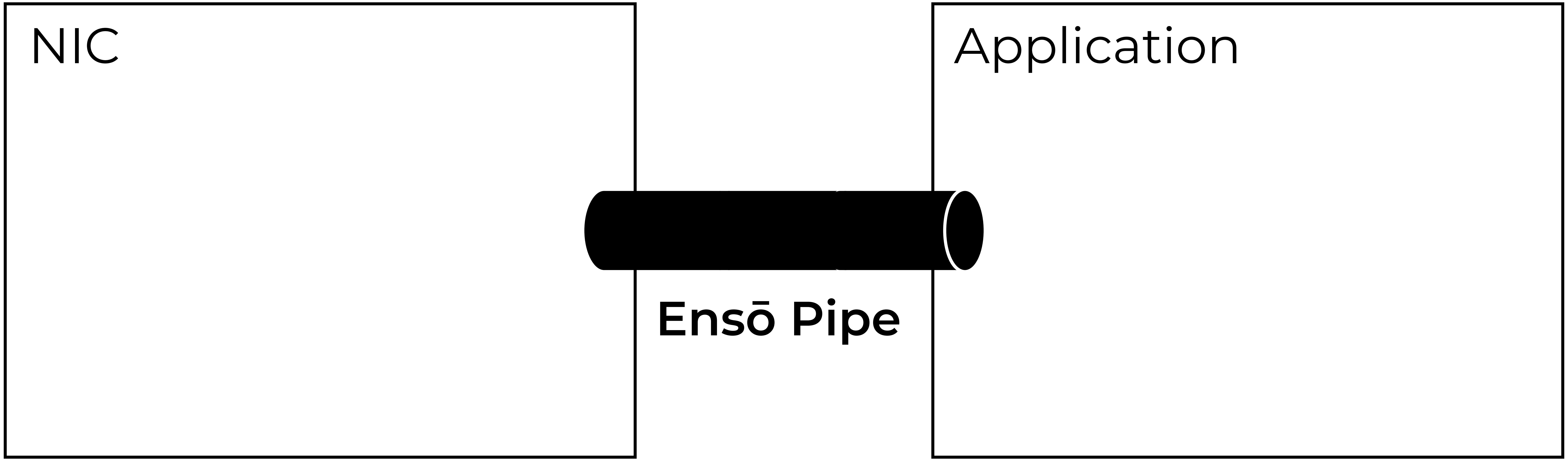
**Key Idea:** Streaming abstraction



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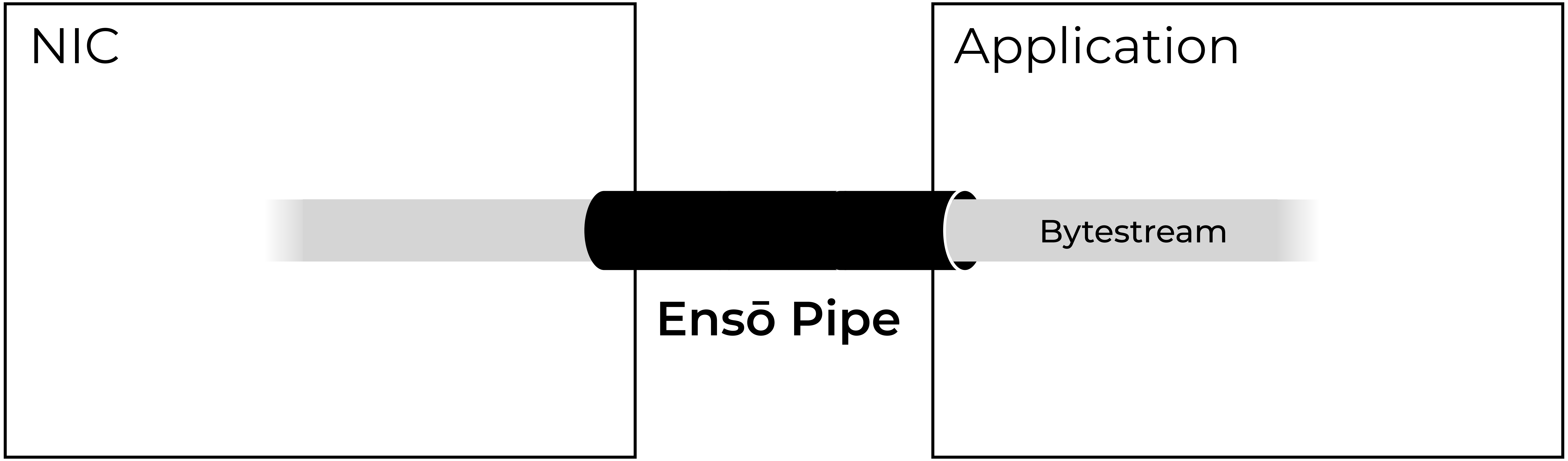

# What is a Streaming Abstraction?

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Provide the illusion of an unbounded buffer

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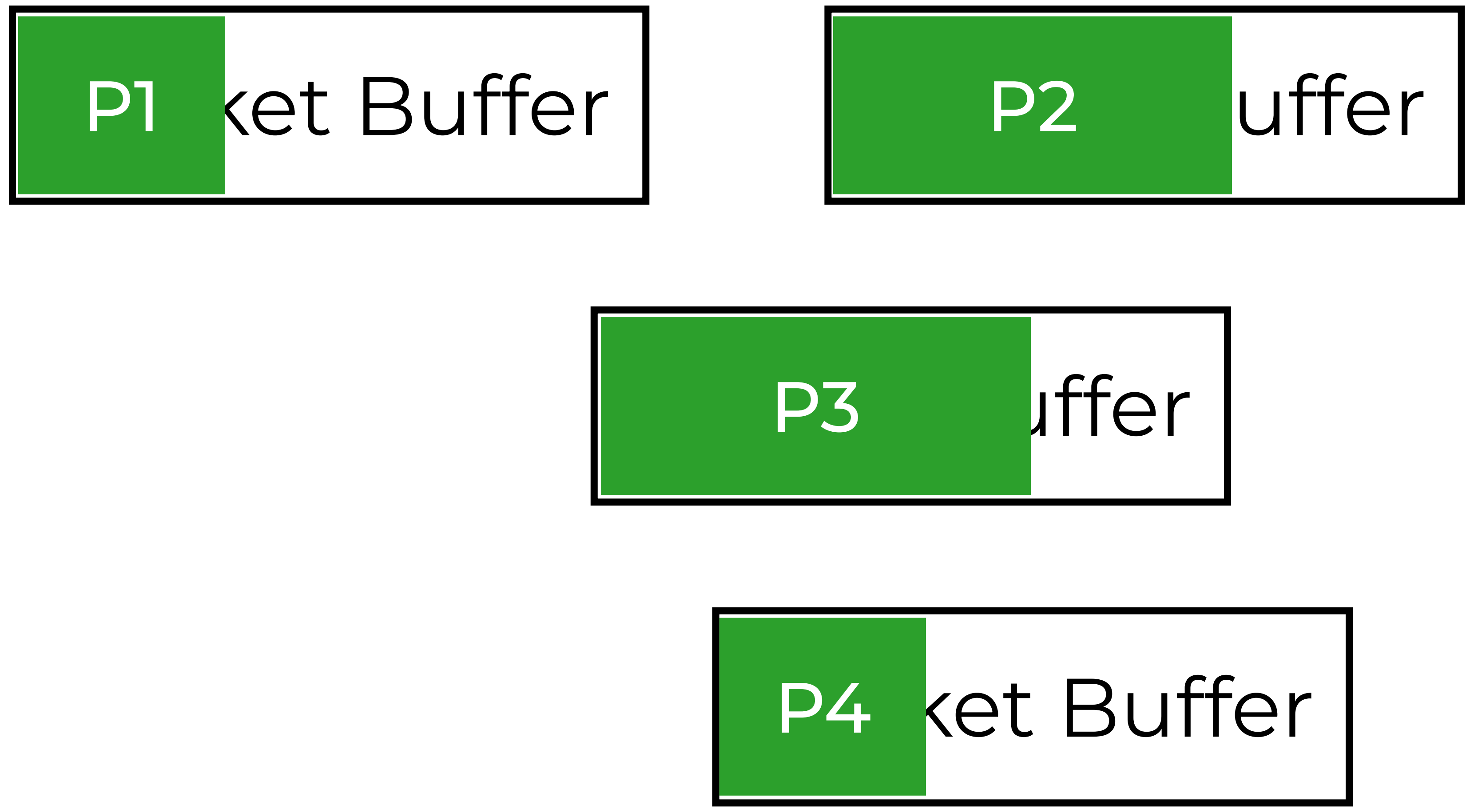


Packetized Abstraction

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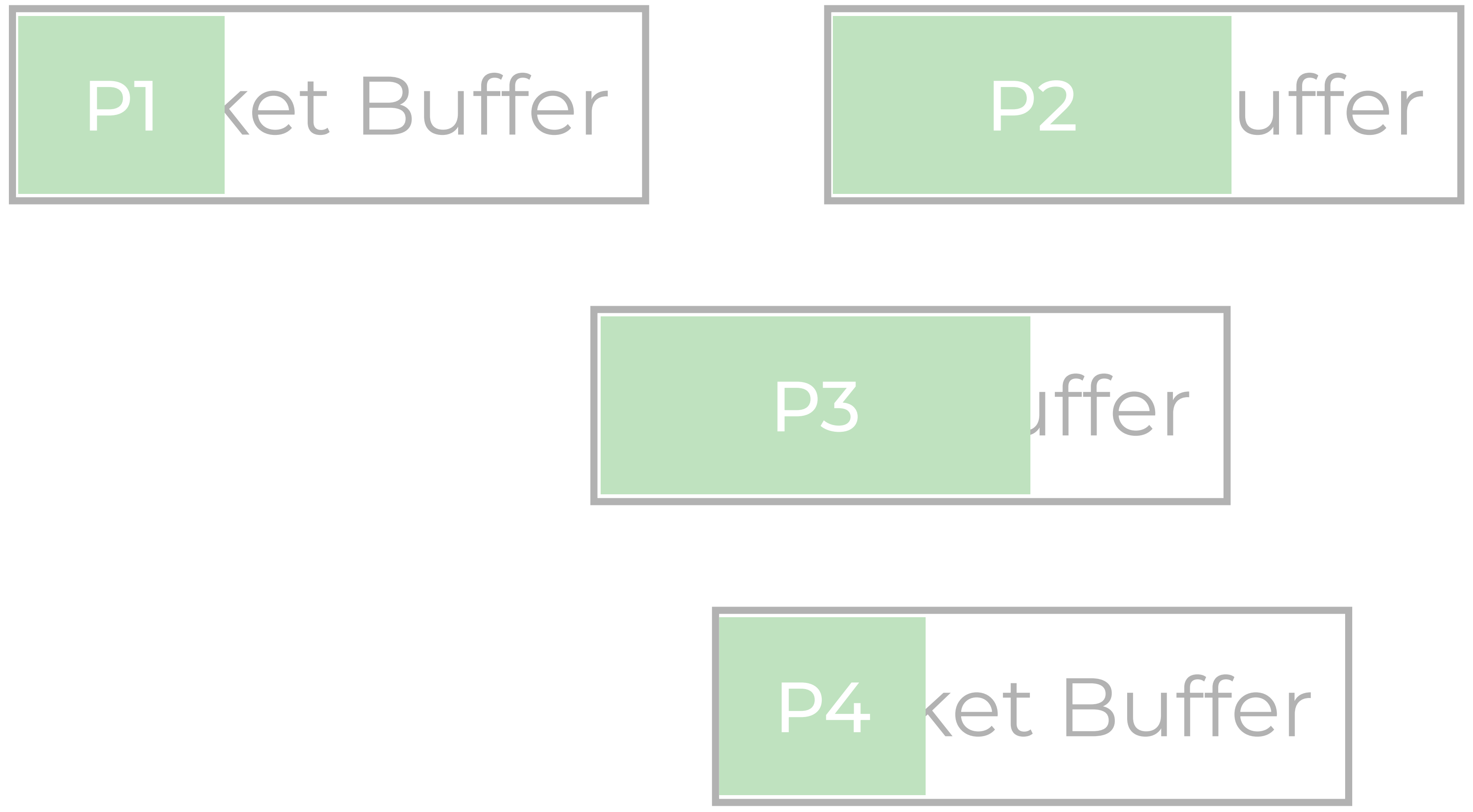


Unbounded Buffer

Packetized Abstraction

Streaming Abstraction

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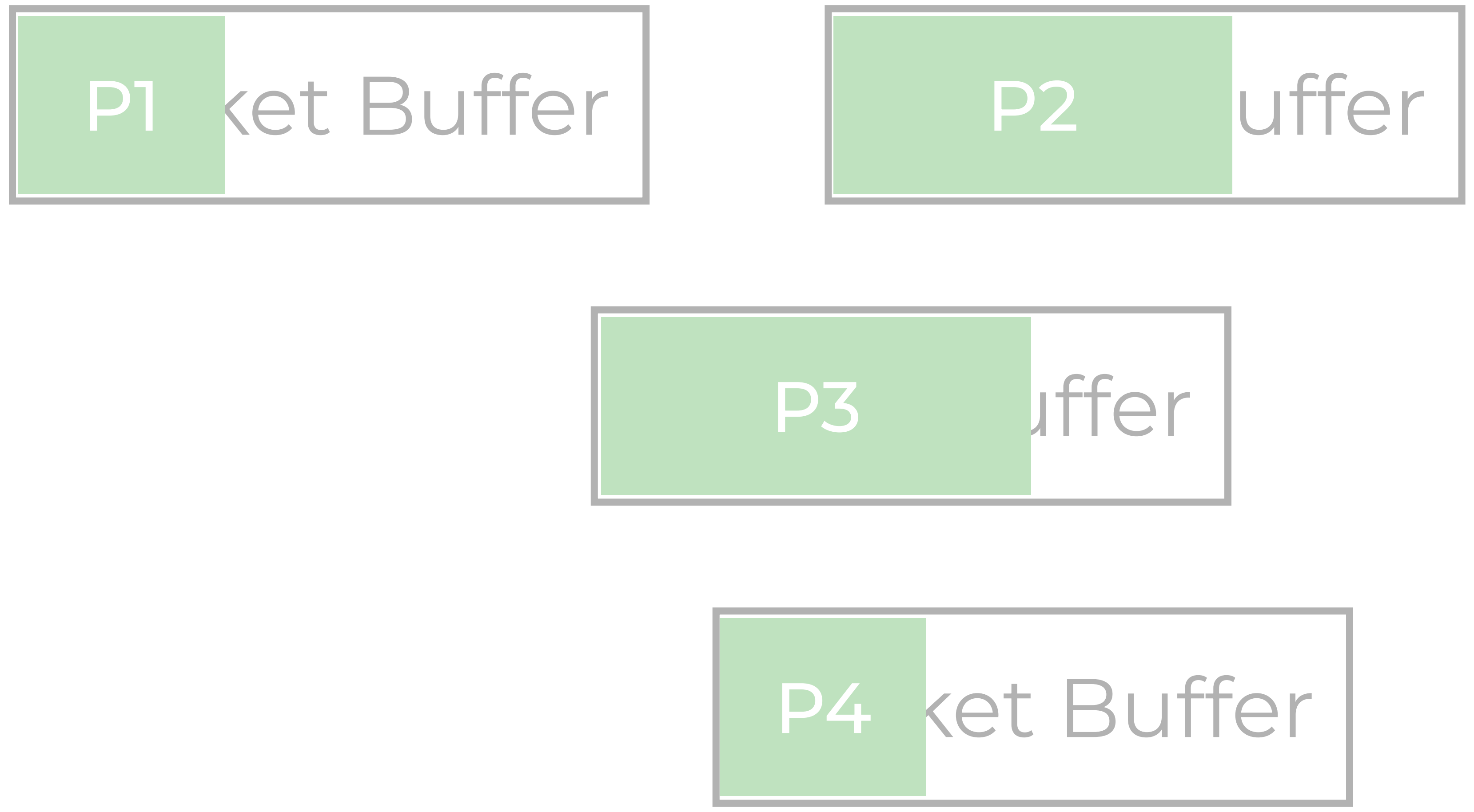



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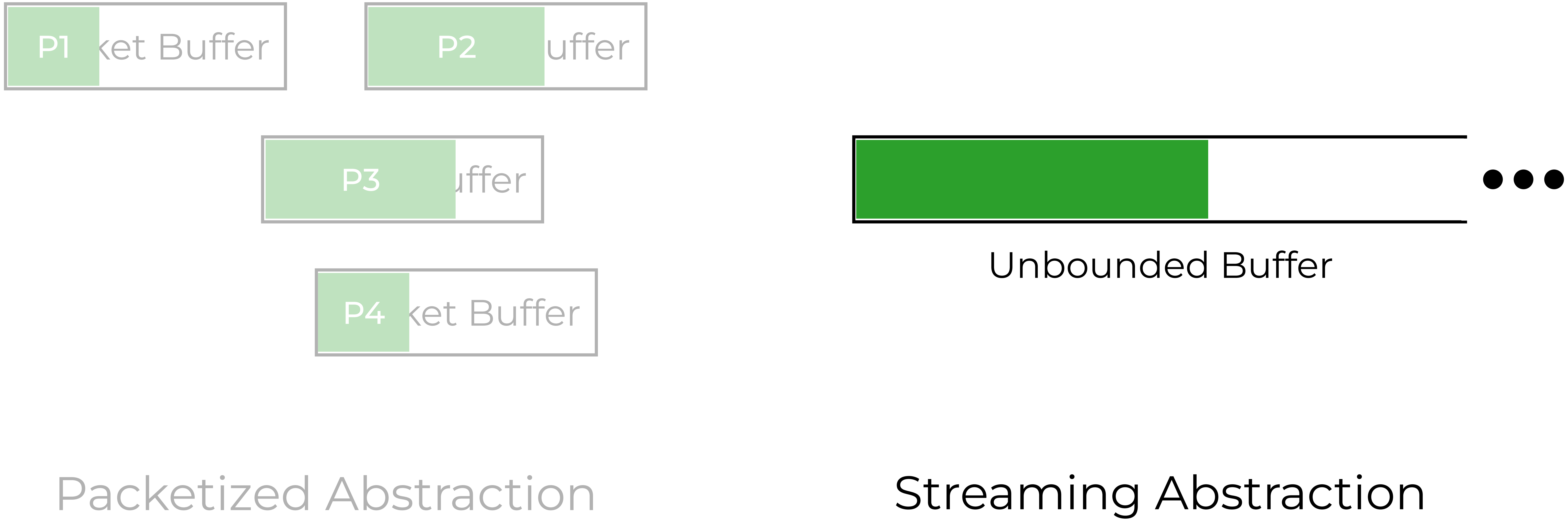

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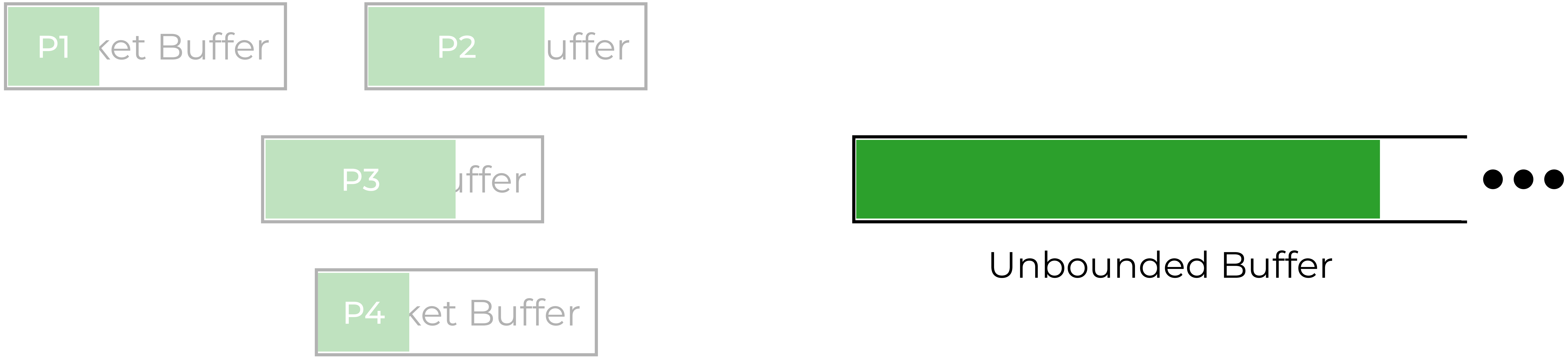
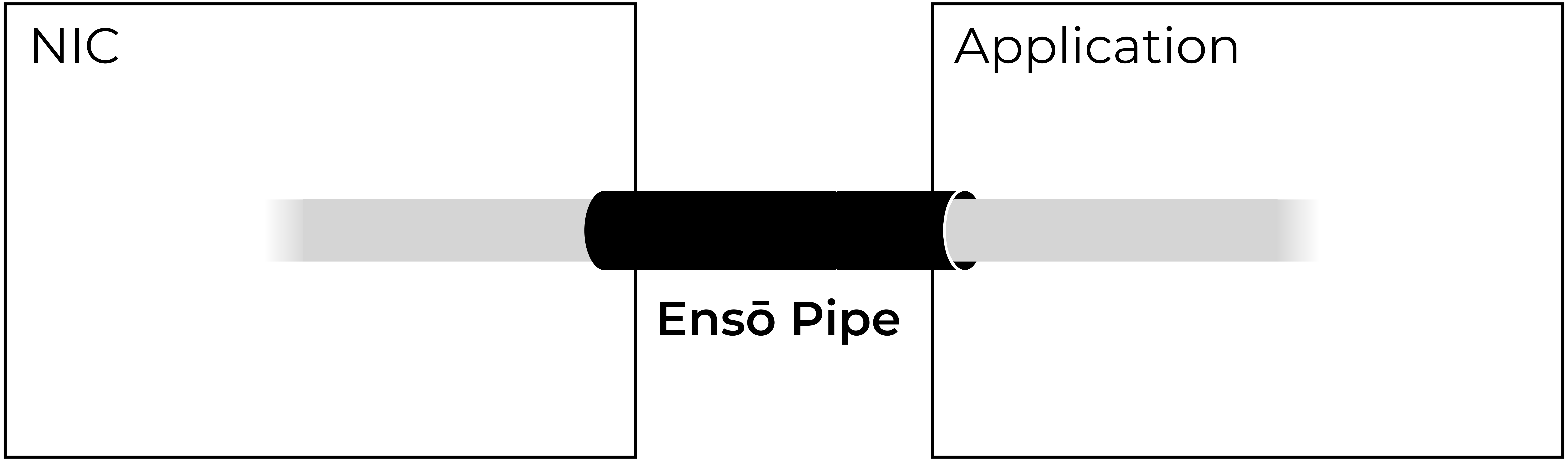



Packetized Abstraction

Streaming Abstraction

# Flexibility of a Streaming Abstraction

**Example 1:** NIC with no offloads



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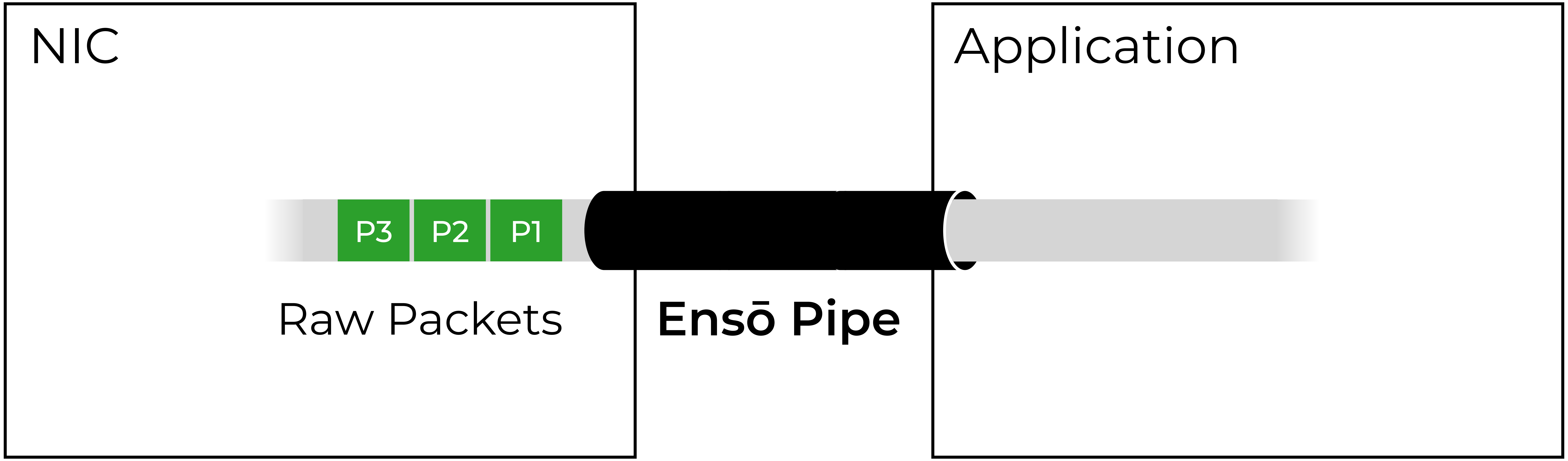
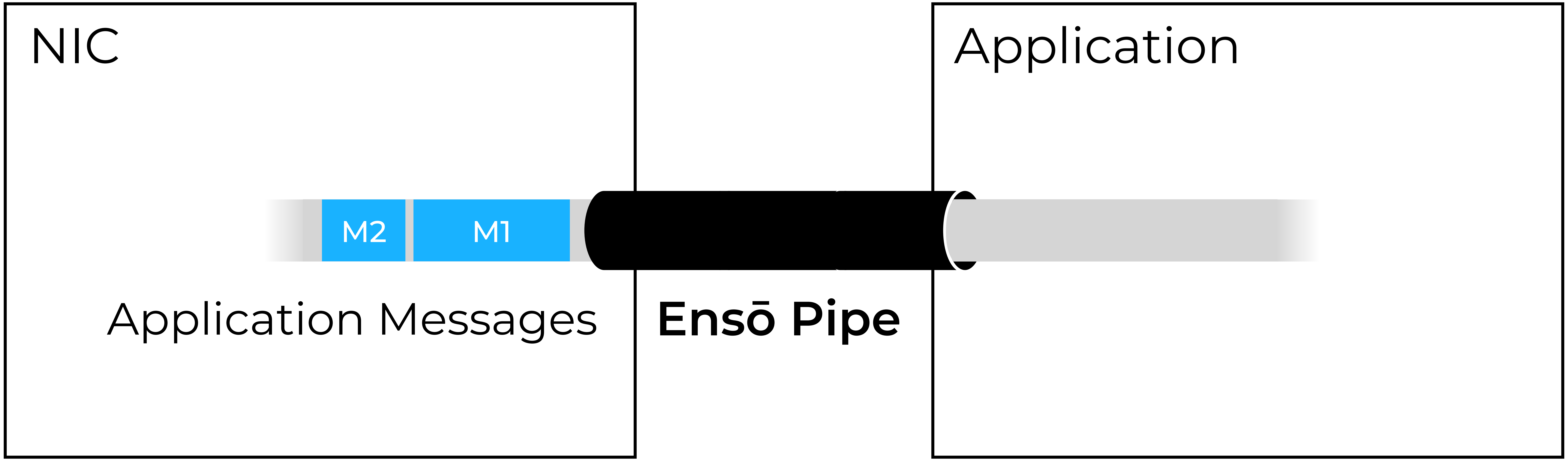


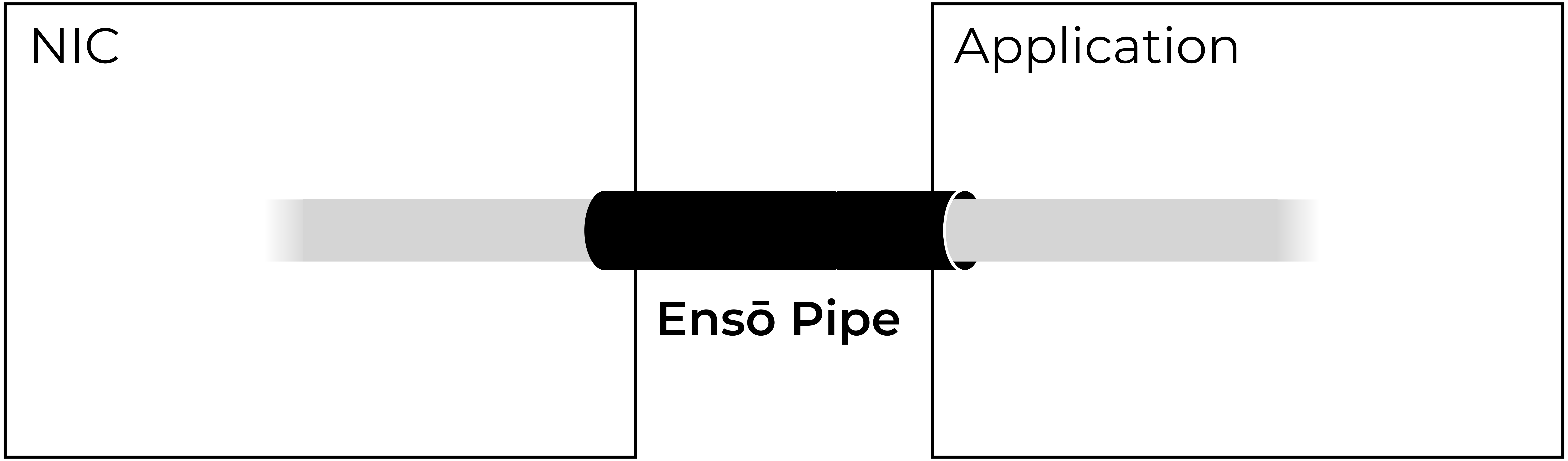
# Flexibility of a Streaming Abstraction

**Example 2:** NIC that is aware of application-level messages



# Flexibility of a Streaming Abstraction

**Example 3:** NIC that implements a transport protocol



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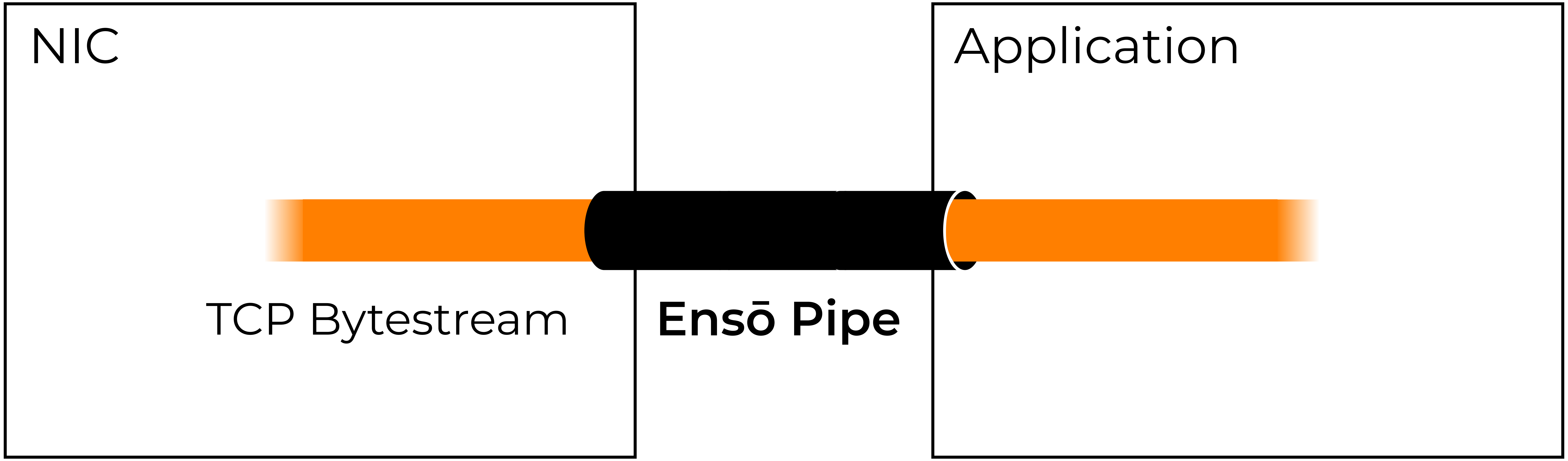

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② How can a streaming abstraction improve performance?

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| Ensō Pipe |
|---|

Each pipe consists of a single contiguous buffer

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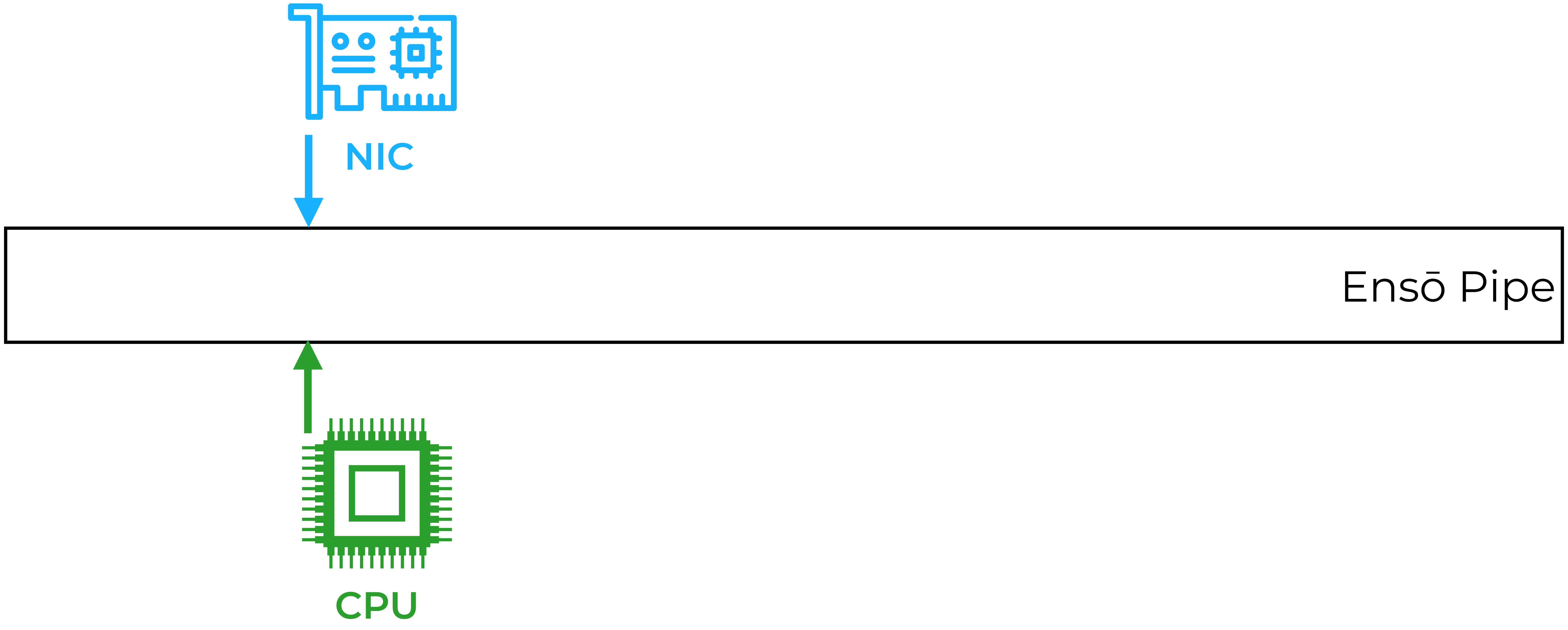


Each pipe consists of a single contiguous buffer

We treat this buffer as a ring buffer for data

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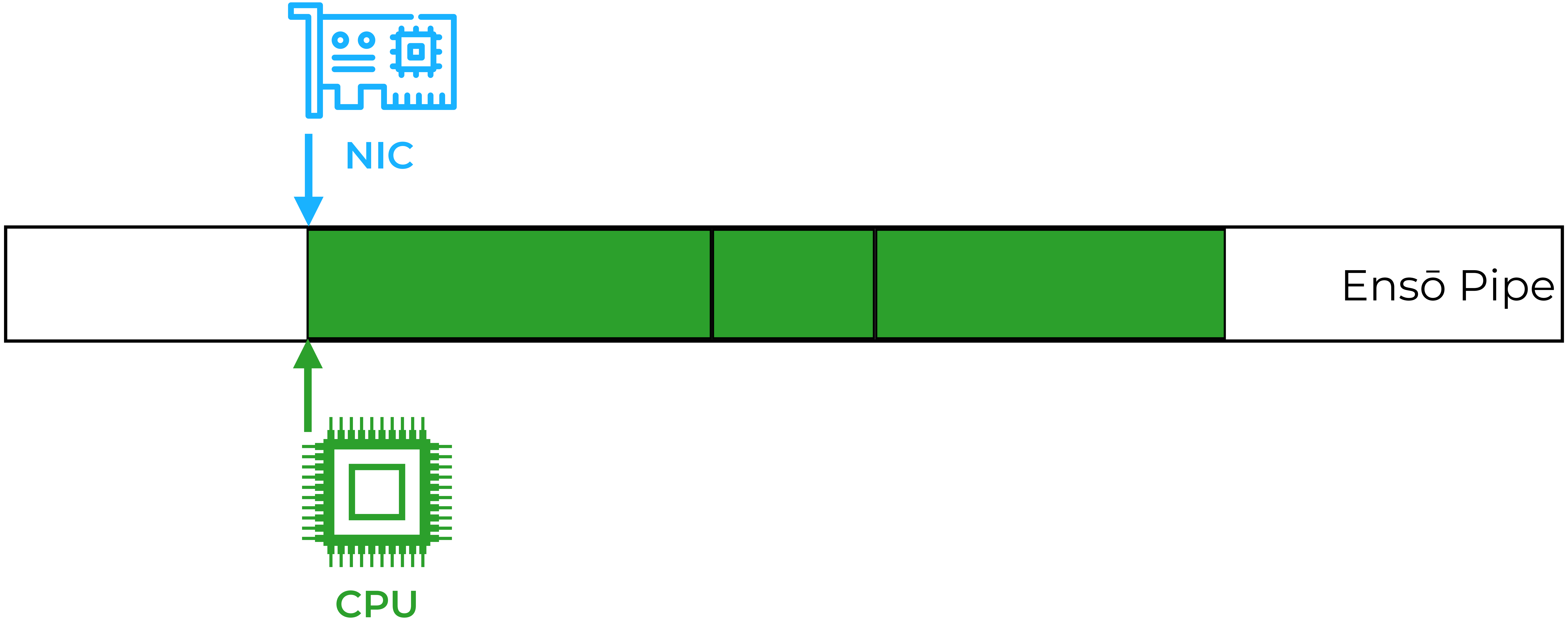


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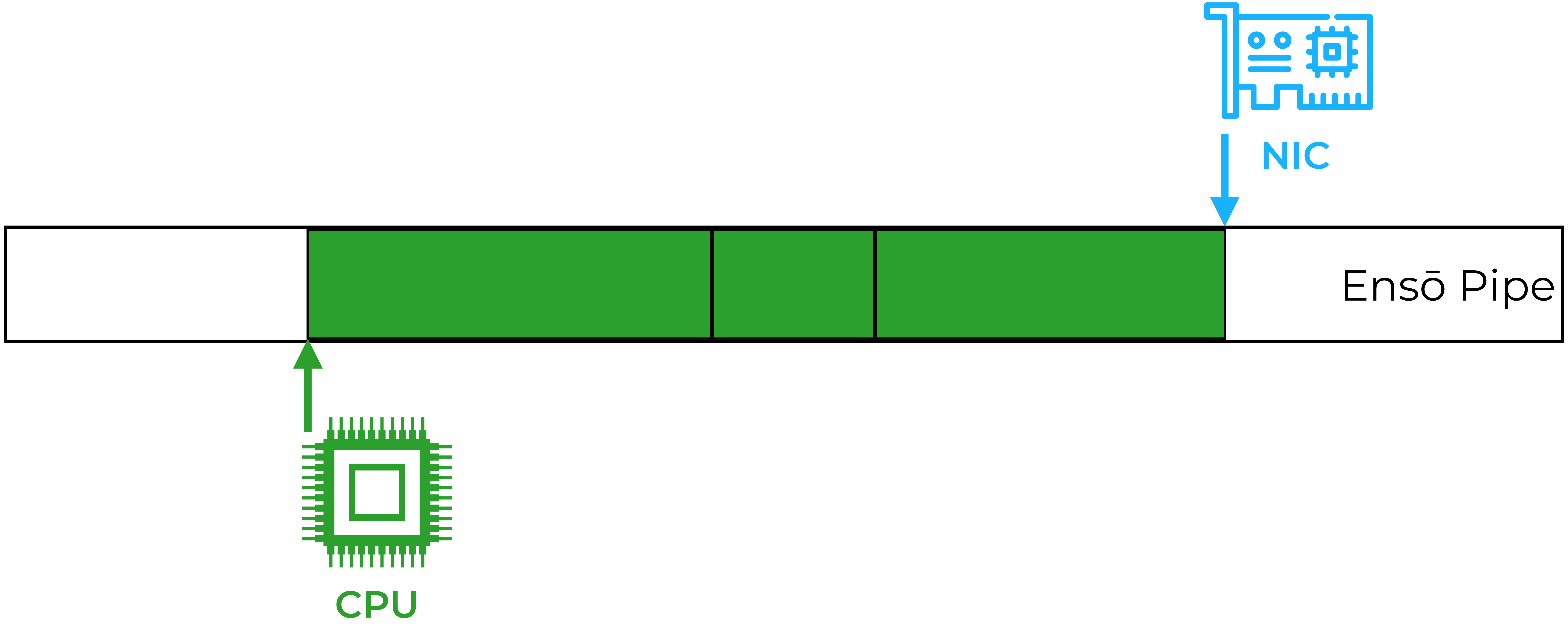


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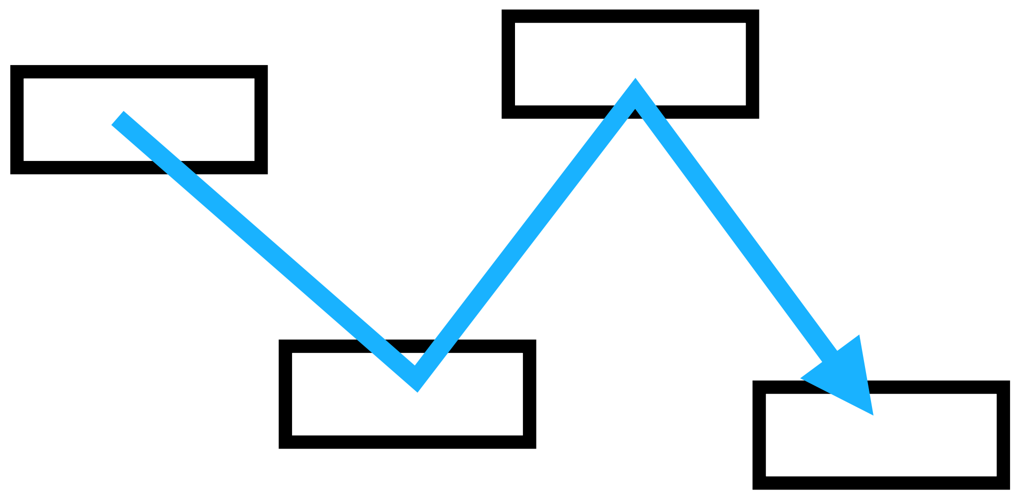
Packetized
Interface



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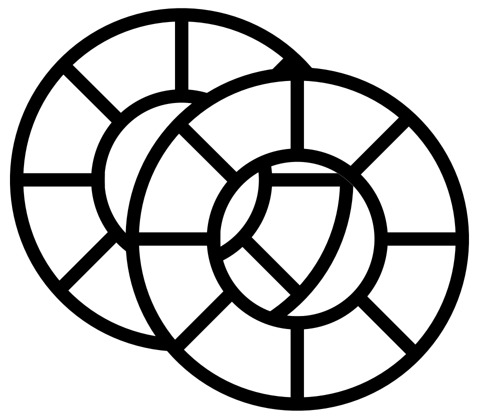

Metadata Overhead

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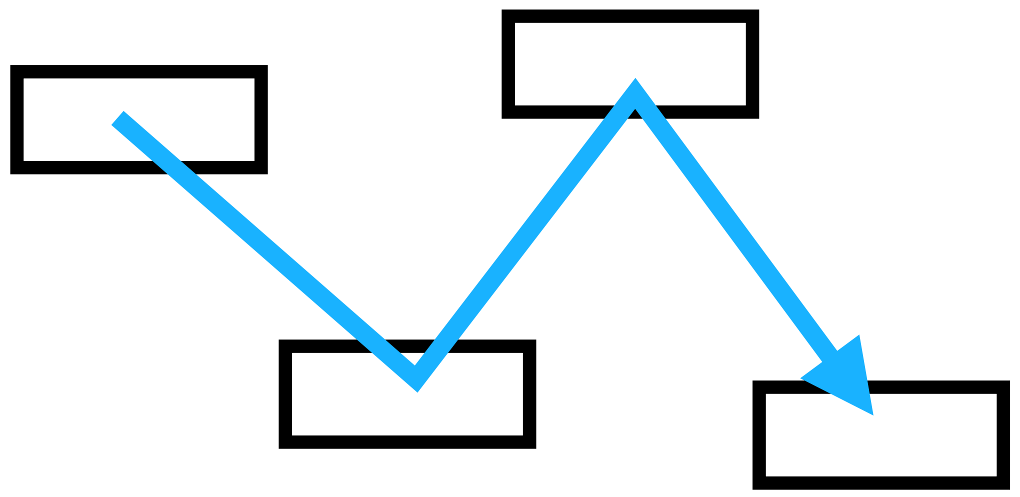

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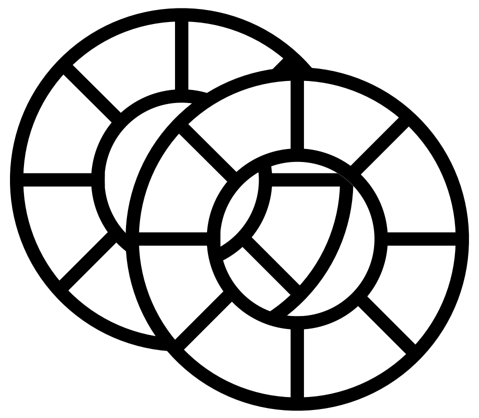

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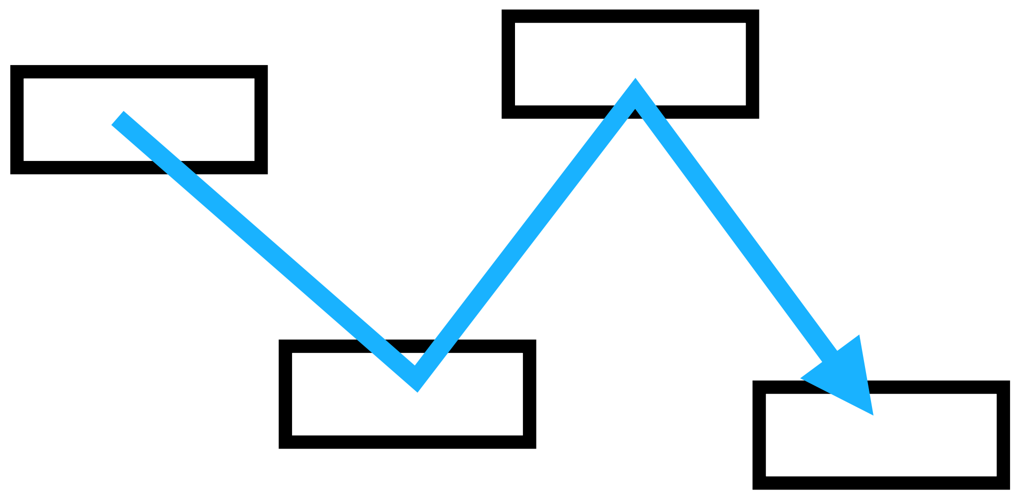

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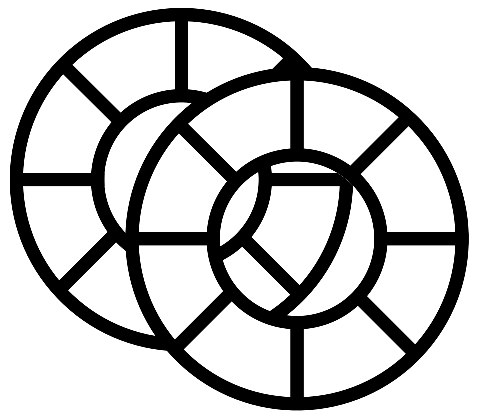

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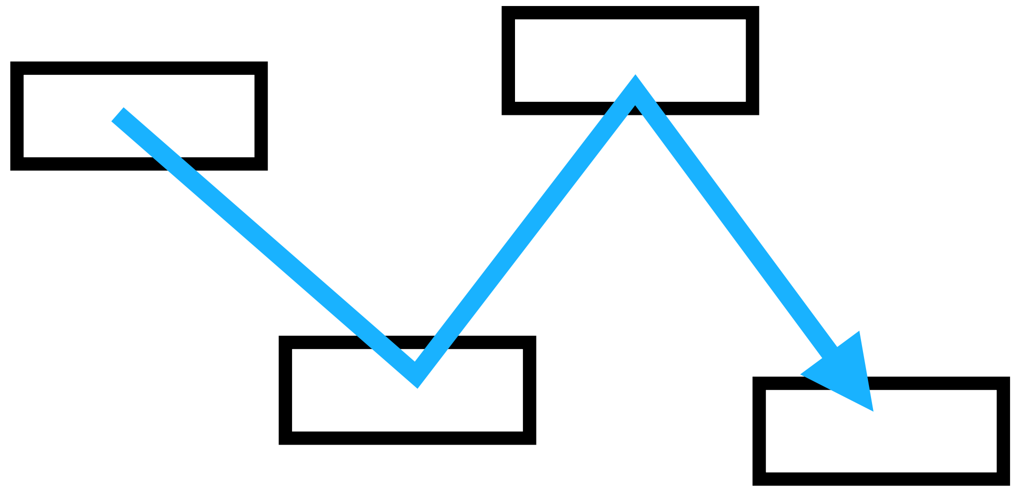

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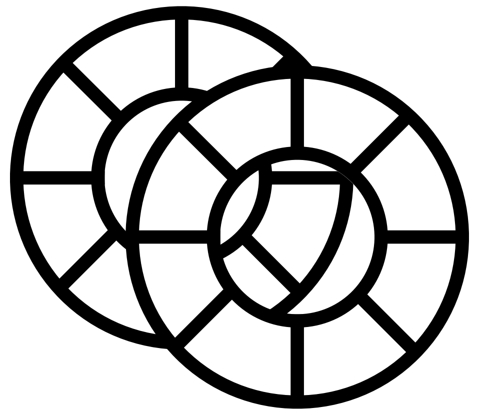

Metadata Overhead

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Sequential Memory Access

Reduces L1 misses by 95.9%
and L2 misses by 99.5%

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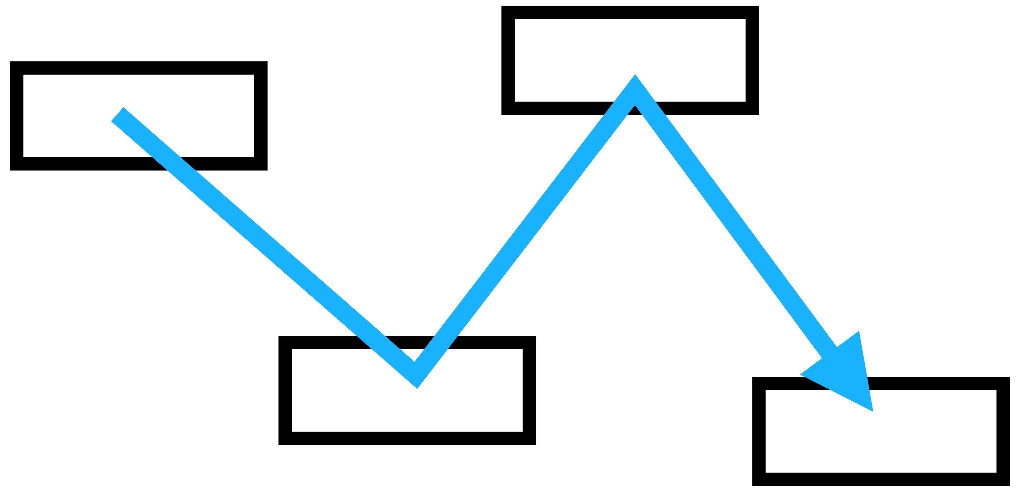
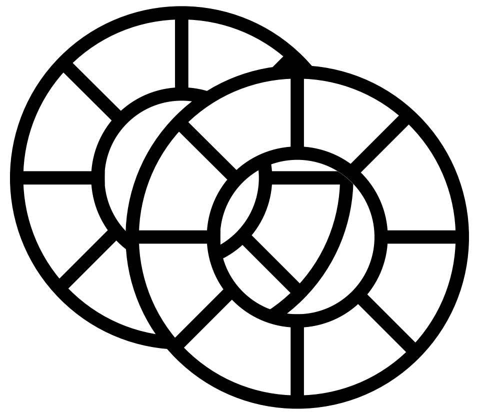
Packetized Interface



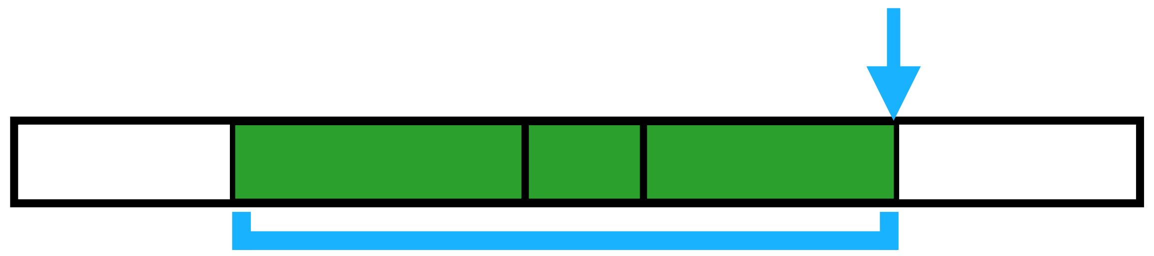
Poor Cache Interaction



Metadata Overhead

Ensō

Sequential Memory Access



Notifying Batches

Reduces L1 misses by 95.9%
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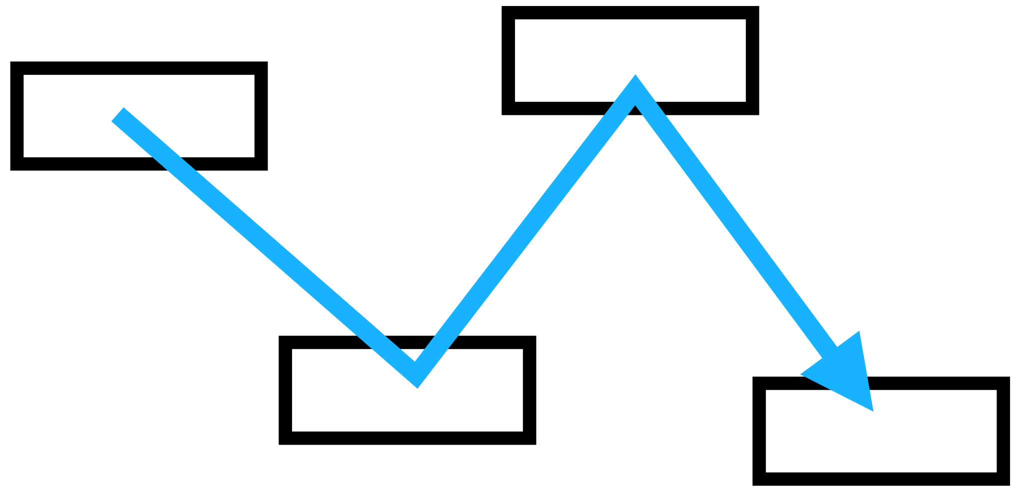

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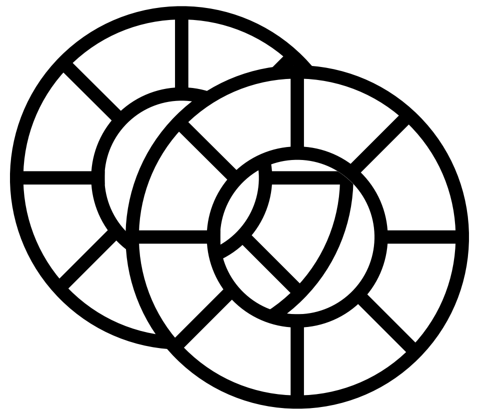

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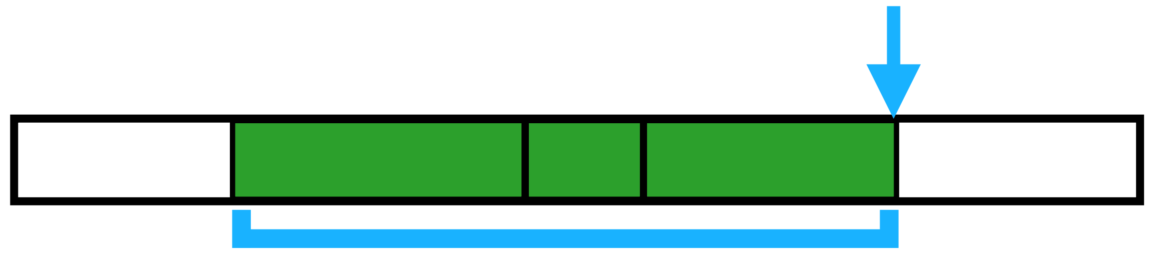

Notifying Batches

Reduces PCIe metadata traffic by 96.9%

# How often should the NIC notify a batch?

RX Ensō Pipe

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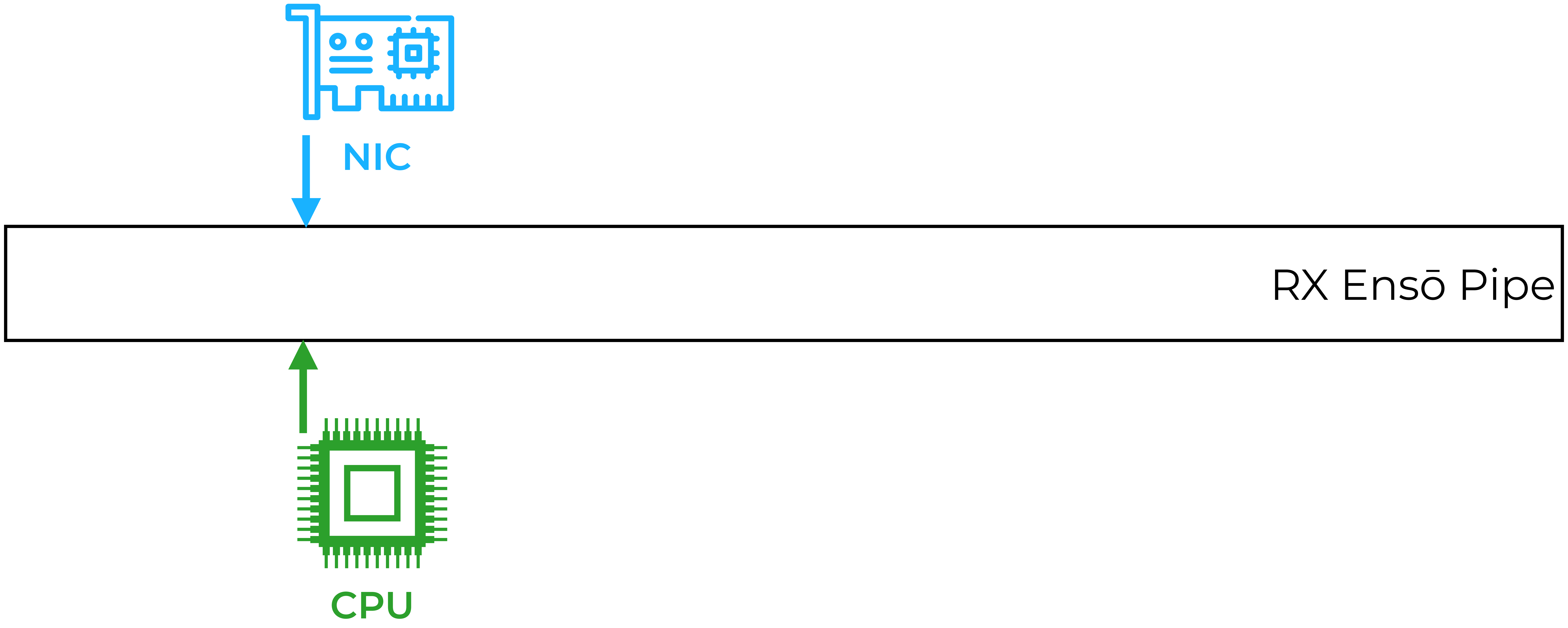
**Naïve strategy:** send an update for *every* piece of data



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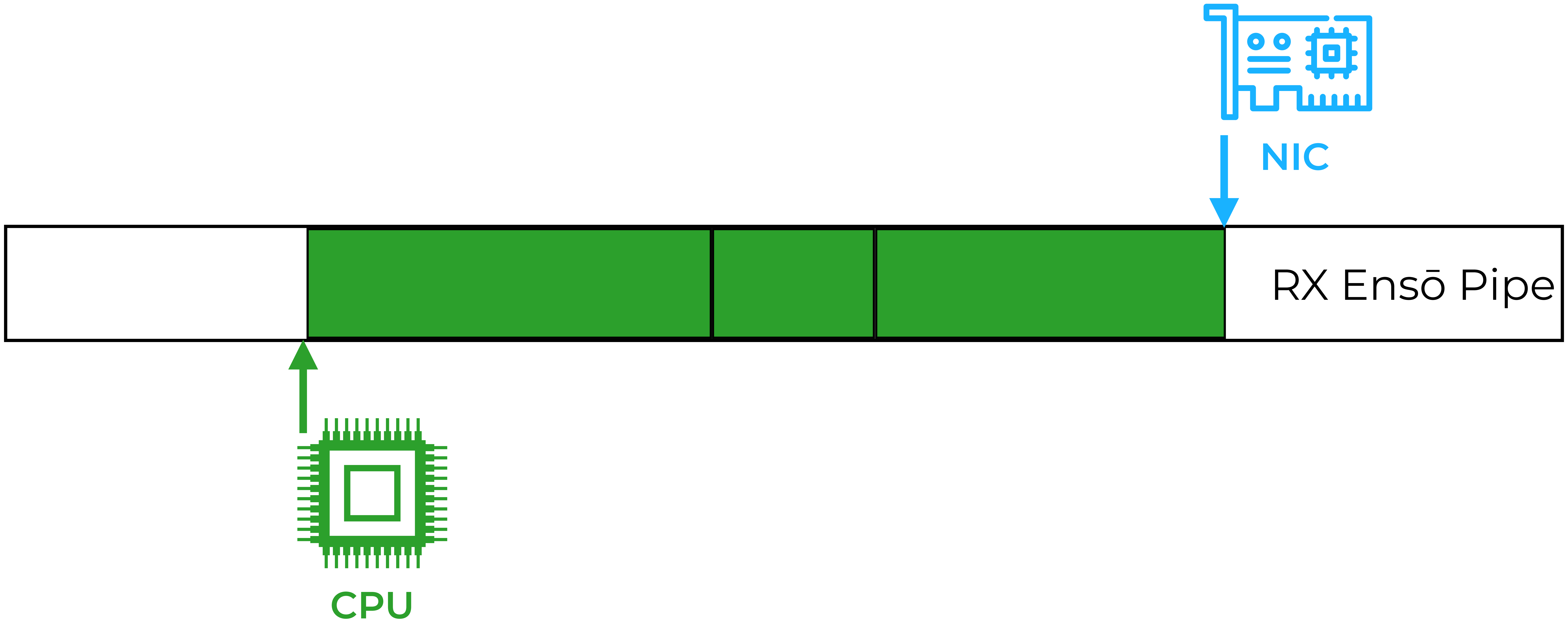

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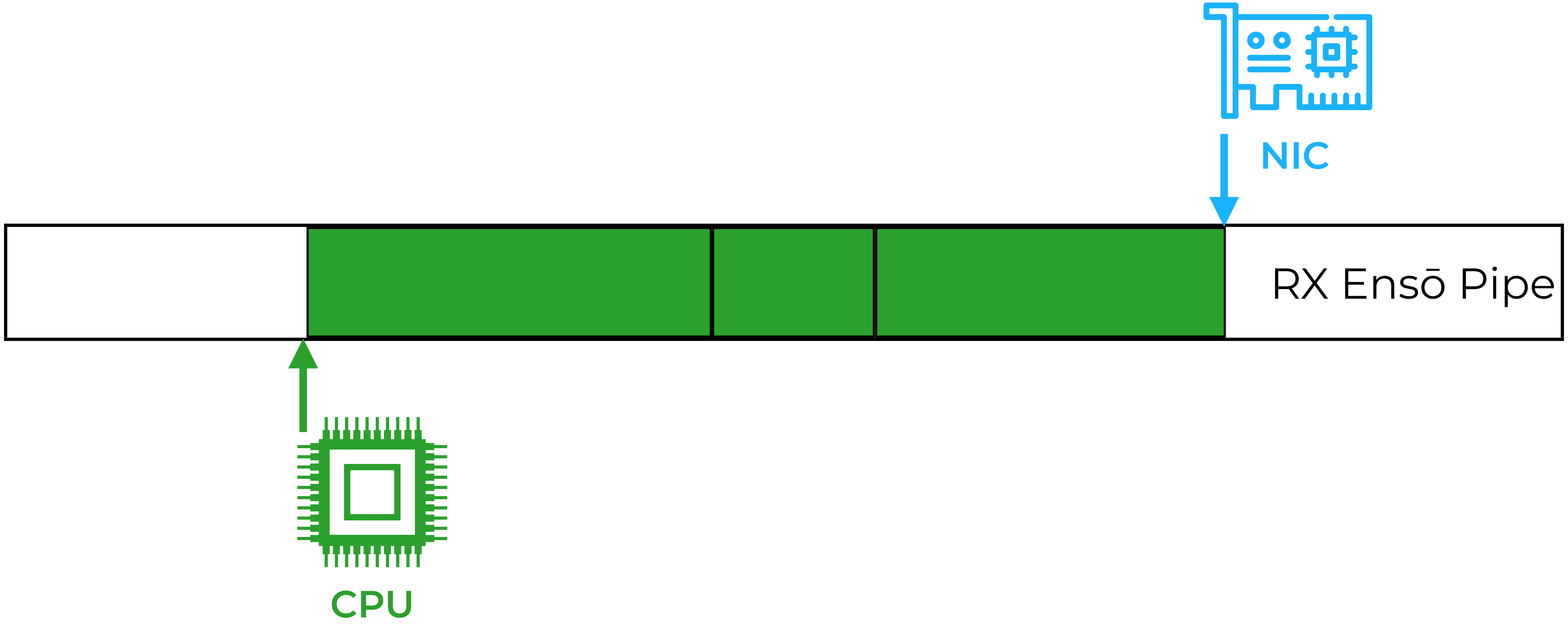



**Problem:** Per-packet overhead

# Notification Pacing in Ensō

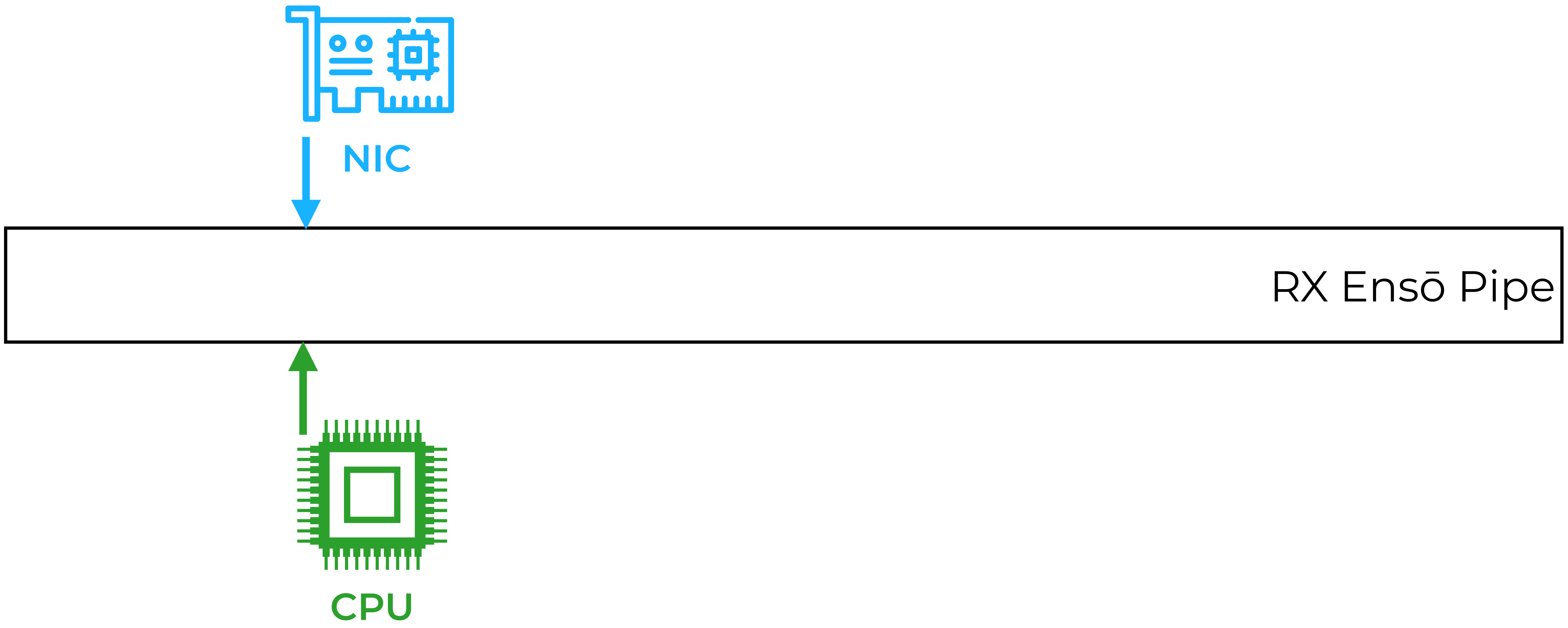
Ensō combines two techniques

① Reactive Notifications

② Notification Prefetching

# ① Reactive Notifications

The NIC updates its pointer in *reaction* to CPU pointer updates



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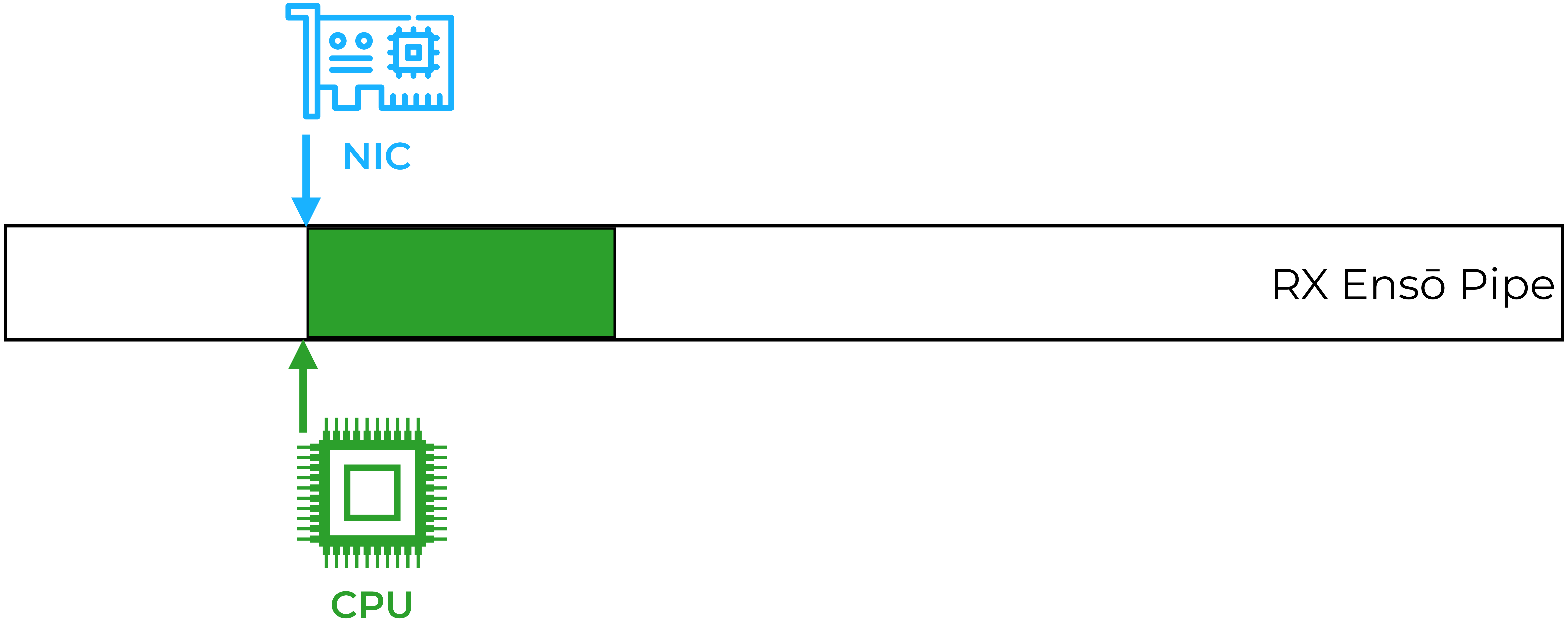

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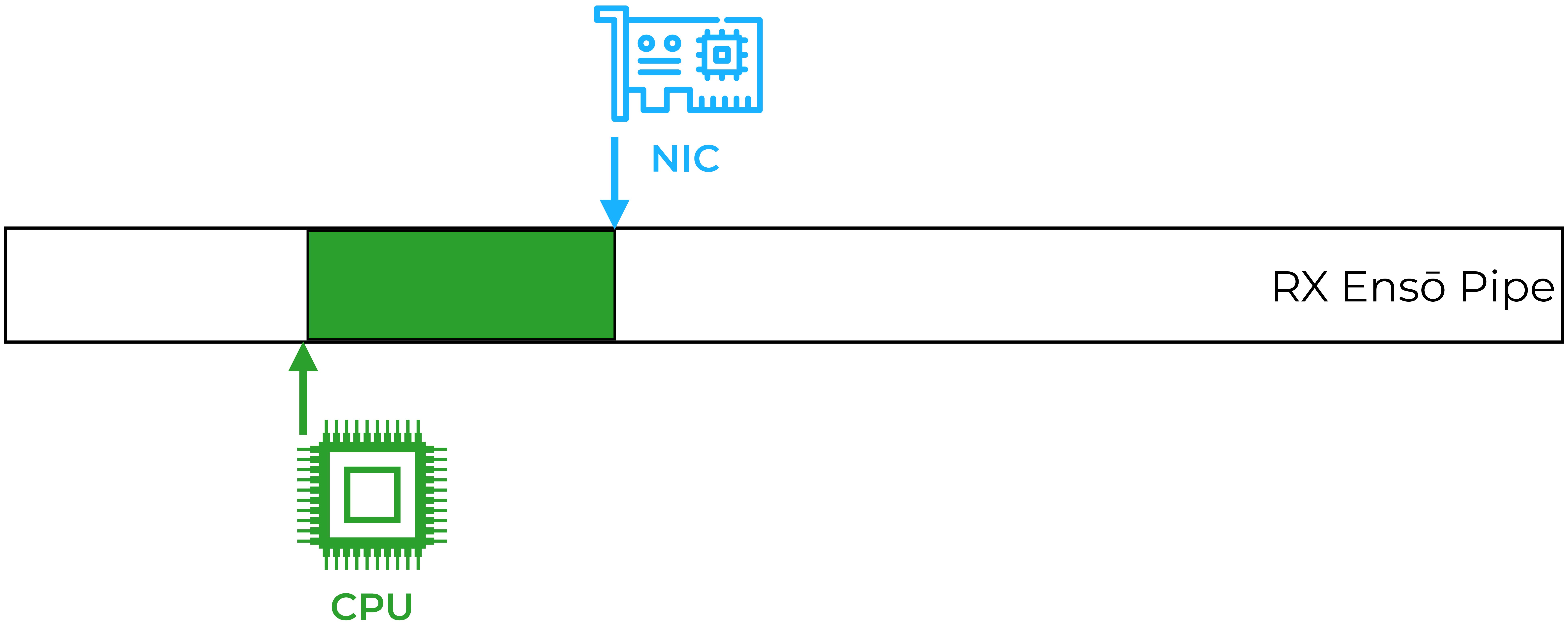

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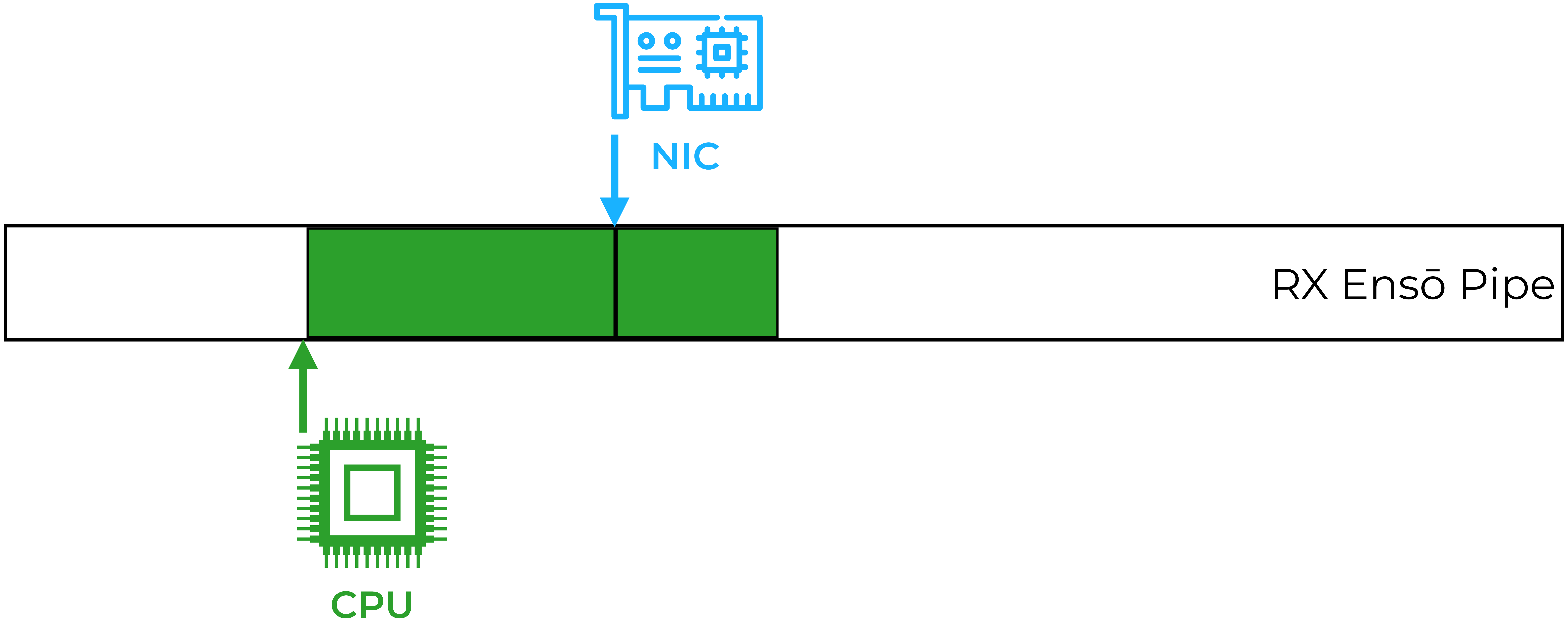

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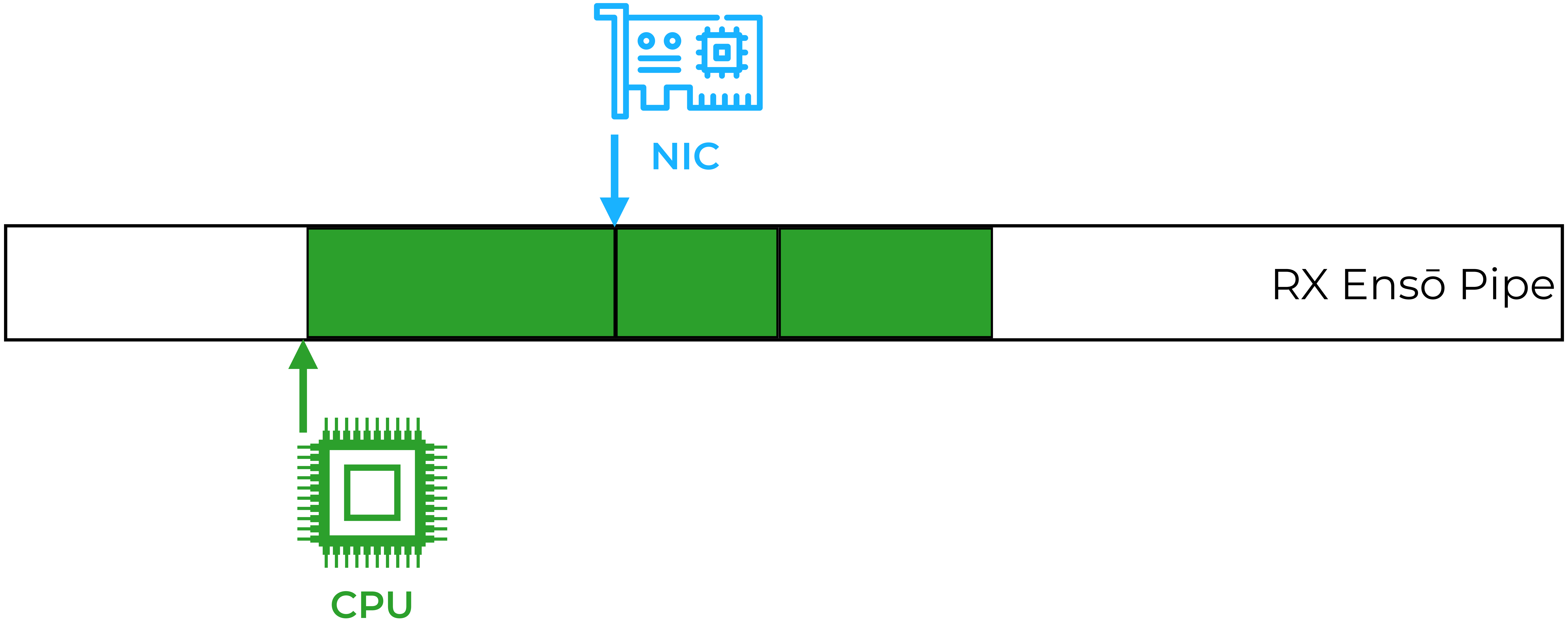

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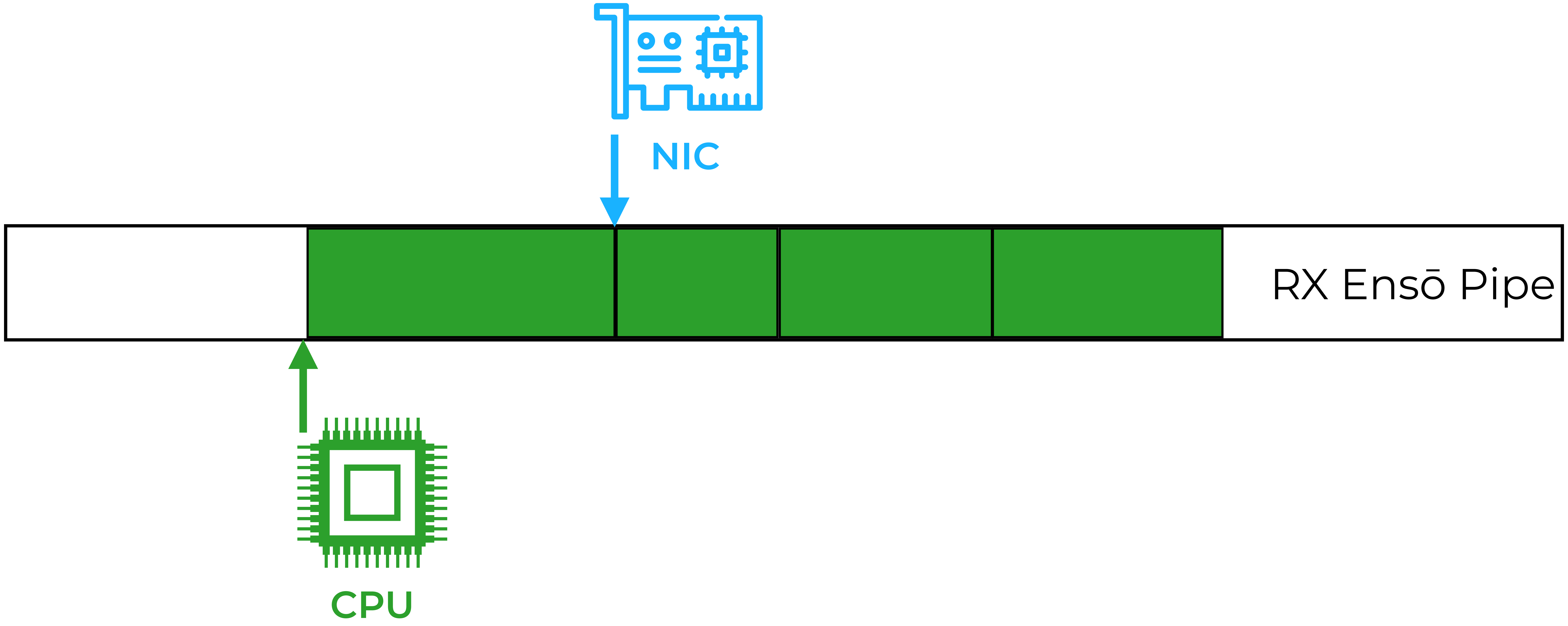

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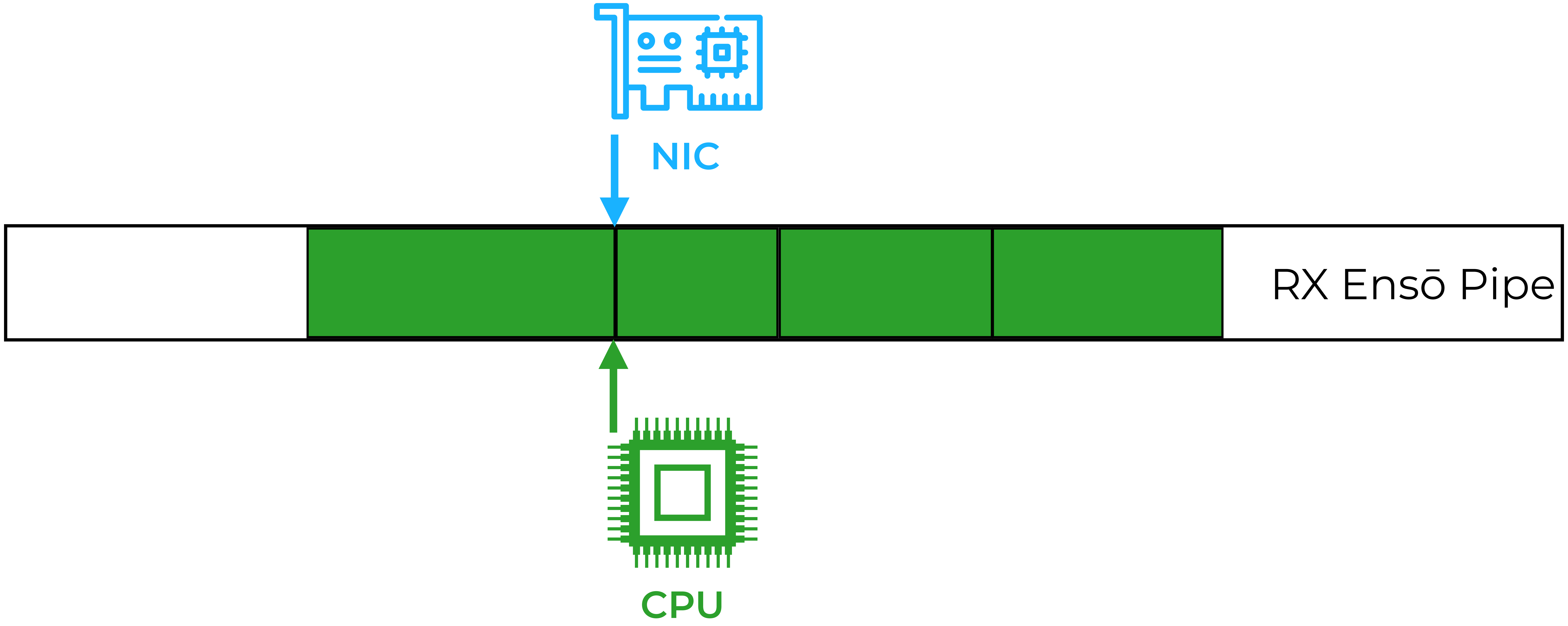

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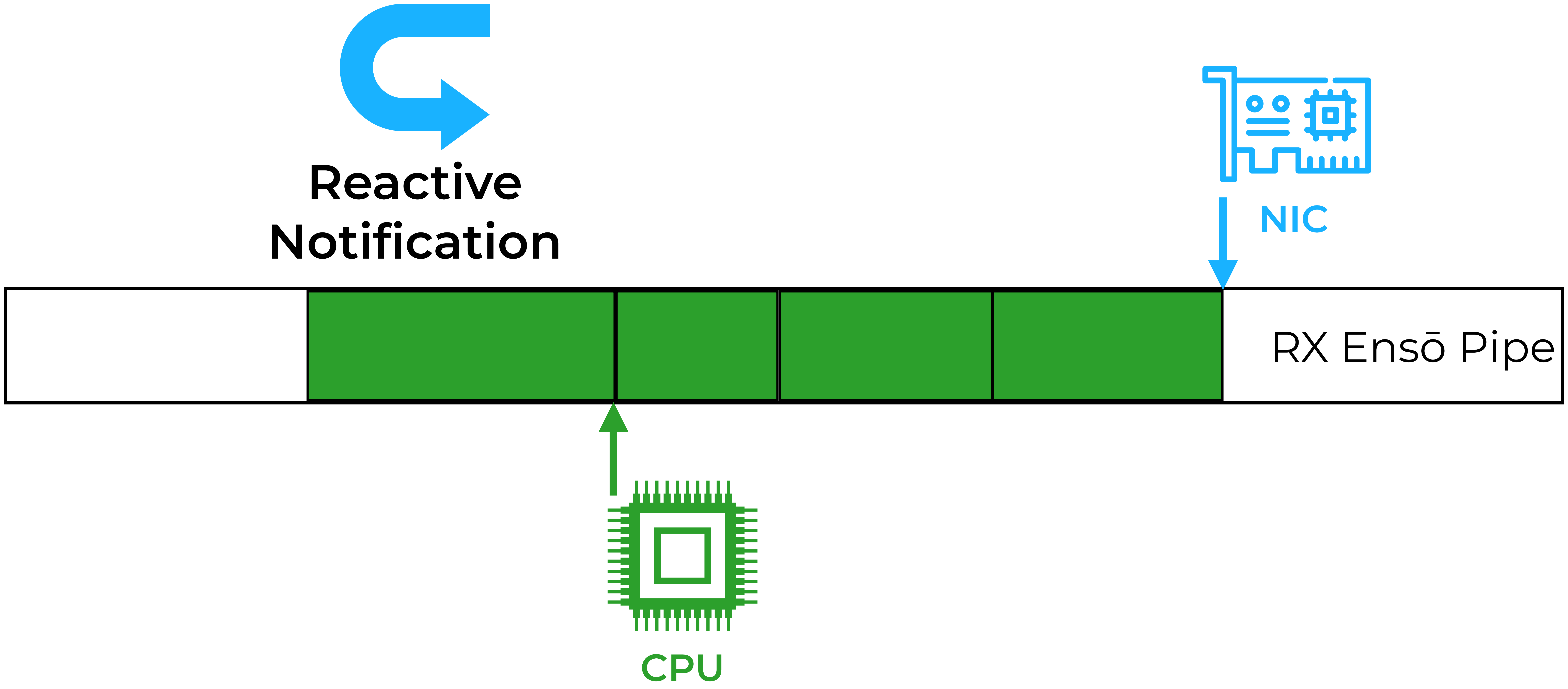

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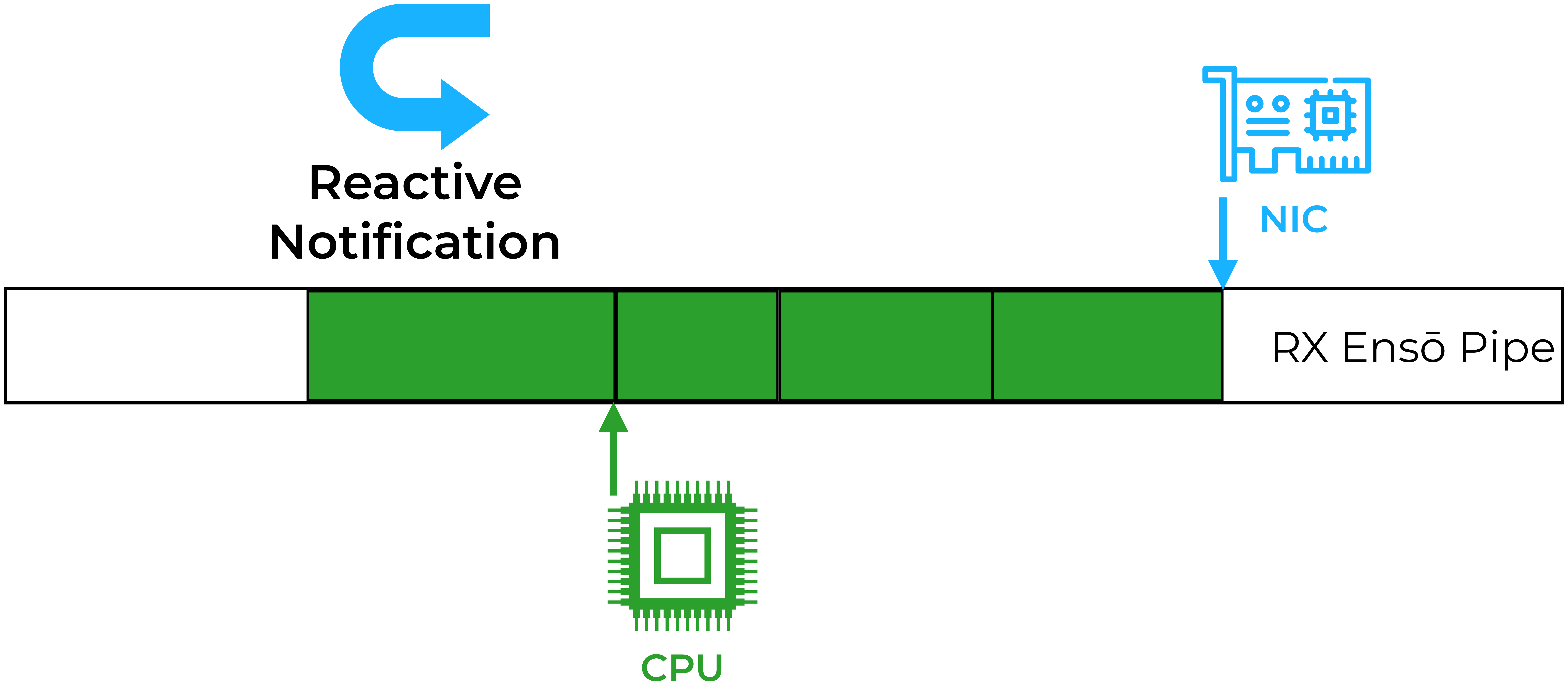
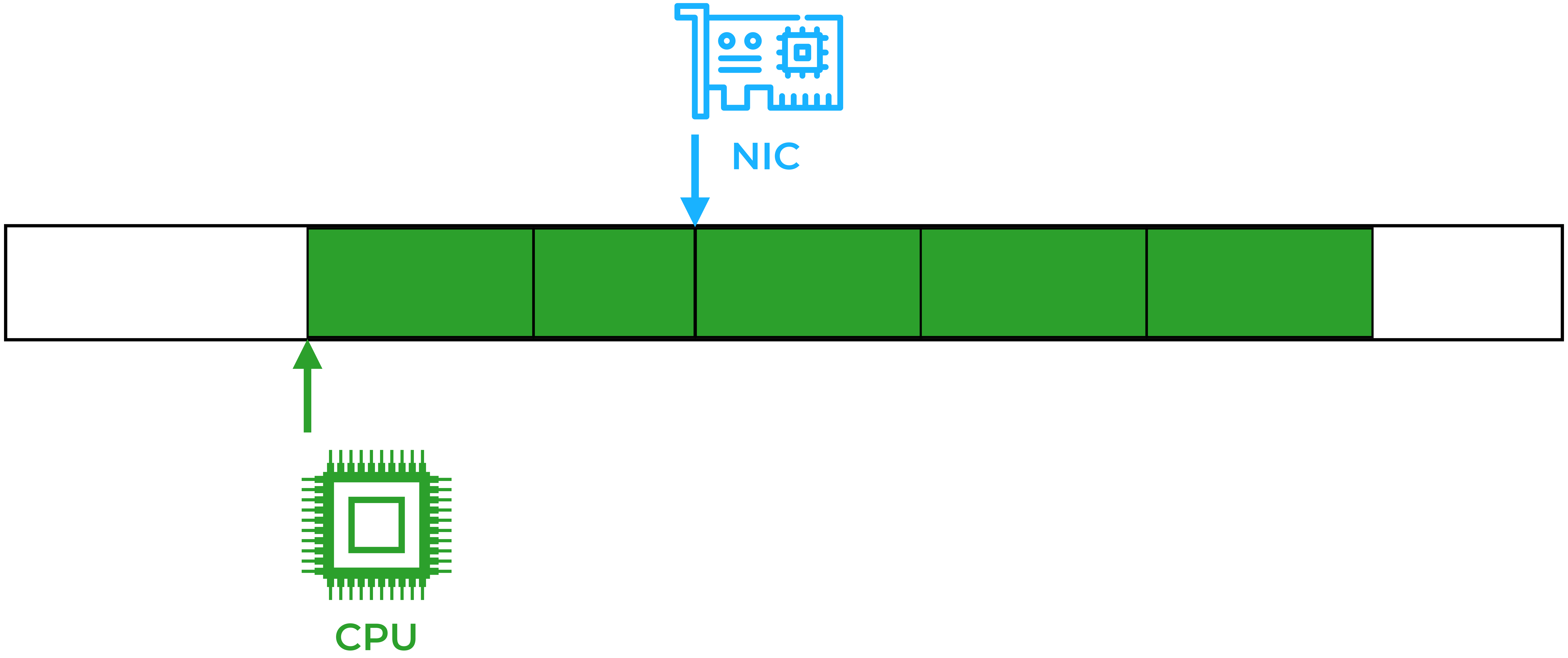



**Only sends notifications that are strictly necessary**

# Problem: PCIe Latency

Software may need to wait up to 1 PCIe RTT for a notification



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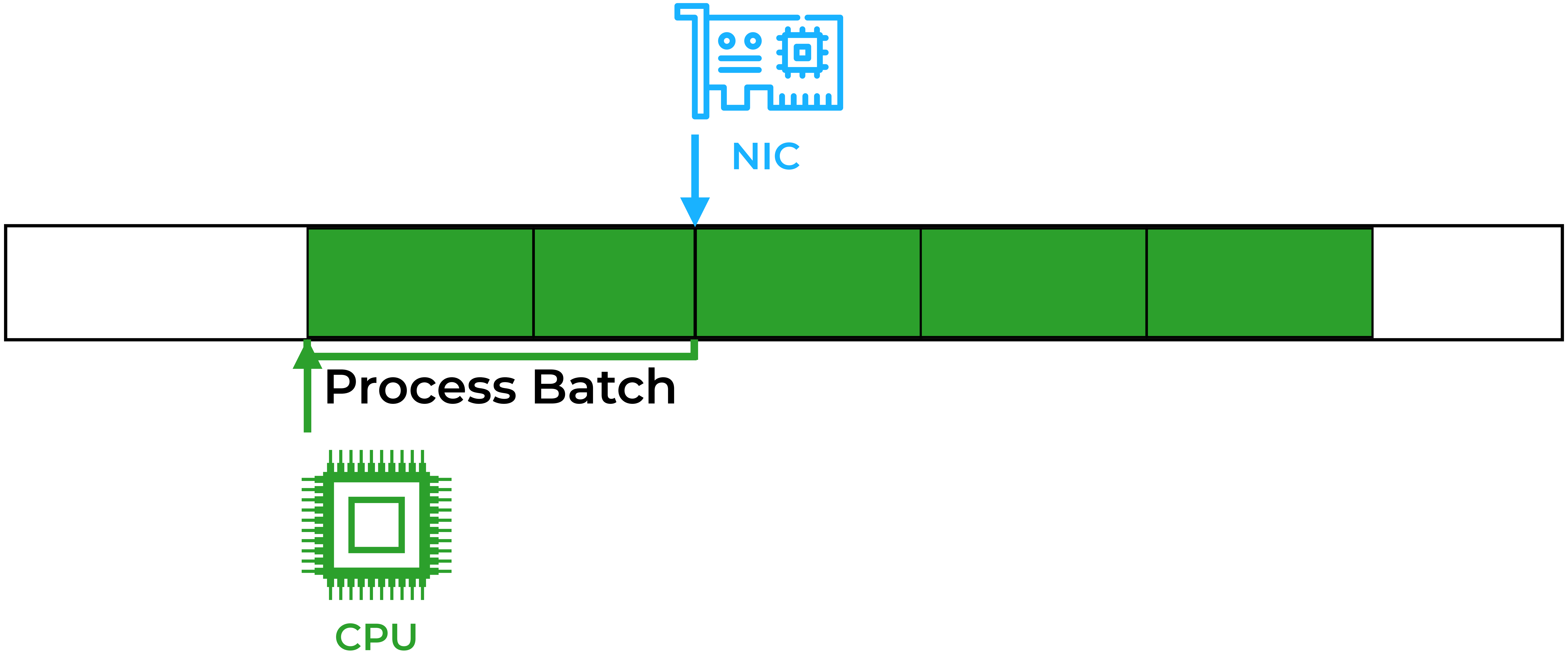

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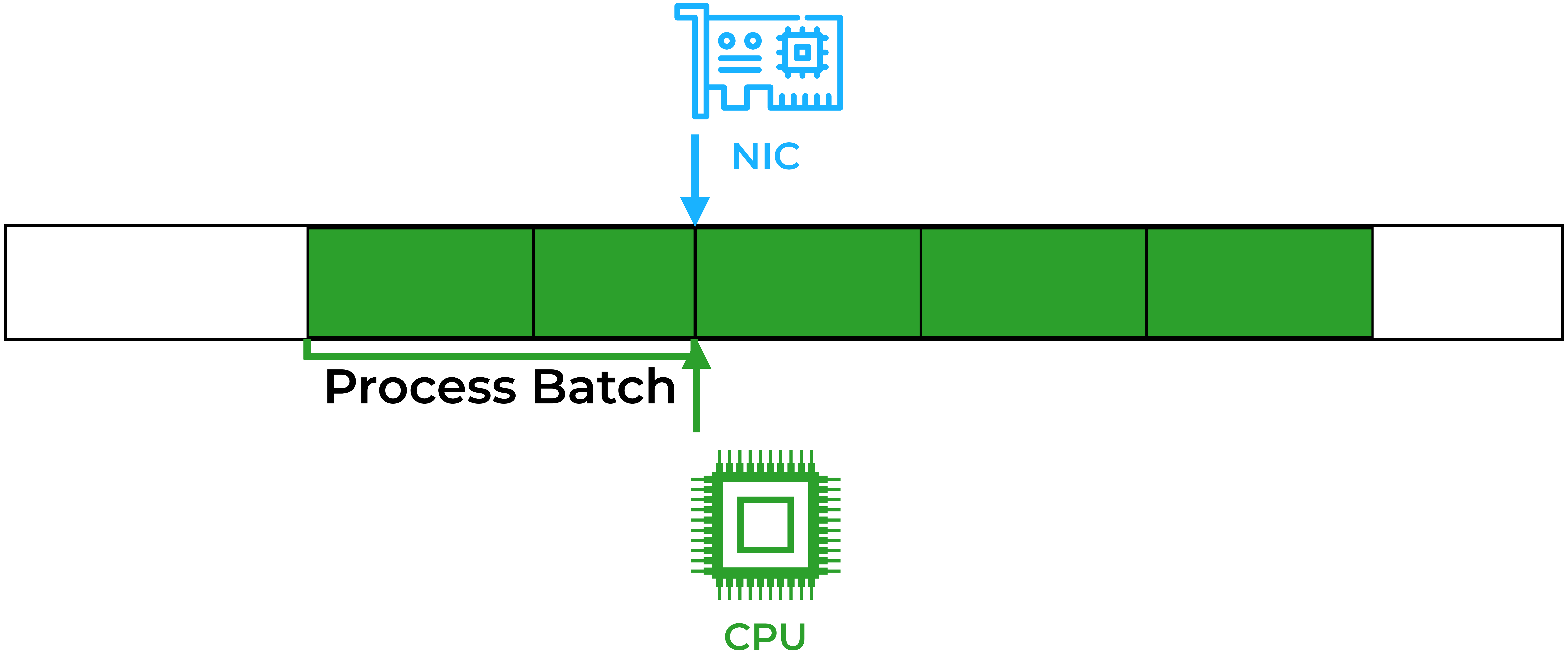

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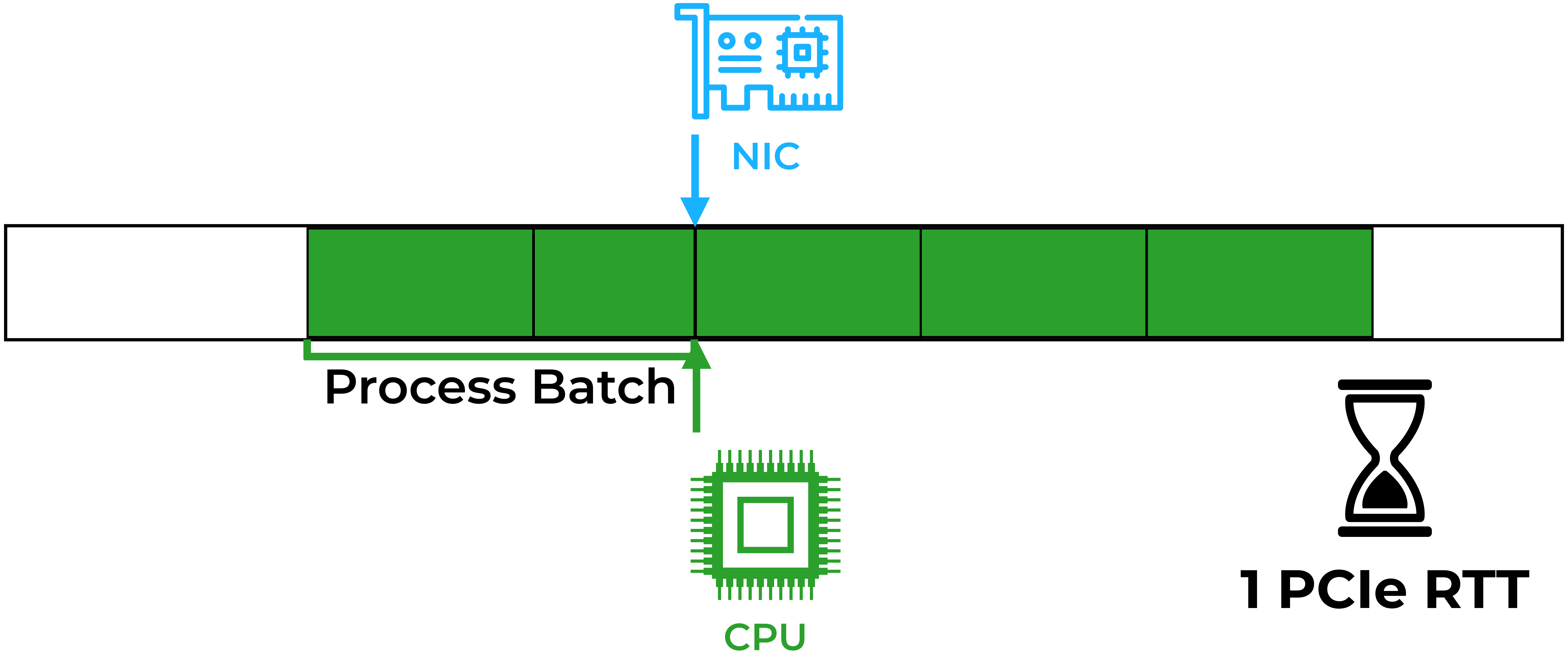

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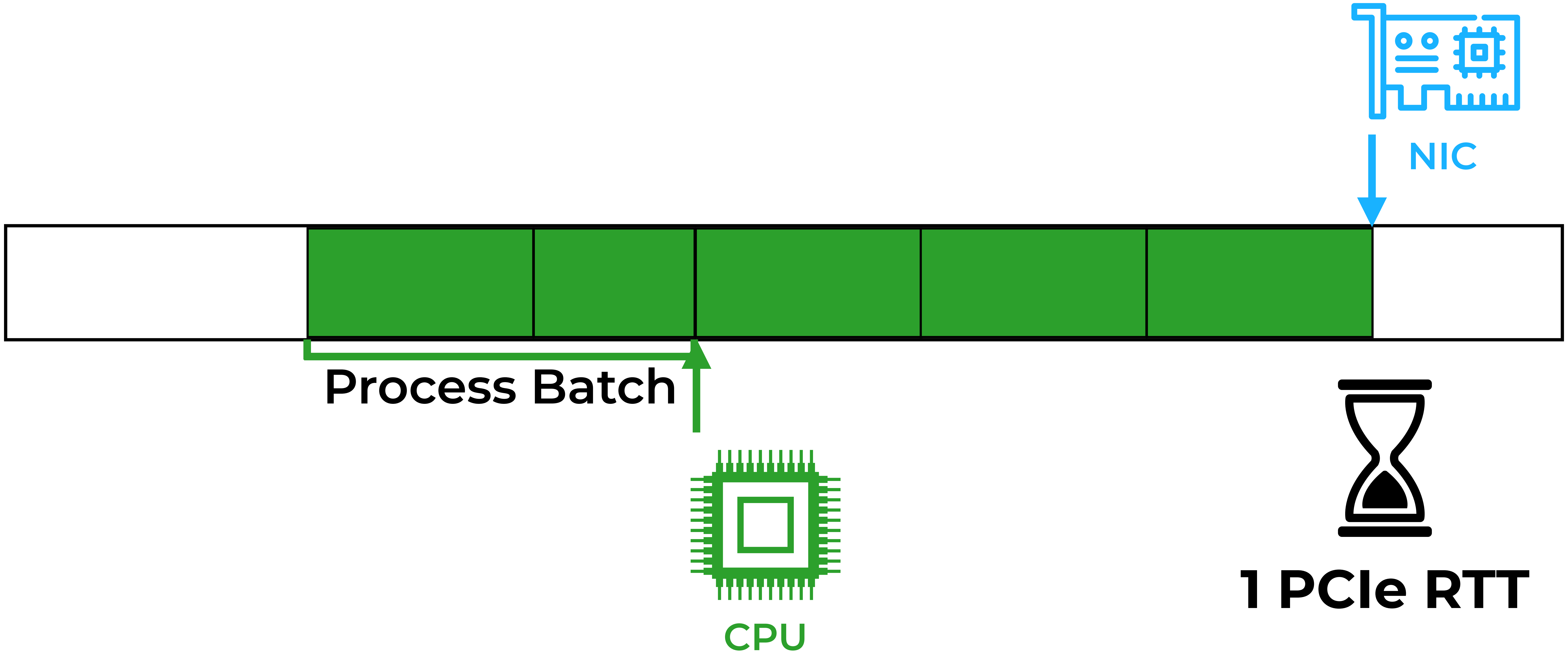

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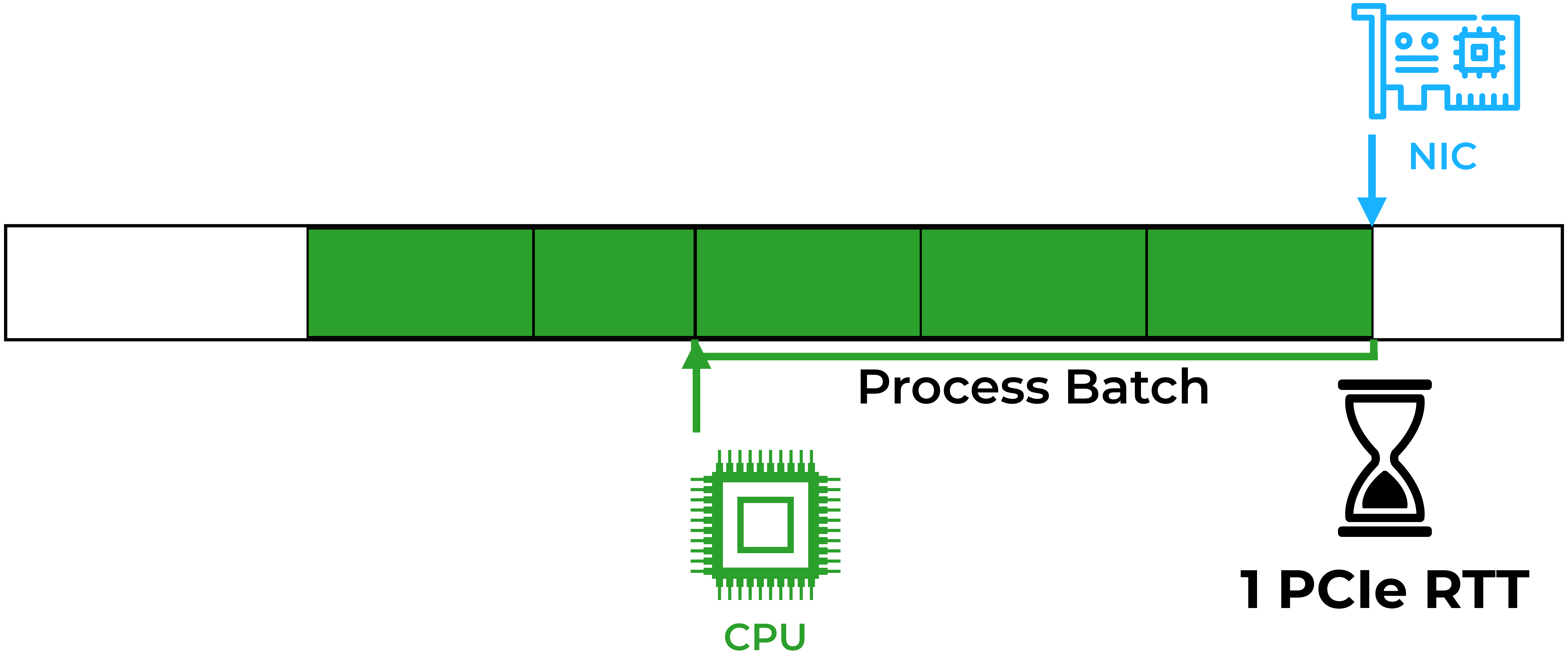
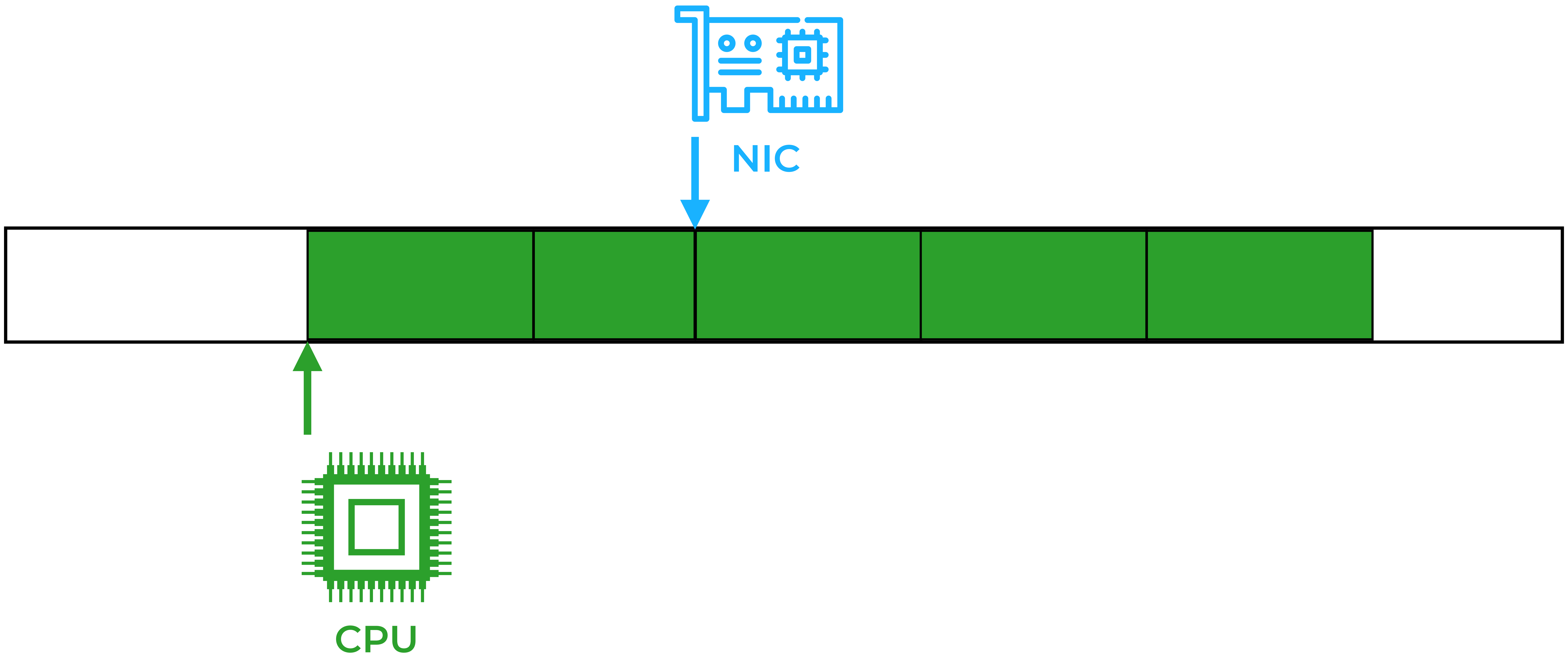


# ② Notification Prefetching

Software can *explicitly* request pointer updates from the NIC



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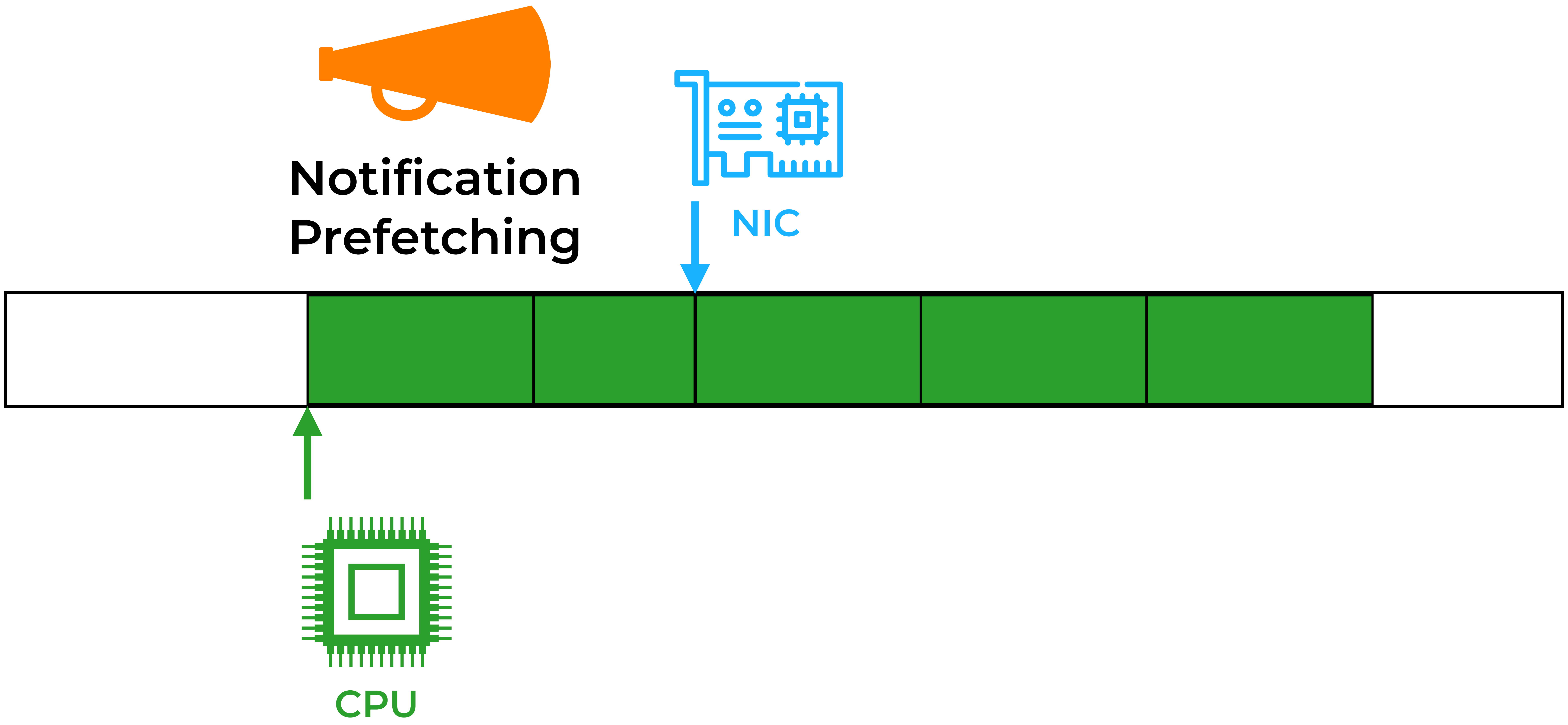

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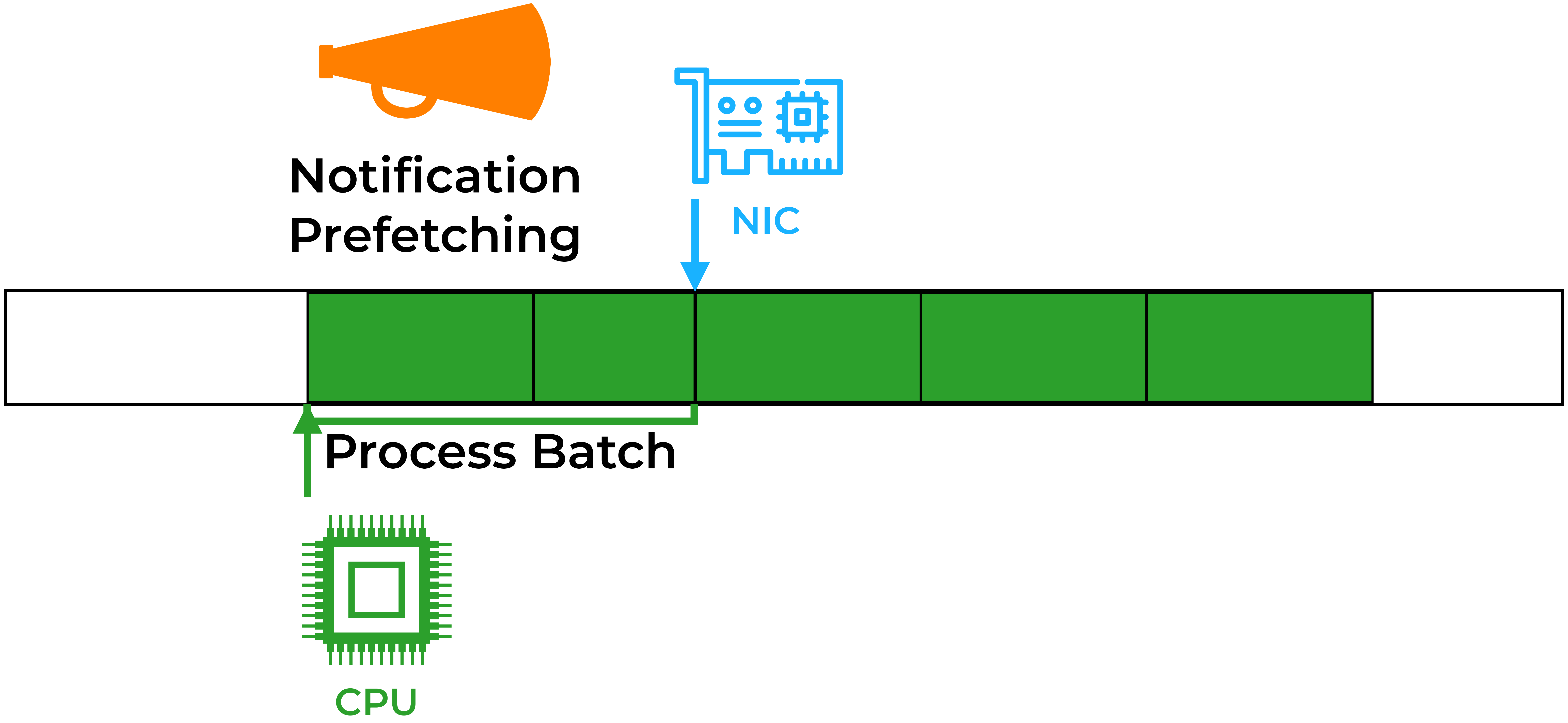

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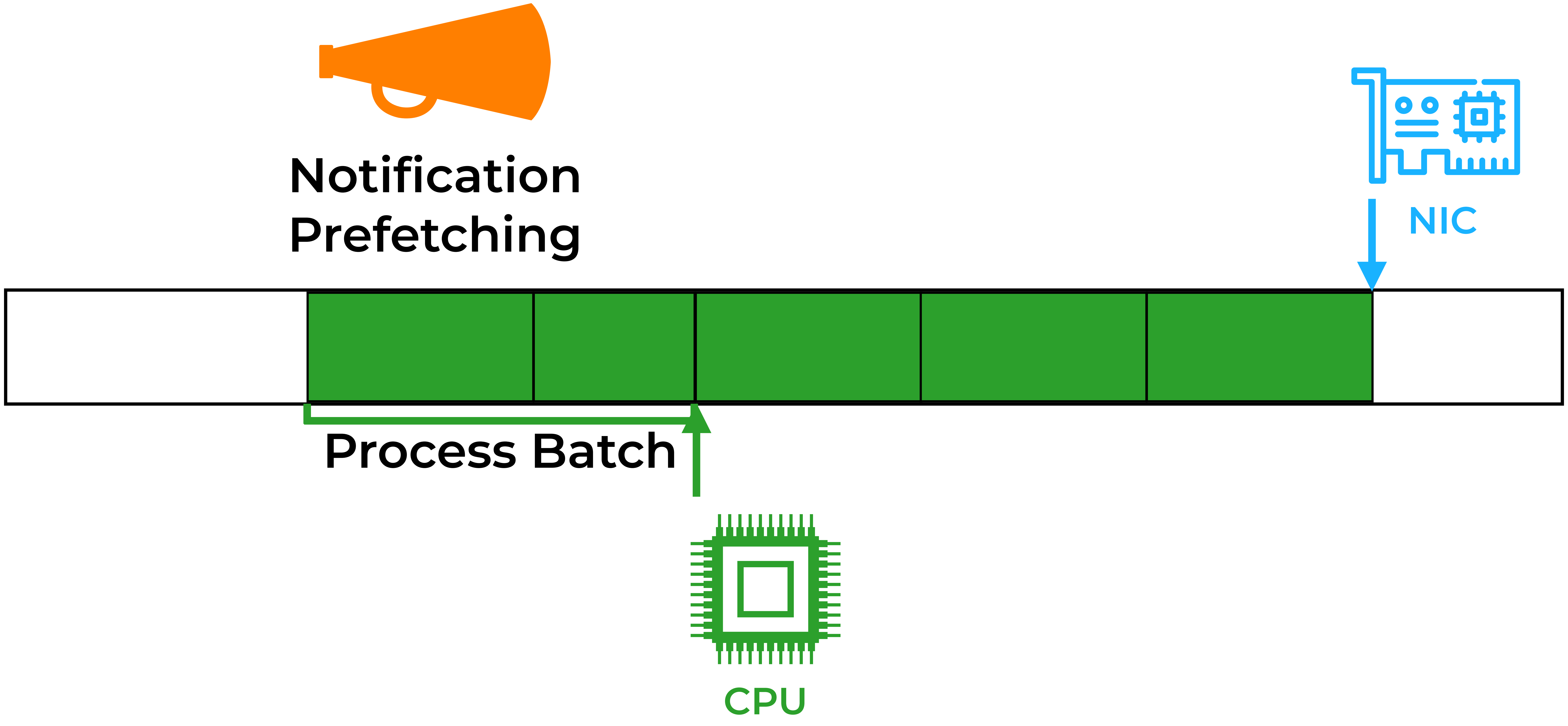

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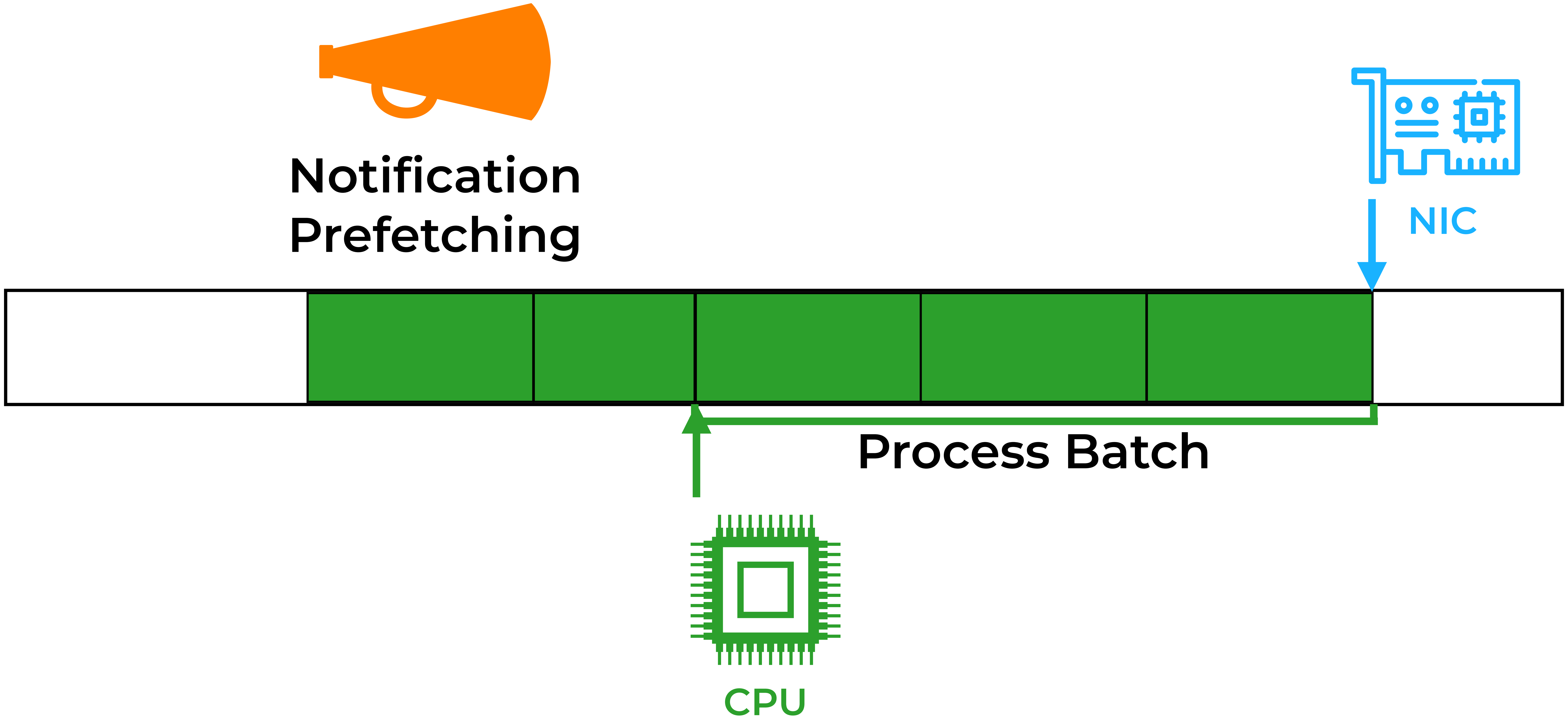

# Many other design challenges...

How to notify pointer updates efficiently?

How to deal with data that wrap around?

How to design a scalable hardware?

How to avoid copies in applications that send data back (e.g., Network Functions)?

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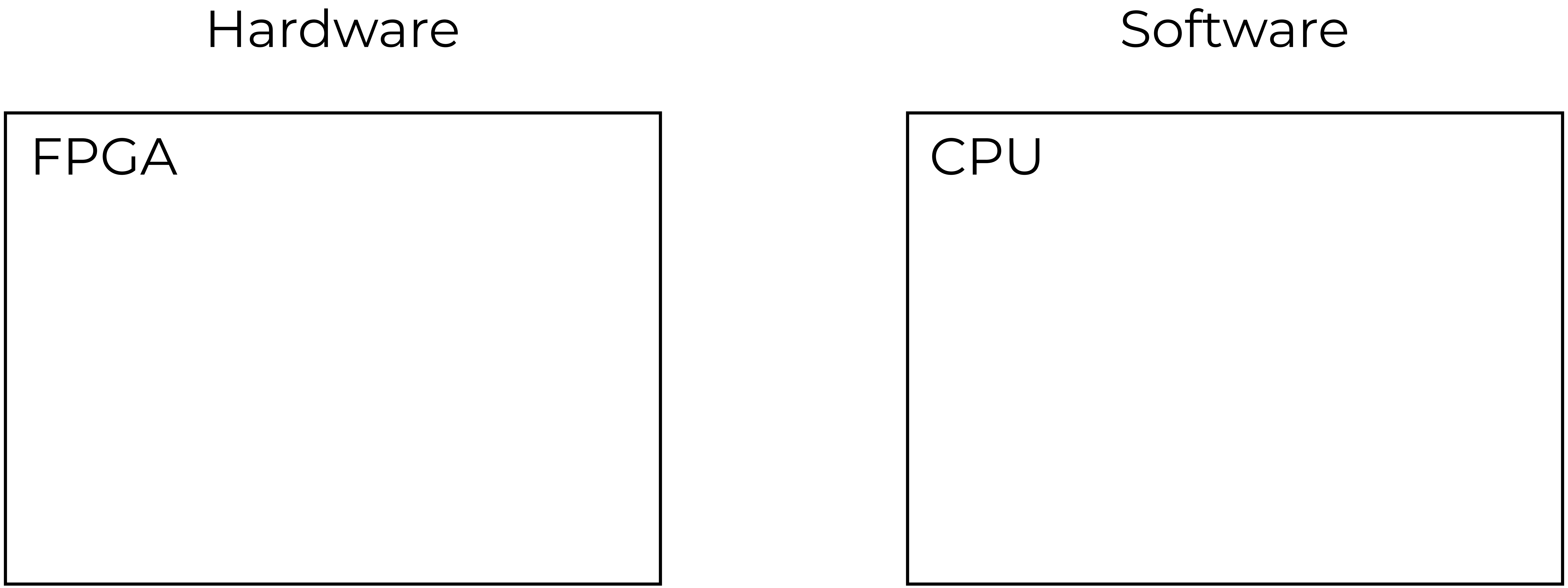
**Refer to the paper for details**

# Ensō Implementation



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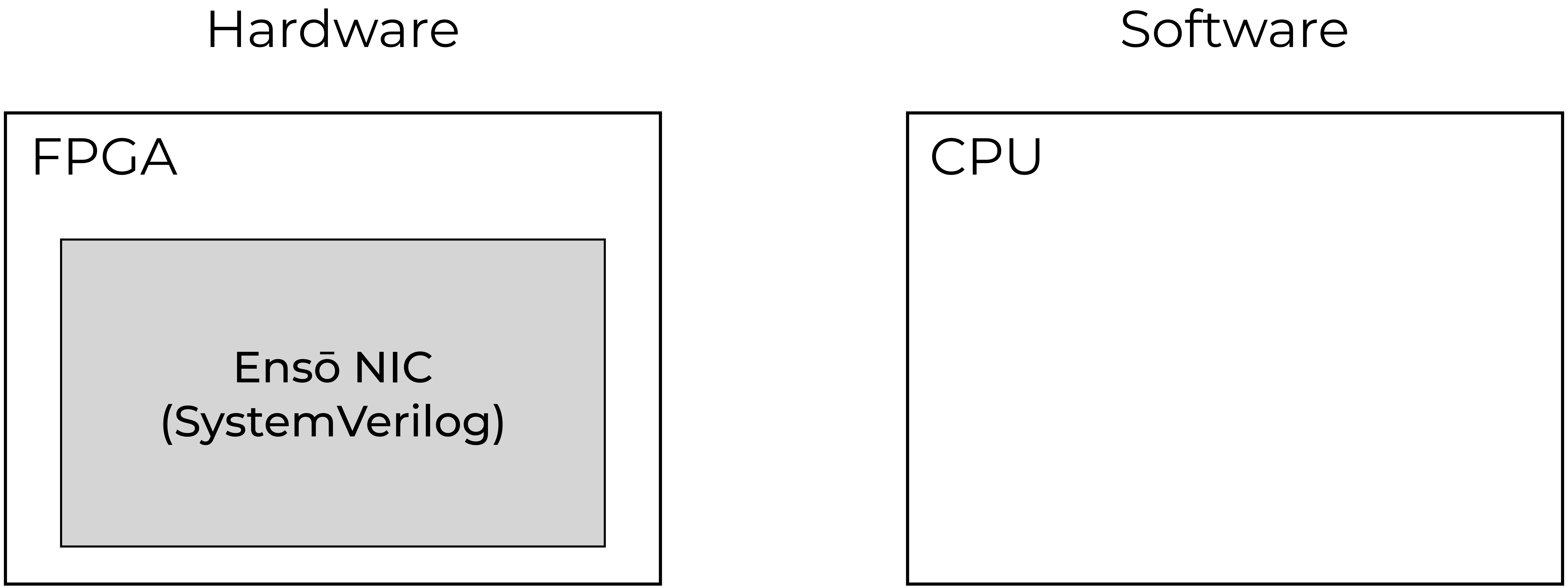

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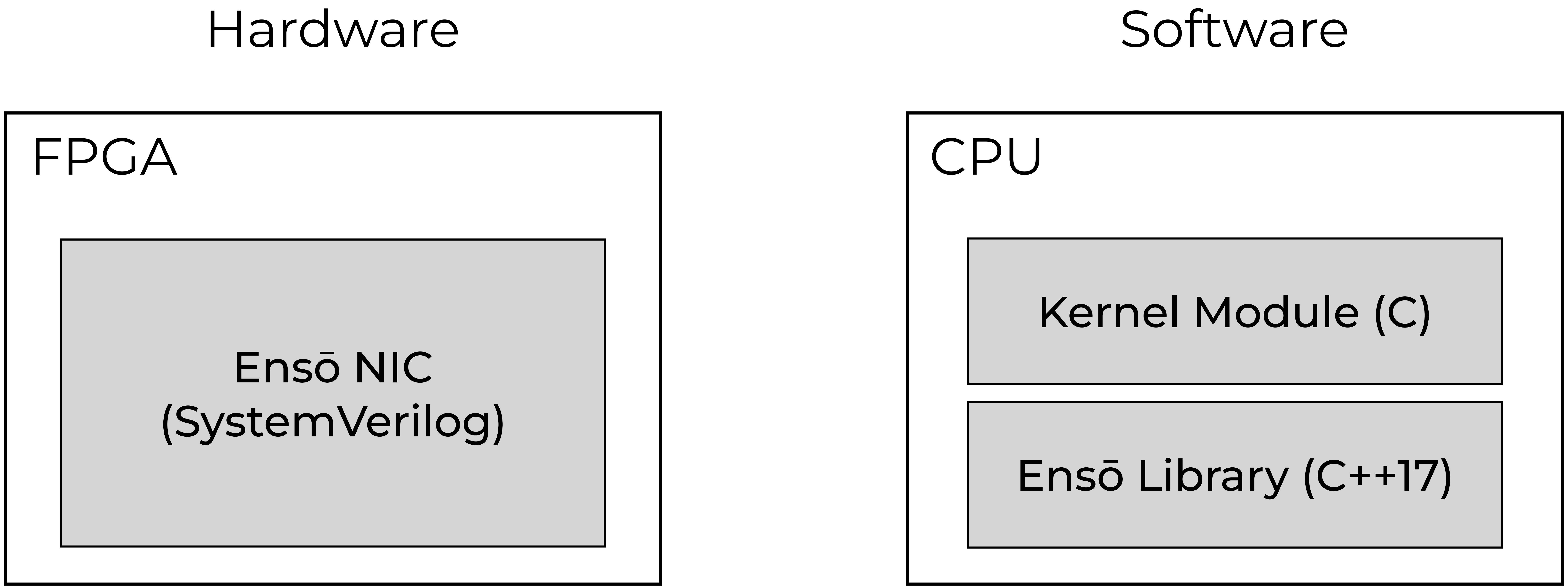
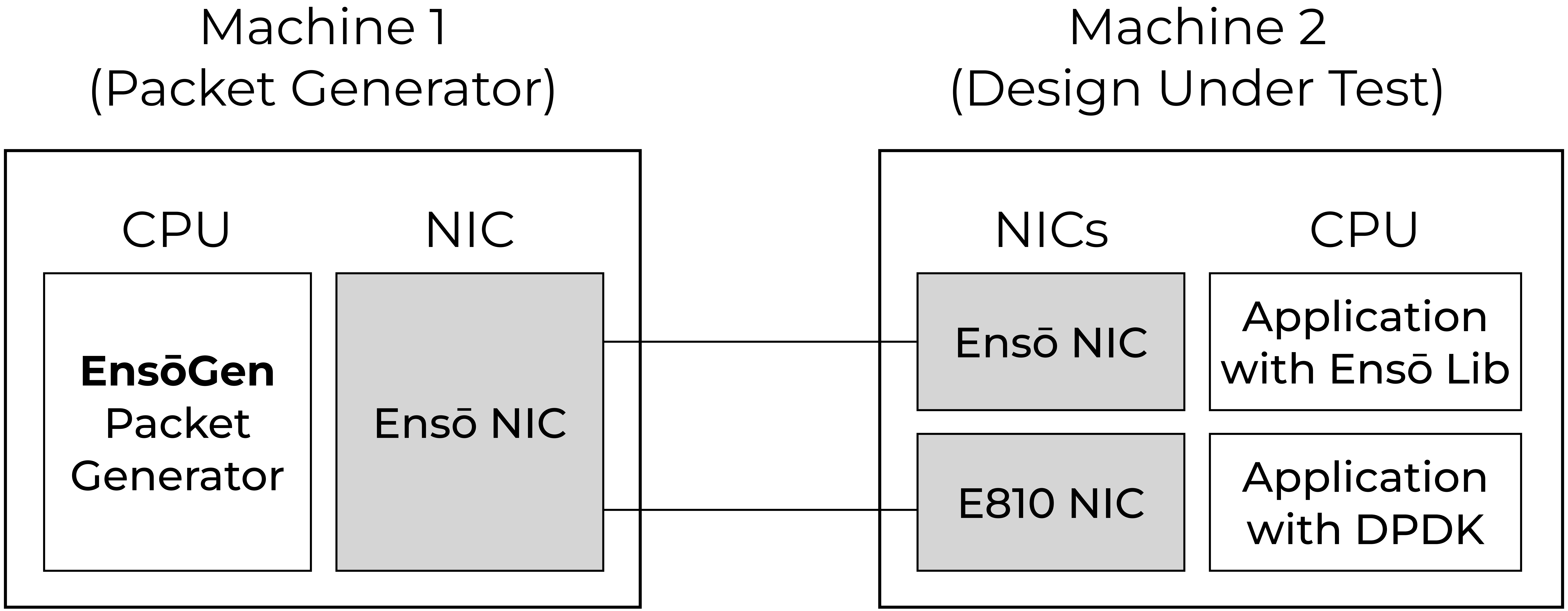
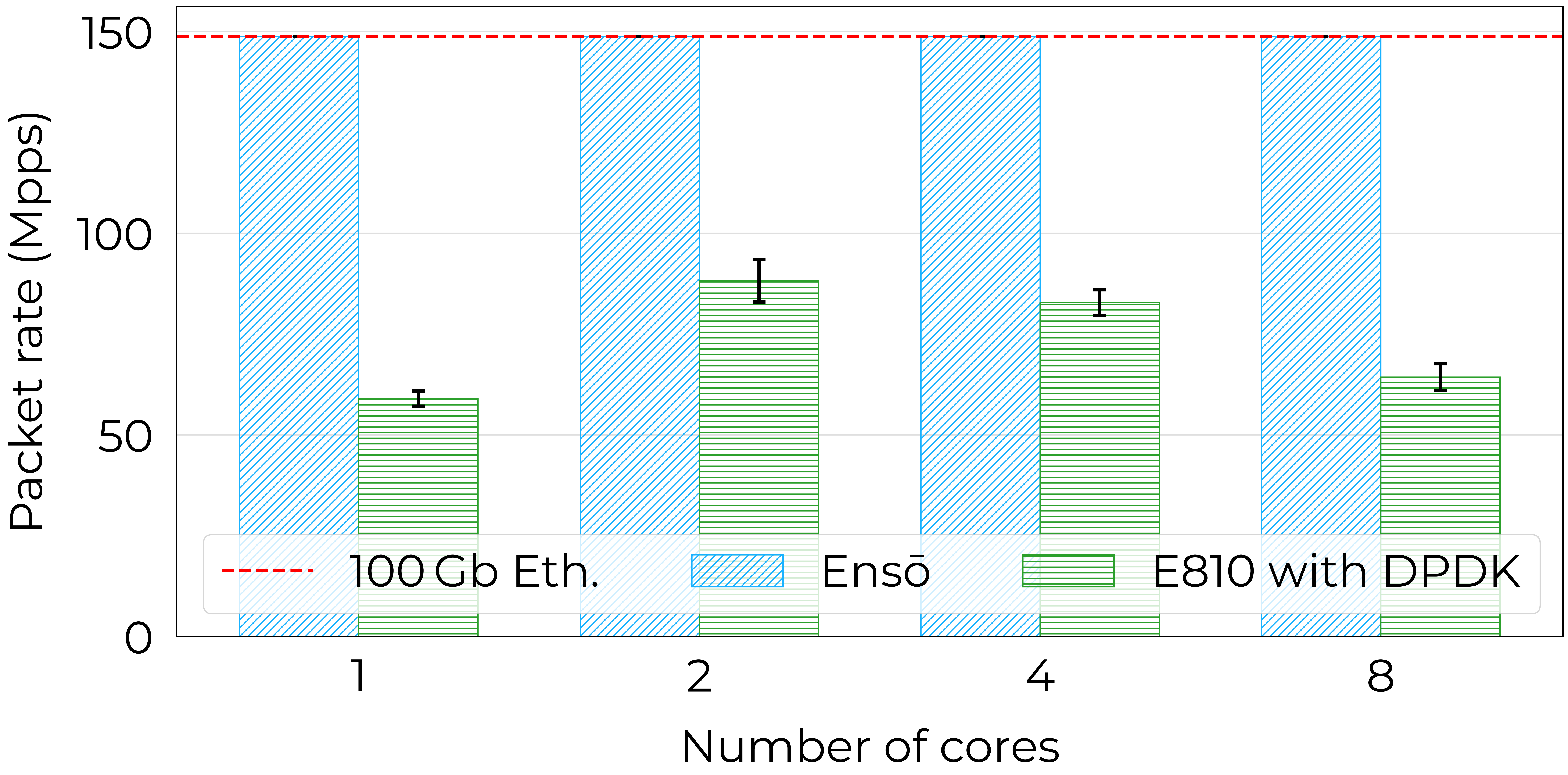


# Evaluation



Machine 1
(Packet Generator)
CPU
NIC
**EnsōGen**
Packet
Generator
Ensō NIC
Machine 2
(Design Under Test)
NICs
CPU
Ensō NIC
Application
with Ensō Lib
E810 NIC
Application
with DPDK

# Ensō achieves 100 Gbps line rate (148.8 Mpps) using a single core



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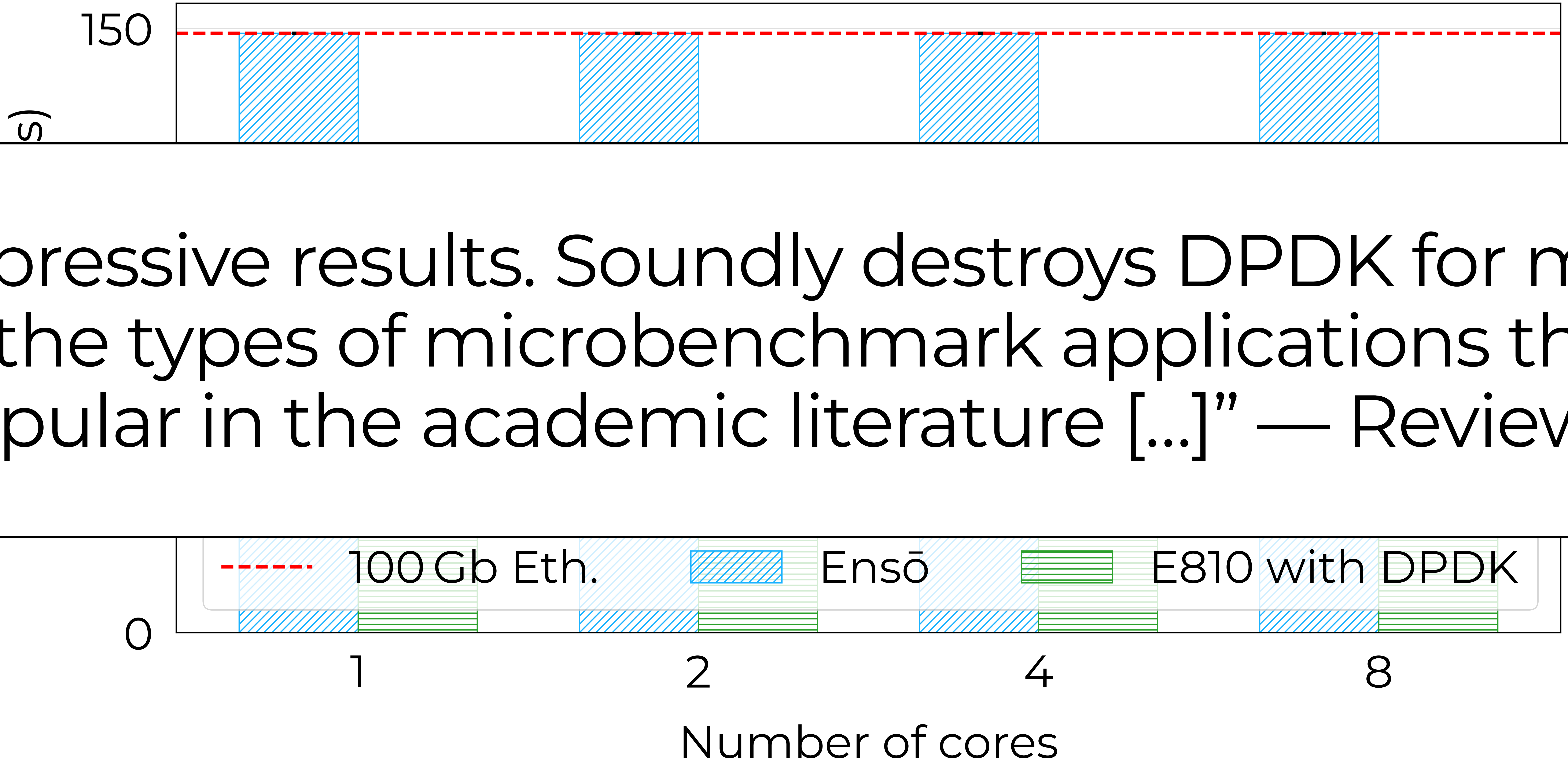
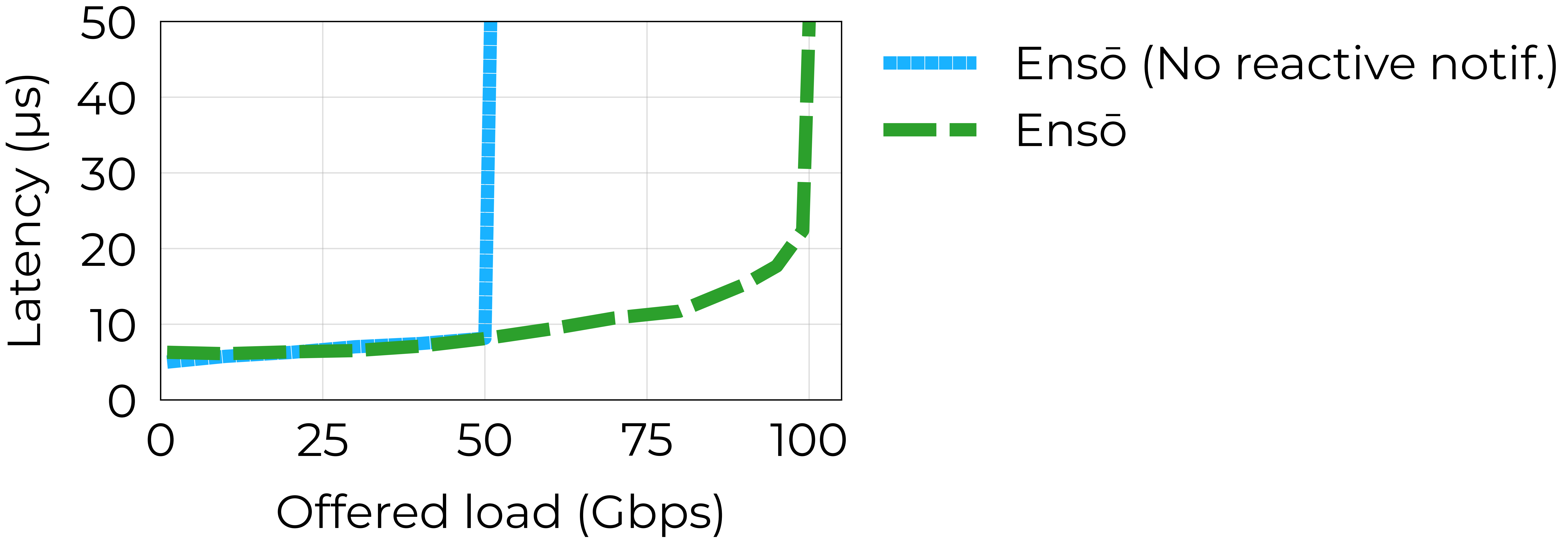



"Impressive results. Soundly destroys DPDK for many of the types of microbenchmark applications that are popular in the academic literature [...]" — Reviewer D

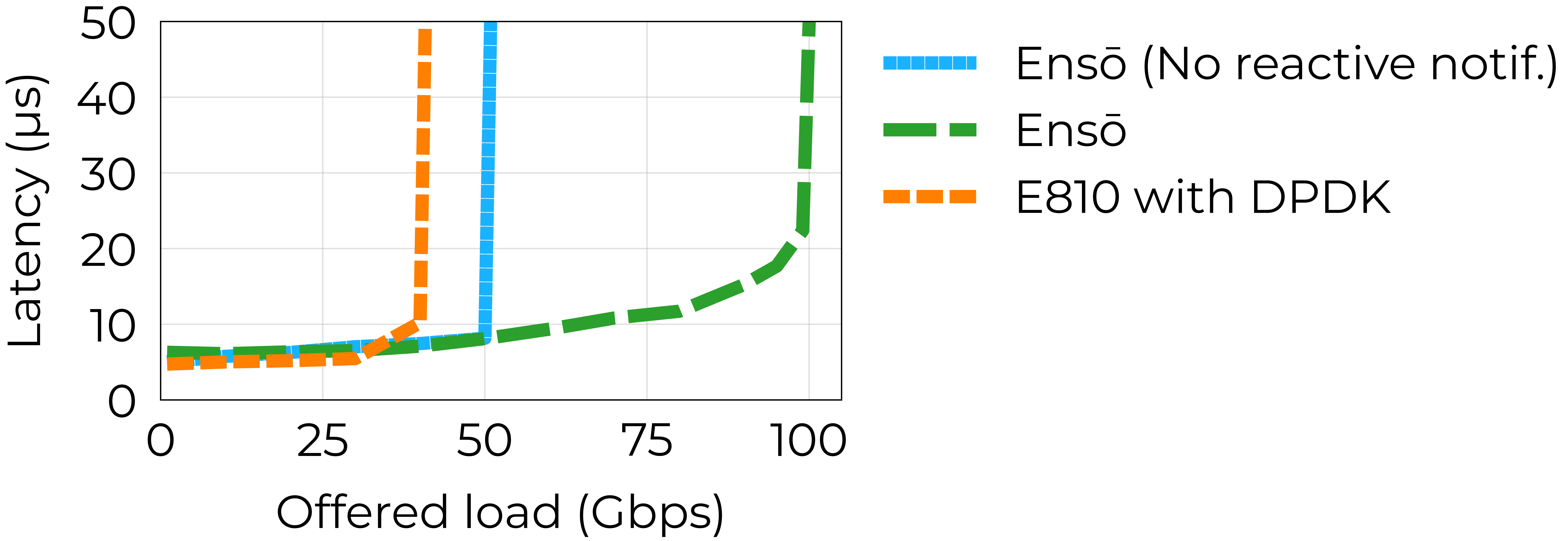
# Ensō improves application throughput by up to 6x

| Application | Throughput Improvement |
|---|---|
| Maglev Load Balancer [NSDI ’16] | Up to 6x |
| Network Telemetry with NitroSketch [SIGCOMM ’19] | Up to 3.5x |
| MICA Key-Value Store [NSDI ’14] | Up to 47% |
| Log Monitor | Up to 95% |

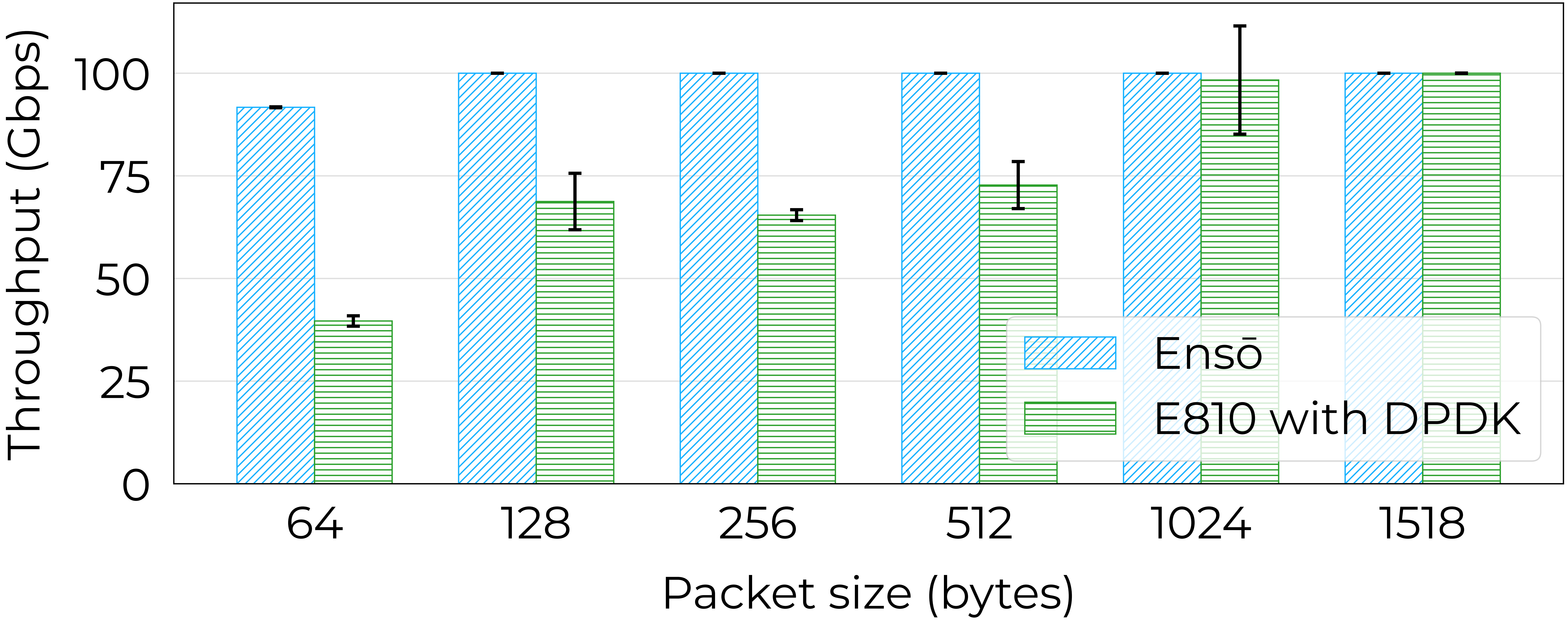
# Reactive Notifications + Notification Prefetching improve throughput without impairing latency



# Ensō achieves similar latency to the E810 NIC with DPDK, while sustaining a much greater load



# Ensō outperforms the packetized interface even when copying data



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Ensō is open source: enso.cs.cmu.edu

Contact: sadok@cmu.edu