Ensō

A Streaming Interface for NIC-Application Communication

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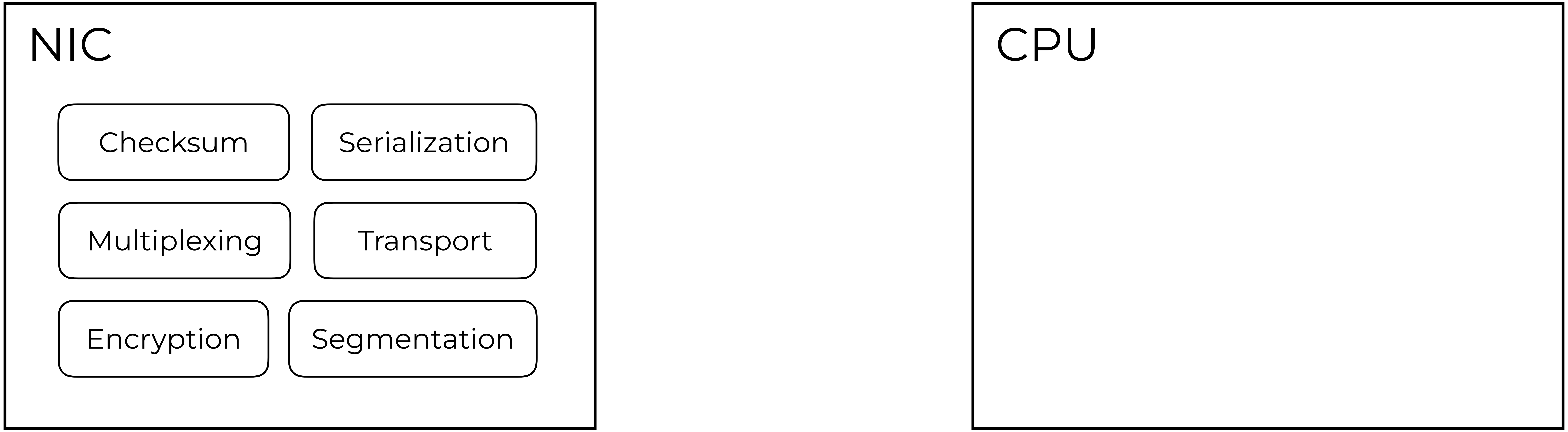
Microsoft
UNIVERSITY of WASHINGTON
intel

Two trends in high-performance networking

NIC

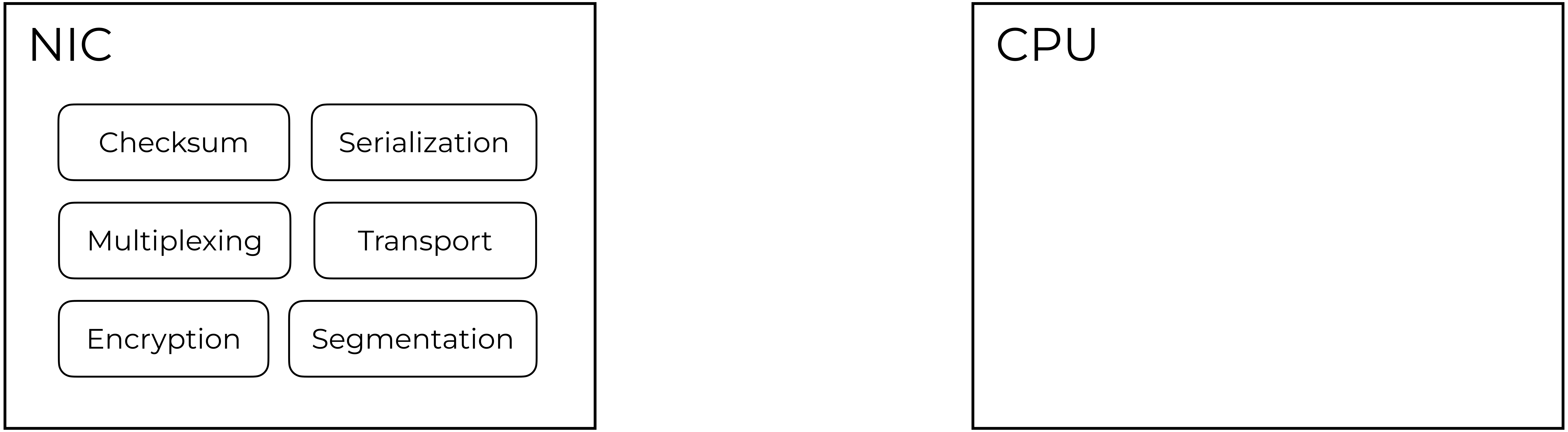
CPU

Two trends in high-performance networking



NIC offloads

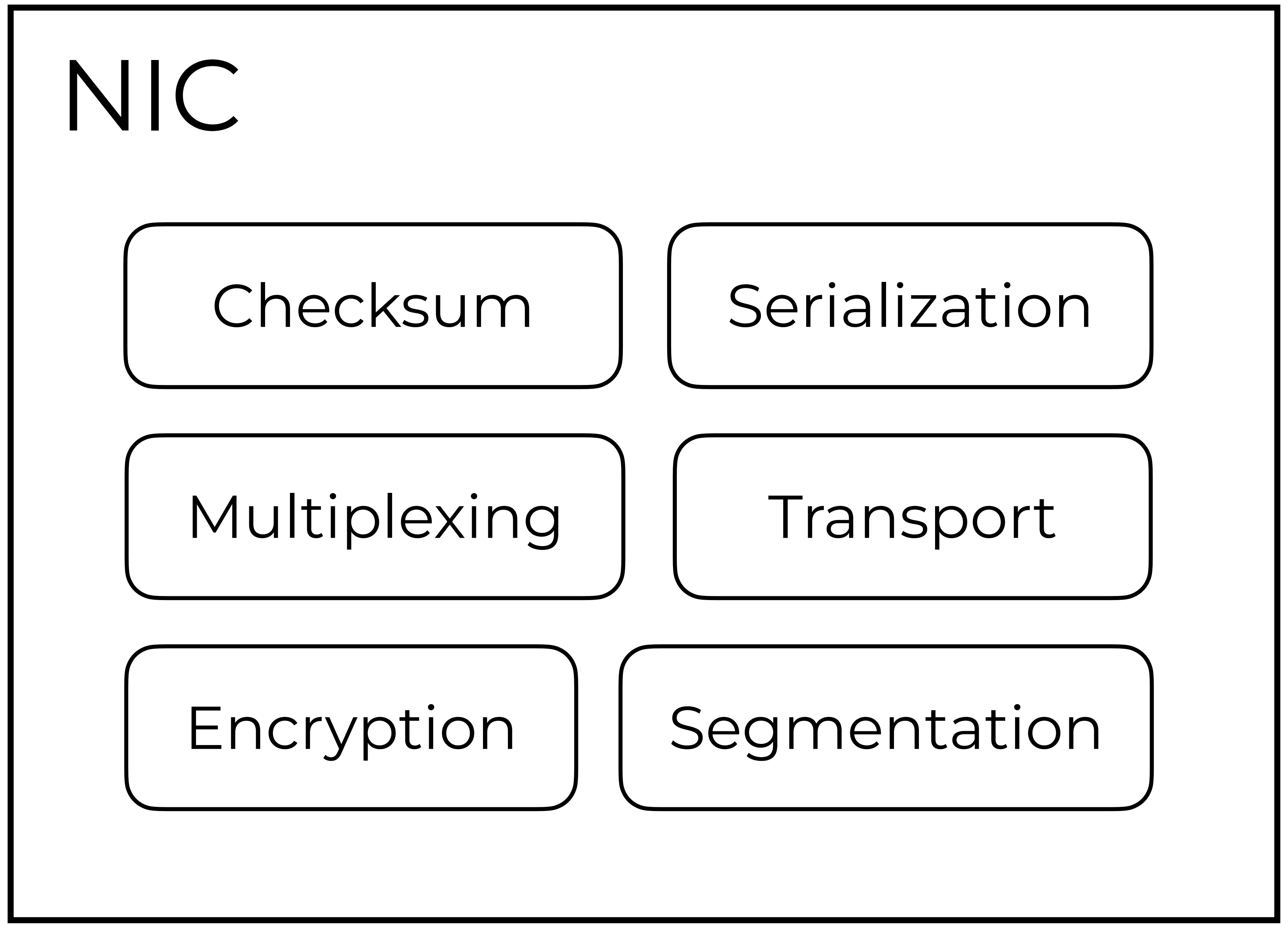
Two trends in high-performance networking



NIC offloads

Offloads operate at
higher network layers

Two trends in high-performance networking



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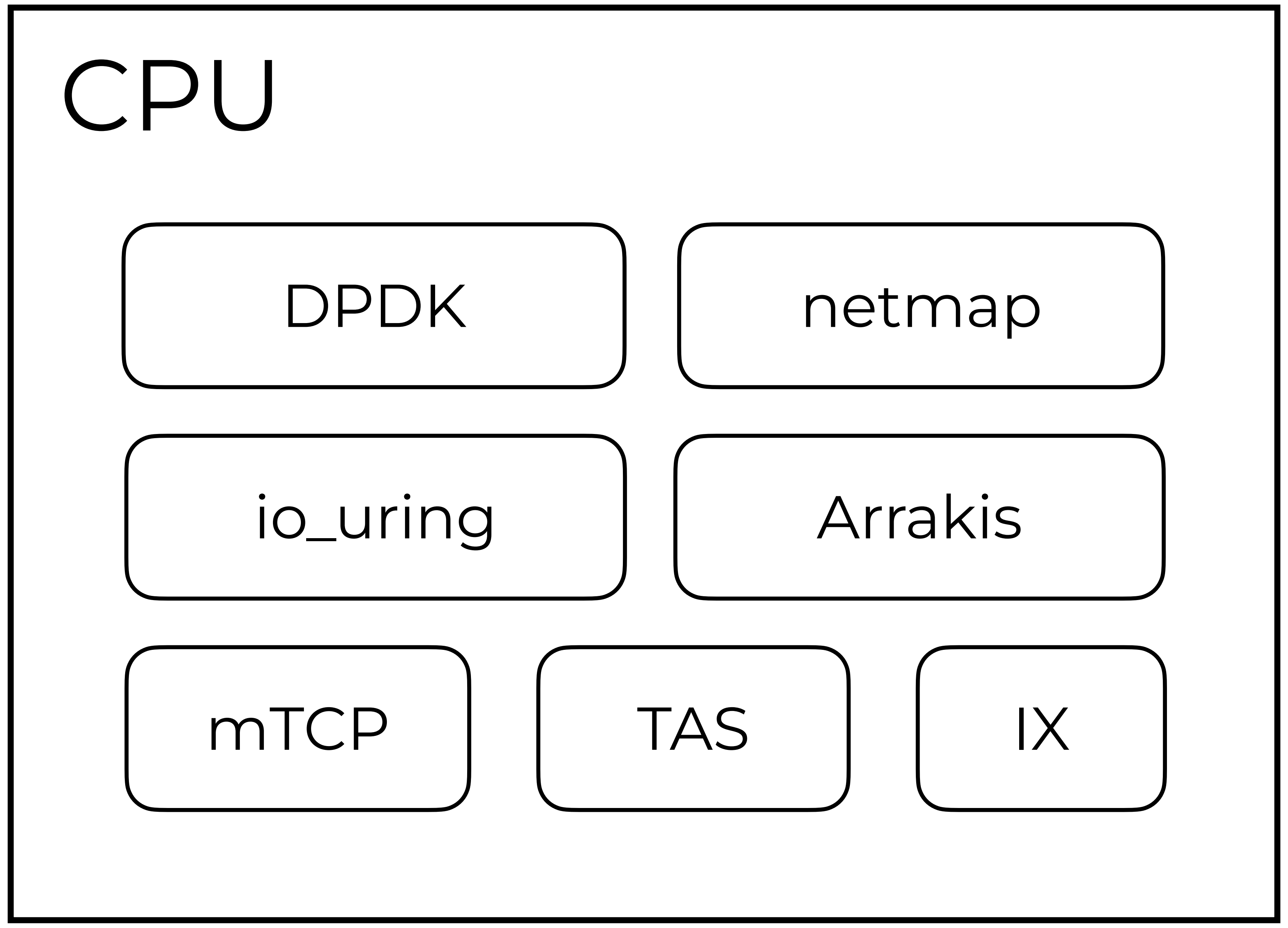

Efficient network stacks

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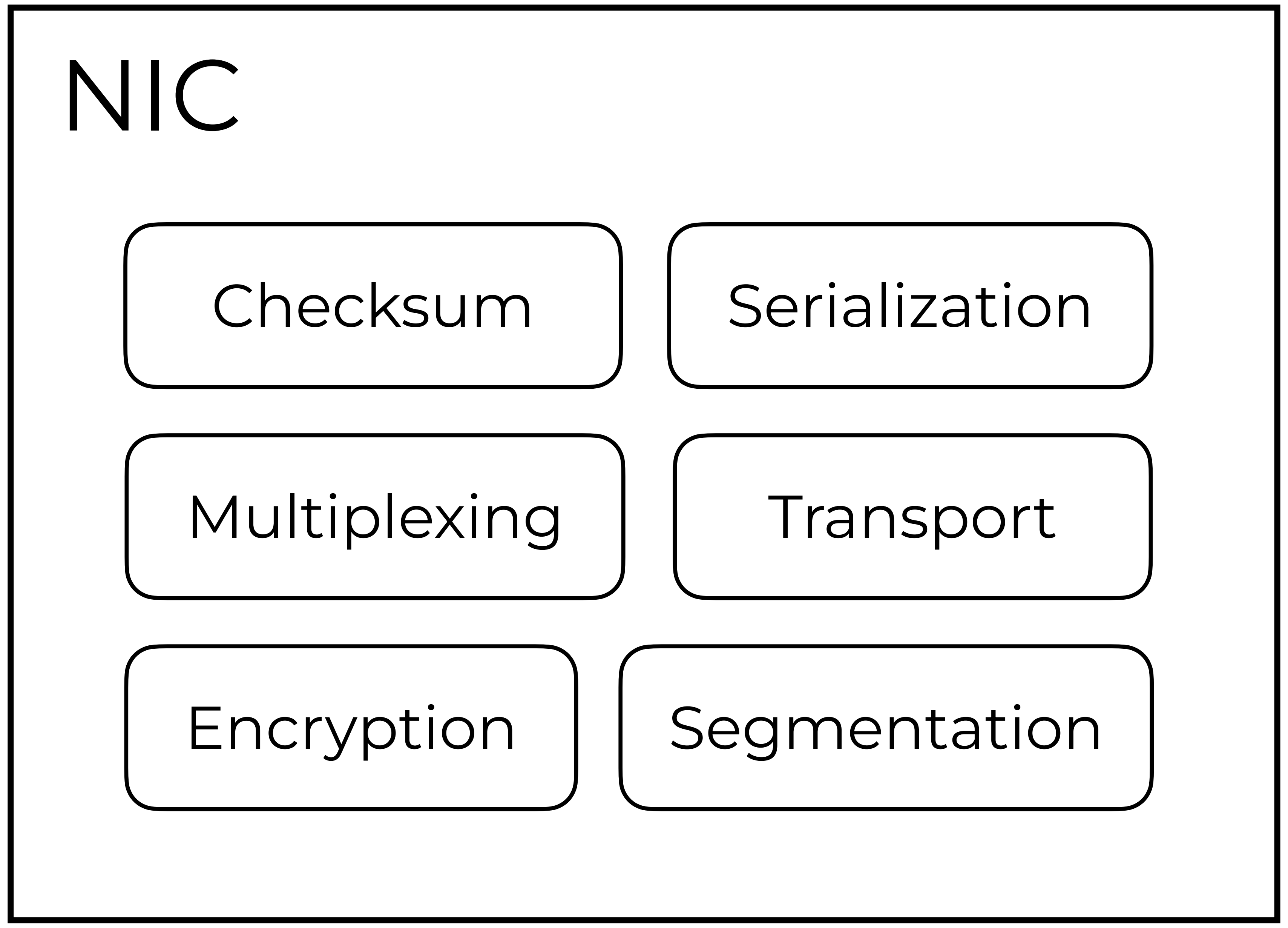

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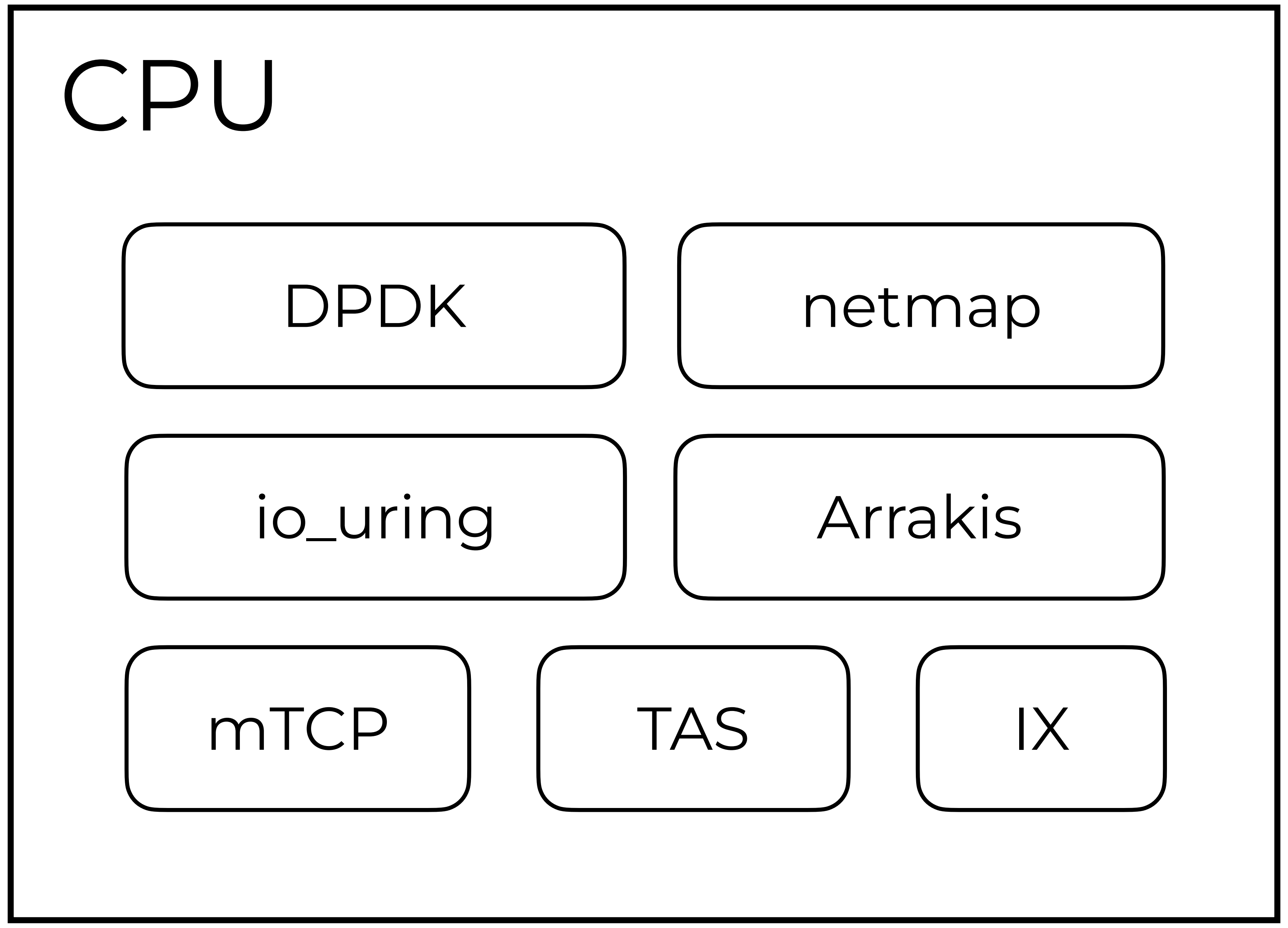

Efficient network stacks

Often bypass the kernel
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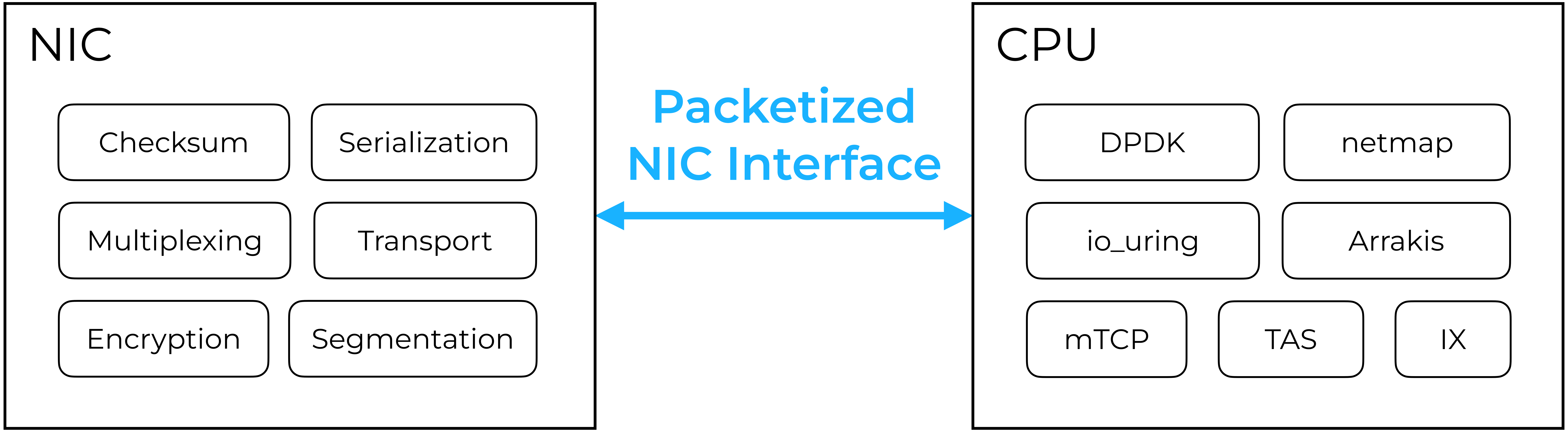
Two trends in high-performance networking



NIC offloads

Efficient network stacks

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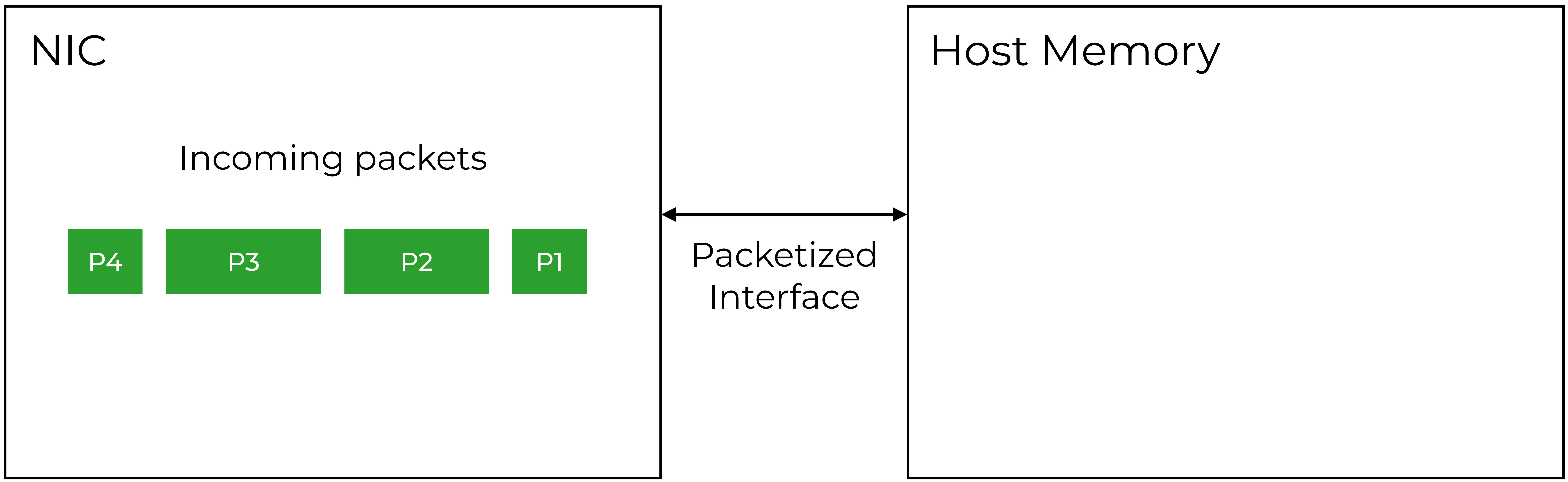
This Talk:

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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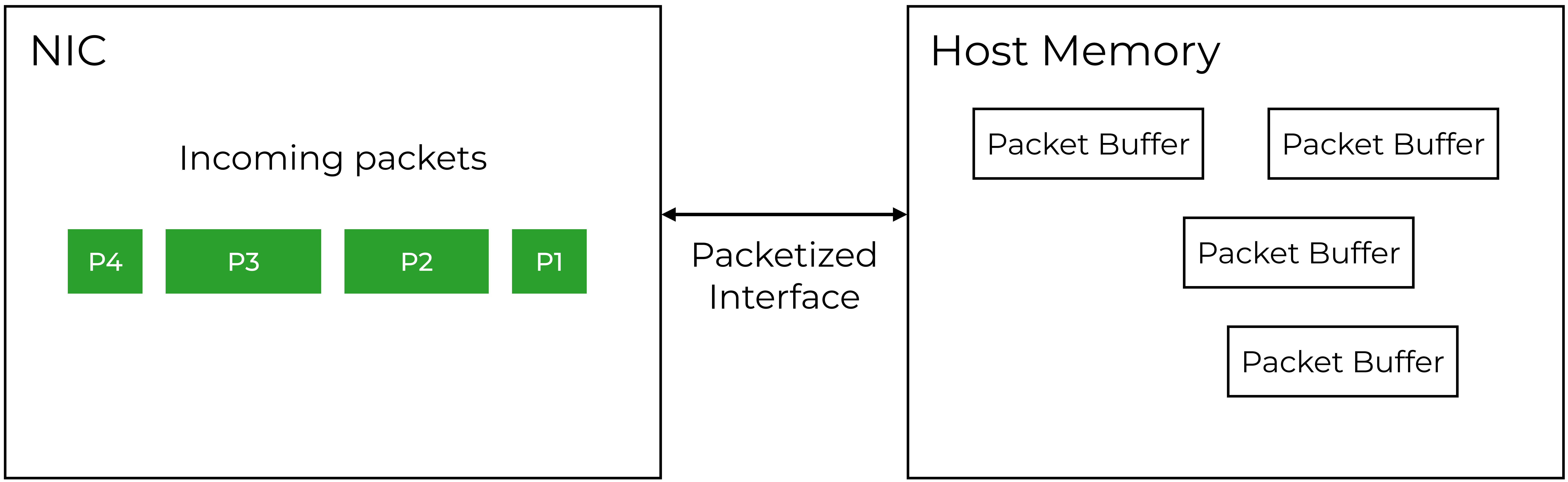

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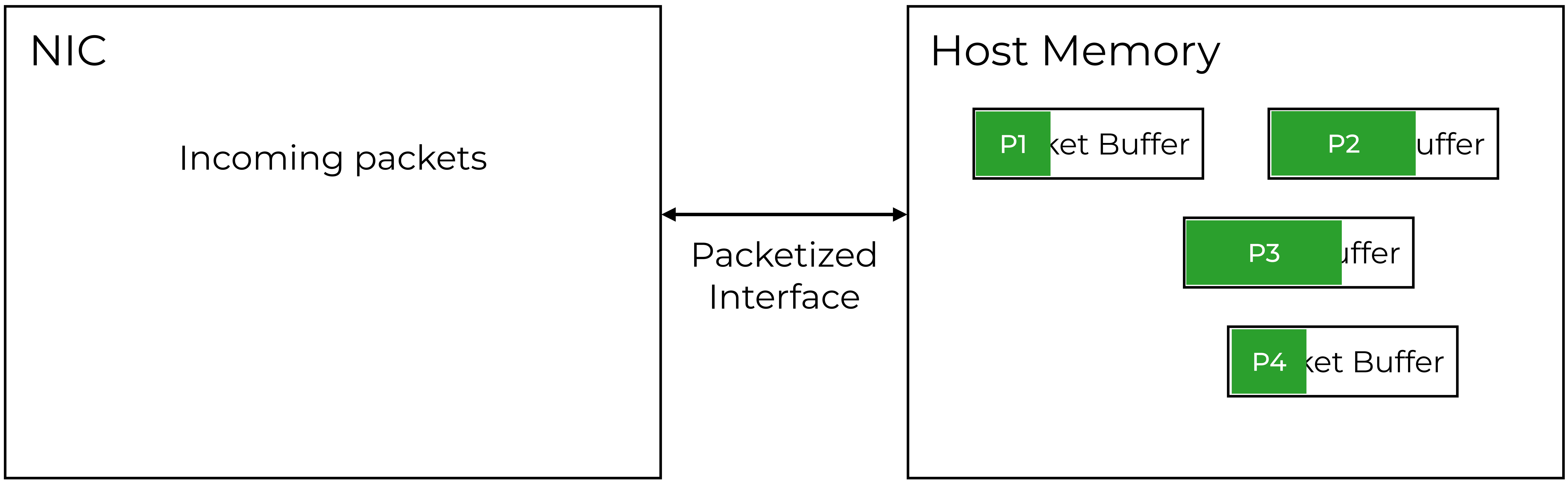
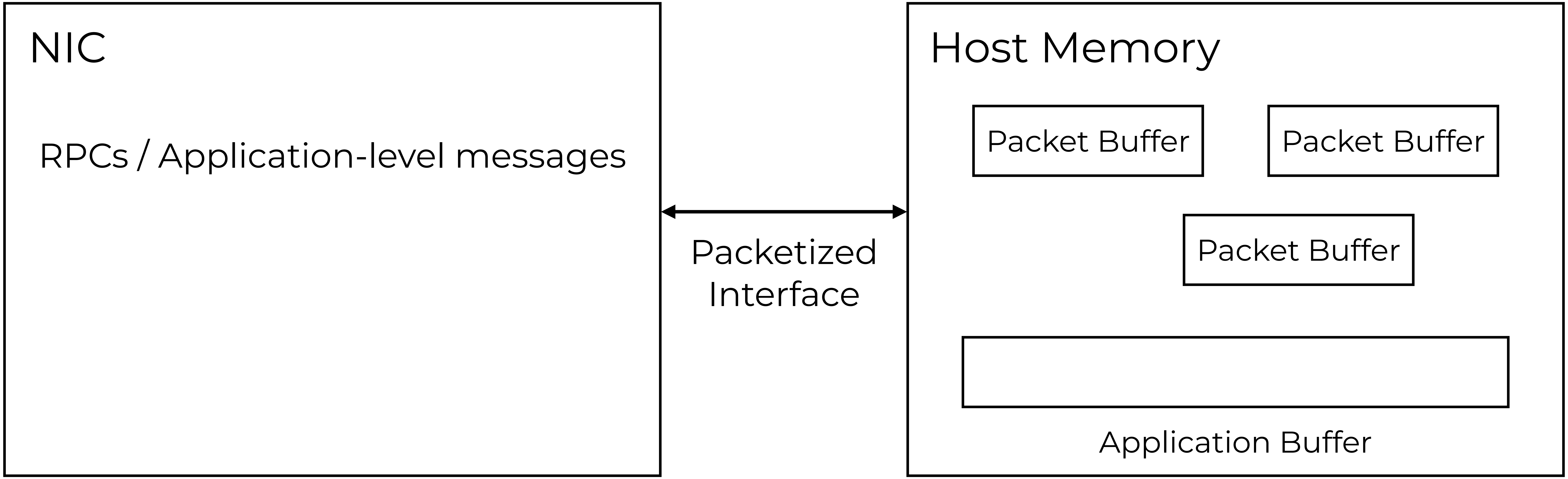


Problem #1 Packetized Abstraction

Packetized abstraction is unsuitable for higher-level offloads



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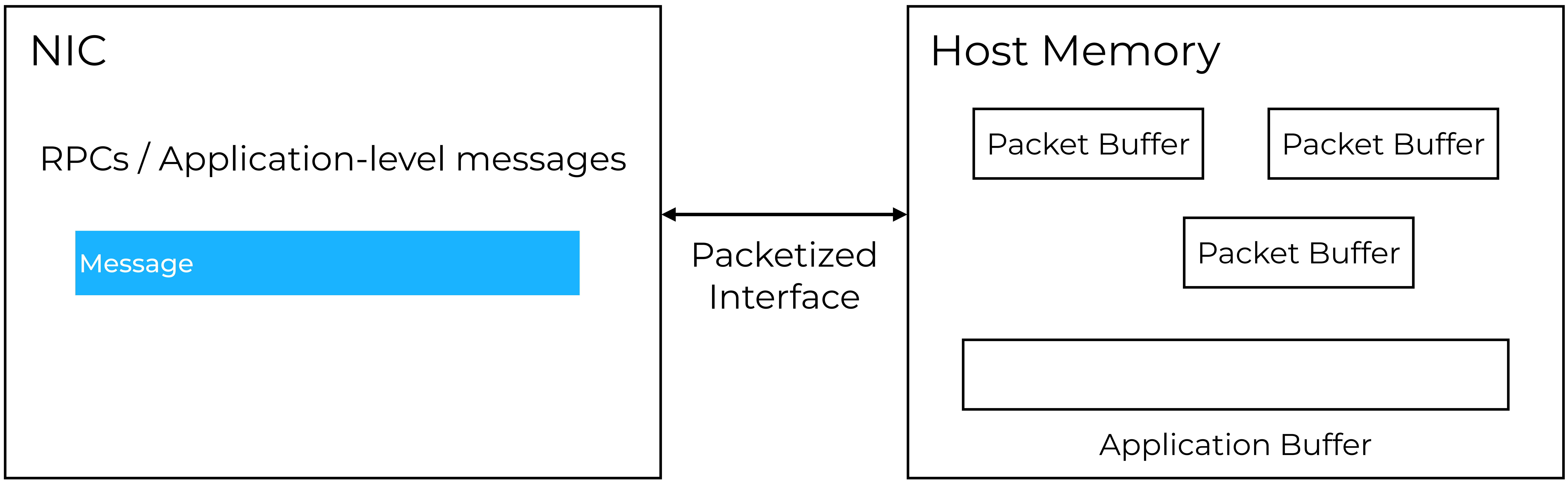

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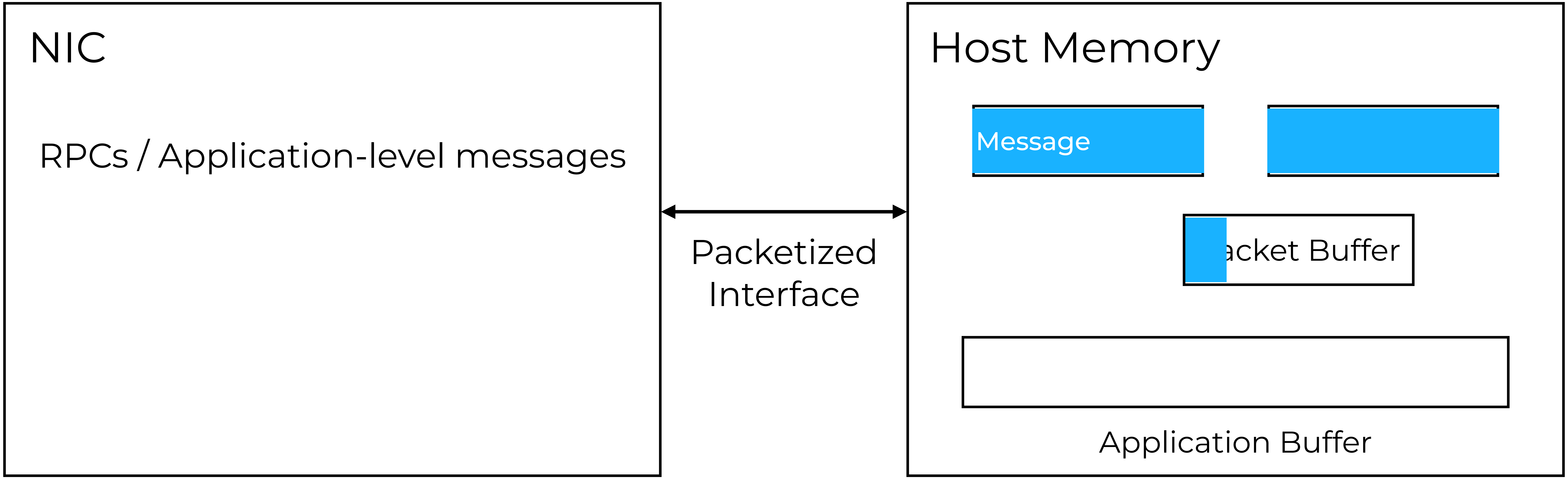

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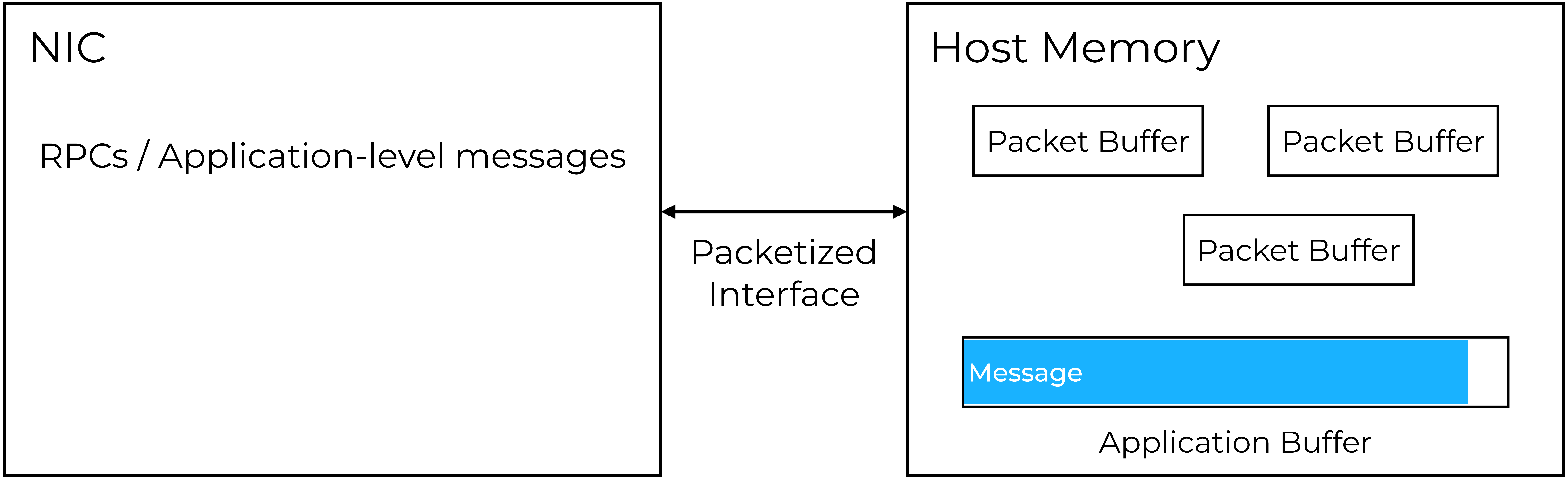

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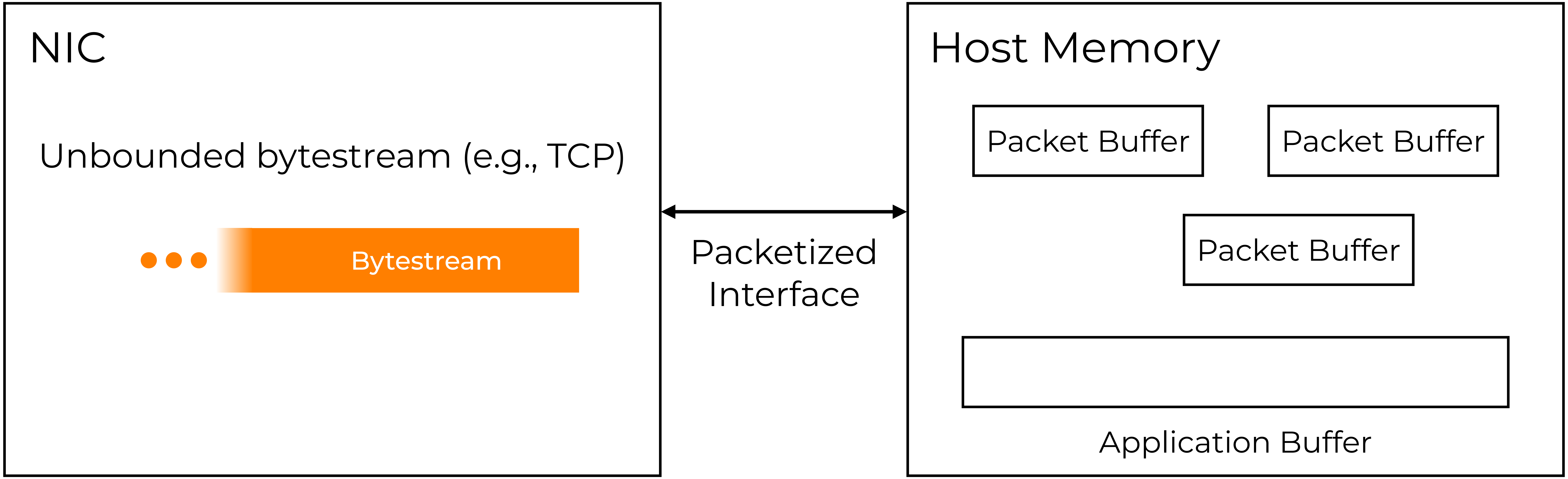

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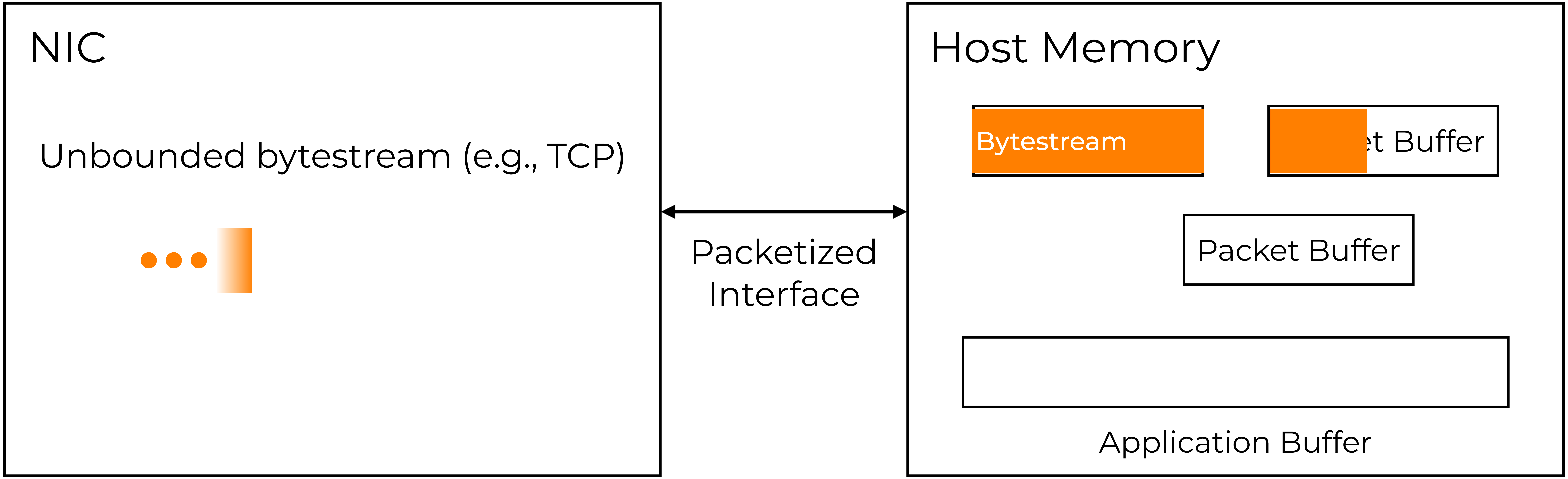

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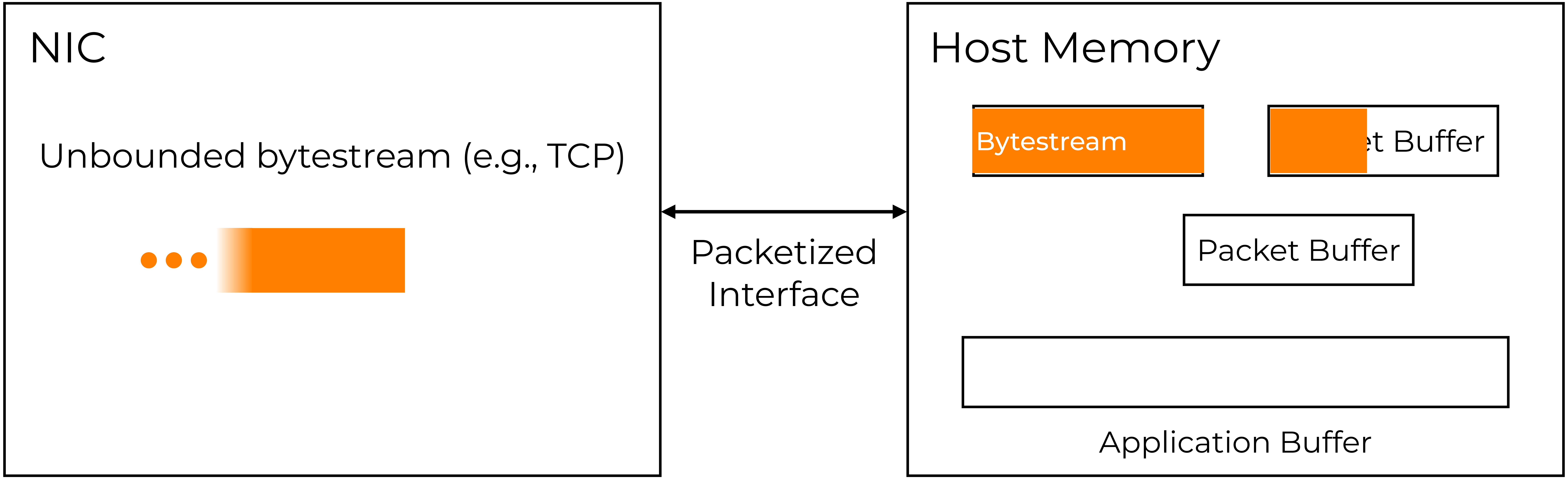

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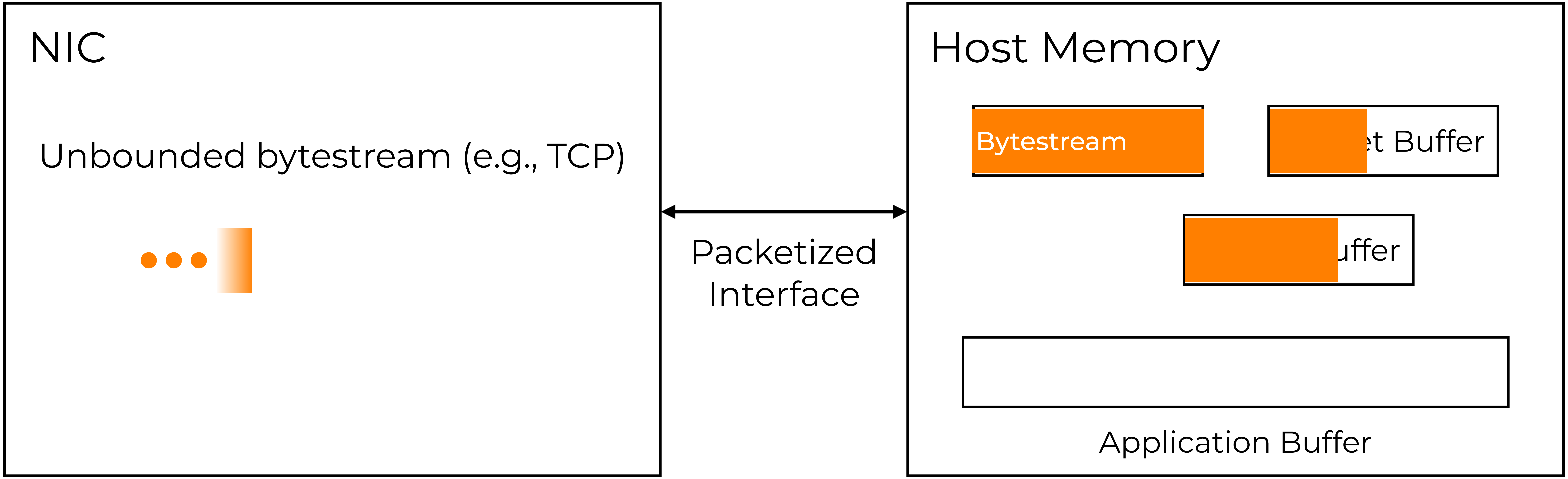

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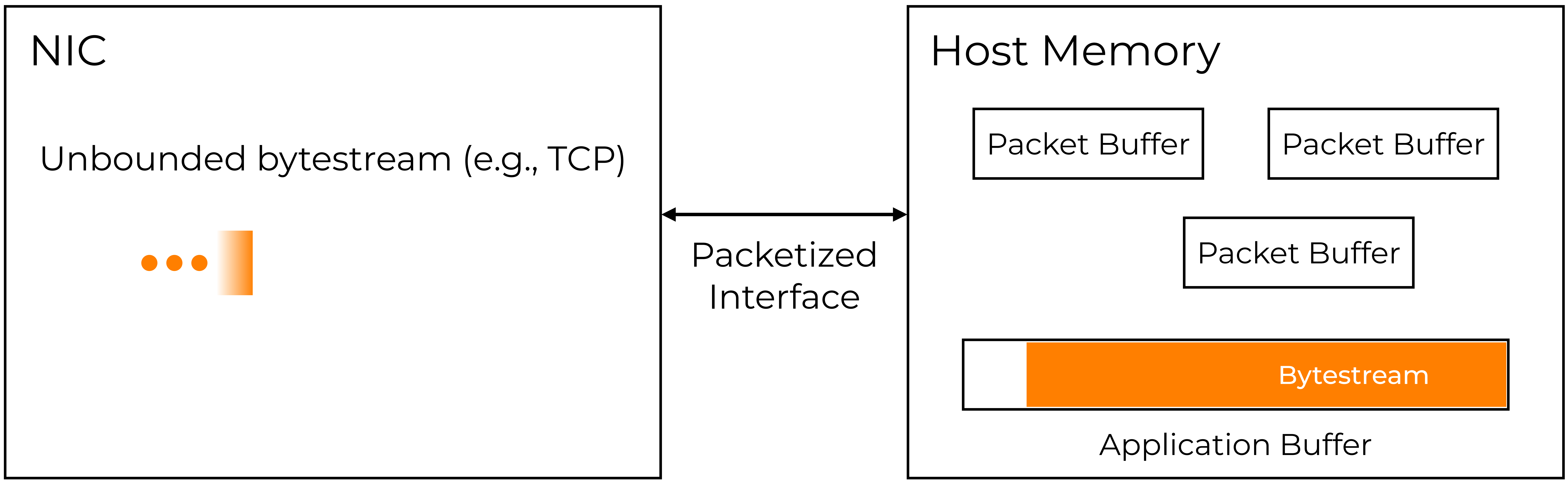
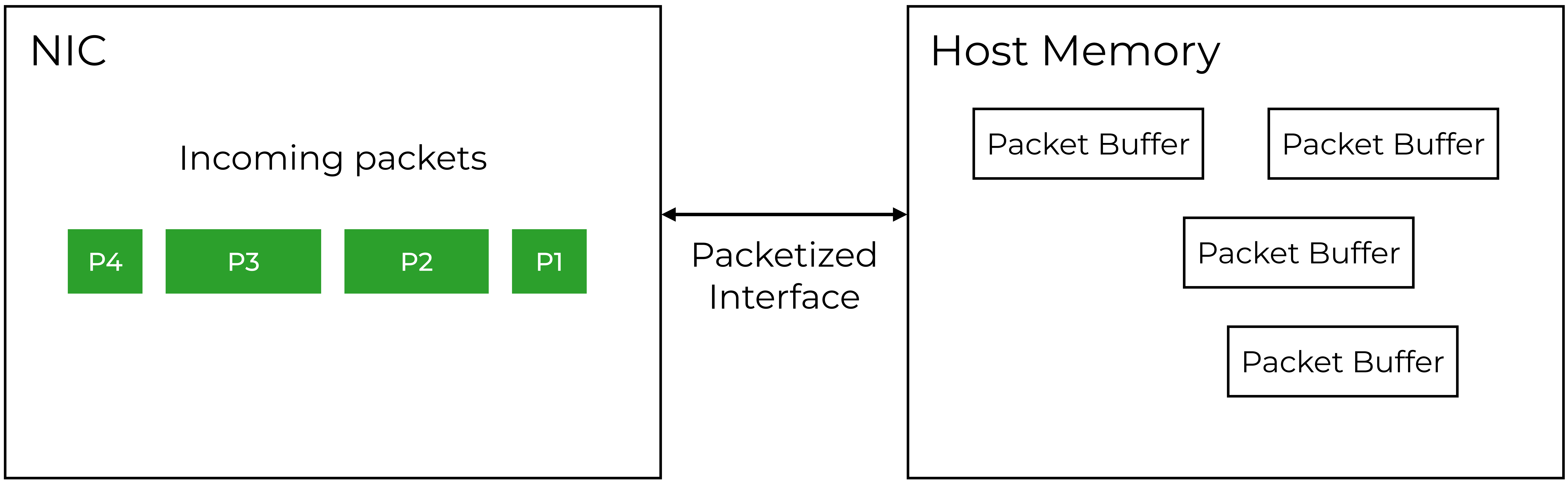


Problem #2 Poor Cache Interaction

Poor cache interaction due to chaotic memory access



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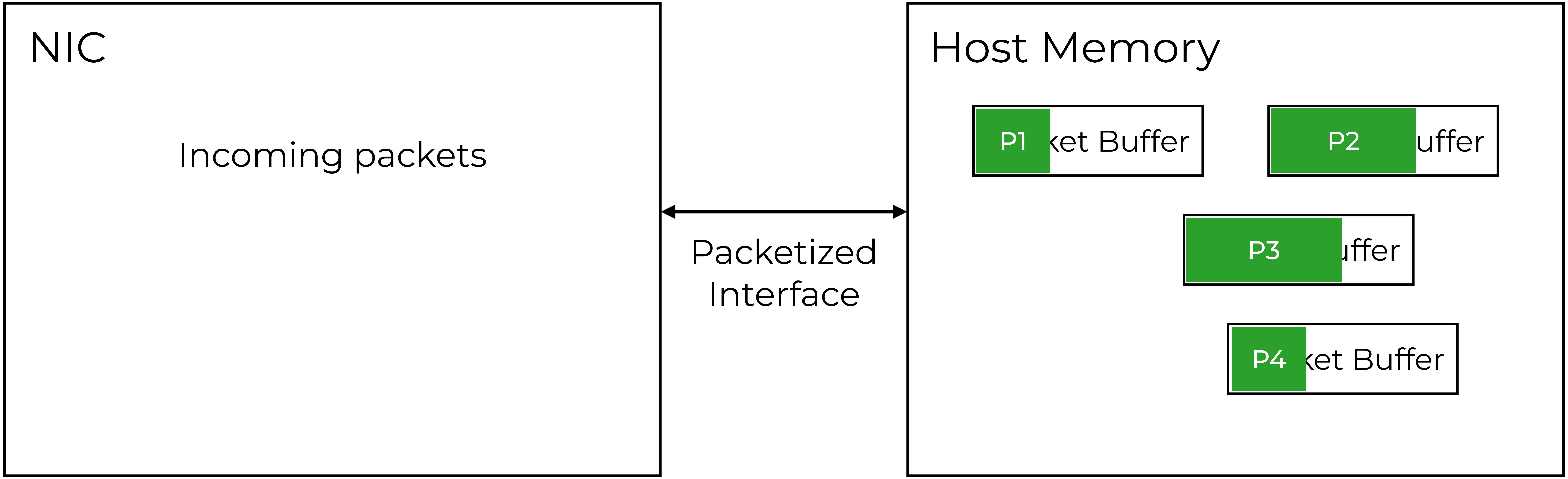

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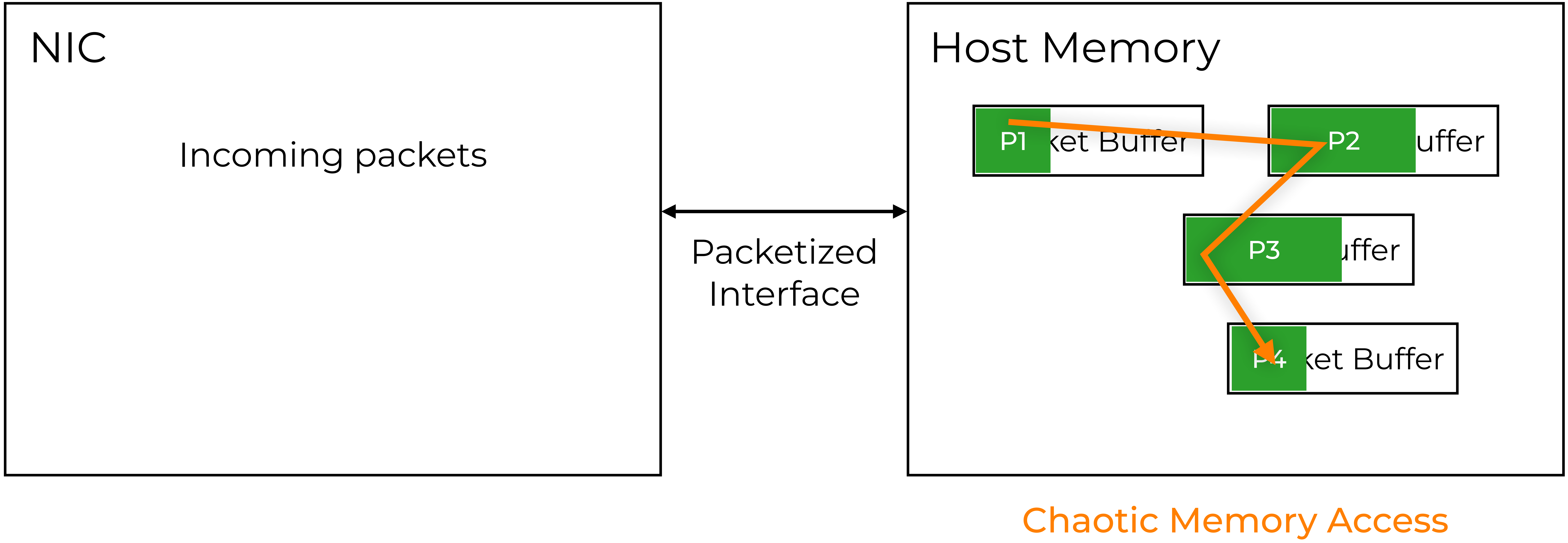

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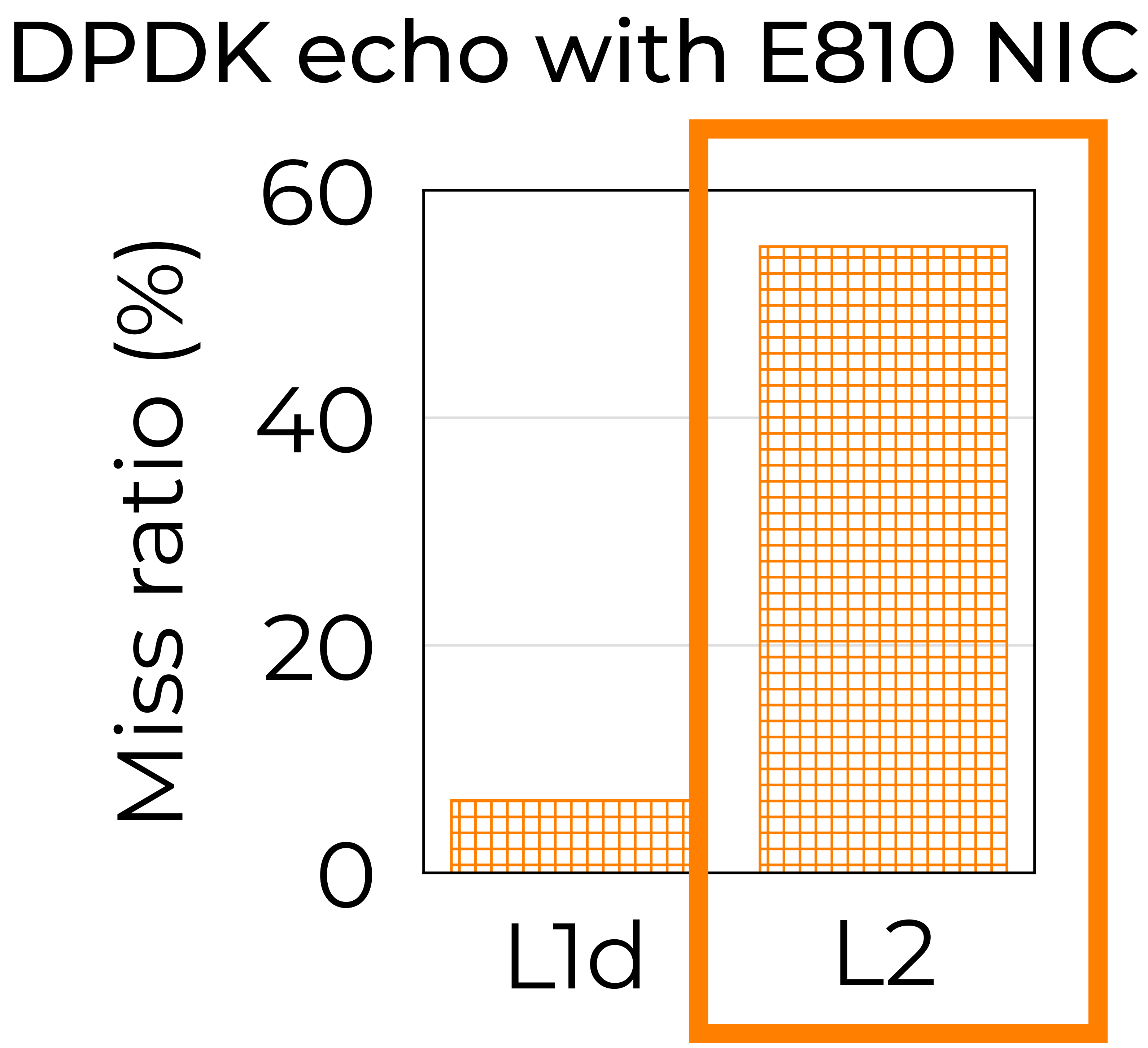
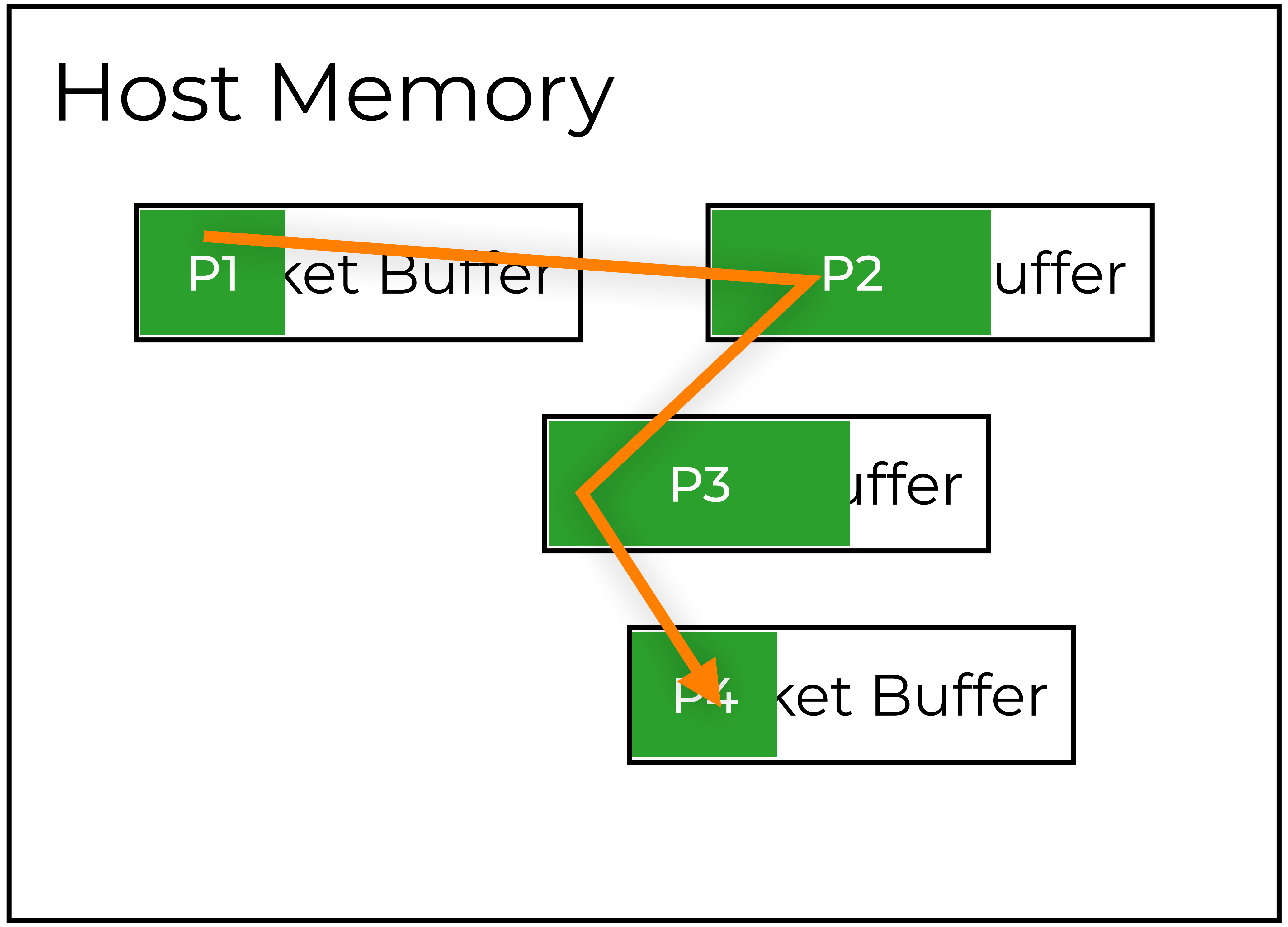


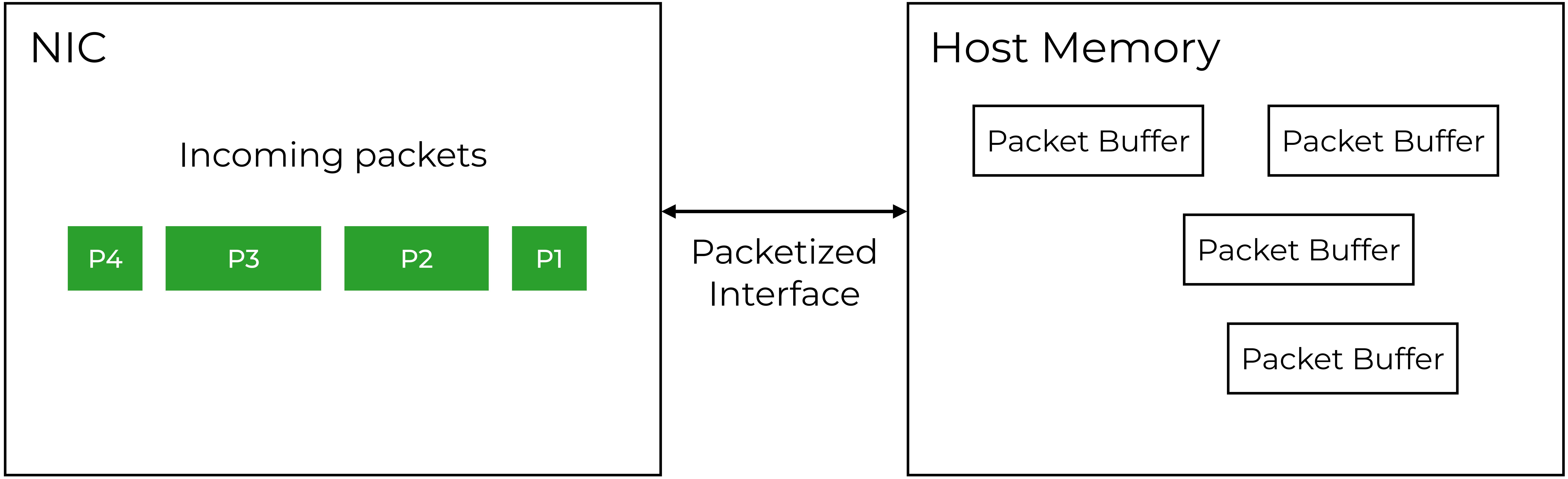


55% Miss Ratio for the L2 Cache

Chaotic Memory Access

Problem #3 Metadata Overhead

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



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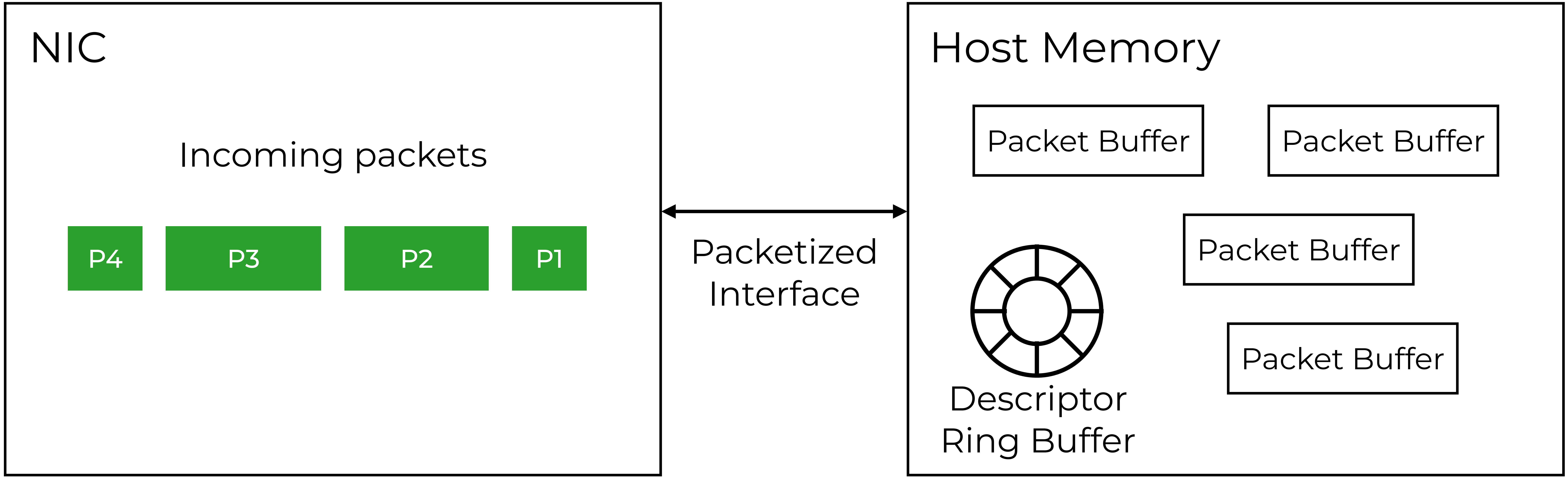

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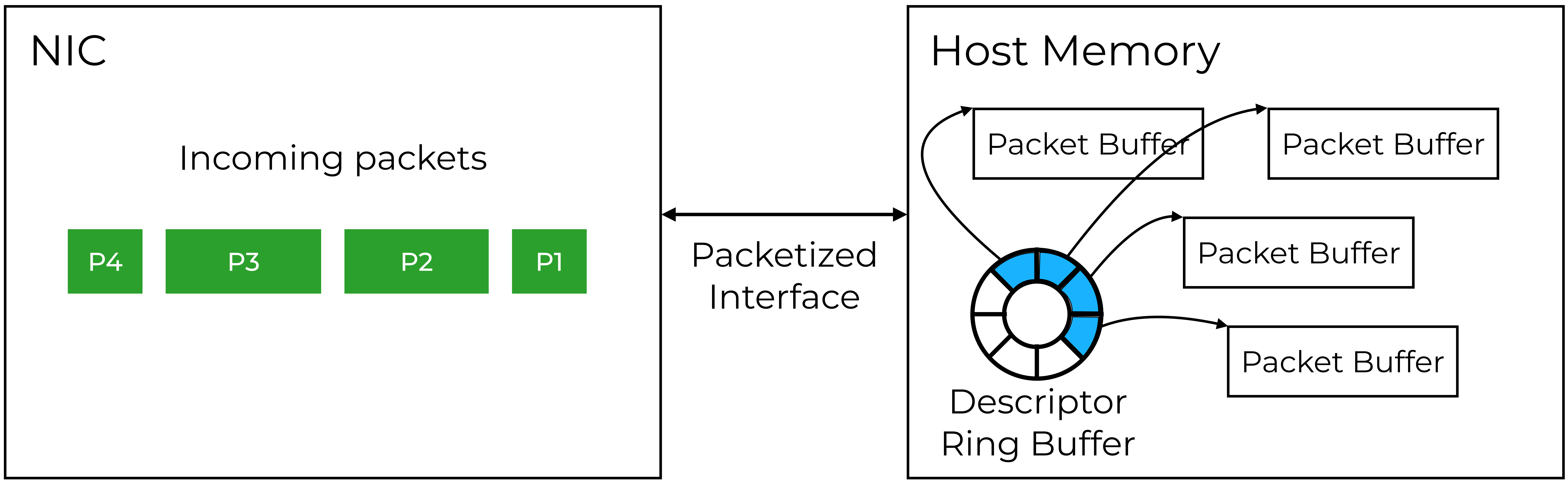

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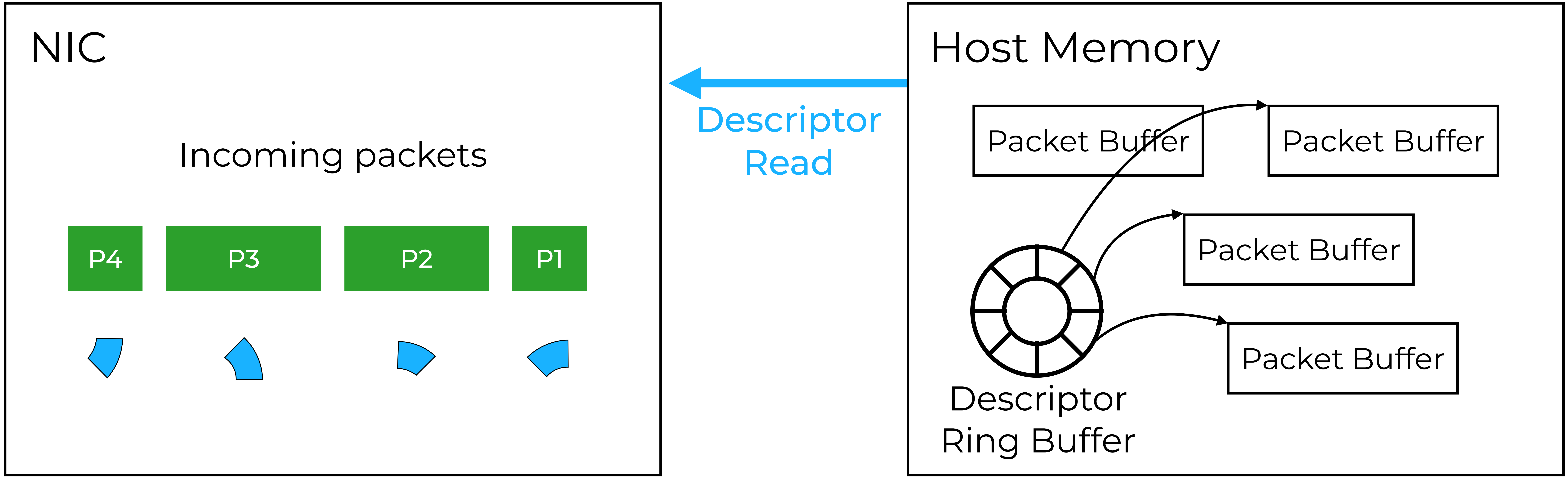

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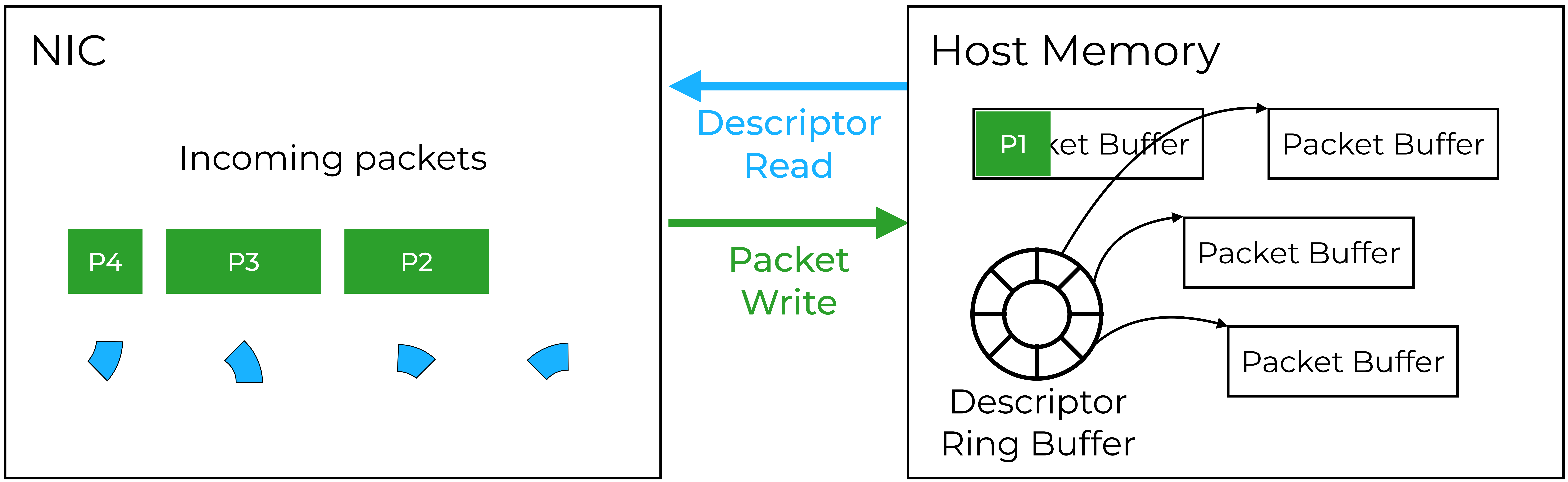

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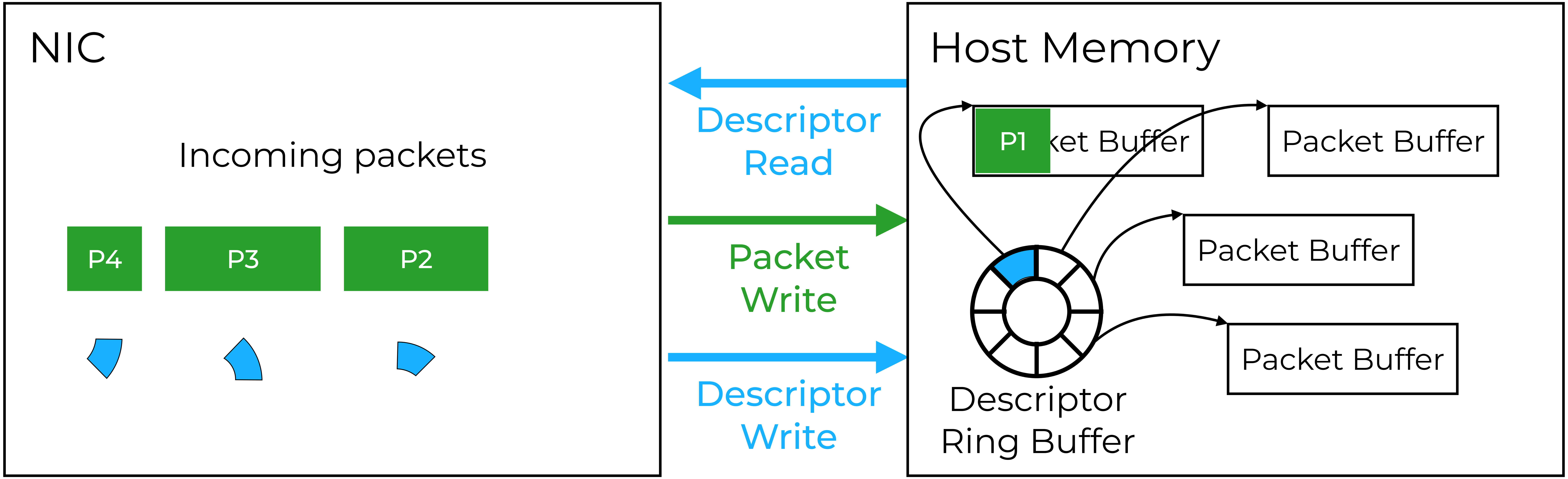

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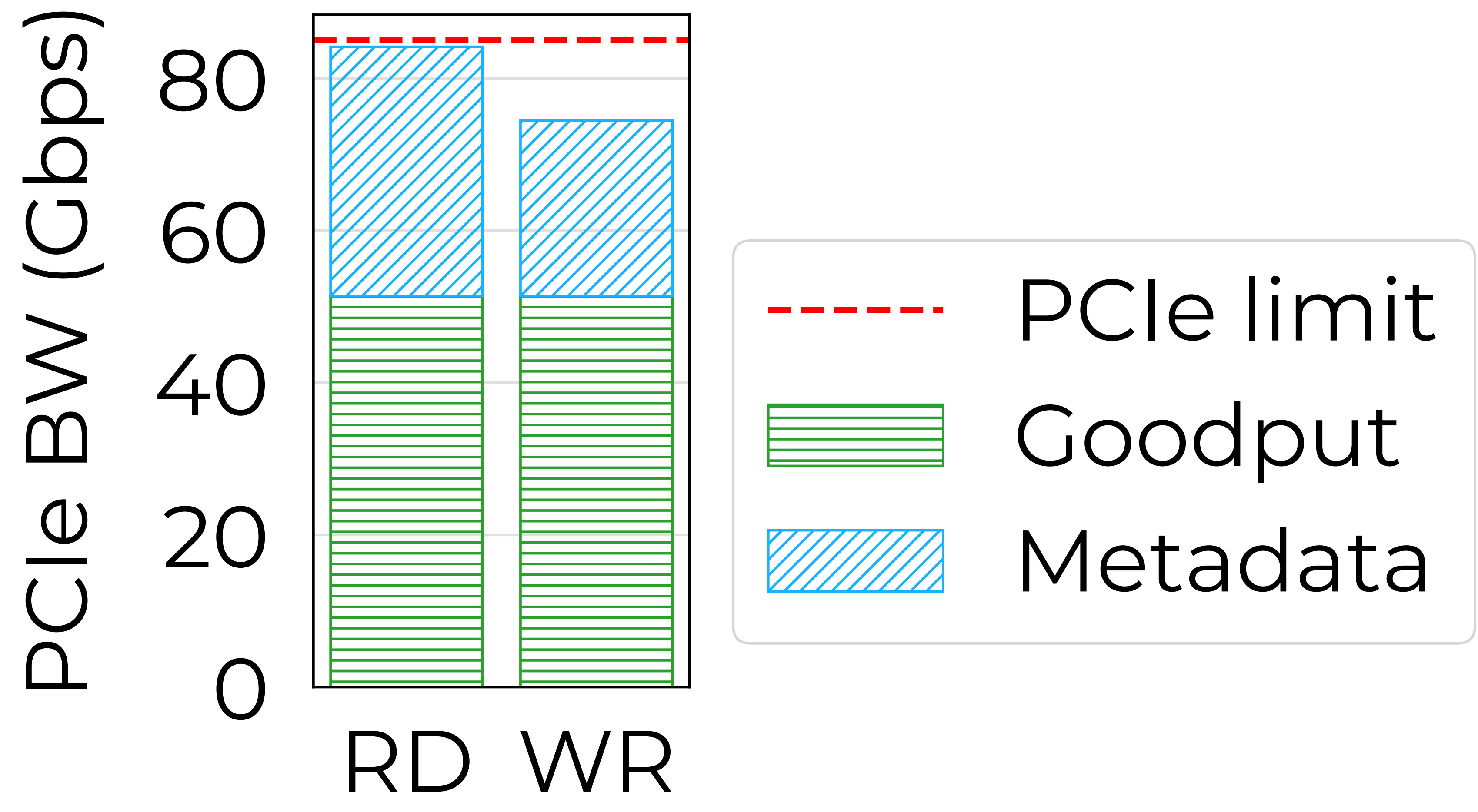
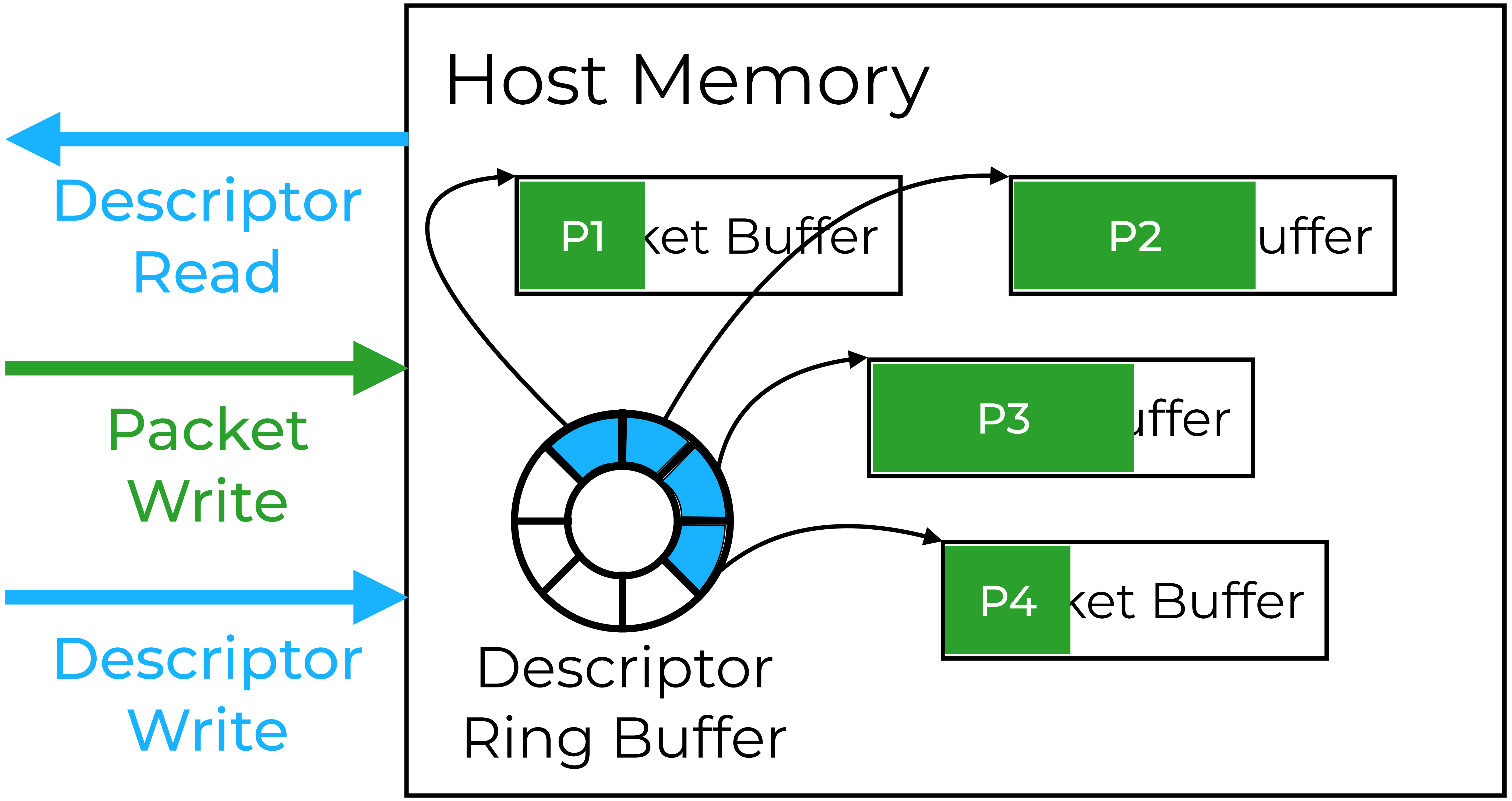
DPDK echo with E810 NIC



Up to 39% of PCIe bandwidth consumed with metadata



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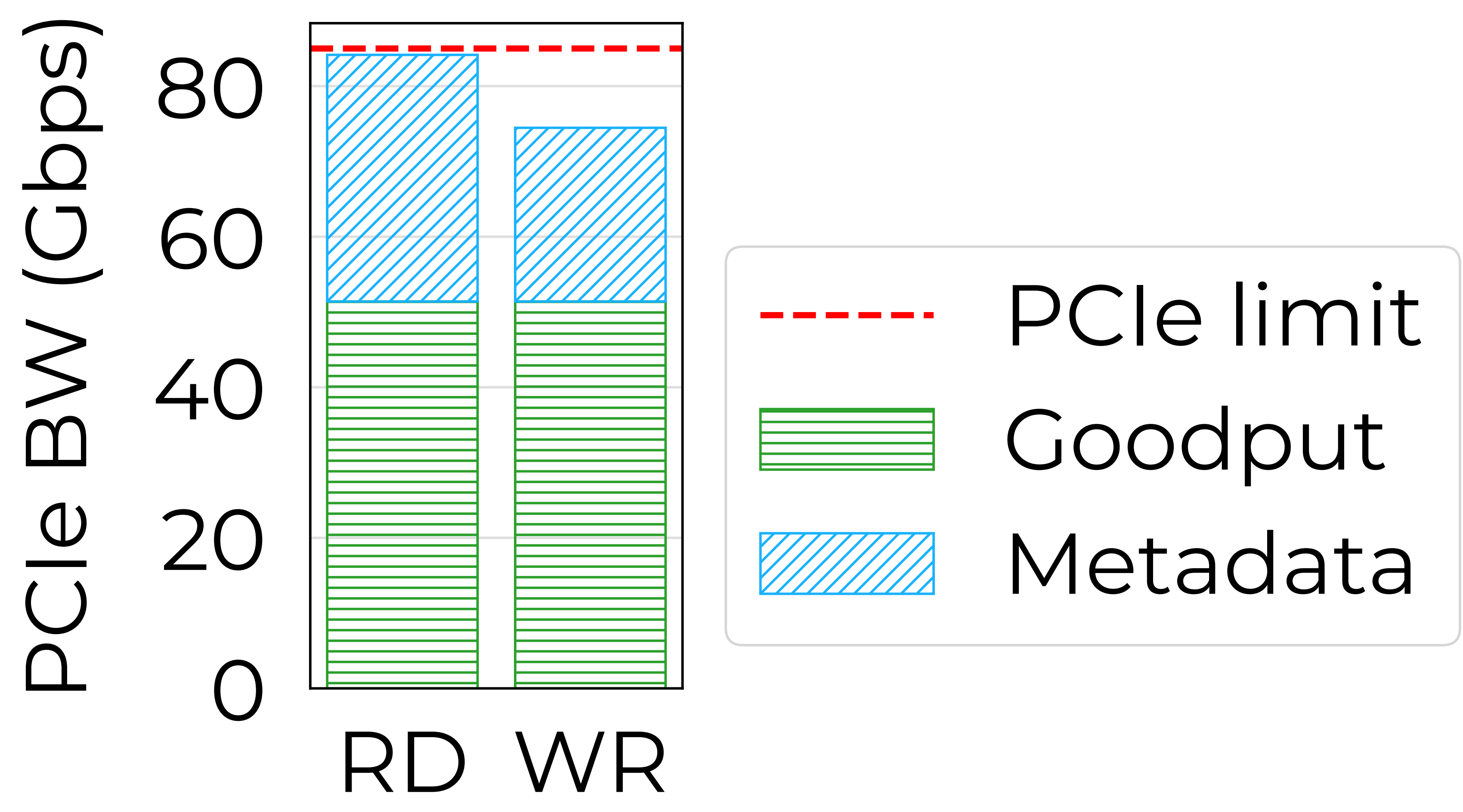
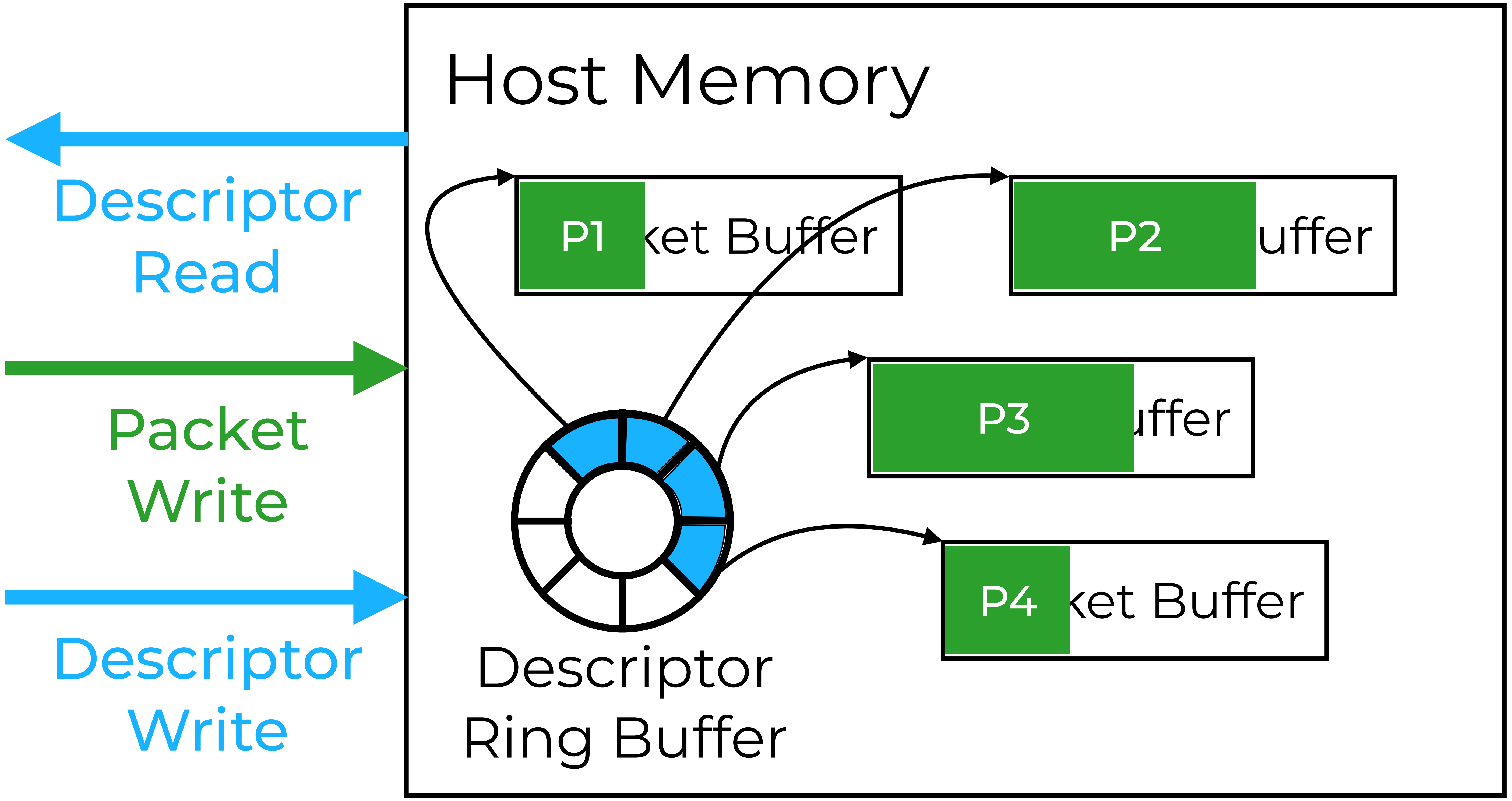
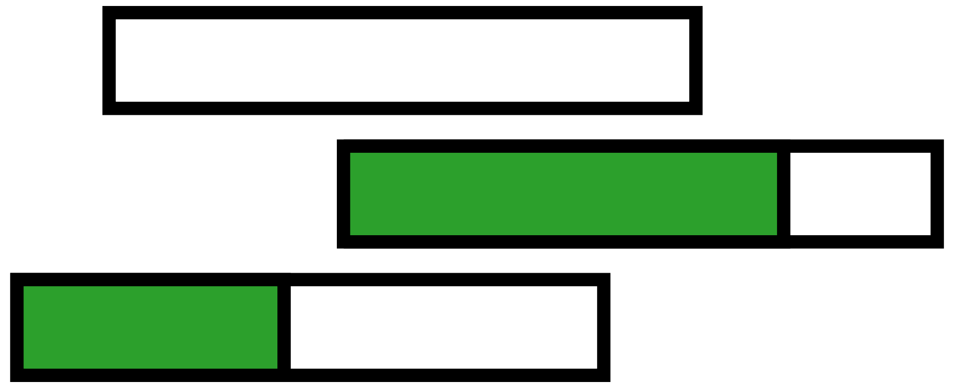




Up to 39% of PCIe bandwidth consumed with metadata

Similar process to transmit packets

Mismatch between how NICs are used and their interface



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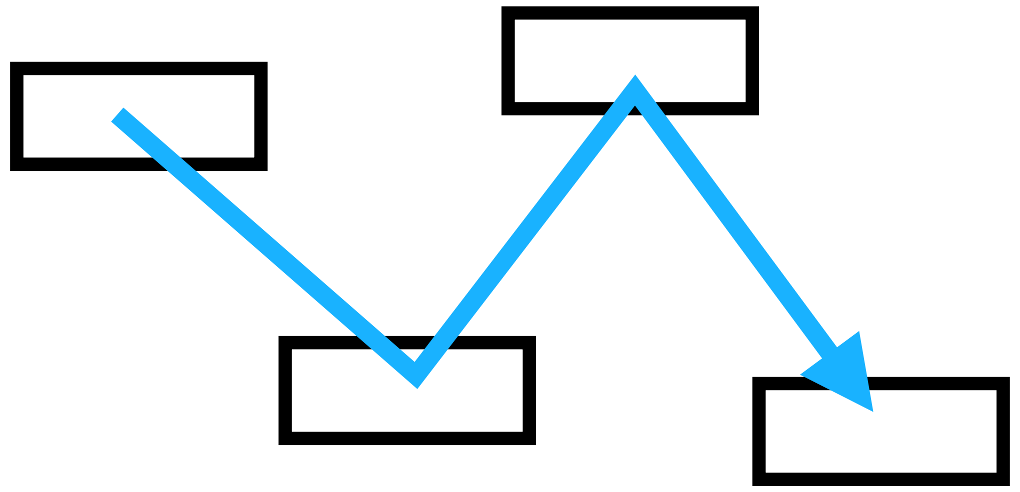

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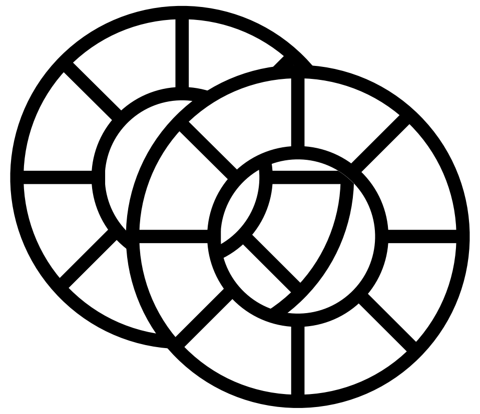

#3 Metadata Overhead

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New interface for NIC-Application Communication

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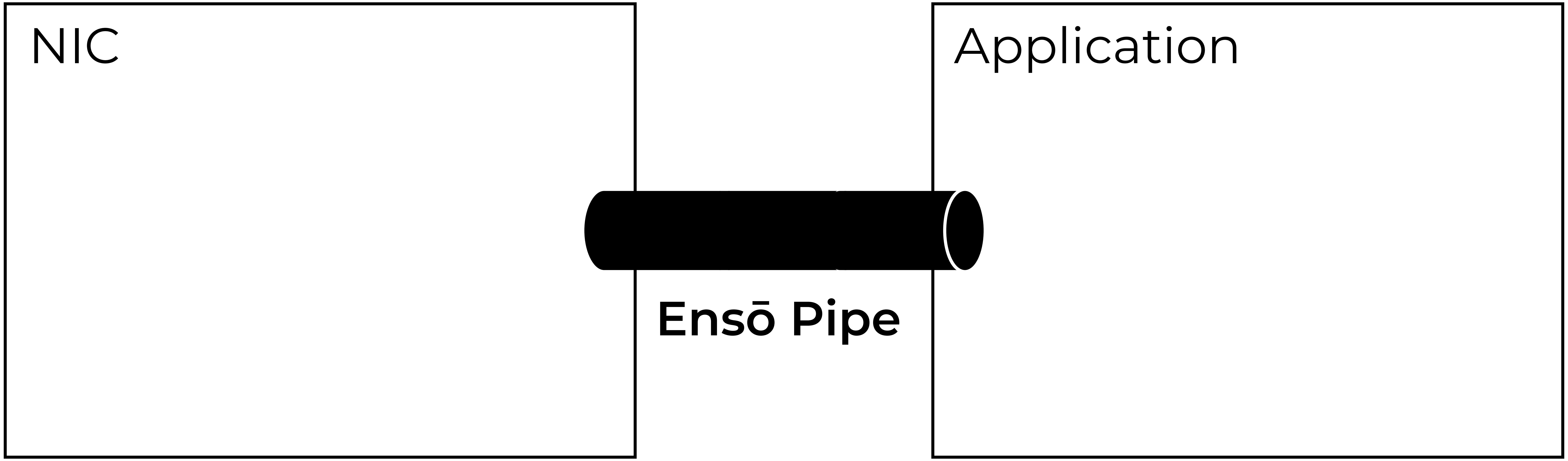
Key Idea: Streaming abstraction



Ensō

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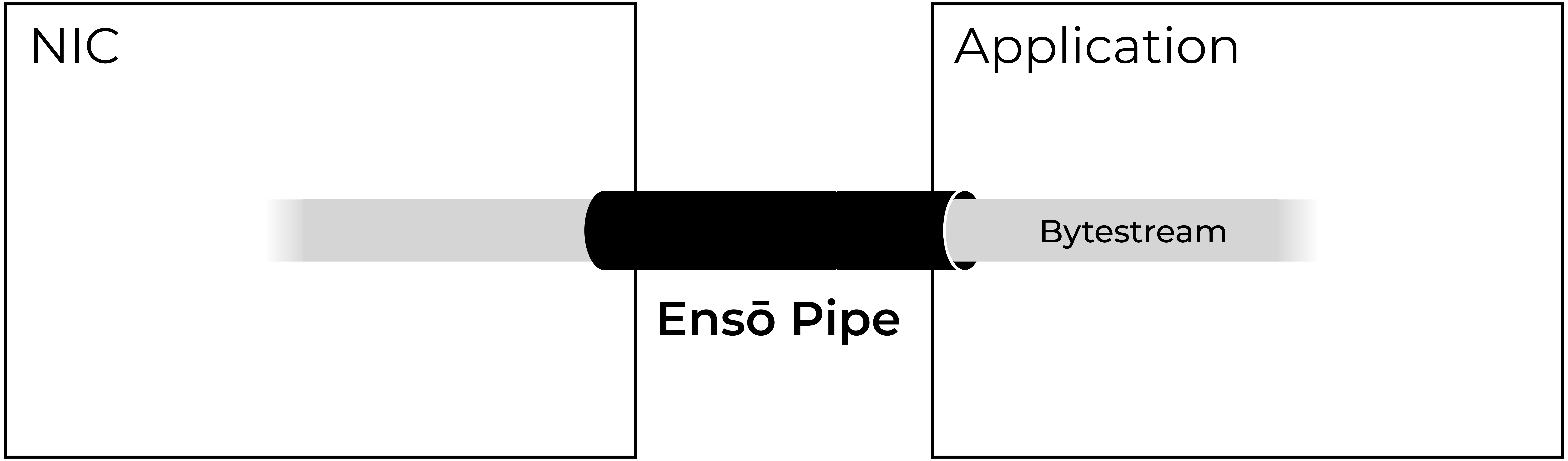

What is a Streaming Abstraction?

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Provide the illusion of an unbounded buffer

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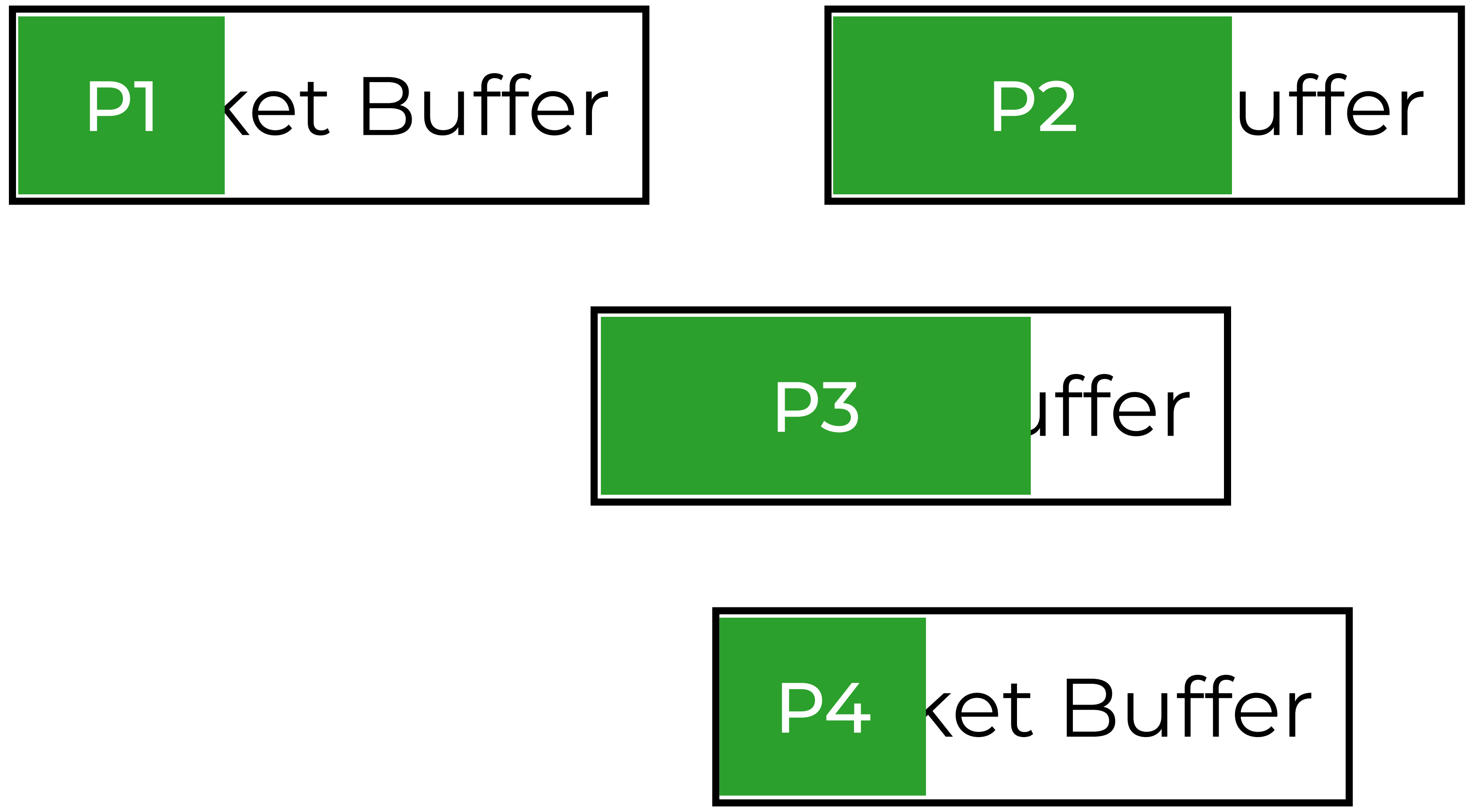

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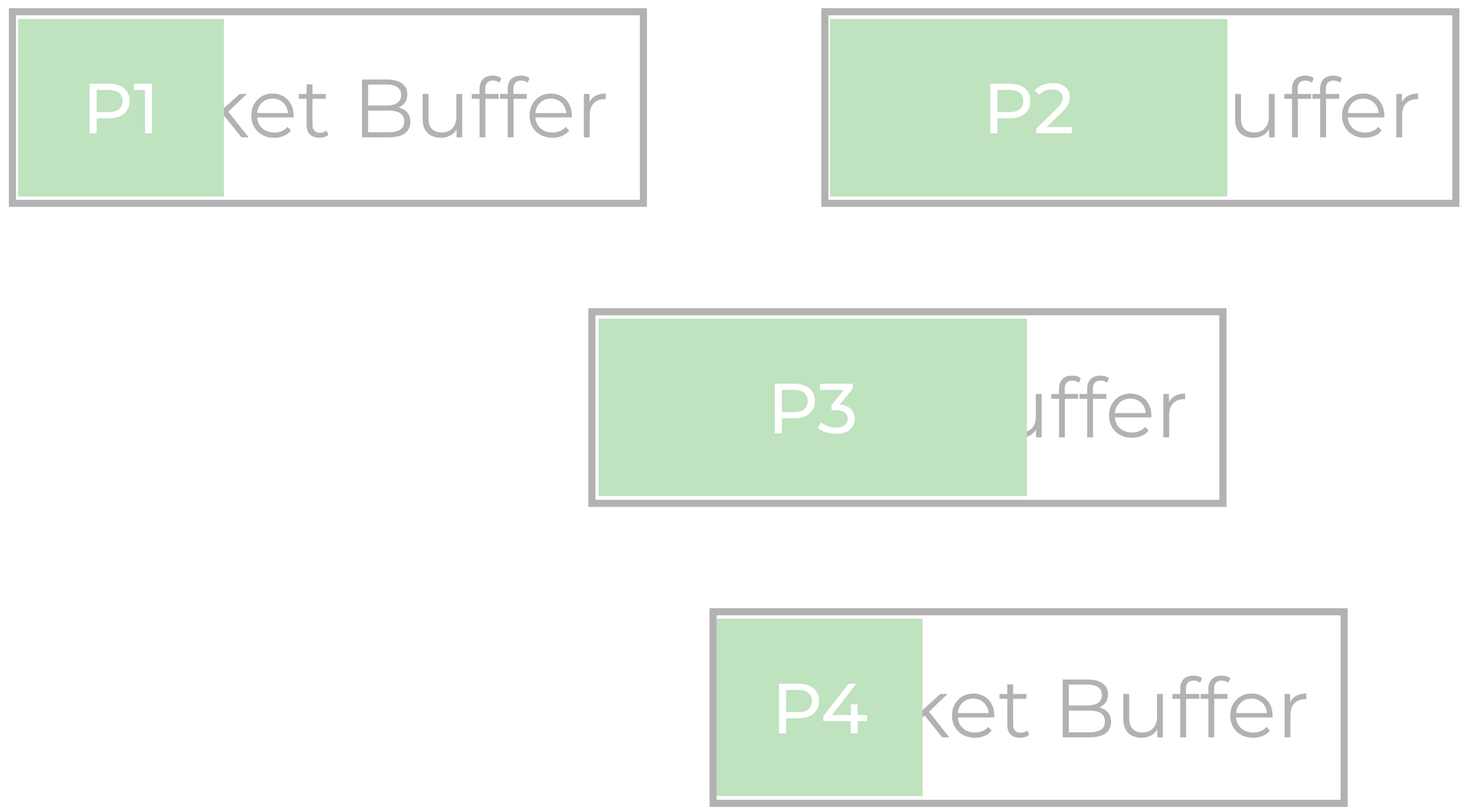

Packetized Abstraction

Unbounded Buffer

Streaming Abstraction

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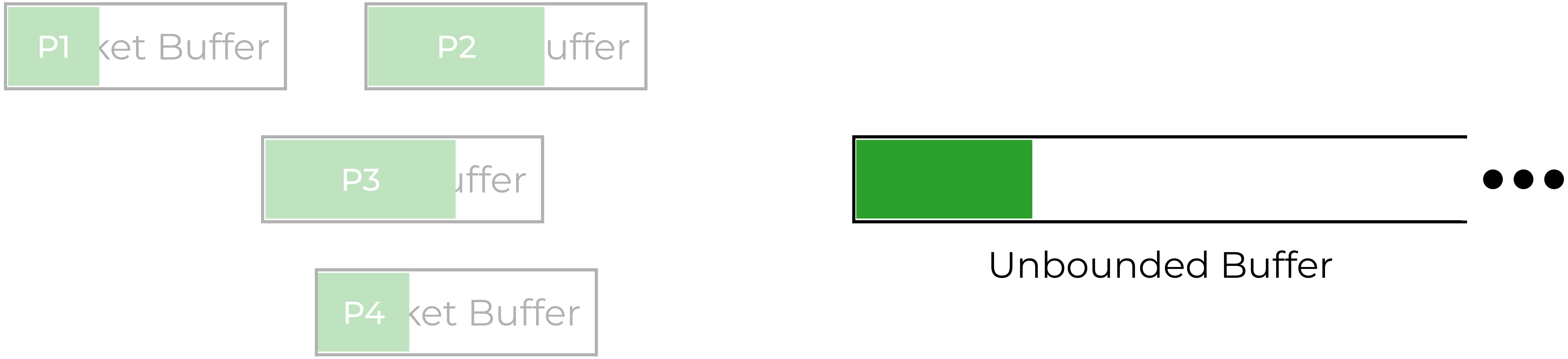

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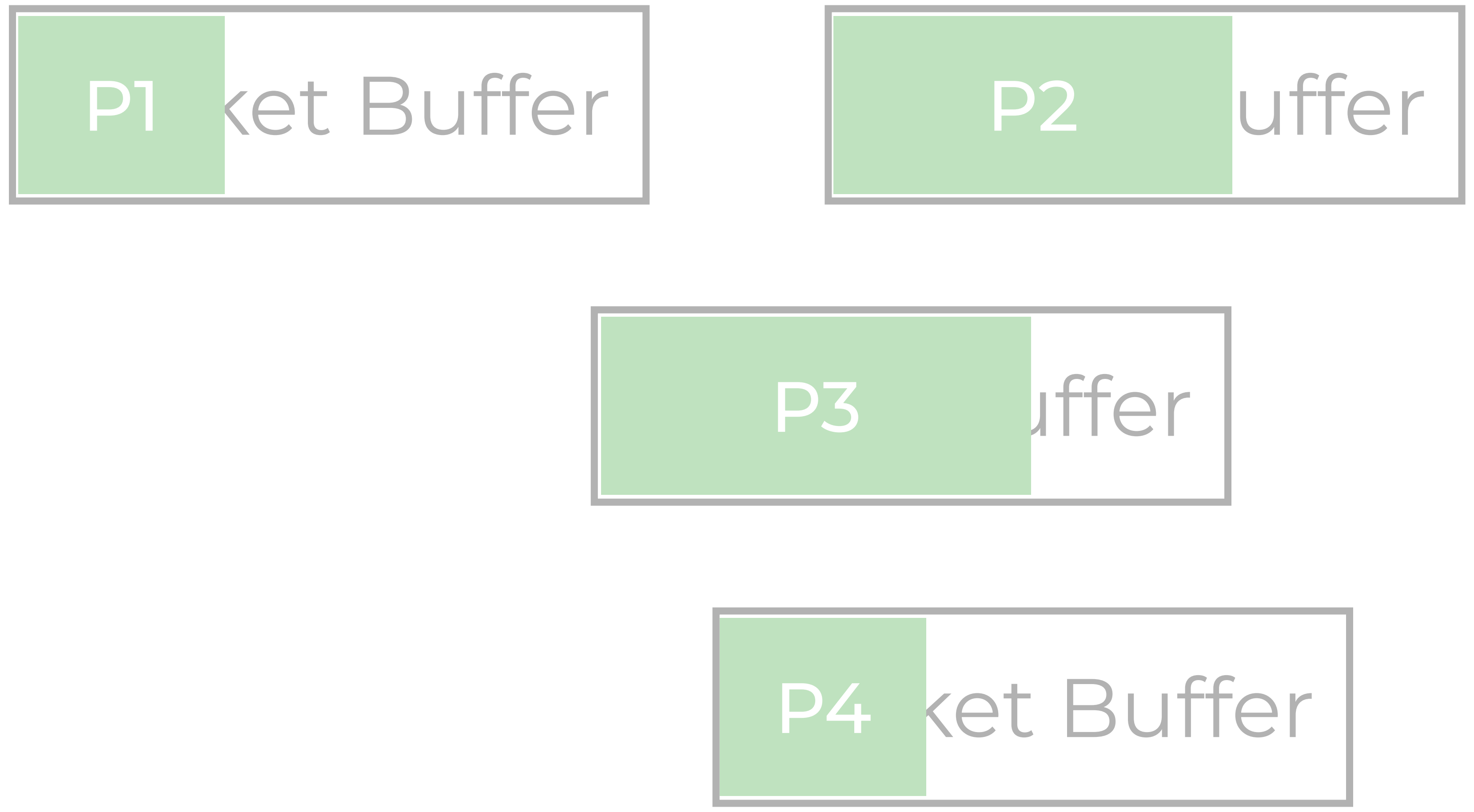

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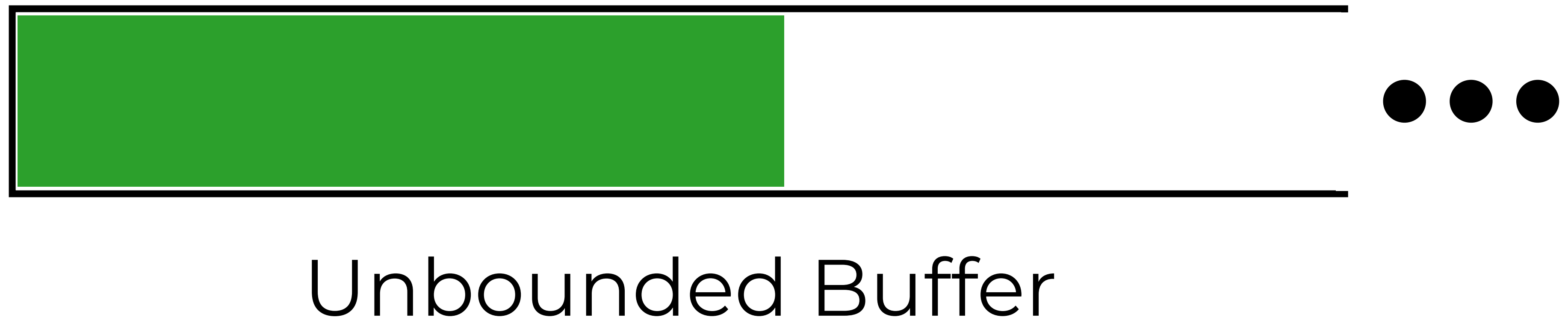

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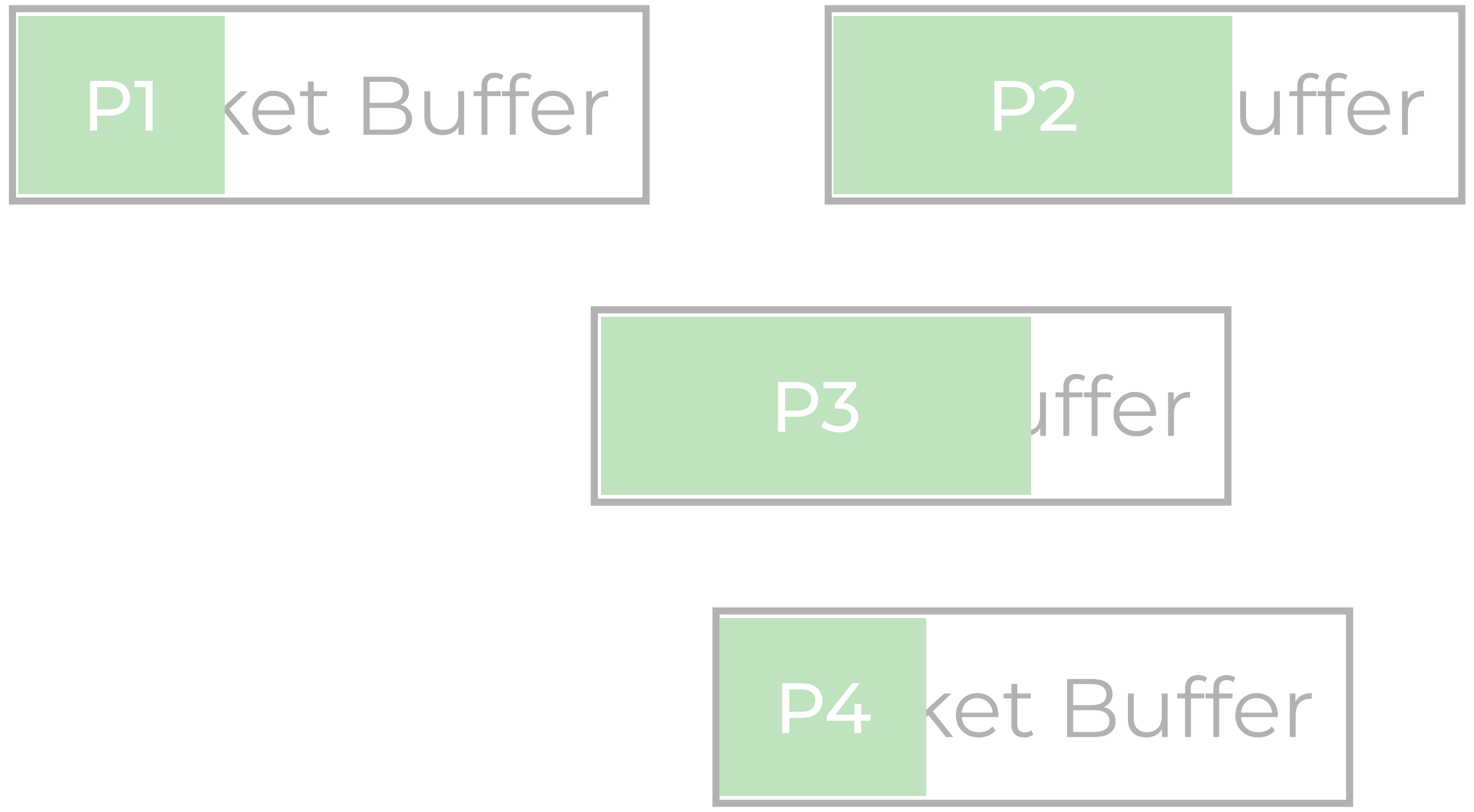

Unbounded Buffer

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Streaming Abstraction

Flexibility of a Streaming Abstraction

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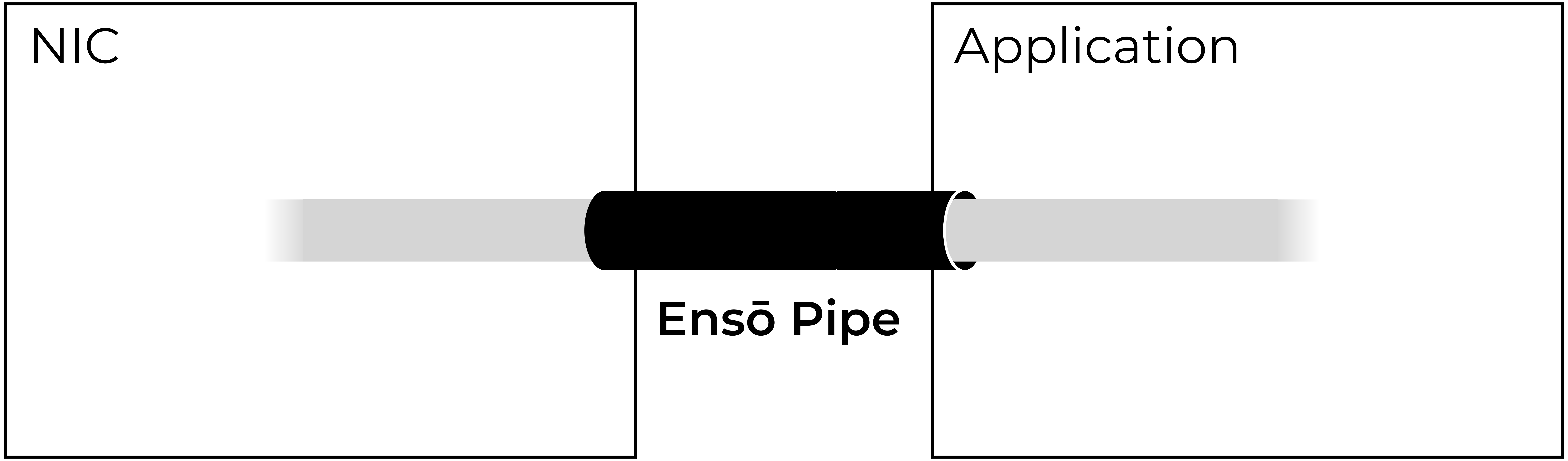

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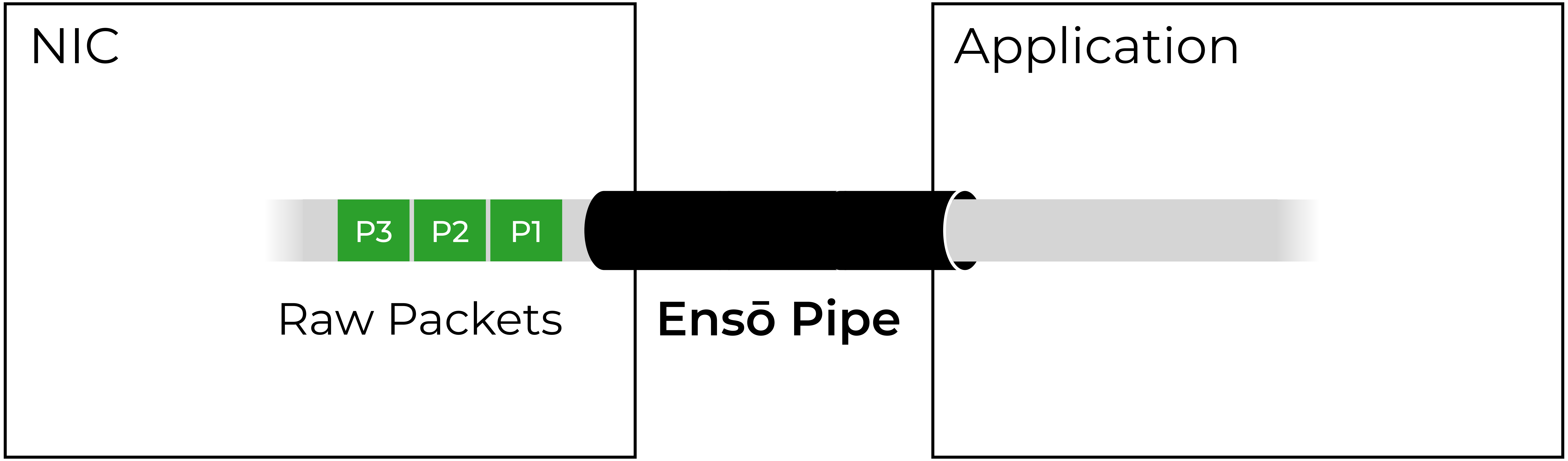
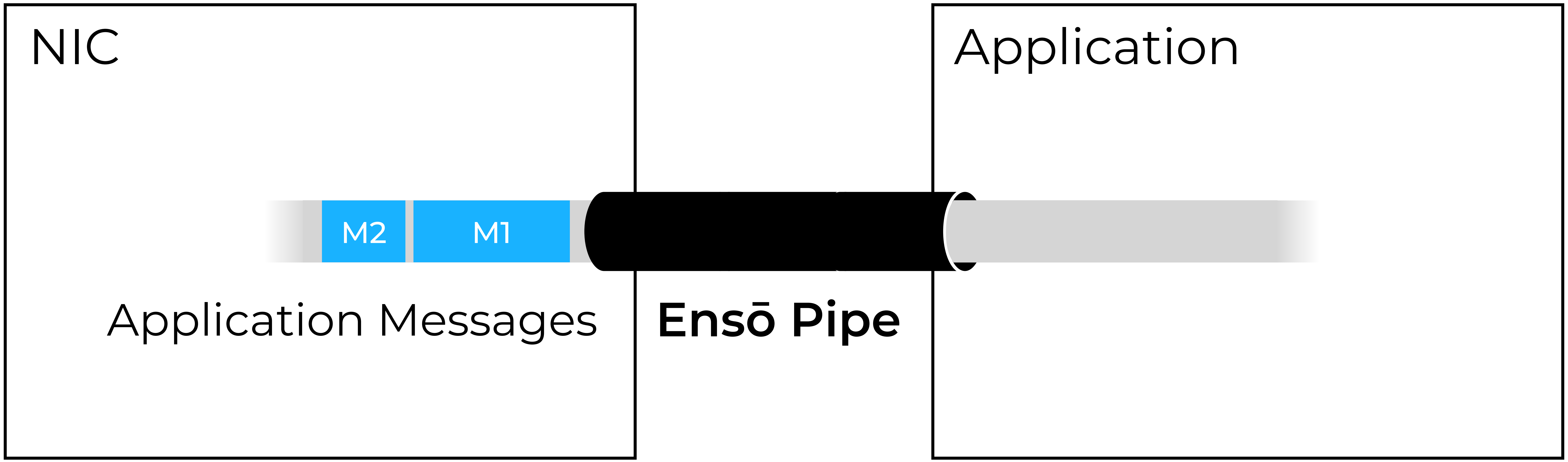


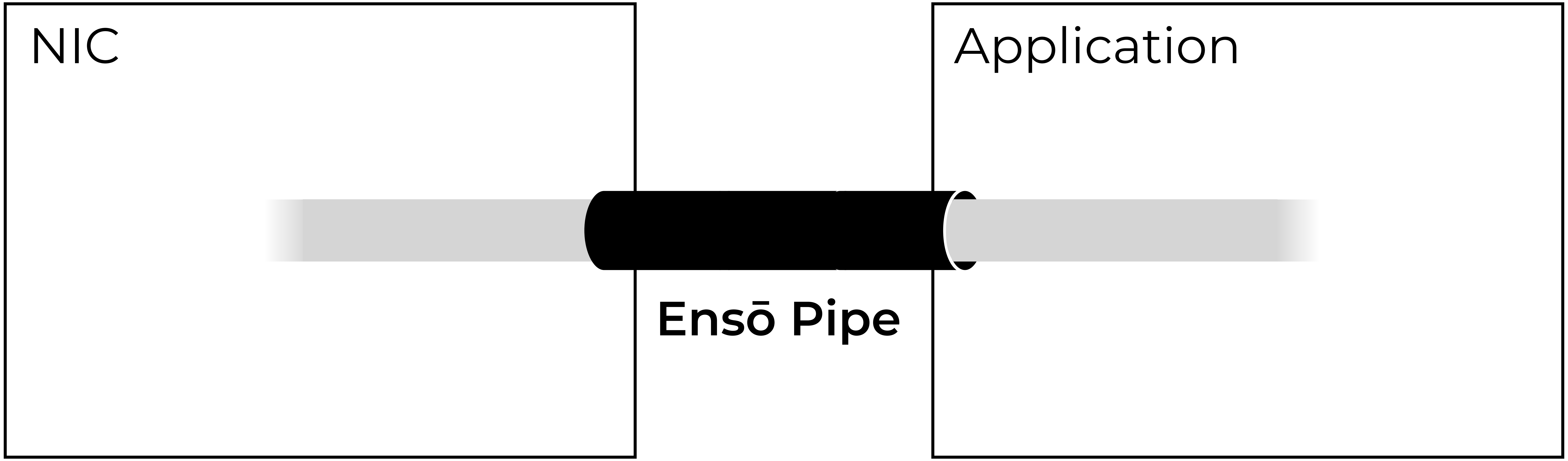
Flexibility of a Streaming Abstraction

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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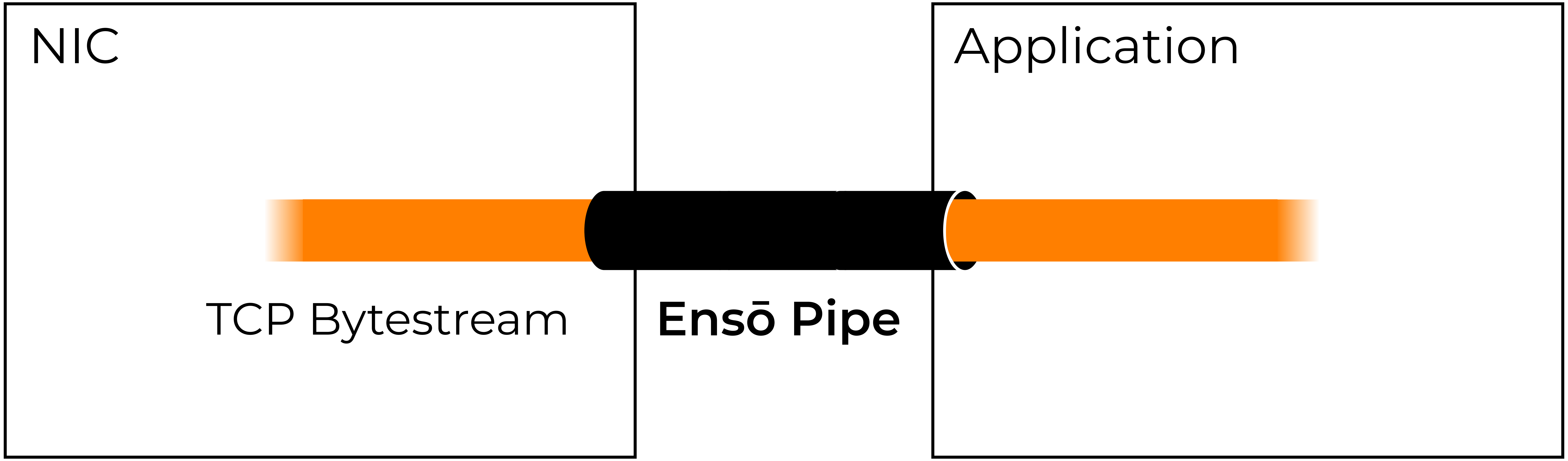

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Ensō Pipe

Each pipe consists of a single contiguous buffer

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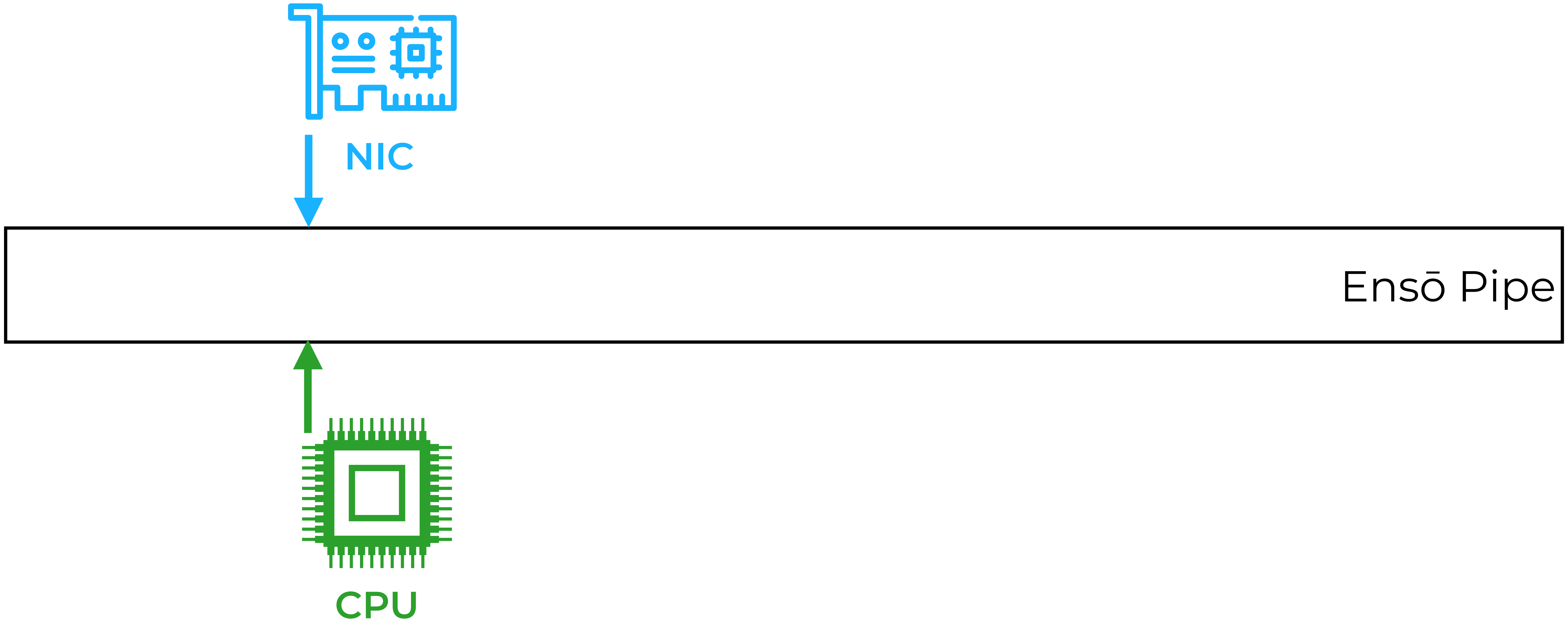

Each pipe consists of a single contiguous buffer

We treat this buffer as a ring buffer for data

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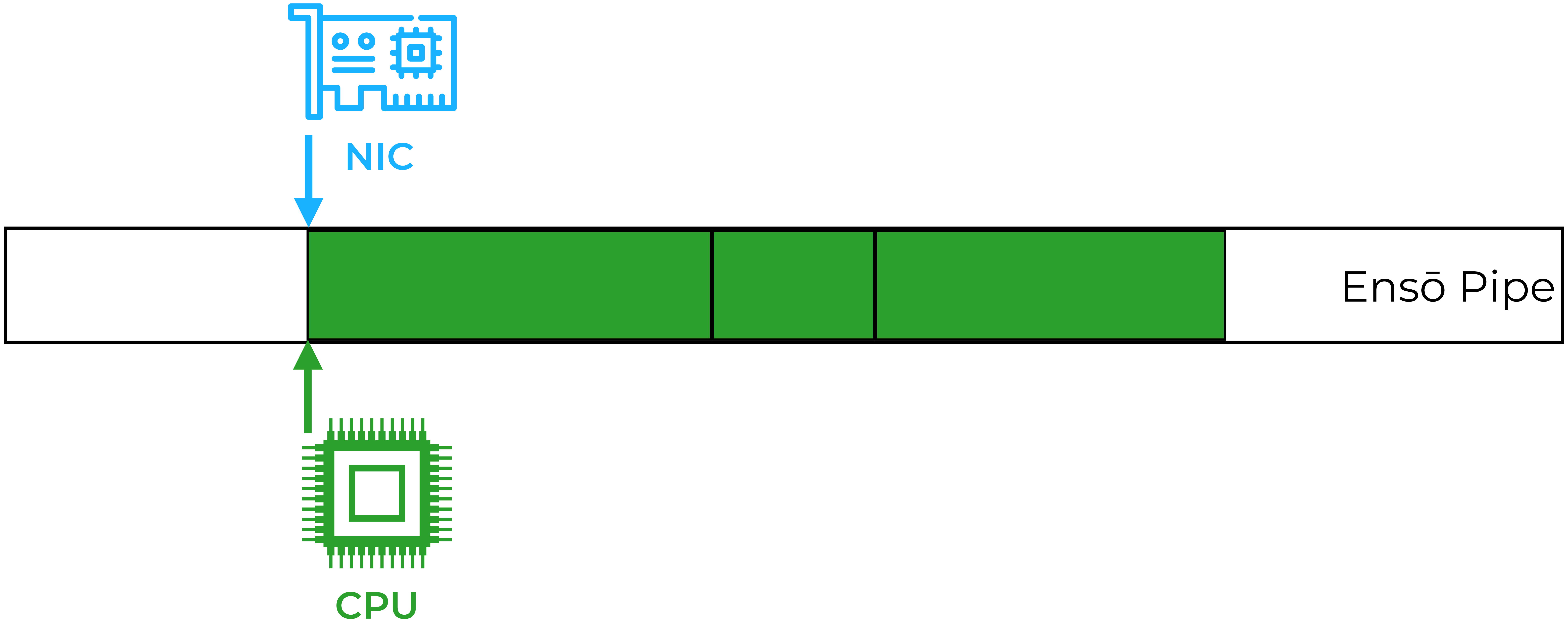

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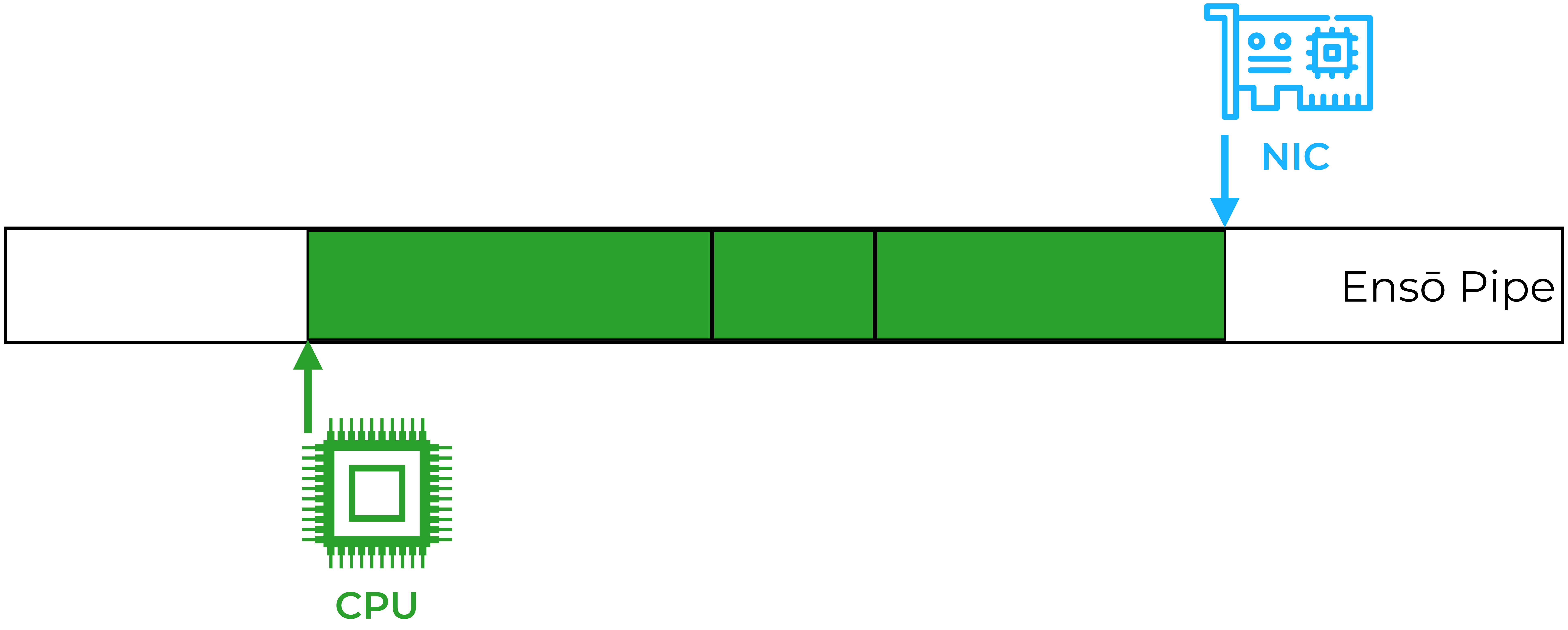

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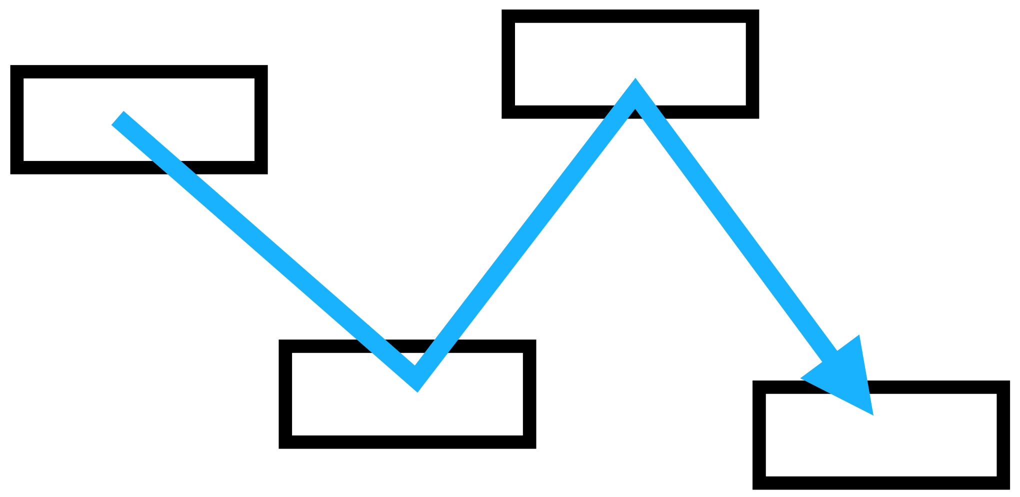
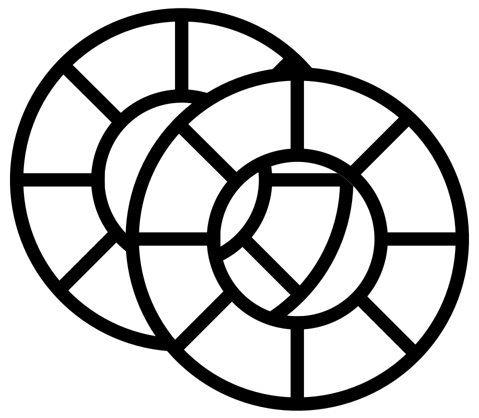
Packetized
Interface



Poor Cache Interaction



Metadata Overhead

② How can a streaming abstraction improve performance?

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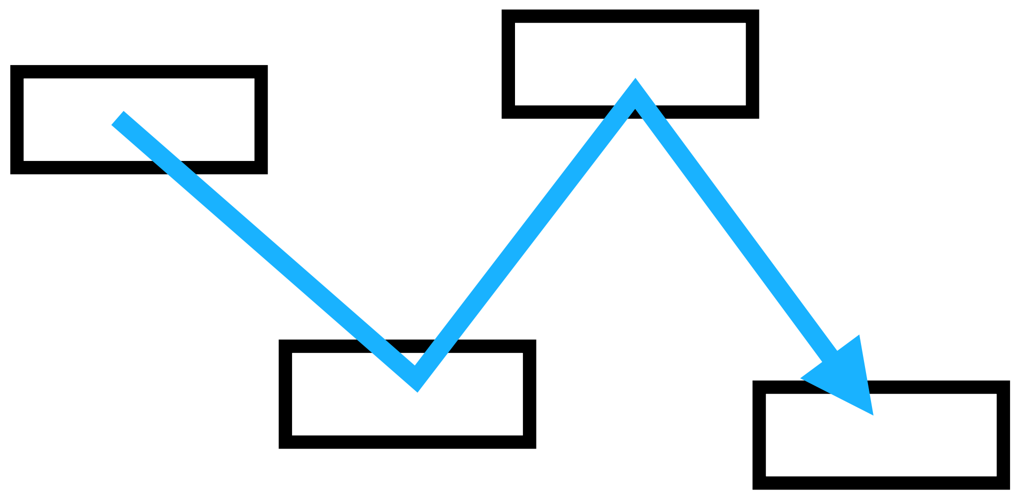

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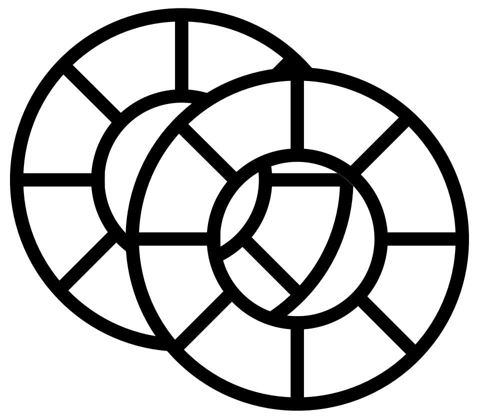

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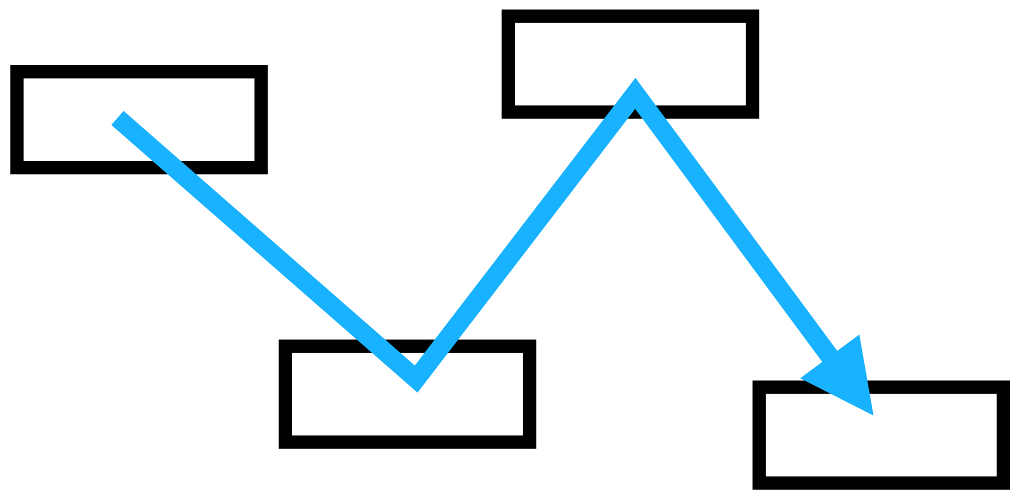

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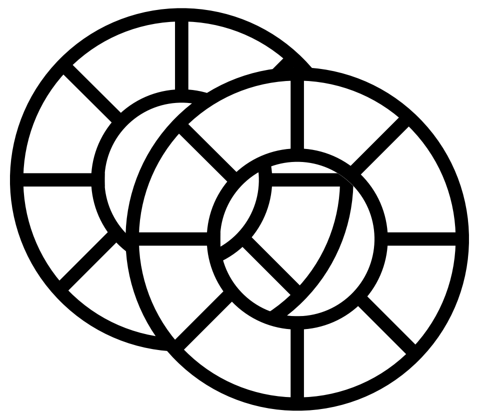

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Sequential Memory Access

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Packetized
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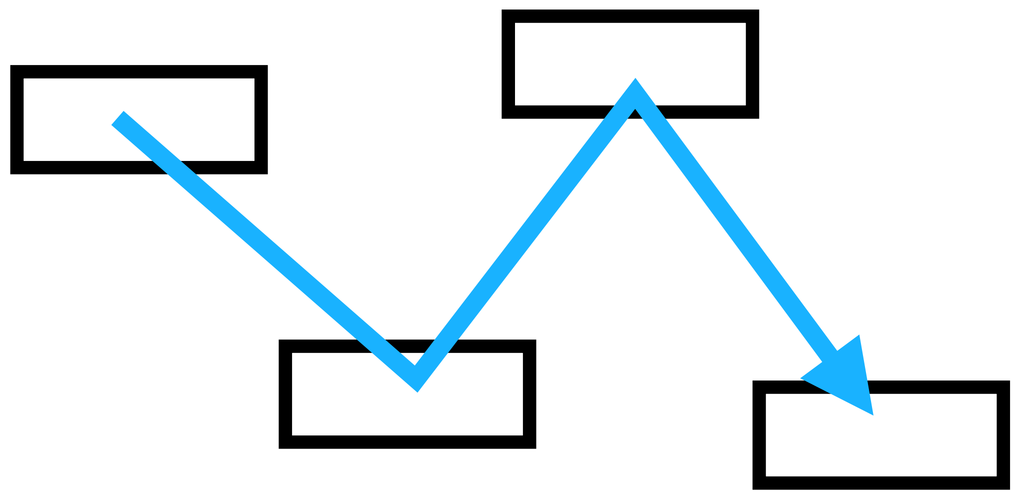

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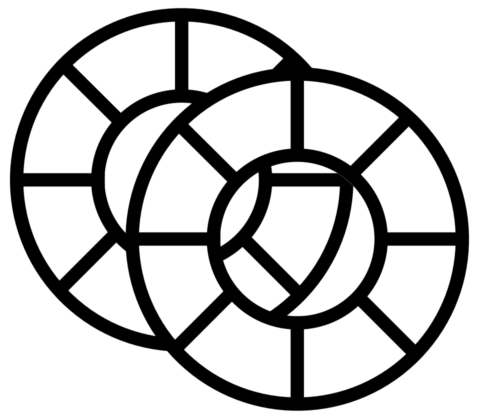

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Sequential Memory Access

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

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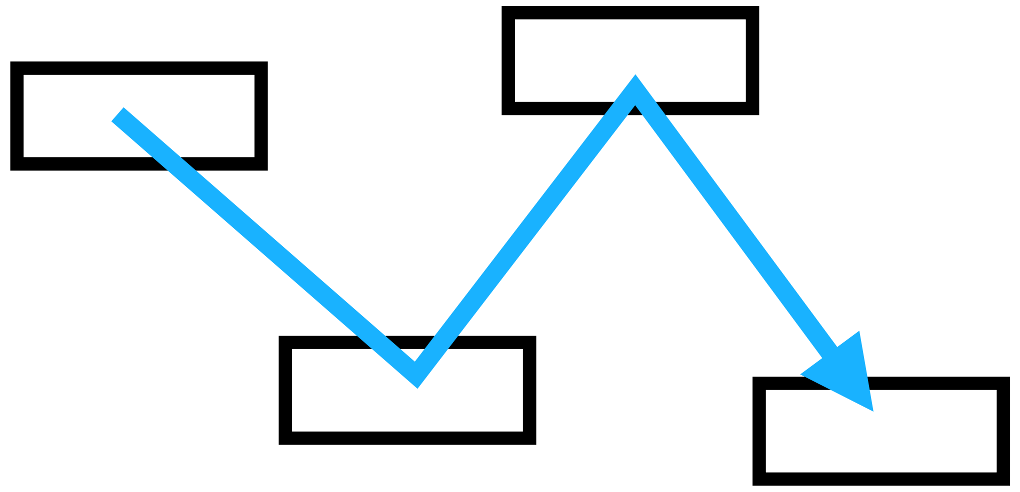
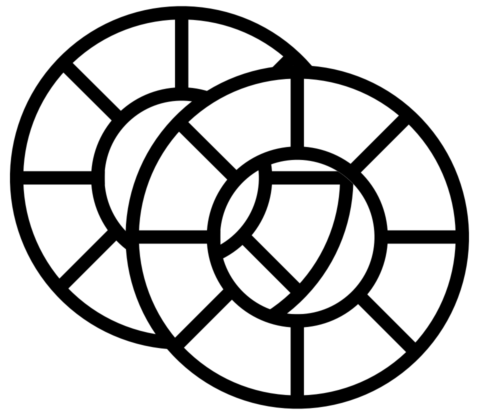
Packetized Interface



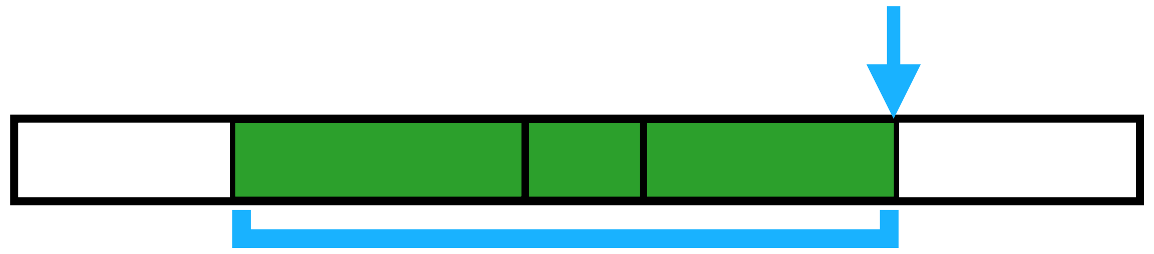
Poor Cache Interaction



Metadata Overhead

Ensō

Sequential Memory Access



Notifying Batches

Reduces L1 misses by 95.9%
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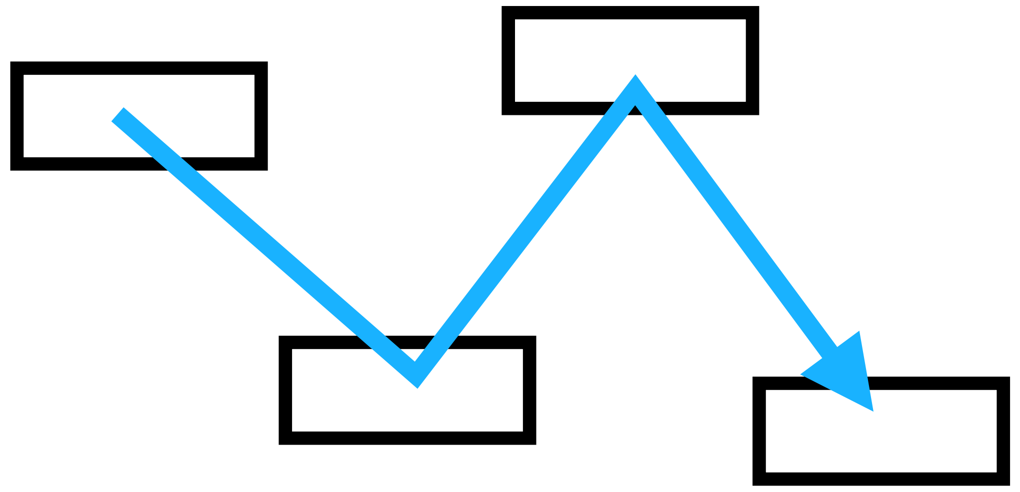

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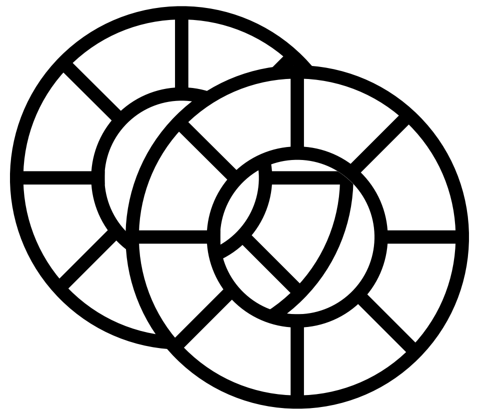

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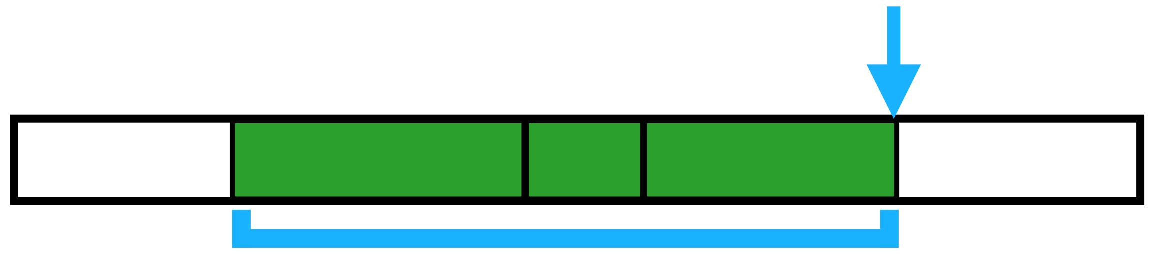

Notifying Batches

Reduces PCIe metadata traffic by 96.9%

How often should the NIC notify a batch?

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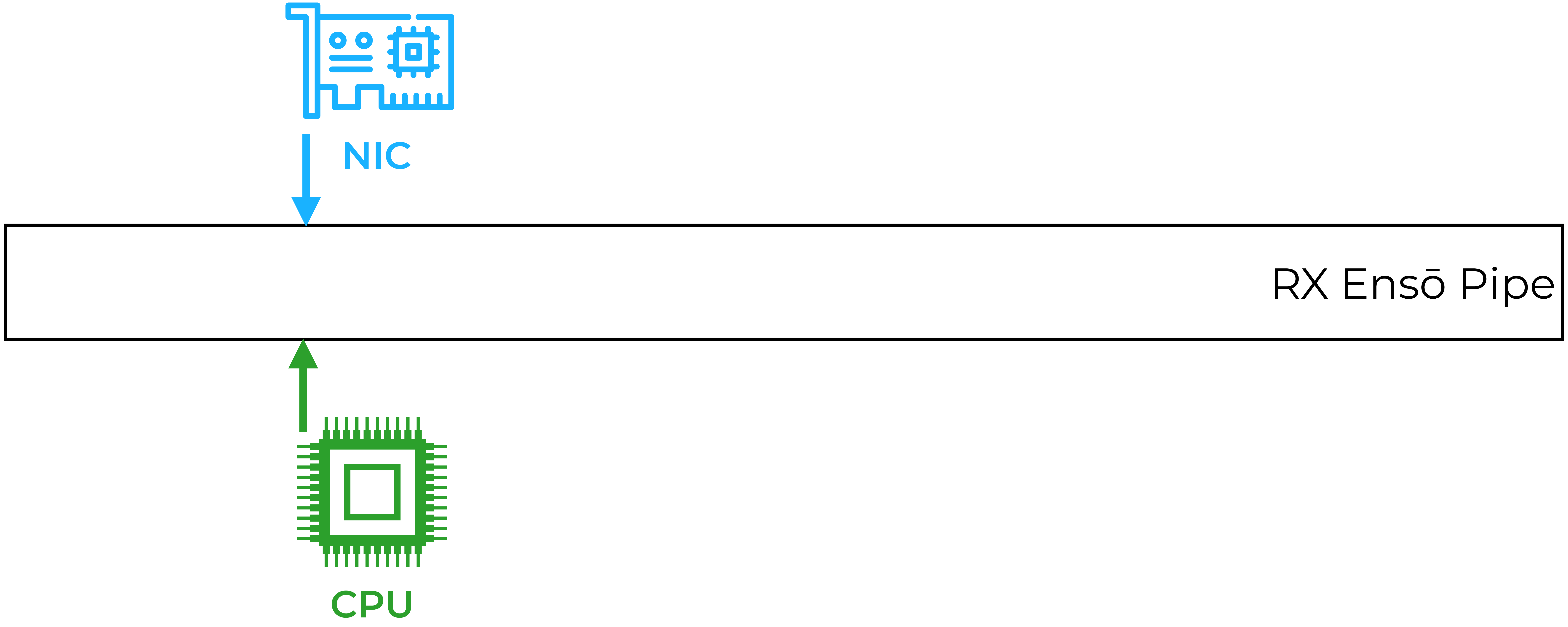
Naïve strategy: send an update for *every* piece of data



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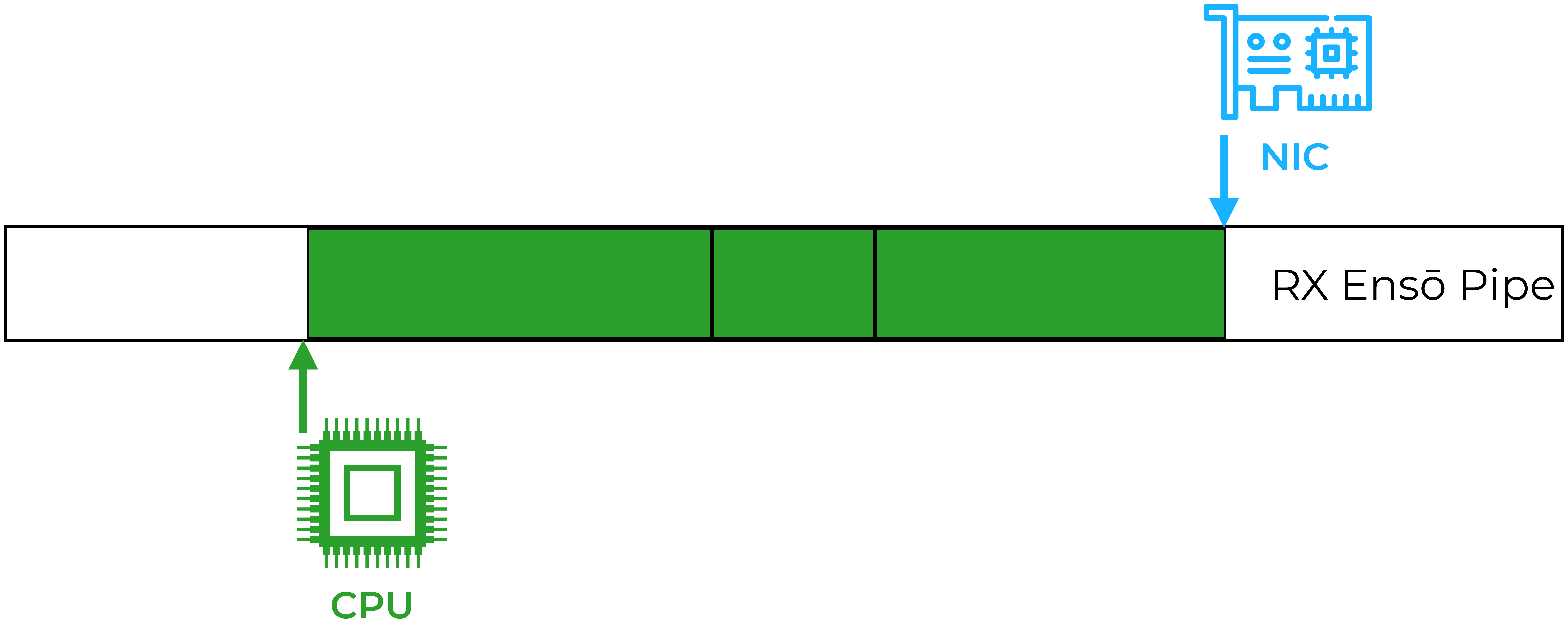

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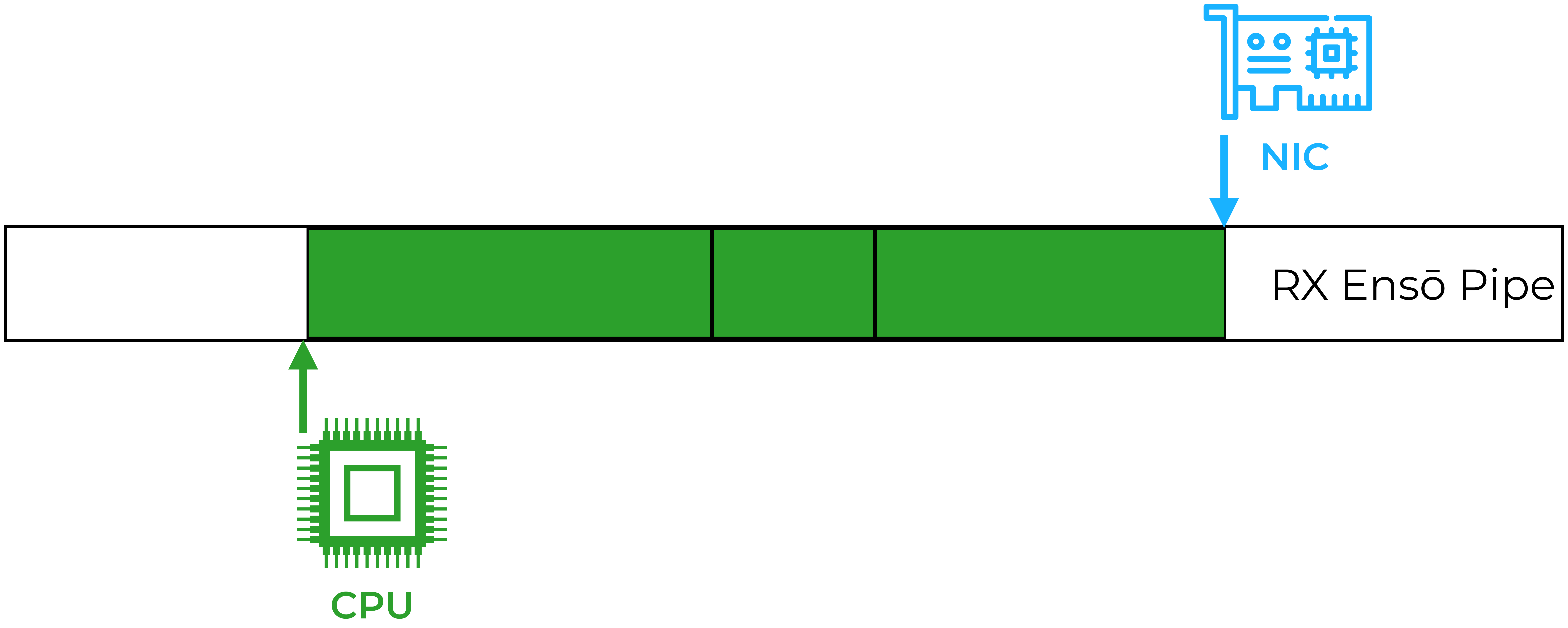
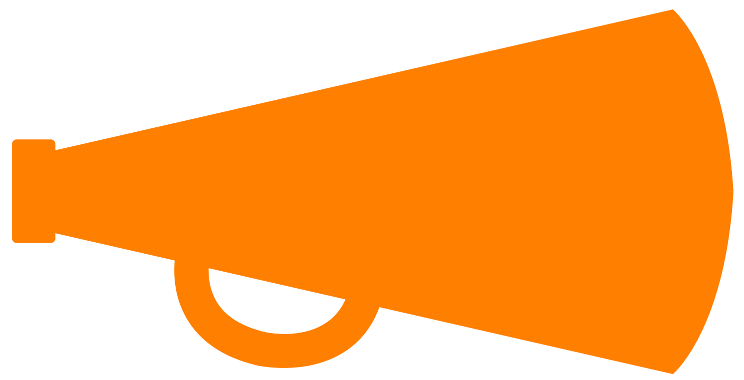


Problem: Per-packet overhead

Notification Pacing in Ensō

Ensō combines two techniques

① Reactive Notifications



② Notification Prefetching

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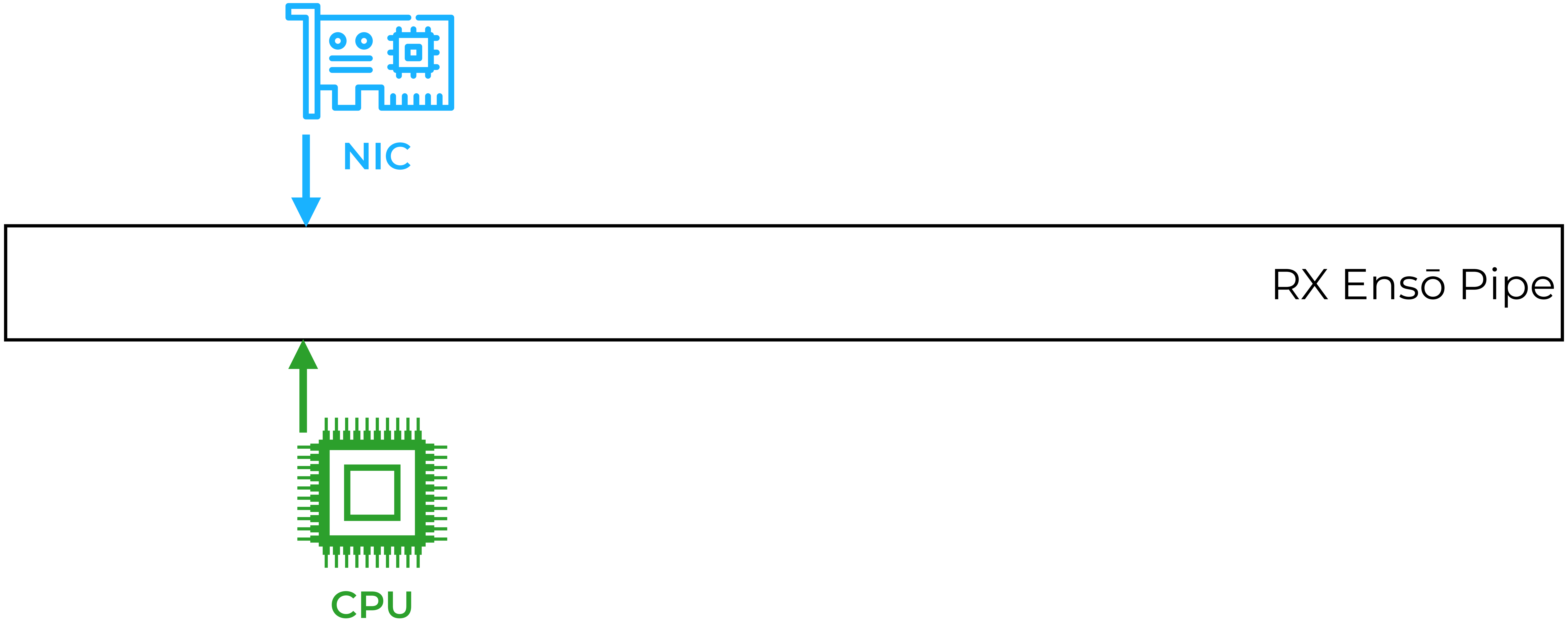
The NIC updates its pointer in *reaction* to CPU pointer updates



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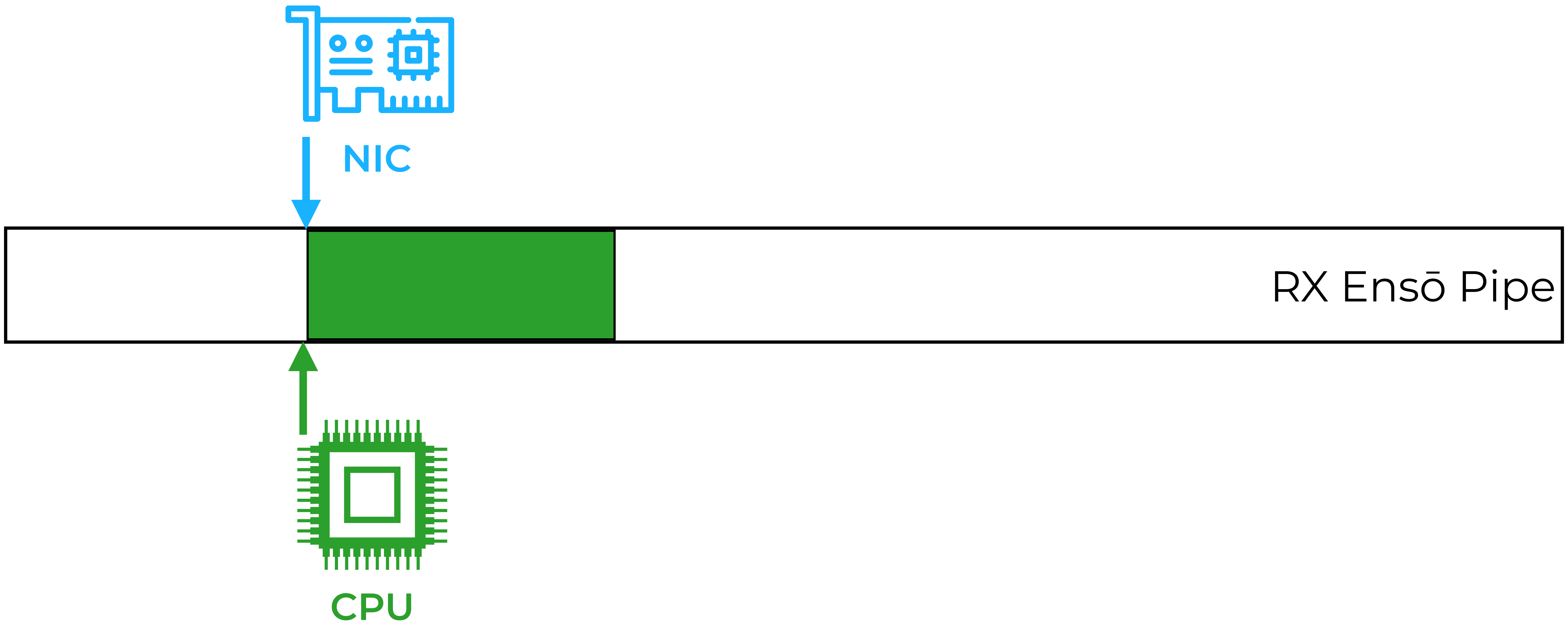

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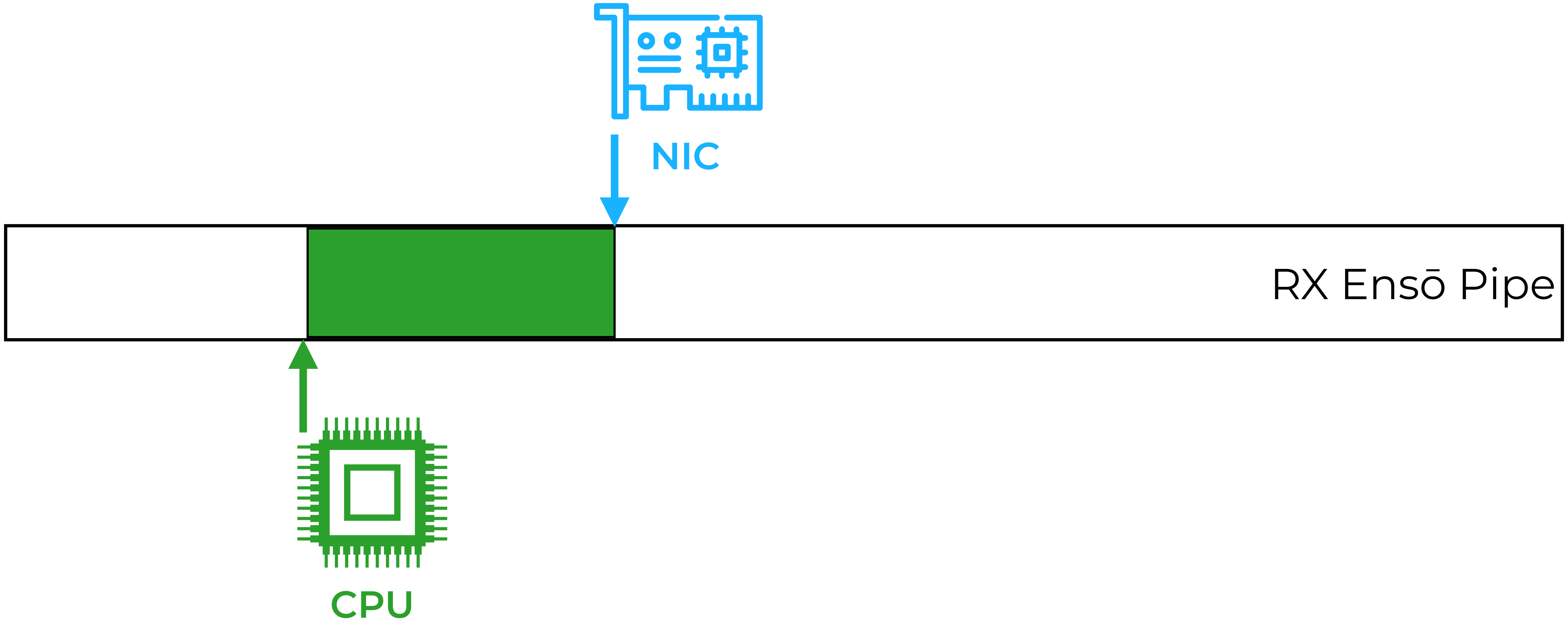

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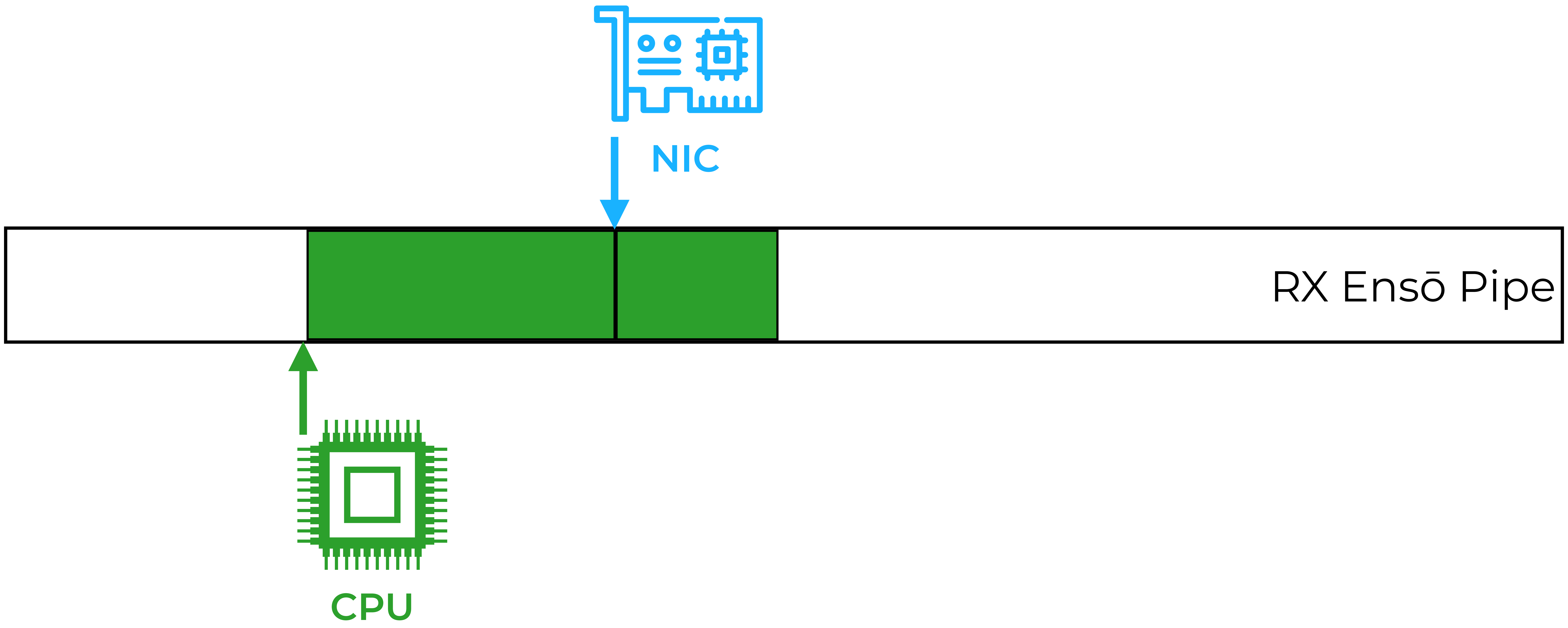

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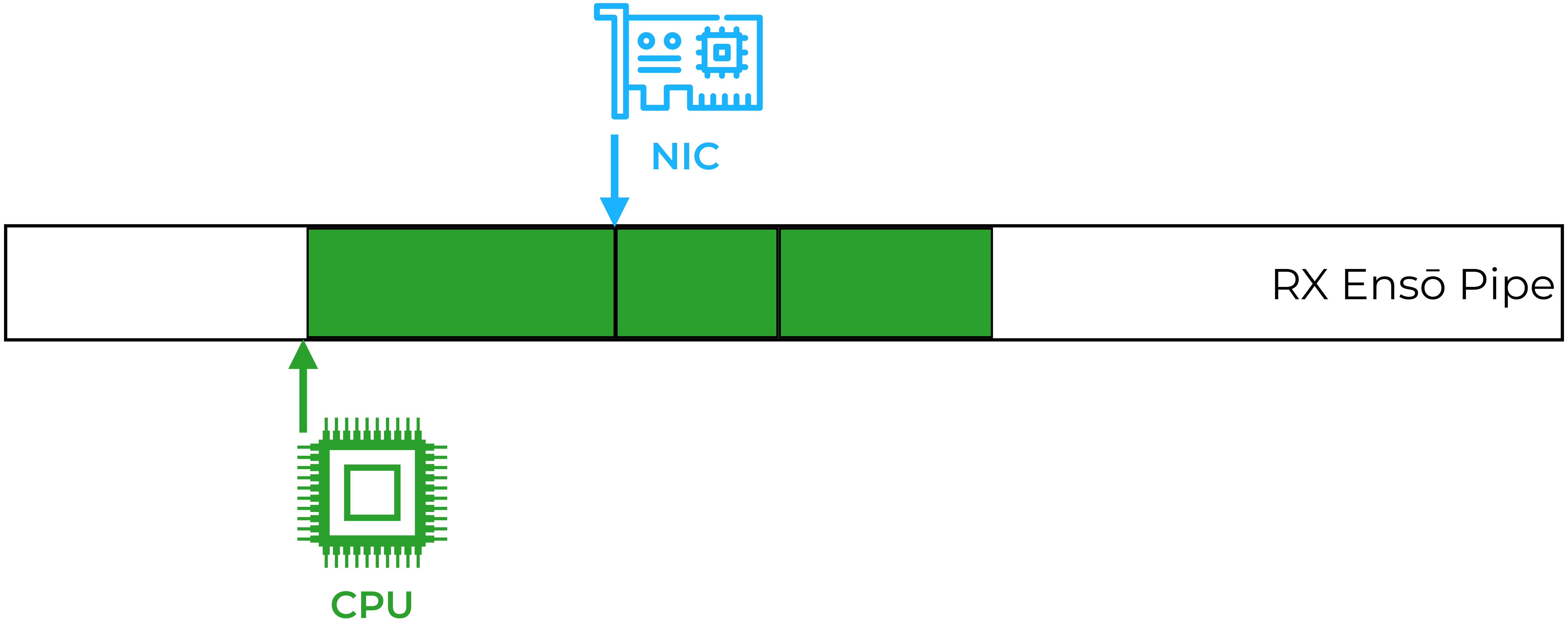

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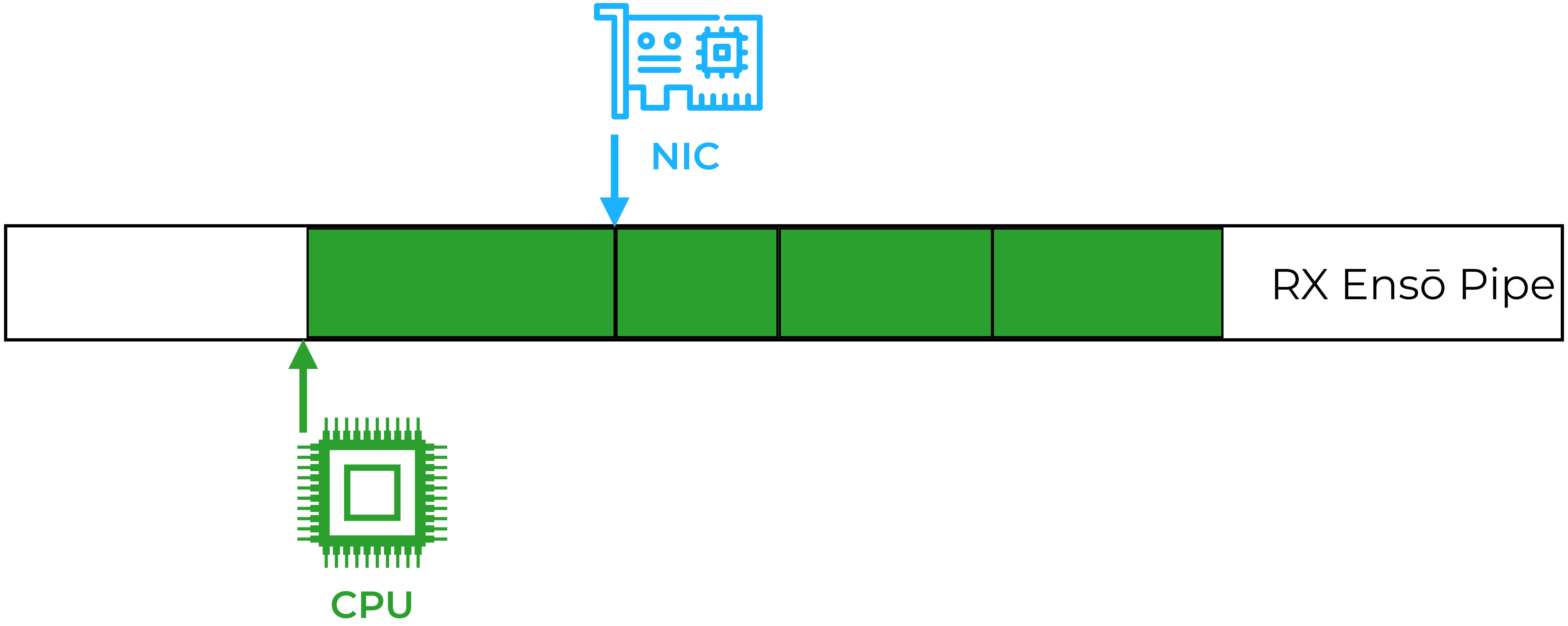

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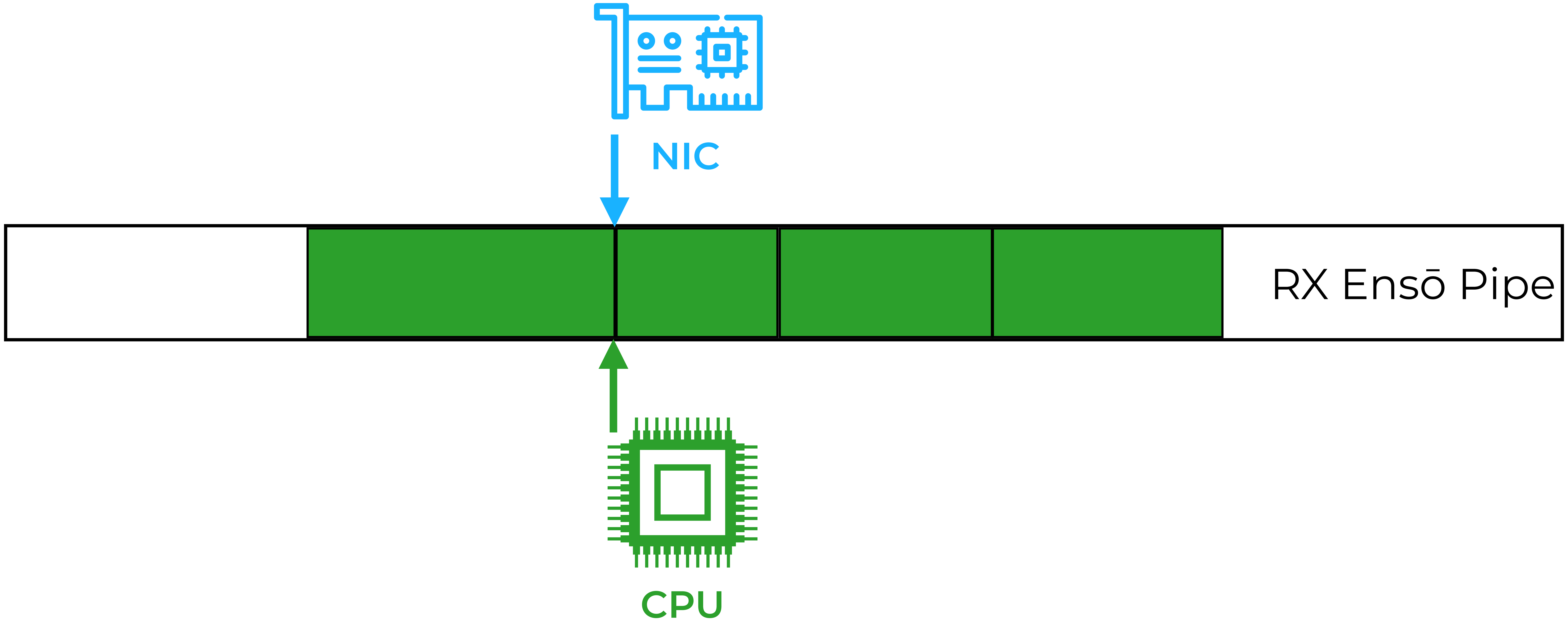

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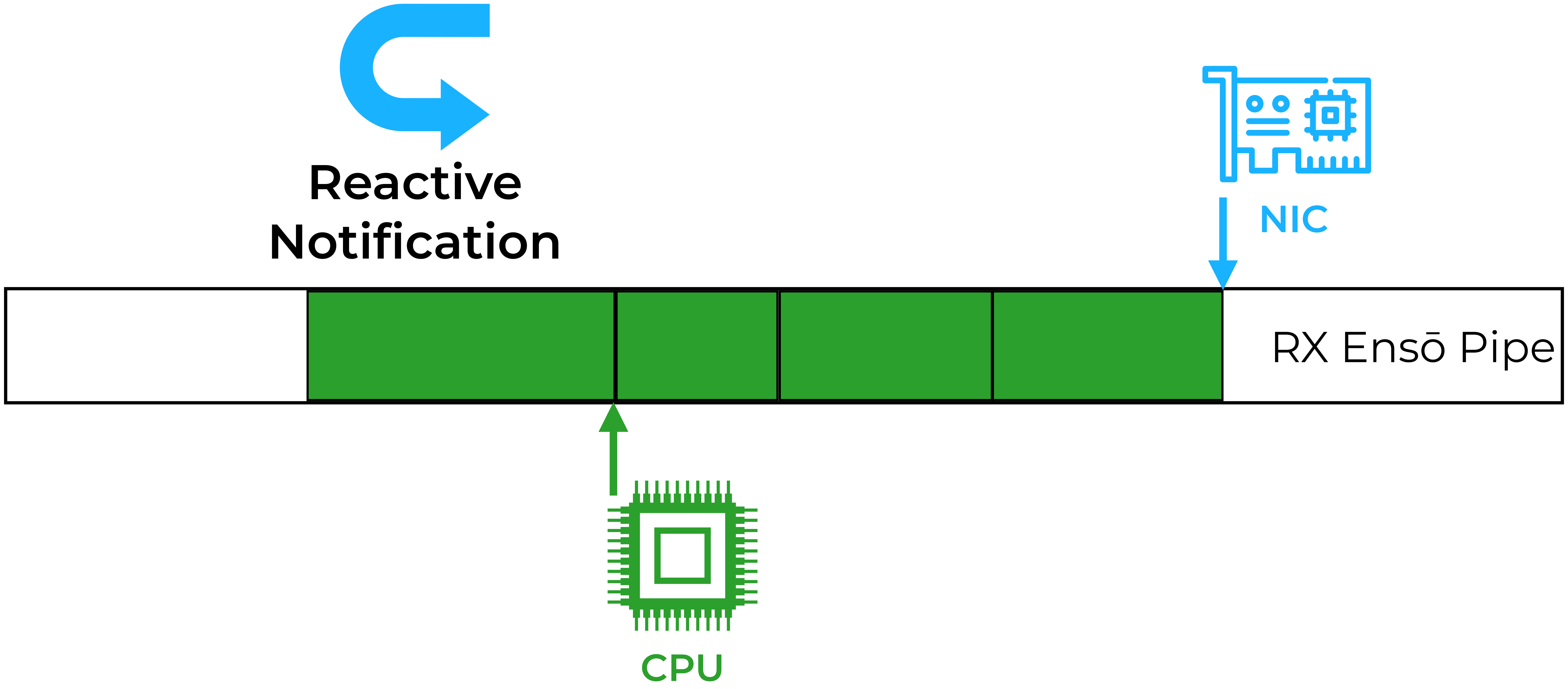

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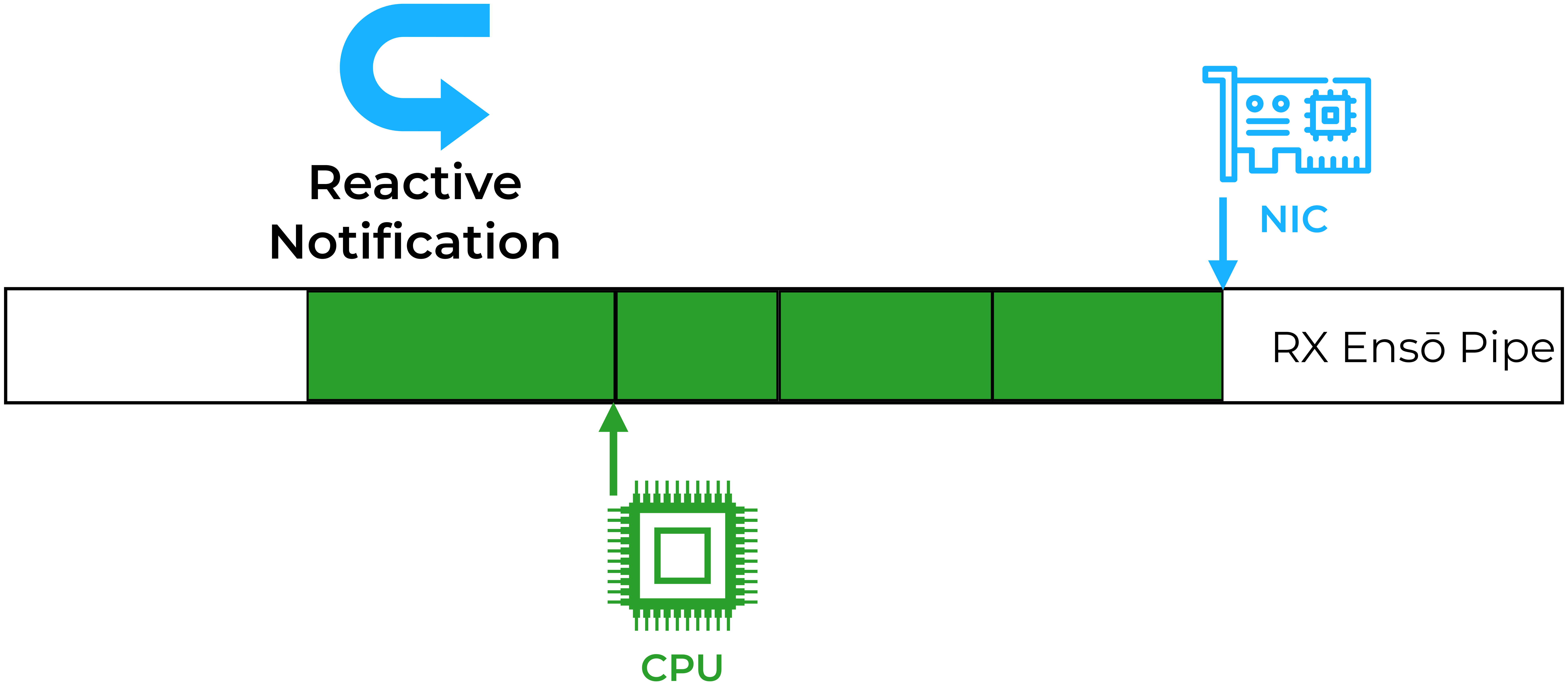
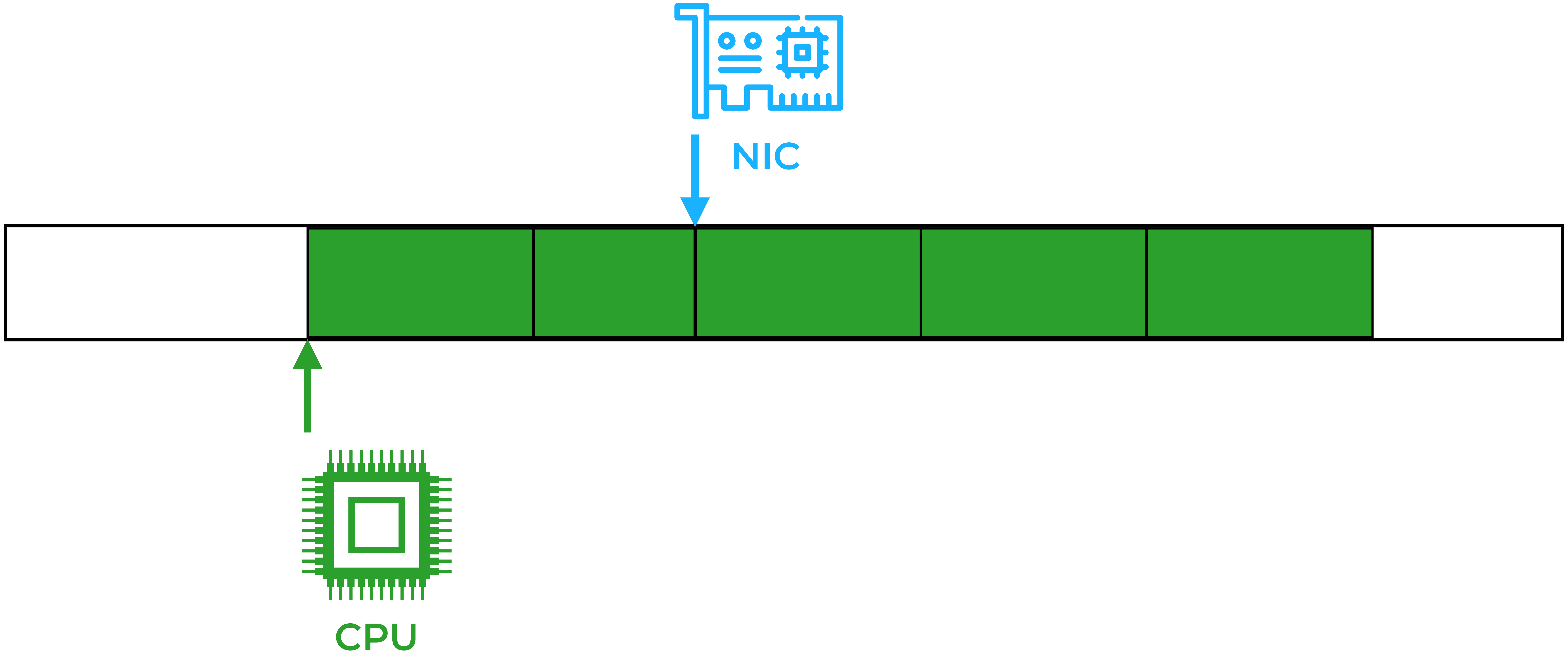


Only sends notifications that are strictly necessary

Problem: PCIe Latency

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



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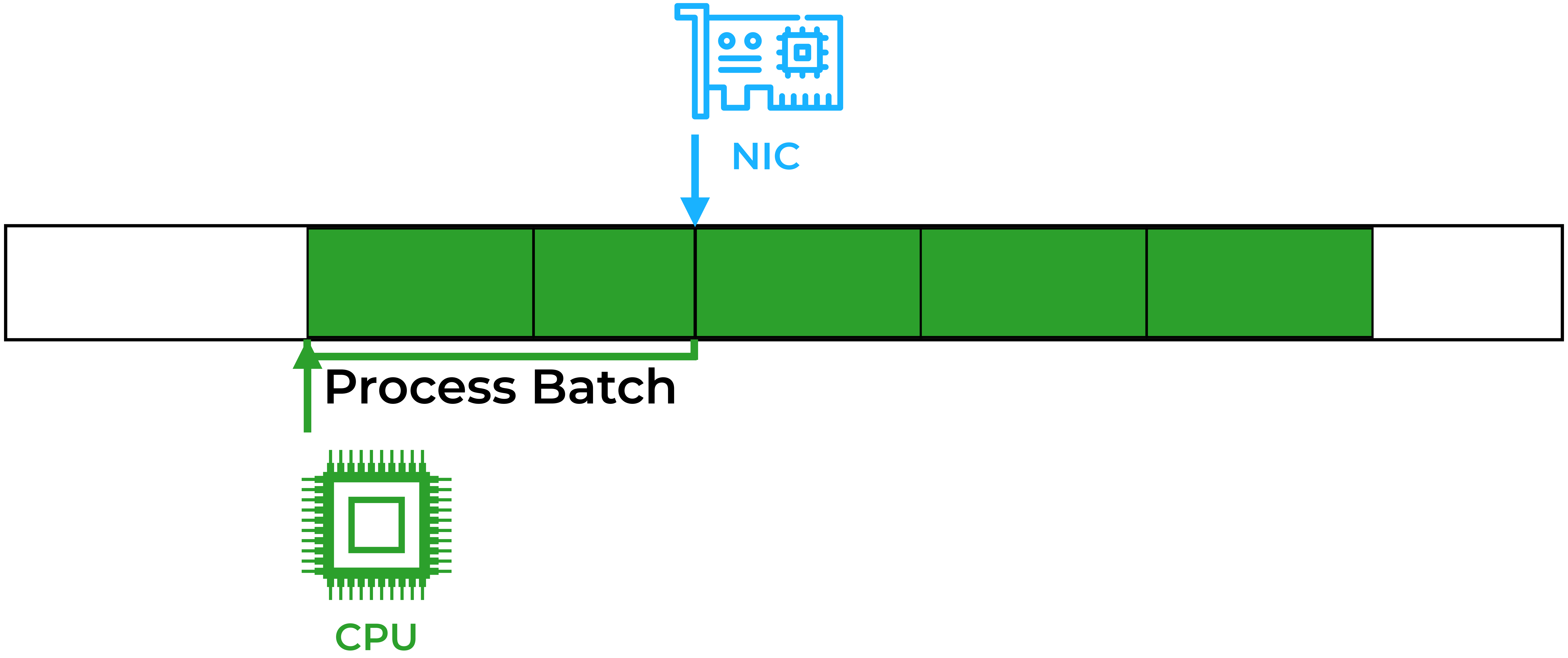

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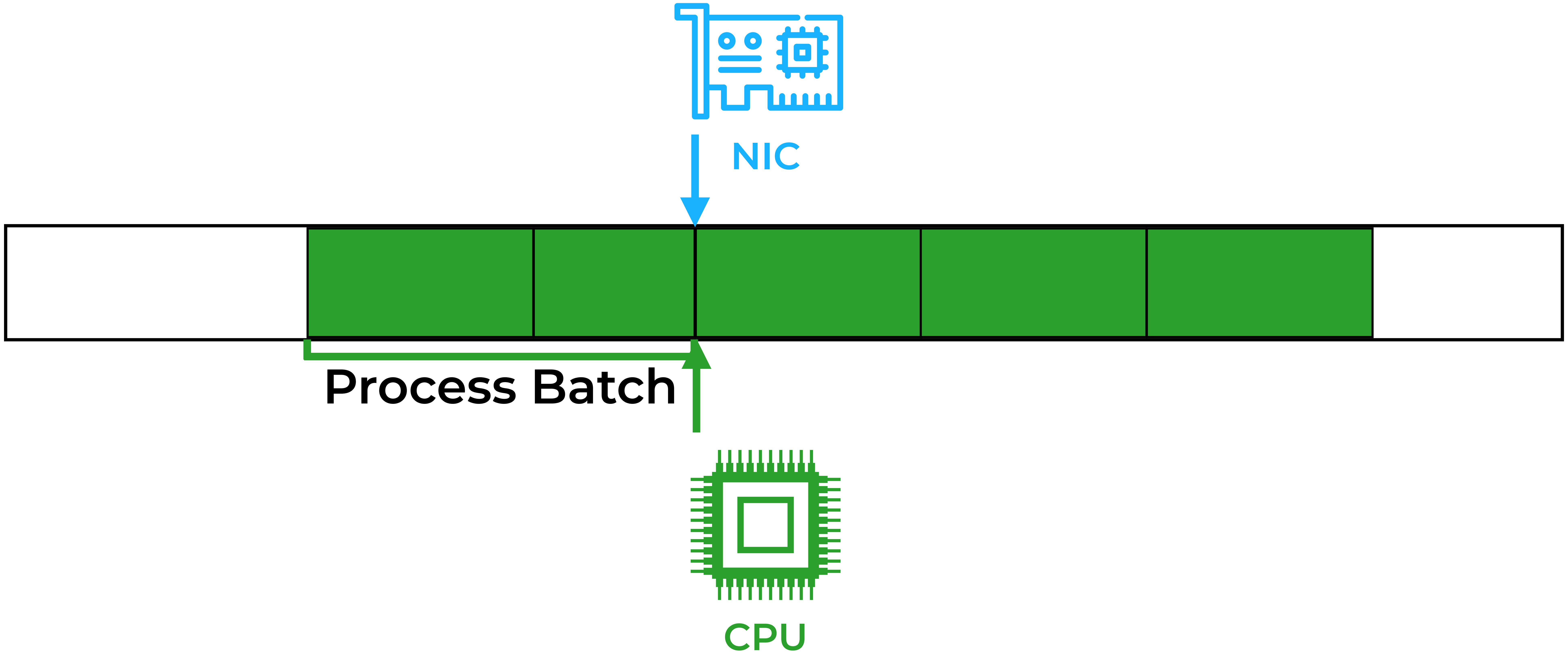

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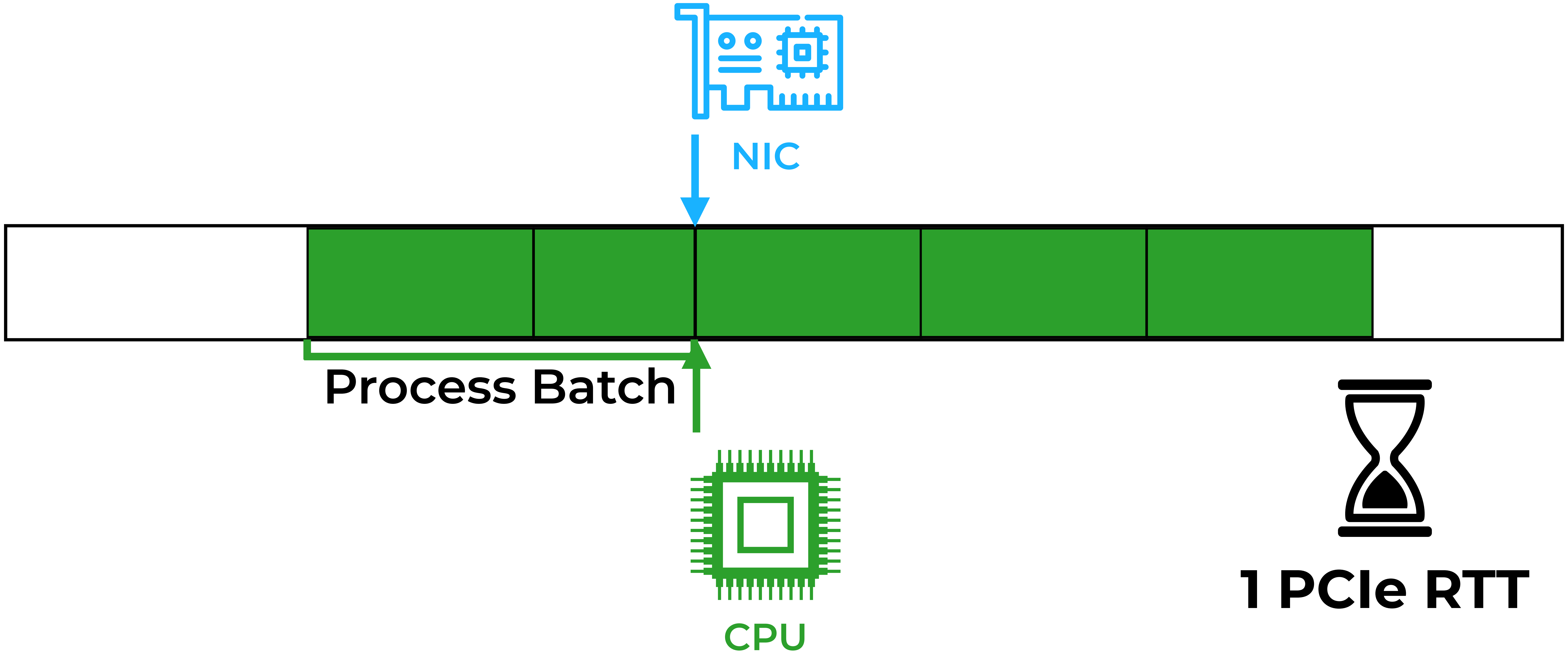

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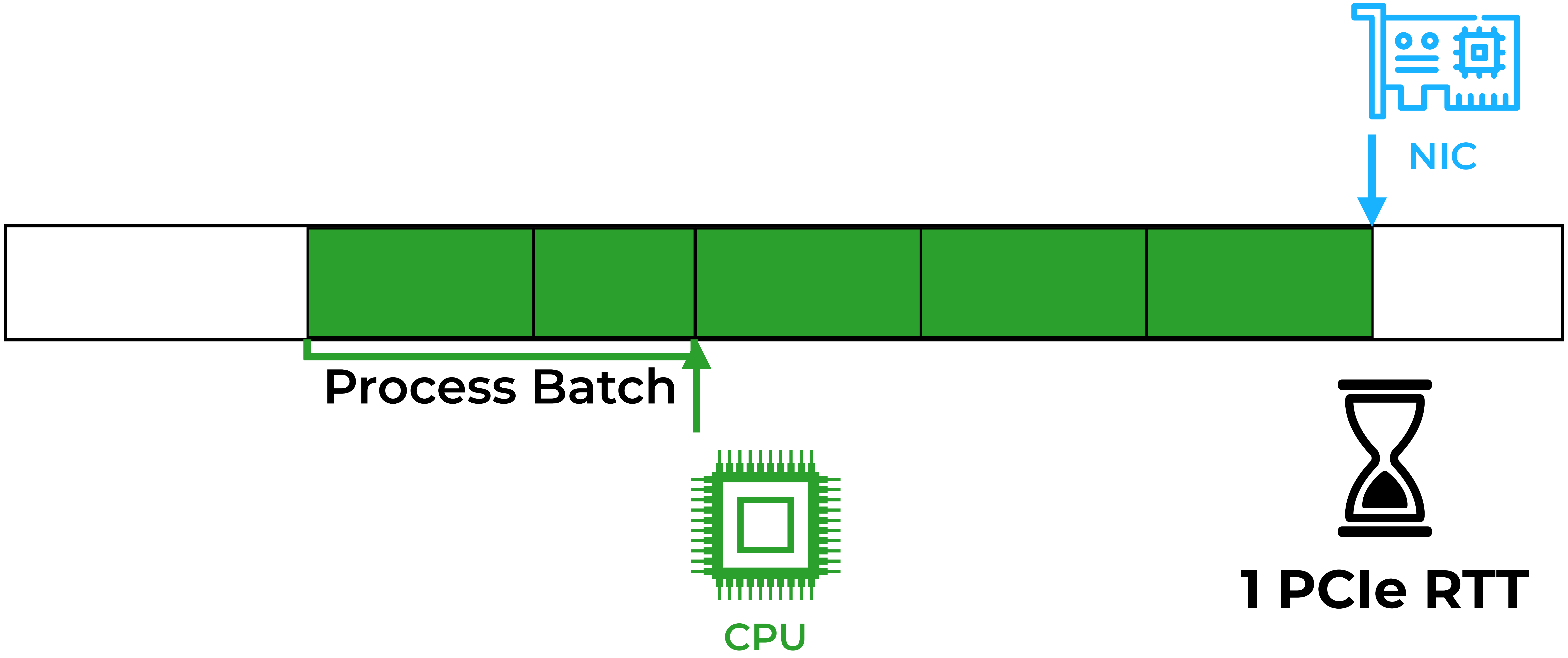

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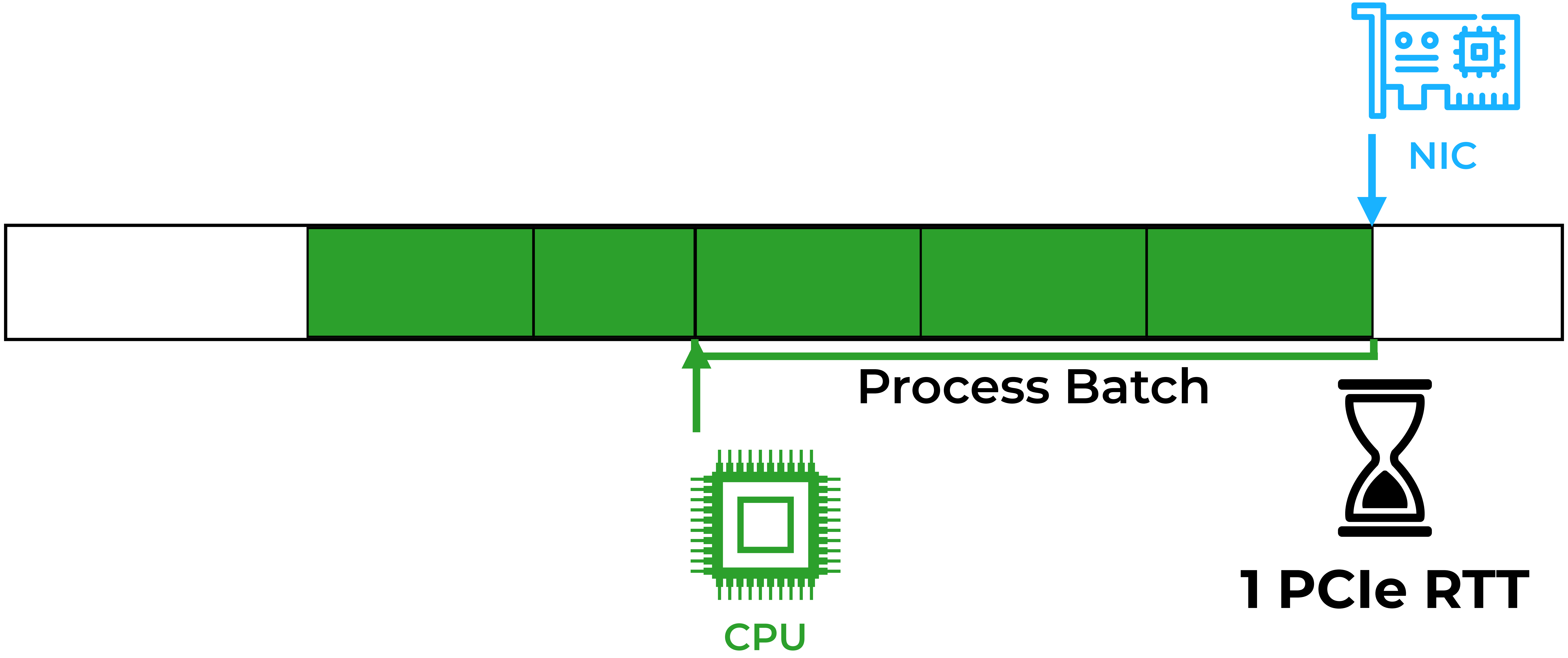
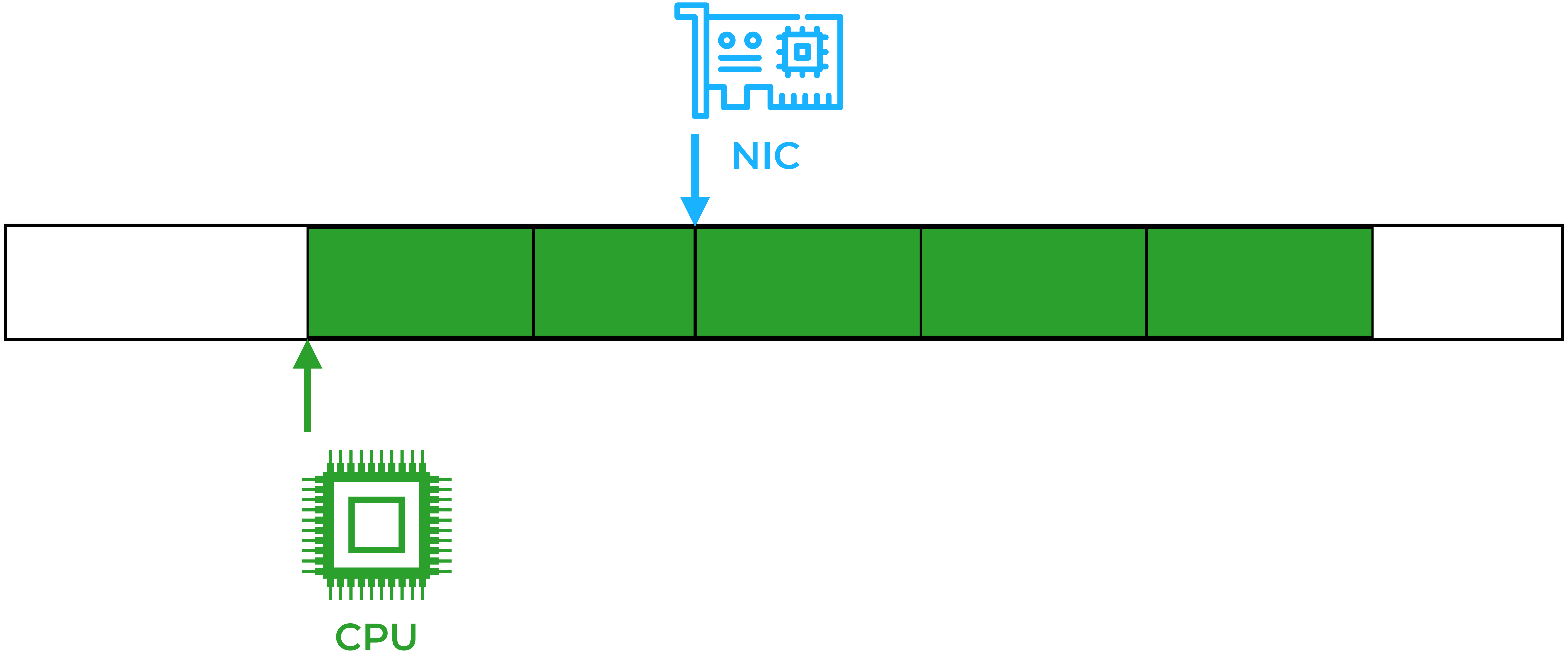


② Notification Prefetching

Software can *explicitly* request pointer updates from the NIC



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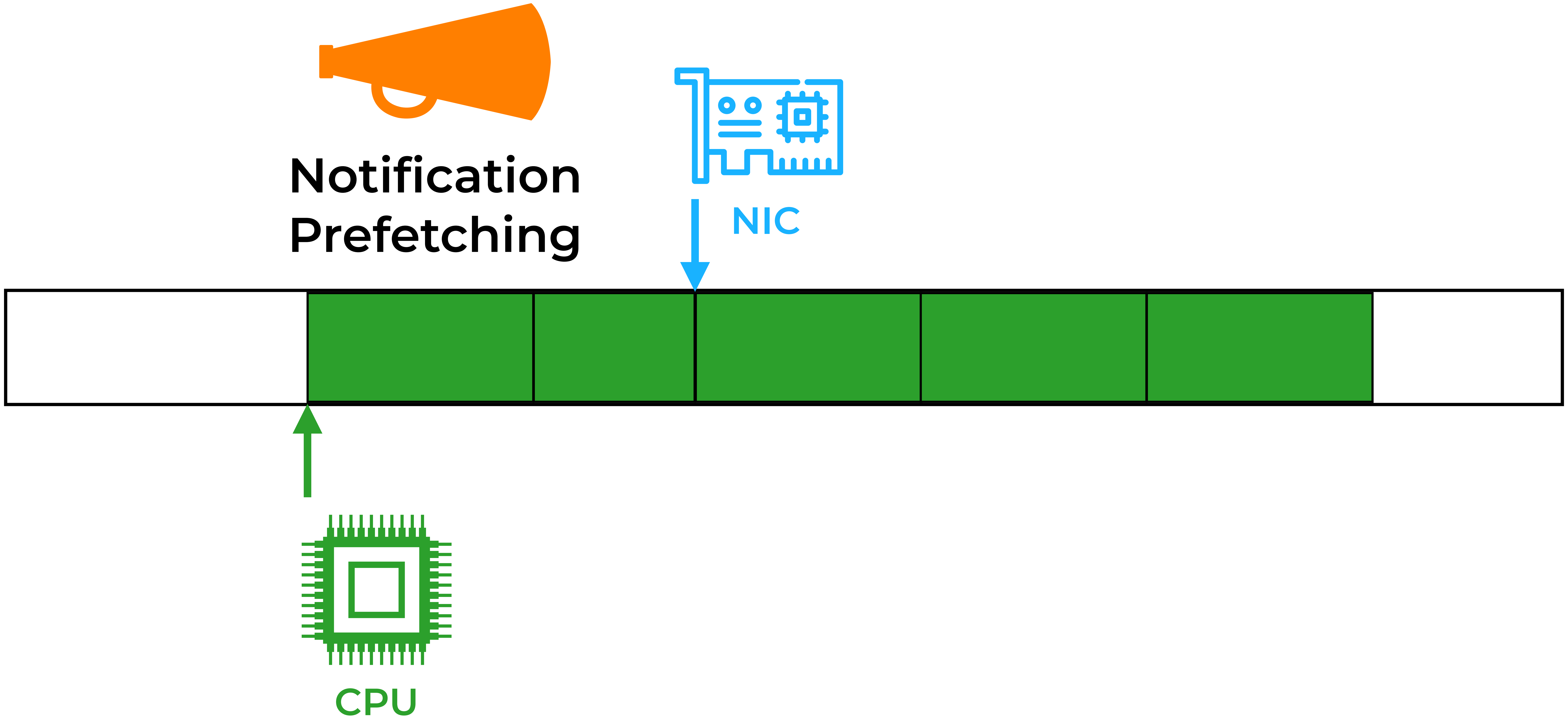

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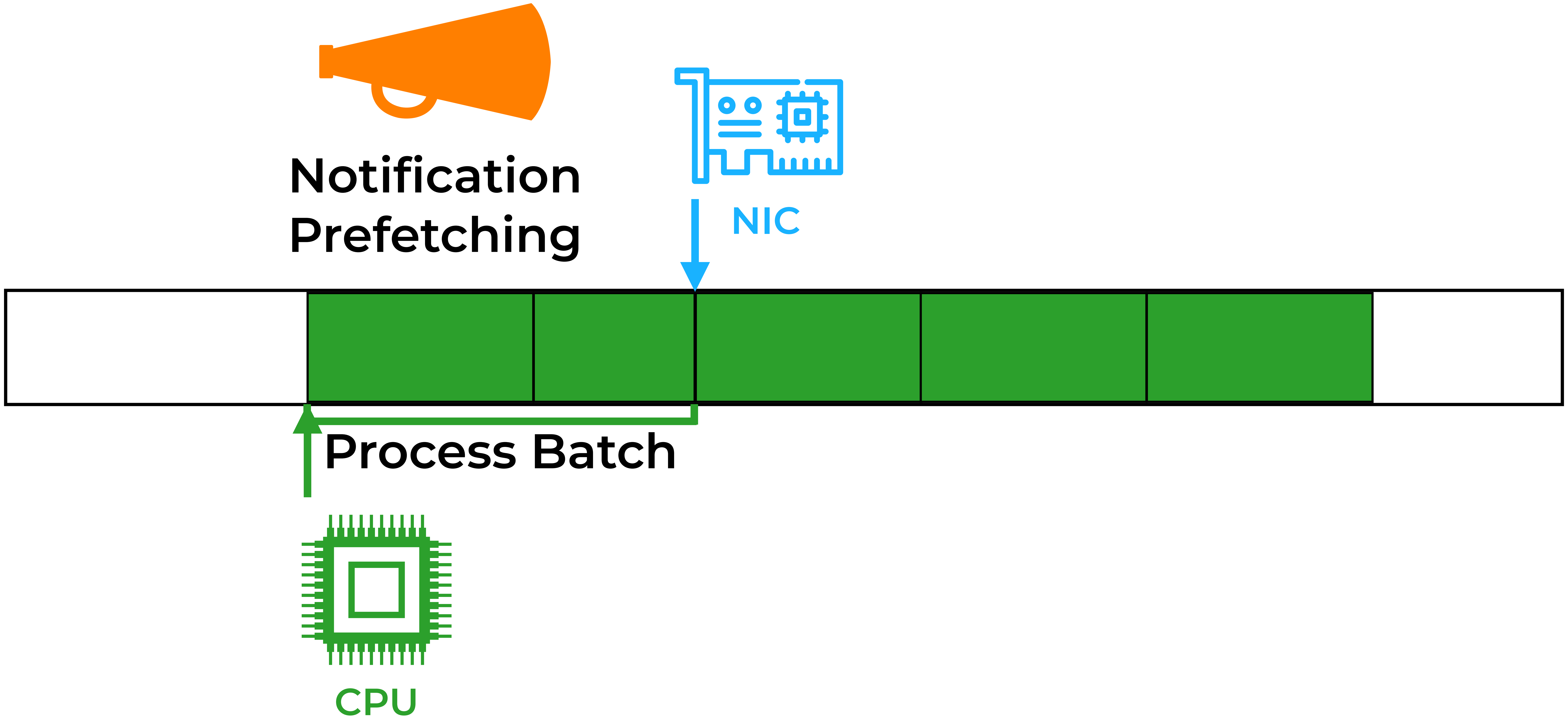

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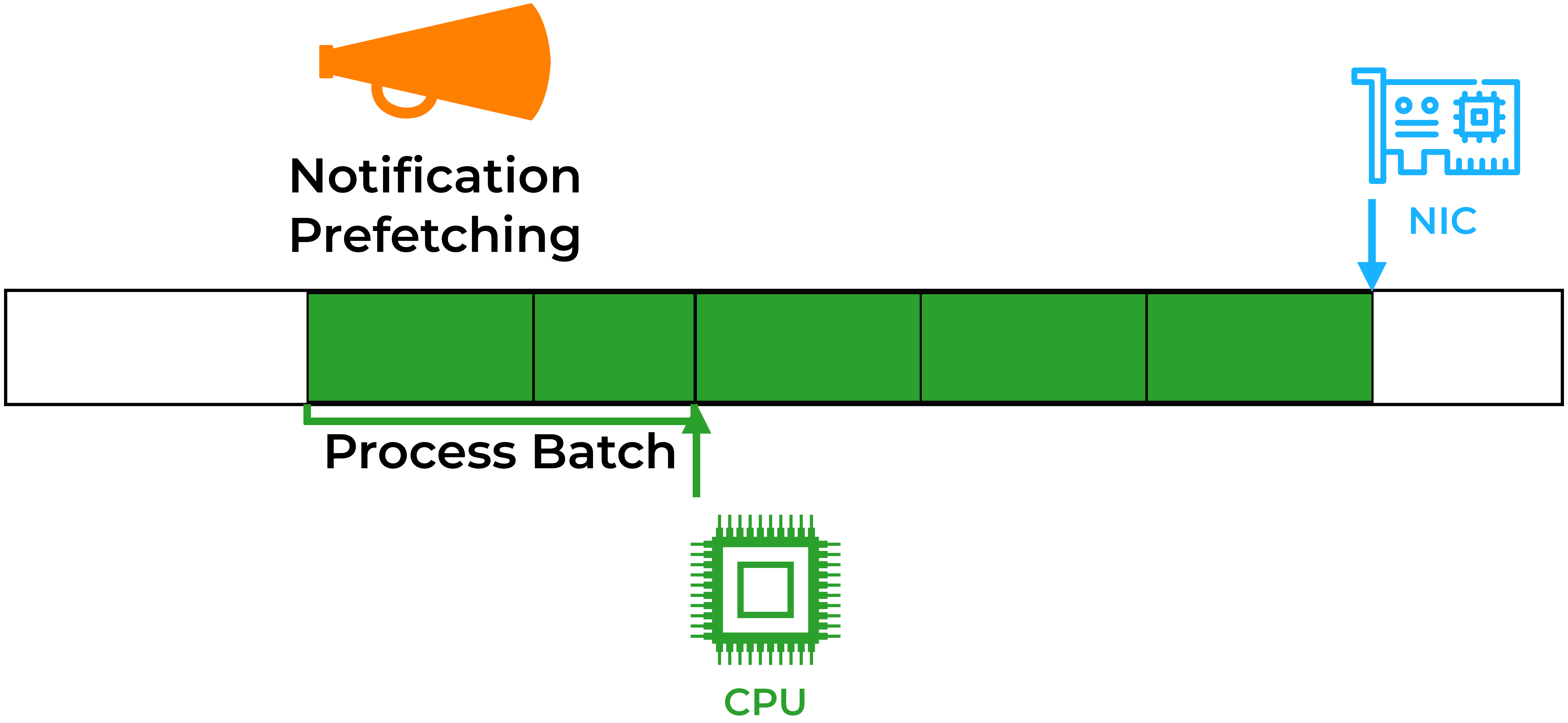

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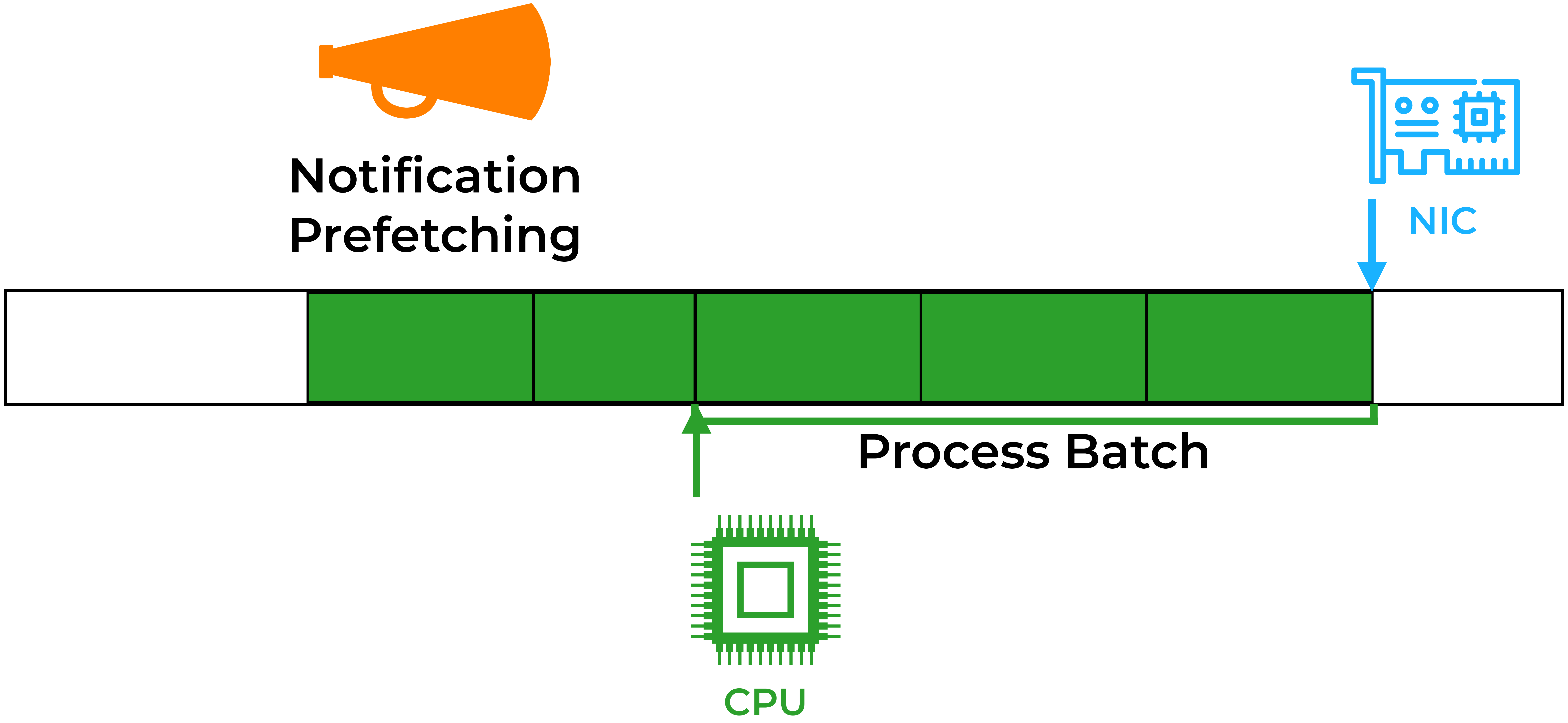

Many other design challenges...

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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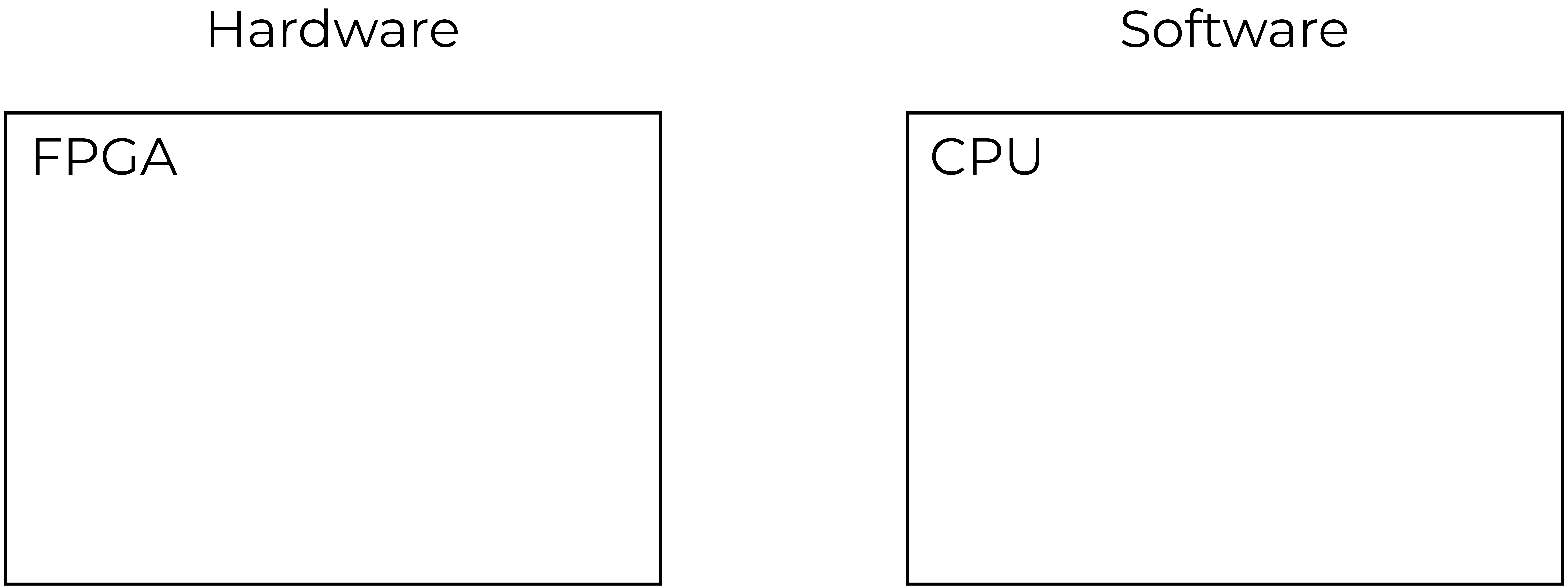
Refer to the paper for details

Ensō Implementation



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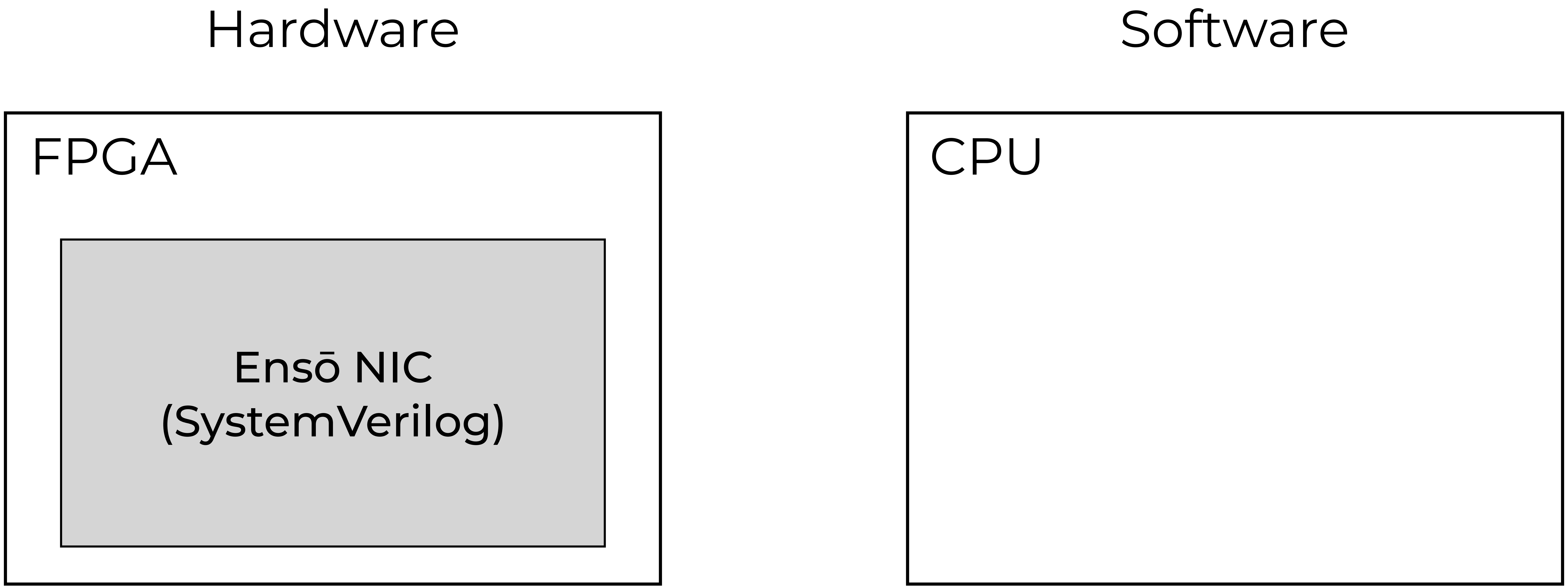

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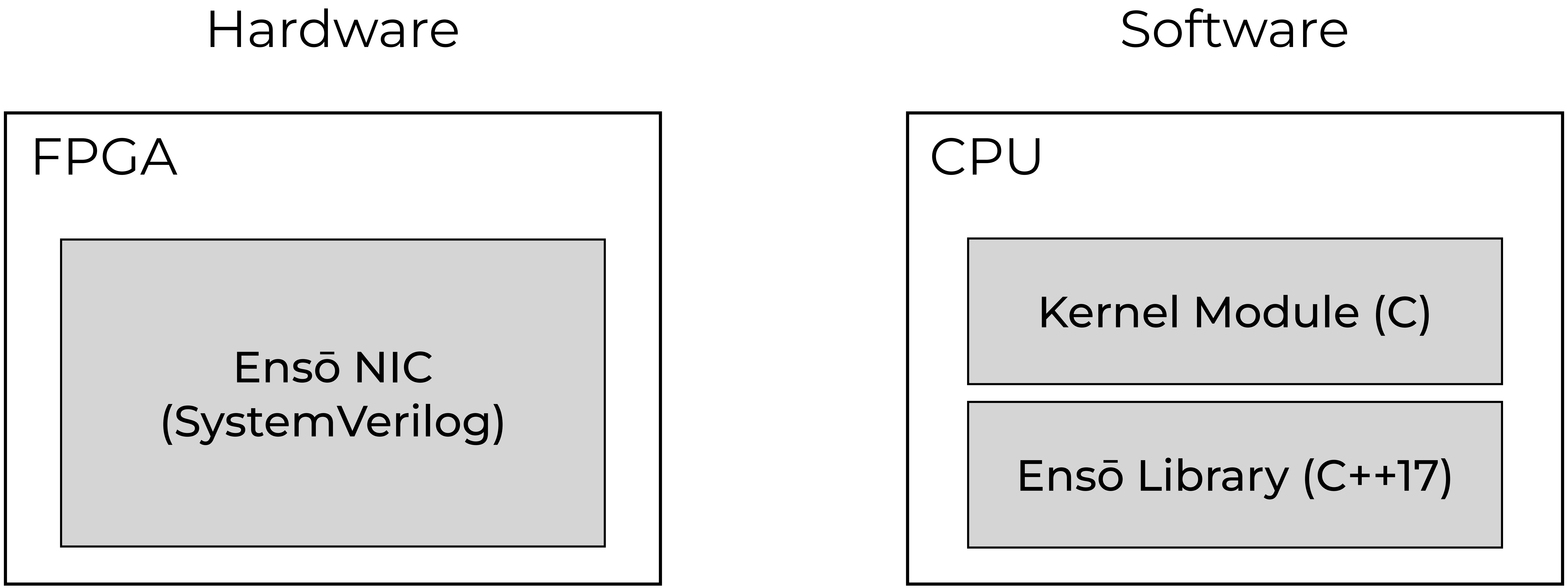
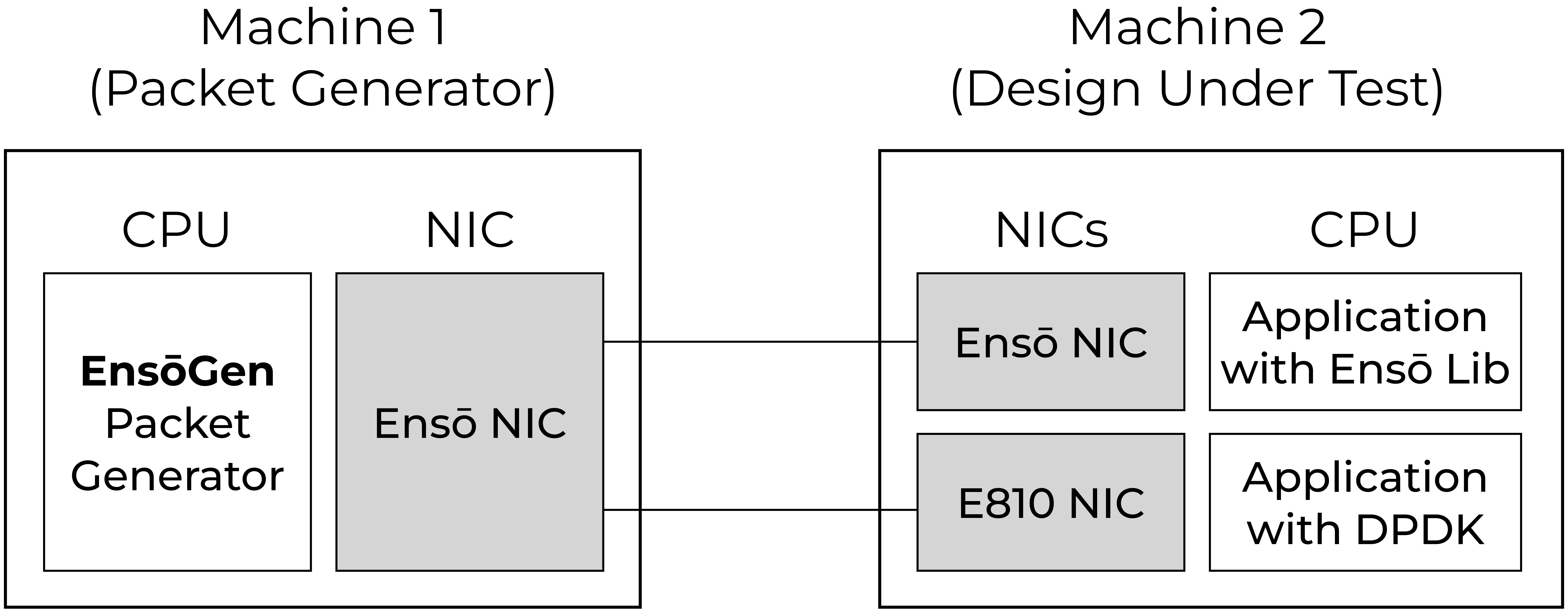
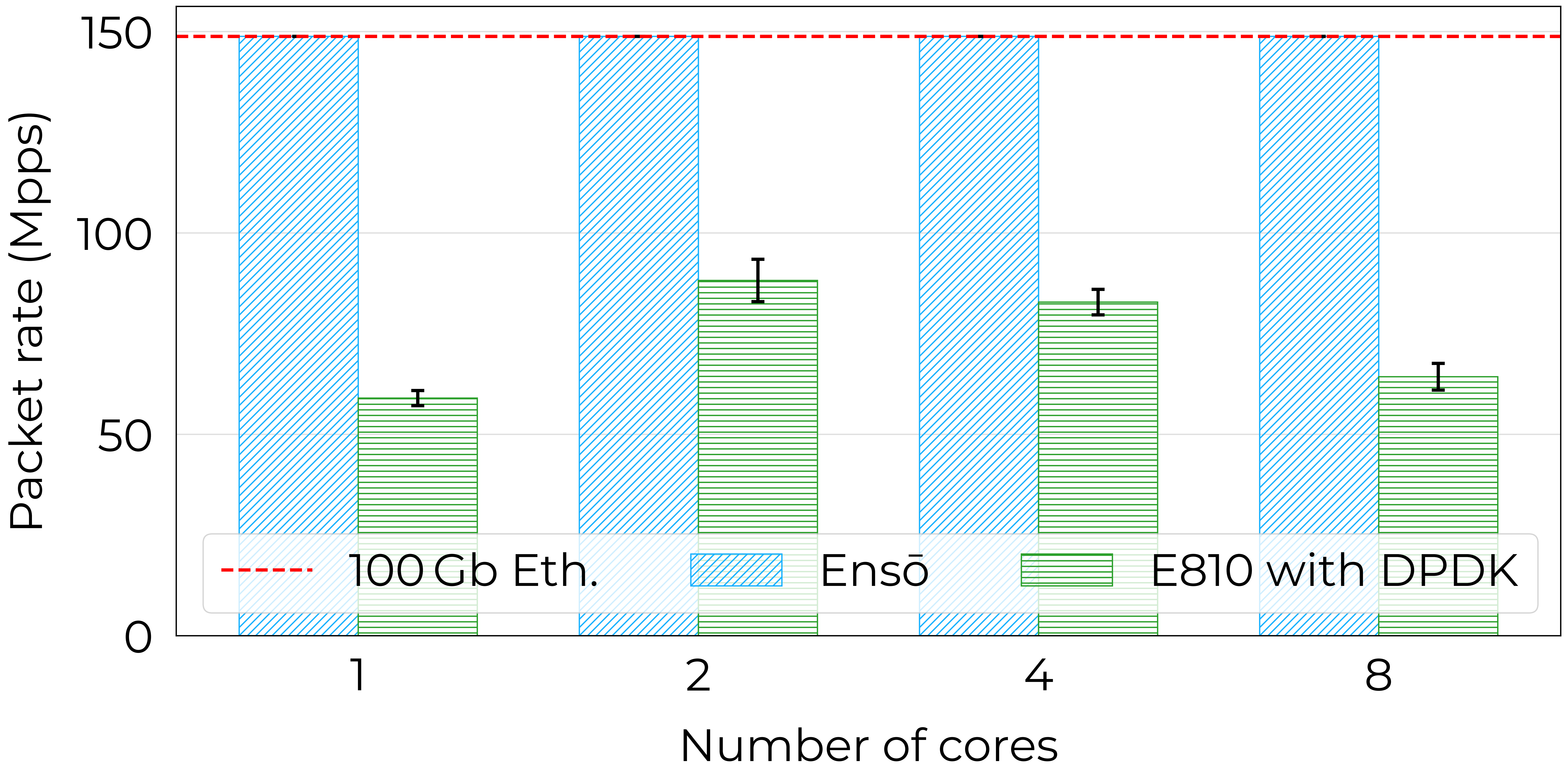


Evaluation



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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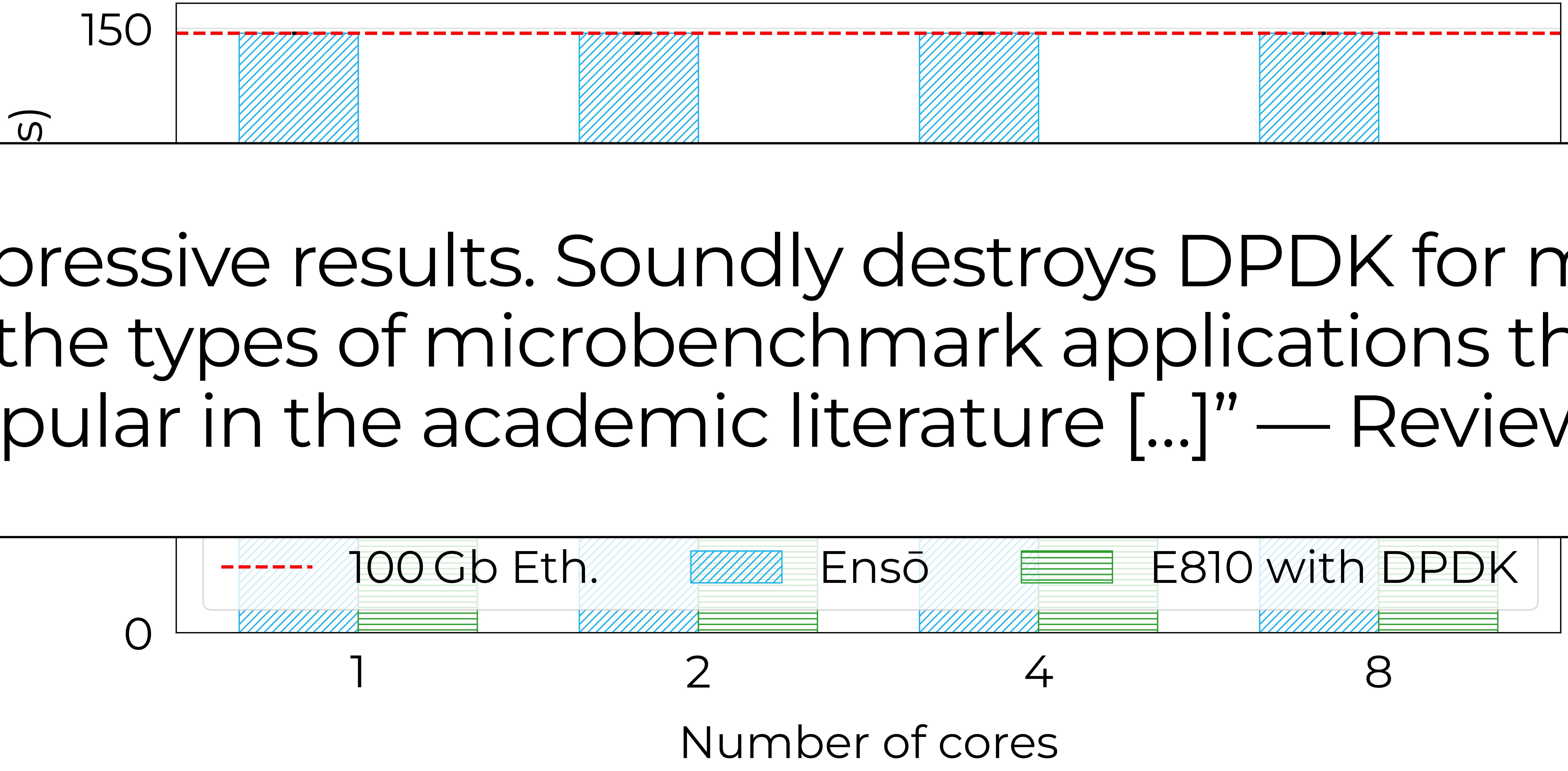
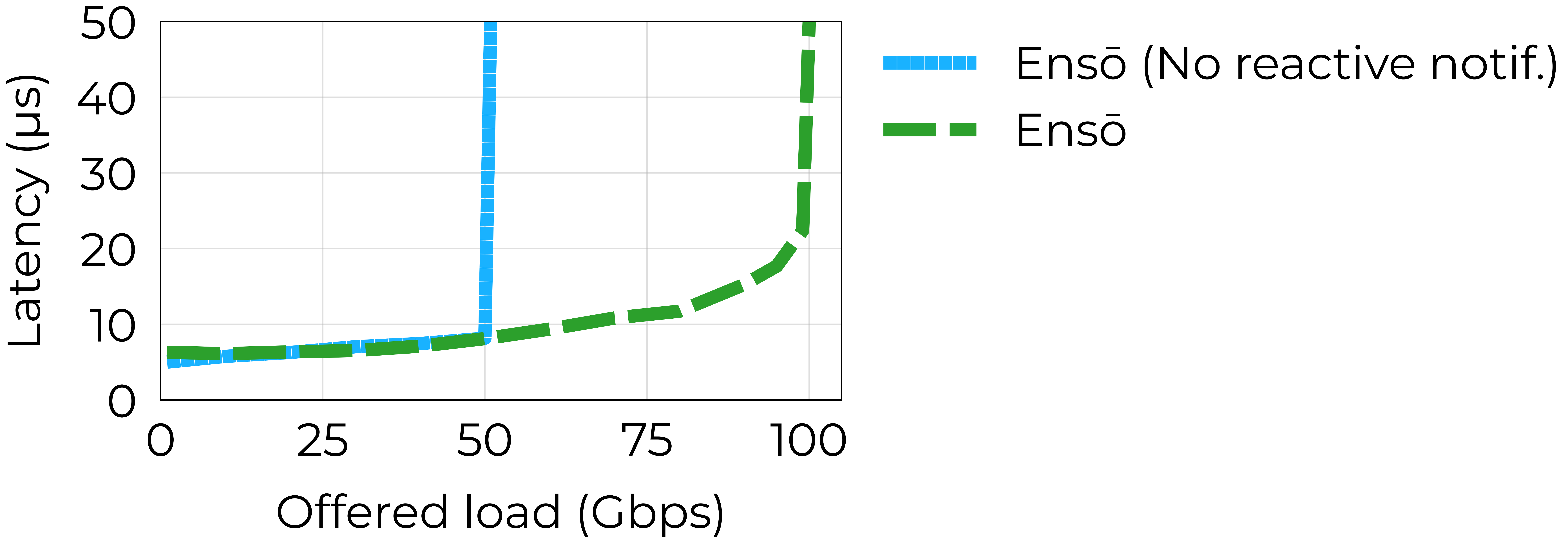


“Impressive results. Soundly destroys DPDK for many of the types of microbenchmark applications that are popular in the academic literature [...]” — Reviewer D

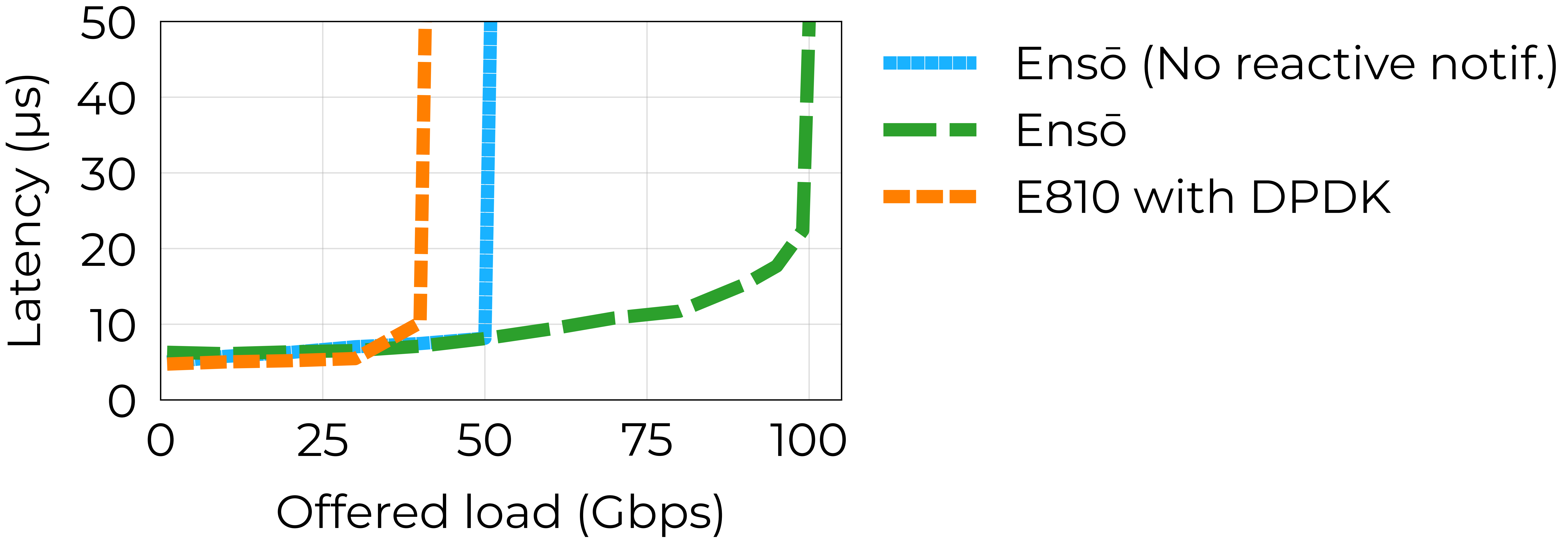
Ensō improves application throughput by up to 6x

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%

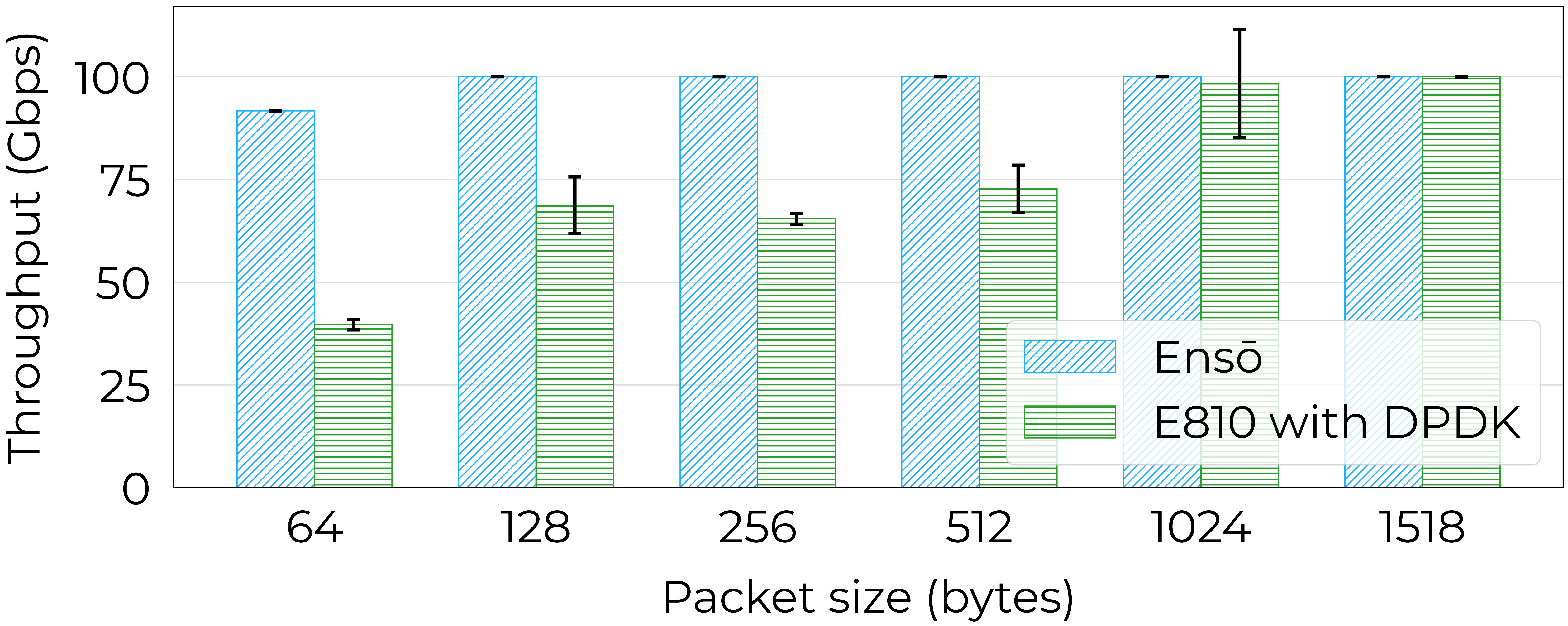
Reactive Notifications + Notification Prefetching improve throughput without impairing latency



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



Conclusion

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Ensō is open source: enso.cs.cmu.edu

Contact: sadok@cmu.edu