Network stack specialization for performance

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Motivation

Providers are scaling out rapidly. Key aspects:

- ~~1 machine:N functions~~ → N machines:1 function
- Performance is critical
- Scalability on multicore systems
- Cost & energy concerns

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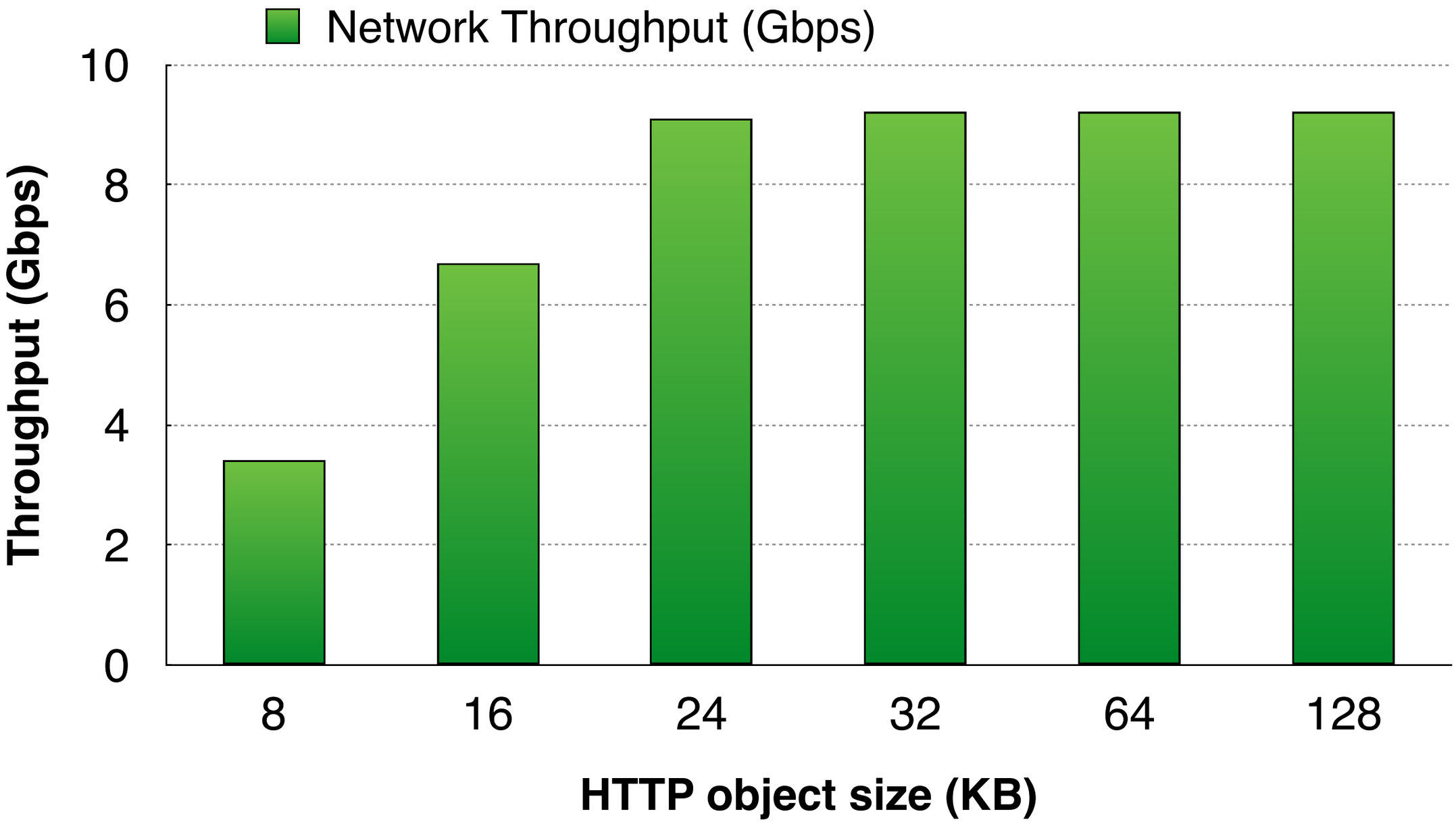
Are general-purpose stacks the right solution for that kind of role?

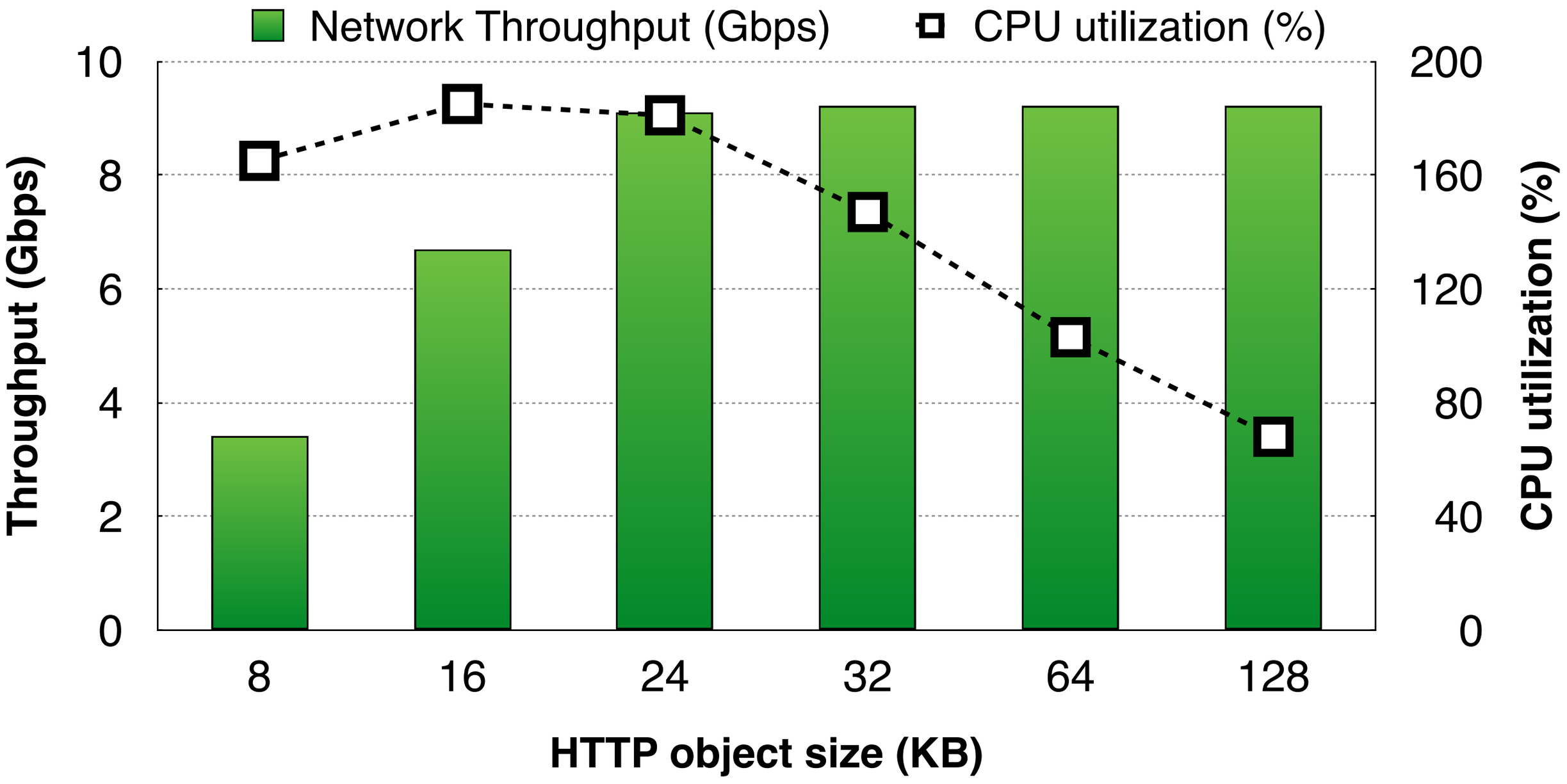
The Problem

- Conventional stacks are great for bulk transfers, but what about short ones?

The Problem


Network Throughput (Gbps)
Throughput (Gbps)
10
8
6
4
2
0
8
16
24
32
64
128
HTTP object size (KB)

The Problem


Network Throughput (Gbps)
CPU utilization (%)
Throughput (Gbps)
CPU utilization (%)
0
2
4
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8
10
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40
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160
200
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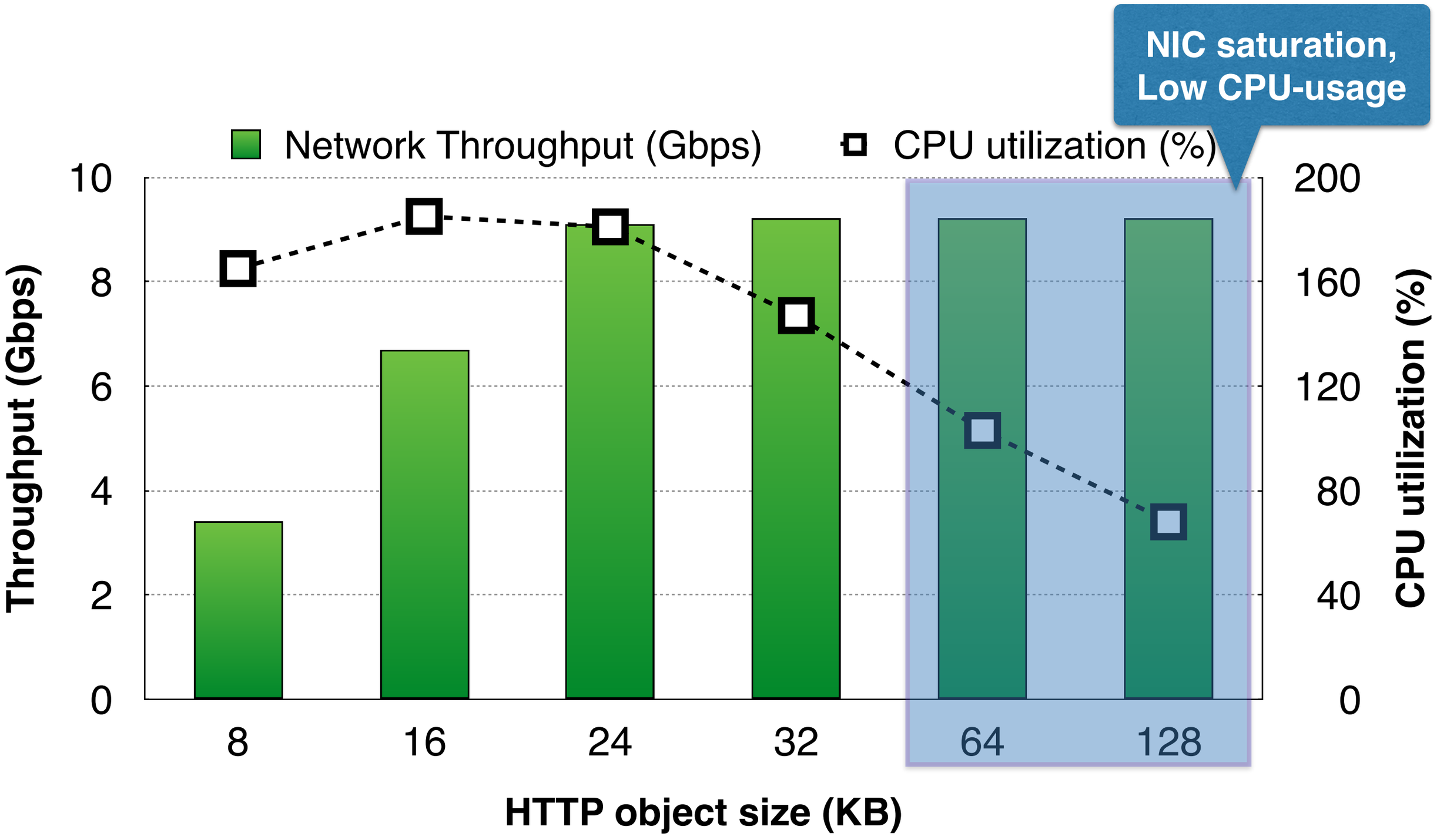
The Problem


NIC saturation,
Low CPU-usage
Network Throughput (Gbps)
CPU utilization (%)
Throughput (Gbps)
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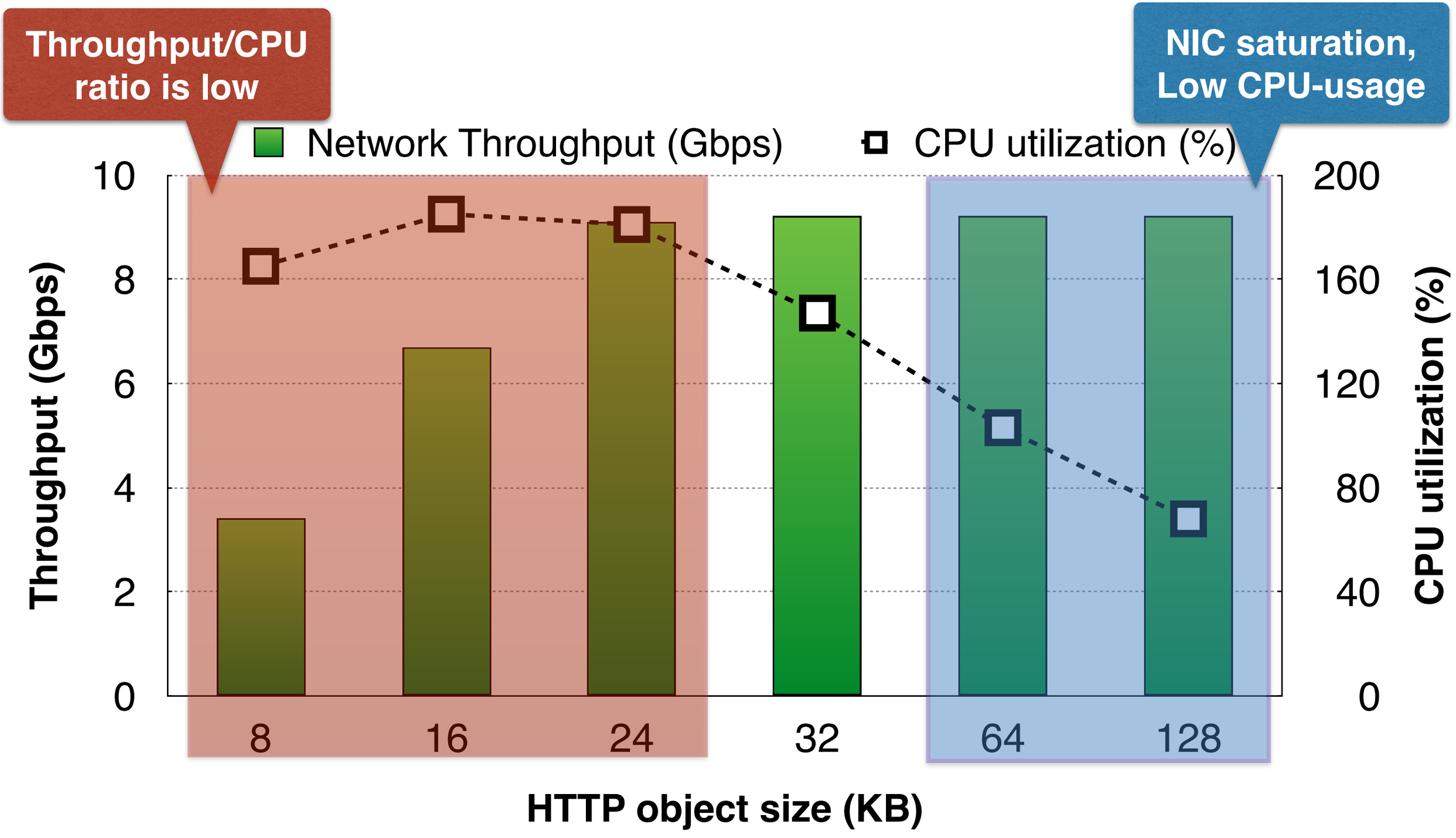
Throughput/CPU ratio is low
NIC saturation, Low CPU-usage
Network Throughput (Gbps)
CPU utilization (%)
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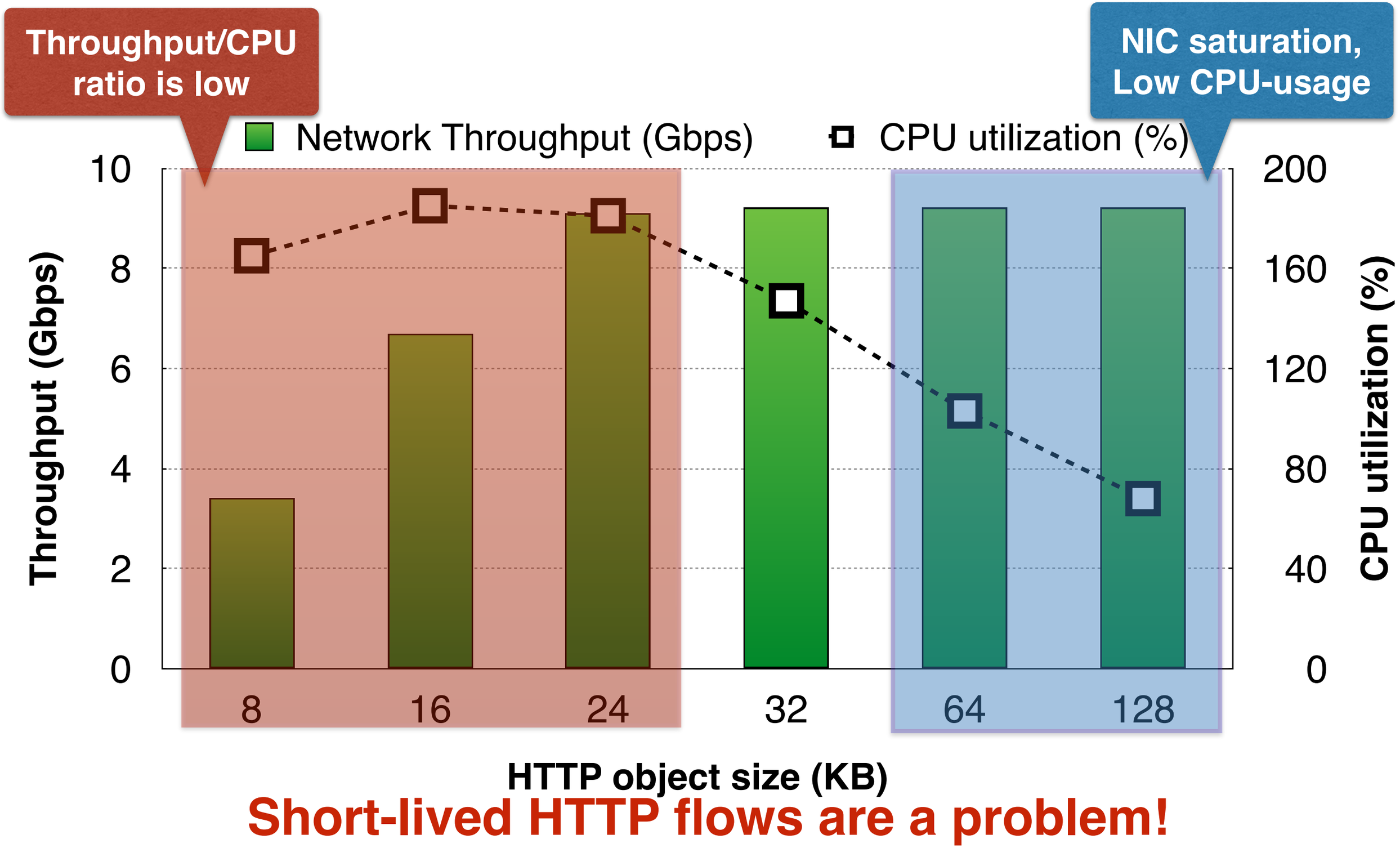

Short-lived HTTP flows are a problem!

Why is this important?

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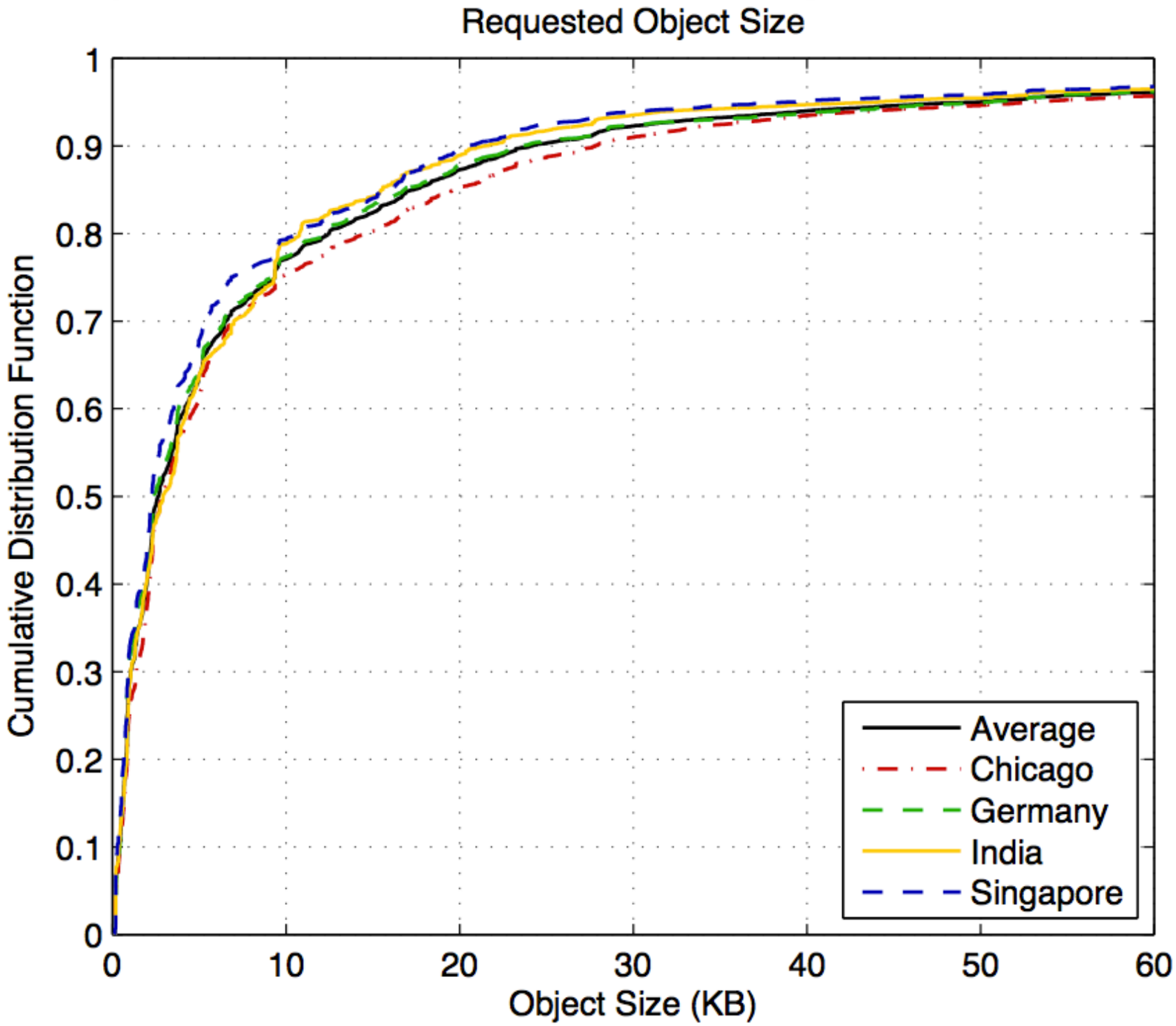

Distribution based on traces from Yahoo! CDN [Al-Fares et'al 2011]

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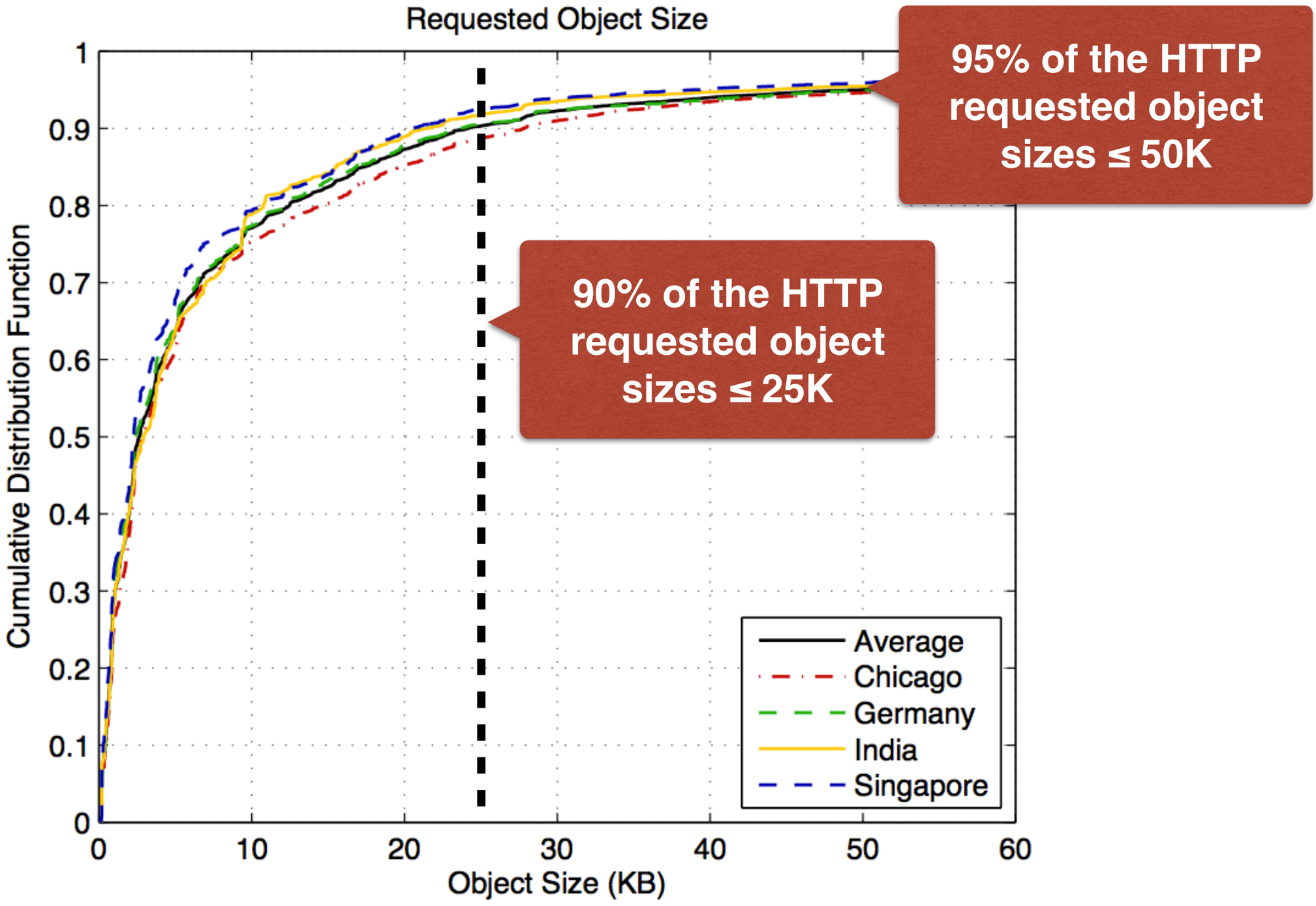

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Design Goals

Design a network stack that:

- Allows transparent flow of memory from NIC to the application and vice versa

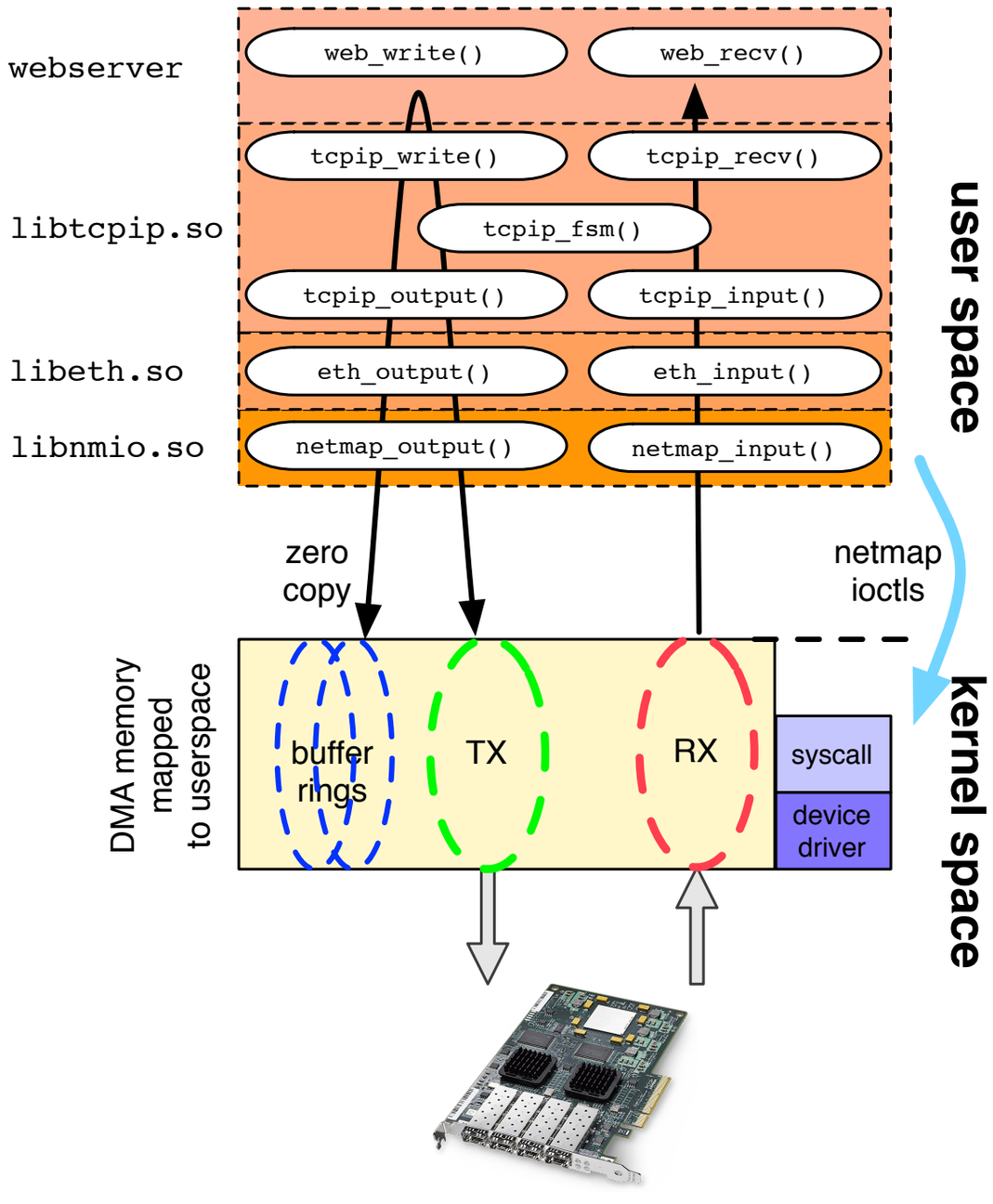
- Reduces system costs (e.g., batching, cache-locality, lock- and sharing-free, CPU-affinity)

- Exploits application-specific knowledge to reduce repetitive processing costs (e.g. TCP segmentation of web objects, checksums)

Sandstorm: A specialized webserver stack

Prototyped on top of FreeBSD's netmap framework:

- **`libnmio`**: abstracting netmap-related I/O
- **`libeth`**: lightweight ethernet layer
- **`libtcpip`**: optimized TCP/IP layer
- application: simple HTTP server that serves static content

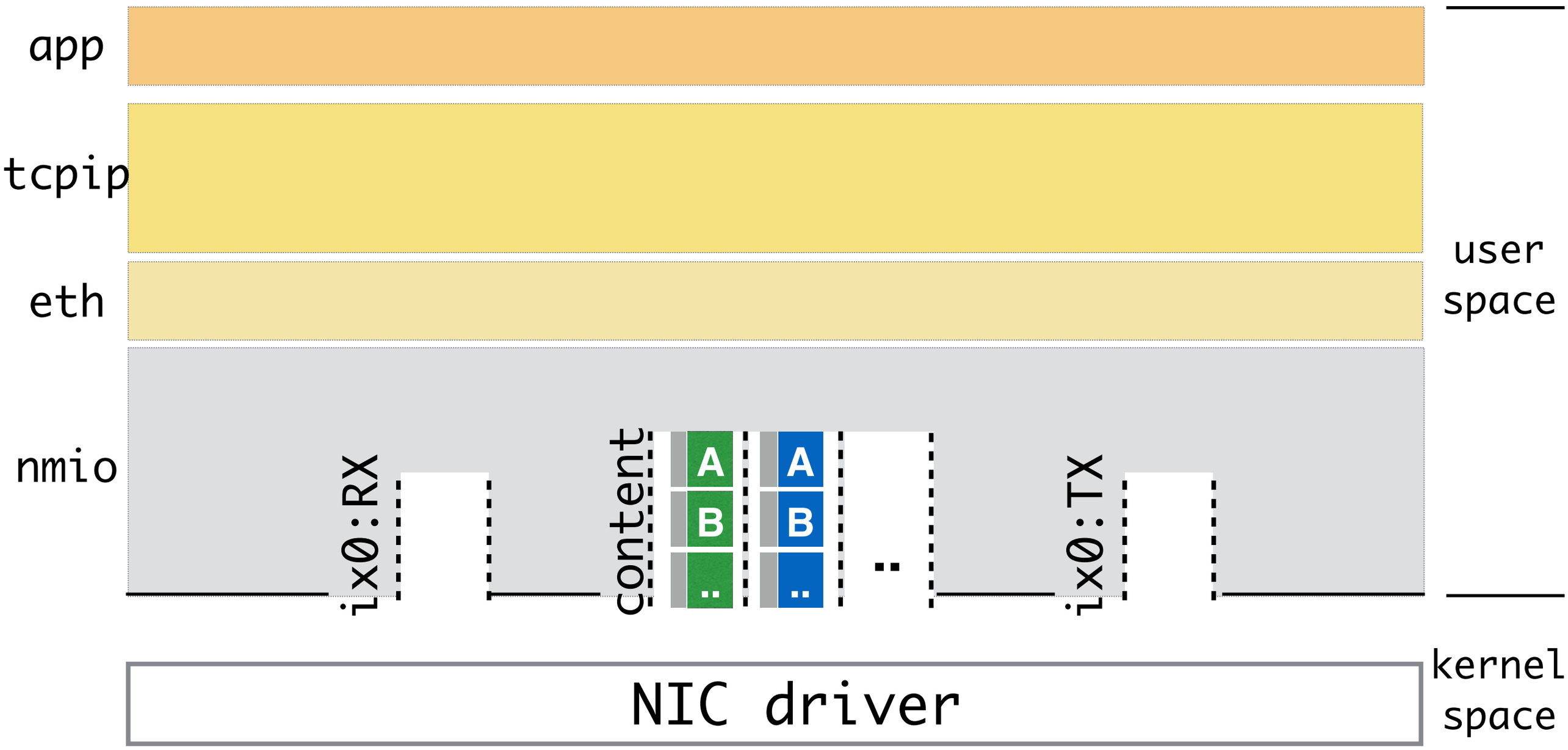


Sandstorm: A specialized webserver stack

Key decisions (some of them):

- Application & stack are merged into the same process address space
- Static content is pre-segmented into network packets and *a-priori* loaded to DRAM
- Received packet frames are processed in-place on the RX rings, w/o memory copying/buffering
- RX/TX packet batching greatly amortizes the system call overhead
- Bufferless, synchronous model (no socket layer)

Sandstorm Architecture (10,000ft view)



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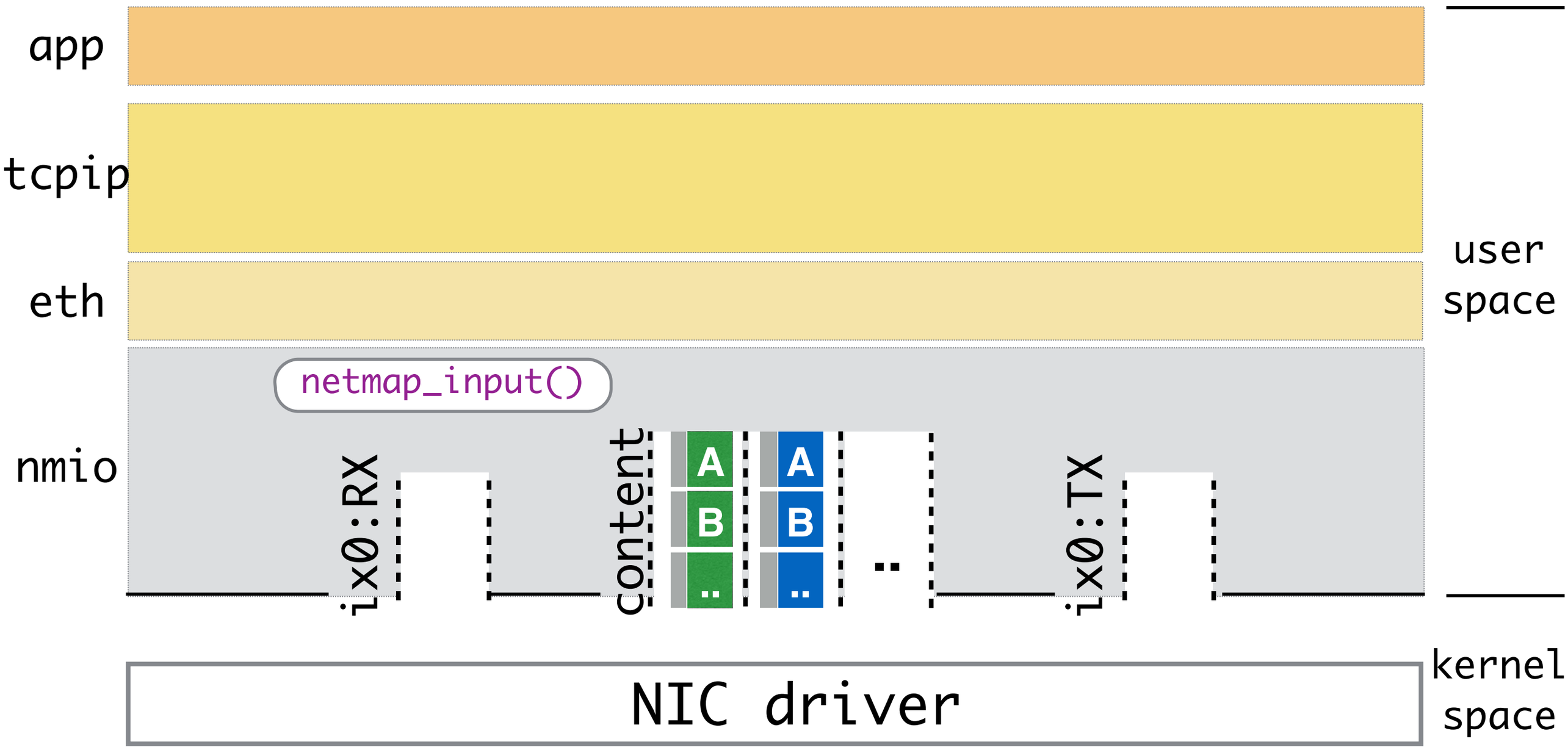

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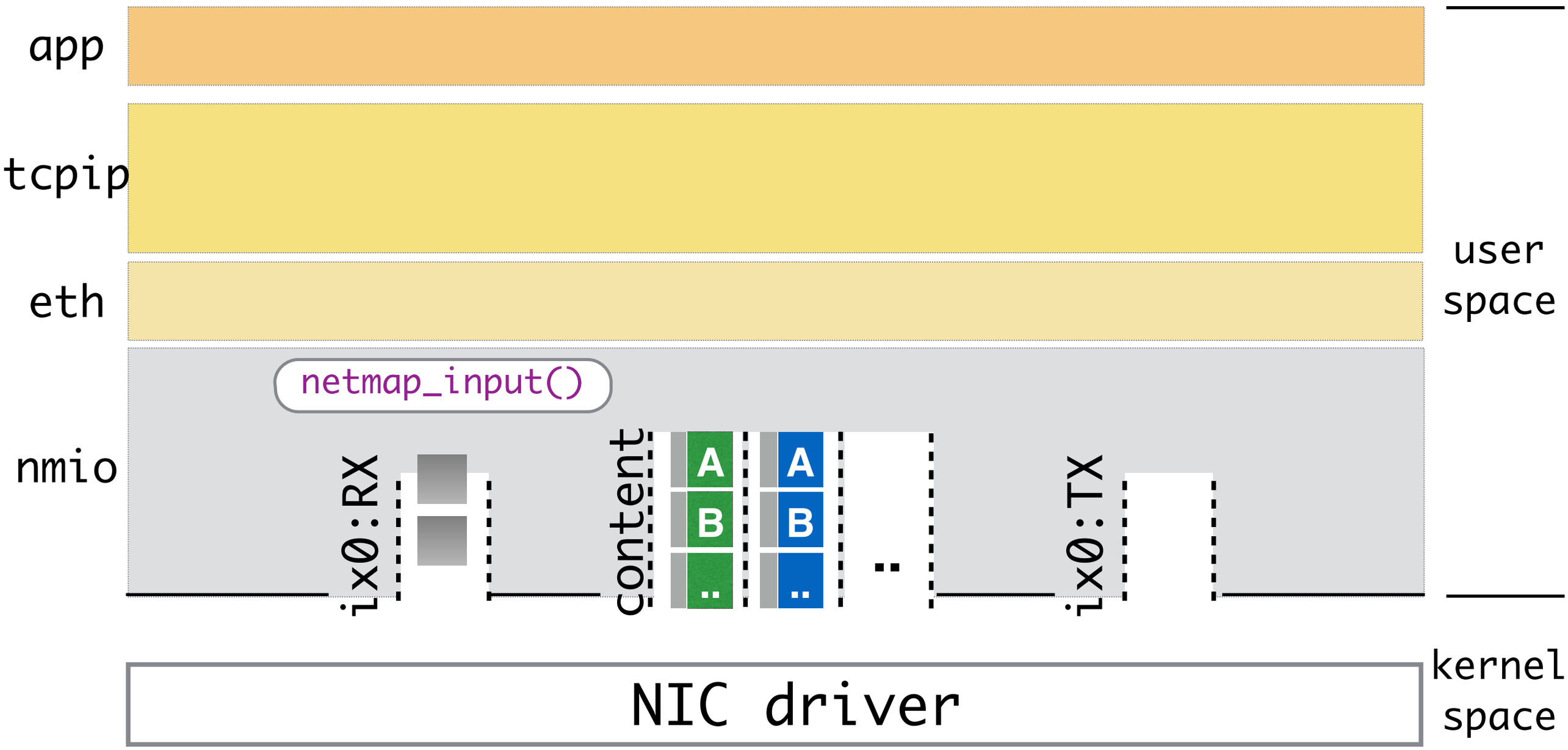

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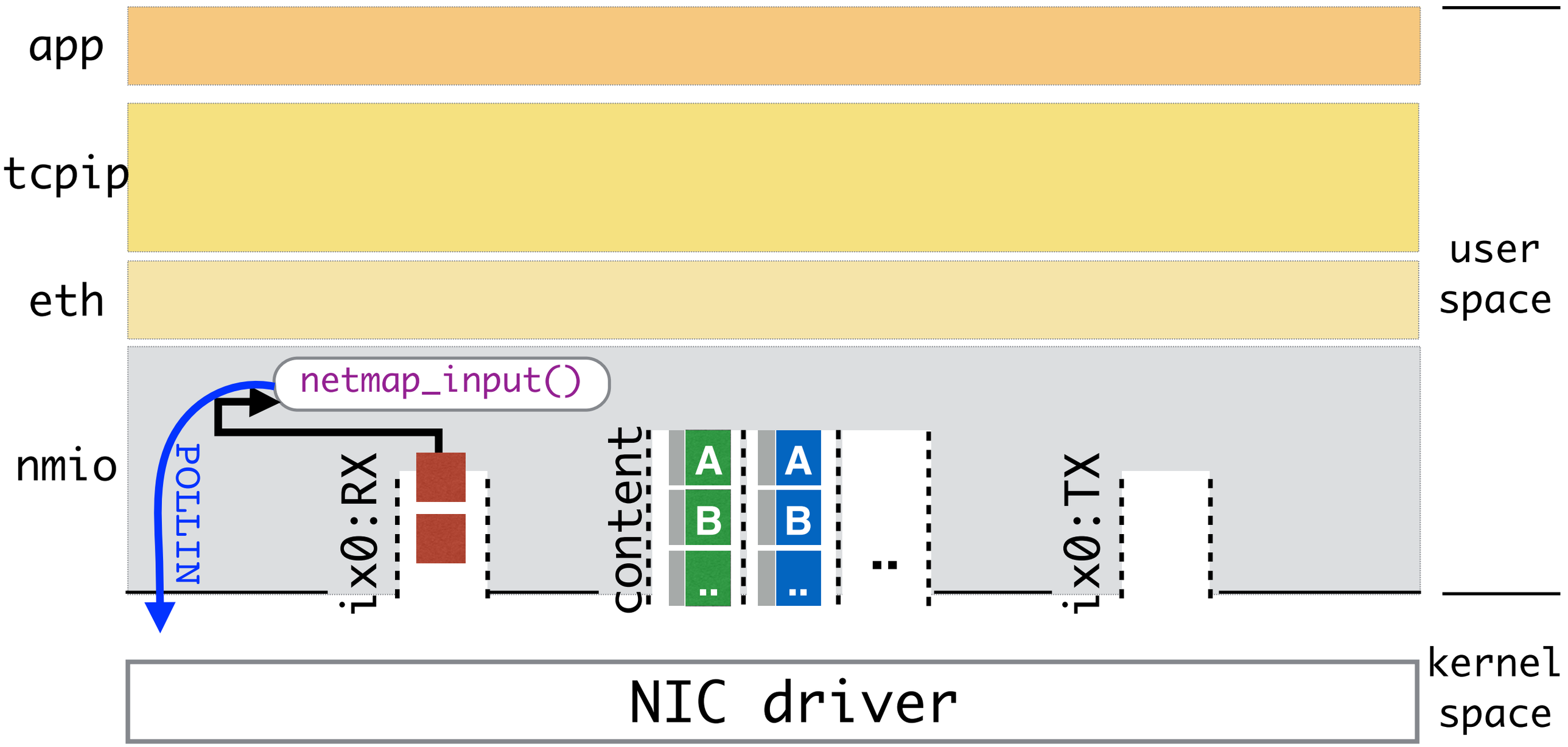

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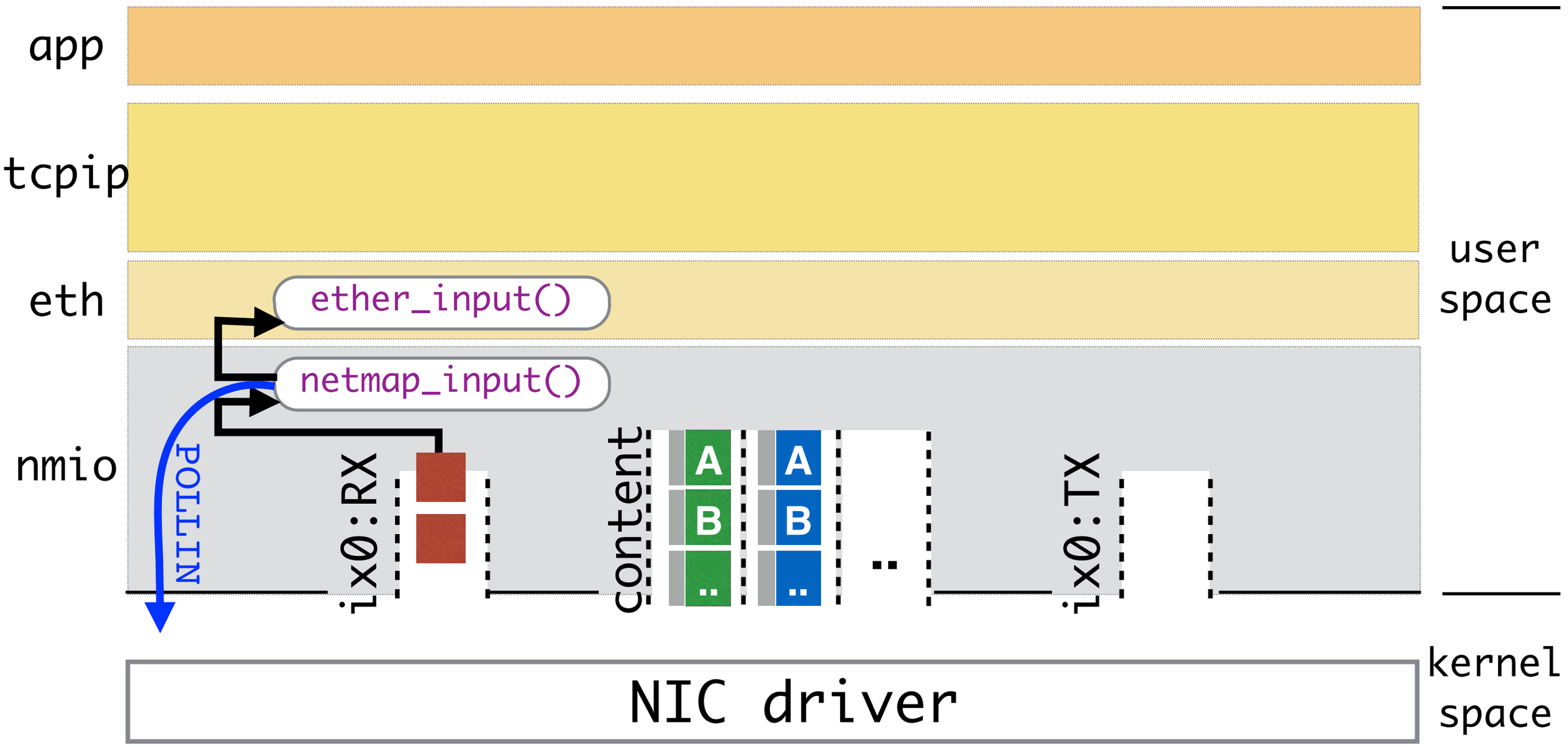

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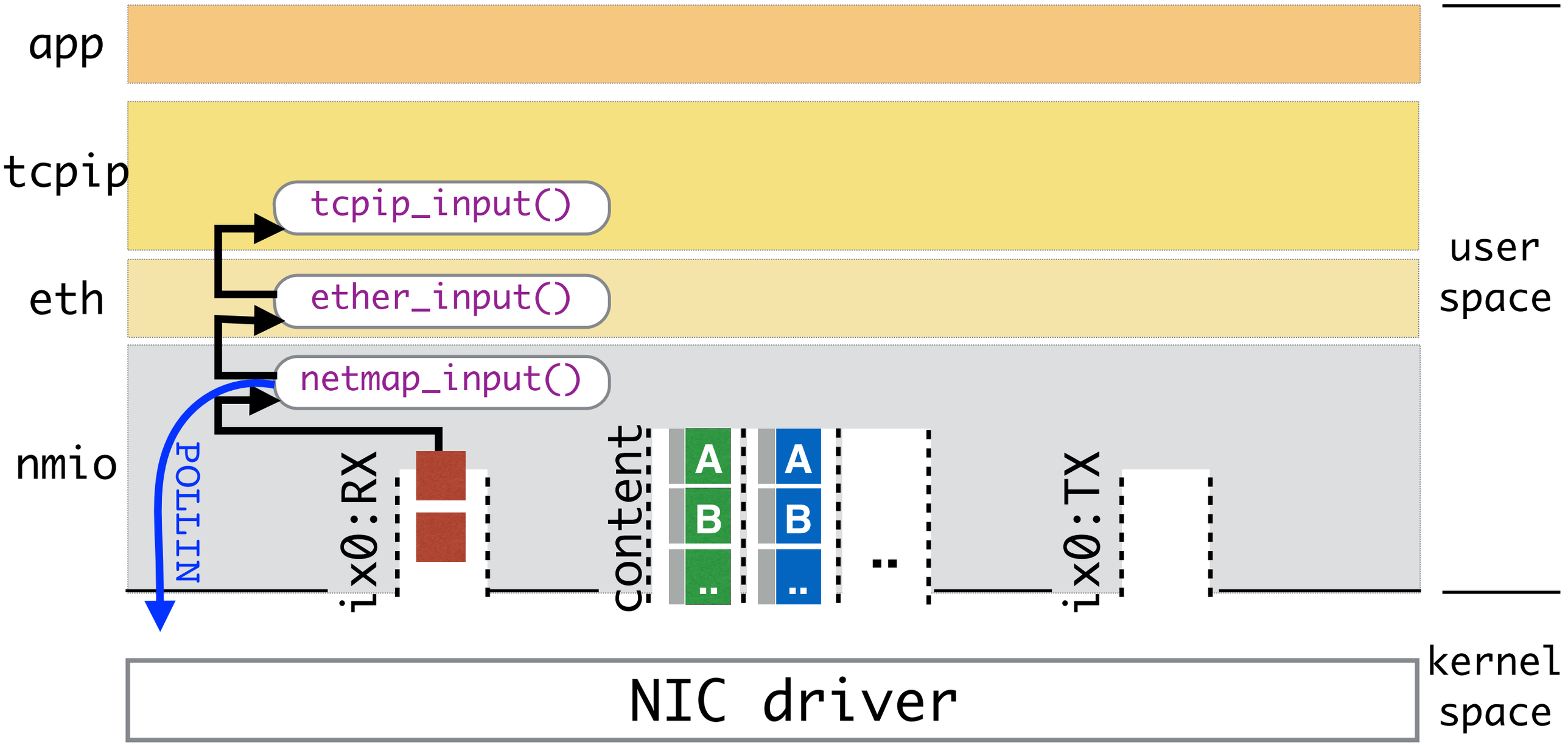

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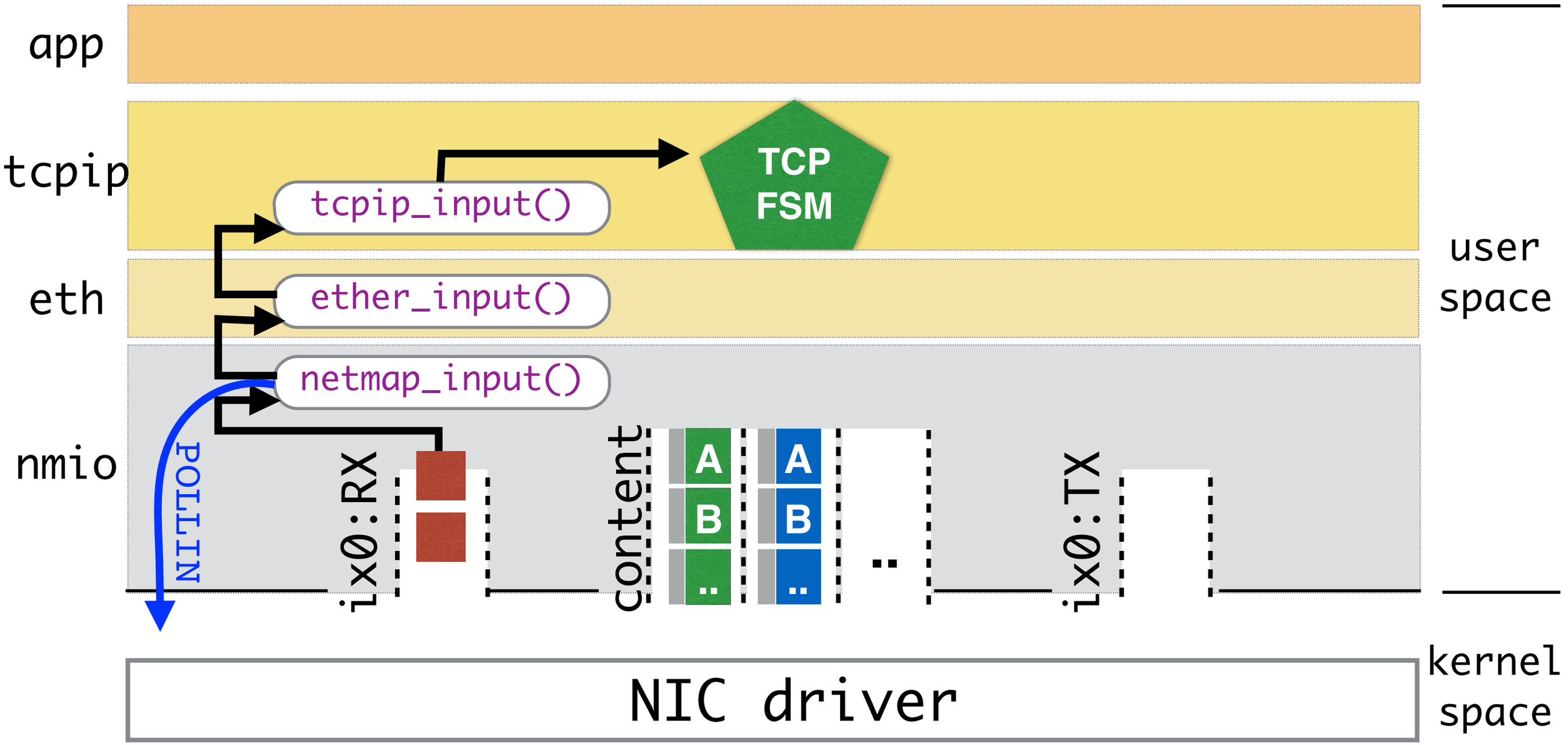

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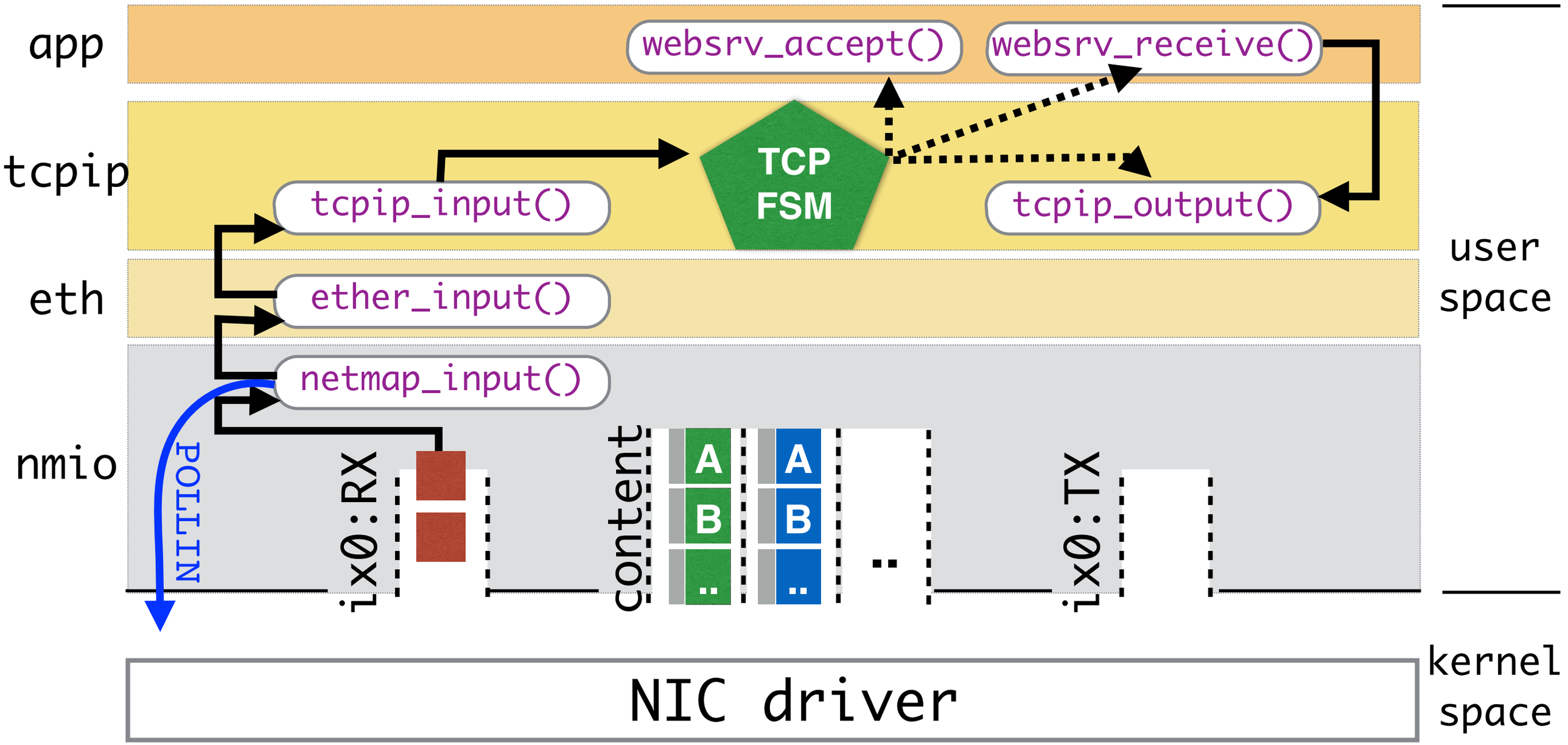

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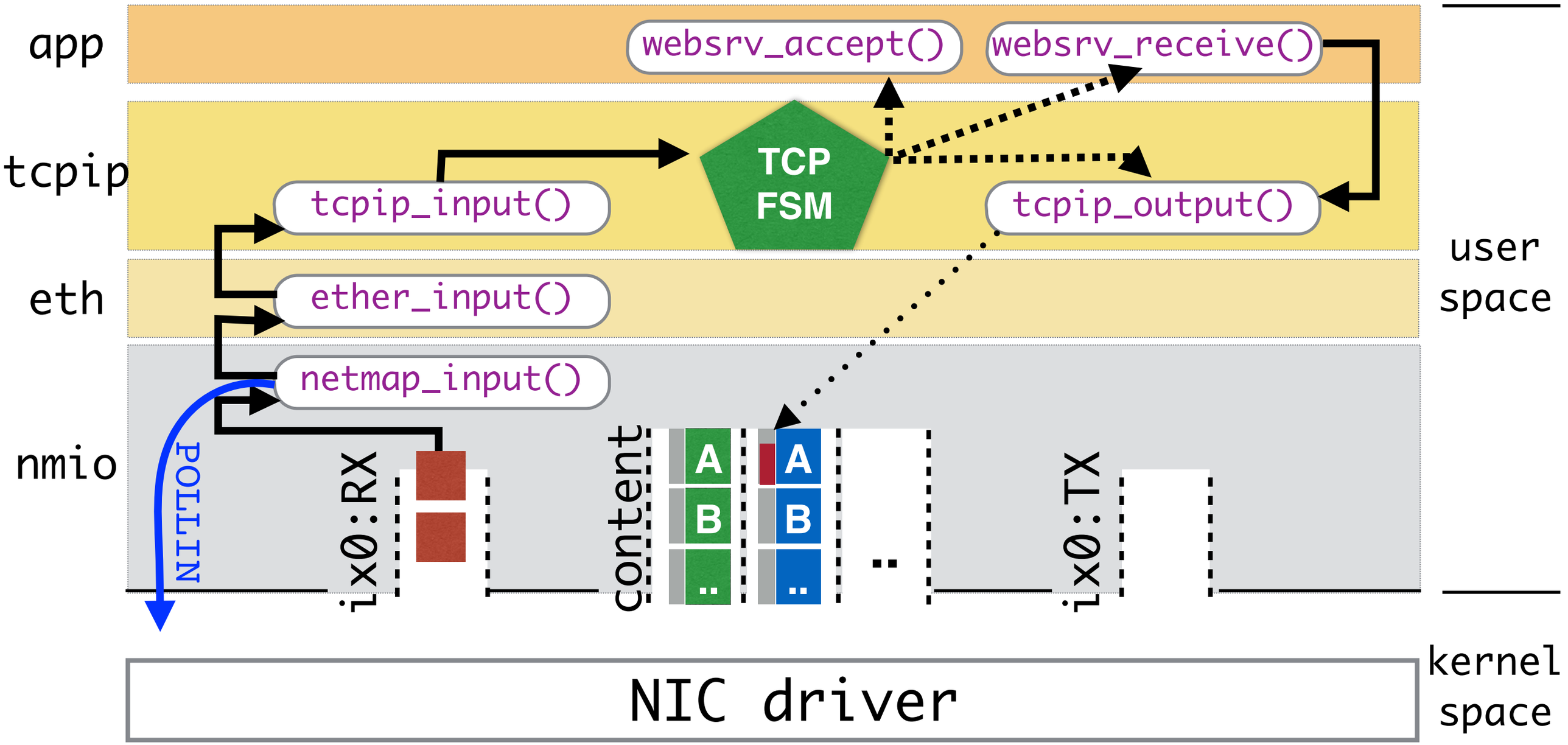

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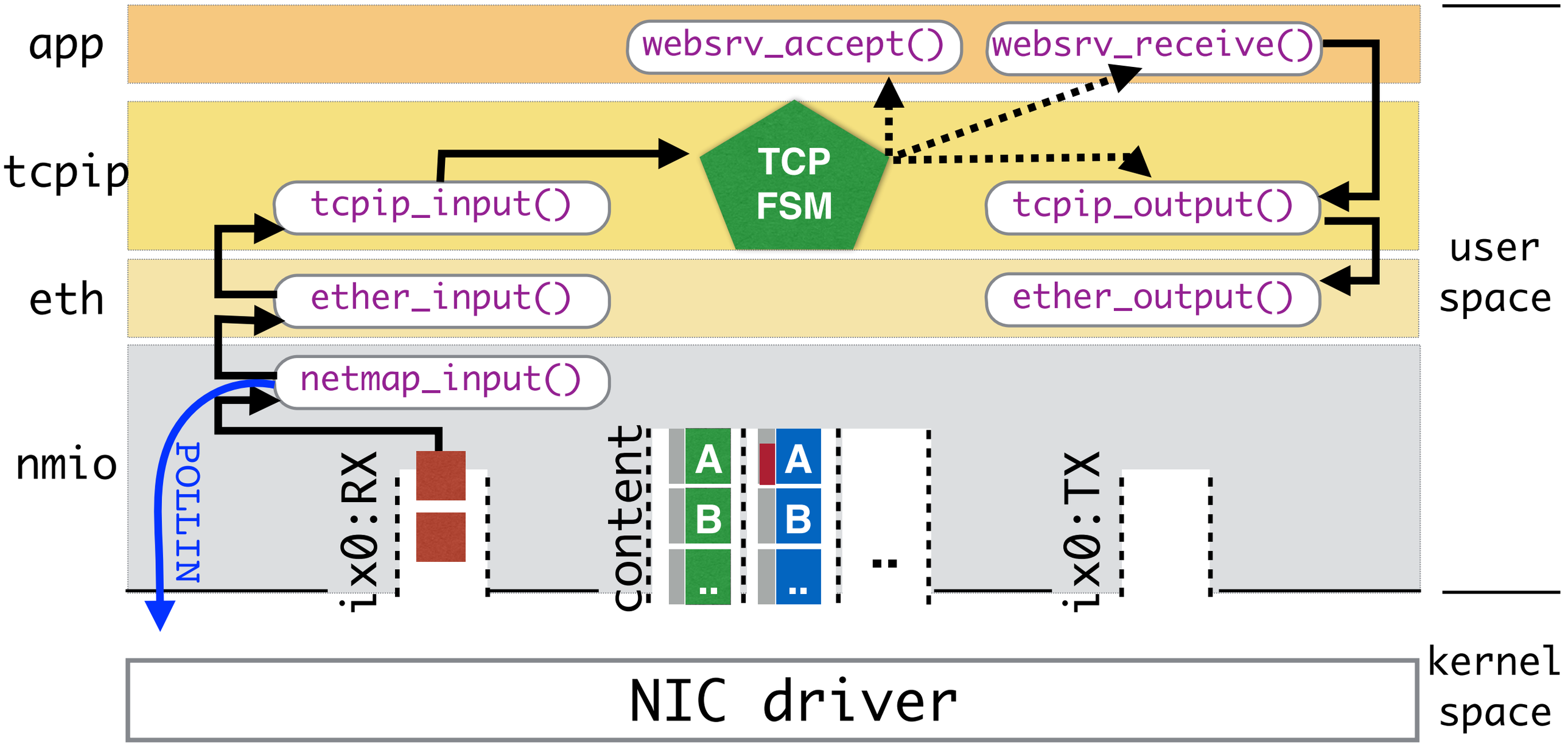

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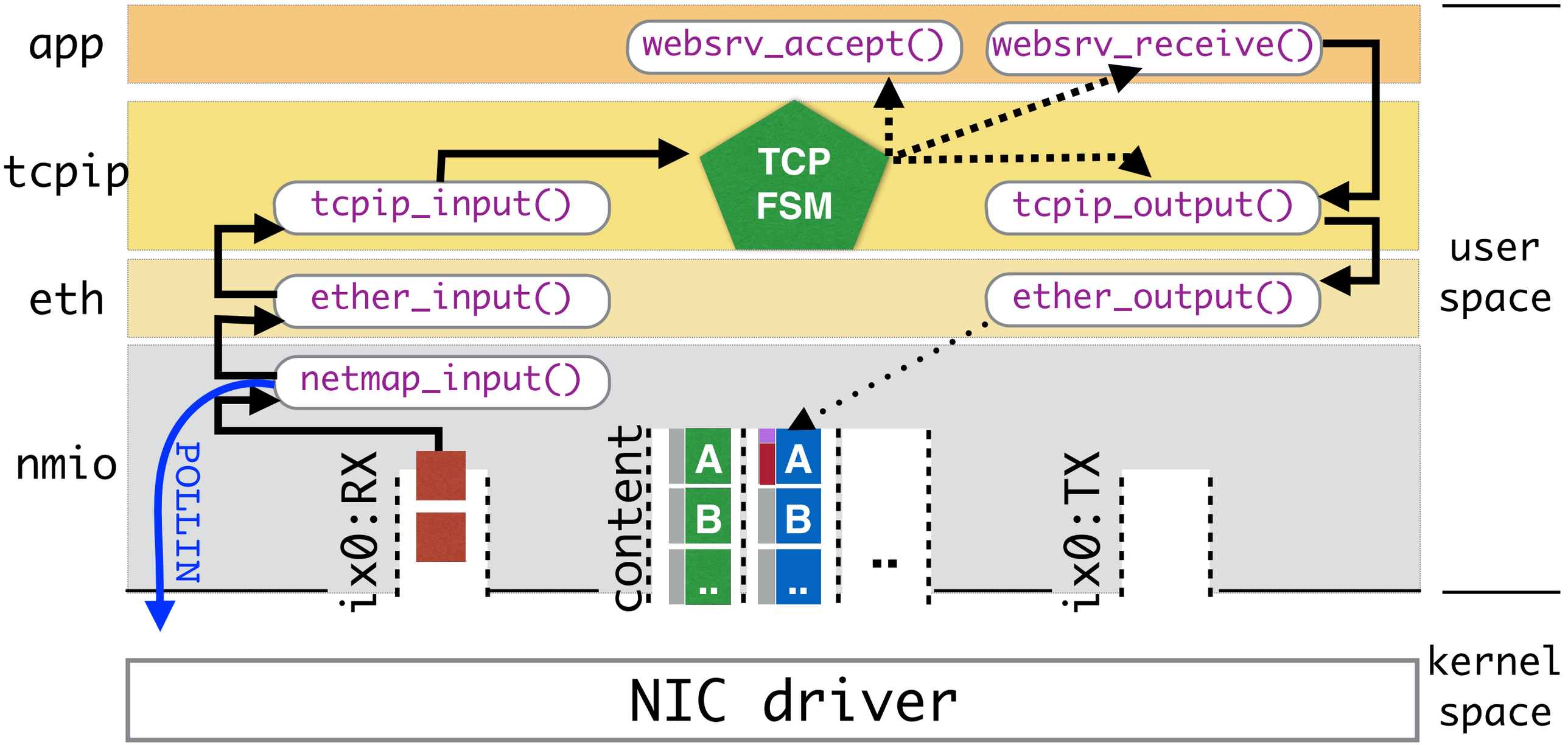

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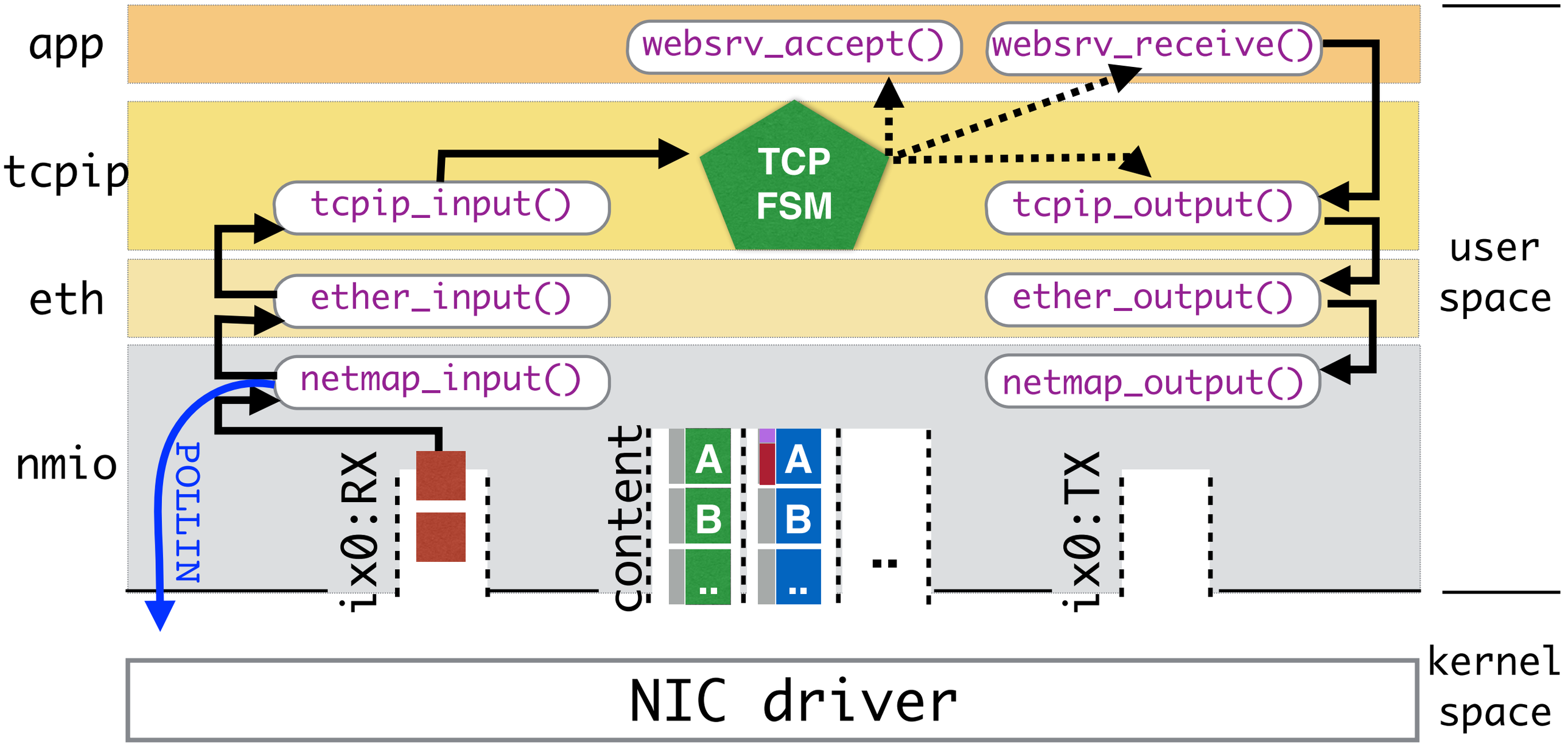

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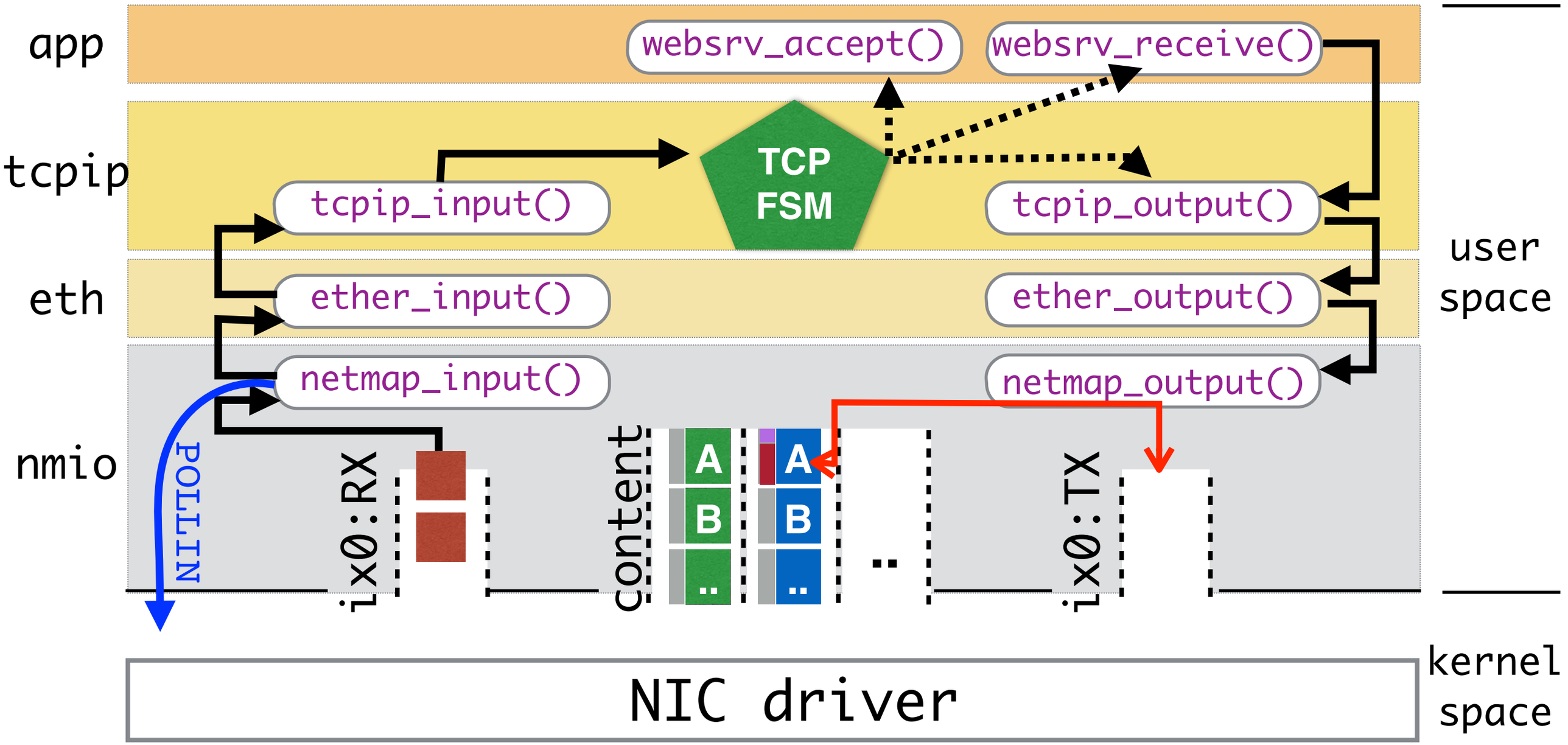

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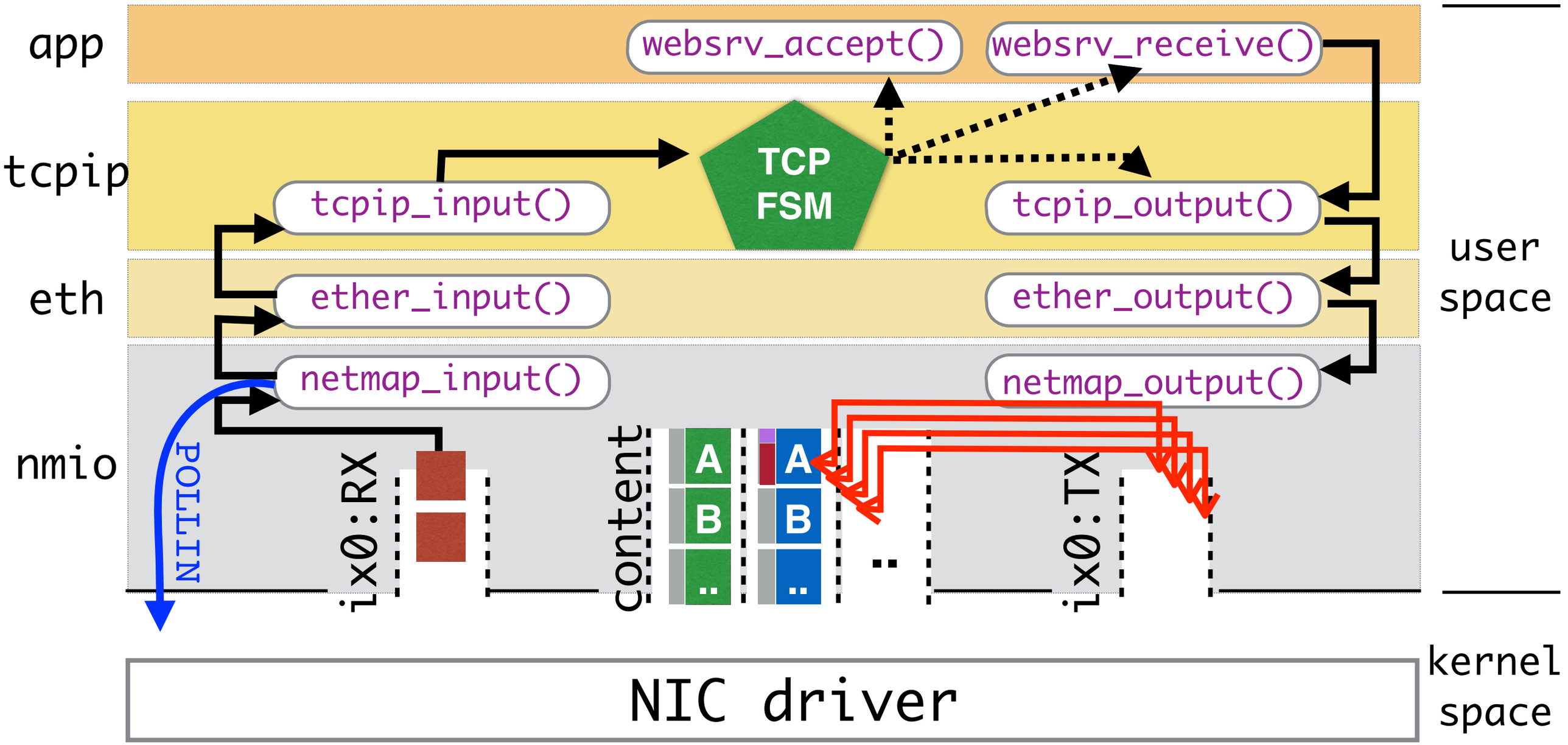

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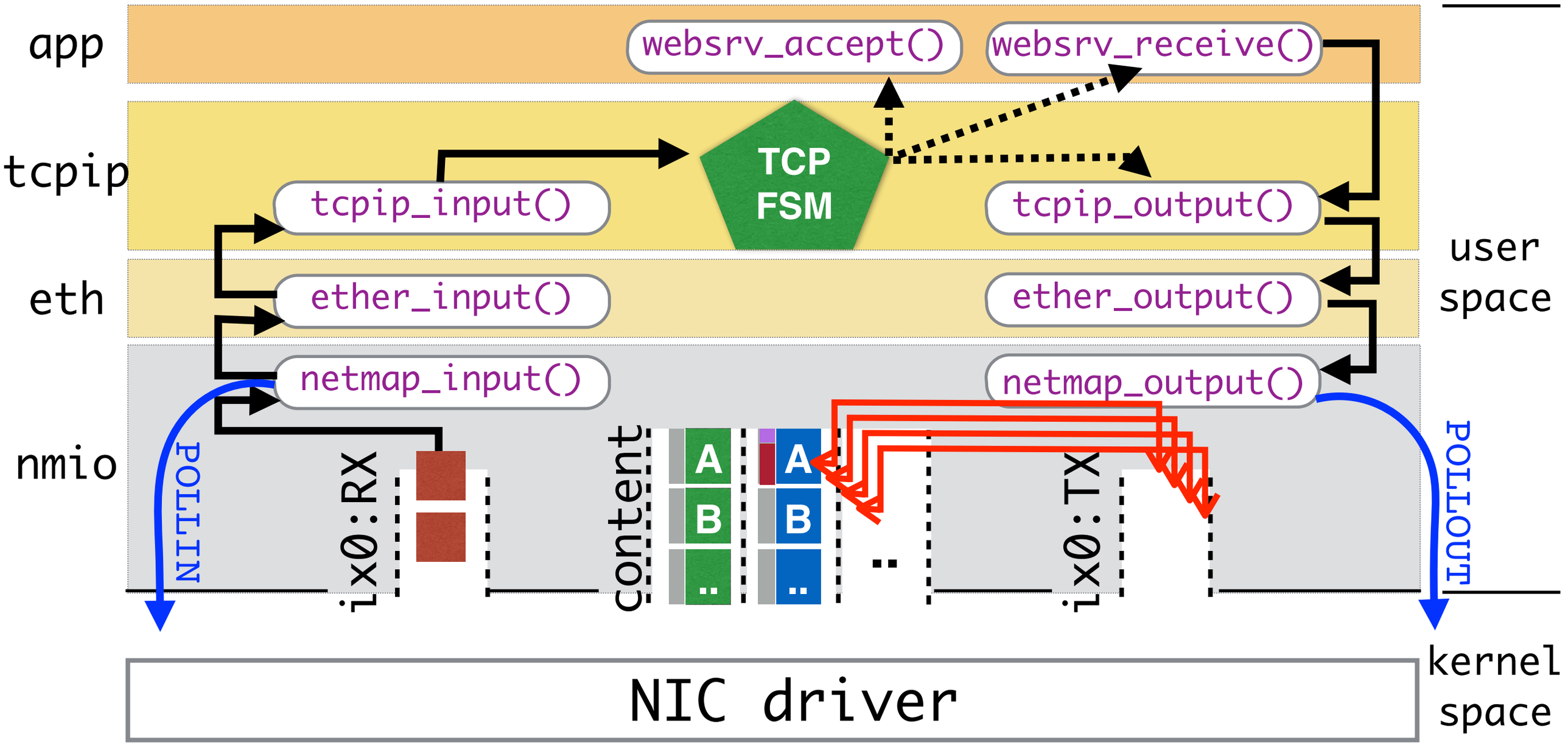
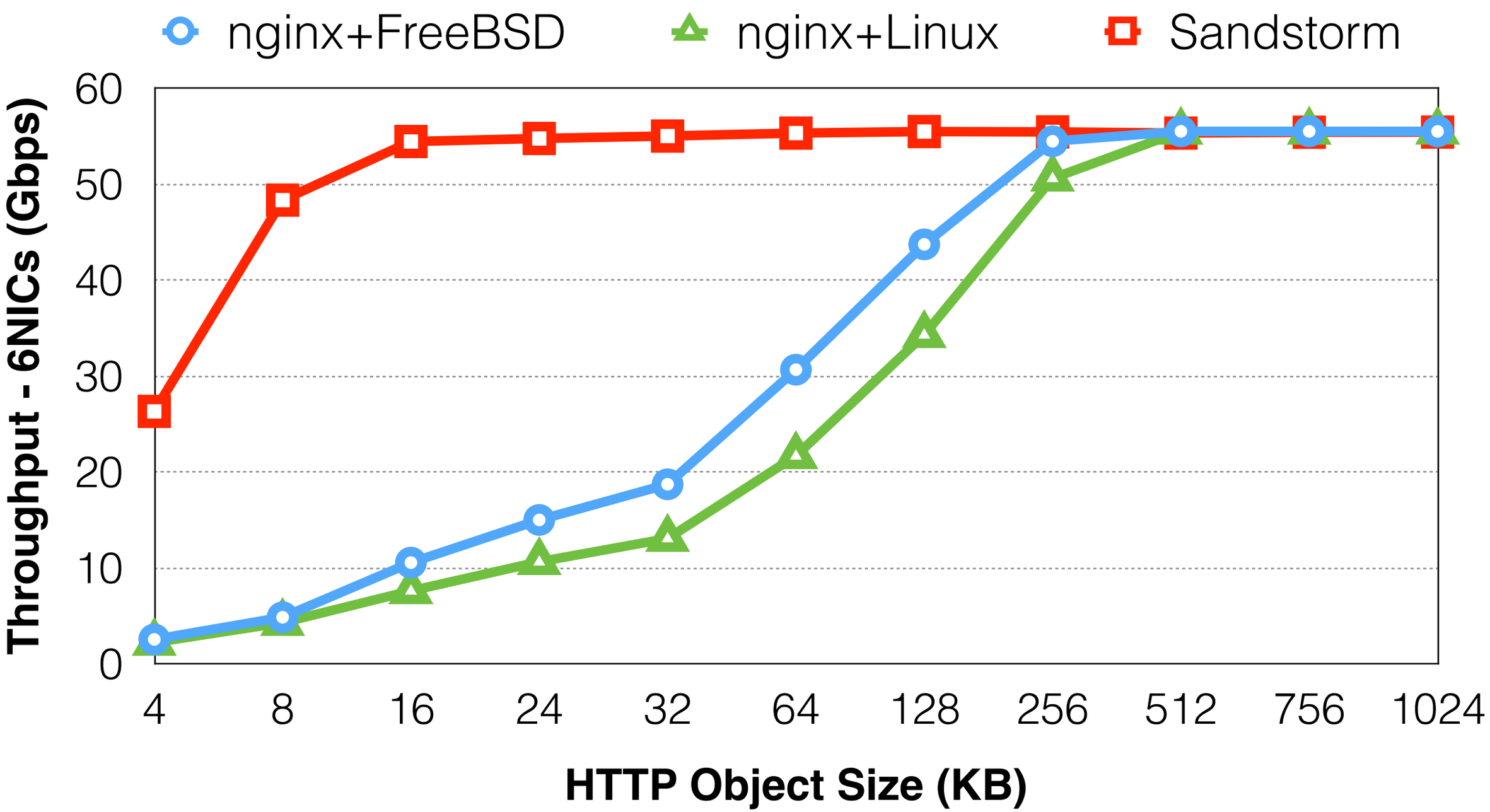
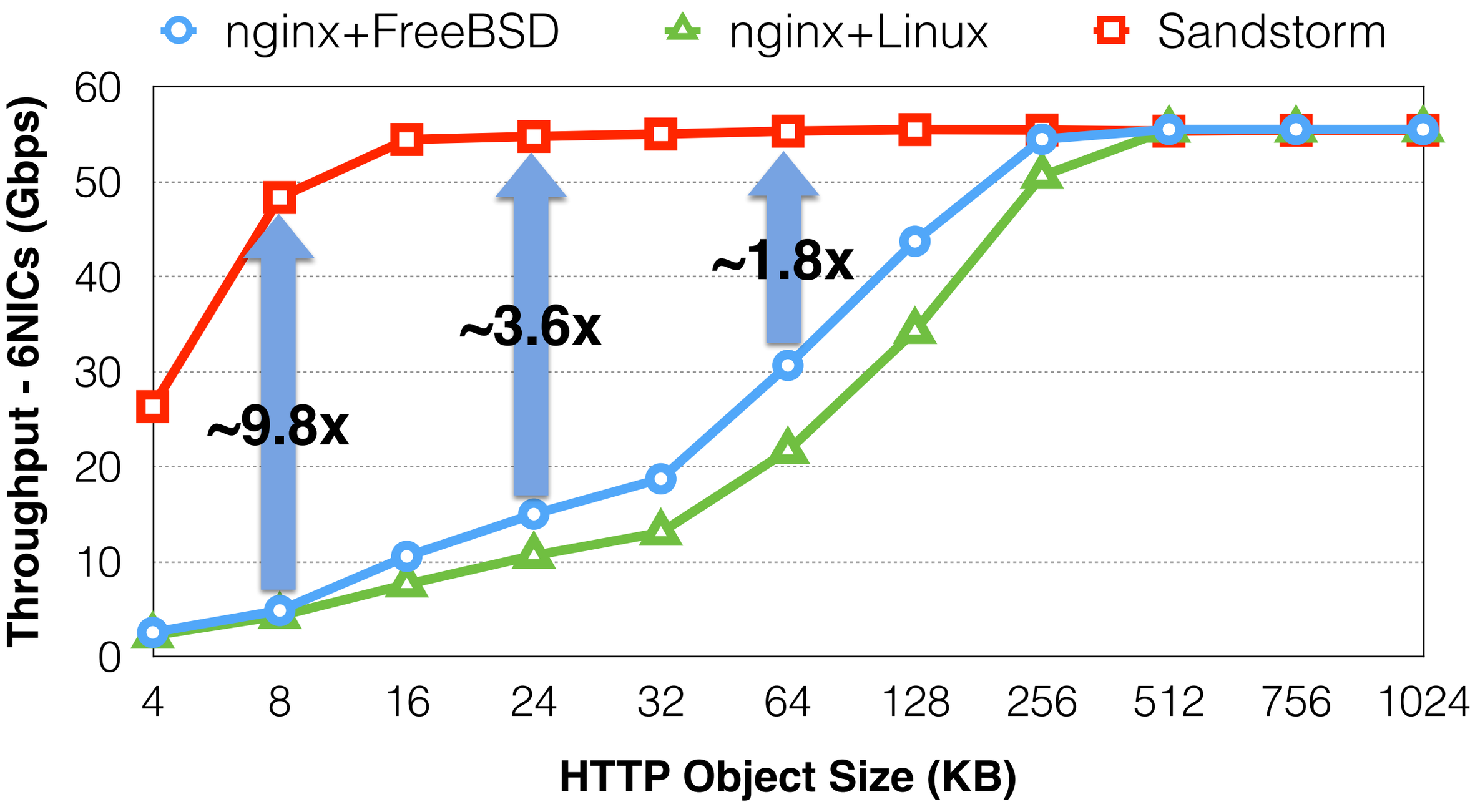


Evaluation


nginx+FreeBSD
nginx+Linux
Sandstorm
Throughput - 6NICs (Gbps)
60
50
40
30
20
10
0
4
8
16
24
32
64
128
256
512
756
1024
HTTP Object Size (KB)

Evaluation


nginx+FreeBSD
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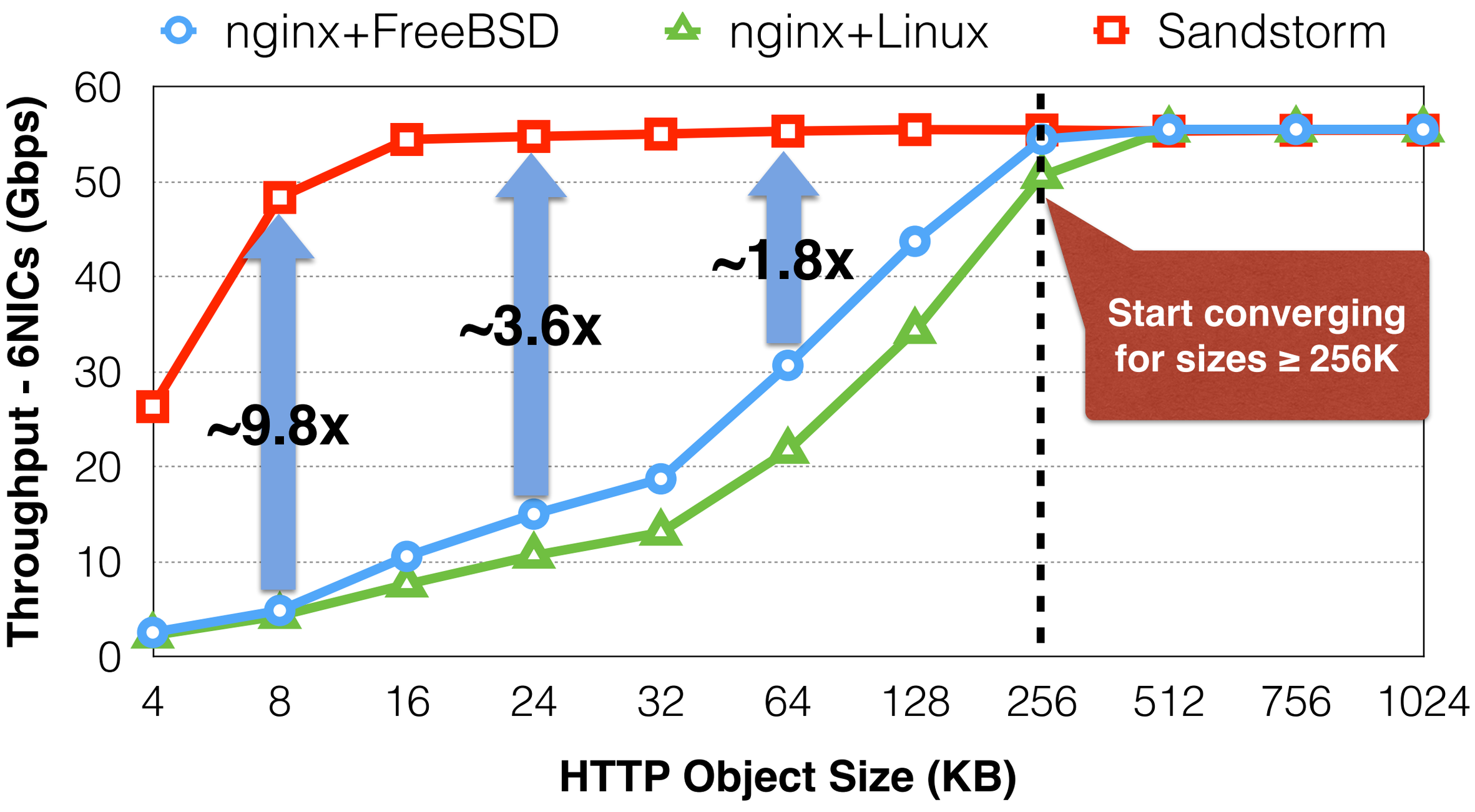
Sandstorm
Throughput - 6NICs (Gbps)
60
50
40
30
20
10
0
~9.8x
~3.6x
~1.8x
4
8
16
24
32
64
128
256
512
756
1024
HTTP Object Size (KB)

Evaluation

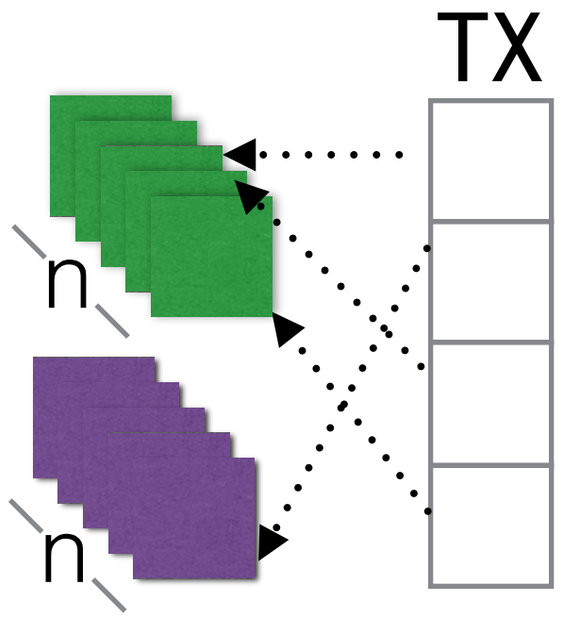

nginx+FreeBSD
nginx+Linux
Sandstorm
Throughput - 6NICs (Gbps)
60
50
40
30
20
10
0
~9.8x
~3.6x
~1.8x
Start converging for sizes ≥ 256K
4
8
16
24
32
64
128
256
512
756
1024
HTTP Object Size (KB)

To copy or not to copy?

zerocopy

```
/* Get src and destination slots */
struct netmap_slot *bf = &ppool->slot[slotindex];
struct netmap_slot *tx = &txring->slot[cur];

/* zero-copy packet */
tx->buf_idx = bf->buf_idx;
tx->len = bf->len;
tx->flags = NS_BUF_CHANGED;
```

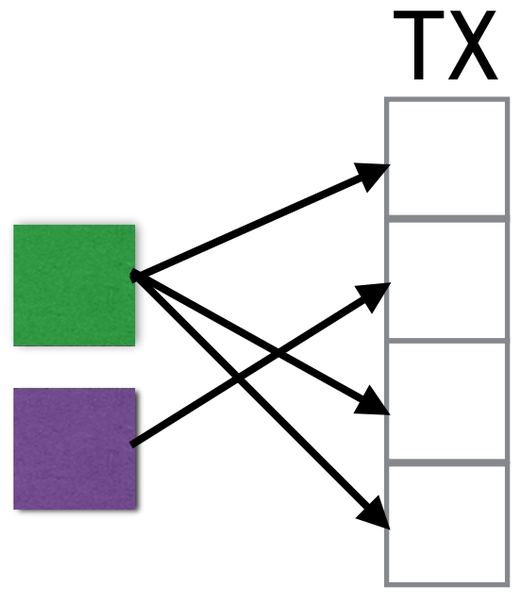


OR

memcpy

```
/* Get source and destination bufs */
char *srcp = NETMAP_BUF(ppool, bf->buf_idx);
char *dstp = NETMAP_BUF(txring, tx->buf_idx);

/* memcpy packet */
memcpy(dstp, srcp, bf->len);
tx->len = bf->len;
```



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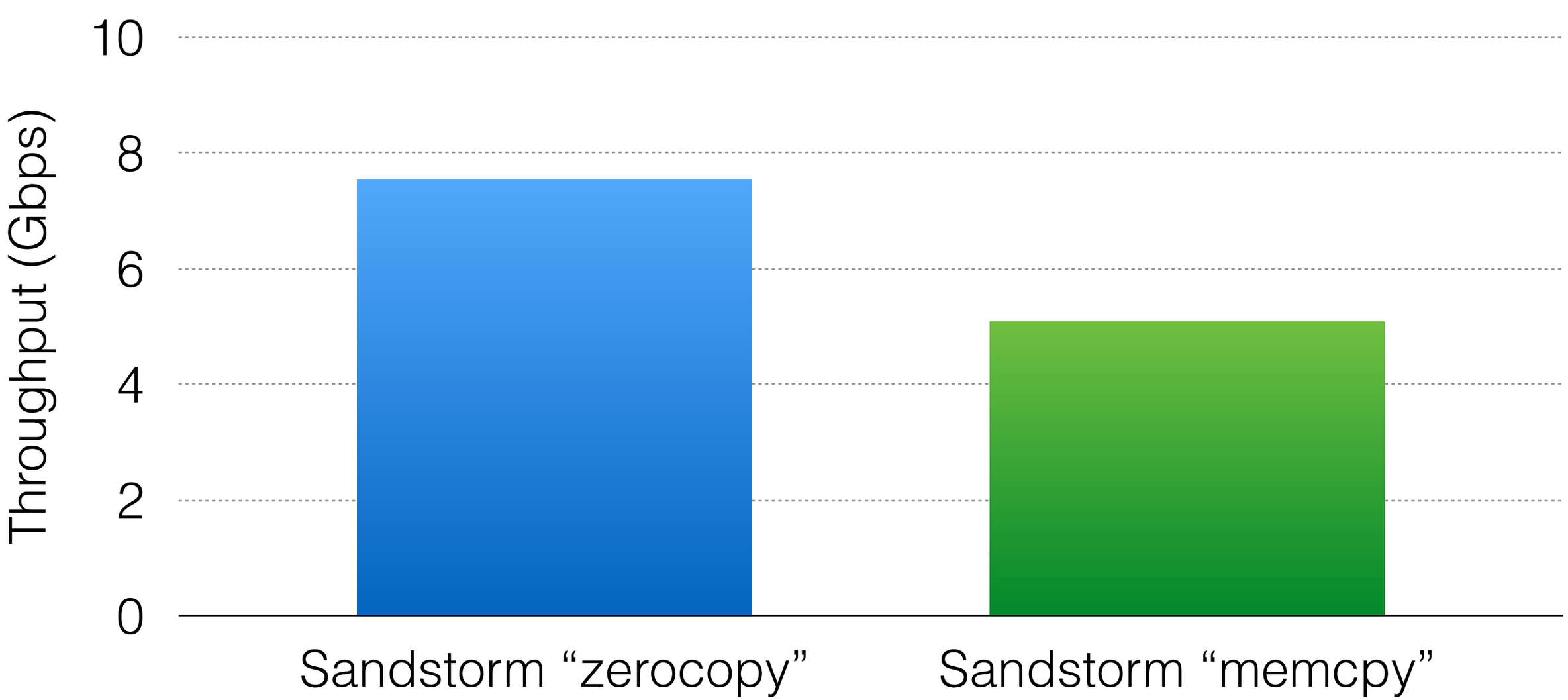
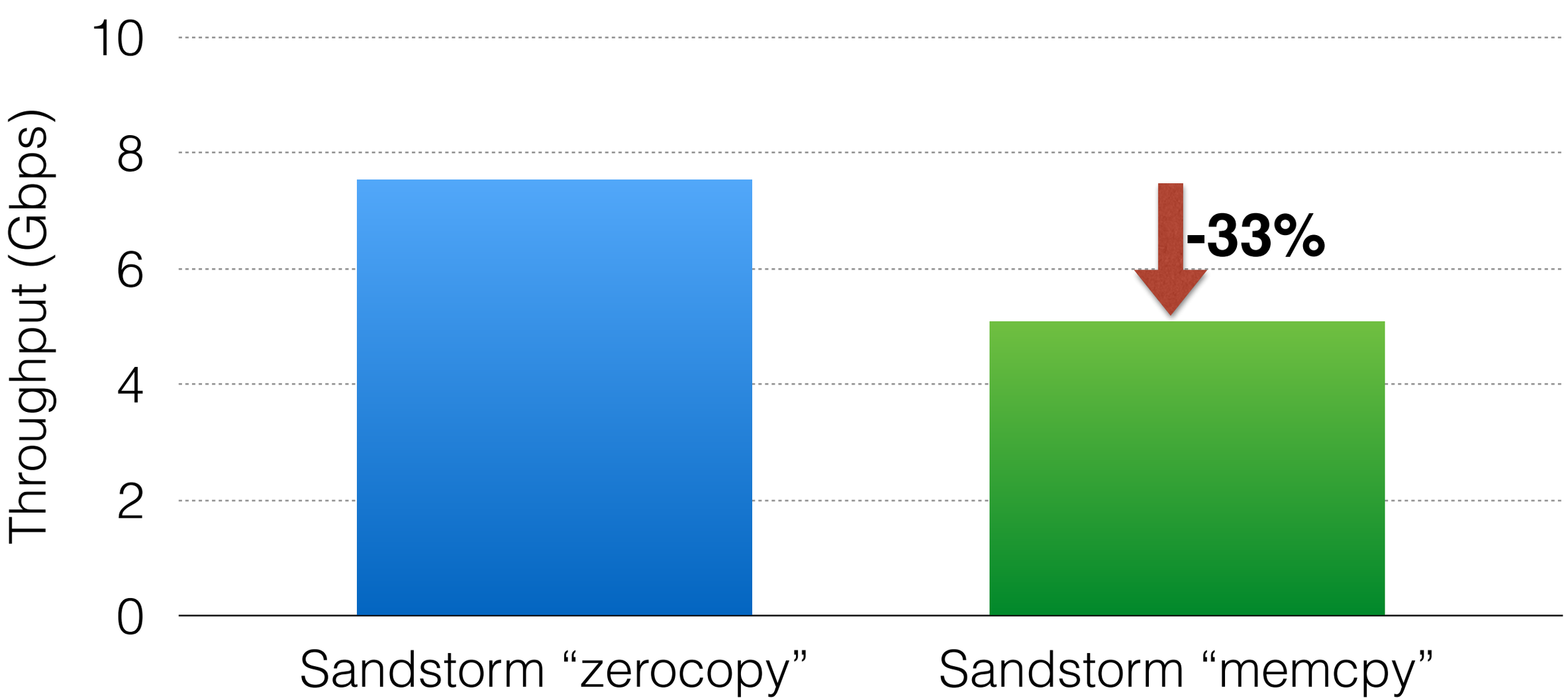


Intel Core 2 (2006)

Serving a 24KB HTTP object

To copy or not to copy?



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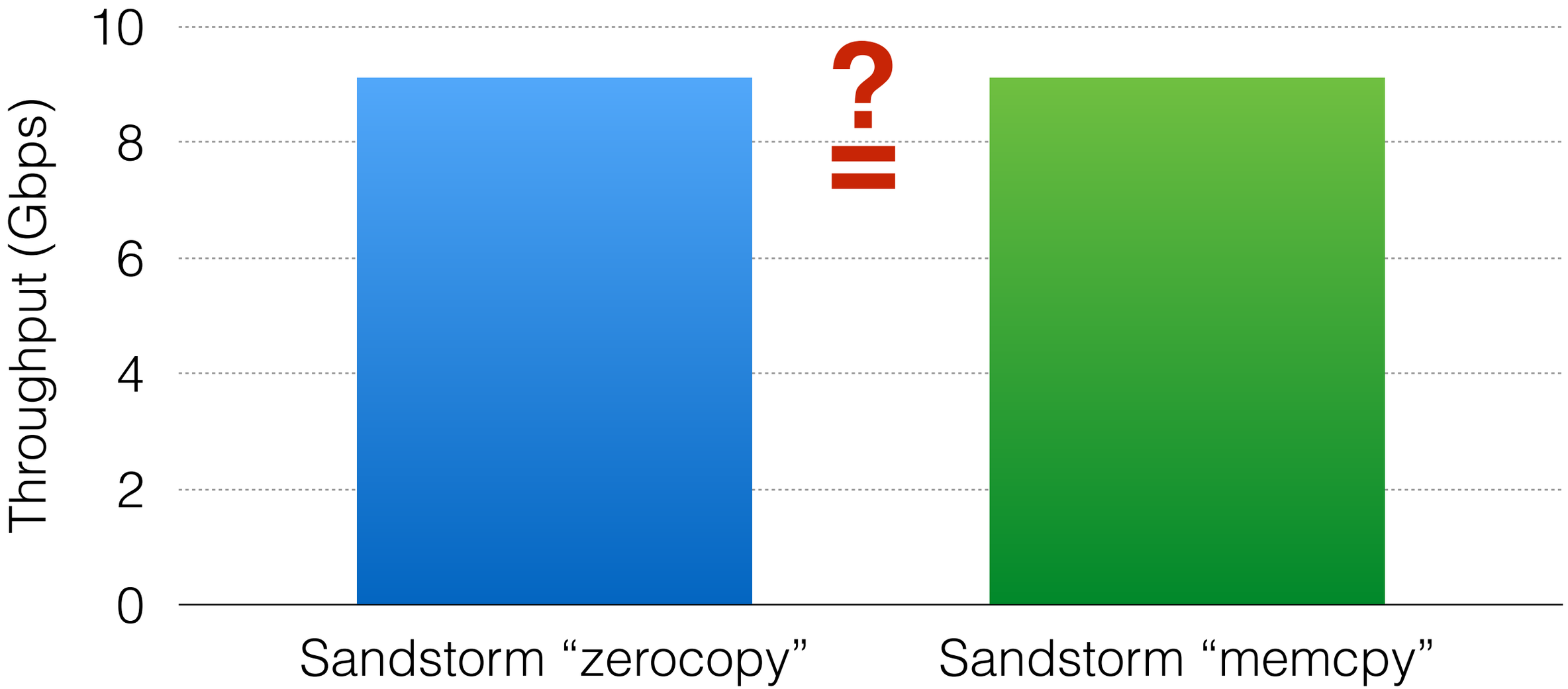
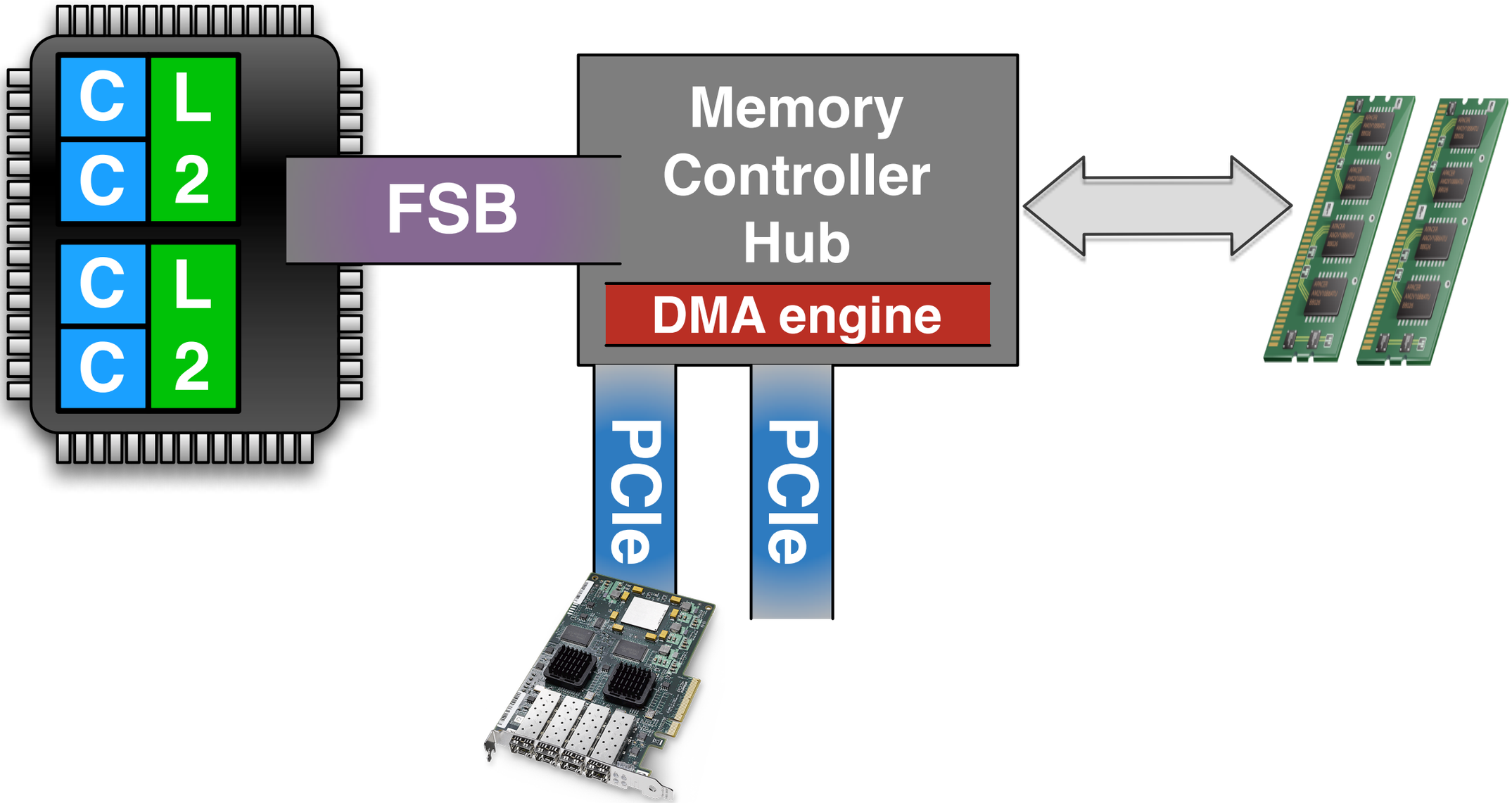


Intel Sandybridge (2013)

Serving a 24KB HTTP object

CPU microarchitecture ~2006



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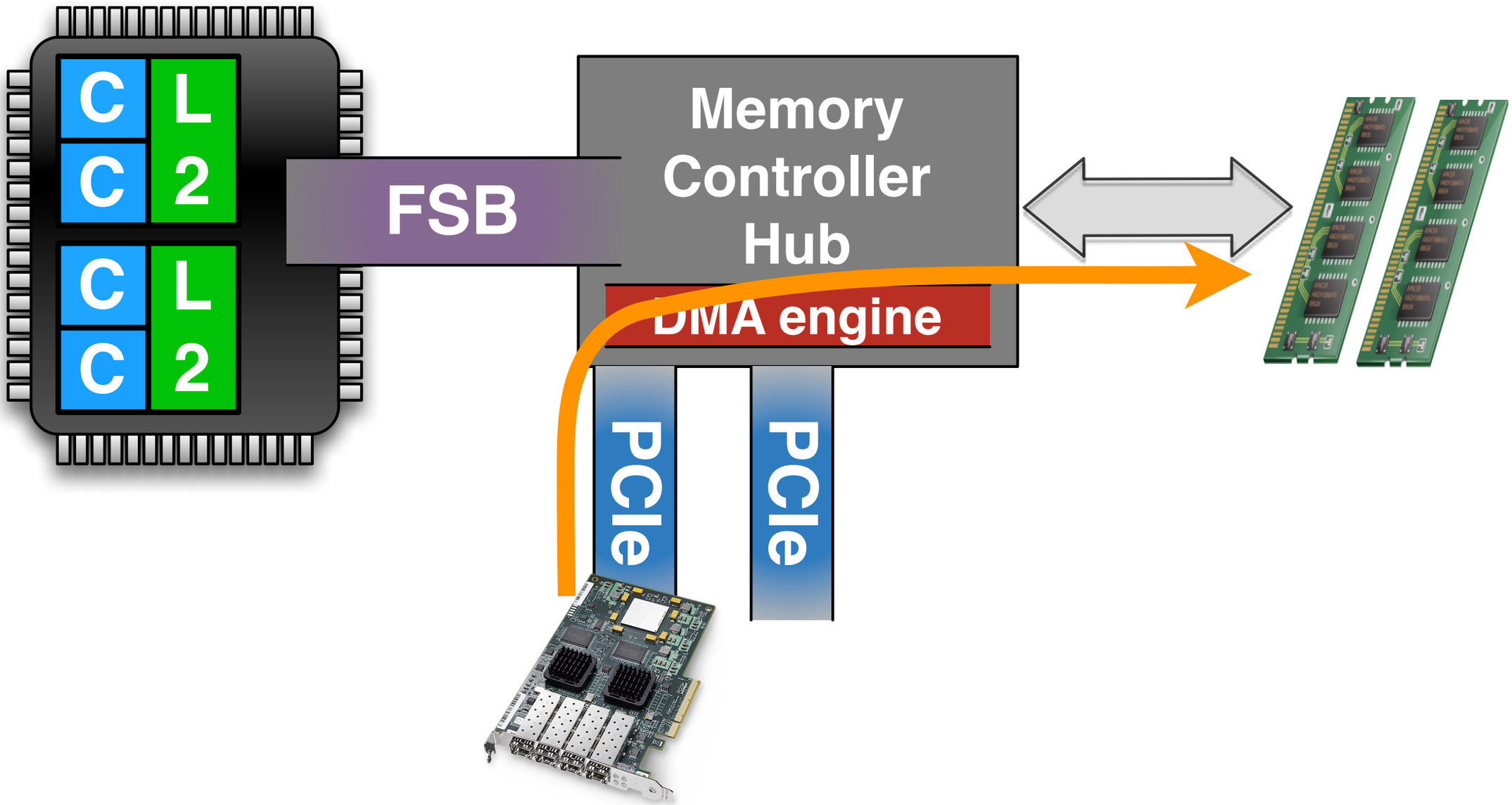

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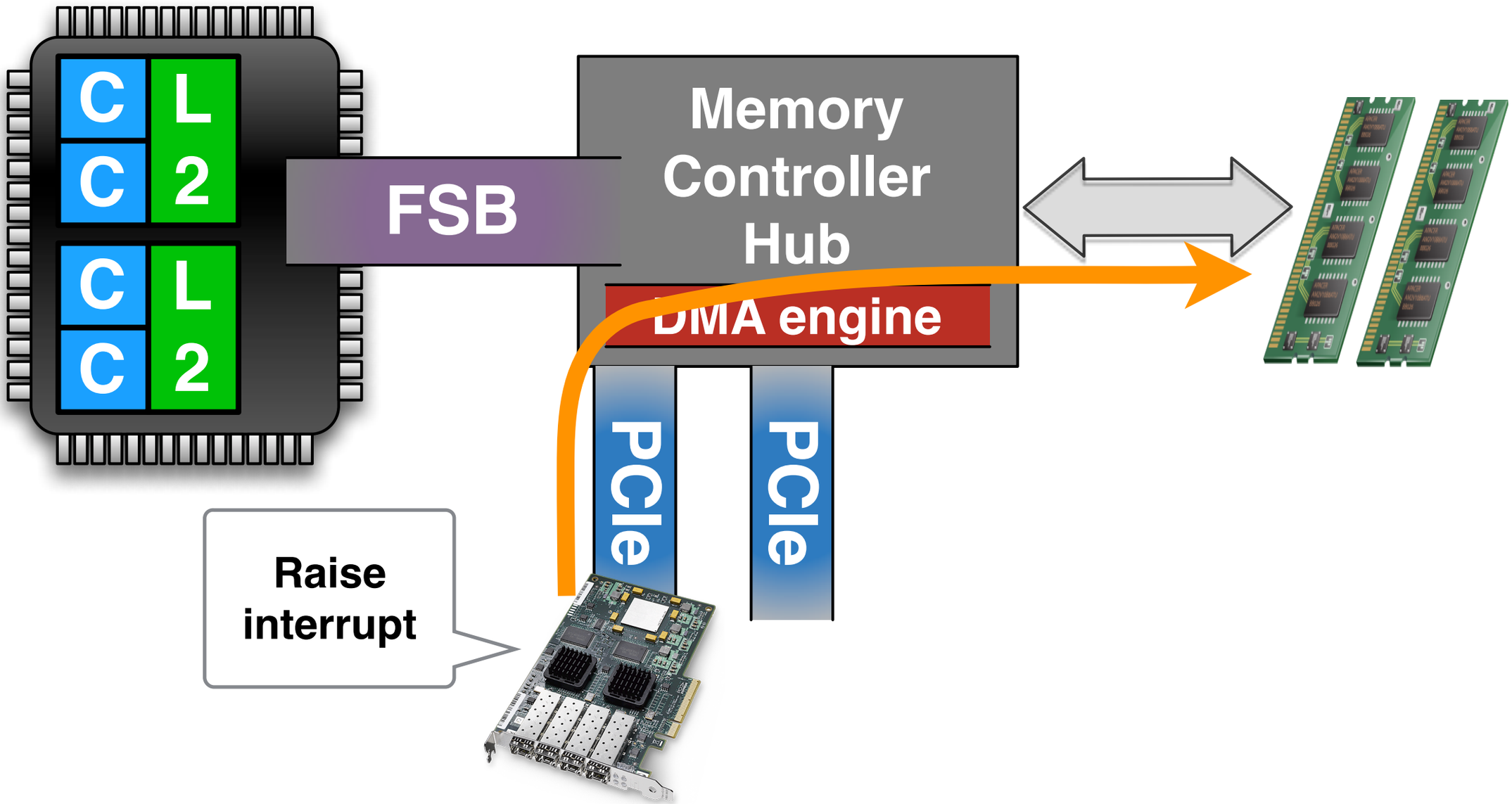

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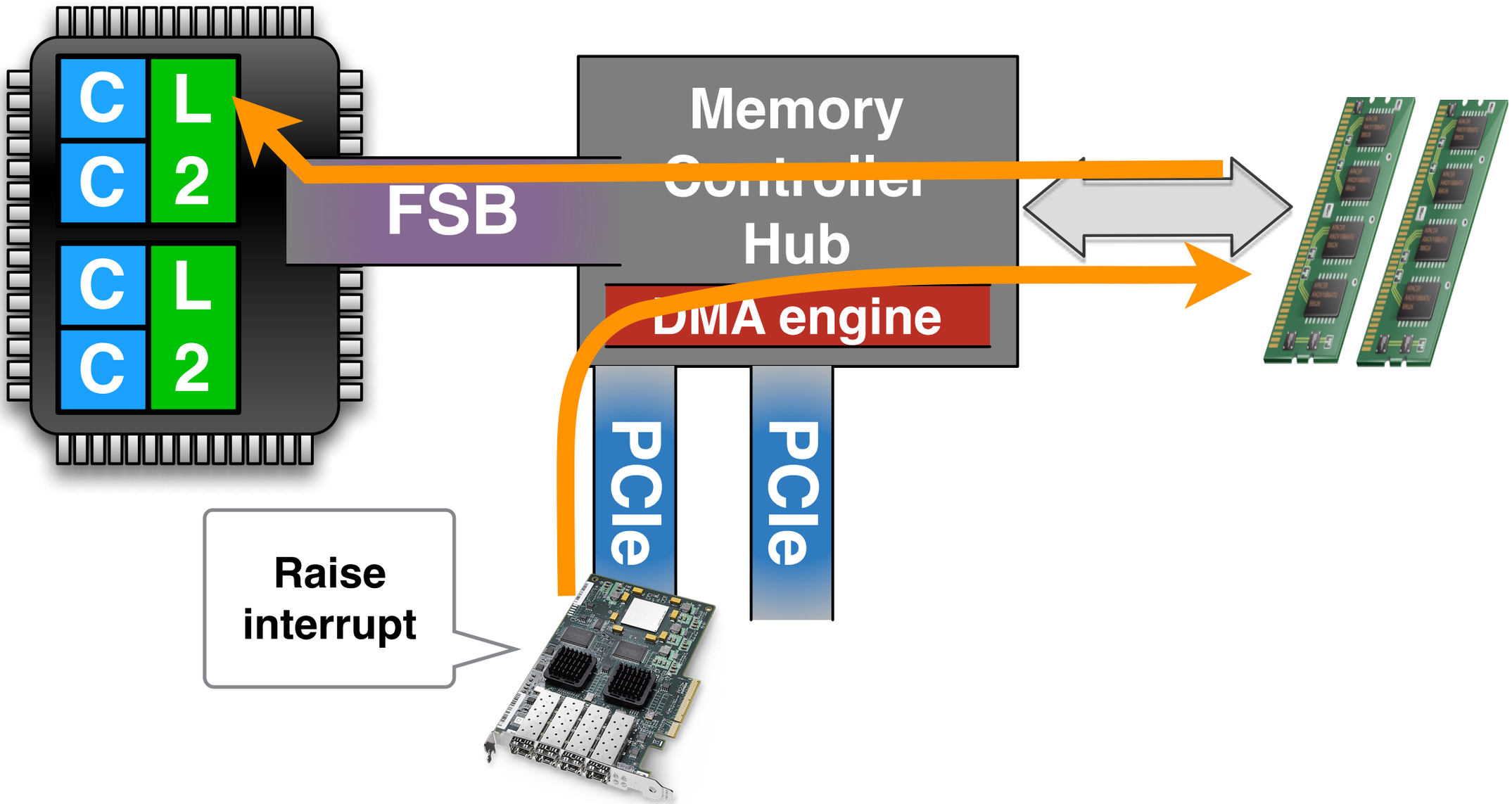

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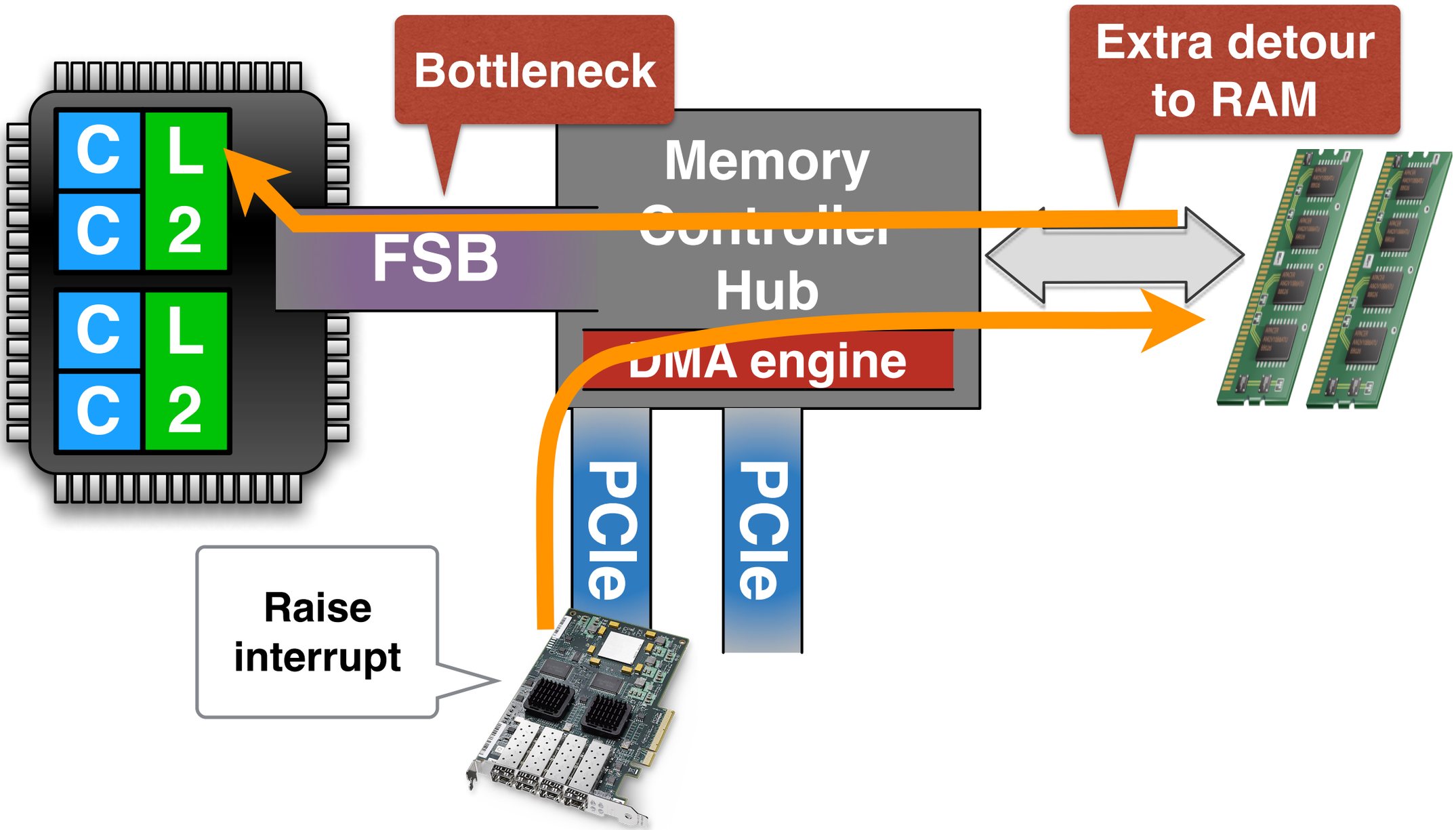
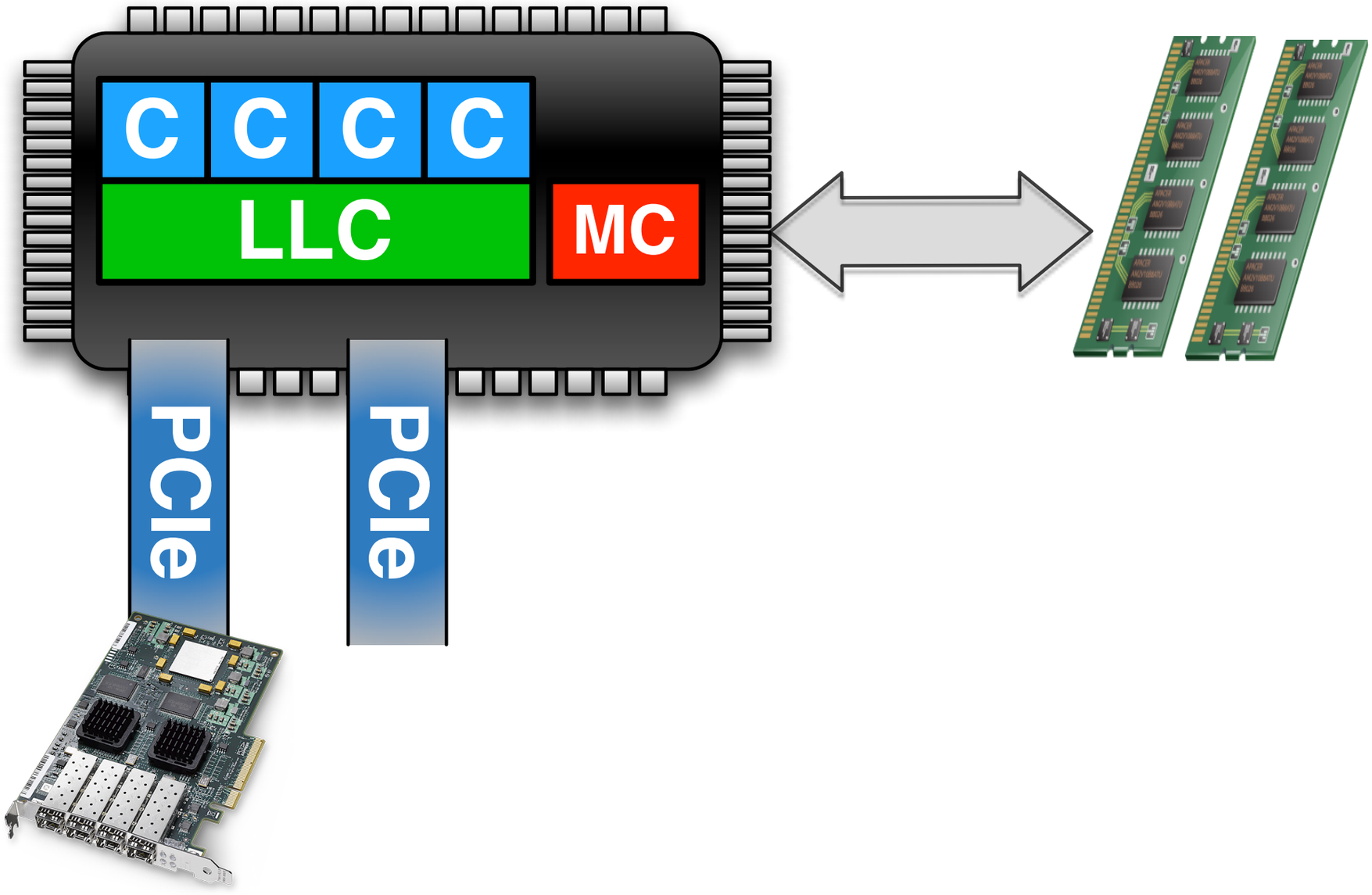


CPU microarchitecture ~2013



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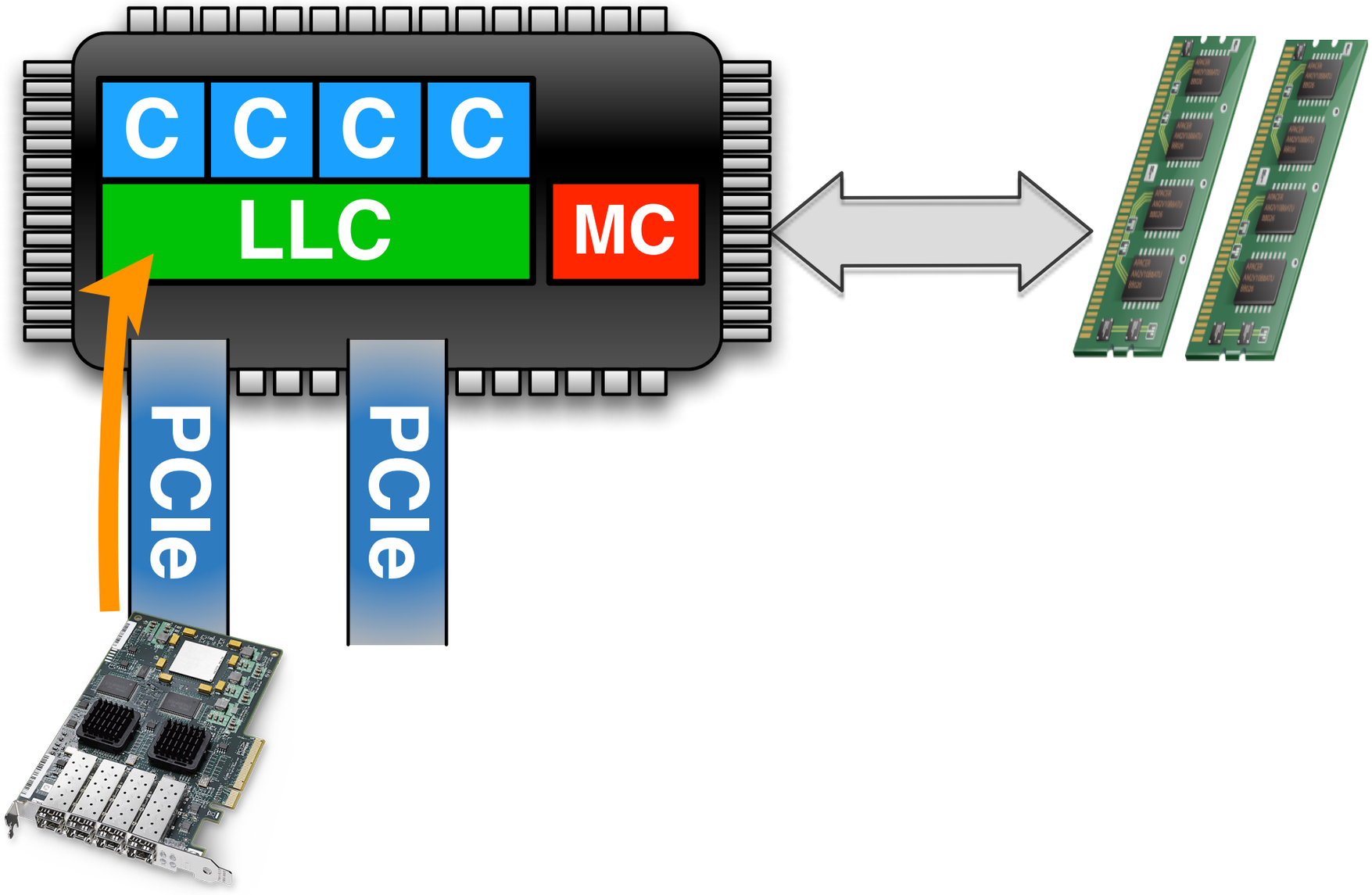

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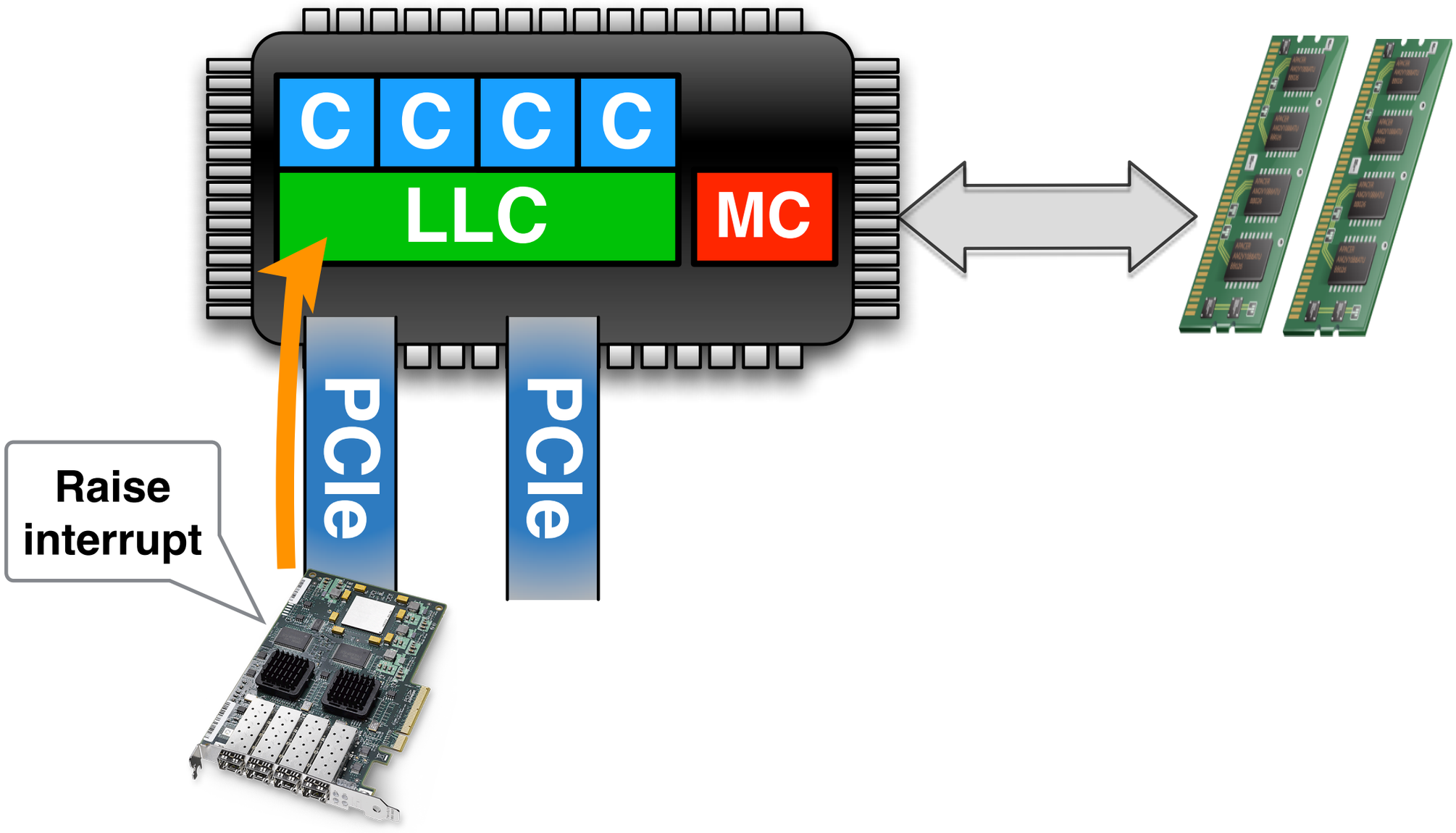

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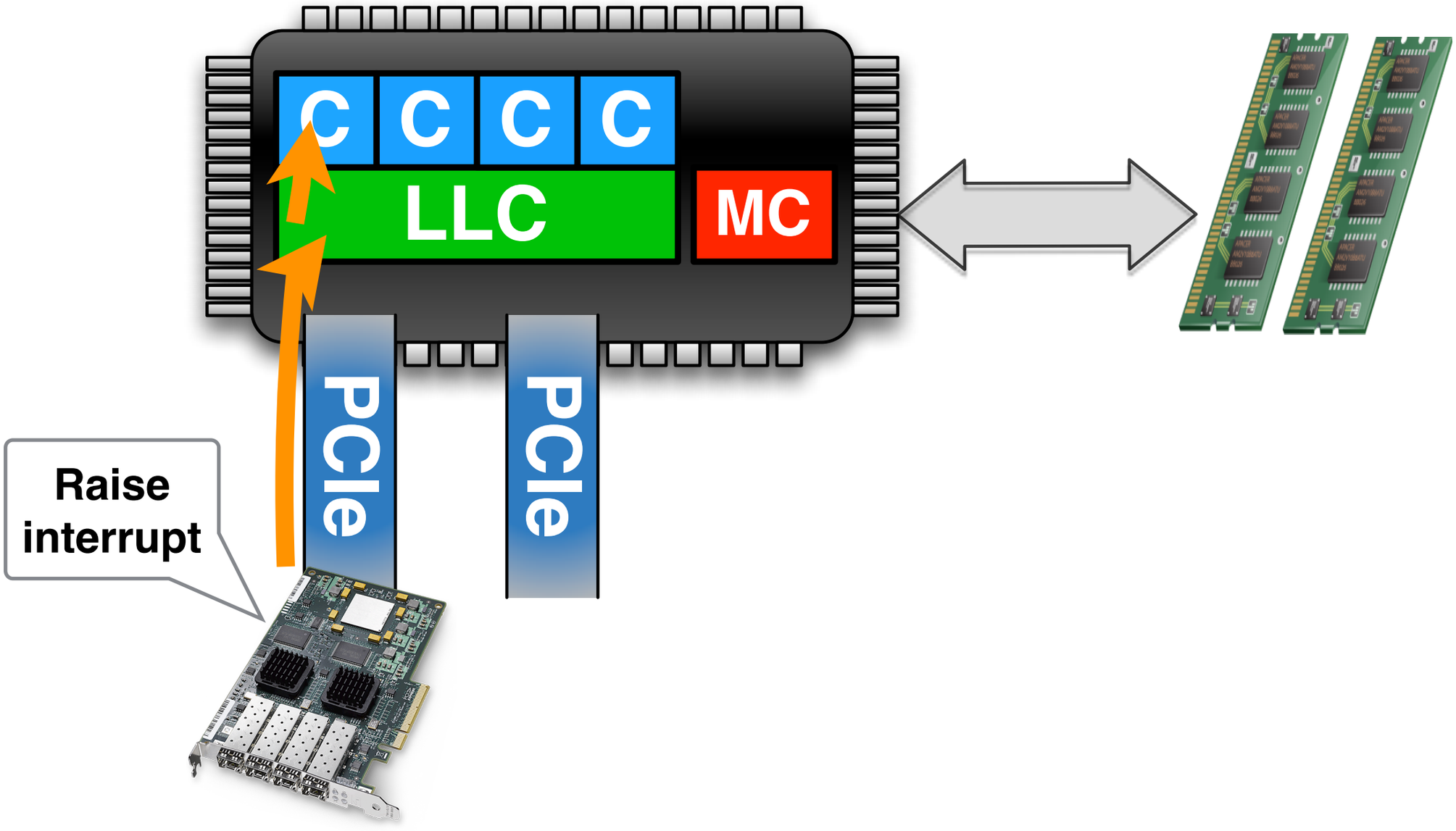

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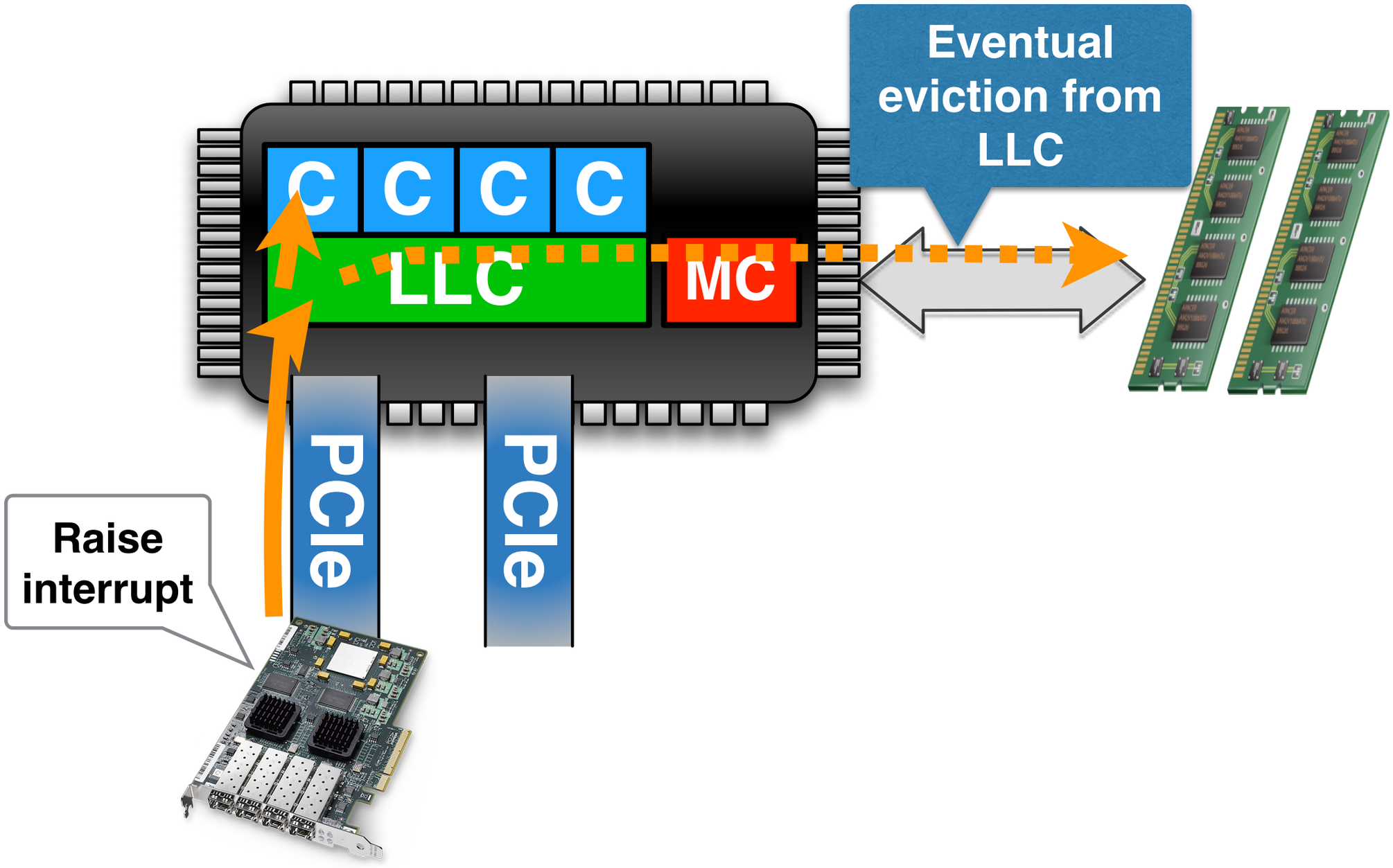

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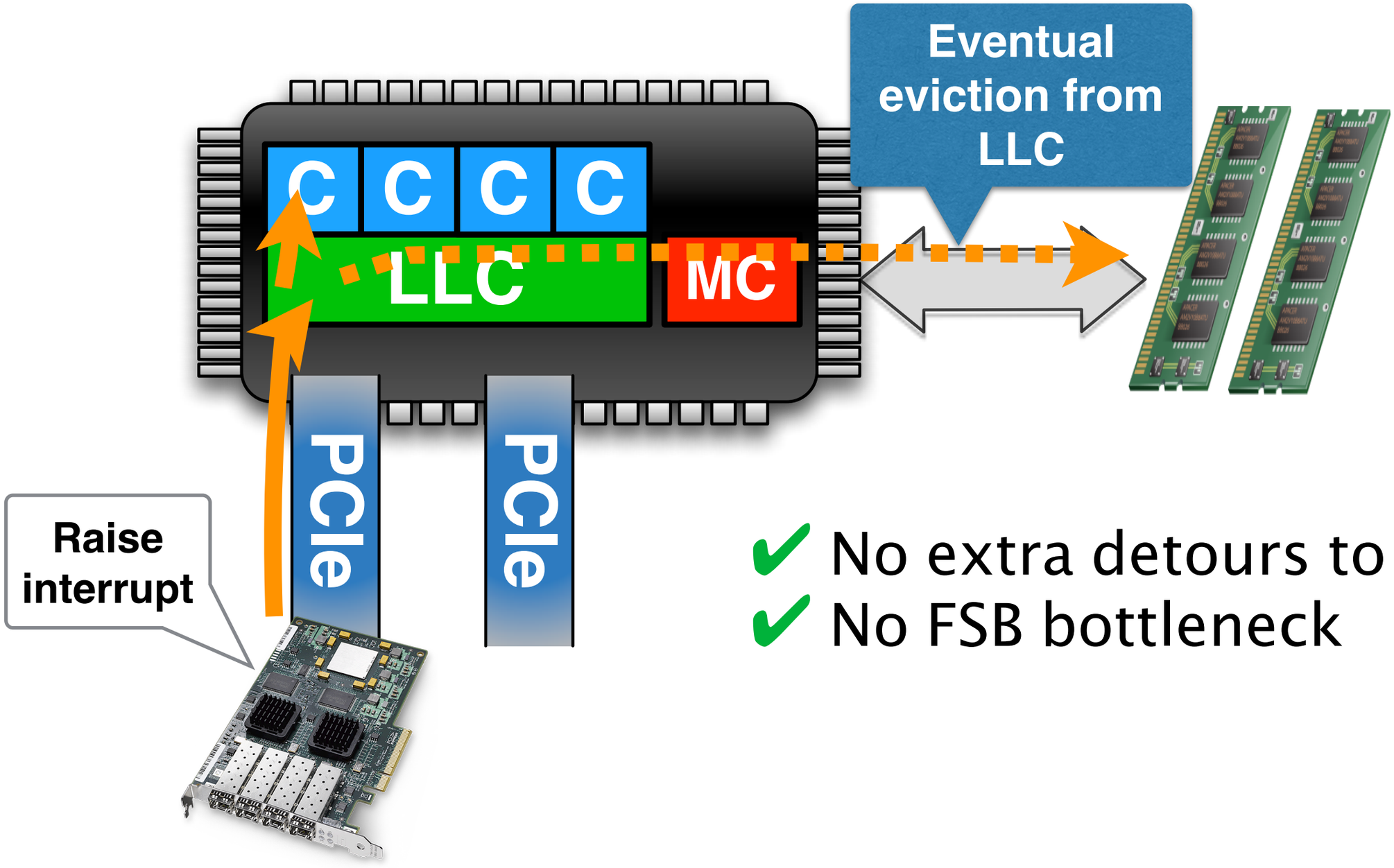

✔ No extra detours to DRAM
✔ No FSB bottleneck

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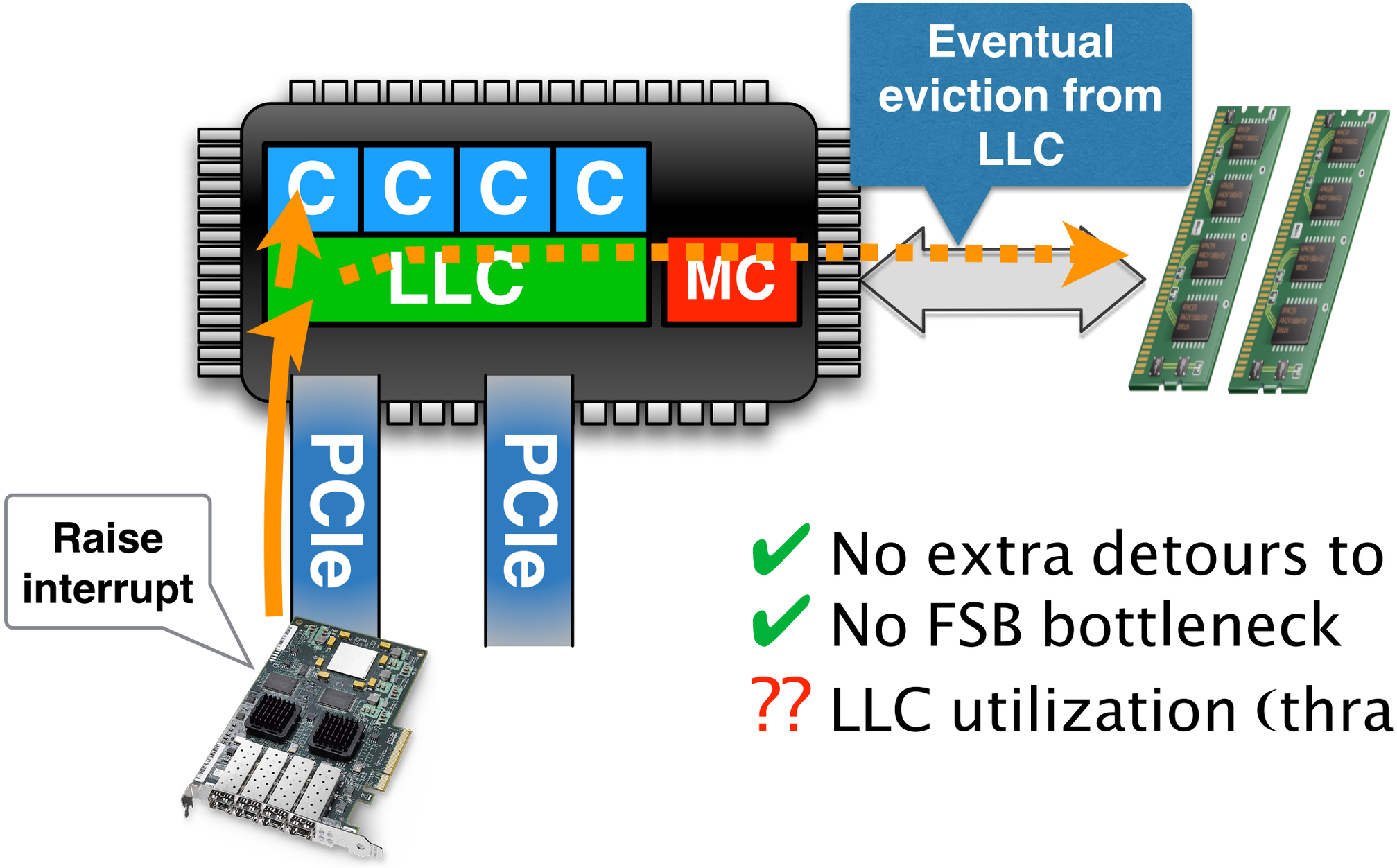

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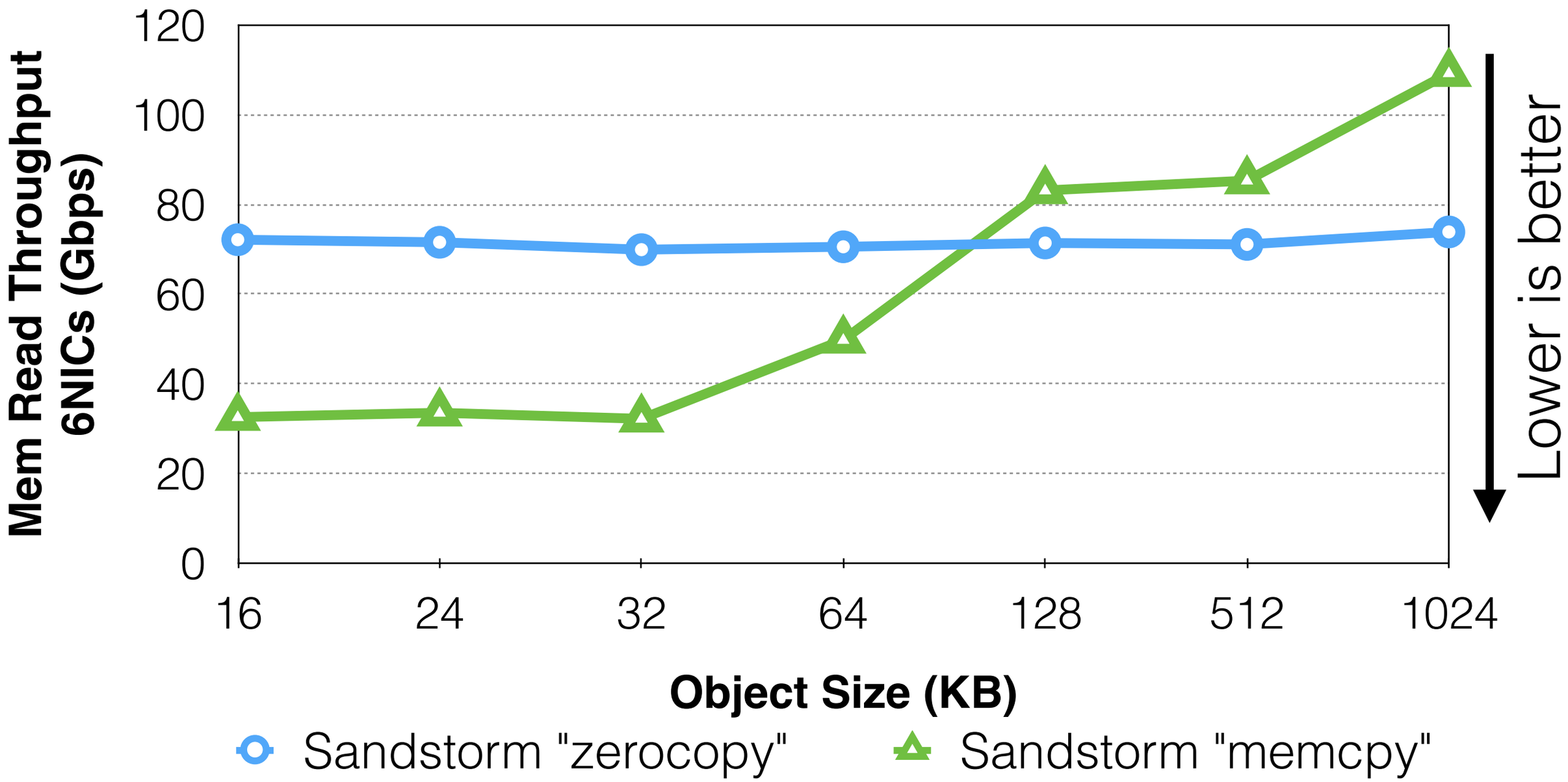
✔ No FSB bottleneck

?? LLC utilization (thrashing?)

HW/SW Intersection

- Should HW architecture evolution be considered a **“black box”** for networked systems development?



Generality of Specialization

Natural fit for:

- Web & DNS servers (Sandstorm, Namestorm — check our paper)
- In-memory Key-Value stores
- RPC-based services
- Rate-adaptive video streaming applications (with MPEG-DASH or Apple HLS)

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Limitations:

- Possibly not a good fit for CPU- and/or filesystem-intensive applications
- Blocking in application-layer cannot be tolerated

Conclusions

General-purpose stacks:

- Great for bulk transfers, bad for short ones (but web is dominated by small-sized objects!)
- Picked a lot of generality in favor of flexibility (we don't need it for application-specific clusters)
- Hard to tune/profile/debug

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- Linear scaling on multicore systems
- Low CPU utilization

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Specialized network stacks not only viable, but necessary!

Backup Slides

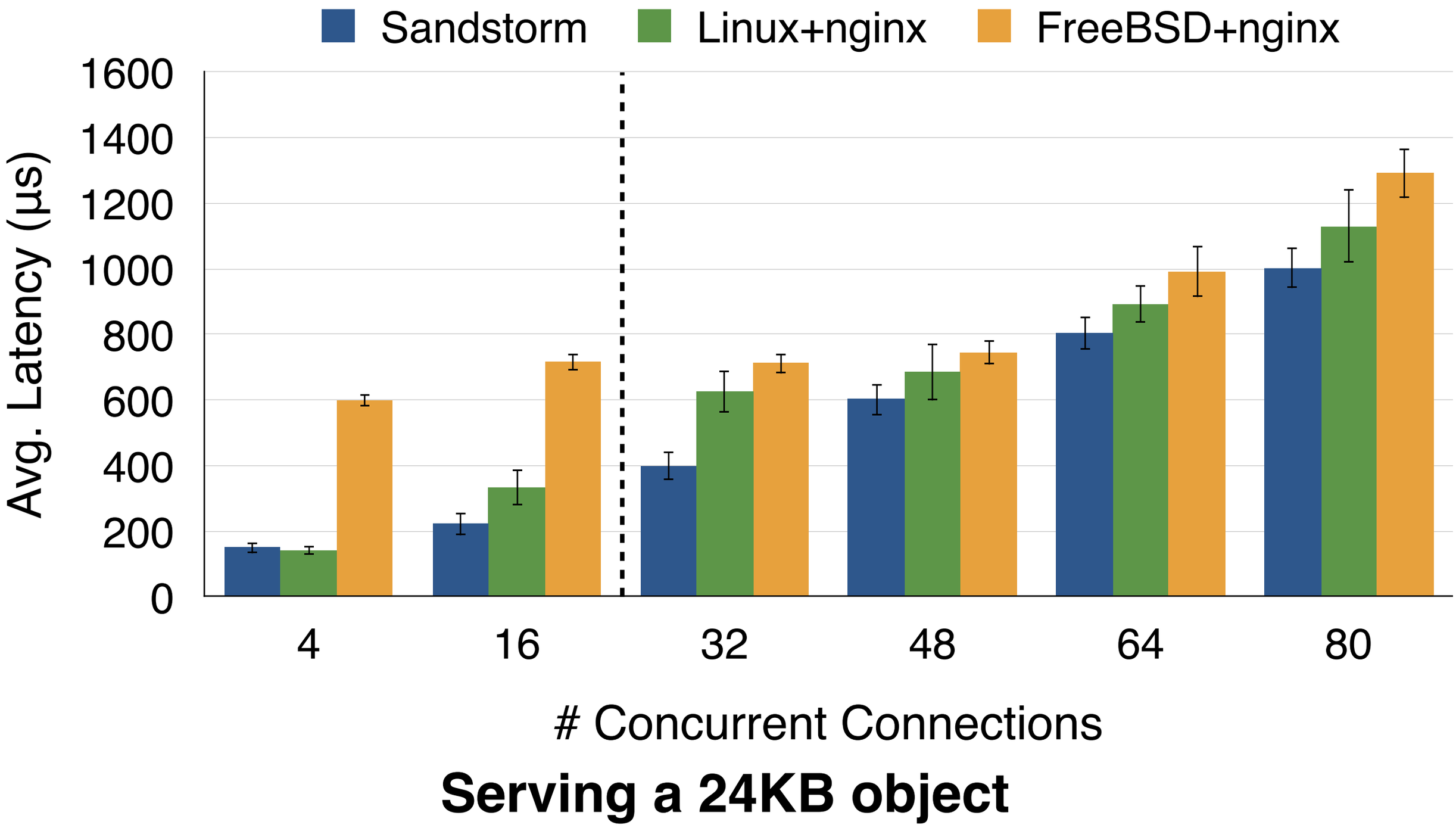
Supported TCP features

- Follows RFC 793, with Reno congestion control

Limitations:

- Support of the required TCP subset to serve incoming connections (not initiating them)
- TCP reordering not supported (not needed with typical HTTP requests)

Latency



Serving a 24KB object

Overview

Problems with general-purpose stacks:

- System-call overhead
- Shared accept-queue, PCB locks
- Cache-unfriendly due to async. design
- Memory-related overhead (e.g., mbuf alloc./copying)

Solutions with specialized stacks:

- Packet batching
- Share- & Lock-free design, per-core state
- Process-to-completion, cache-friendly, incr. cksum
- Pre-packetization, no memory copying/buffering