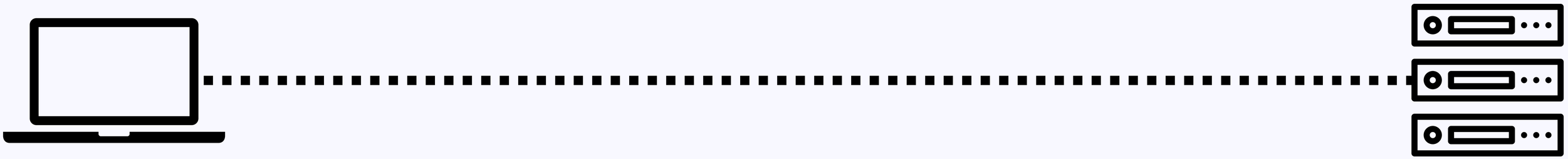
NetBricks: Taking the V out of NFV

Aurojit Panda, Sangjin Han, Keon Jang, Melvin Walls, Sylvia Ratnasamy, Scott Shenker
UC Berkeley, Google, ICSI

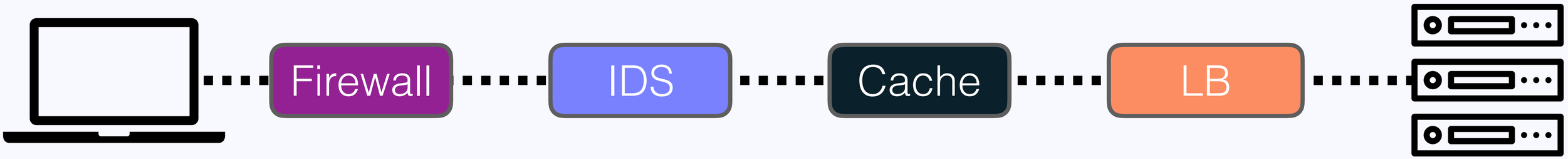
NETSYS

What is NFV?

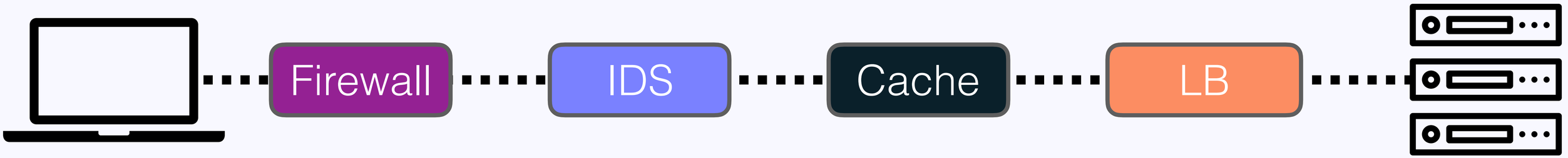
A Short Introduction to NFV

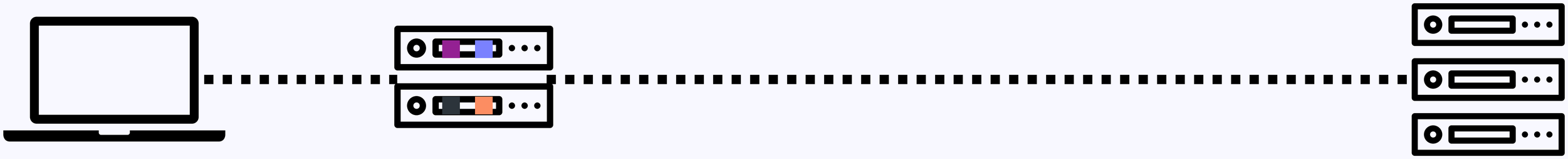


A Short Introduction to NFV



A Short Introduction to NFV





Why NFV?

- Simplifies **adding new functionality**: Deploy new software.

Why NFV?

- Simplifies **adding new functionality**: Deploy new software.
- Simplifies **developing new functionality**: Write software vs design hardware

Why NFV?

- Simplifies **adding new functionality**: Deploy new software.
- Simplifies **developing new functionality**: Write software vs design hardware
- Reuse **management tools** from other domains.

Why NFV?

- Simplifies **adding new functionality**: Deploy new software.
- Simplifies **developing new functionality**: Write software vs design hardware
- Reuse **management tools** from other domains.
- **Consolidation**: Reduce number of hardware boxes in the network.

NFV Requirements

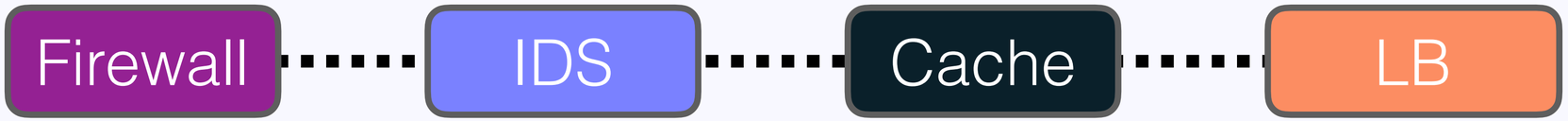
- **High Packet Rates**: Must keep up with line rate which is >10MPPS

NFV Requirements

- **High Packet Rates**: Must keep up with line rate which is >10MPPS
- **Low Latency**: Used for applications like VoIP and video conferencing

NFV Requirements

- **High Packet Rates**: Must keep up with line rate which is >10MPPS
- **Low Latency**: Used for applications like VoIP and video conferencing
- **NF Chaining**: Packets go through sequence of NFs



Challenges for NFV

Challenges for NFV

- **Running NFs**
  - **Isolation** and **Performance**

Challenges for NFV

- **Running NFs**
  - **Isolation** and **Performance**

- **Building NFs**
  - **High-Level Programming** and **Performance**

Running NFs

Isolation

- **Memory Isolation**: Each NF's memory cannot be accessed by other NFs.

Isolation

- **Memory Isolation**: Each NF's memory cannot be accessed by other NFs.
- **Packet Isolation**: When chained, each NF processes packets in isolation.

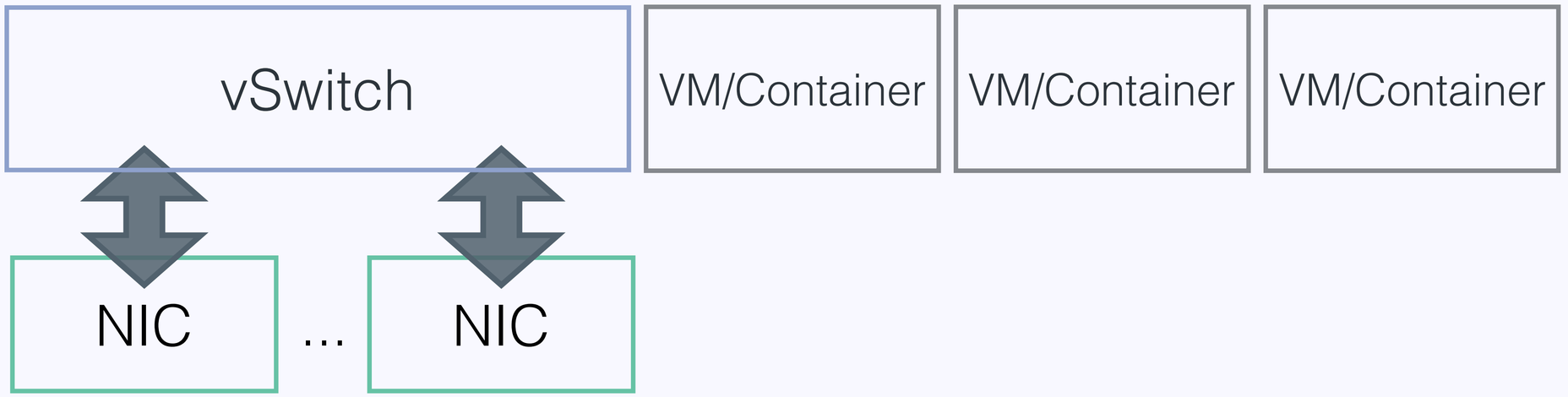
Isolation

- **Memory Isolation**: Each NF's memory cannot be accessed by other NFs.
- **Packet Isolation**: When chained, each NF processes packets in isolation.
- **Performance Isolation**: One NF does not affect another's performance.

Isolation

- **Memory Isolation**: Each NF's memory cannot be accessed by other NFs.
- **Packet Isolation**: When chained, each NF processes packets in isolation.
- ~~**Performance Isolation**: One NF does not affect another's performance.~~

Current Solution

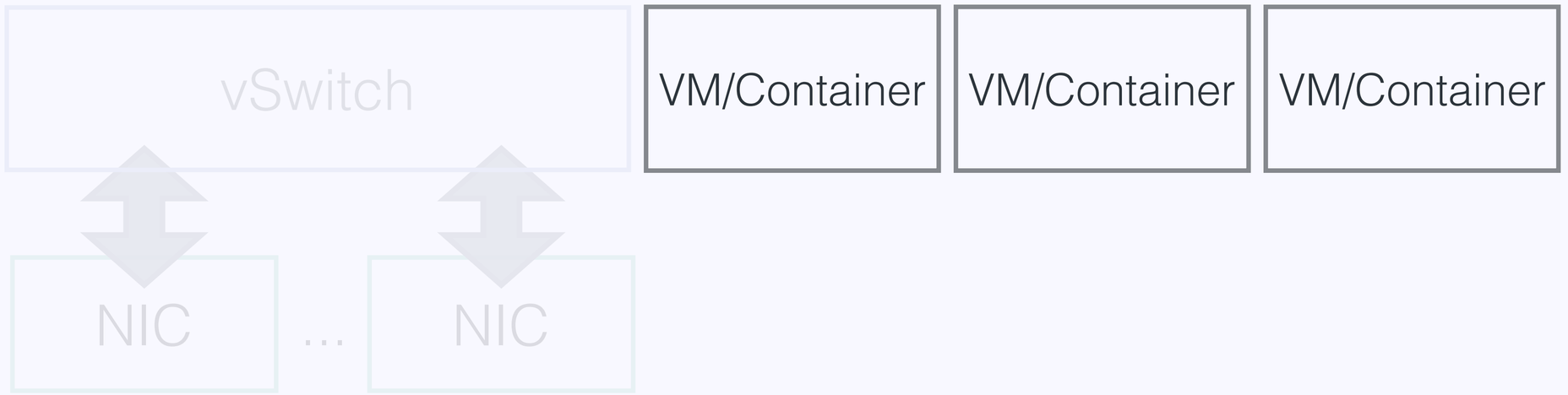


Memory Isolation

Packet Isolation

Performance

Current Solution

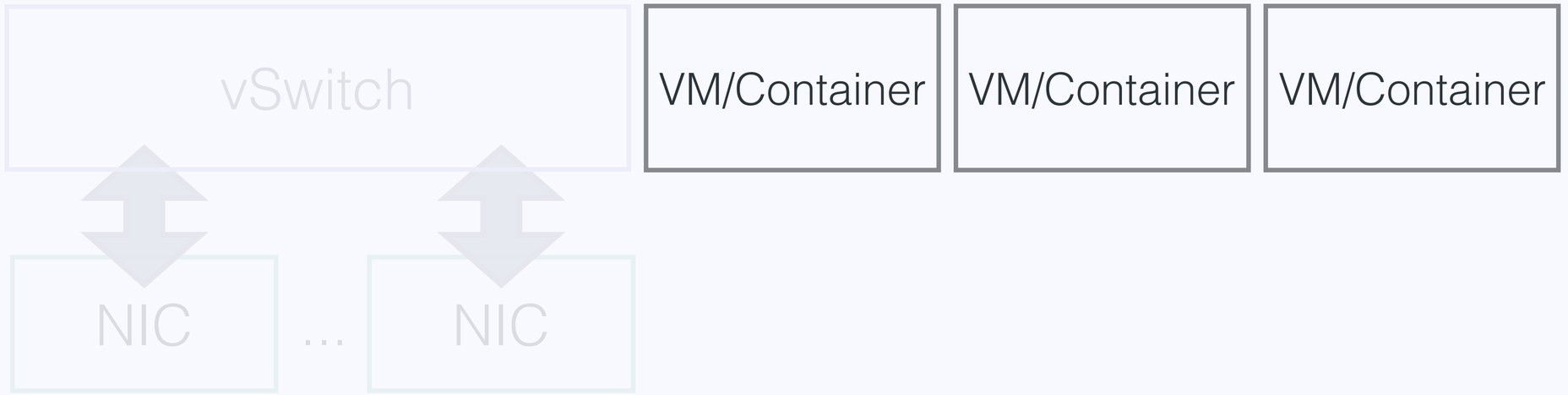


Memory Isolation

Packet Isolation

Performance

Current Solution

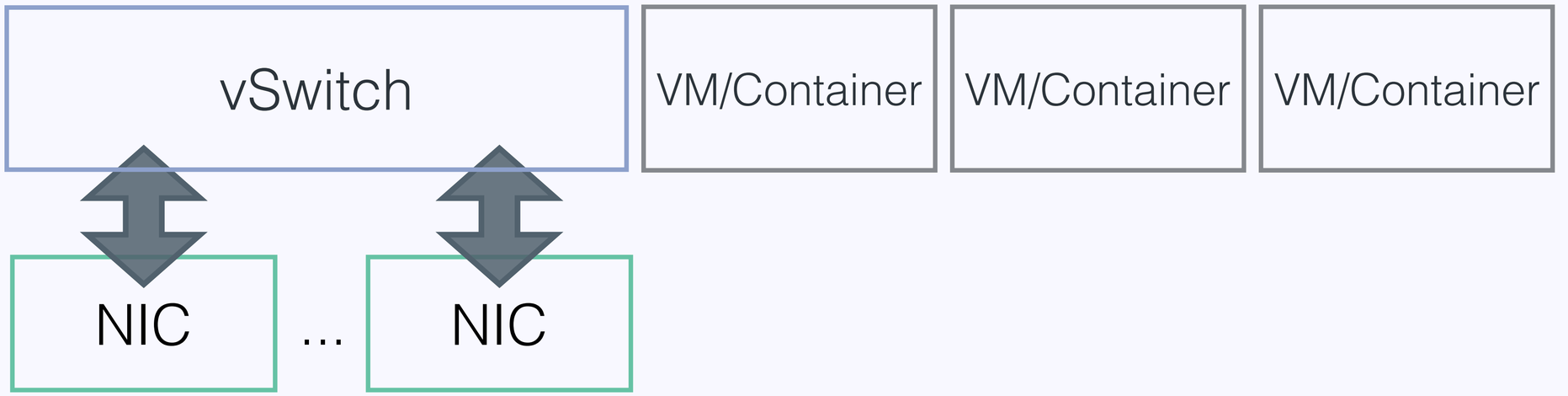


✔Memory Isolation

Packet Isolation

Performance

Current Solution

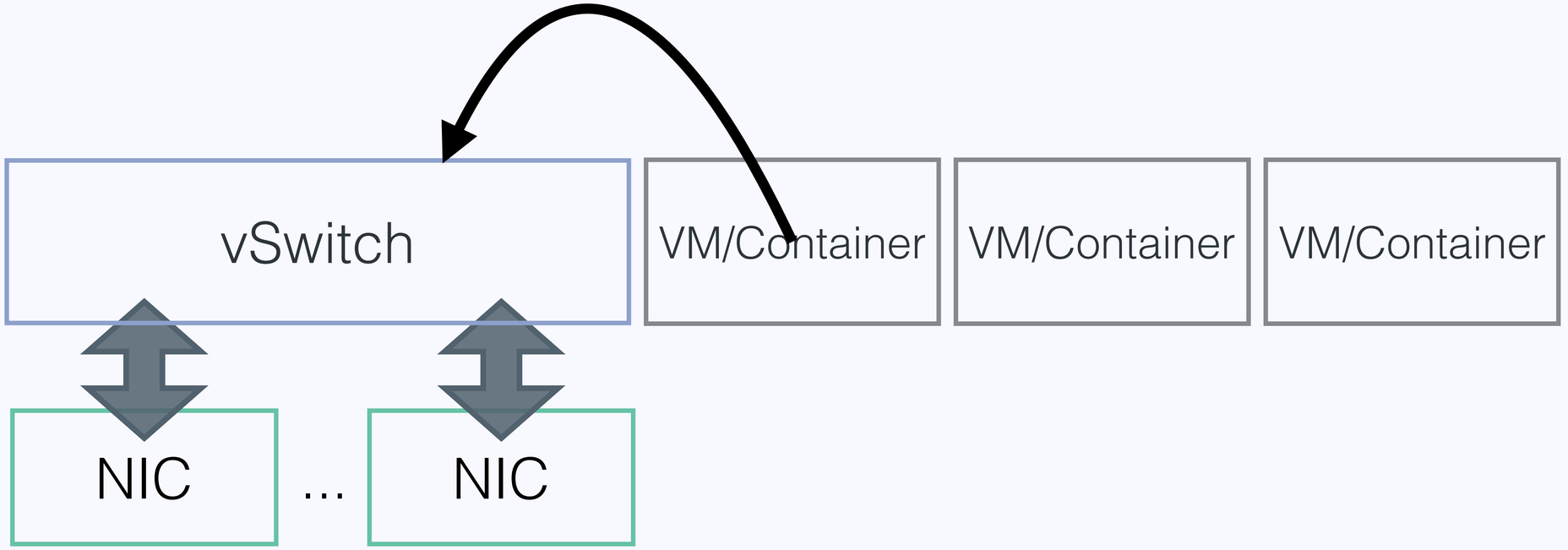


✔Memory Isolation

Packet Isolation

Performance

Current Solution

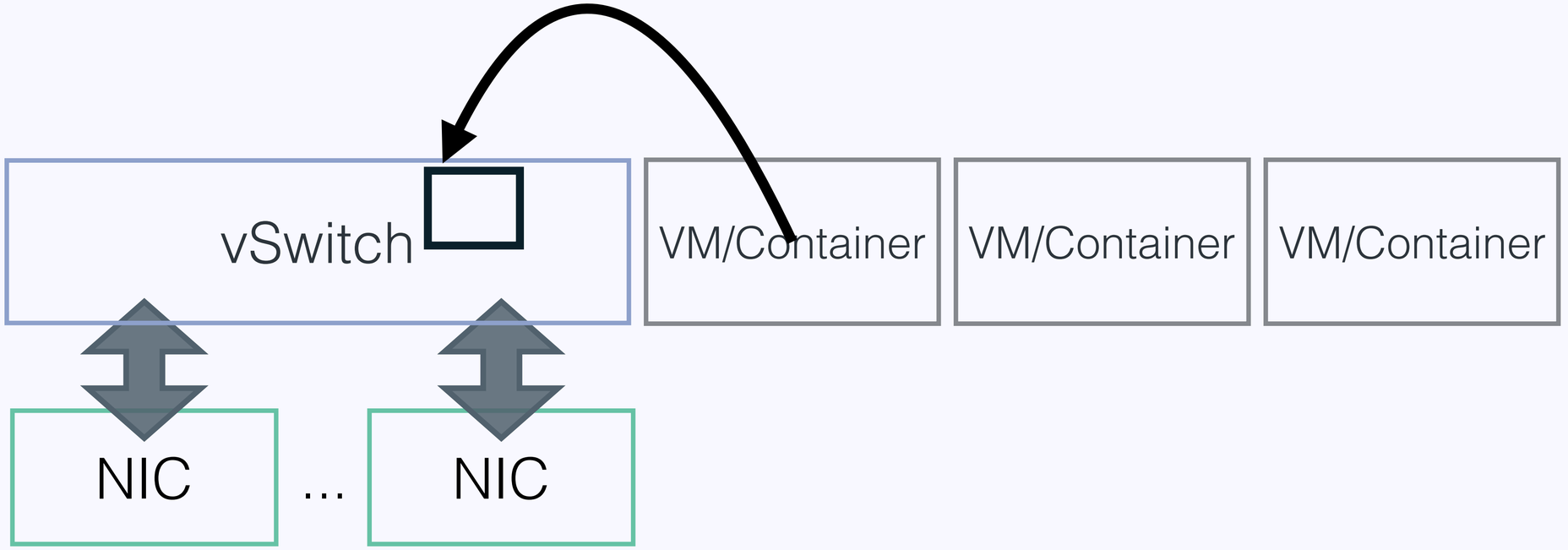


✔Memory Isolation

Packet Isolation

Performance

Current Solution

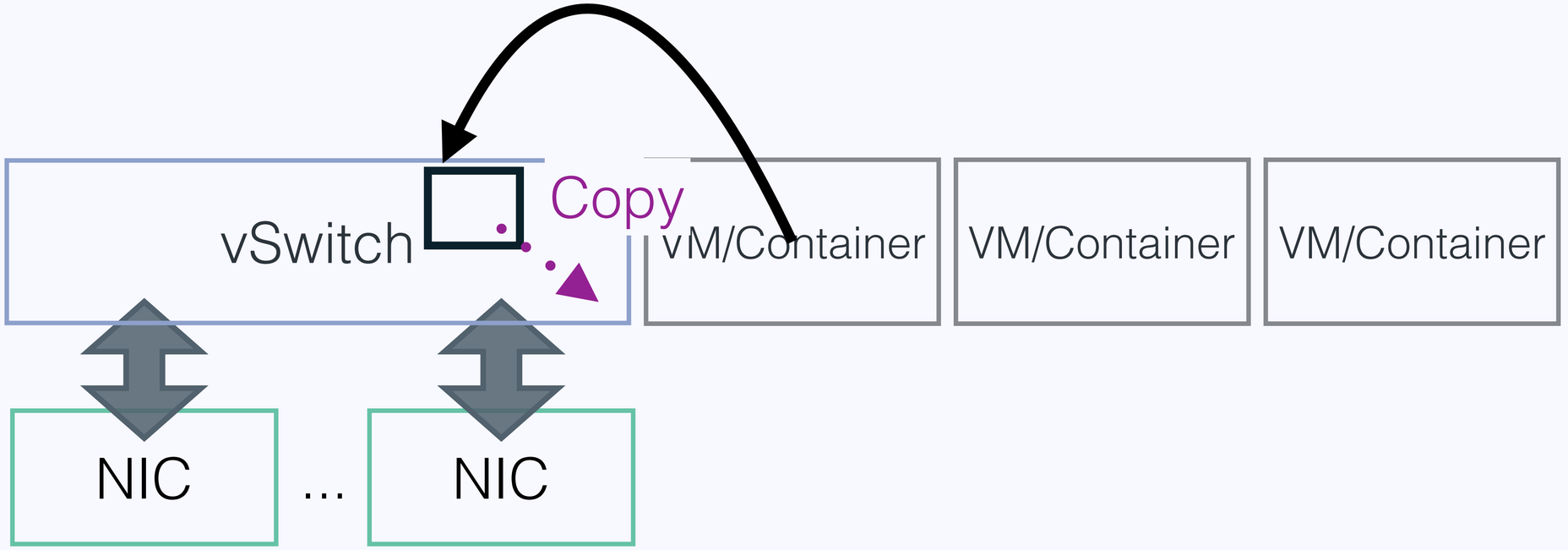


✔Memory Isolation

Packet Isolation

Performance

Current Solution

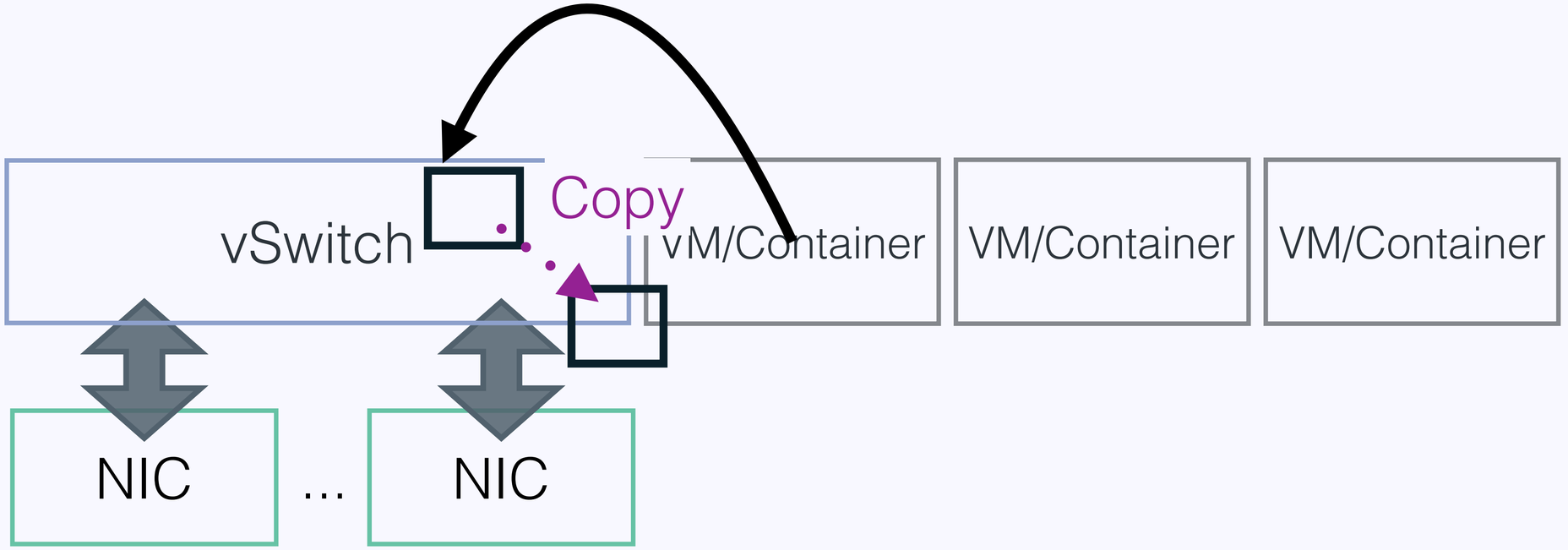


✔Memory Isolation

Packet Isolation

Performance

Current Solution

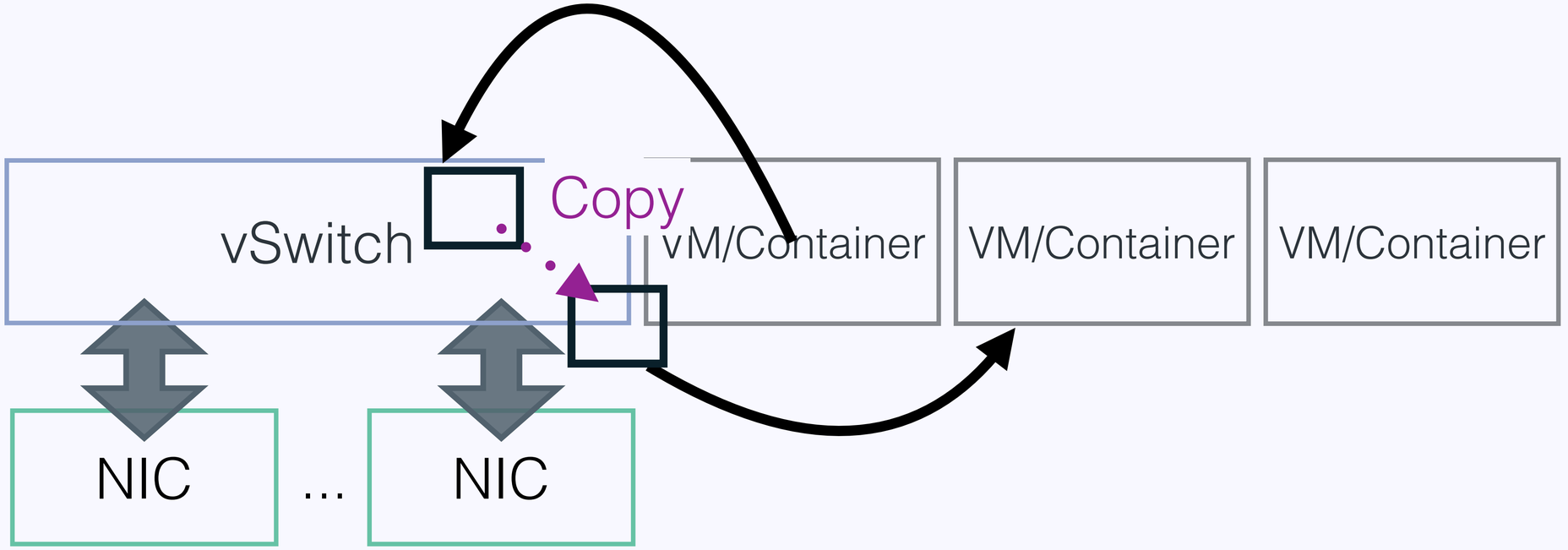


✔Memory Isolation

Packet Isolation

Performance

Current Solution

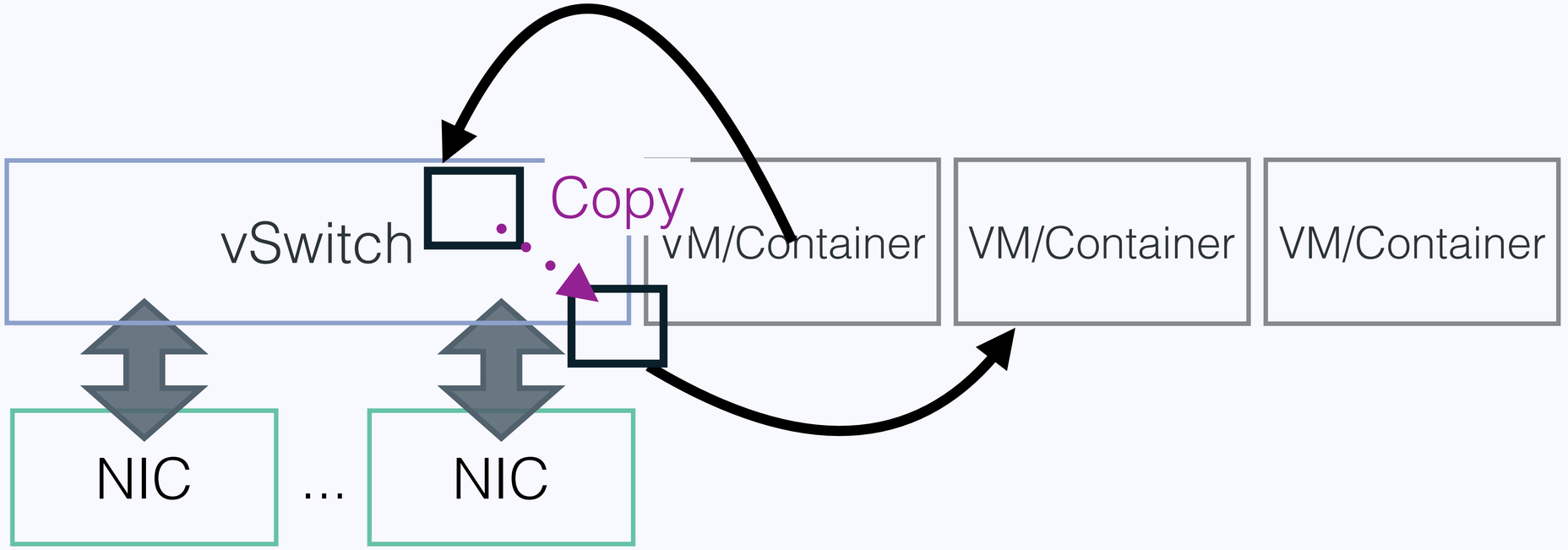


✔Memory Isolation

Packet Isolation

Performance

Current Solution

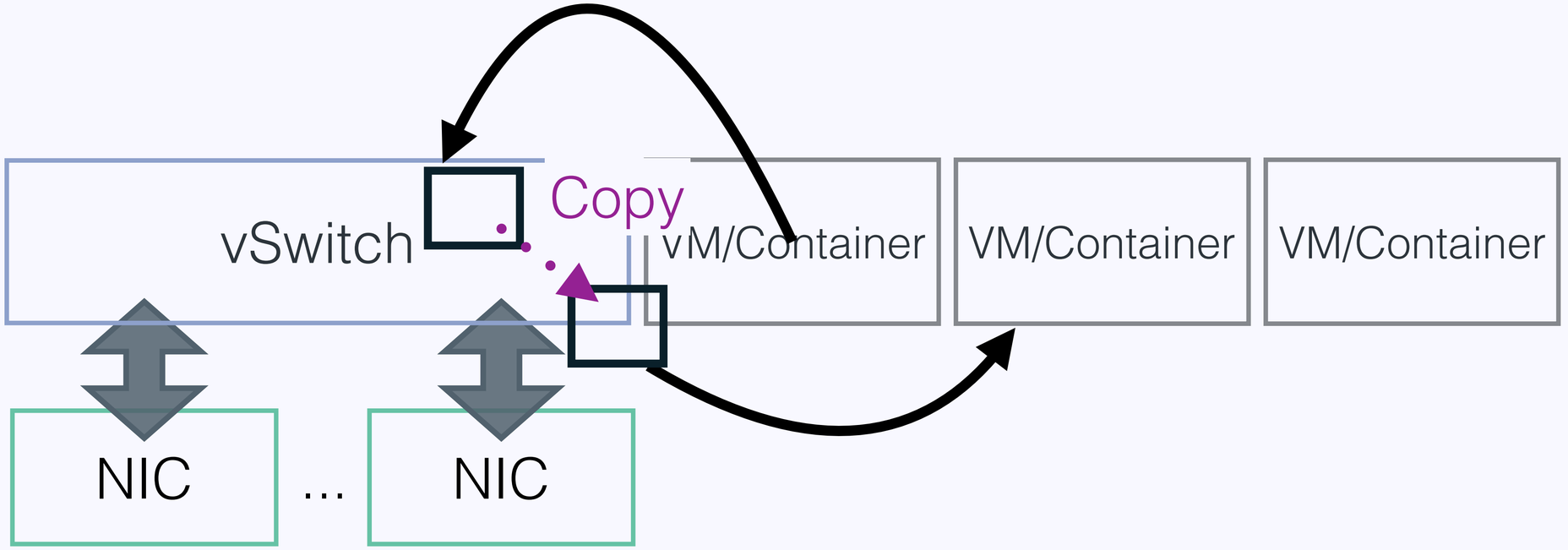


✔Memory Isolation

✔ Packet Isolation

Performance

Current Solution

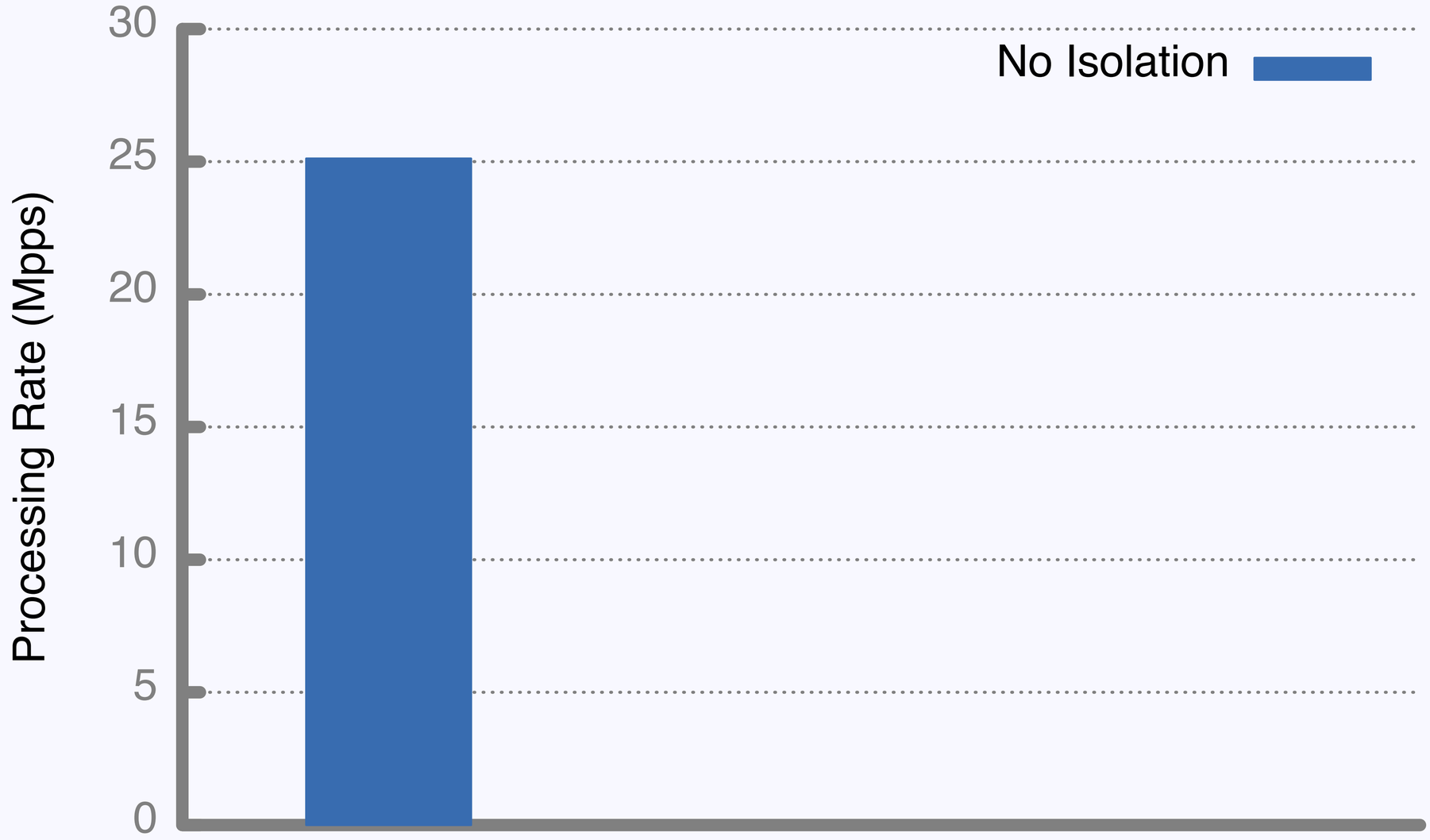


✔Memory Isolation

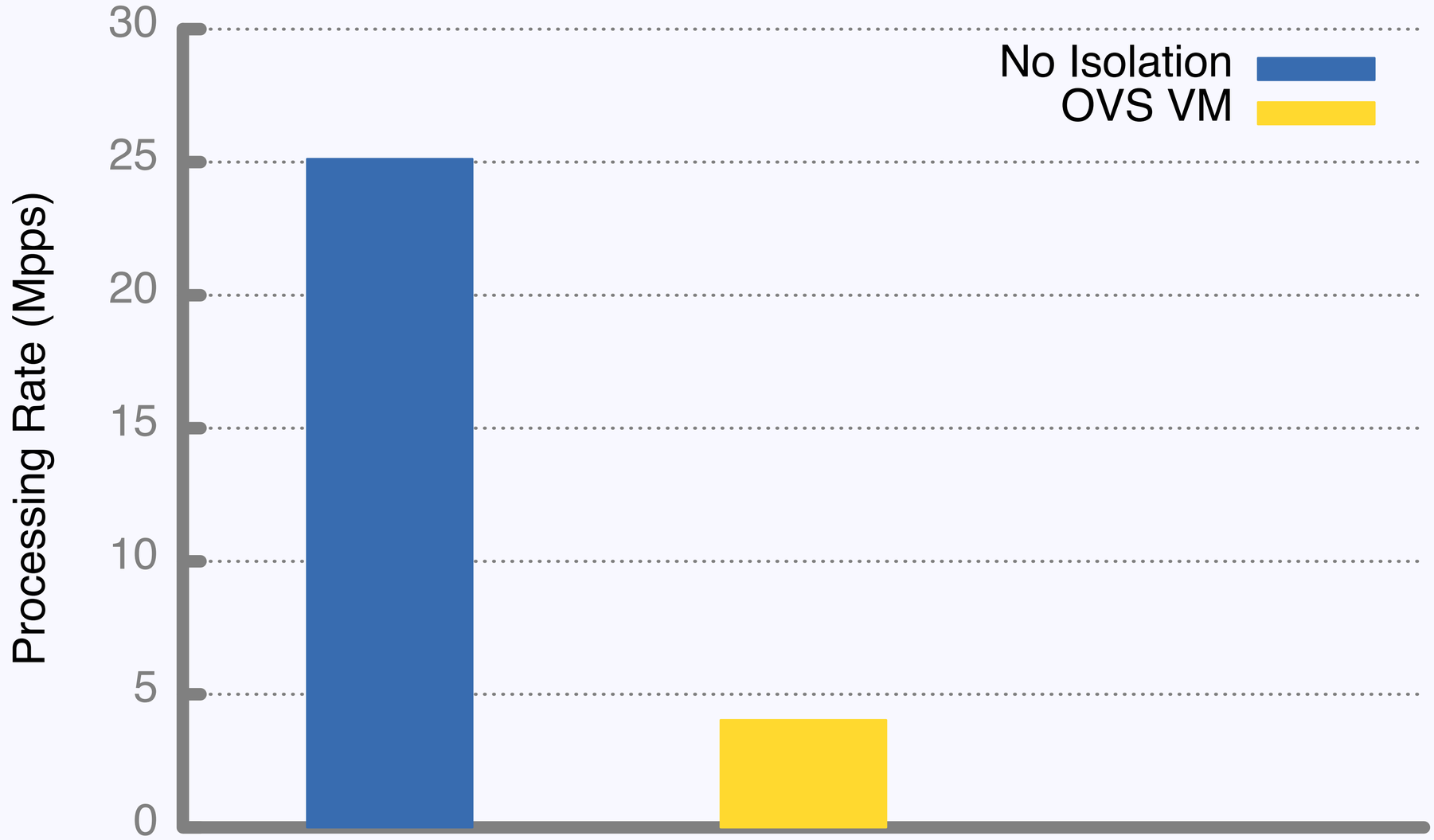
✔ Packet Isolation

✗ Performance

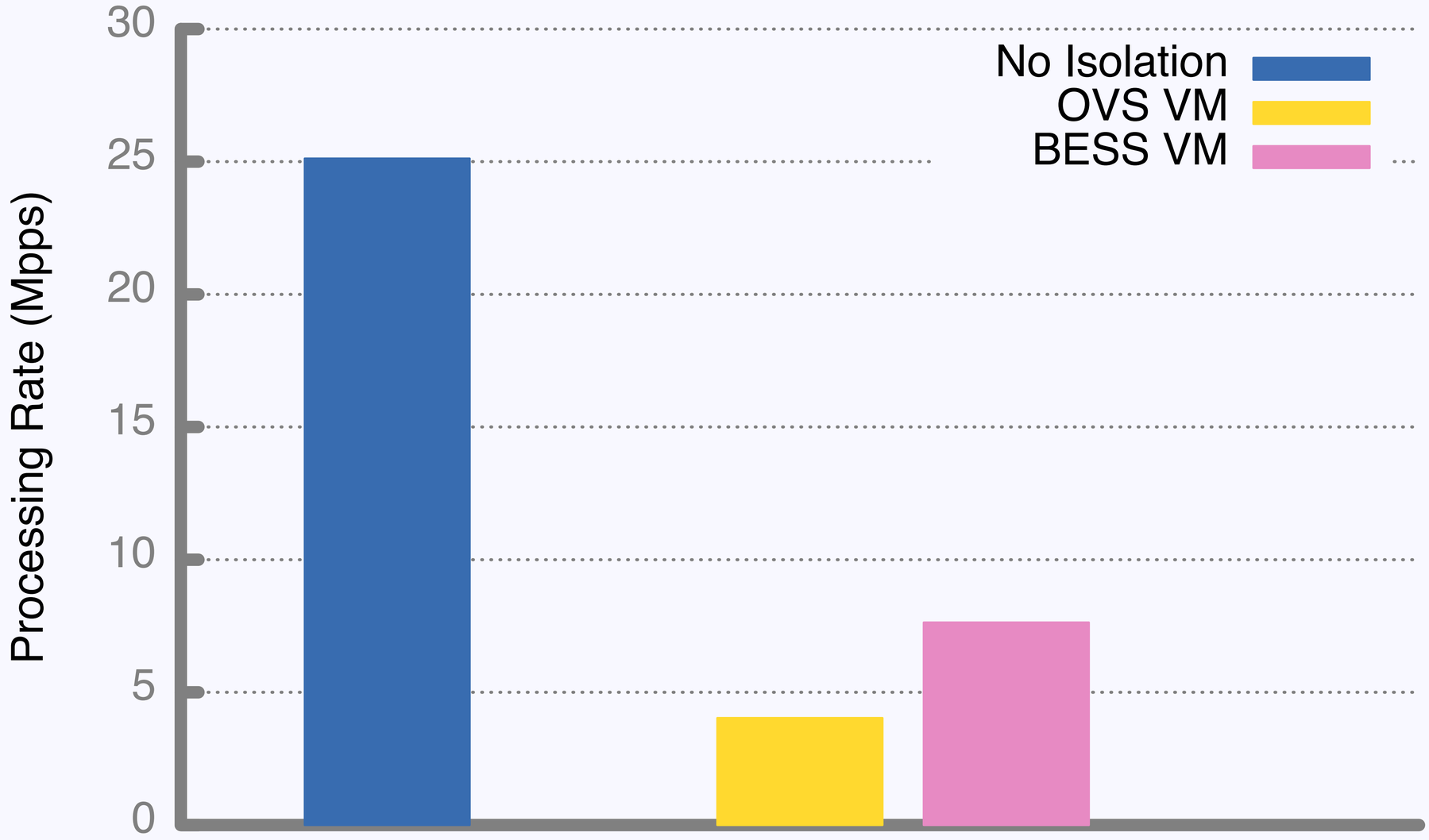
Isolation Costs Performance



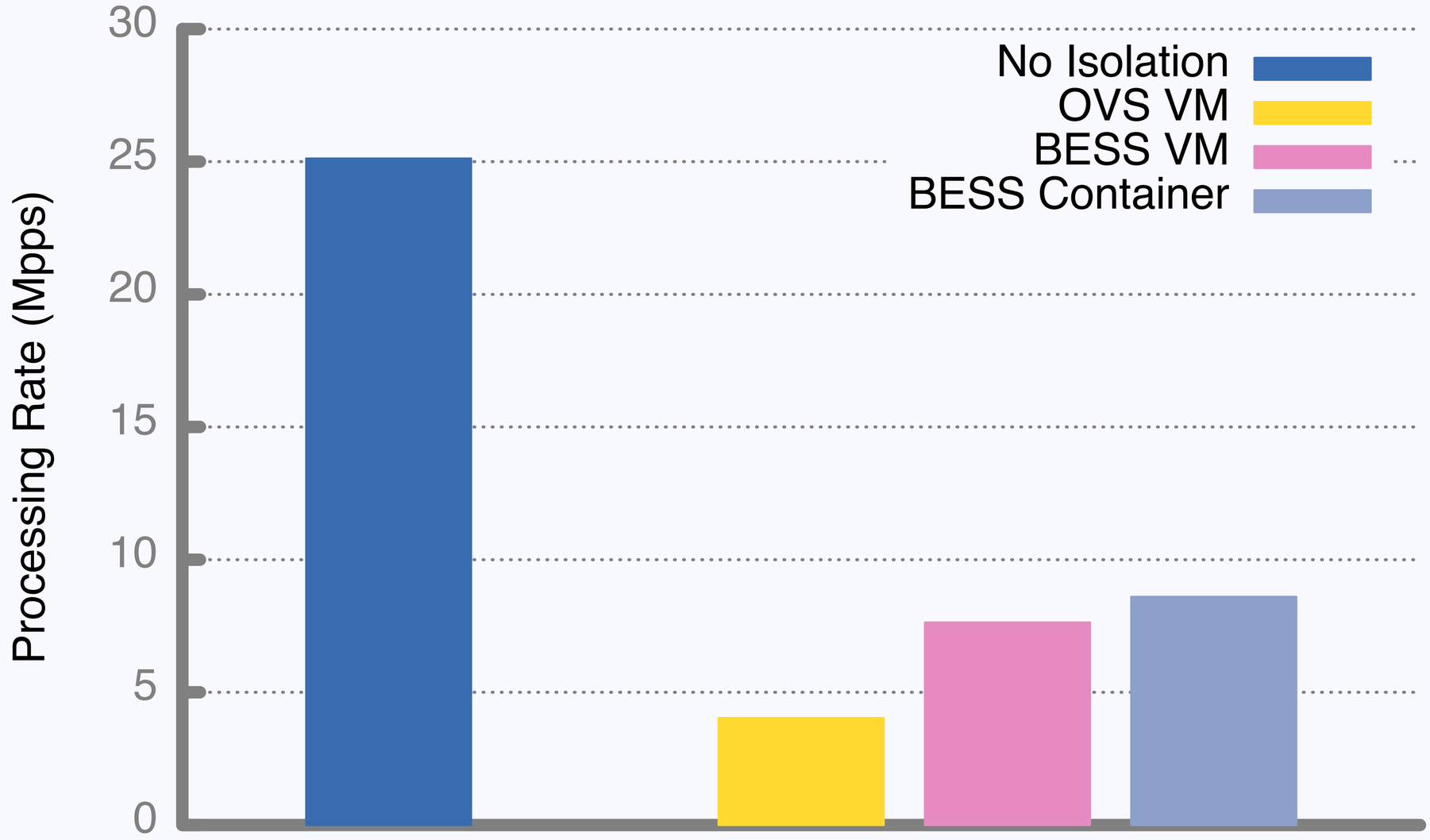
Isolation Costs Performance



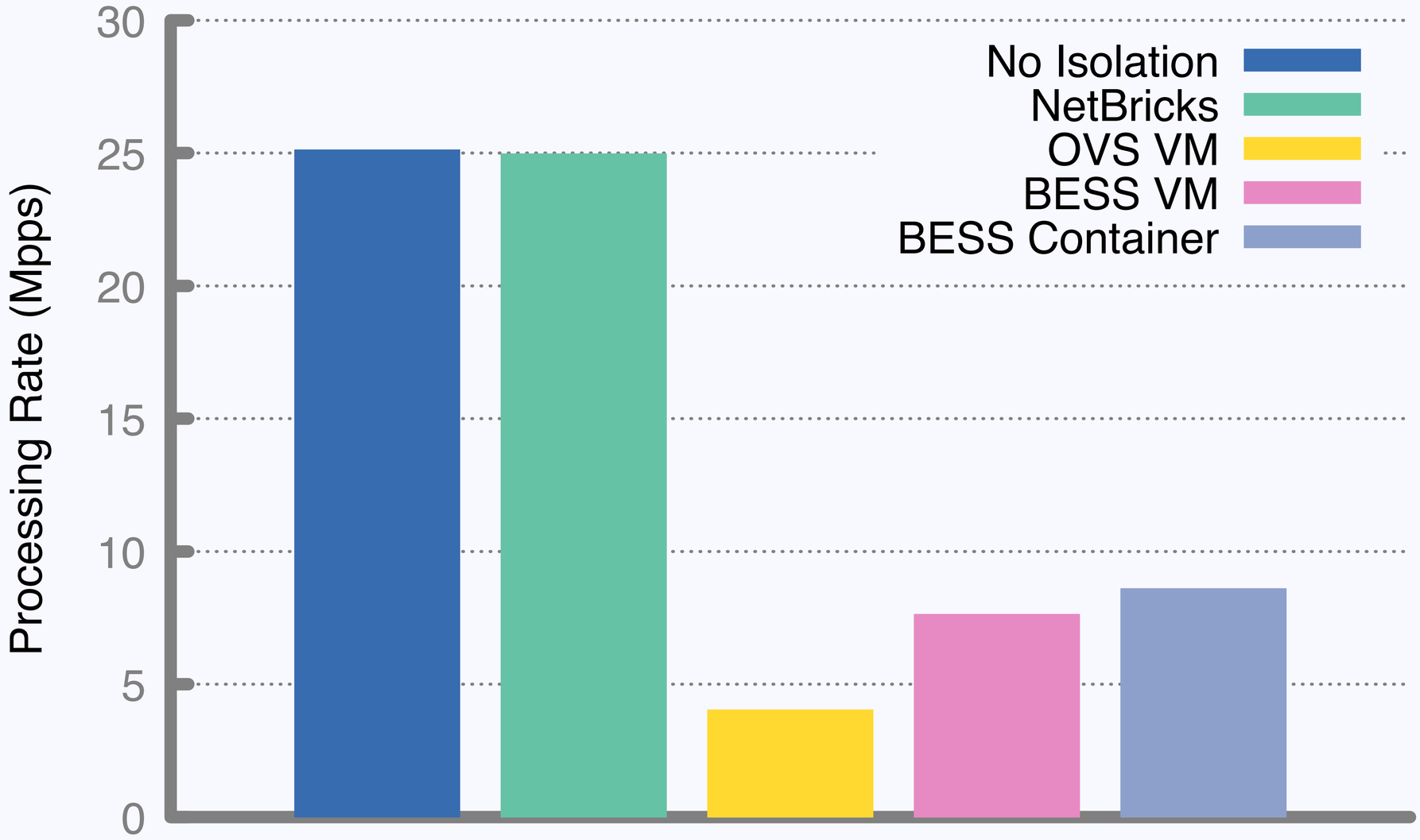
Isolation Costs Performance



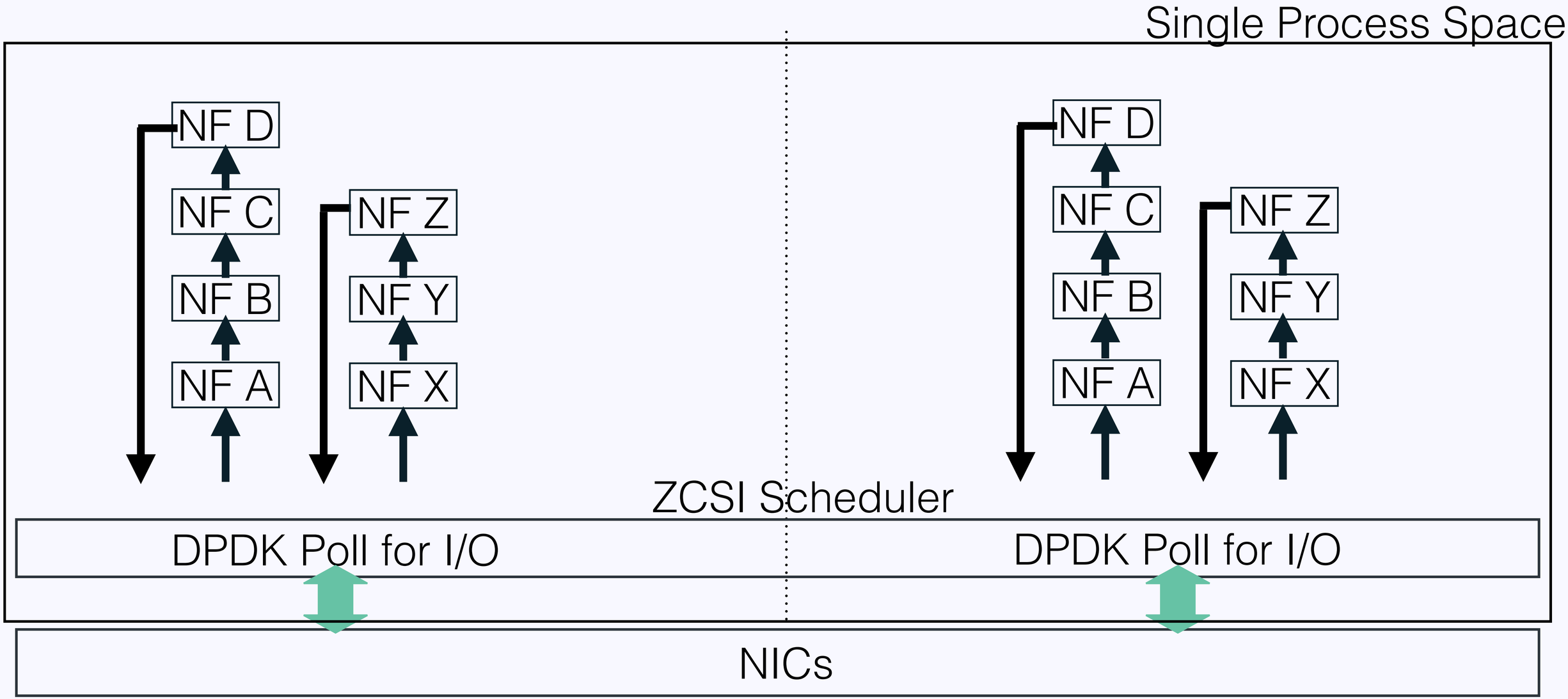
Isolation Costs Performance



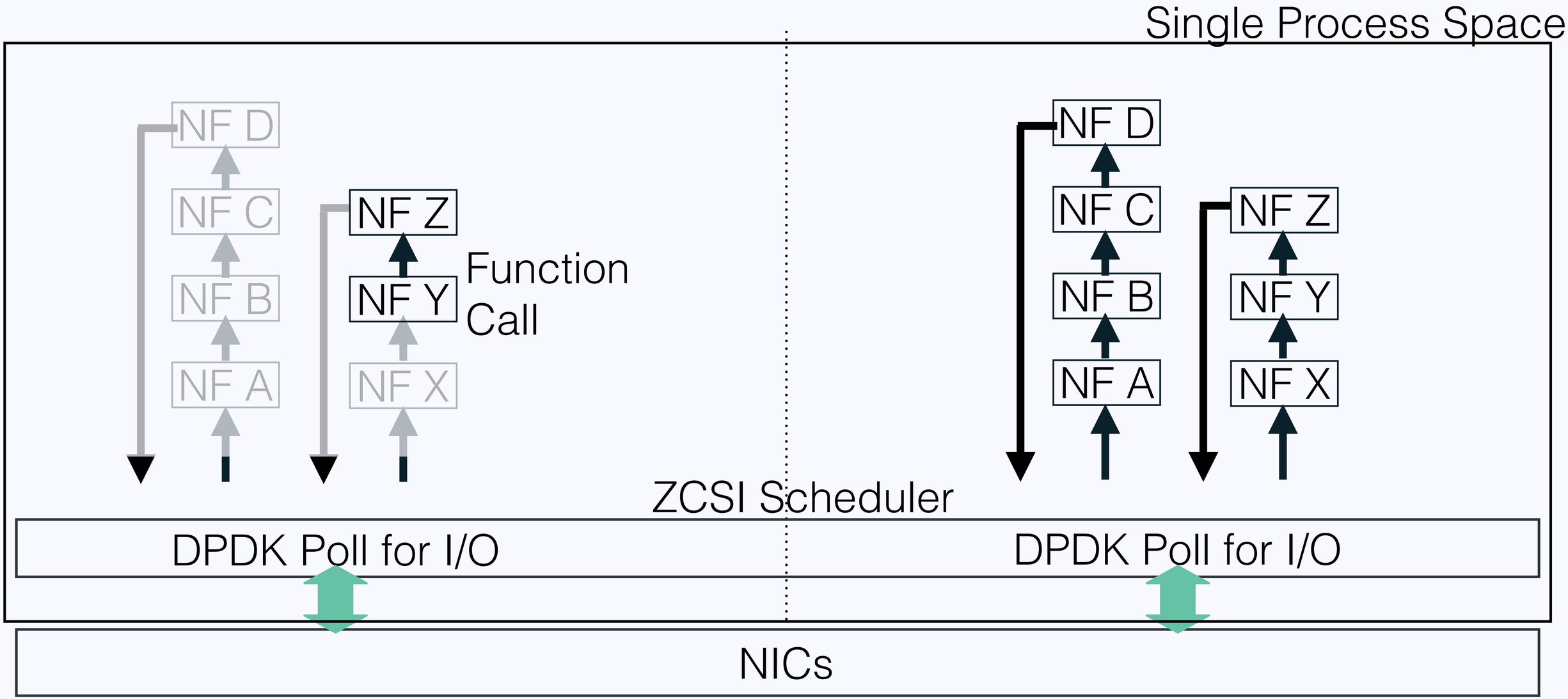
Isolation Costs Performance



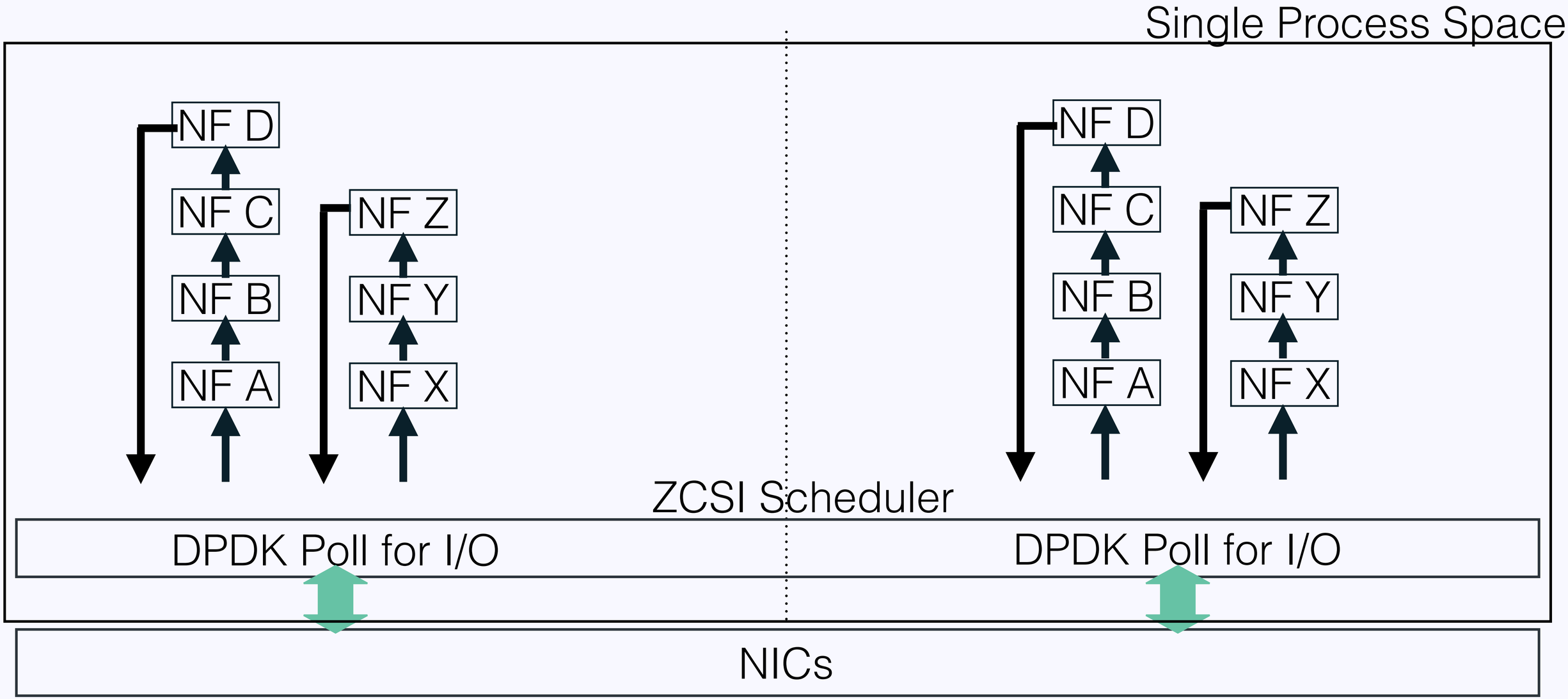
NetBricks Runtime Architecture



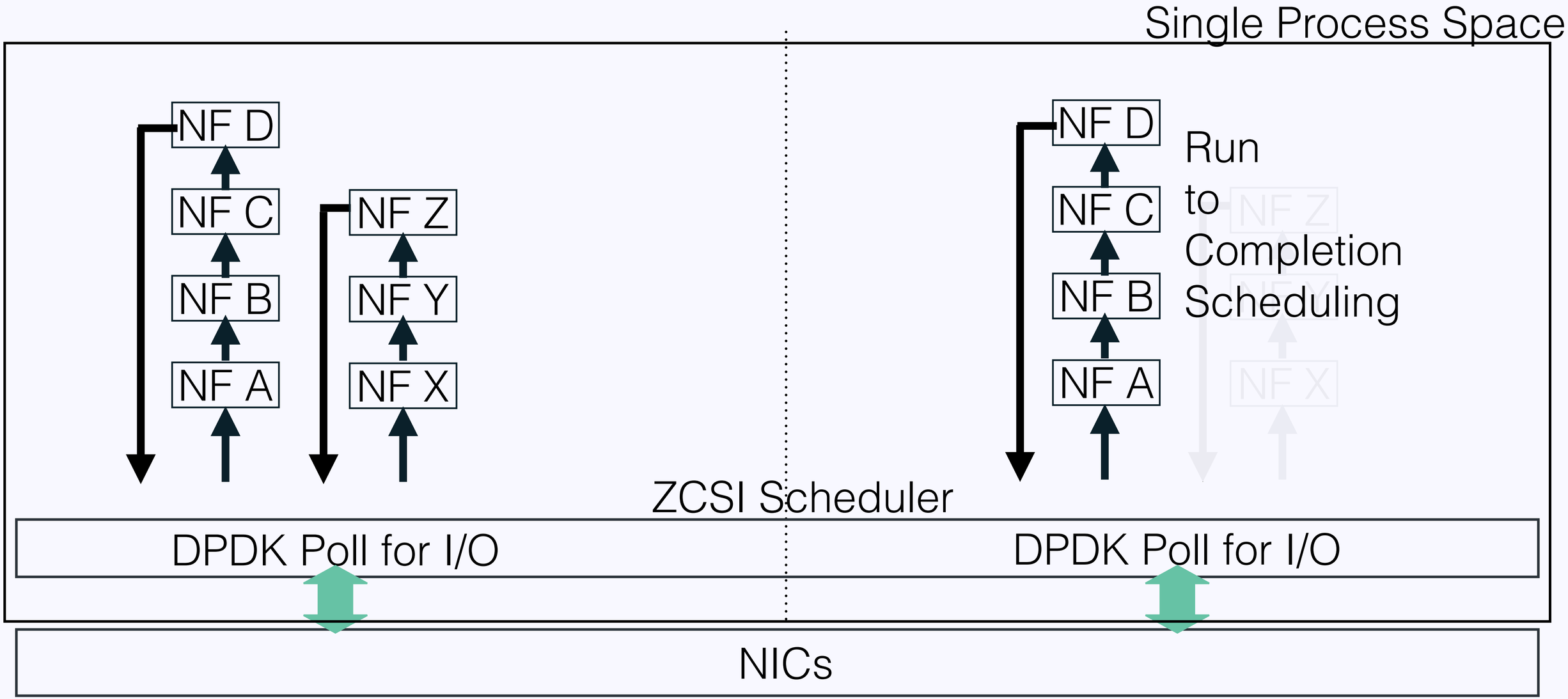
NetBricks Runtime Architecture



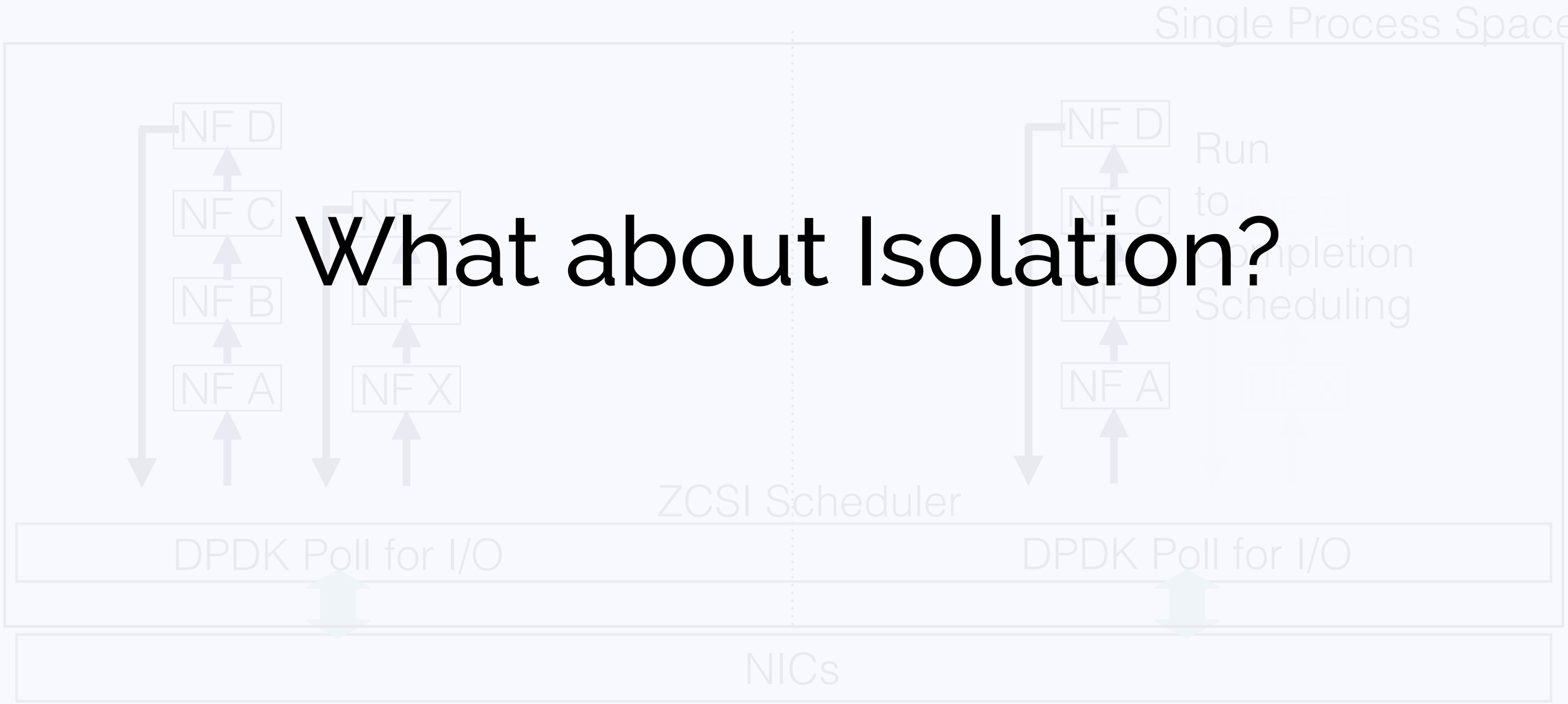
NetBricks Runtime Architecture



NetBricks Runtime Architecture



What about Isolation?



ZCSI: Zero Copy Soft Isolation

- VMs and containers impose cost on packets crossing isolation boundaries.

ZCSI: Zero Copy Soft Isolation

- VMs and containers impose cost on packets crossing isolation boundaries.
- **Insight**: Use type checking (compile time) and runtime checks for isolation.
  - Isolation costs largely paid at compile time (small runtime costs).

Our Approach

- Disallow pointer arithmetic in NF code: use safe subset of languages.

Our Approach

- Disallow pointer arithmetic in NF code: use safe subset of languages.
- Type checks + array bounds checking provide **memory isolation**.

Our Approach

- Disallow pointer arithmetic in NF code: use safe subset of languages.
- Type checks + array bounds checking provide **memory isolation**.
- Build on unique types for **packet isolation**.

Our Approach

- Disallow pointer arithmetic in NF code: use safe subset of languages.
- Type checks + array bounds checking provide **memory isolation**.
- Build on unique types for **packet isolation**.
  - Unique types ensure references destroyed after certain calls.

Our Approach

- Disallow pointer arithmetic in NF code: use safe subset of languages.
- Type checks + array bounds checking provide **memory isolation**.
- Build on unique types for **packet isolation**.
  - Unique types ensure references destroyed after certain calls.
  - Ensure only one NF has a reference to a packet.

Our Approach

- Disallow pointer arithmetic in NF code: use safe subset of languages.
- Type checks + array bounds checking provide **memory isolation**.
- Build on unique types for **packet isolation**.
  - Unique types ensure references destroyed after certain calls.
  - Ensure only one NF has a reference to a packet.
  - Enables zero copy packet I/O.

Our Approach

- Disallow pointer arithmetic in NF code: use safe subset of languages.
- Type checks + array bounds checking provide **memory isolation**.
- Build on unique types for **packet isolation**.
  - Unique types ensure references destroyed after certain calls.
  - Ensure only one NF has a reference to a packet.
  - Enables zero copy packet I/O.
- All of these features implemented on top of **Rust**.

Software Isolation

- Provides **memory** and **packet isolation**.

Software Isolation

- Provides **memory** and **packet isolation**.
- Improved **consolidation**: multiple NFs can share a core.

Software Isolation

- Provides **memory** and **packet isolation**.
- Improved **consolidation**: multiple NFs can share a core.
  - Function call to NF (~ few cycles) vs context switch (~1µs).

Software Isolation

- Provides **memory** and **packet isolation**.
- Improved **consolidation**: multiple NFs can share a core.
  - Function call to NF (~ few cycles) vs context switch (~1µs).
- Reduce **memory** and **cache pressure**.

Software Isolation

- Provides **memory** and **packet isolation**.
- Improved **consolidation**: multiple NFs can share a core.
  - Function call to NF (~ few cycles) vs context switch (~1µs).
- Reduce **memory** and **cache pressure**.
  - Zero copy I/O => do not need to copy packets around.

Challenges for NFV

- **Running NFs**
  - **Isolation** and **Performance**

- **Building NFs**
  - **High-Level Programming** and **Performance**

How to write NFs?

- **Current**: NF writers concerned about meeting performance targets

How to write NFs?

- **Current**: NF writers concerned about meeting performance targets
  - Low level abstractions (I/O, cache aware data structures) and low level code.

How to write NFs?

- **Current**: NF writers concerned about meeting performance targets
  - Low level abstractions (I/O, cache aware data structures) and low level code.
- Spend lots of time optimizing how abstractions are used to get performance.

How to write NFs?

- **Current**: NF writers concerned about meeting performance targets
  - Low level abstractions (I/O, cache aware data structures) and low level code.
- Spend lots of time optimizing how abstractions are used to get performance.
- **Observation**: NFs exhibit common patterns: abstract and optimize these.

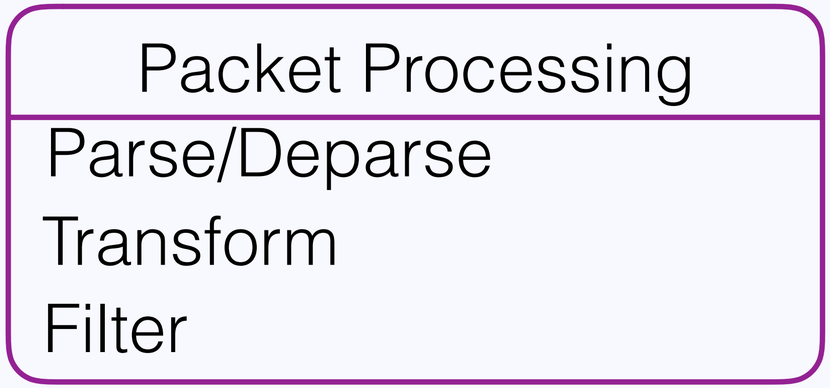
How to write NFs?

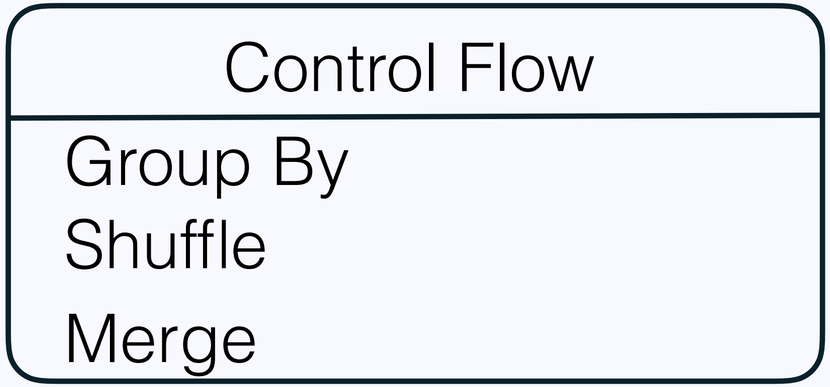
- **Current**: NF writers concerned about meeting performance targets
  - Low level abstractions (I/O, cache aware data structures) and low level code.
- Spend lots of time optimizing how abstractions are used to get performance.
- **Observation**: NFs exhibit common patterns: abstract and optimize these.
- What happened in other areas

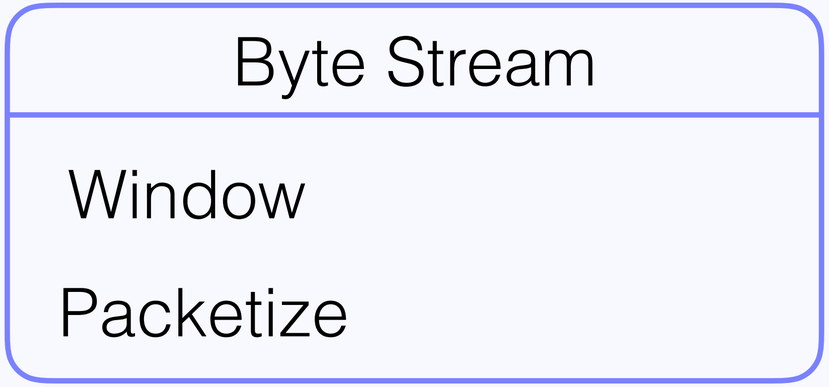
How to write NFs?

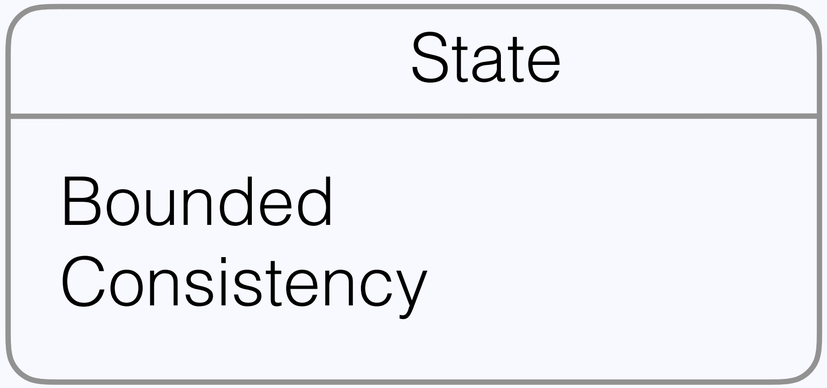
- **Current**: NF writers concerned about meeting performance targets
  - Low level abstractions (I/O, cache aware data structures) and low level code.
- Spend lots of time optimizing how abstractions are used to get performance.
- **Observation**: NFs exhibit common patterns: abstract and optimize these.
- What happened in other areas
  - MPI to Map Reduce, etc.

Abstractions









Abstractions

Packet Processing	
Parse/Deparse	Header
Transform	UDF
Filter	UDF

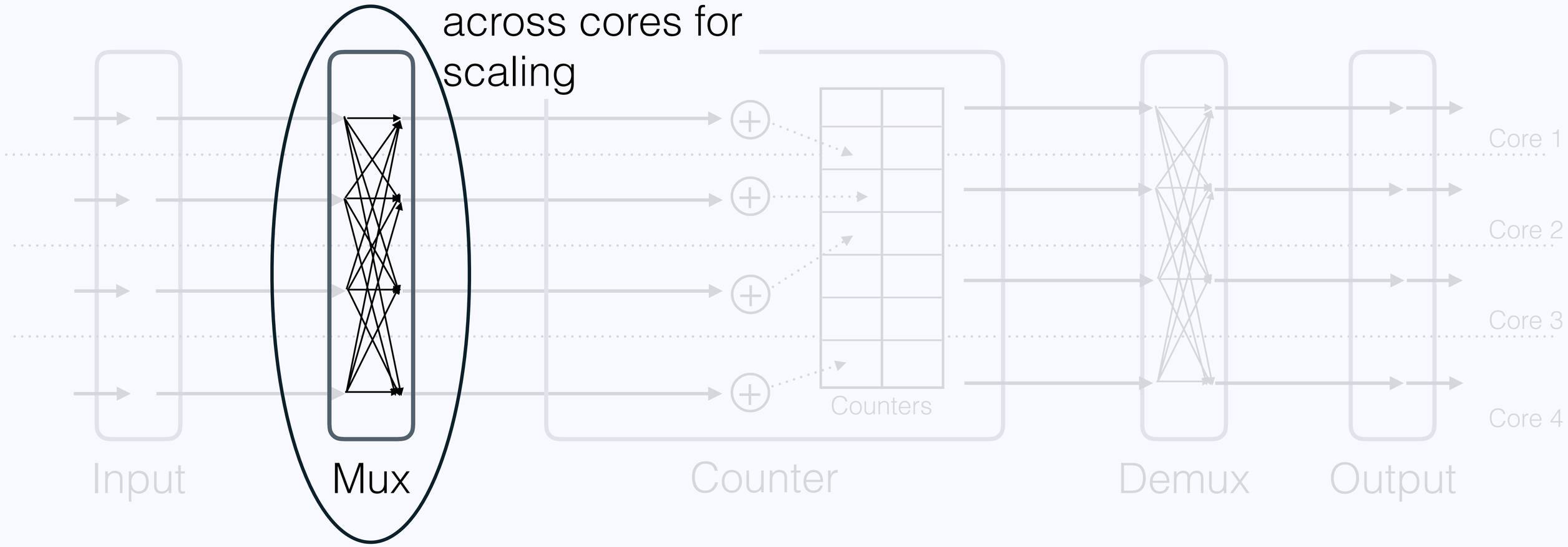
Control Flow	
Group By	UDF
Shuffle	UDF
Merge	

Byte Stream	
Window	UDF
Packetize	UDF

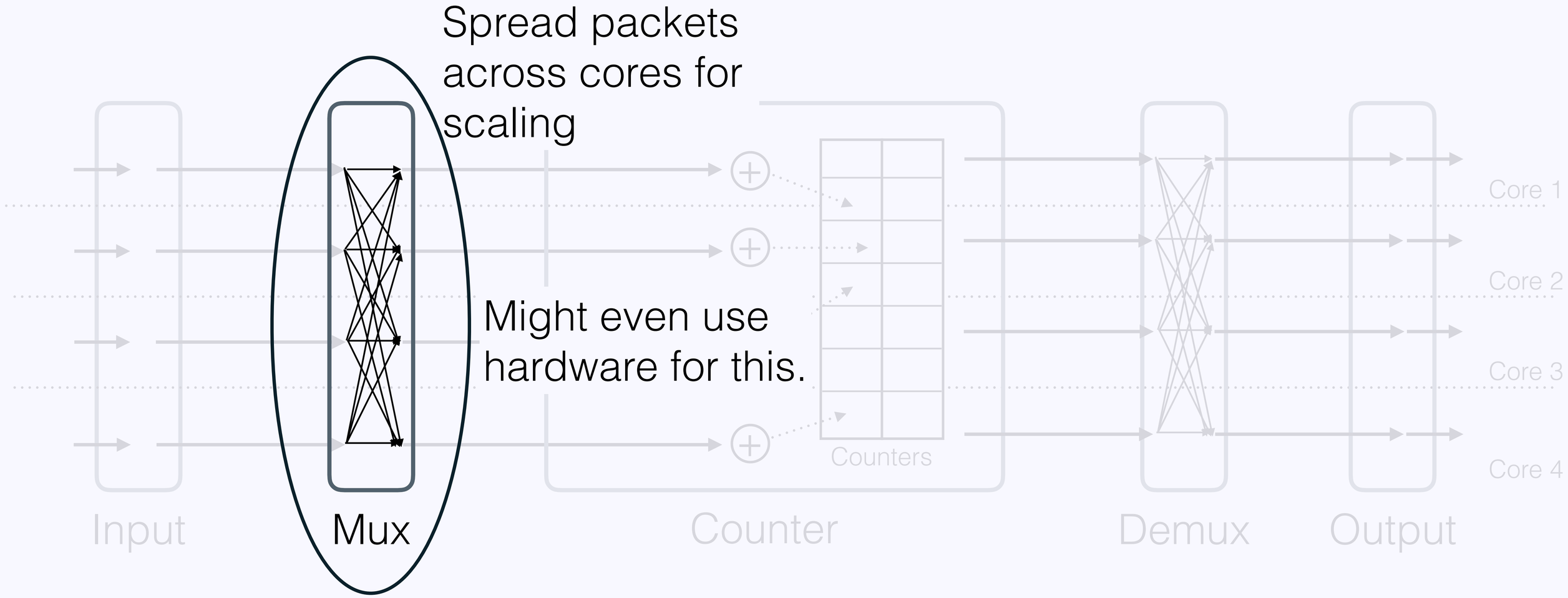
State
Bounded
Consistency

Shuffle Abstraction

Spread packets across cores for scaling



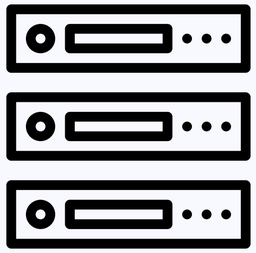
Shuffle Abstraction



Example NF: Maglev

- **Maglev**: Load balancer from Google (NSDI'16).
- Main contribution: a **novel consistent hashing algorithm.**
  - Most of the work in common optimization: batching, scaling cross core.
- NetBricks implementation: **105 lines, 2 hours of time**.
- Comparable performance to optimized code

Managing NFs



E2 (SOSP'15)

Stratos

FTMB (SIGCOMM '15)

FlowTags (NSDI '14)

Building and Running NFs

No Isolation

CoMB (NSDI'12)
xOMB (ANCS'12)

VM Isolation

ClickOS (NSDI'14)
NetVM (IEEE TNSM)
HyperSwitch (ATC'13)
mSwitch (SOSR'15)

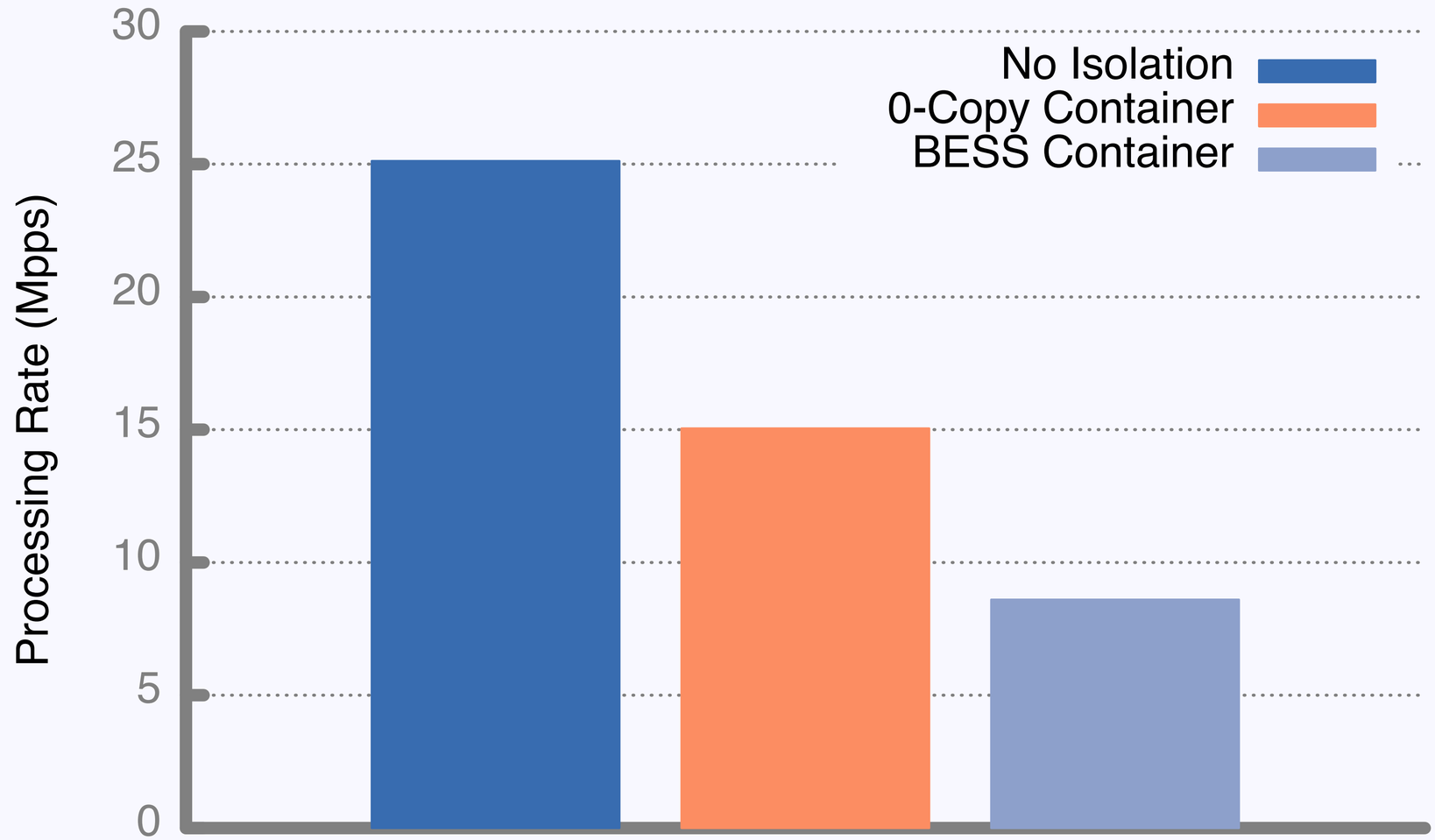
Conclusion

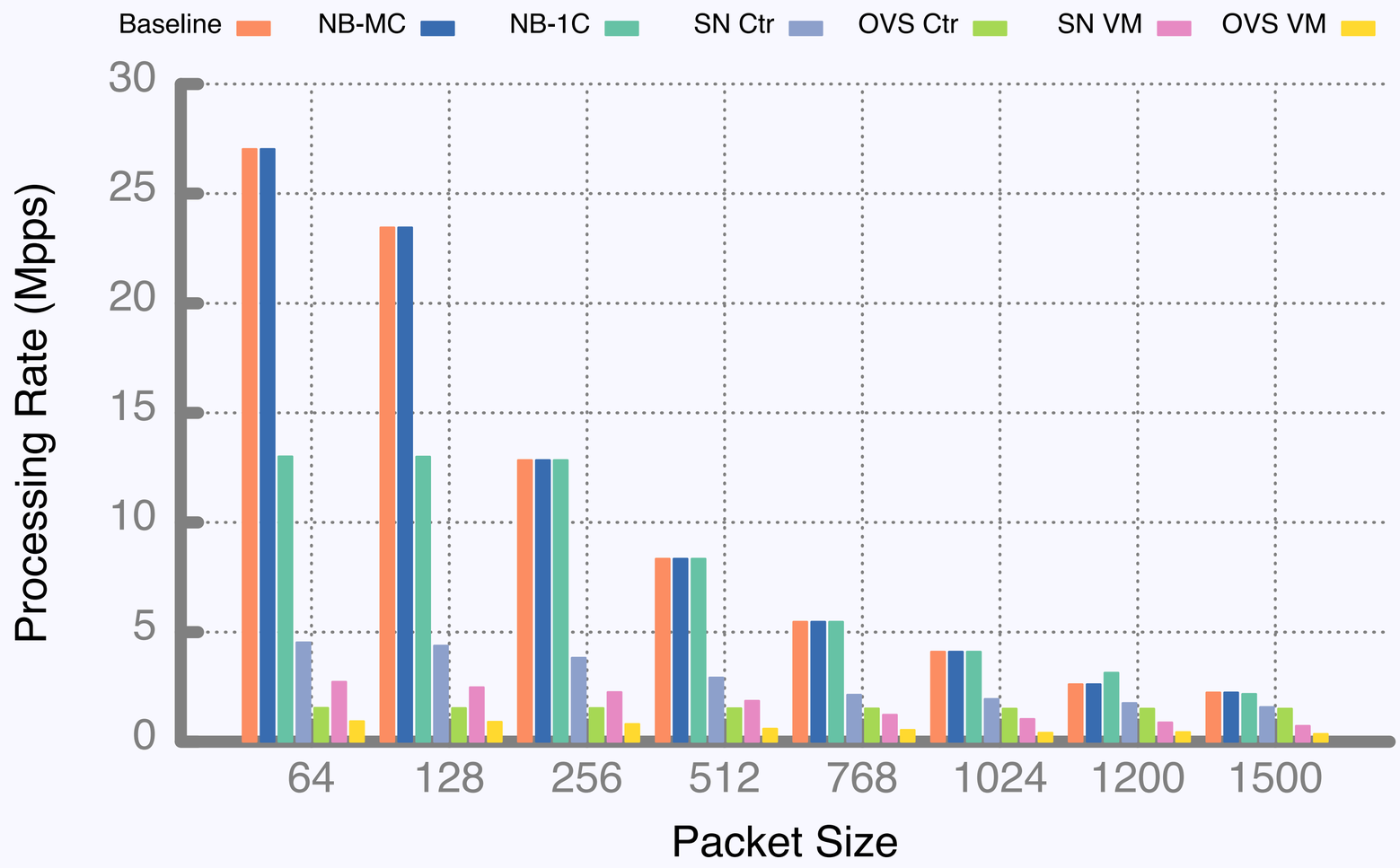
- Software isolation is necessary for high performance NFV.
  - Type checking + bound checking + unique types.
- Performance is not anathema to high-level programming
  - Abstract operators + UDF simplify development.

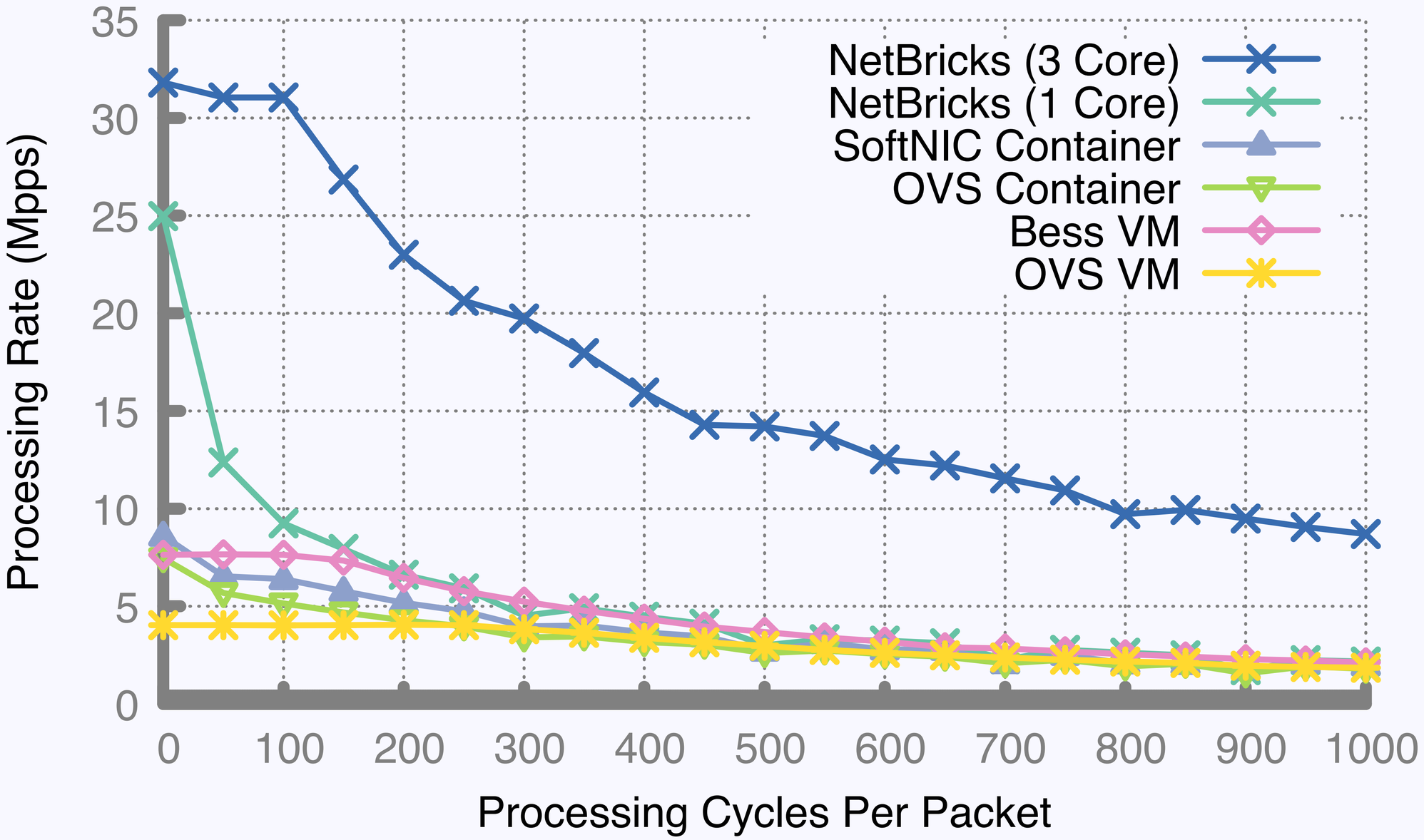
Code available at **http://netbricks.io/**

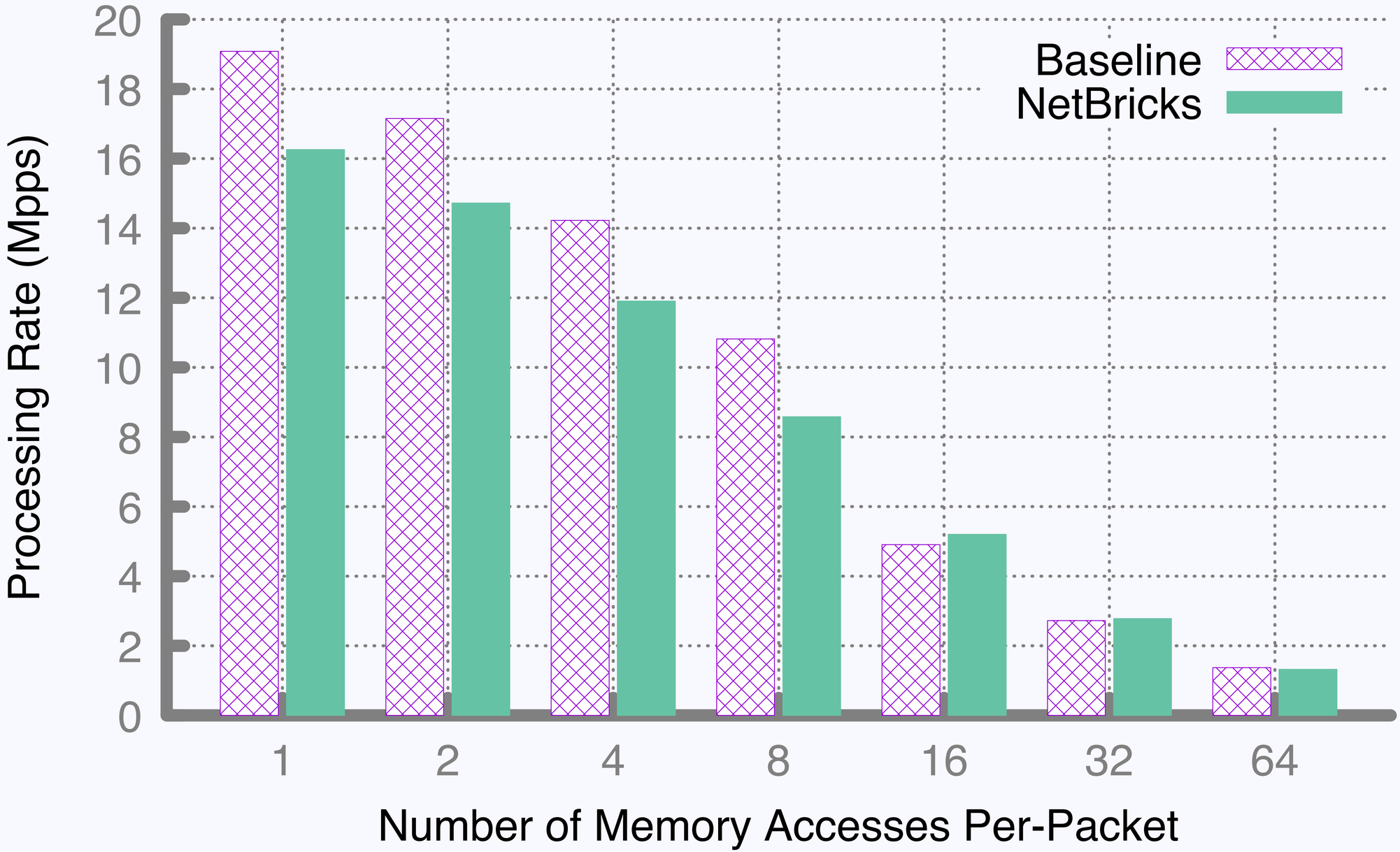
Backup

Both Memory Isolation and I/O Induce Overheads




Baseline
NB-MC
NB-1C
SN Ctr
OVS Ctr
SN VM
OVS VM
Processing Rate (Mpps)
30
25
20
15
10
5
0
64
128
256
512
768
1024
1200
1500
Packet Size


Processing Rate (Mpps)
35
30
25
20
15
10
5
0
0
100
200
300
400
500
600
700
800
900
1000
Processing Cycles Per Packet
NetBricks (3 Core)
NetBricks (1 Core)
SoftNIC Container
OVS Container
Bess VM
OVS VM


Processing Rate (Mpps)
20
18
16
14
12
10
8
6
4
2
0
Baseline
NetBricks
1
2
4
8
16
32
64
Number of Memory Accesses Per-Packet