LemonNFV: Consolidating Heterogeneous Network Functions at Line Speed

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Danfeng Shan[1], Peng Zhang[1]

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XI'AN JIAOTONG UNIVERSITY

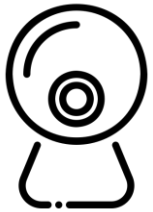
NUS
National University
of Singapore

NYU 上海

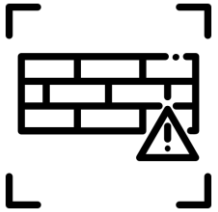
SHANGHAI 纽约大学

Virtualized Network Function (VNF)

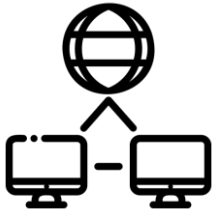
DPI



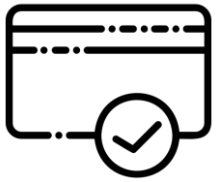
IDS



Firewall



NAT



ACL

VPN

Load Balancer

Virtualized Network Function (VNF)

IDS

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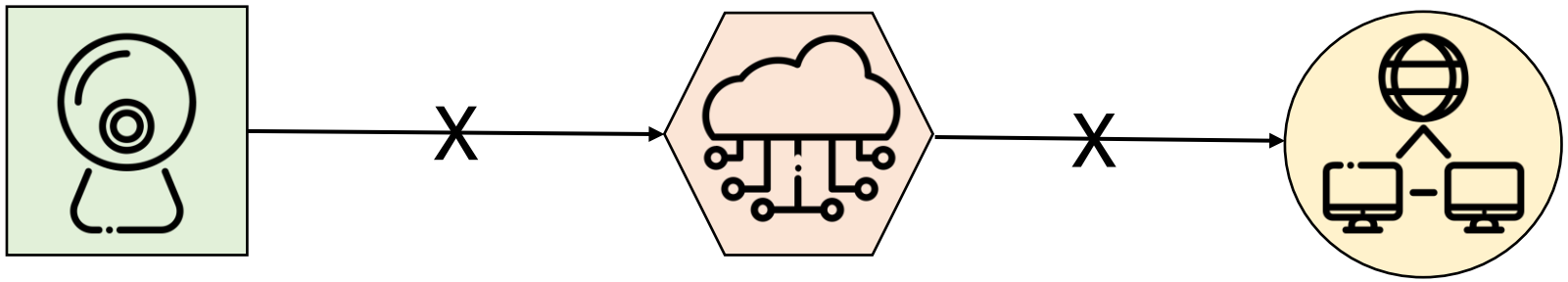
NAT

Heterogeneous NFs Are Not Interoperable



Programming language *Execution model* *State & Packet Abstraction*

Different shapes signify different vendors, and thus interfaces, abstractions, etc.

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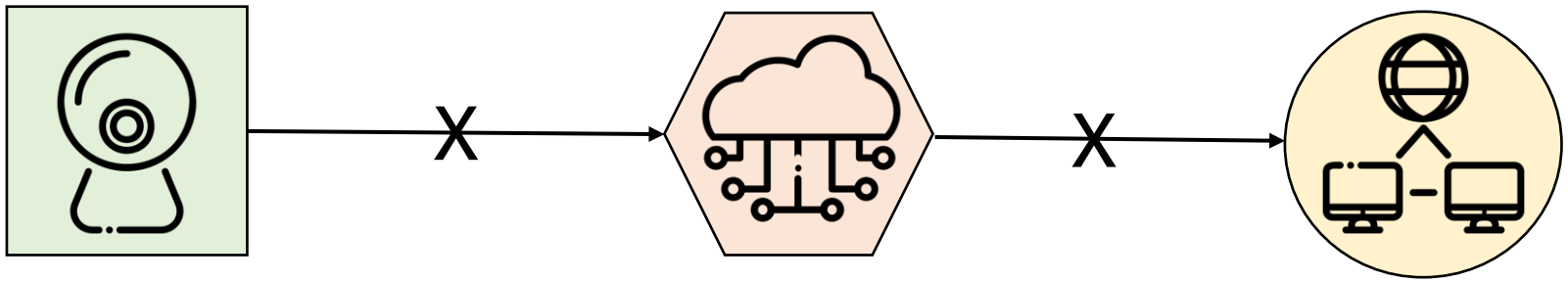

Snort
[LISA ‘99]

NetBricks
[OSDI ‘16]

Click
[ToCS ‘00]

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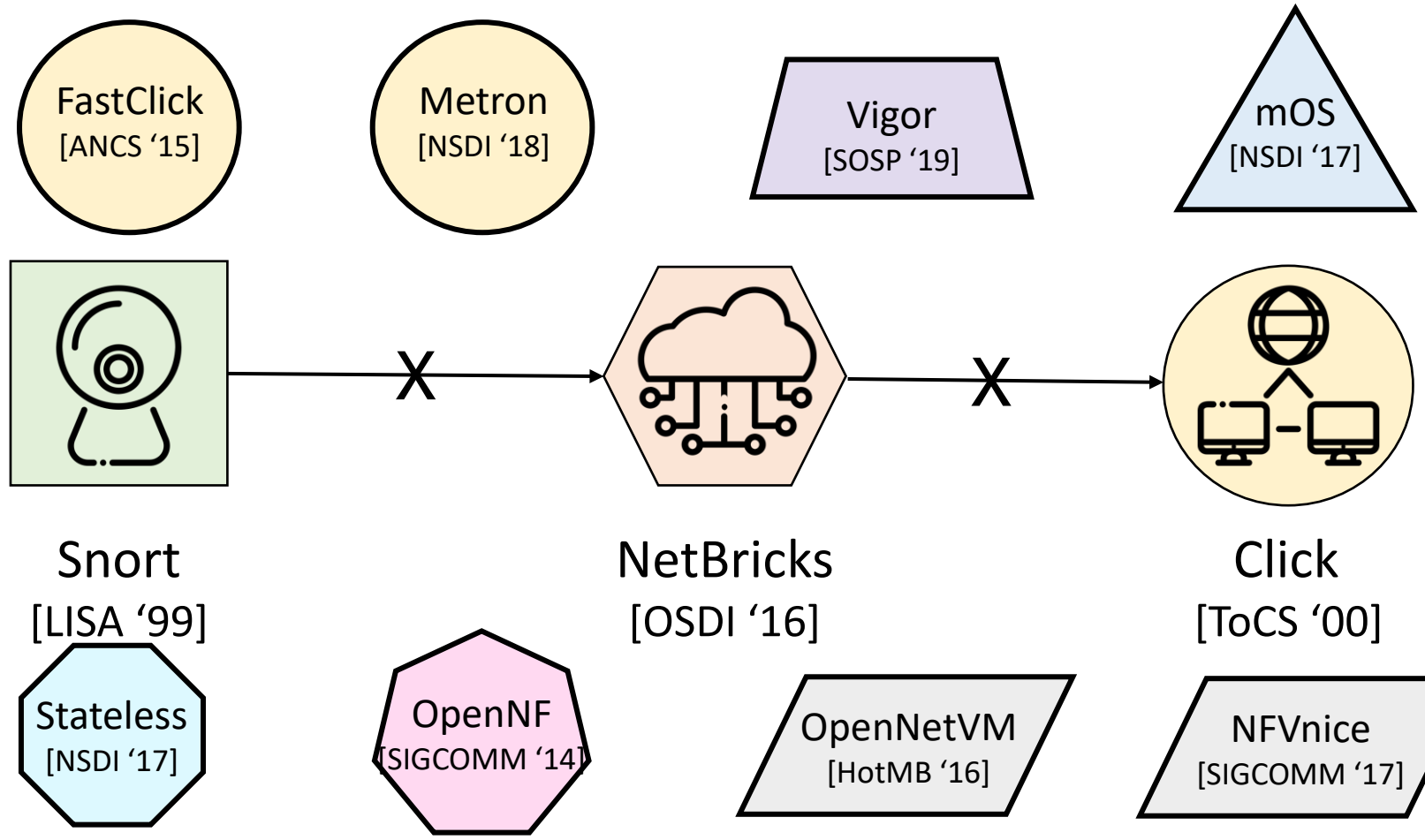

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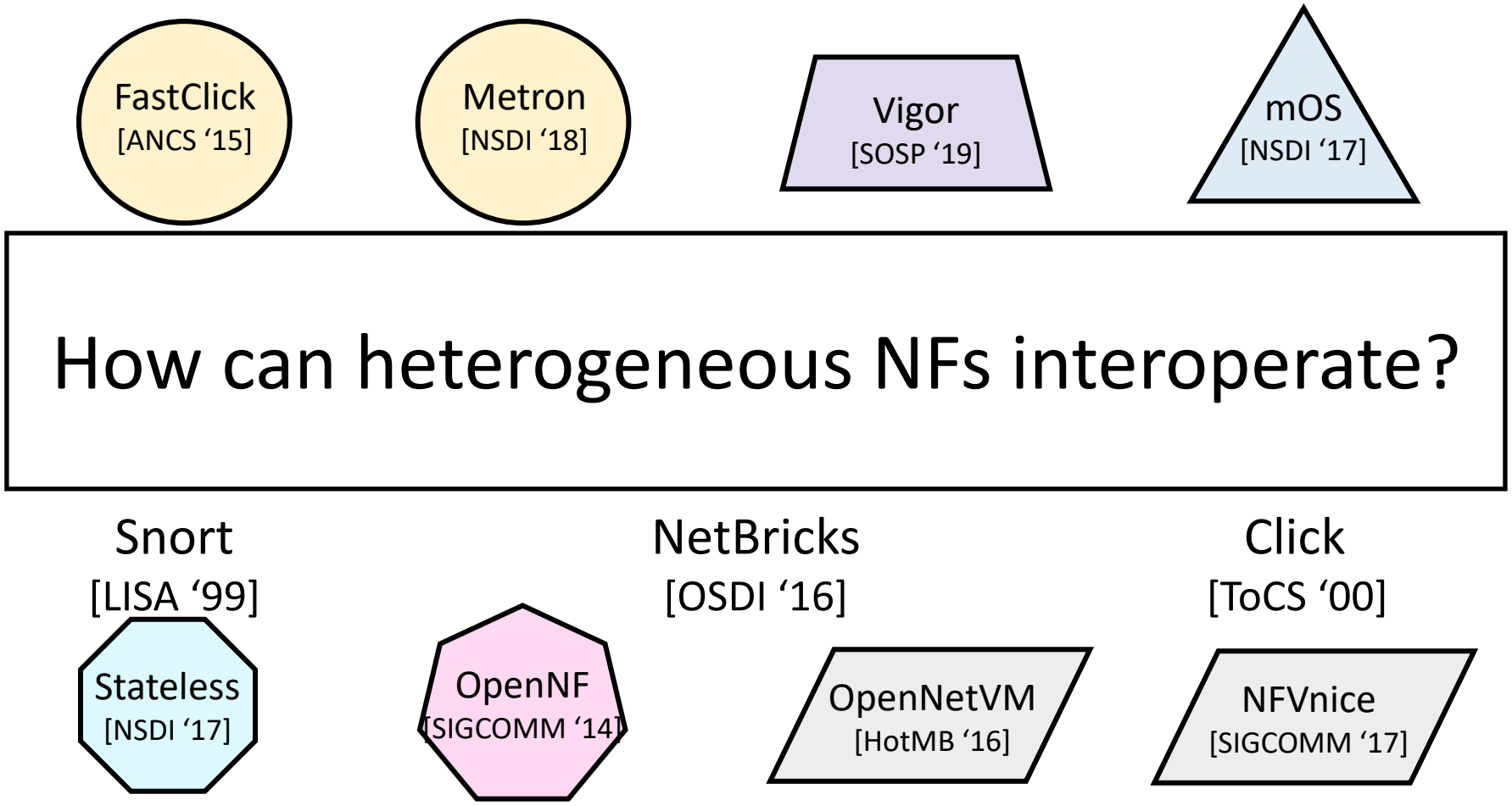

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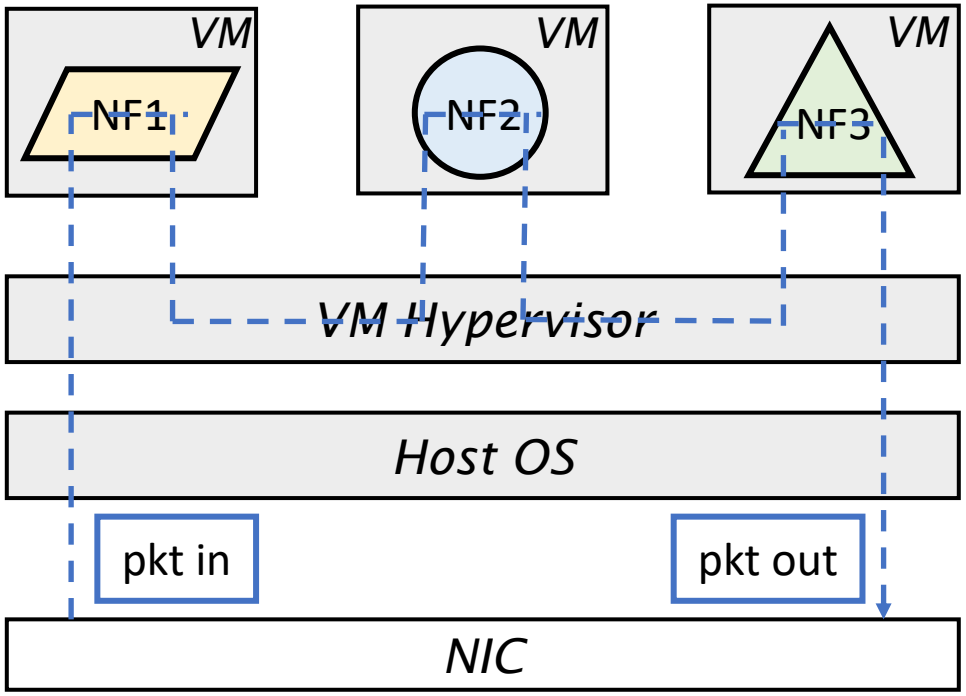
Solution 1: Virtualization



Dilemma: Context Switch vs Inter-Core Traffic

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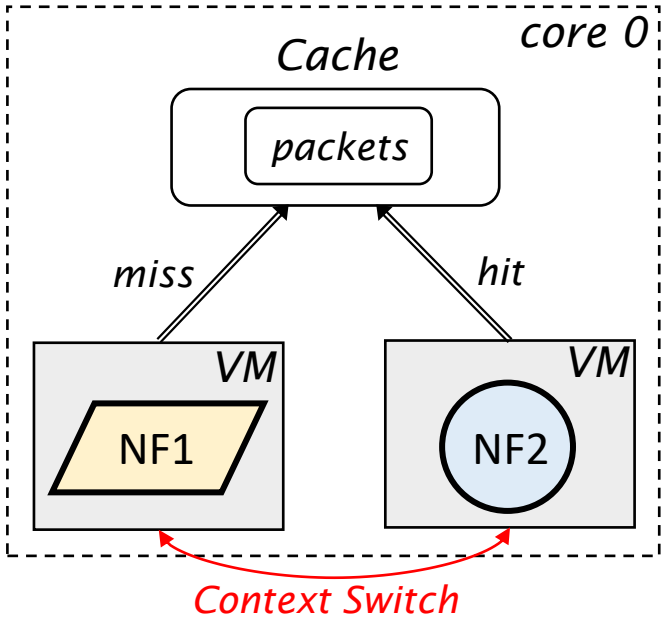

- Scheduling instances on the same core
- Related Work: Quadrant *[SoCC '22]*
  - Reportedly 41.4% more latency[1]

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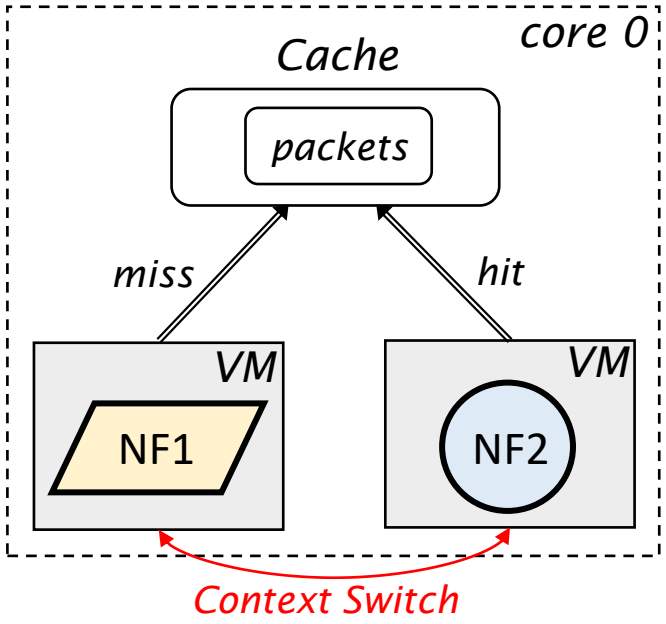

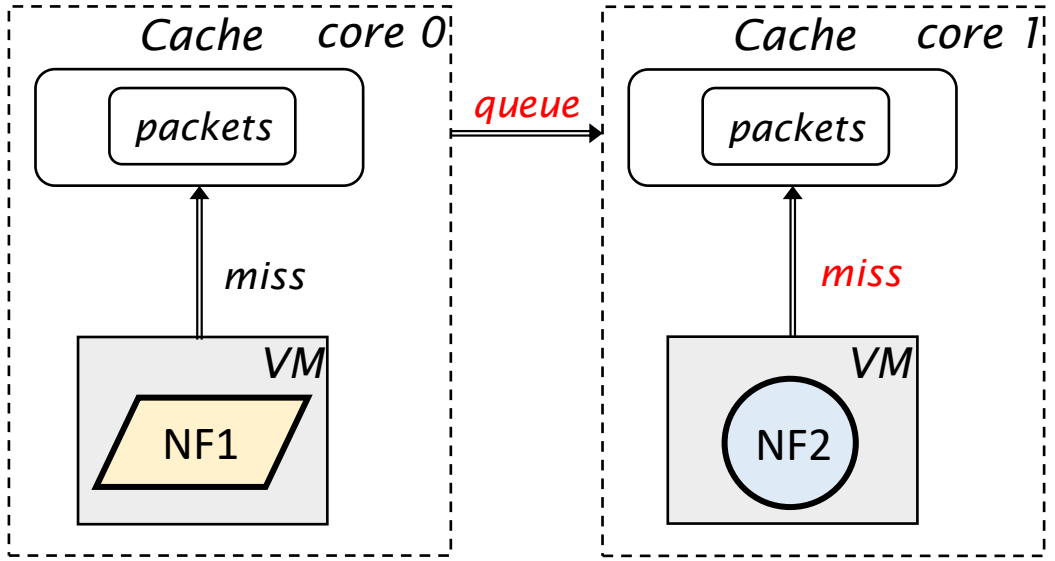

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- Related Work: OpenNetVM *[HotMB '16]*
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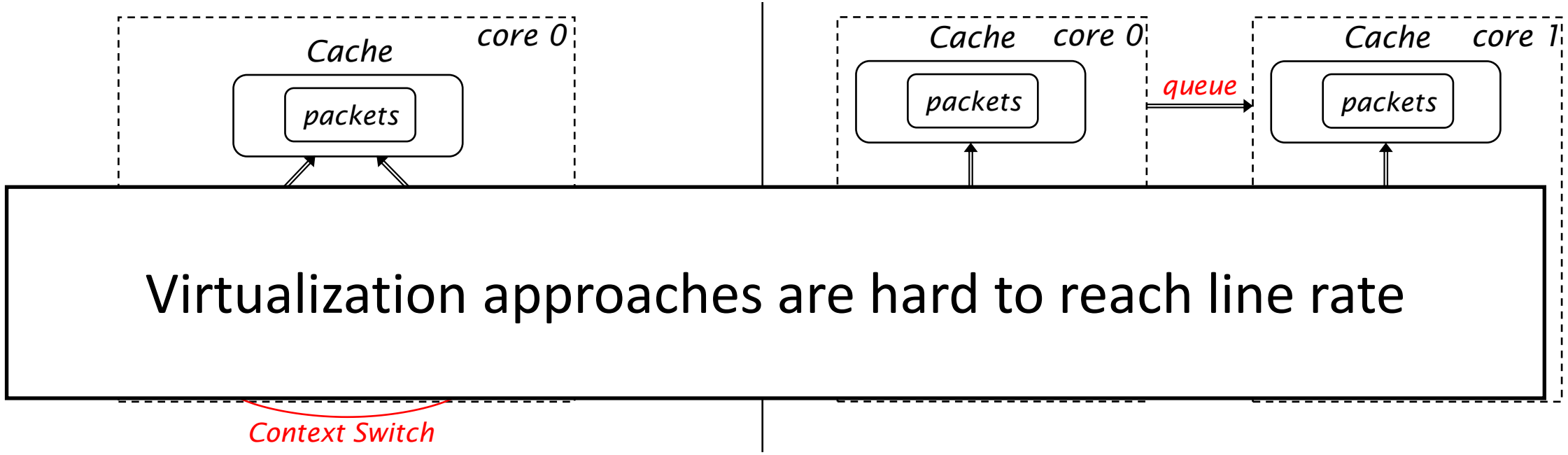

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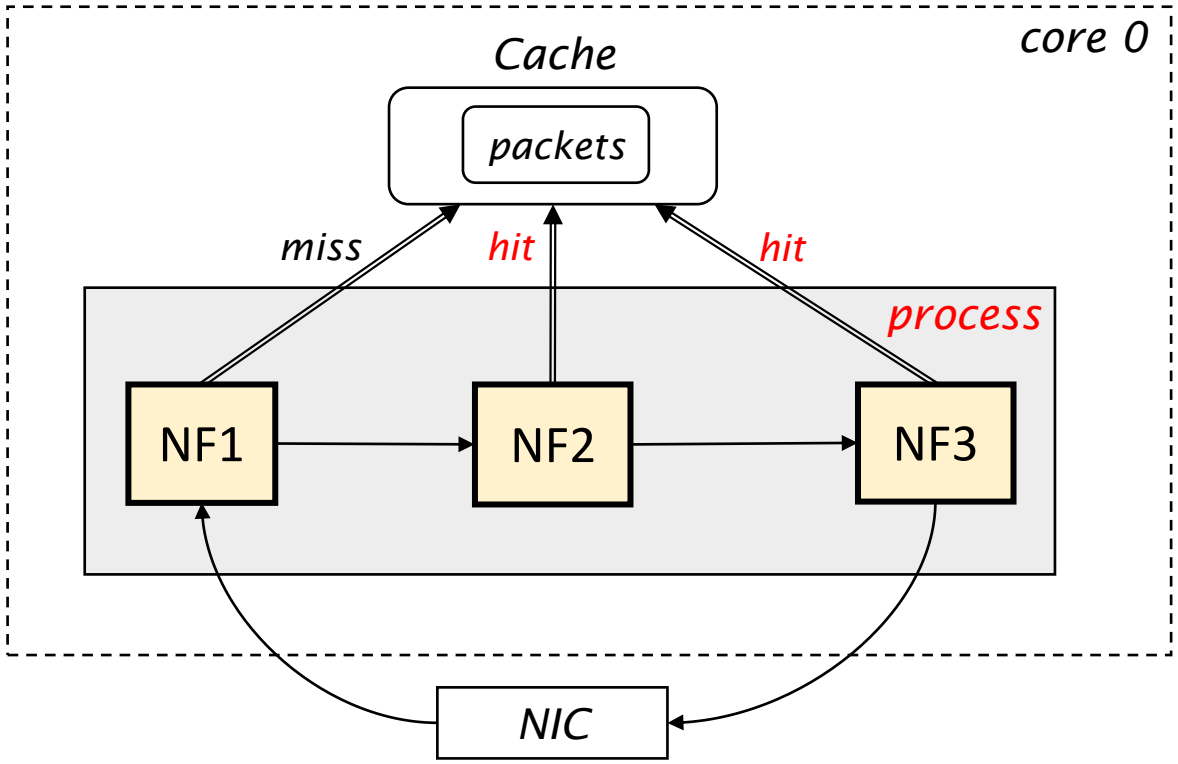
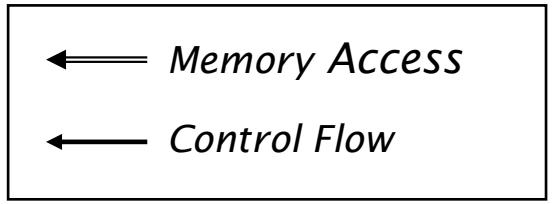


- Fusing all NFs into one process
- No context switching or inter-core traffic



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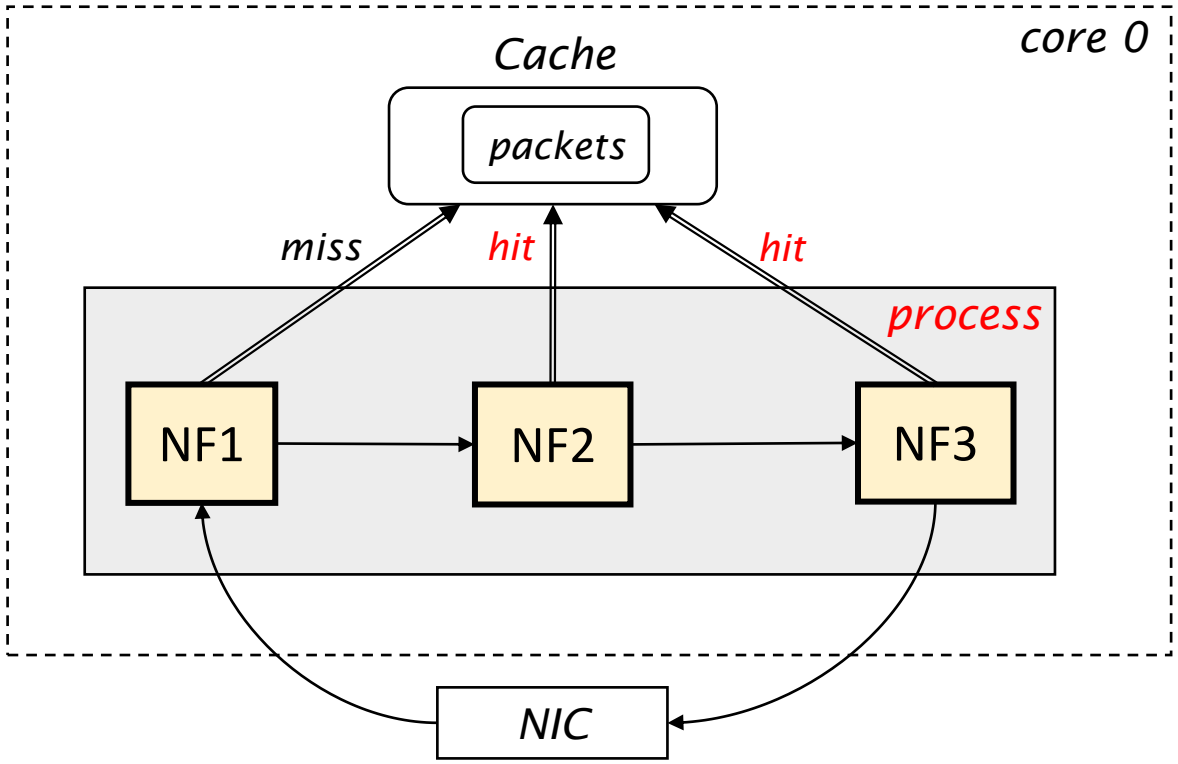
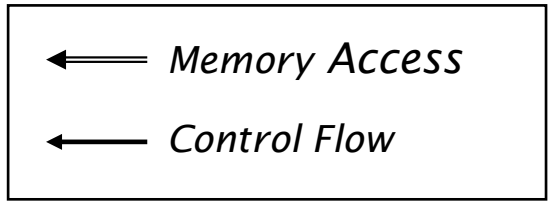
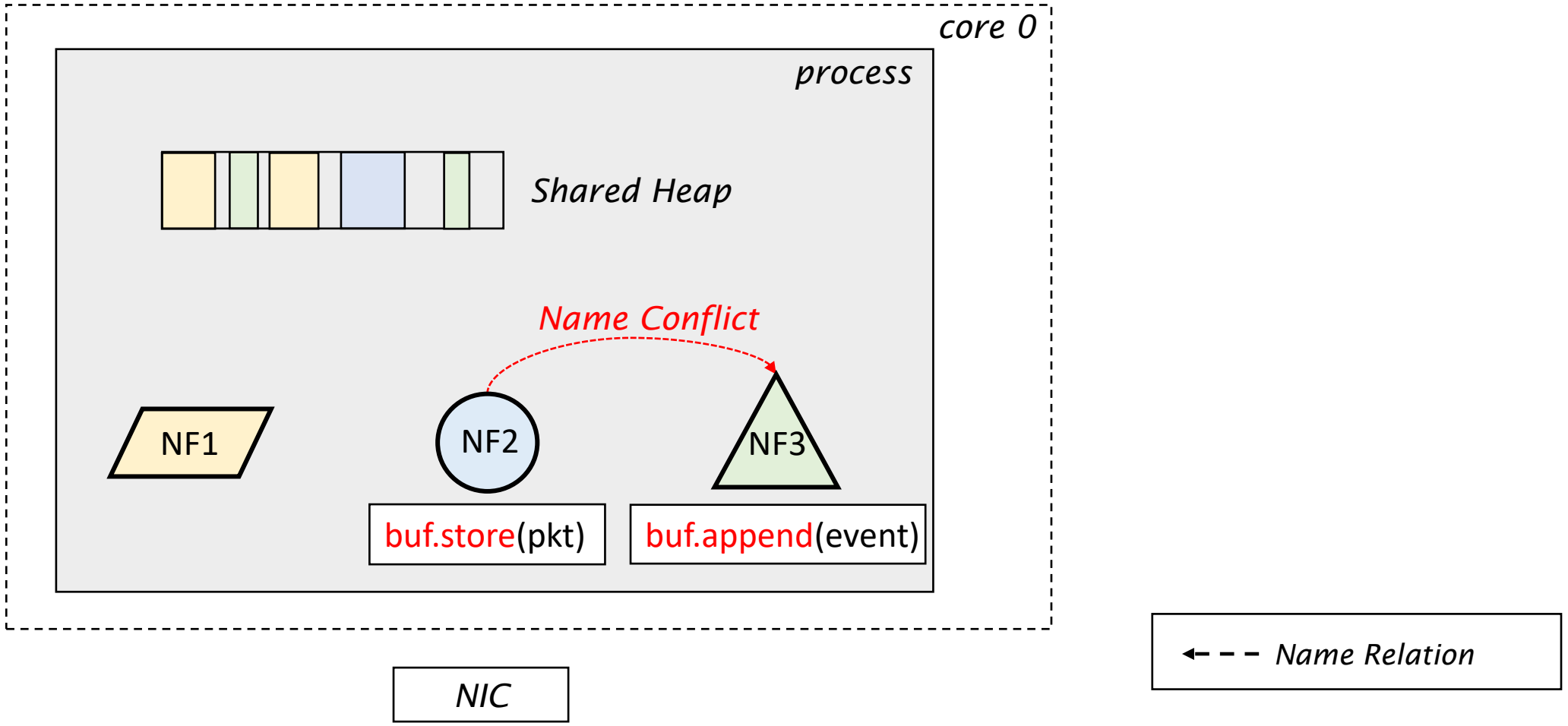


- Fusing all NFs into one process
- No context switching or inter-core traffic
- Requiring huge code modification on heterogeneous NFs



Problem #1: Namespace Conflict



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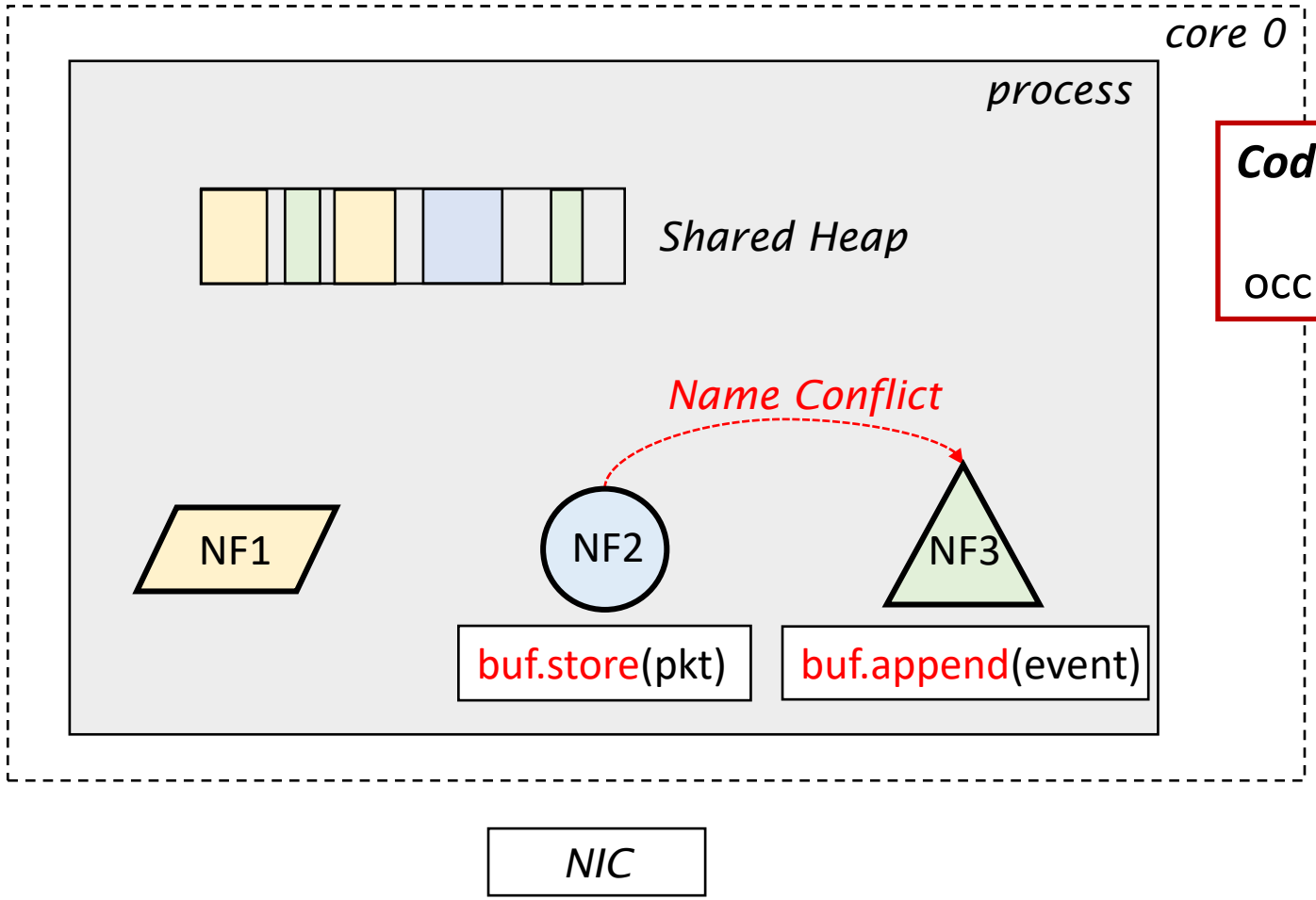
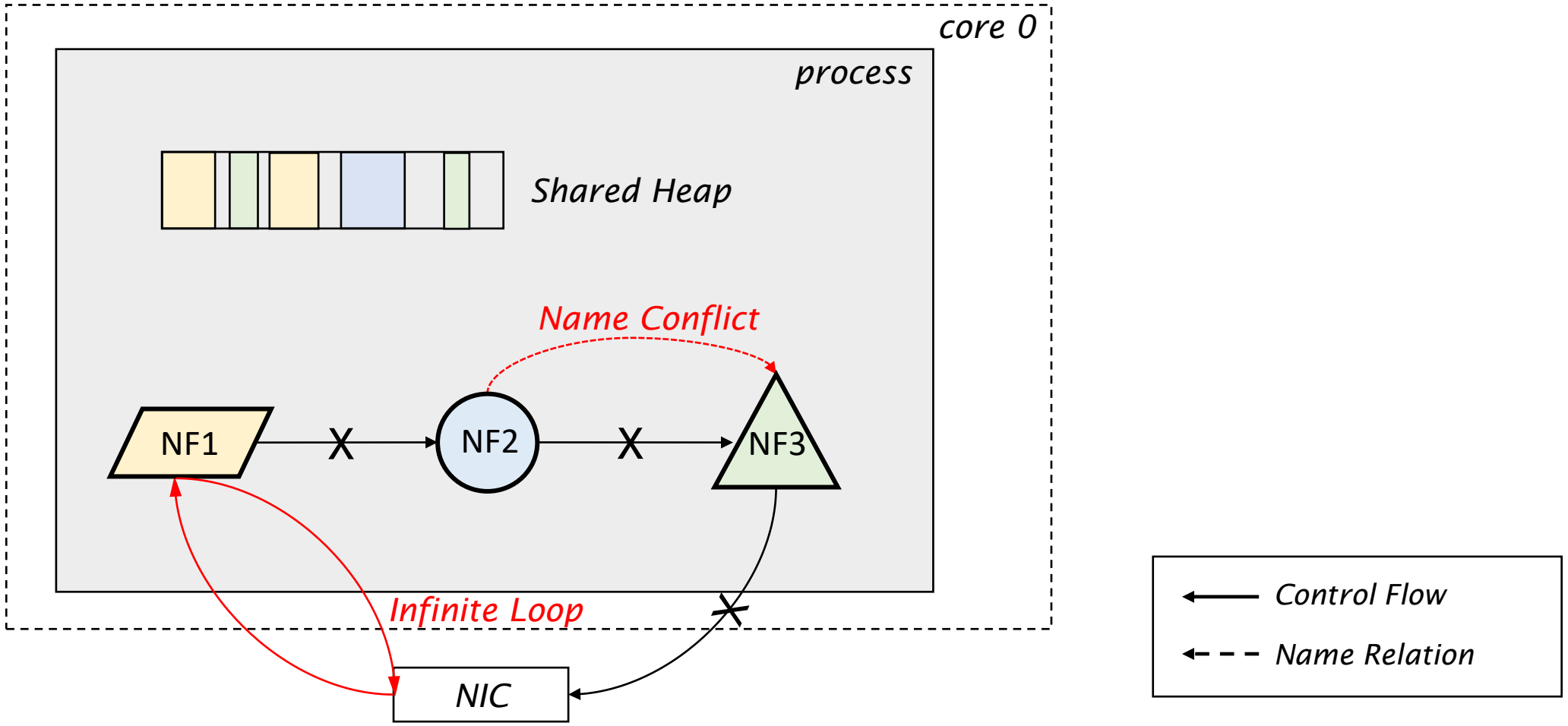


Code Modification

check and replace every occurrence of conflicting names

Name Relation

Problem #2: Private Control Flow



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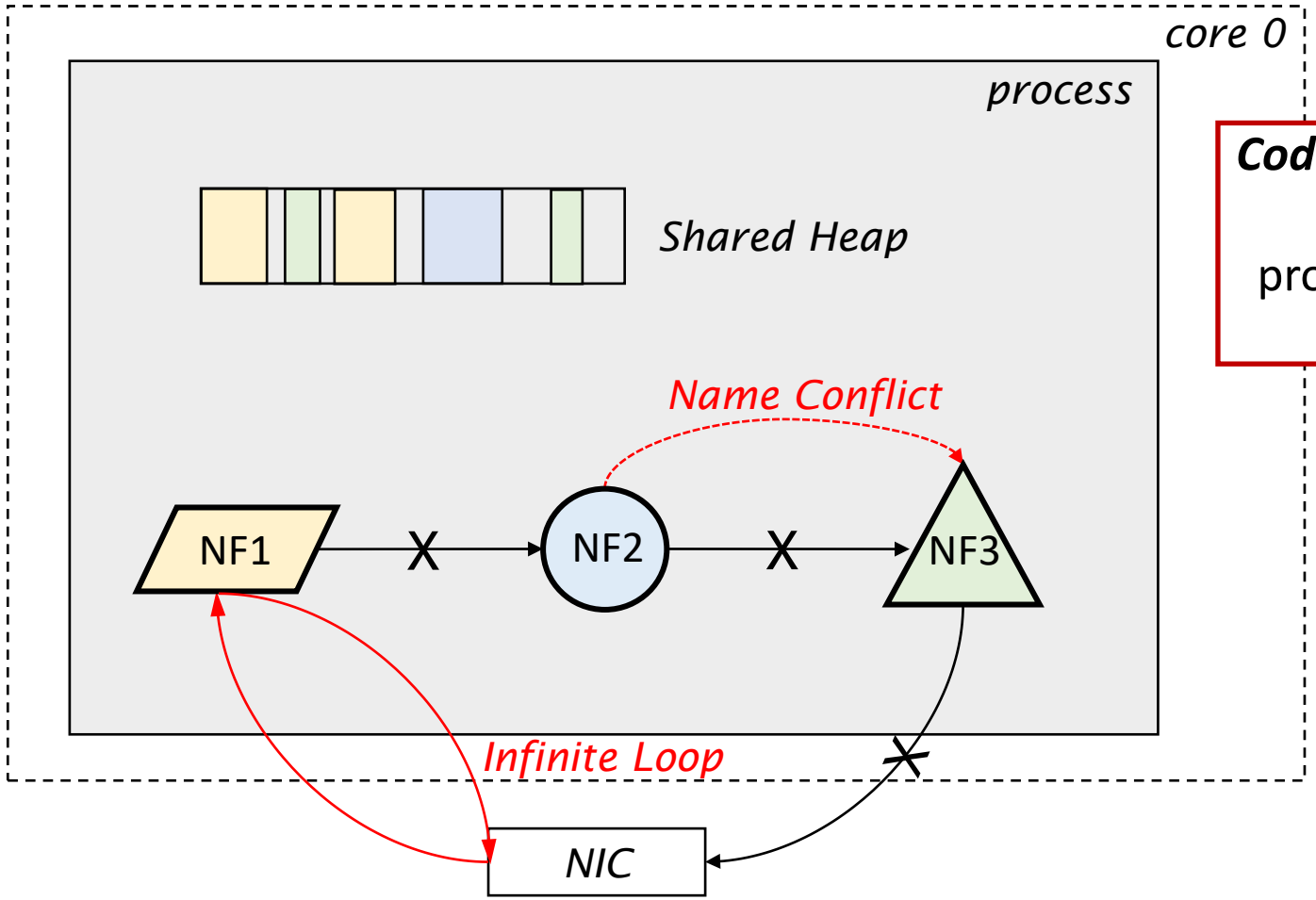
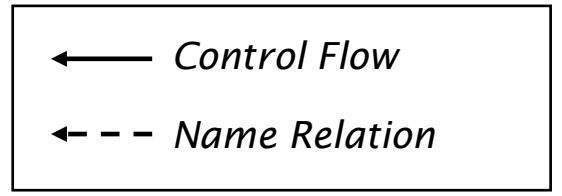
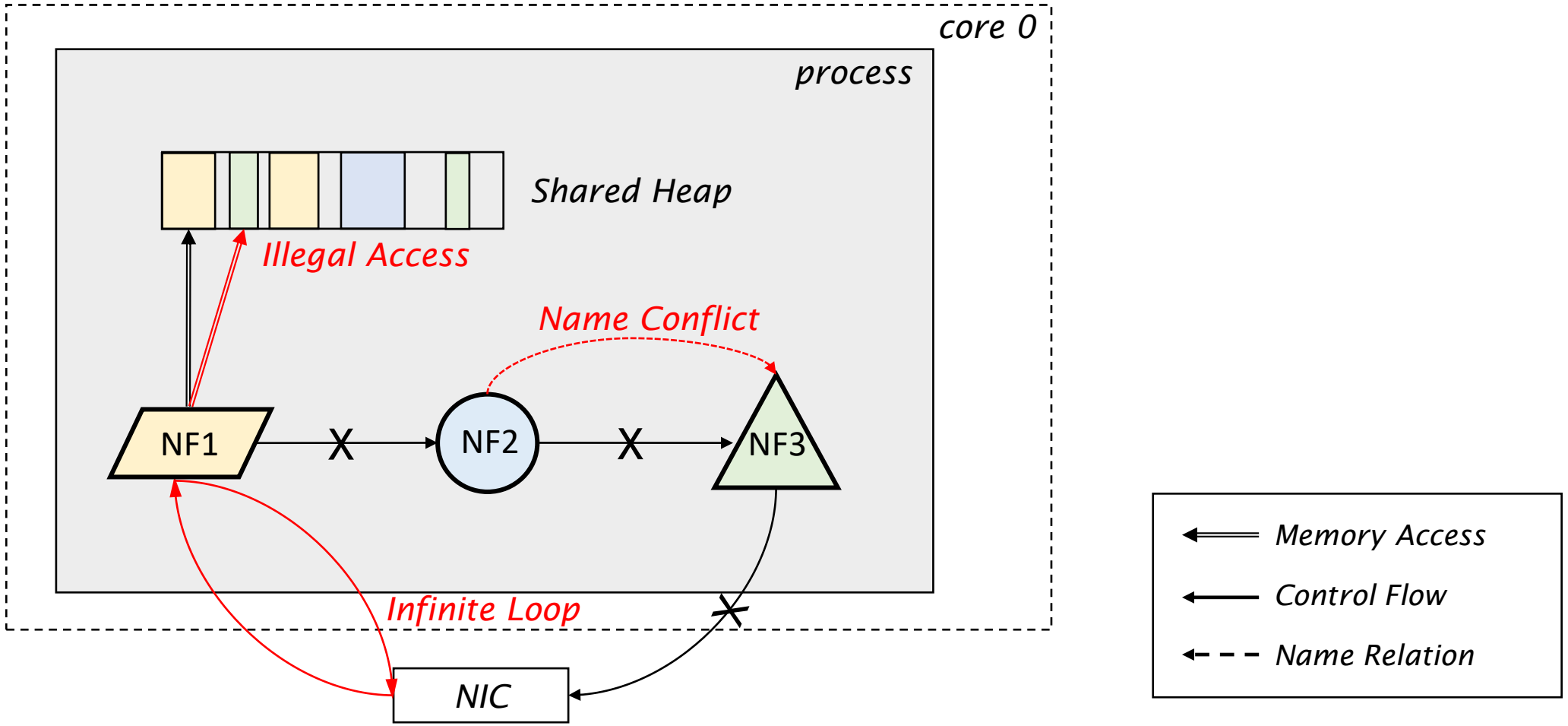


Code Modification

find and extract packet processing logic, and rewrite it without loop



Problem #3: Illegal Memory Access



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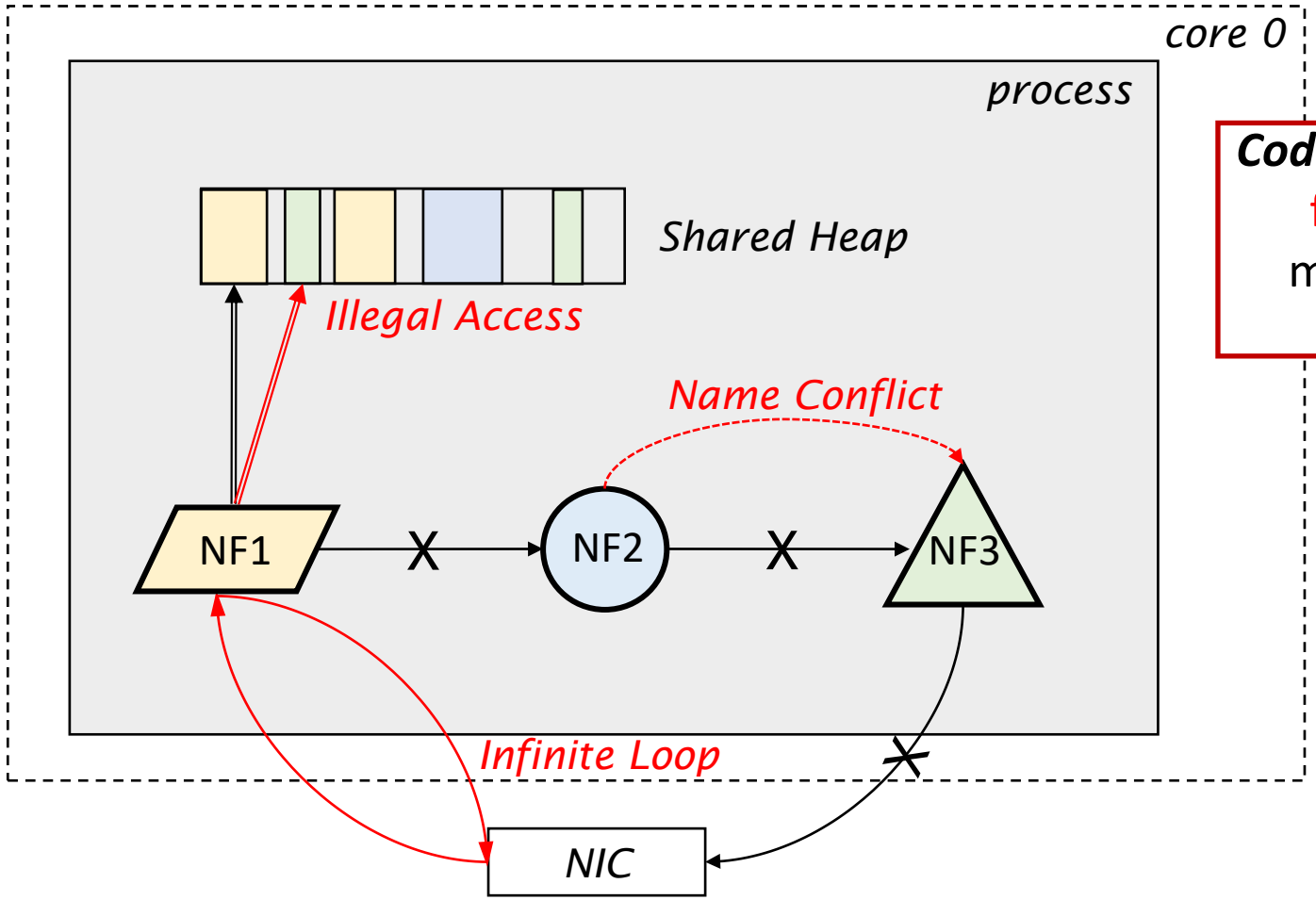
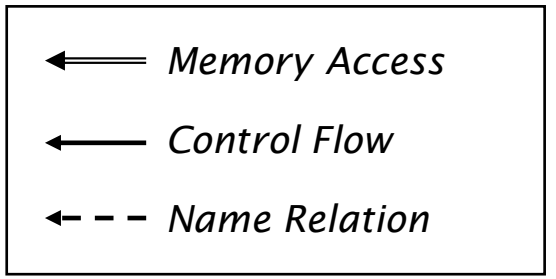


Code Modification

find and instrument every memory access with bound checking



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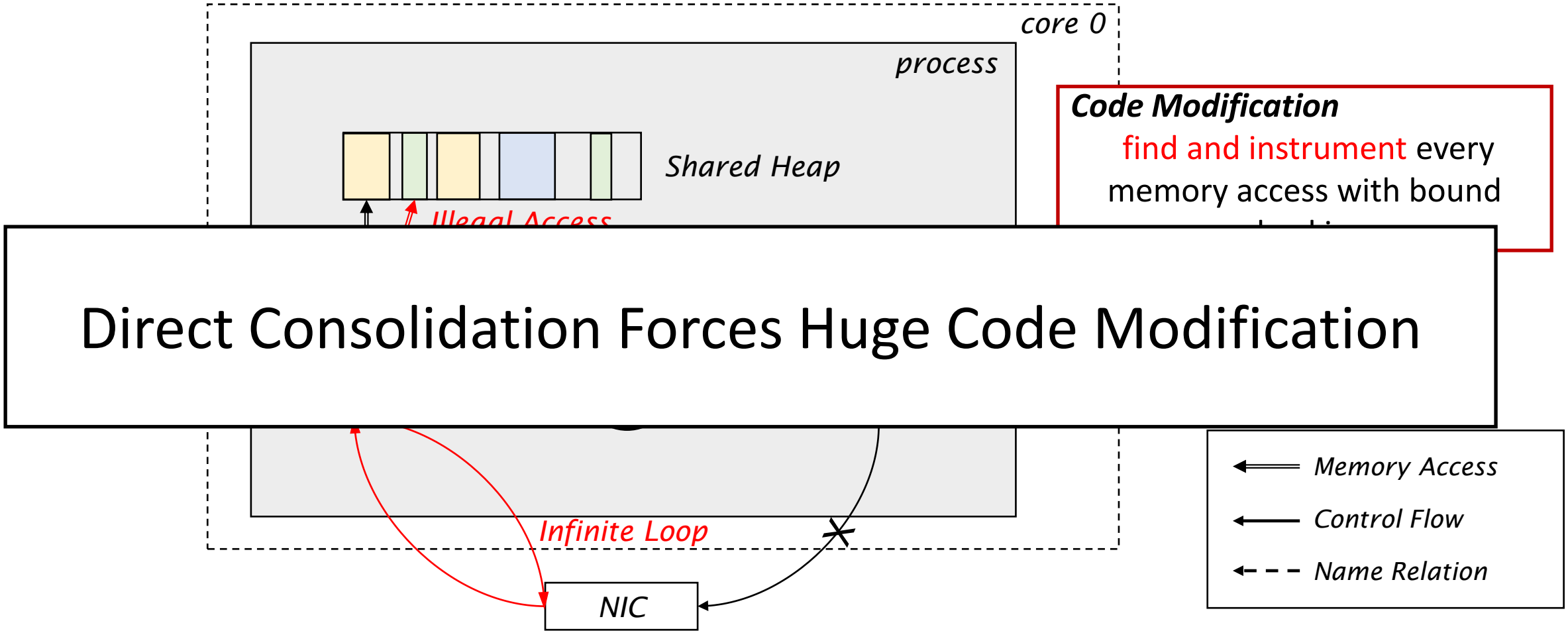
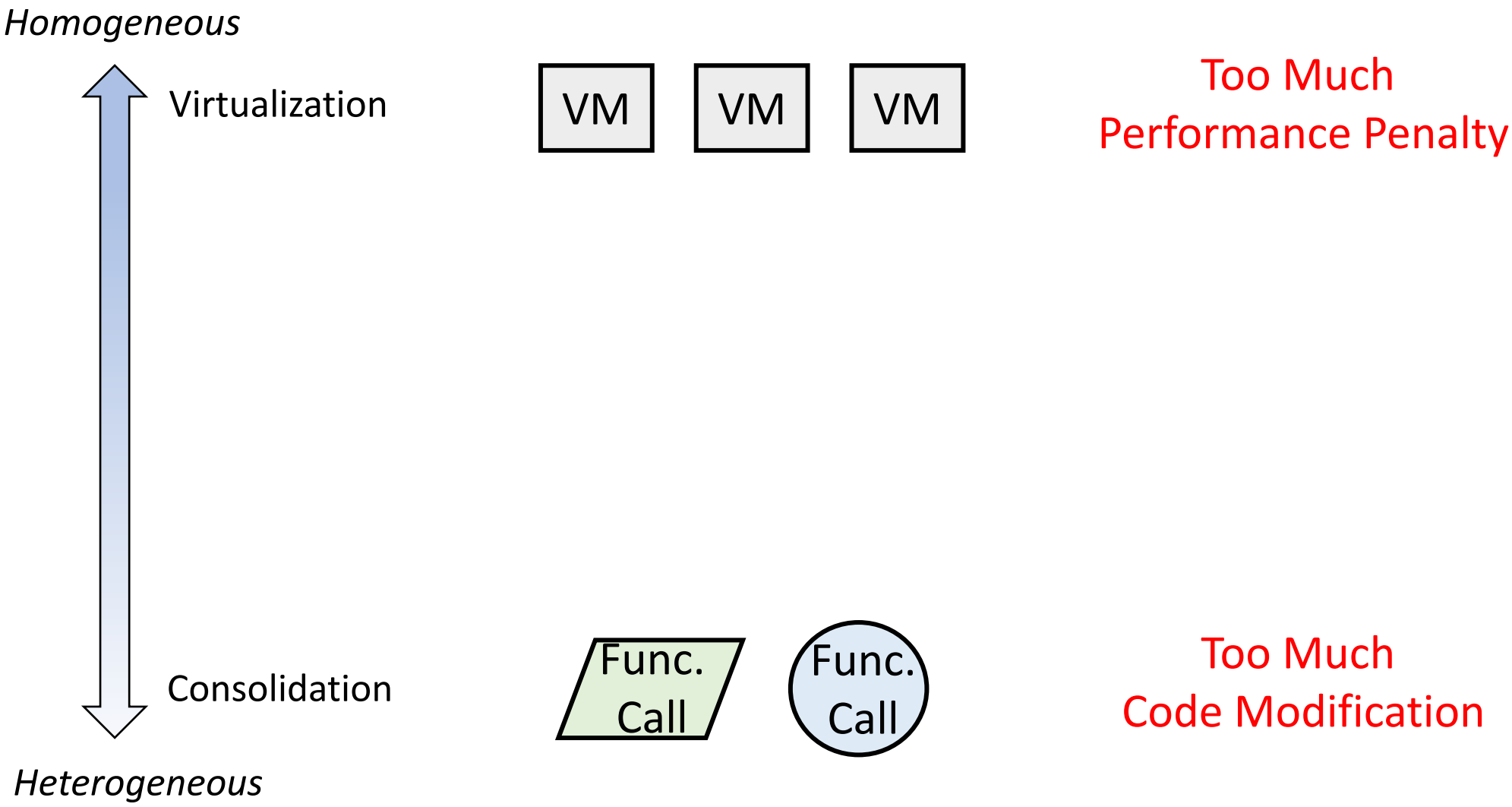
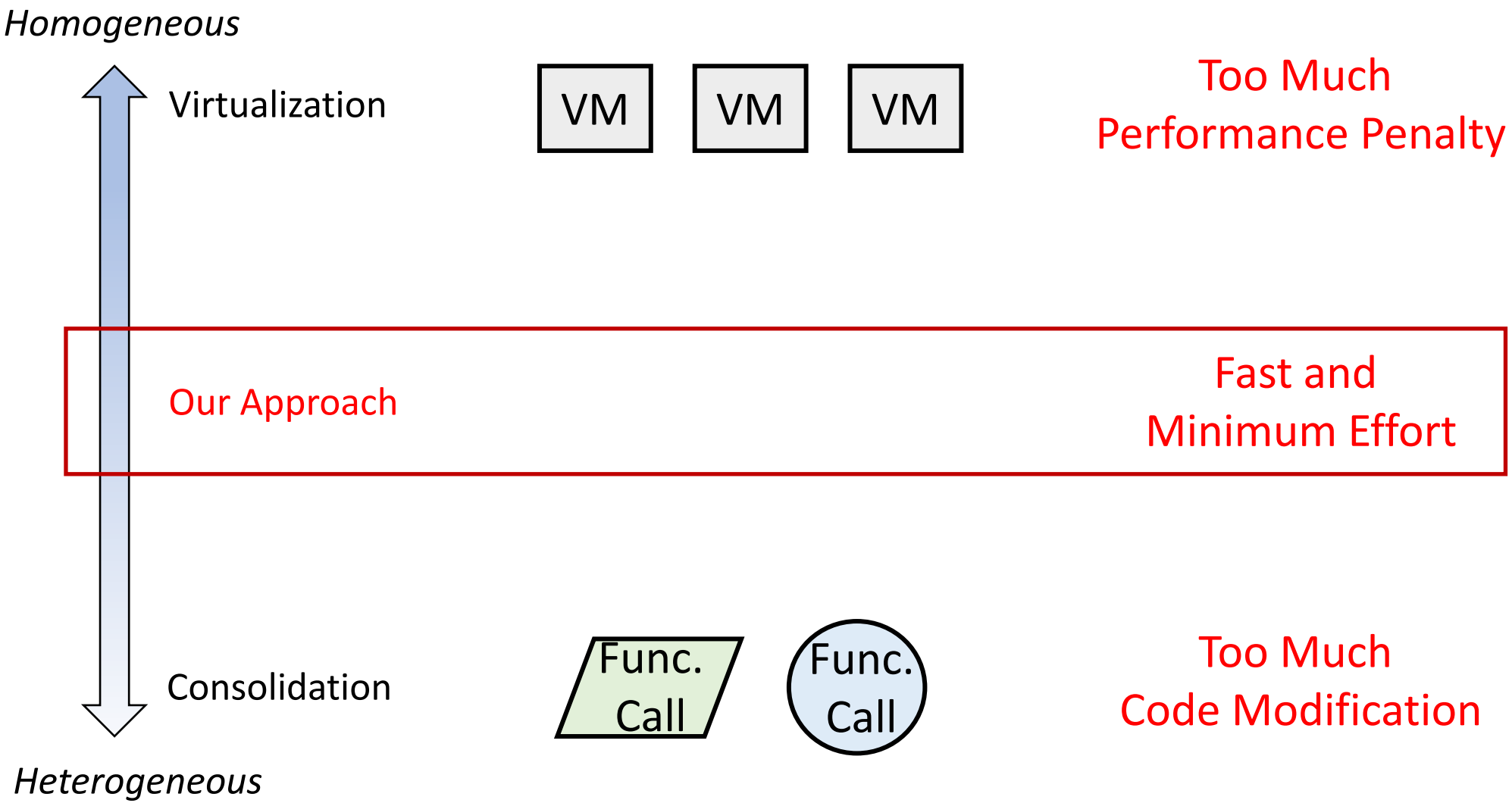


Takeaway on Two Approaches



Our Insight


Homogeneous
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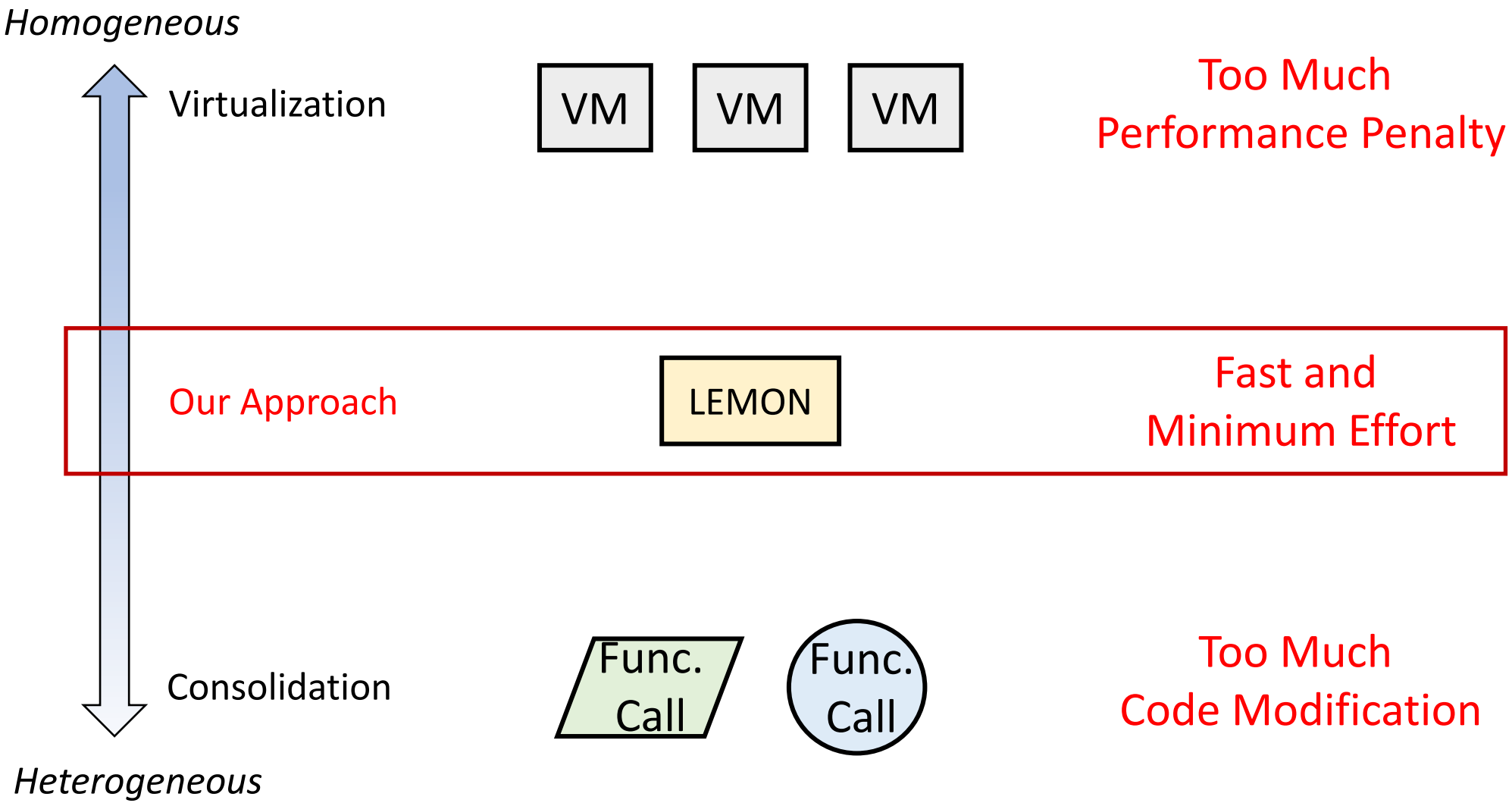
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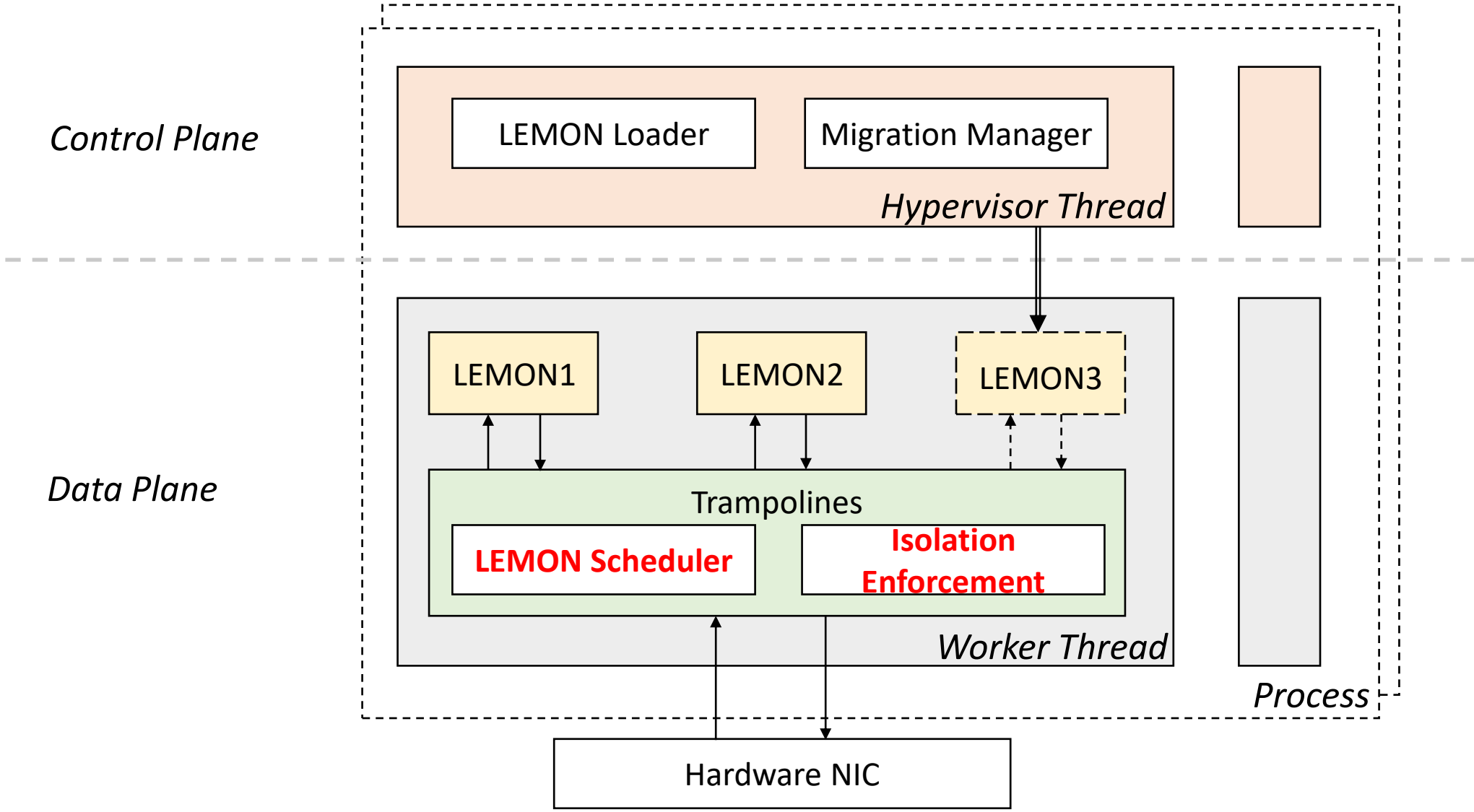
LemonNFV Overview



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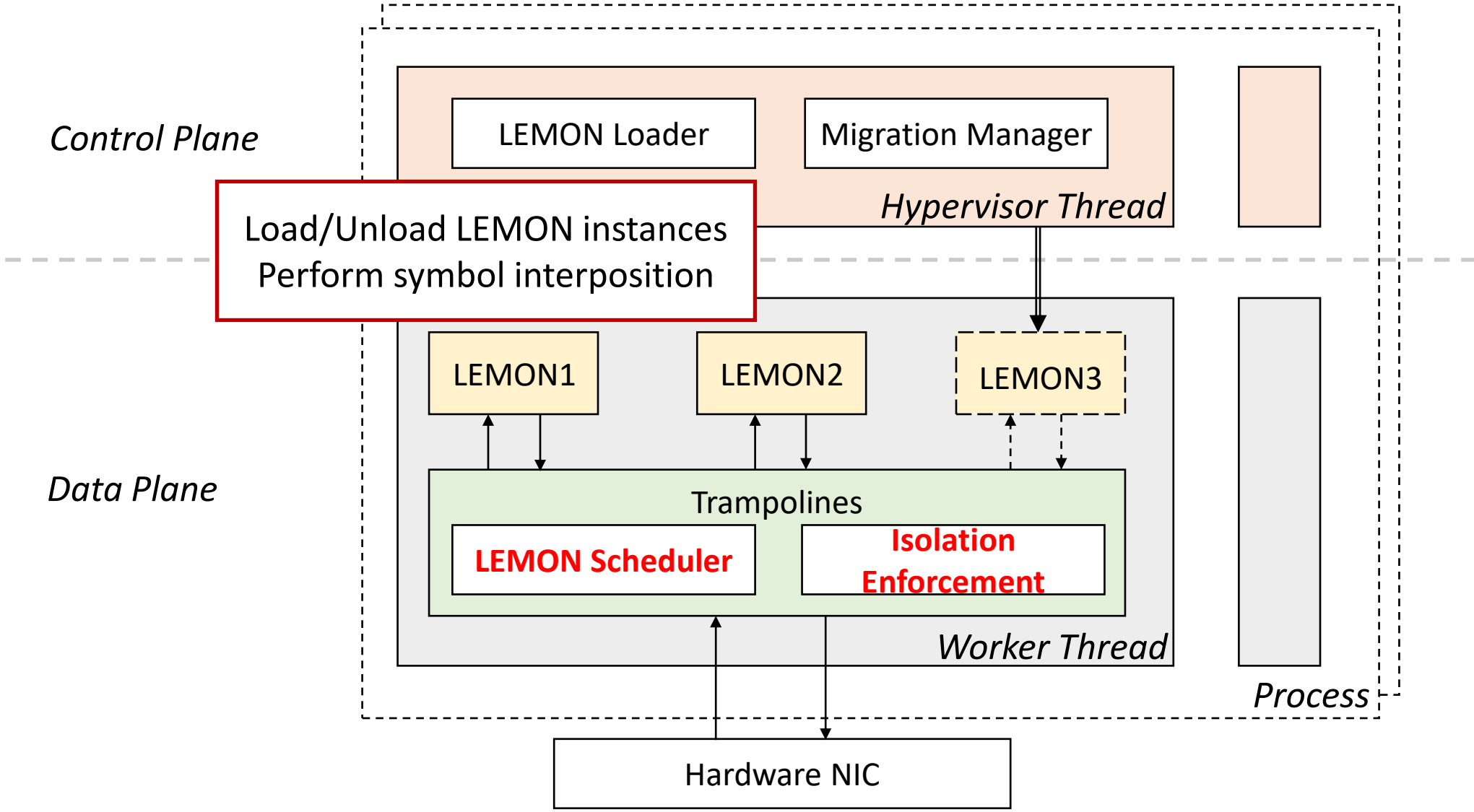

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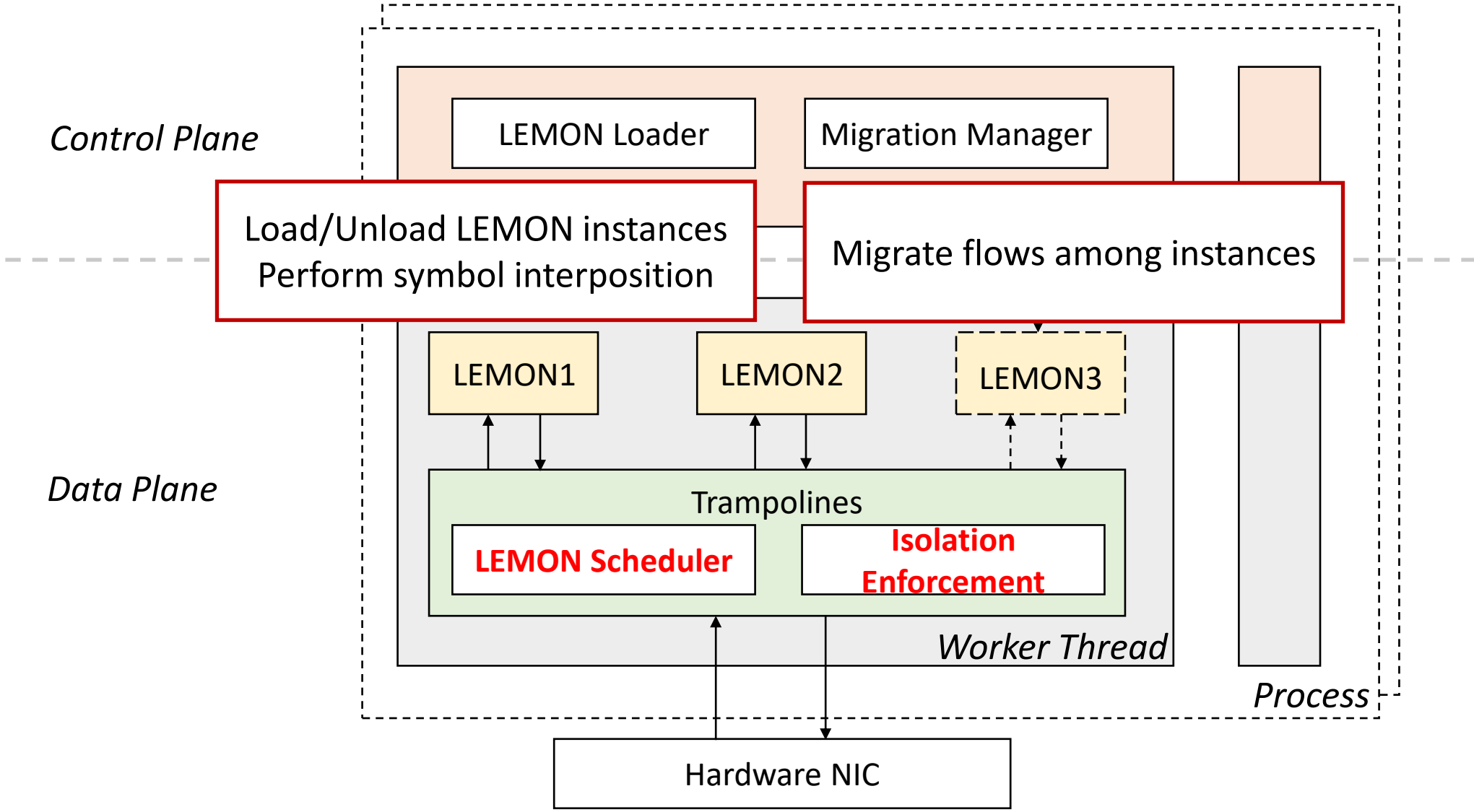

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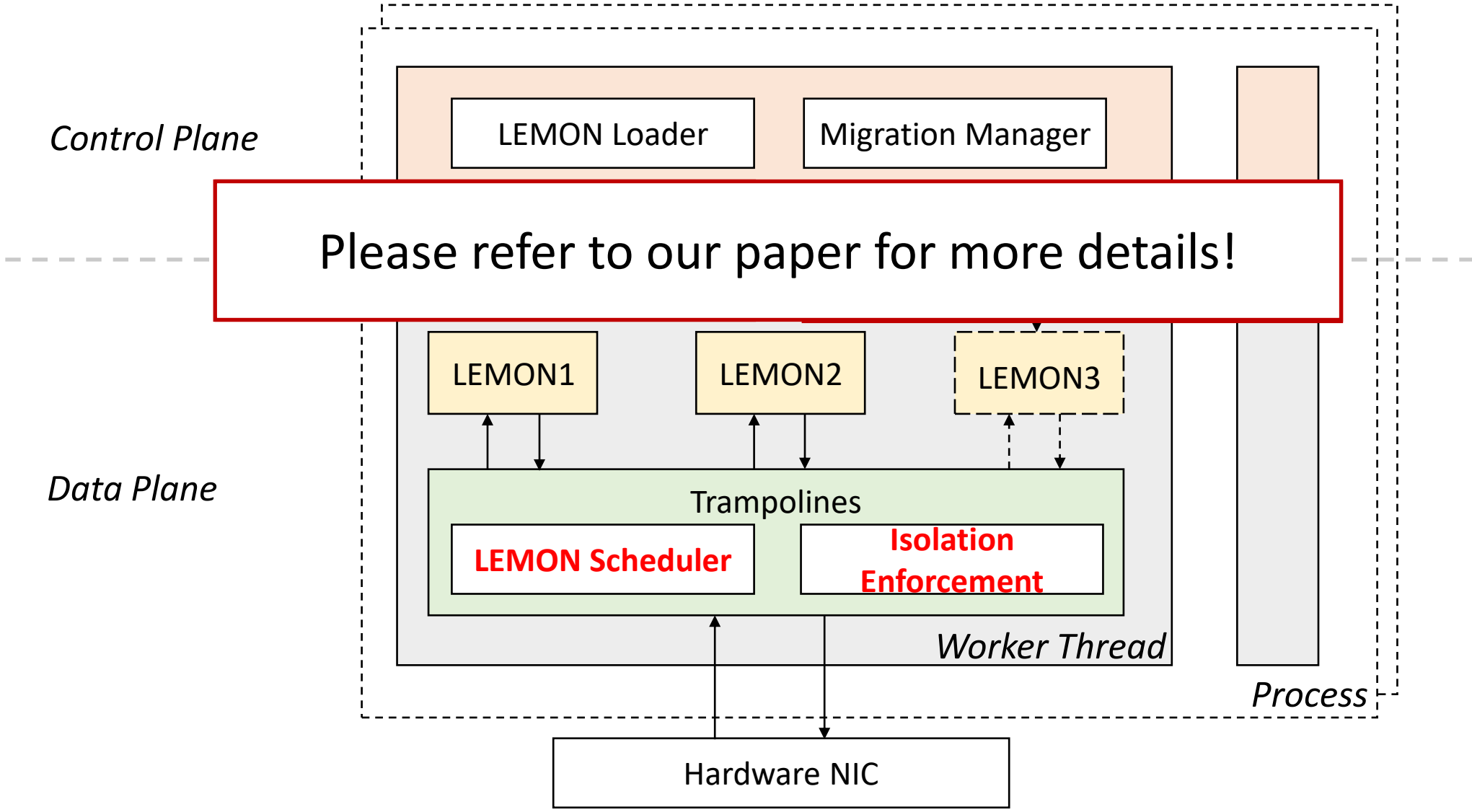

The LEMON Abstraction
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Unmodified, recompiled NF ELF

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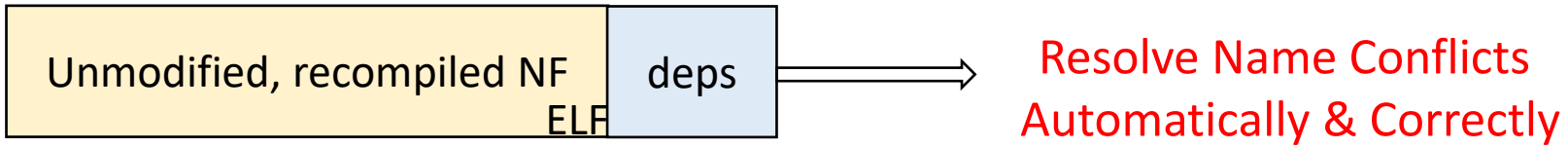

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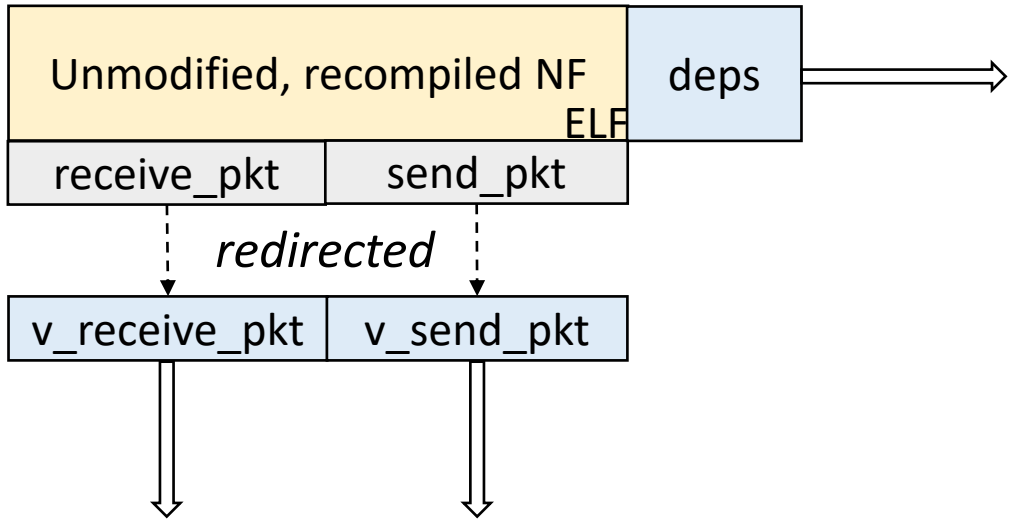

Resolve Name Conflicts
Automatically & Correctly

Find and Schedule Infinite Loops

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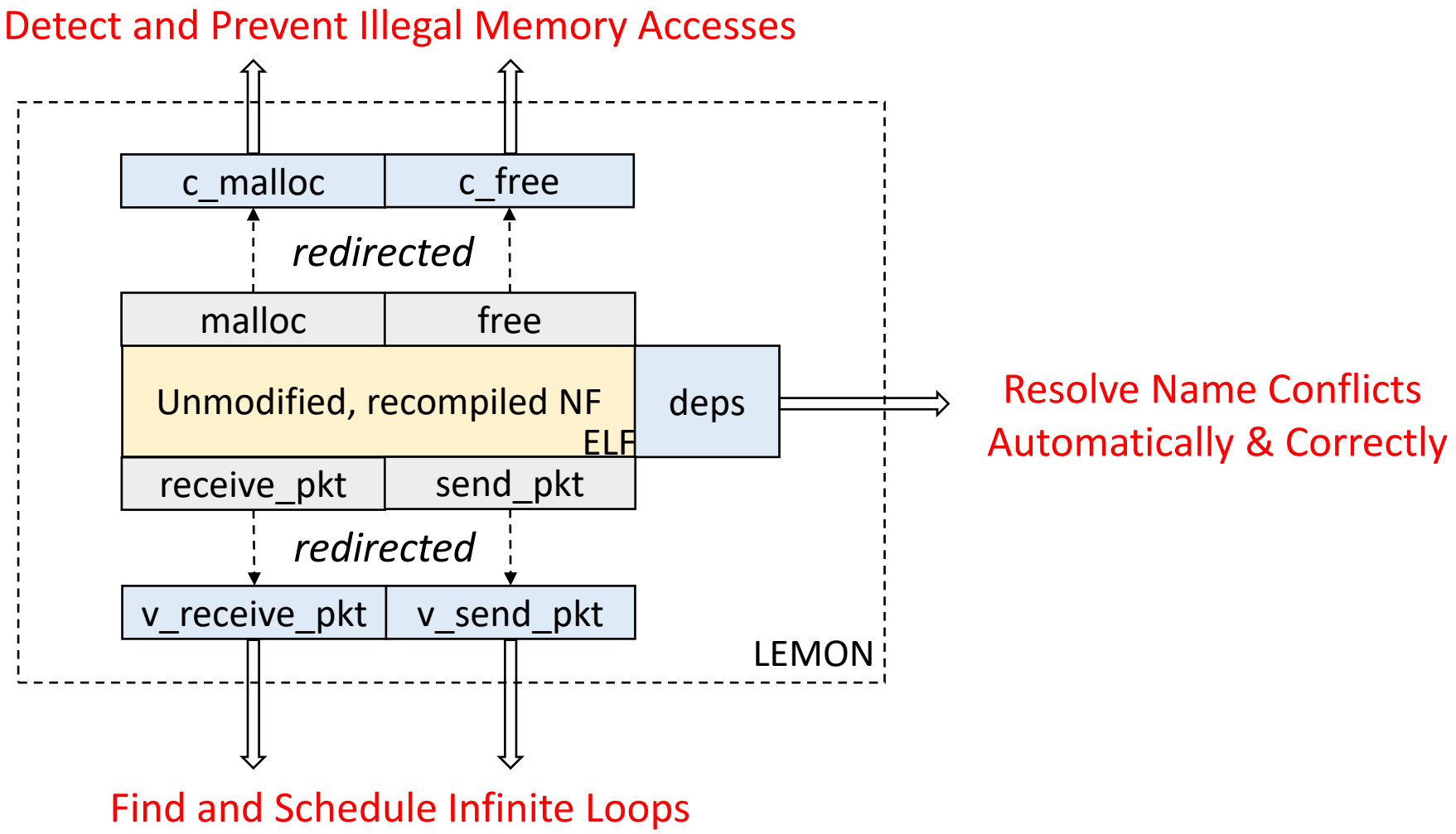
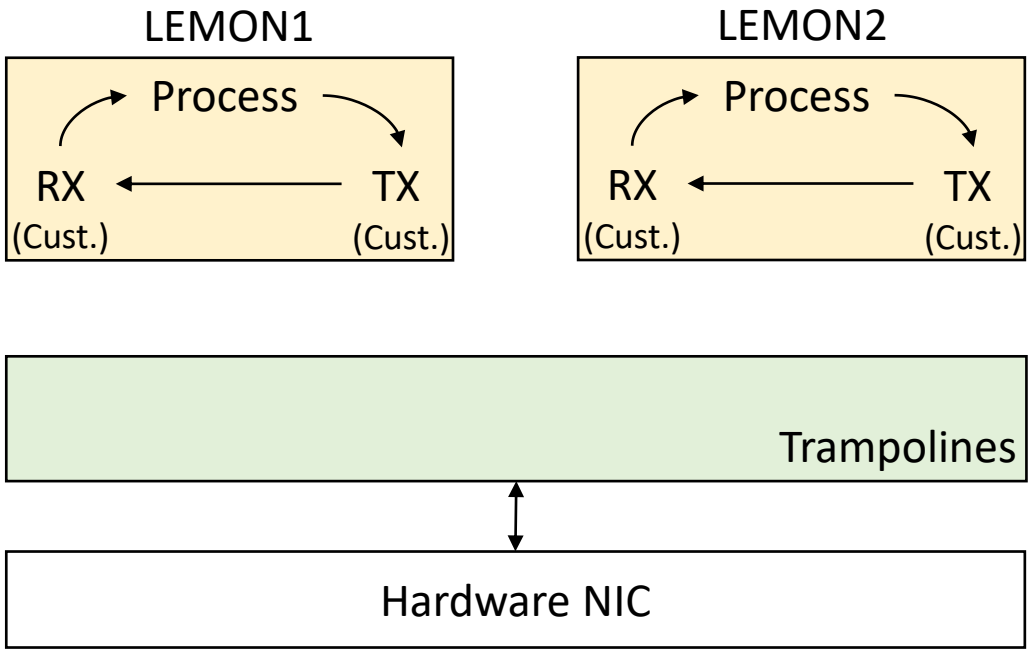


Scheduling the LEMONs with Customized I/O



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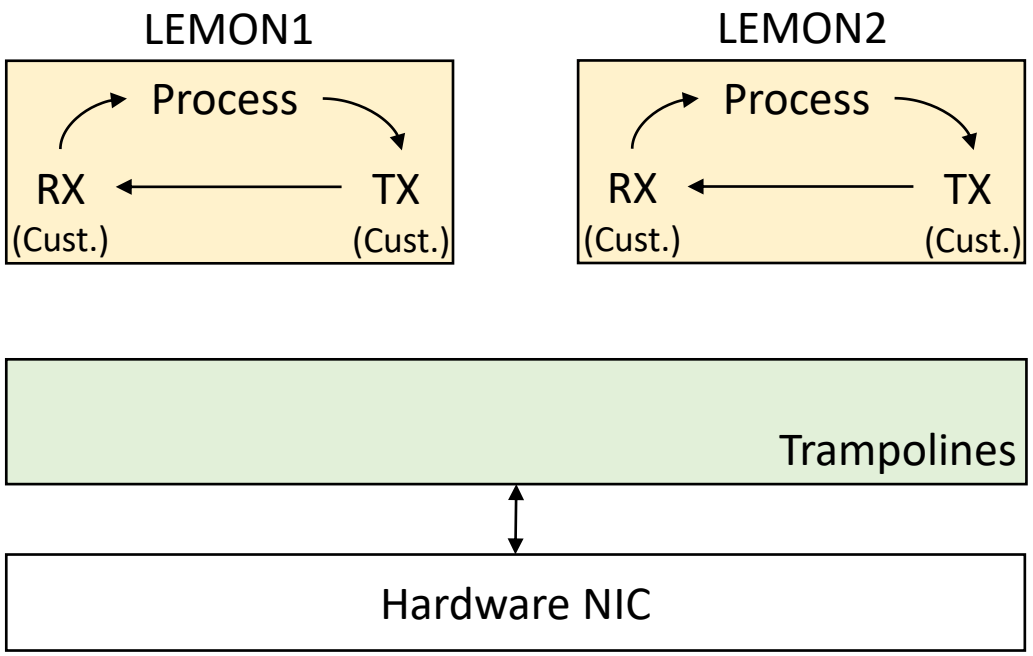

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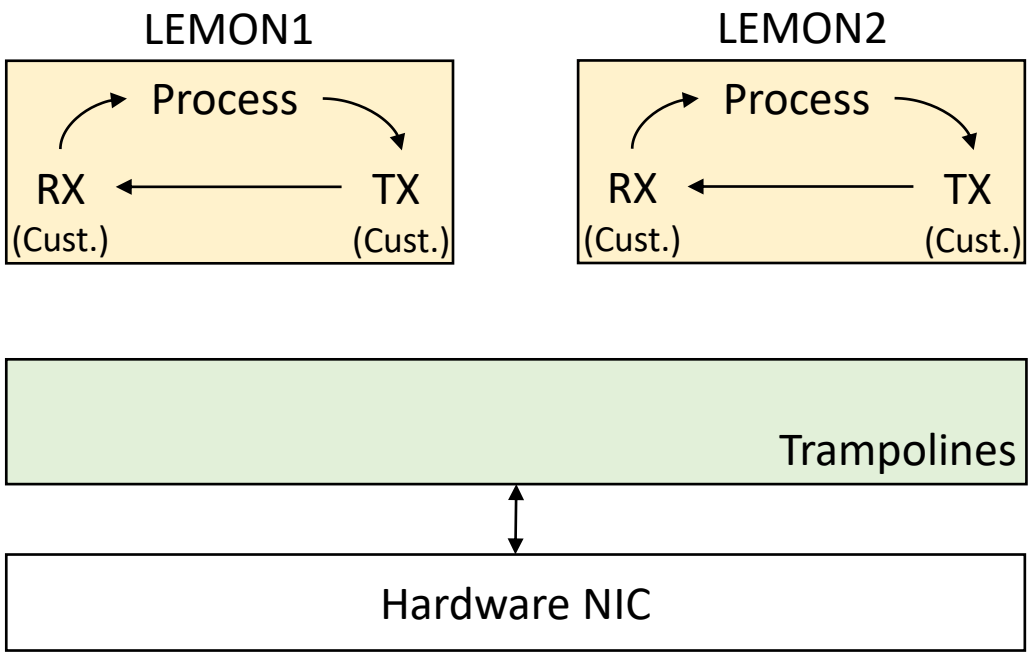

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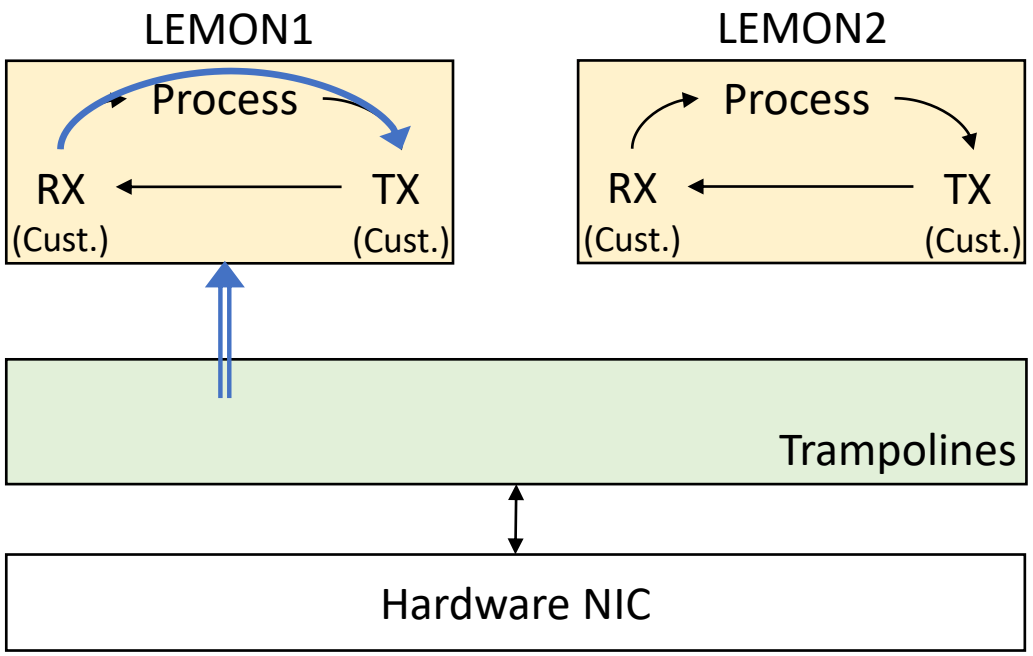

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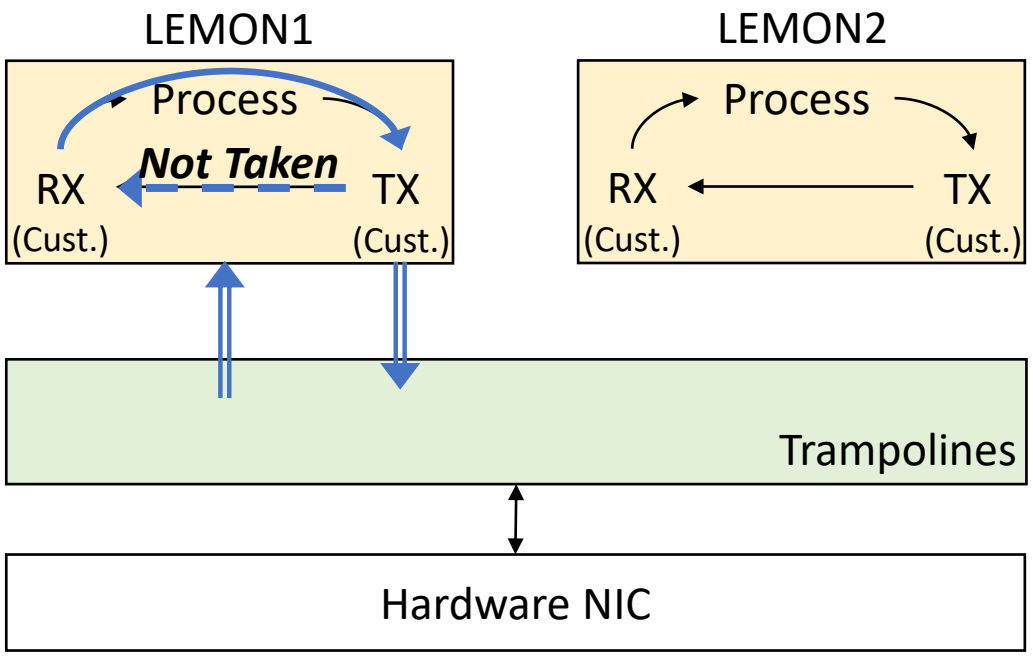

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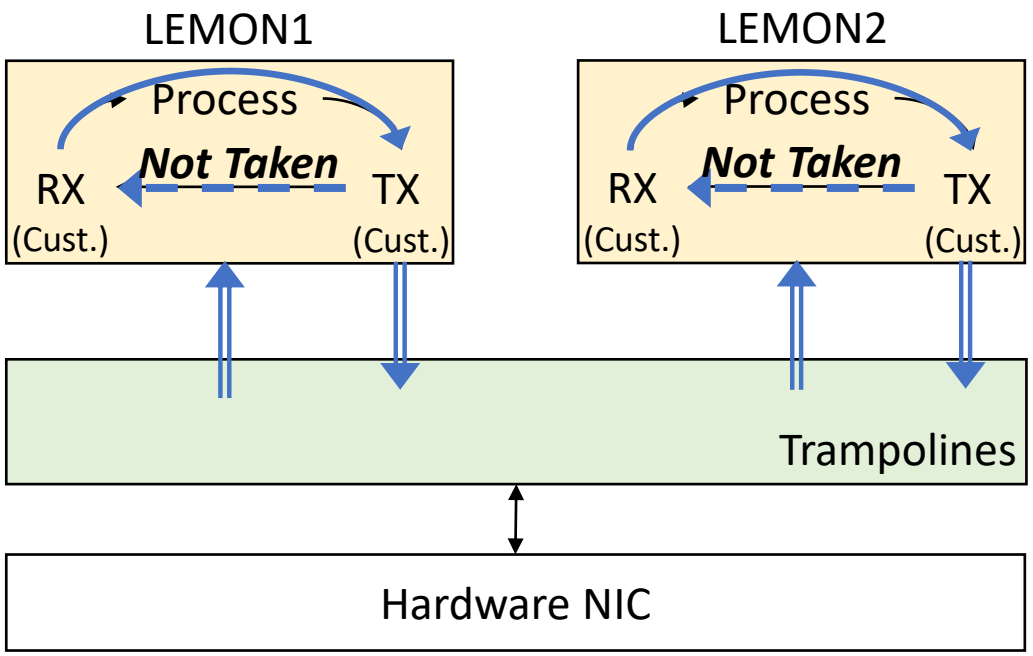

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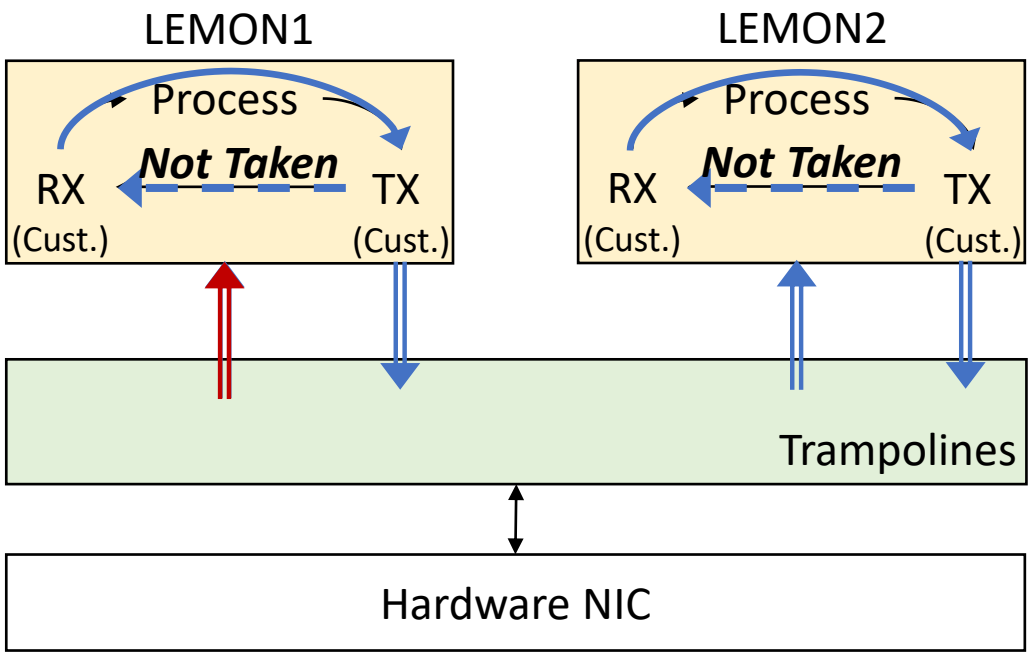

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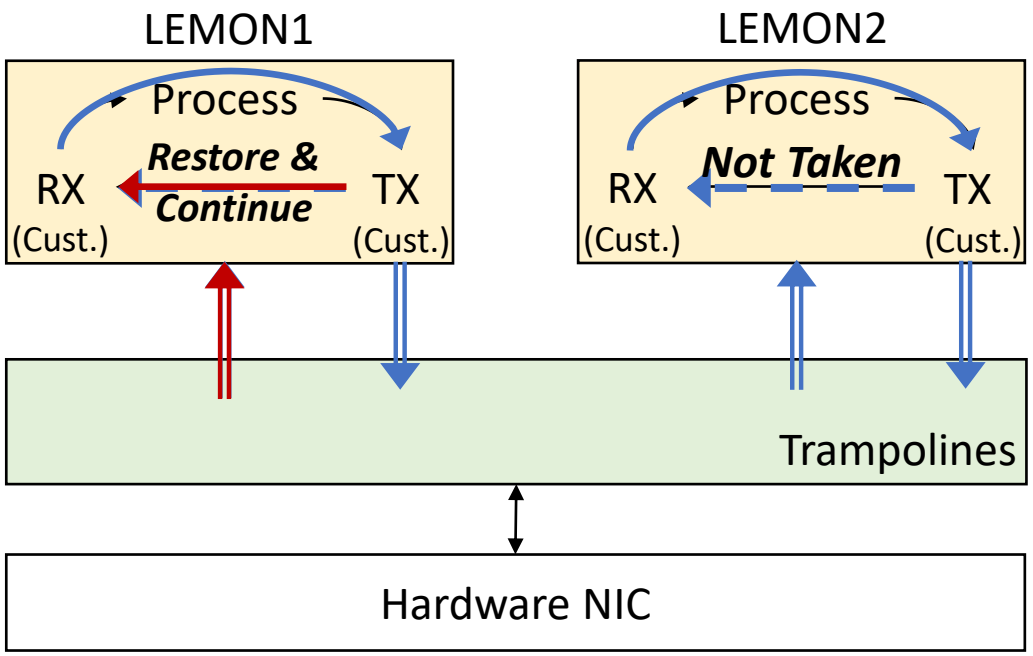

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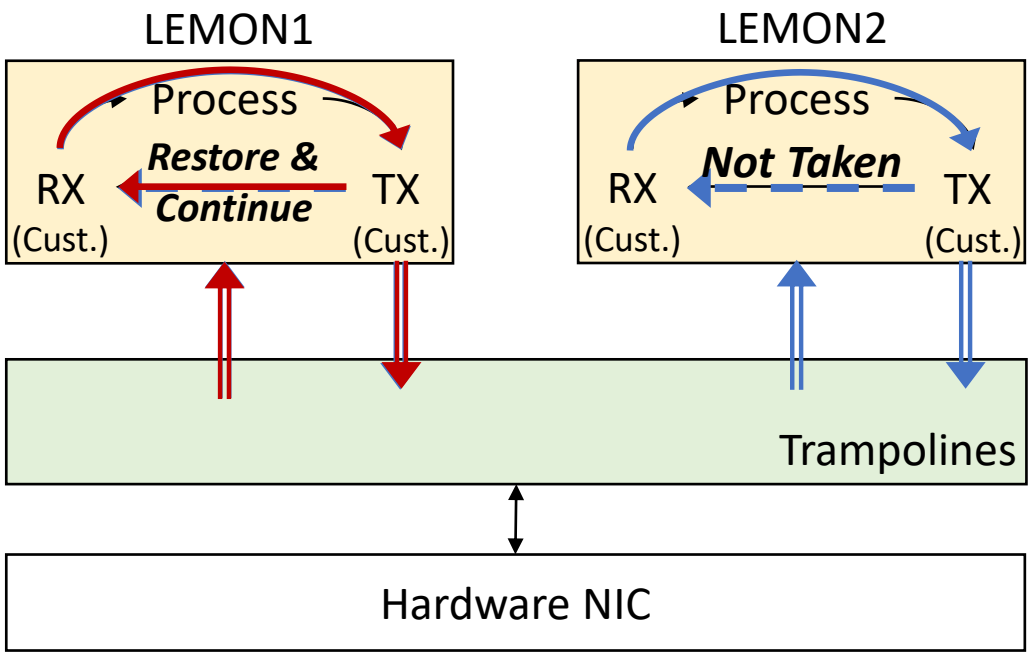

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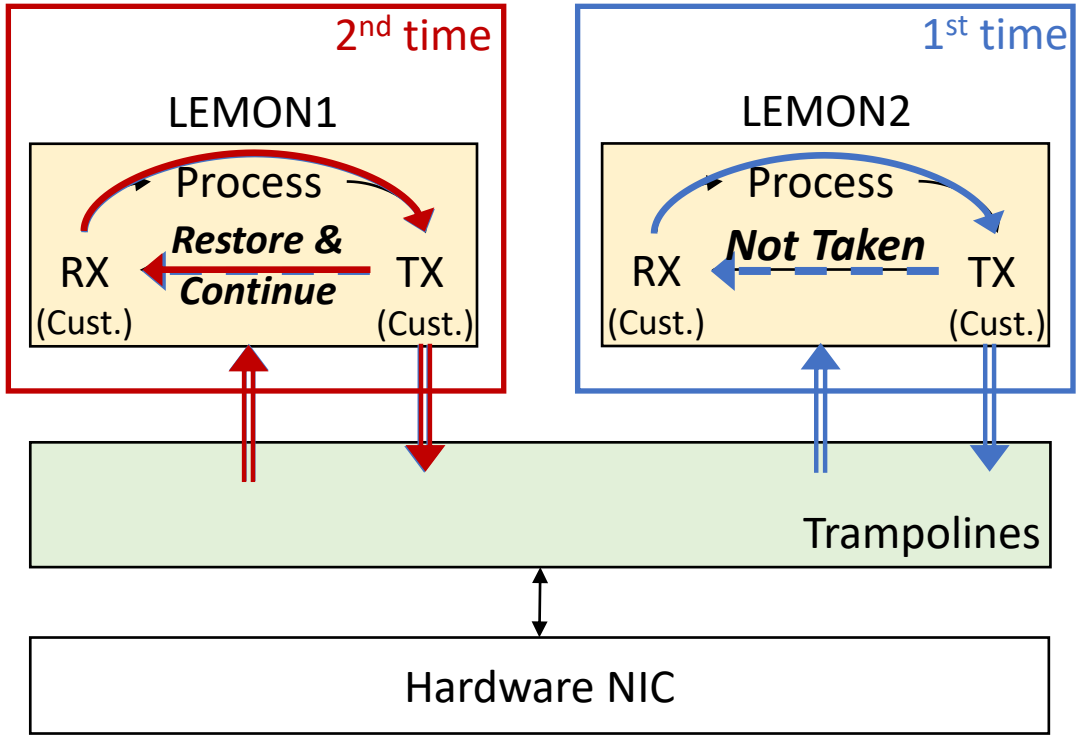
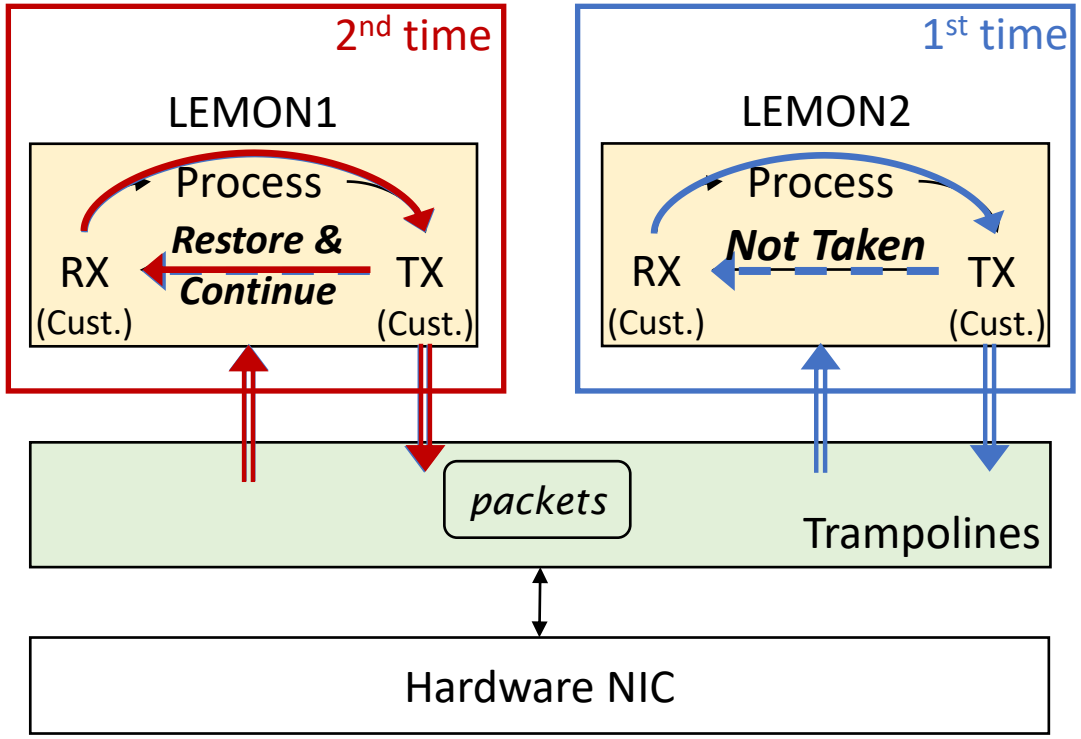


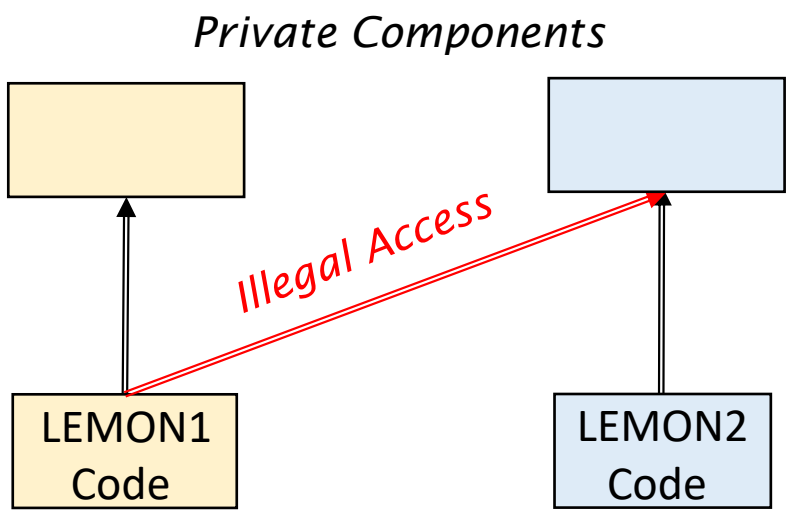
- By default, NFs process packets in an infinite loop
  - RX/TX talks directly to NIC
- Customized I/O does not modify the loop but schedules it
  - Using RX/TX as scheduling points
  - Calling TX saves context and returns to the trampolines
  - The trampolines select the next LEMON and restore its (post-TX) context

Scheduling the LEMONs with Customized I/O



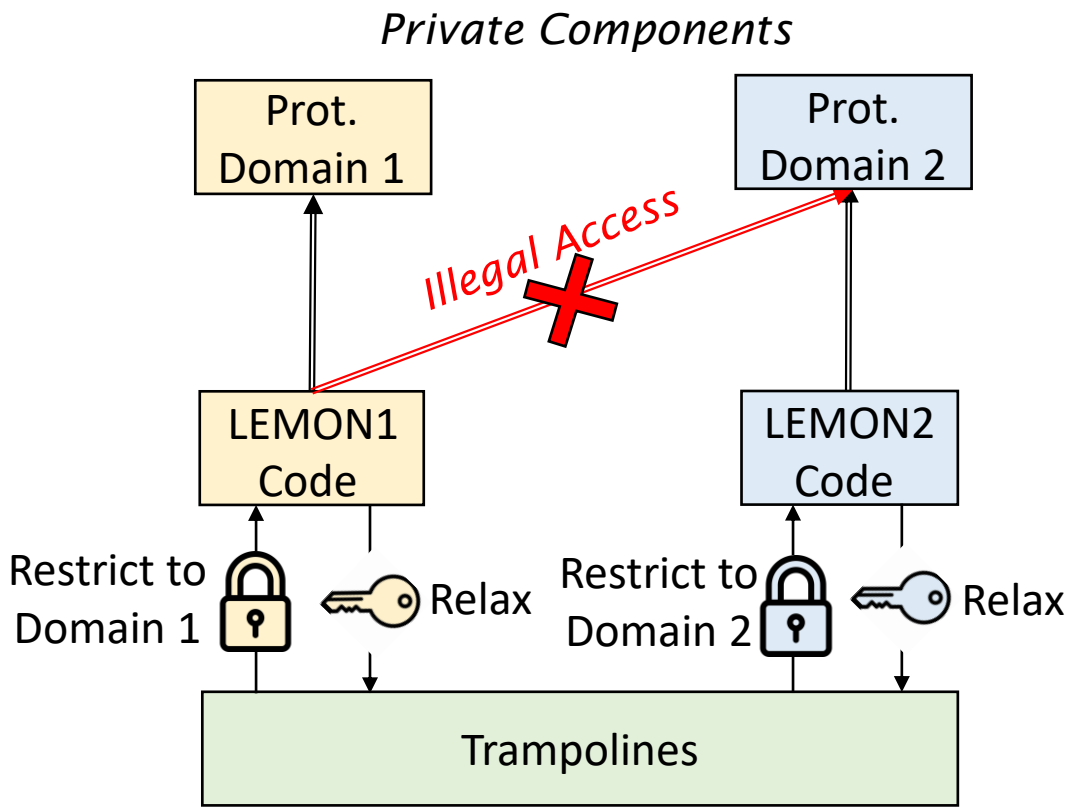
- By default, NFs process packets in an infinite loop
  - RX/TX talks directly to NIC
- Customized I/O does not modify the loop but schedules it
  - Using RX/TX as scheduling points
  - Calling TX saves context and returns to the trampolines
  - The trampolines select the next LEMON and restore its (post-TX) context
  - All LEMONS access packets from buffer inside the trampolines

Preventing Illegal Memory Accesses



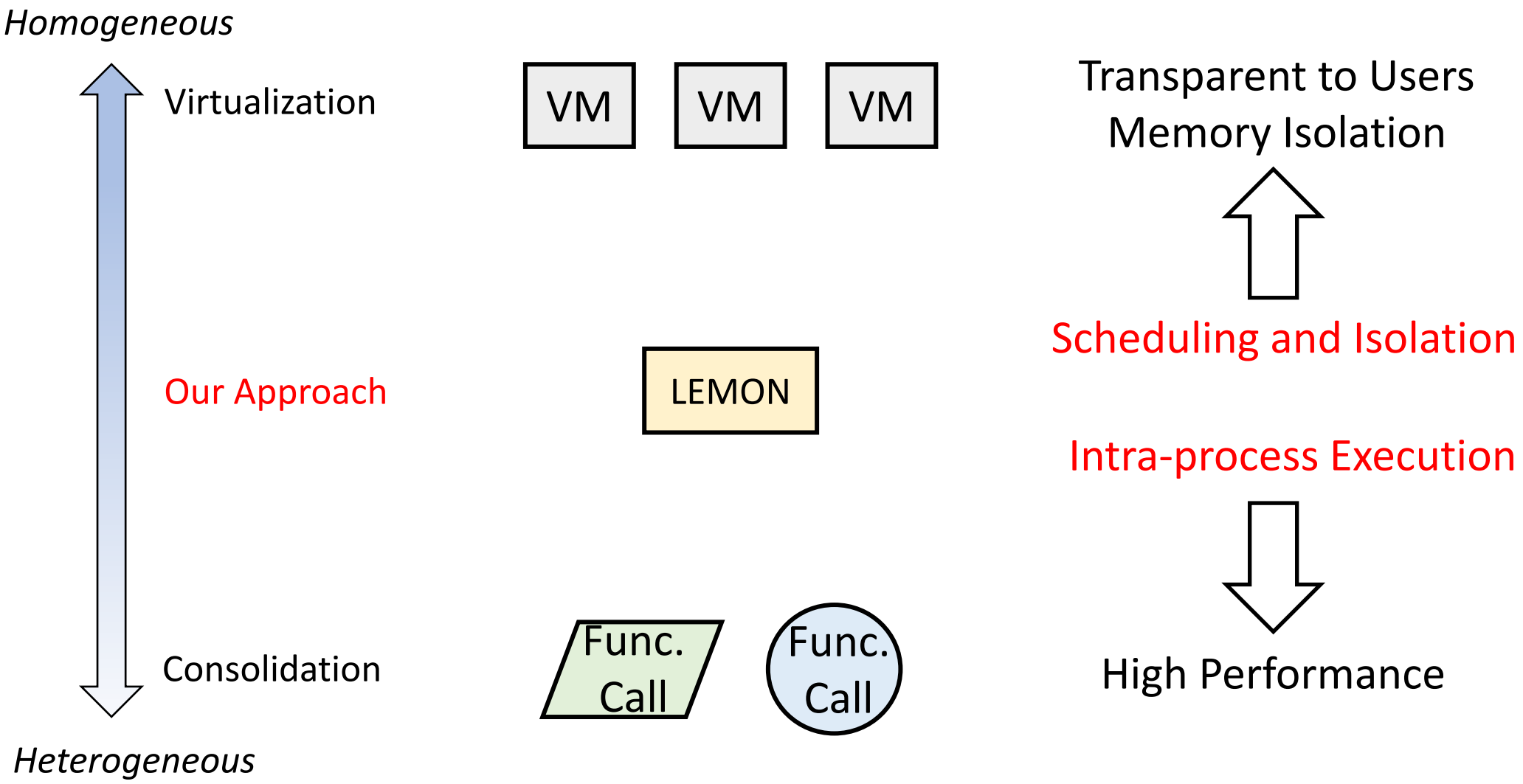
- The design of LEMON creates bounded memory regions
  - Private heap, stack and dependencies instead of shared ones
  - Accesses outside its own region is illegal

Preventing Illegal Memory Accesses



- The design of LEMON creates bounded memory regions
  - Private heap, stack and dependencies instead of shared ones
  - Accesses outside its own region is illegal
- Bounded memory is efficiently isolated by domain switching
  - LemonNFV uses Intel® Protection Key for Userspace (PKU)
  - Restrict access before switching to LEMONs, and relax it before switching back to trampolines

Design Takeaway



Evaluation

- Effort of LemonNFV to consolidate heterogeneous NFs

- Performance compared with State-Of-The-Art NFV systems

Minimum LOC Modification to Interoperation

Heterogeneity of Real World NFs

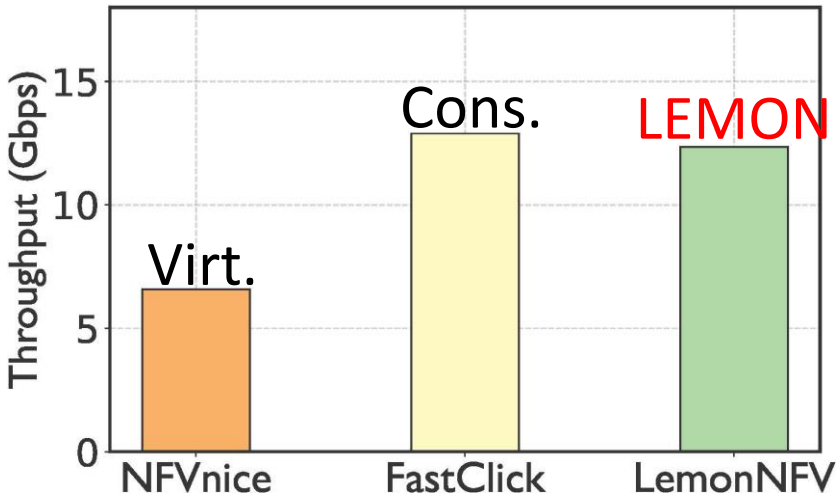
Huge Code Base Of Real World NFs

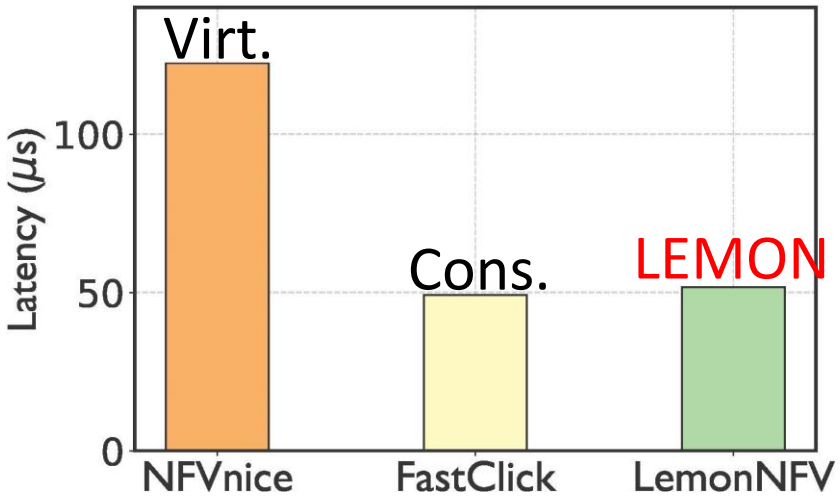
Effort of LemonNFV

NF	Framework	Language	I/O	NF LOC	Framework LOC	Modified LOC
IDS	Rubik	C	DPDK	337	31K	2
NAT	FastClick	C++	DPDK	94	331K	2
ACL	NetBricks	Rust	DPDK	401	58K	8
CT	mOS	C	libpcap	325	139K	4
DPI	nDPI	C	libpcap	4498	121K	2

LemonNFV consolidates heterogeneous NFs without much effort (LOC)

Comparing Performance with State-Of-The-Art



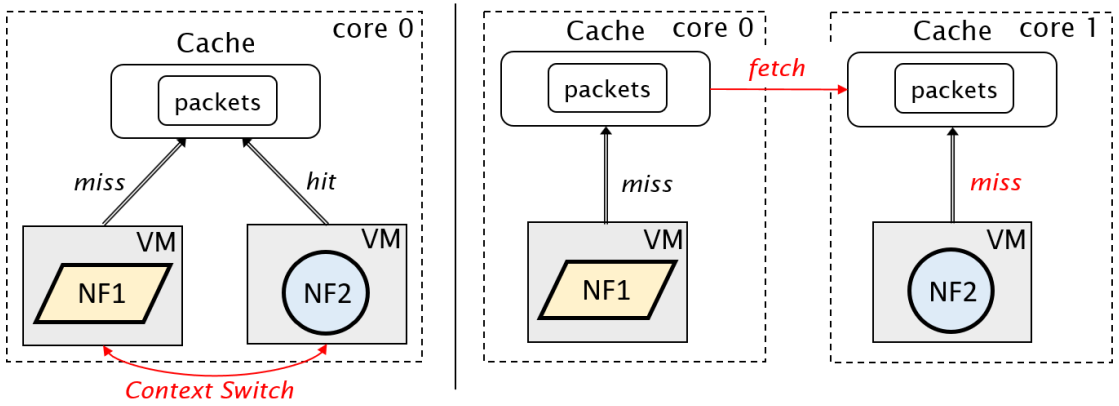


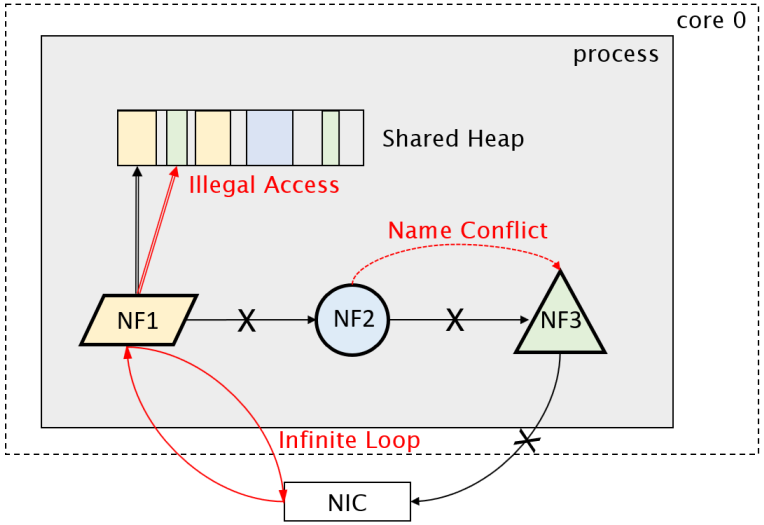
NFVnice: SOTA in virtualization +88% throughput, -58% latency

FastClick: SOTA in consolidation -4.1% throughput, +4.9% latency

LemonNFV consolidates heterogeneous NFs with minor overhead

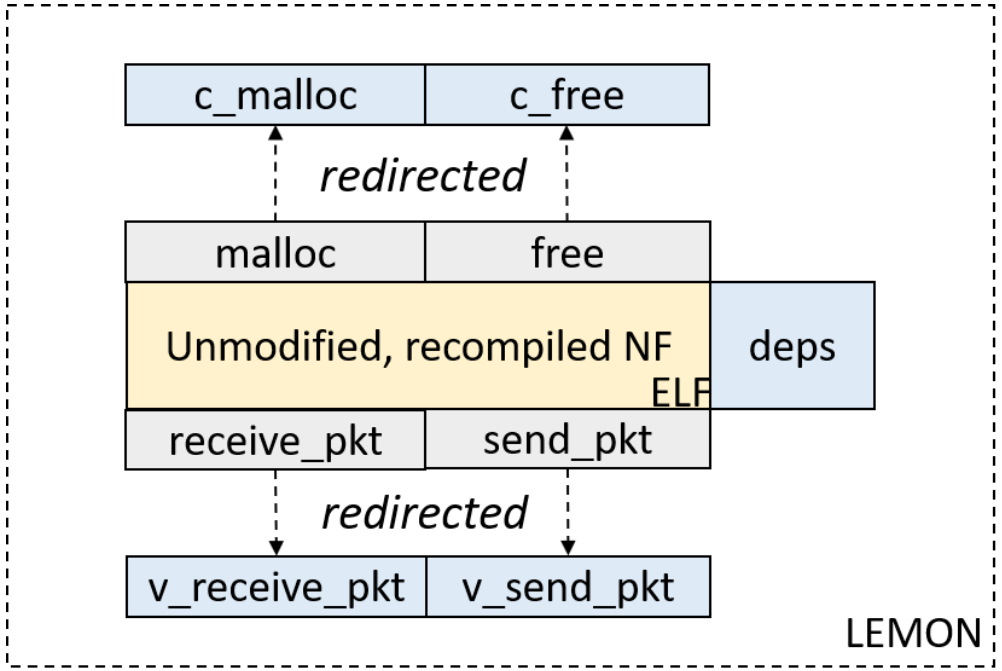
Summary





- Virtualization nor direct consolidation achieves heterogeneous NF interoperation
  - Virtualization overhead
  - Effort of code modification

Summary



- Virtualization nor direct consolidation achieves heterogeneous NF interoperation
  - Virtualization overhead
  - Effort of code modification
- LemonNFV consolidates NFs with minor overhead and effort
  - Designs a unique abstraction LEMON
  - Schedules and isolates LEMONs inside one process

Please Read Our Paper for More Details!

LemonNFV: Consolidating Heterogeneous Network Functions at Line Speed

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