SOCC ACM Symposium on Cloud Computing

Quadrant: A Cloud-Deployable NF Virtualization Platform

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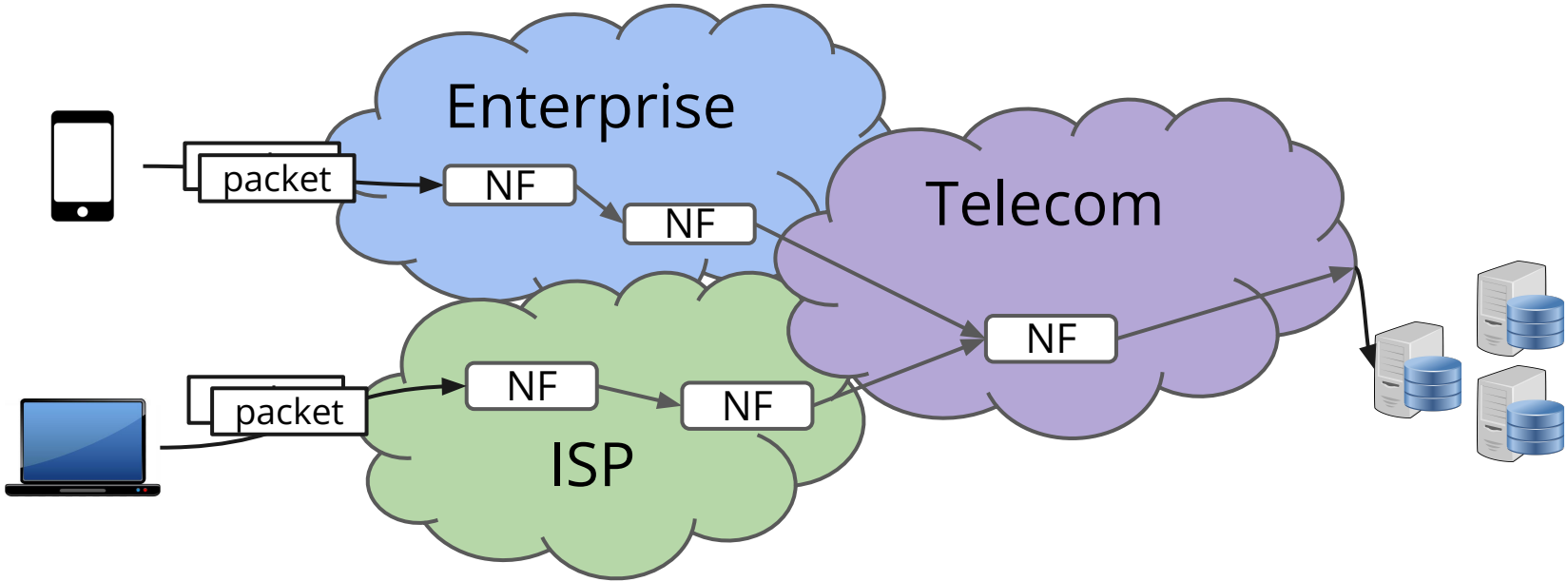
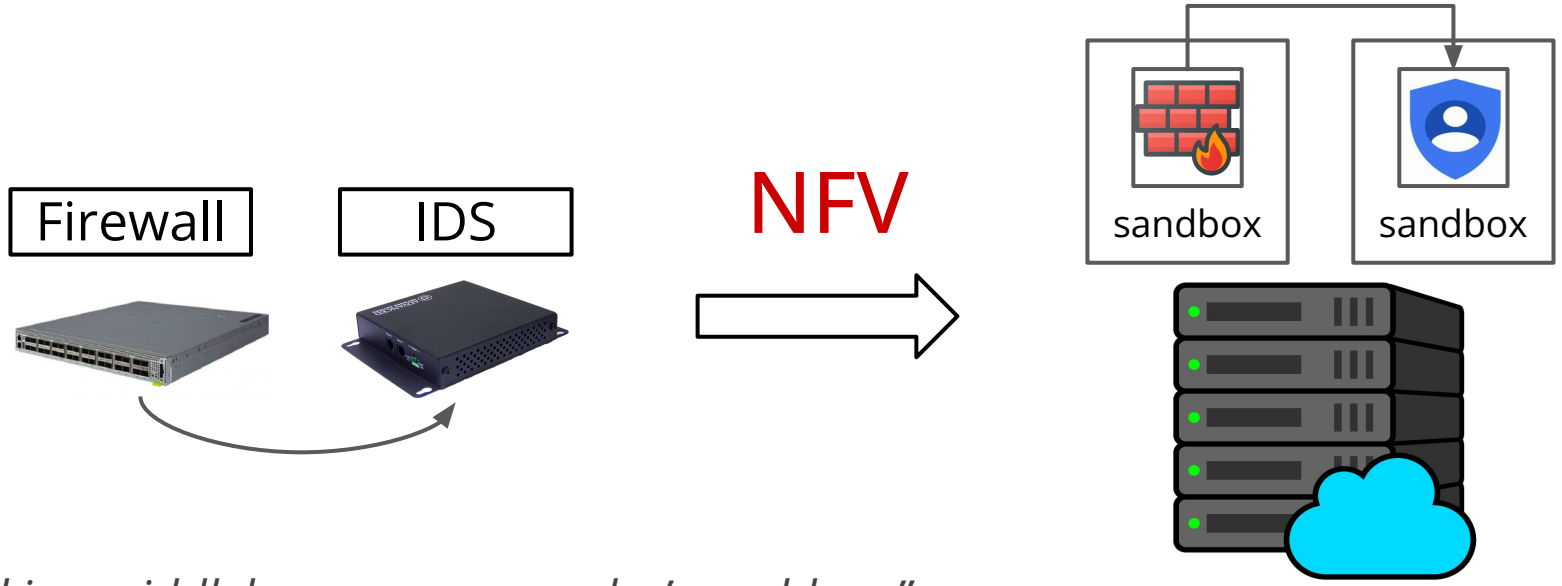
Network Functions (NFs) Perform Packet Processing Tasks

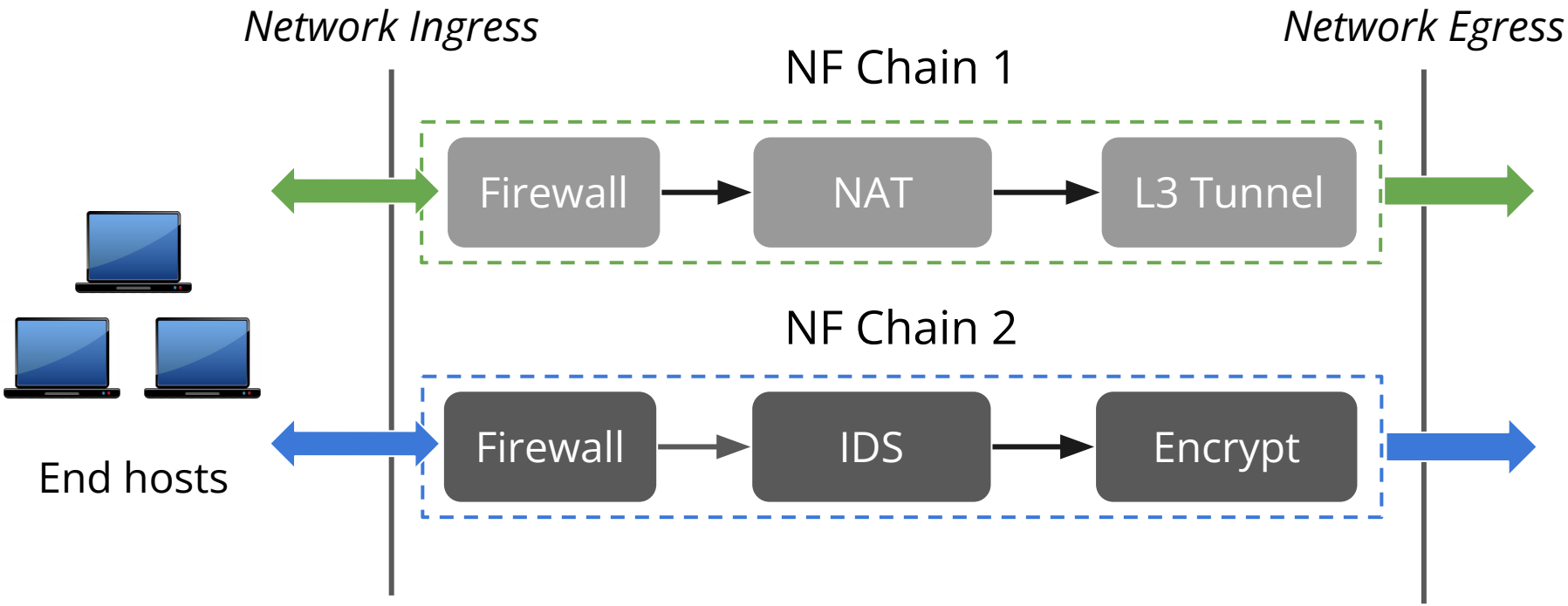


Network Function Virtualization (NFV) Replaces Hardware Middleboxes With Software NFs



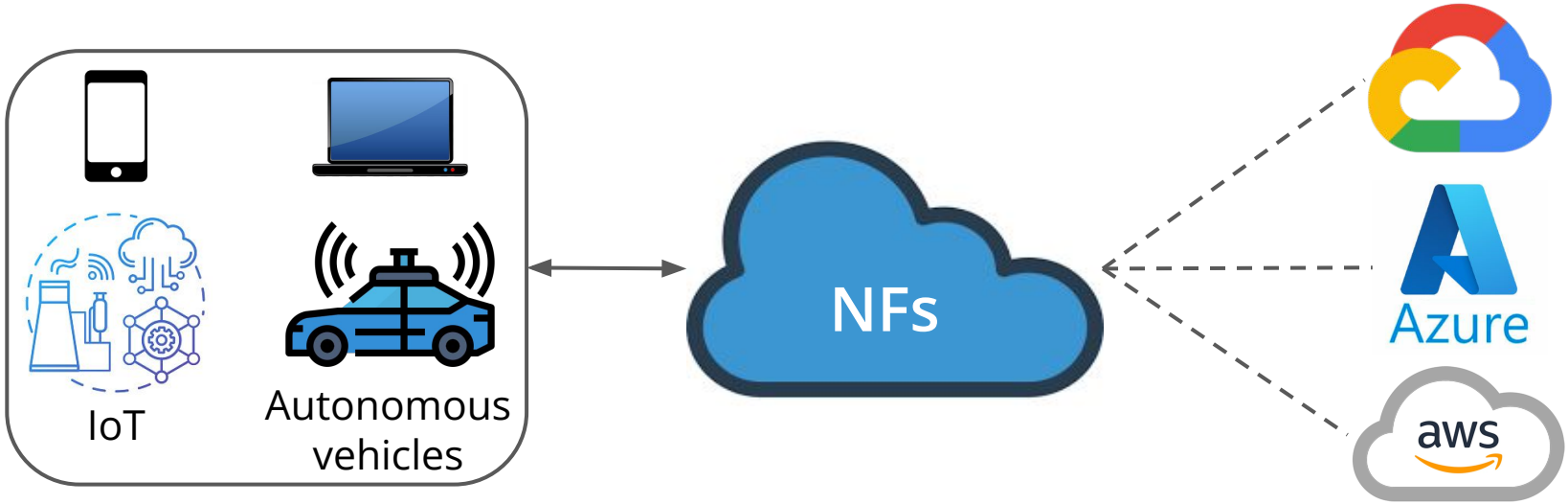
"Making middleboxes someone else's problem."
Aplomb [SIGCOMM '12])

NF Chain: A Sequence of NFs Applied To Traffic



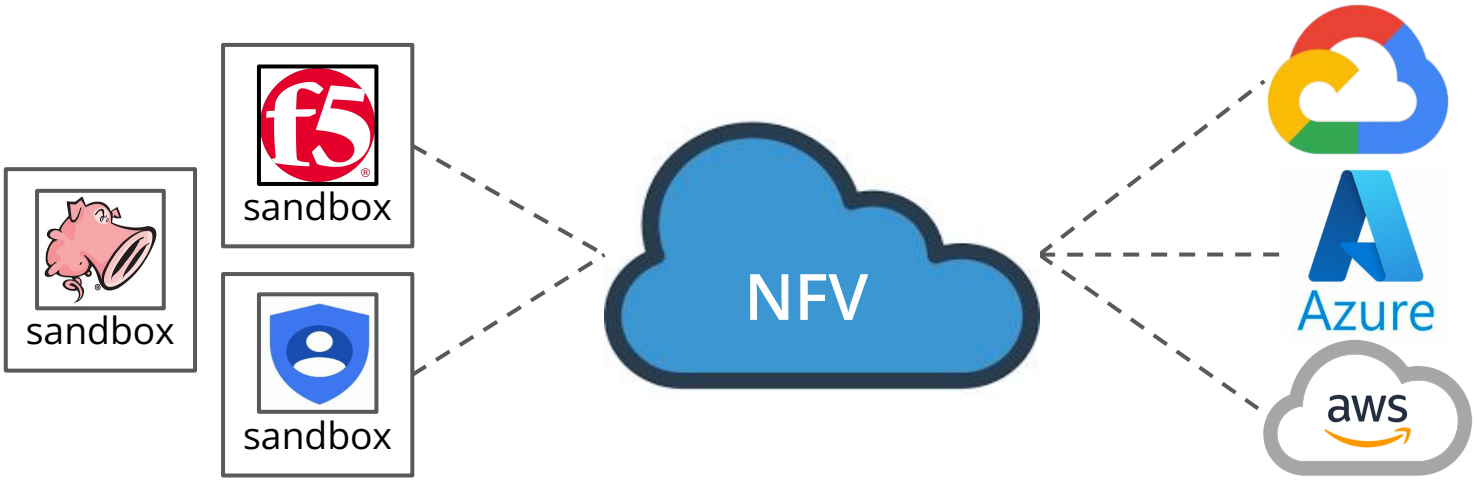
NFV Is Moving Towards Cloud Deployments

E.g. 5G moves towards cloud-hosted cellular NFs



Cloud-deployability Is Becoming A Necessity

To achieve *performance*, *generality*, and *ease of deployment* in the commodity cloud context

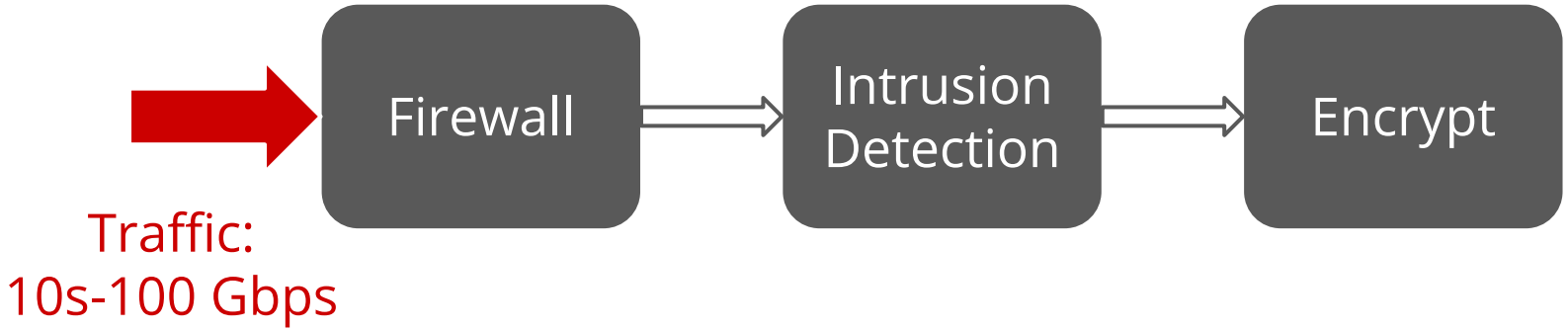


Third-party NFs From Vendors

Commodity Cloud Infra

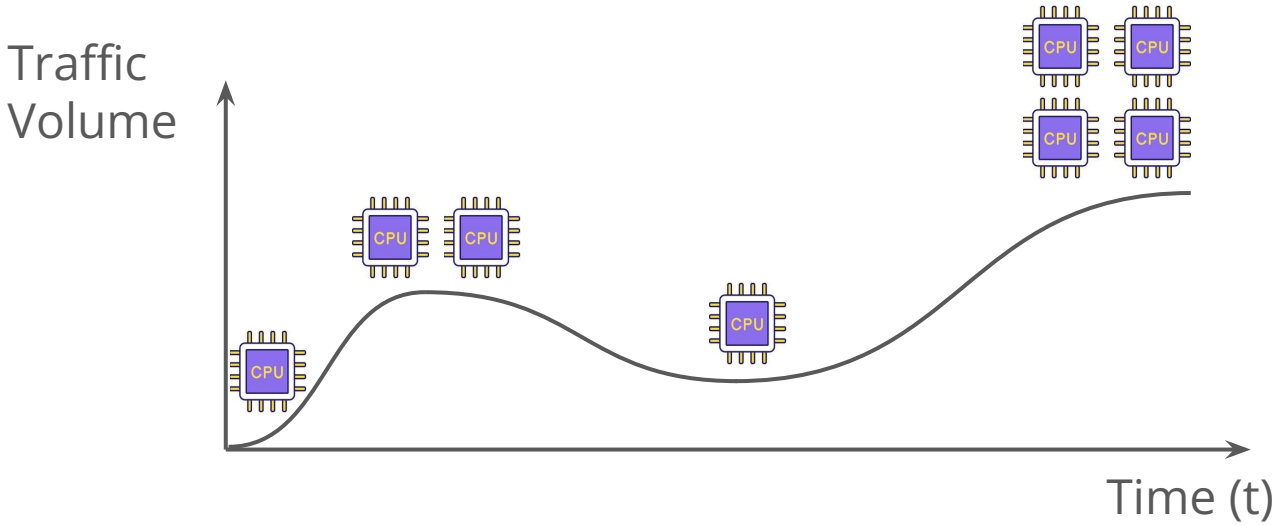
Cloud-deployable NFV Requirements

1. High-performance packet processing
   a. Line-rate throughput



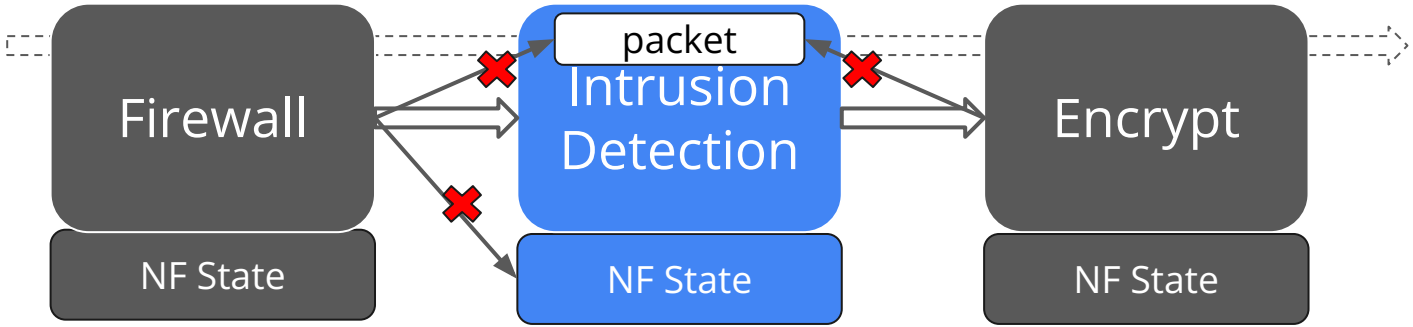
Cloud-deployable NFV Requirements

1. High-performance packet processing
2. Scaling of NF chains
    a. Throughput and latency SLO-adherence



Cloud-deployable NFV Requirements

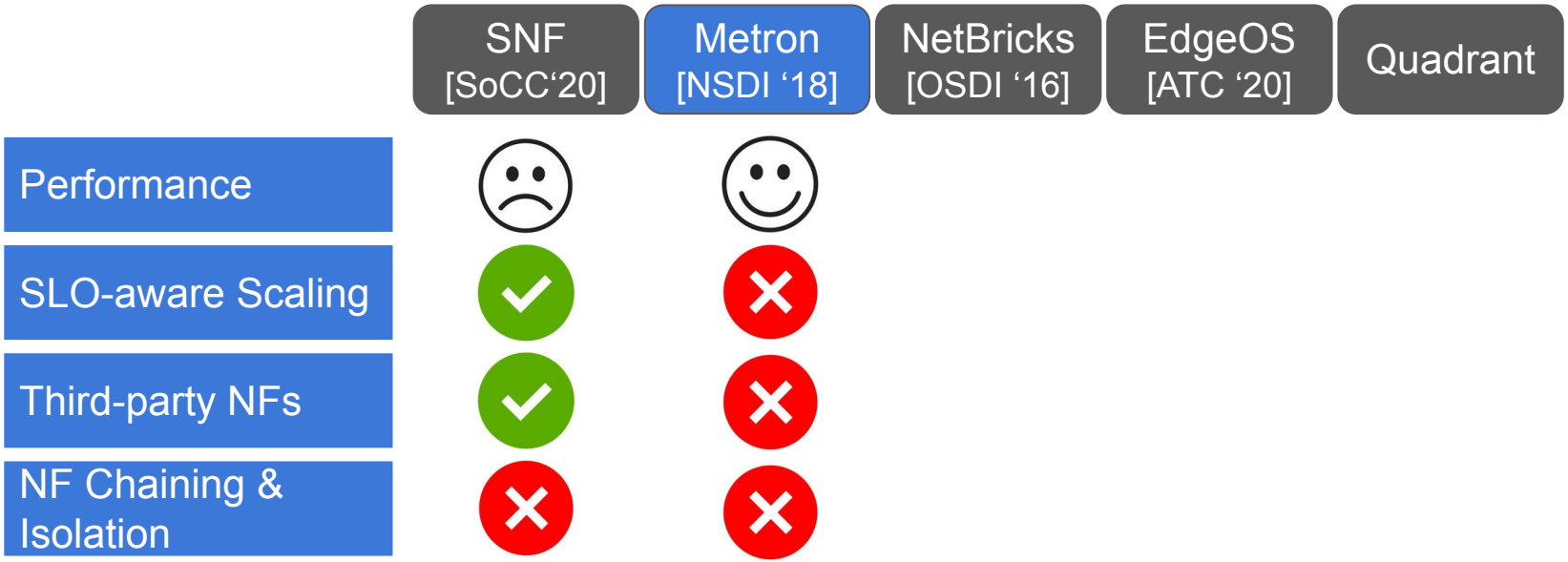
1. High-performance packet processing
2. Scaling of NF chains
3. NF Memory and packet isolation
   a. Each NF has exclusive access to internal state and packets being processed



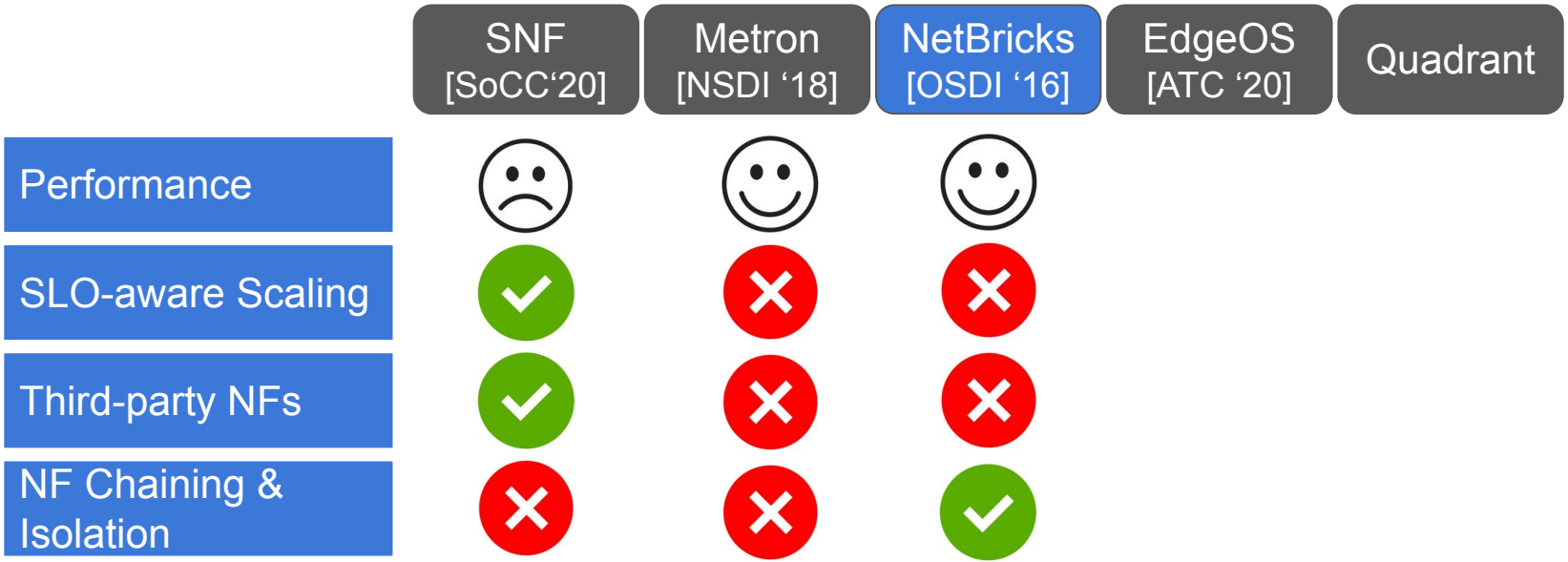
Comparing Cloud-deployable NFV Properties

	SNF [SoCC'20]	Metron [NSDI '18]	NetBricks [OSDI '16]	EdgeOS [ATC '20]	Quadrant
Performance					
SLO-aware Scaling					
Third-party NFs					
NF Chaining & Isolation					

Comparing Cloud-deployable NFV Properties



Comparing Cloud-deployable NFV Properties



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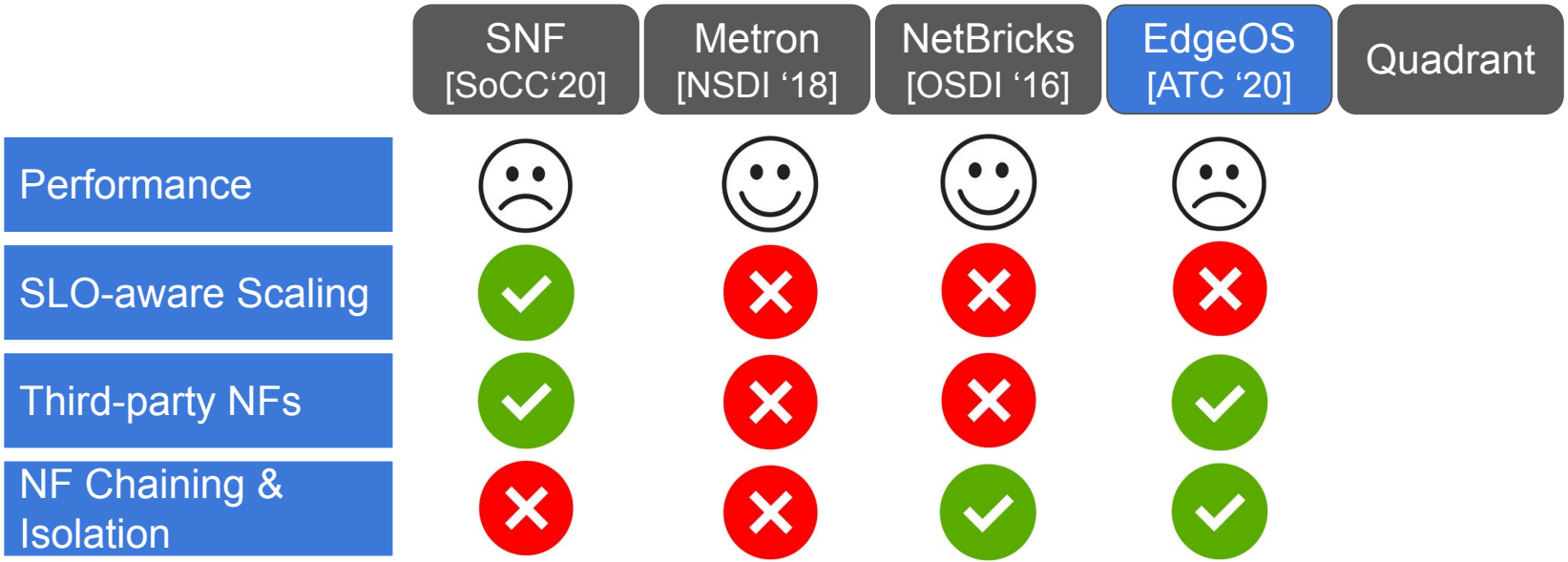
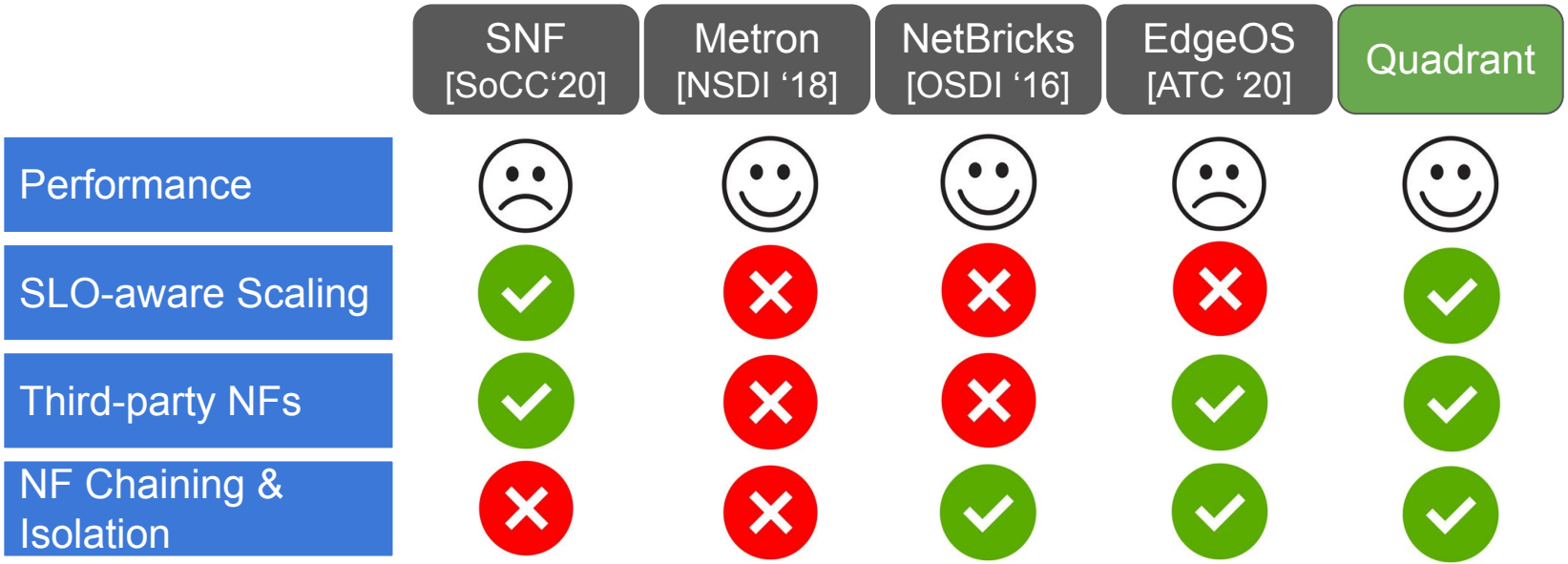


Comparing Cloud-deployable NFV Properties



Goal: Achieving Cloud-deployability In NFV

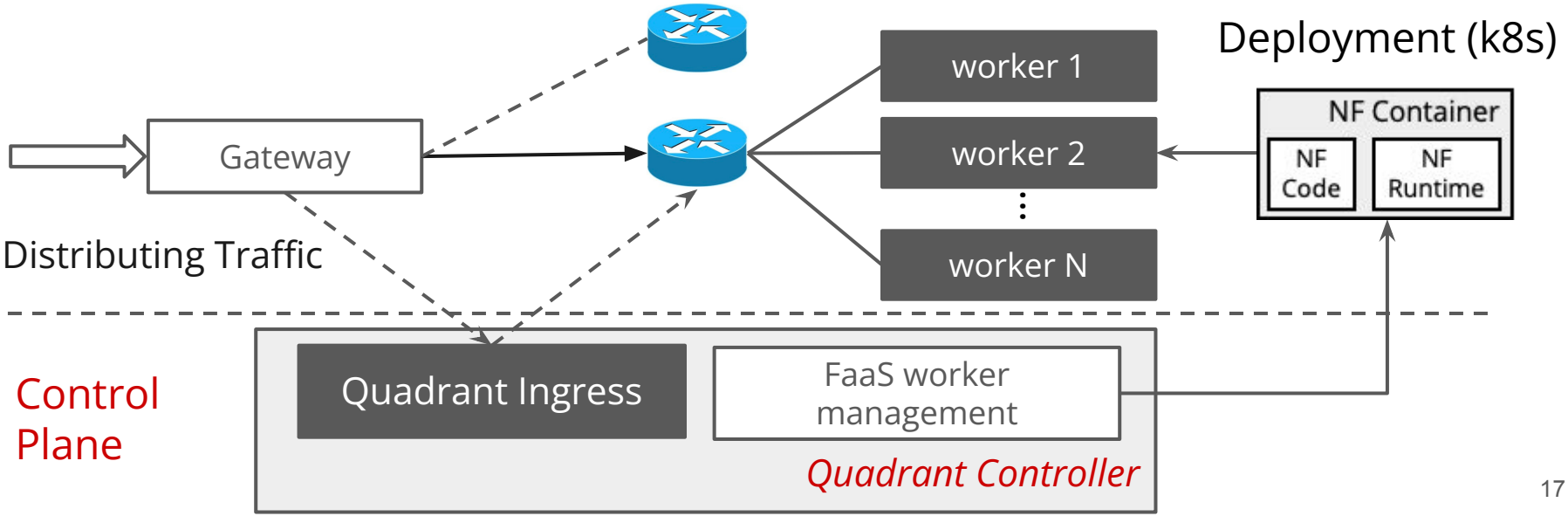
Adapt existing cloud infrastructure to achieve NF chaining, scaling and isolation with high-performance and generality

Quadrant's Contributions

1. High-performance spatiotemporal packet isolation
2. Performance-aware NF scheduling
3. SLO-aware auto-scaling

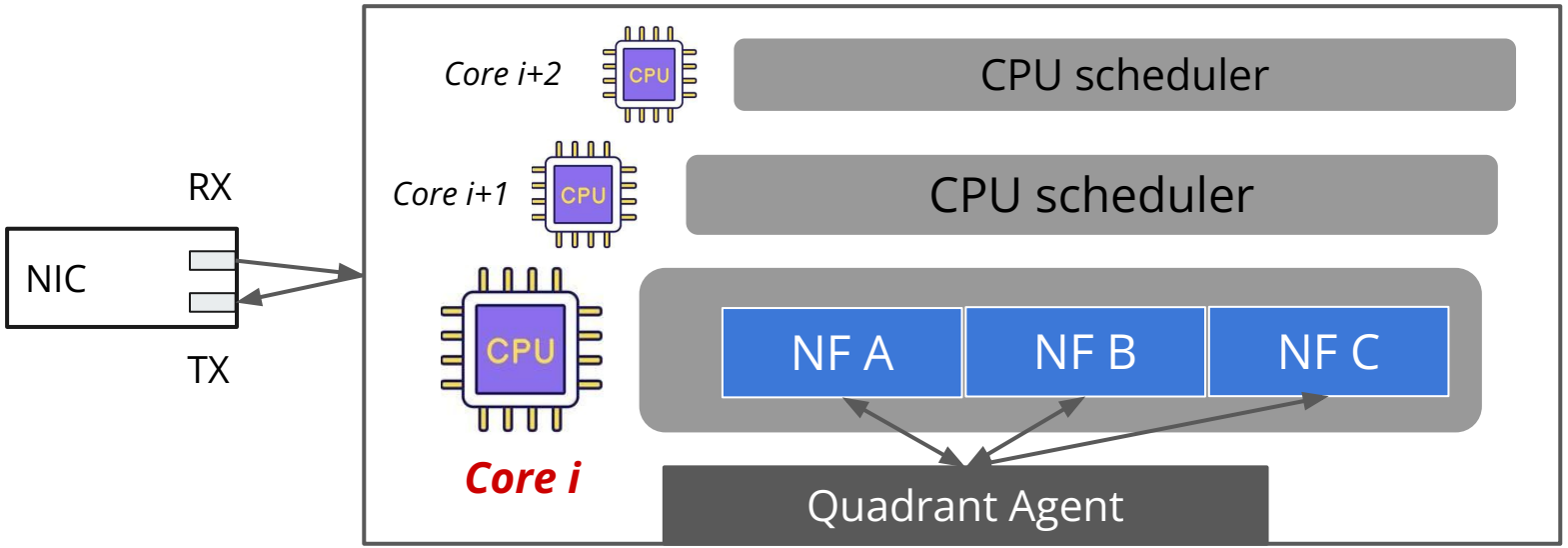
Quadrant Design Overview: Cluster-level

Quadrant deploys NFs as containers, and is built on top of OpenFaaS, reusing Kubernetes, Linux kernel, NICs and switches



Quadrant Design Overview: Server-level

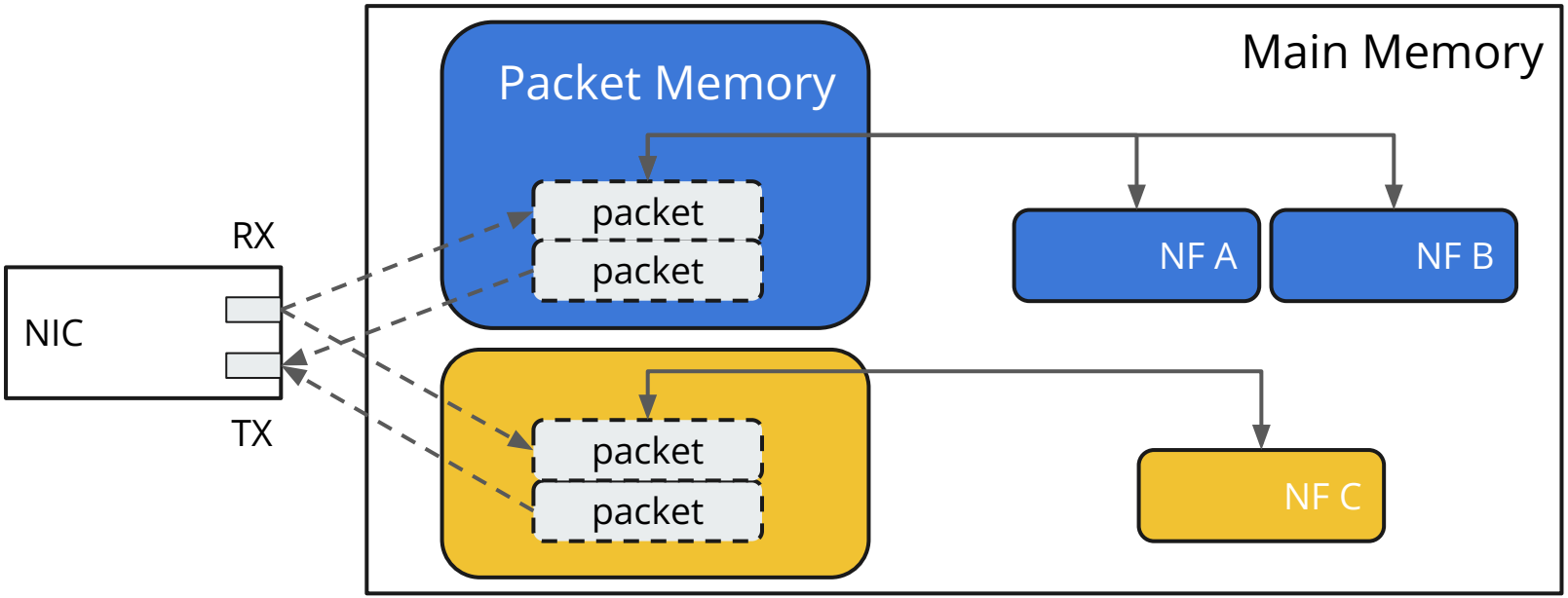
Each Quadrant worker dedicates a core to each chain, applies run-to-completion scheduling to each chain



Quadrant's Contributions

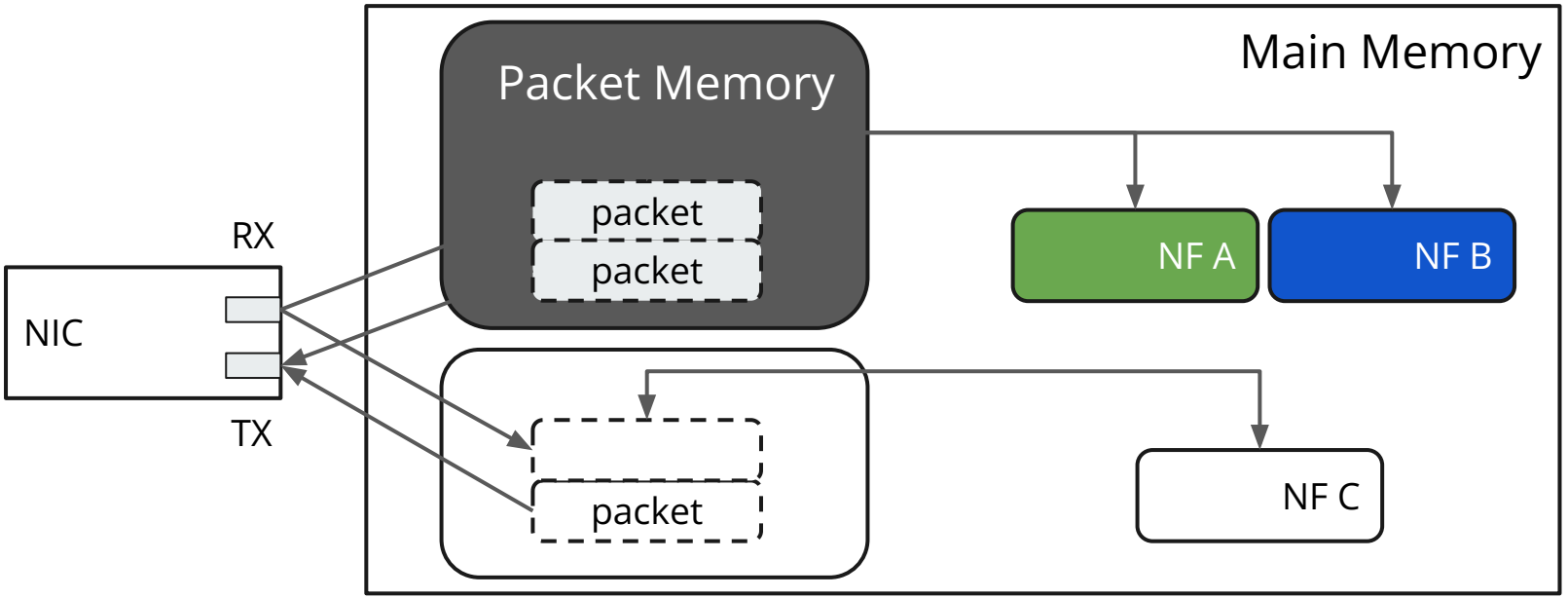
1. High-performance spatiotemporal packet isolation
2. Performance-aware NF scheduling
3. SLO-aware auto-scaling

Our Observation: NFs Can Share Packet Memory When In The Same NF Chain



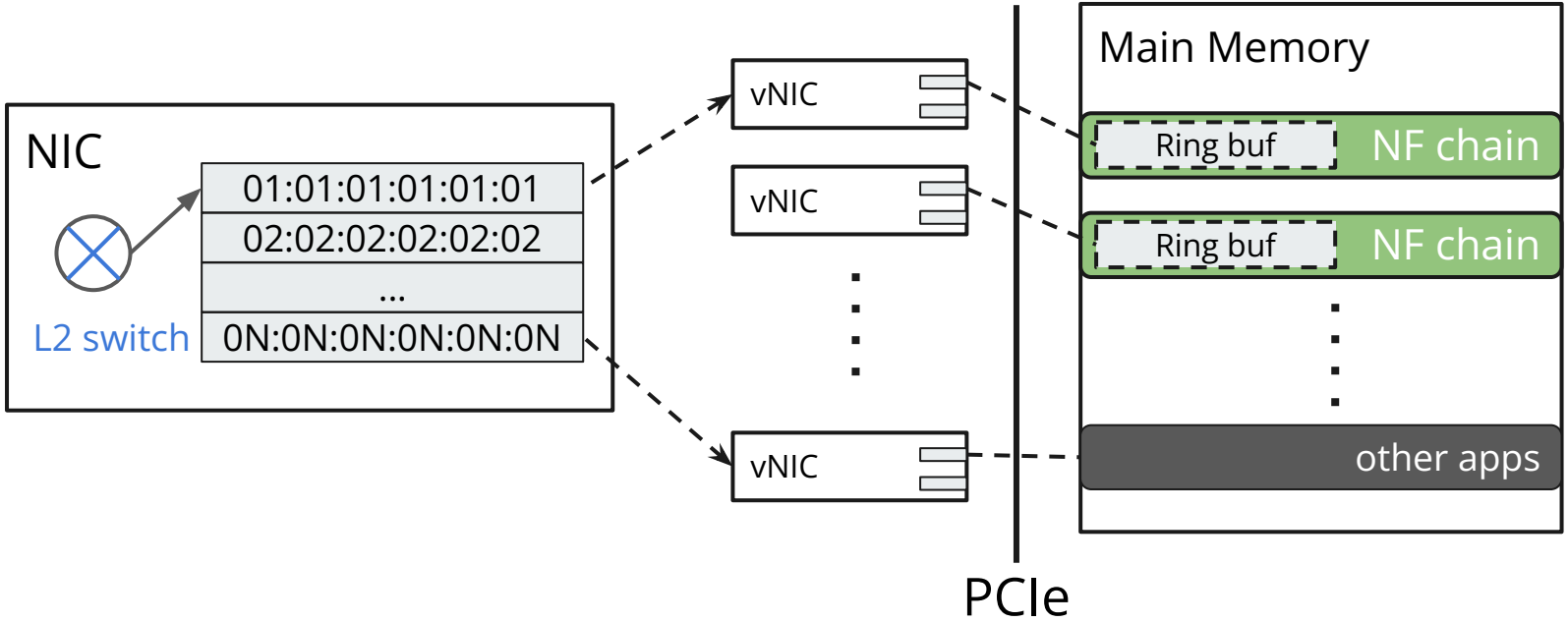
NF Memory And Packet Isolation

NFs are containerized processes with unique NF state memory



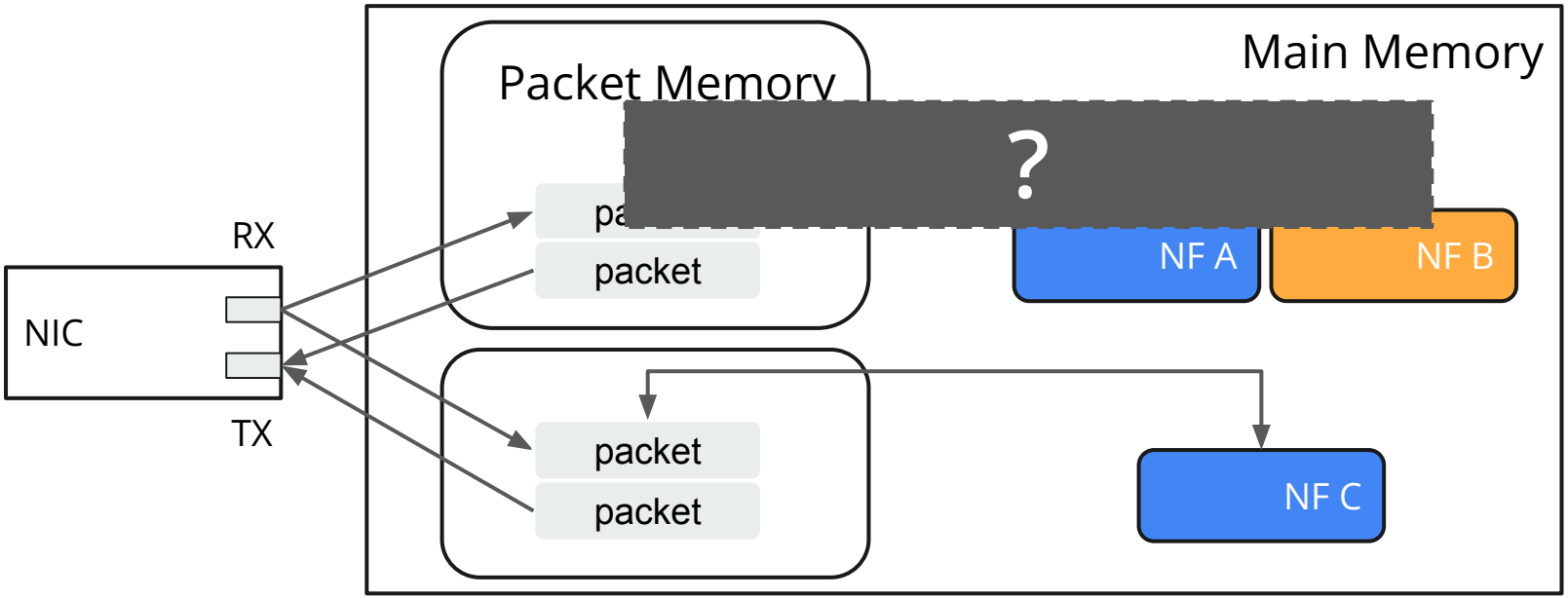
Design: Spatiotemporal Packet Isolation

- Per-chain packet memory: *SR-IOV + per-packet L2 tagging at ToR*



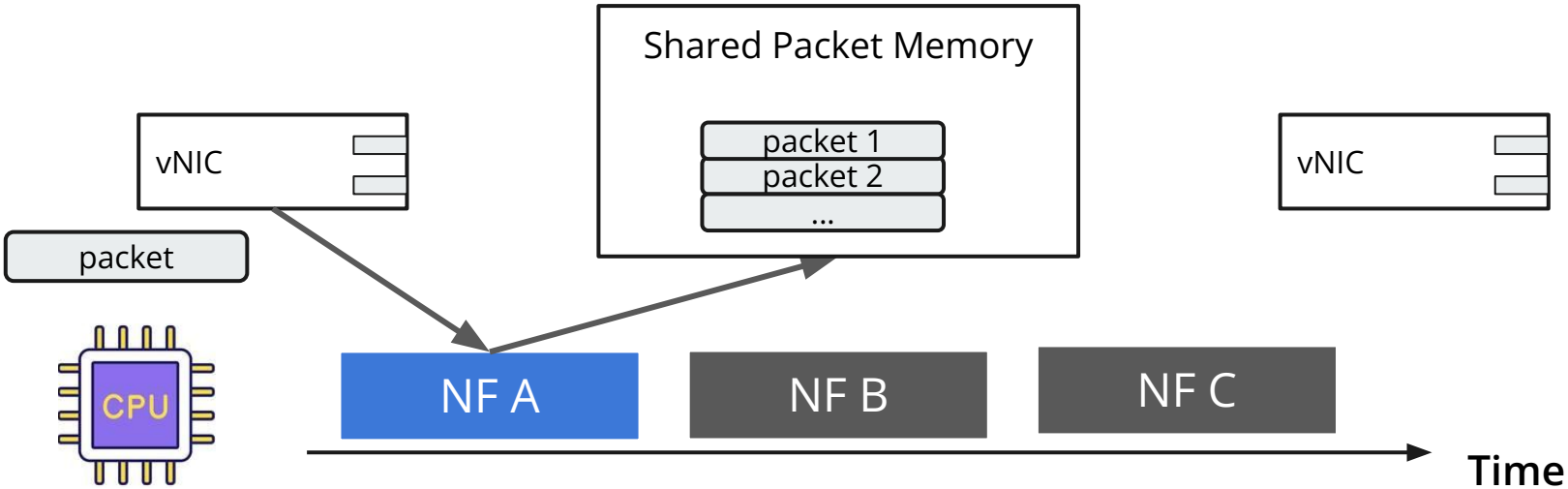
NF Memory And Packet Isolation

How can NFs have unique access to the shared memory?



Design: Spatiotemporal Packet Isolation

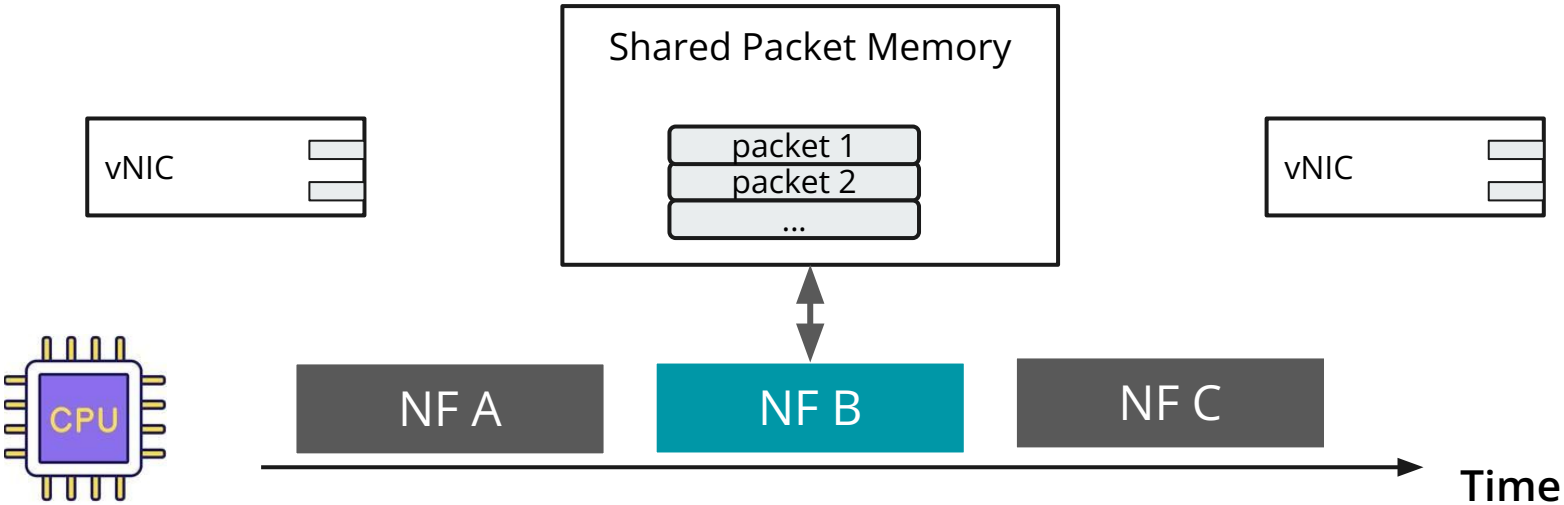
- Controlled memory accesses via *Cooperative Scheduling*



A cooperative scheduler runs at each core

Design: Spatiotemporal Packet Isolation

- Controlled memory accesses via *Cooperative Scheduling*



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Design: Spatiotemporal Packet Isolation

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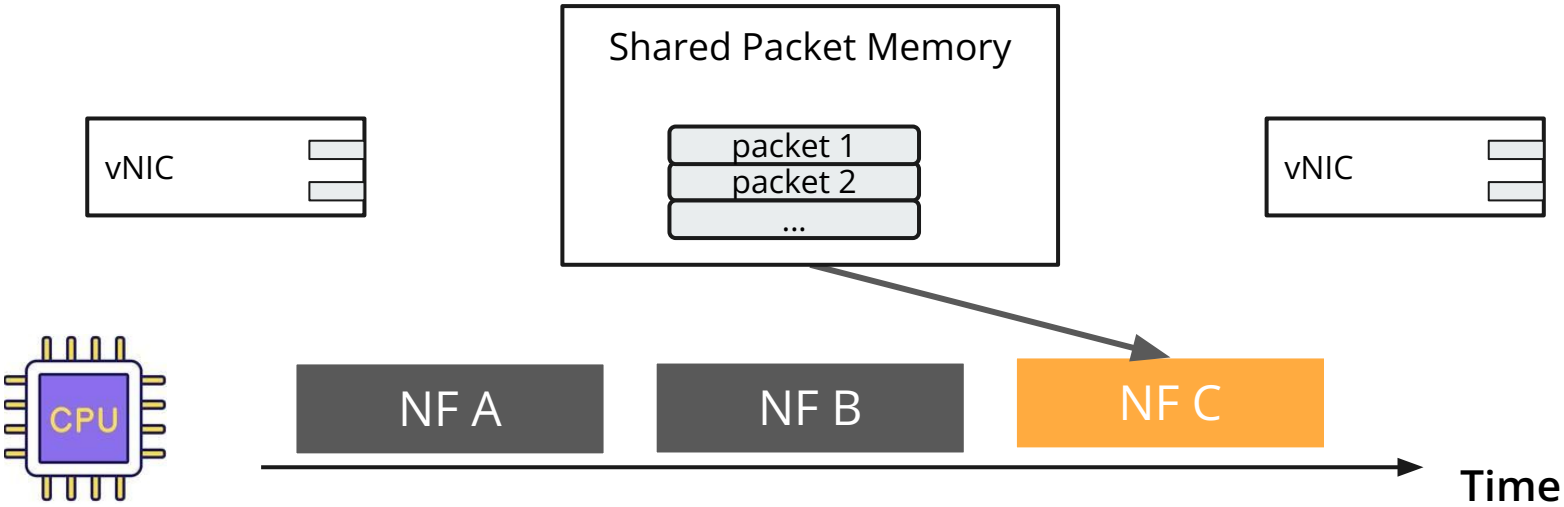

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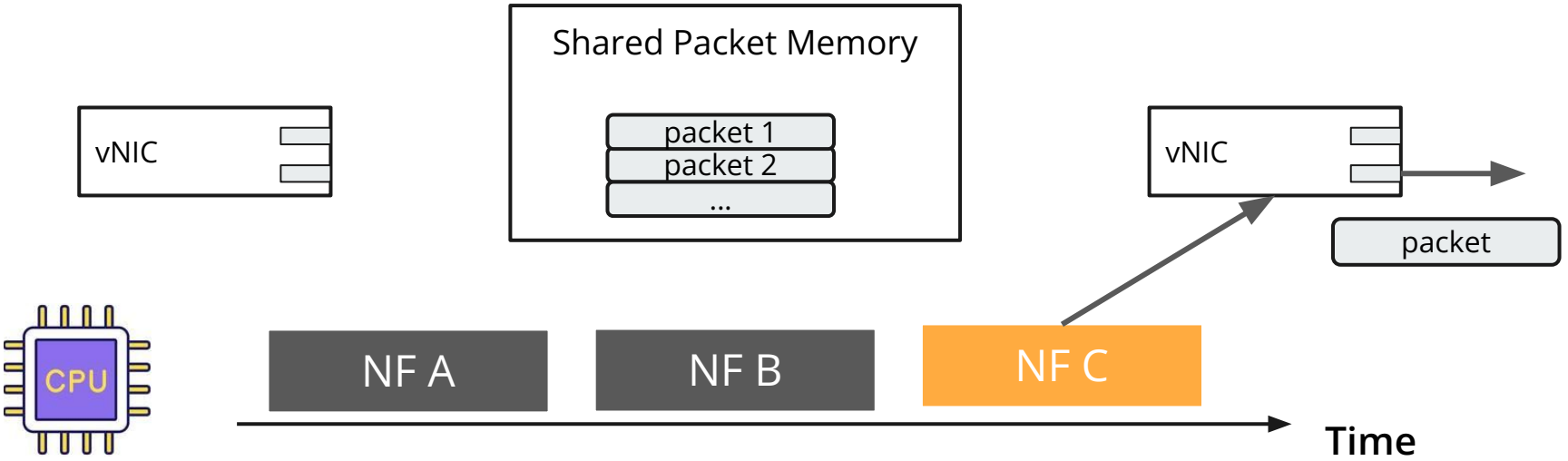
Design: Spatiotemporal Packet Isolation

- Controlled memory accesses via *Cooperative Scheduling*



Quadrant reduces expensive software packet copying

Quadrant's Contributions

1. High-performance spatiotemporal packet isolation
2. Performance-aware NF scheduling
3. SLO-aware auto-scaling

Evaluation

- (Deployability) How many LoCs does Quadrant require?
- (Isolation) How does Quadrant's NF isolation mechanism perform?
- (Scaling) Can Quadrant adapt to dynamic traffic and meet SLOs?
- (Overhead) What are different overheads in Quadrant?
- (Failure) How long does Quadrant recover a failed chain?
- (Ingress) How can Quadrant's ingress mask control-plane latency?
- (Sensitivity) How sensitive is Quadrant to design parameters?

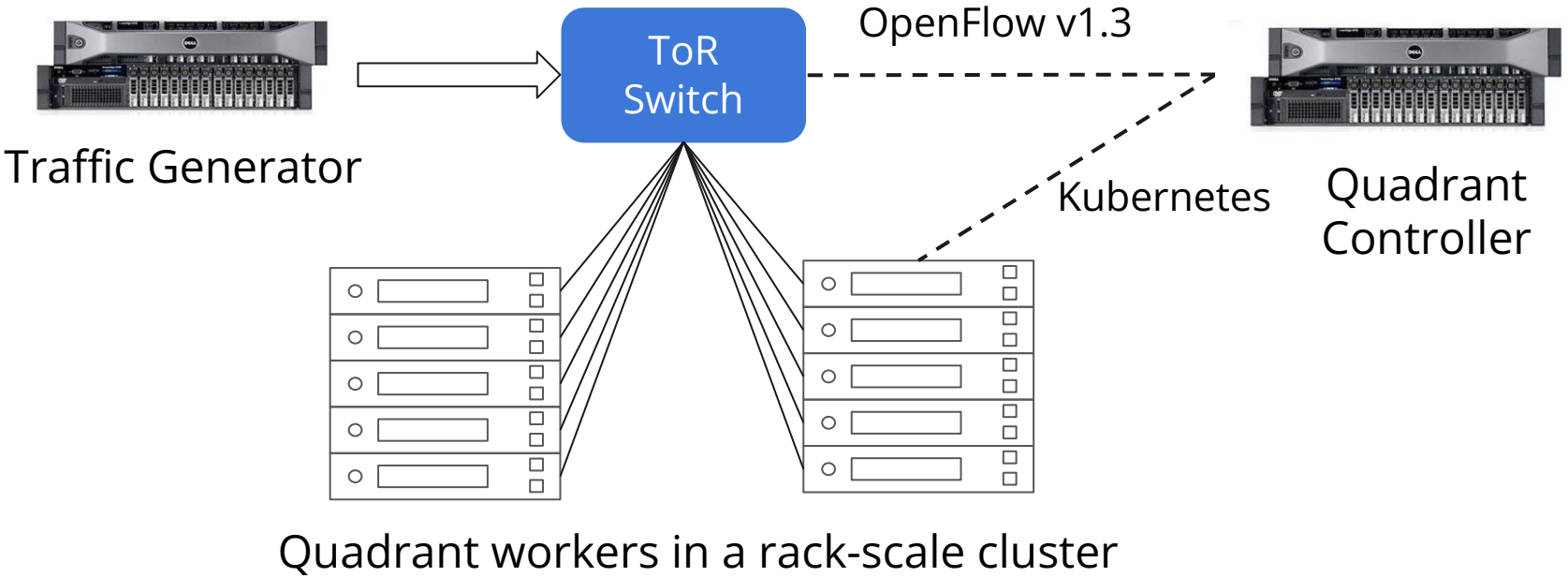
Evaluation

- (Isolation) How does Quadrant's isolation mechanism perform compared to state-of-the-art NFV platforms?

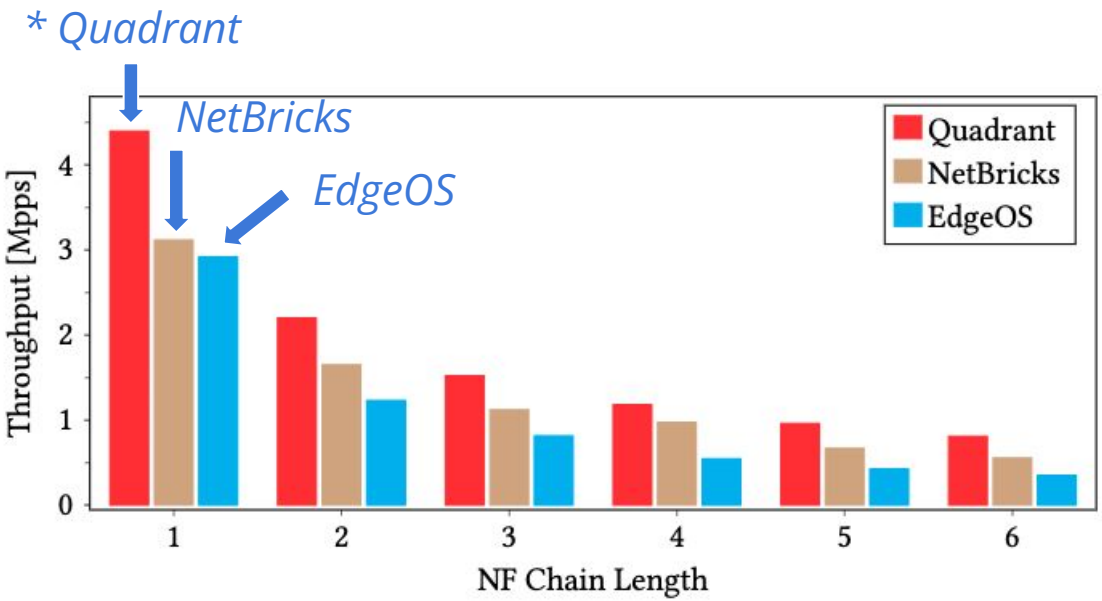
Cloudlab: Build Scientific Infrastructure for Research:
Link: https://www.cloudlab.us/

Implementation

Quadrant is built on top of OpenFaaS (+2.7% LoC)



Isolation: Comparing Per-core Throughput

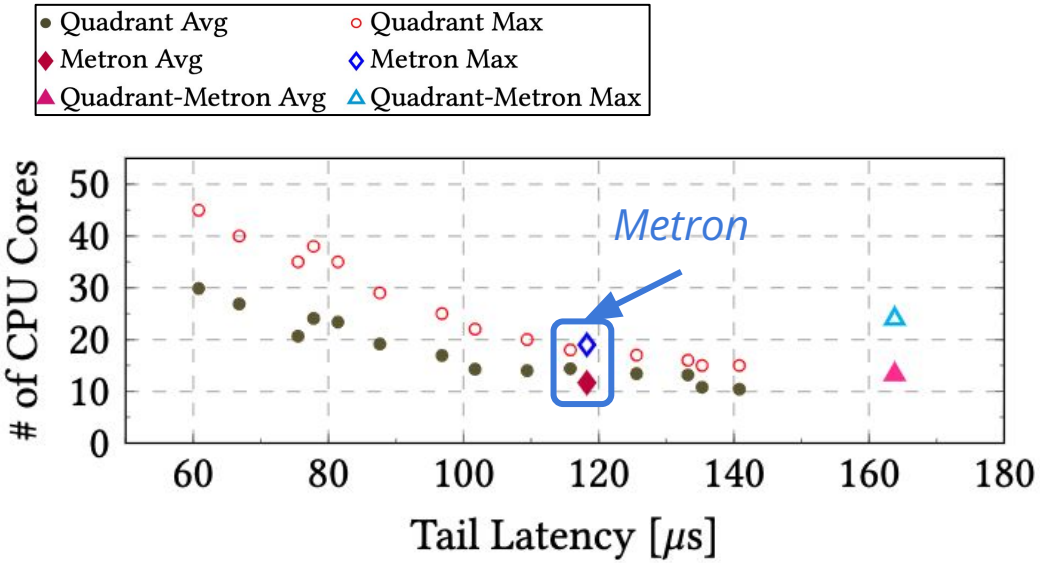


Quadrant outperforms:

- NetBricks: Rust
  - By 1.2 - 1.5x
- EdgeOS: packet copying
  - By 1.6 - 2.3x

Quadrant outperforms SOTA NFV platforms with different isolation mechanisms

Scaling Performance: CPU Core Usage



Quadrant:

- *Avg.: 14.4* cores (+23%)

Metron (no isolation):

- *Avg.: 11.7* cores

Quadrant achieves SLO-aware scaling,
enabling trade-off between latency and efficiency

Quadrant Summary

- Supports NFV in cloud with commodity software and hardware
- Proposes high performance spatiotemporal packet isolation
  - Lightweight inter-NF isolation for third-party NFs
- Proposes SLO-aware auto-scaling
  - Enabling flexible latency-efficiency tradeoffs
  - Less CPU core usage compared to alternatives

Thank you!

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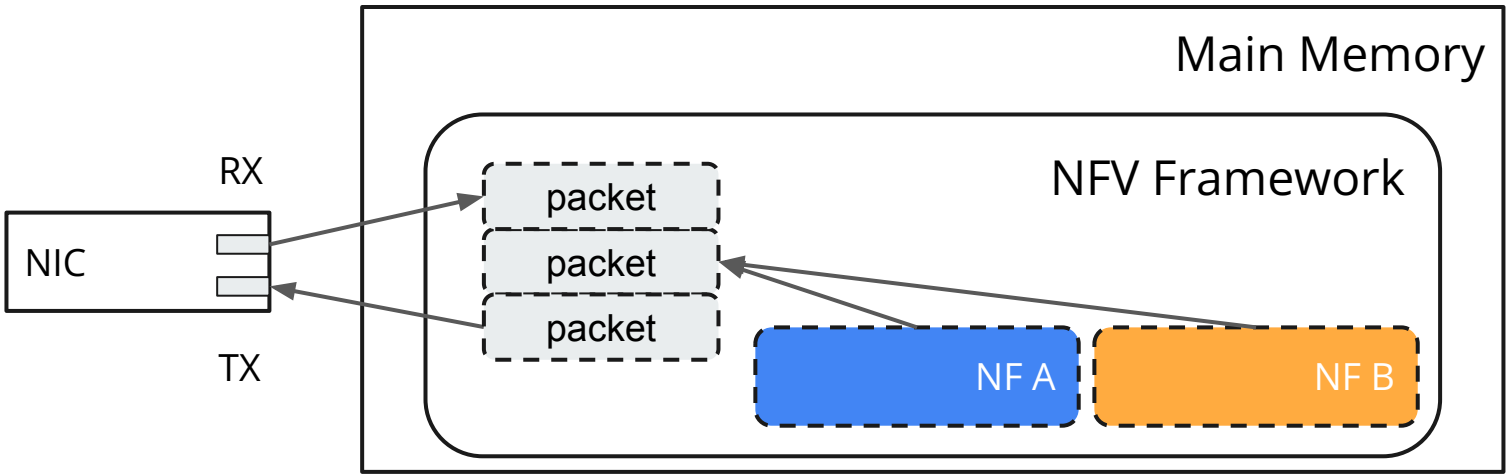
Additional Slides

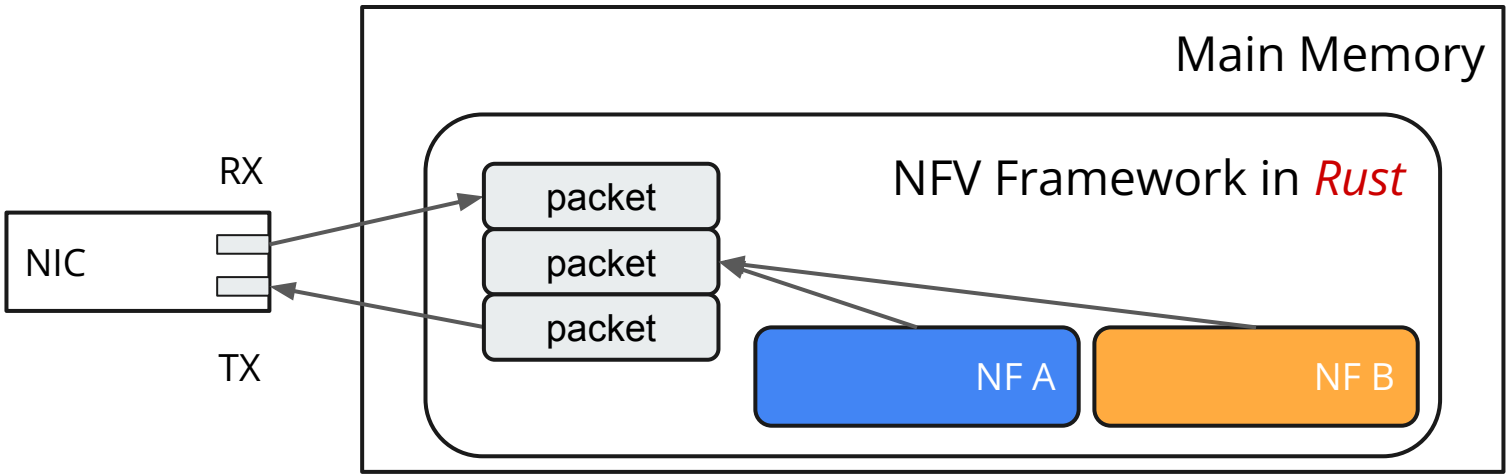
Chaining And Isolation: Limitations of Prior Work

1. High performance but without isolation
   a. Metron [NSDI ‘18]



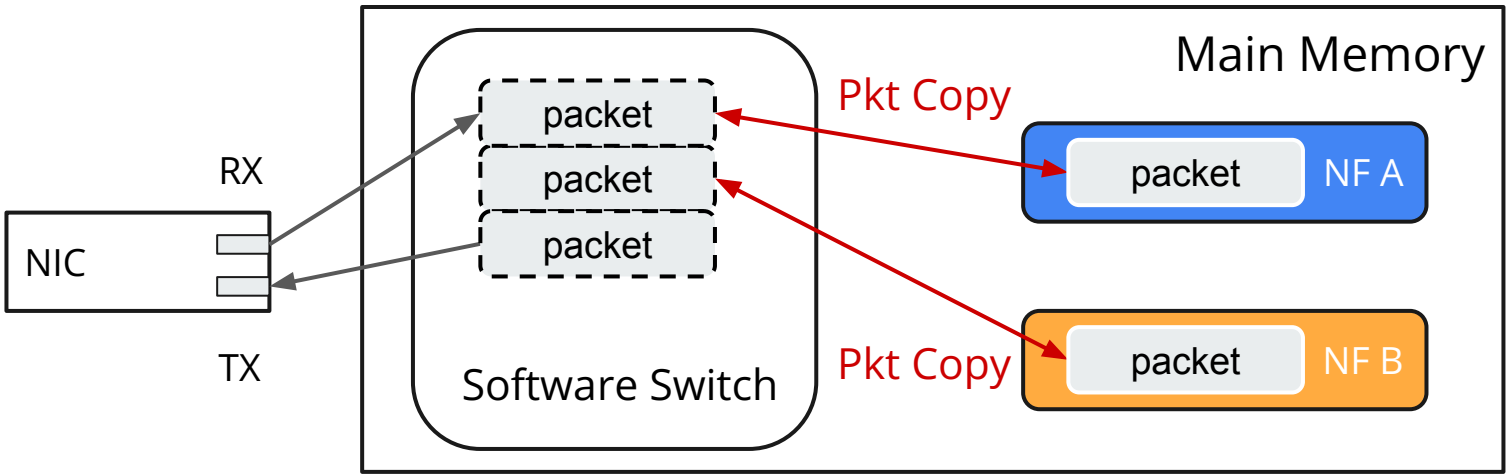
Chaining And Isolation: Limitations of Prior Work

1. High performance but without isolation
2. Isolation without generality / performance
   a. NetBricks [OSDI ‘16], SafeBricks [NSDI ‘18]: using Rust



Chaining And Isolation: Limitations of Prior Work

1. High performance but without isolation
2. Isolation without generality / performance
   a. EdgeOS [ATC '20]: copying packets per NF-hop



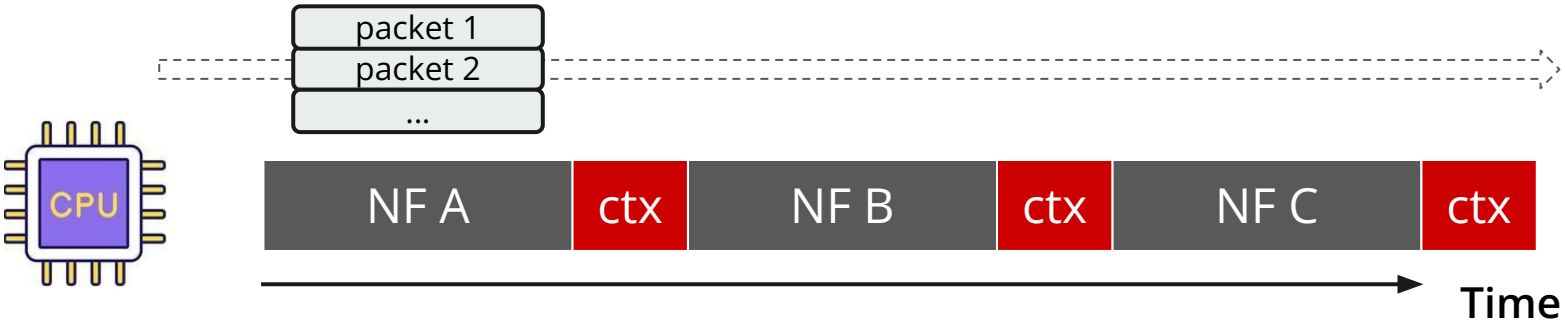
Quadrant's Contributions

1. High-performance spatiotemporal packet isolation
2. Performance-aware NF scheduling
3. SLO-aware auto-scaling

Design: Performance-aware Scheduling

Problem: frequent thread context switches in Cooperative Scheduling

- Key Idea: adjust batch size to bound context switch overhead

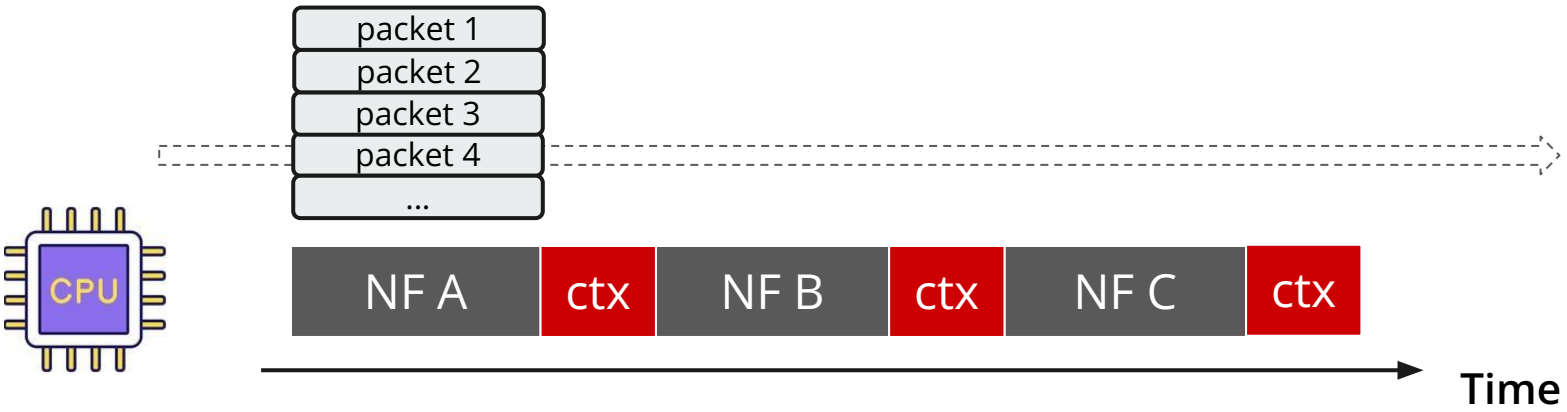


Quadrant executes an NF chain in *run-to-completion* mode.

Design: Performance-aware Scheduling

Problem: frequent thread context switches in Cooperative Scheduling

- Key Idea: adjust batch size to bound context switch overhead



Large batch size when (NF processing time) / (ctx time) decreases

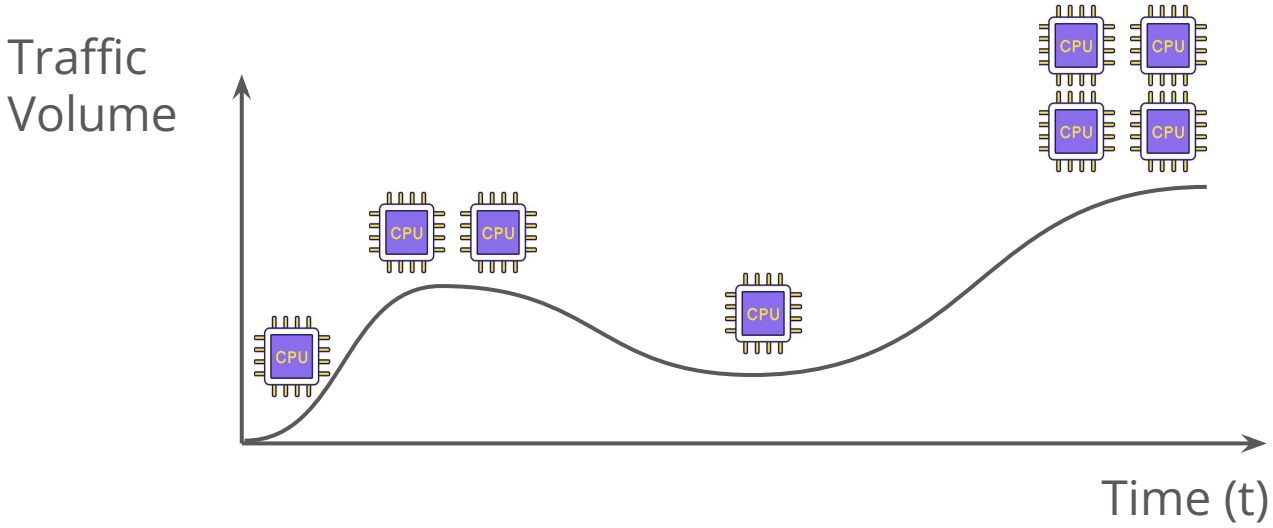
Quadrant's Contributions

1. High-performance spatiotemporal packet isolation
2. Performance-aware NF scheduling
3. SLO-aware auto-scaling

Quadrant Design: SLO-aware Auto-scaling

Auto-scaling is to adapt resources allocated to each NF chain in response to traffic dynamics

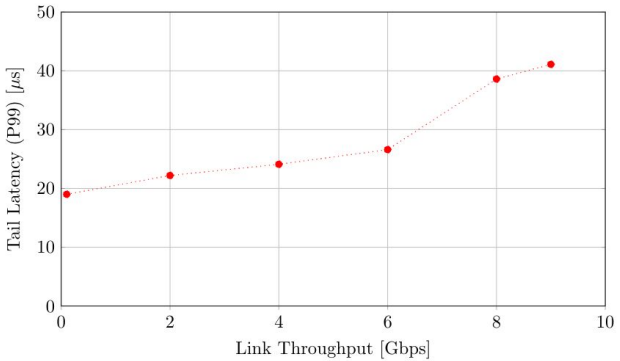
- SLO-aware: minimizing packet losses with a latency objective



Quadrant Design: SLO-aware Auto-scaling

Primary scaling signal: per-chain tail latency estimation

- Key Idea: the tail worker delay + the tail *network transmission delay*

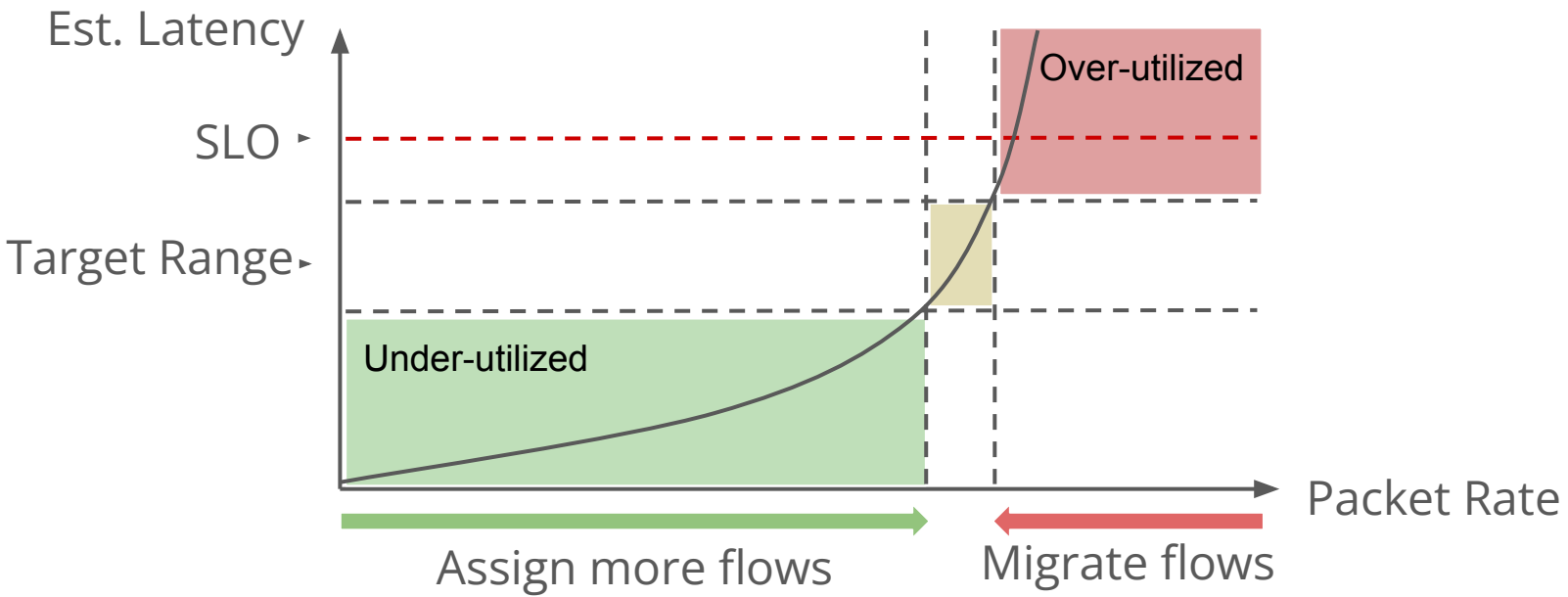


Est. tail worker delay
(based on worst-case per-batch delay)

Est. tail network transmission delay
(worst-case offline-profile)

Quadrant Design: SLO-aware Auto-scaling

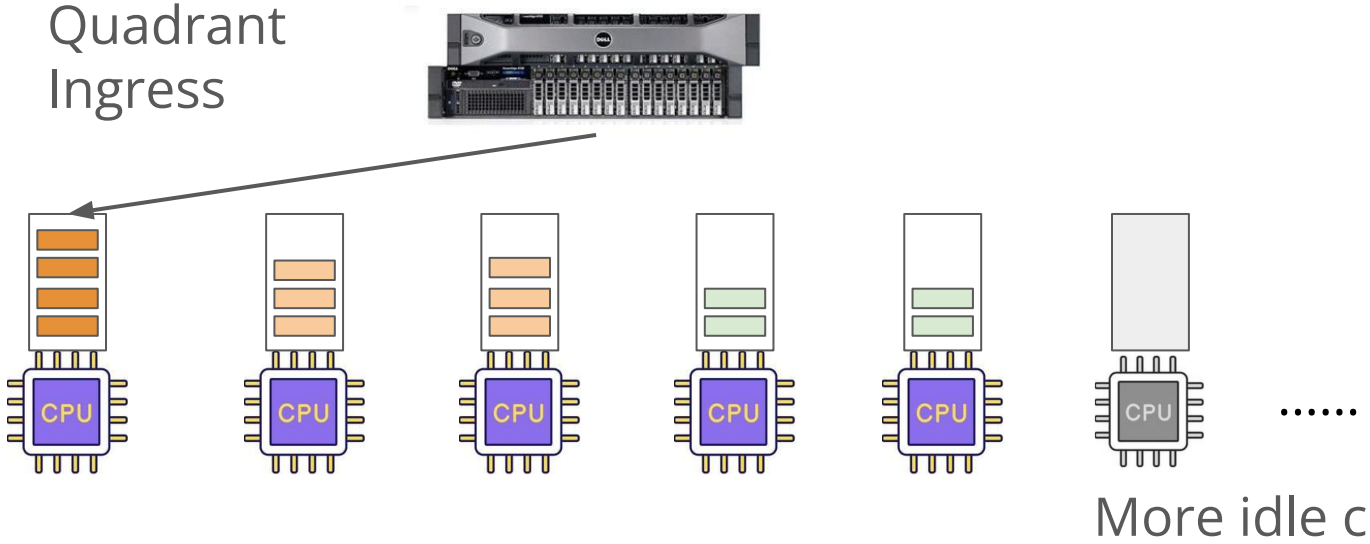
Cluster-scale NF chain auto-scaling: *minimizing # of CPU cores* while preventing latency SLO violations



Quadrant Design: SLO-aware Auto-scaling

Cluster-scale NF chain auto-scaling: *minimizing # of CPU cores*

- Key idea: prioritize the under-utilized core with the highest load



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