Stateless Network Functions:
Breaking the Tight Coupling of State and Processing

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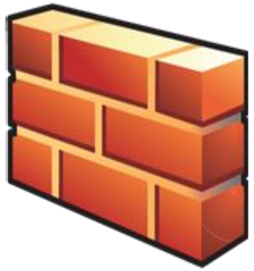
Networks Need Network Functions

Firewall



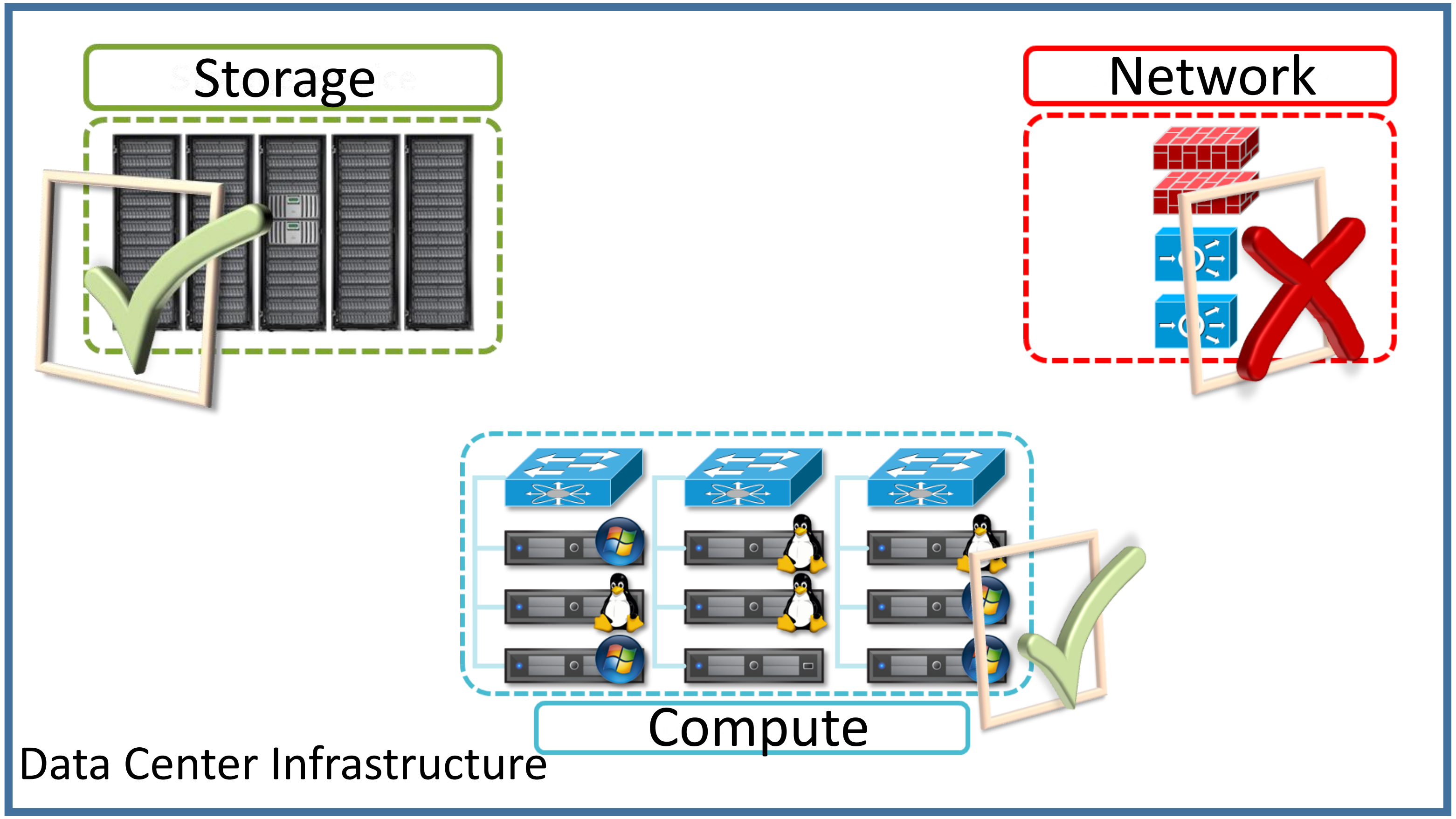
NAT

Intrusion Prevention

Load balancer

To protect and manage the network traffic

Networks Need *Agile* Network Functions



To match the agility of today's (cloud) compute infrastructure

Network Agility -> Easy and Quickly to Use

Seamless Scalability

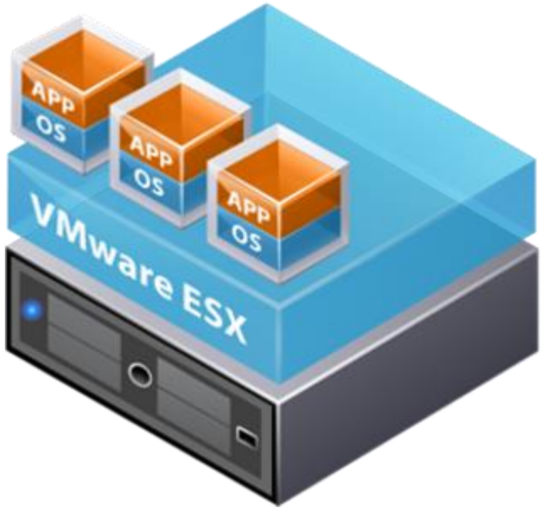
Failure Resiliency

Instant Deployment

Without Sacrificing Performance

Virtual Network Functions to the Rescue ?

Hardware Network Functions

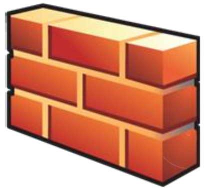


Software Network Functions
(Virtual Machines)

Same core architecture,
same fundamental limit in agility

The Challenge is with The State

- **Firewall** : connection tracking information

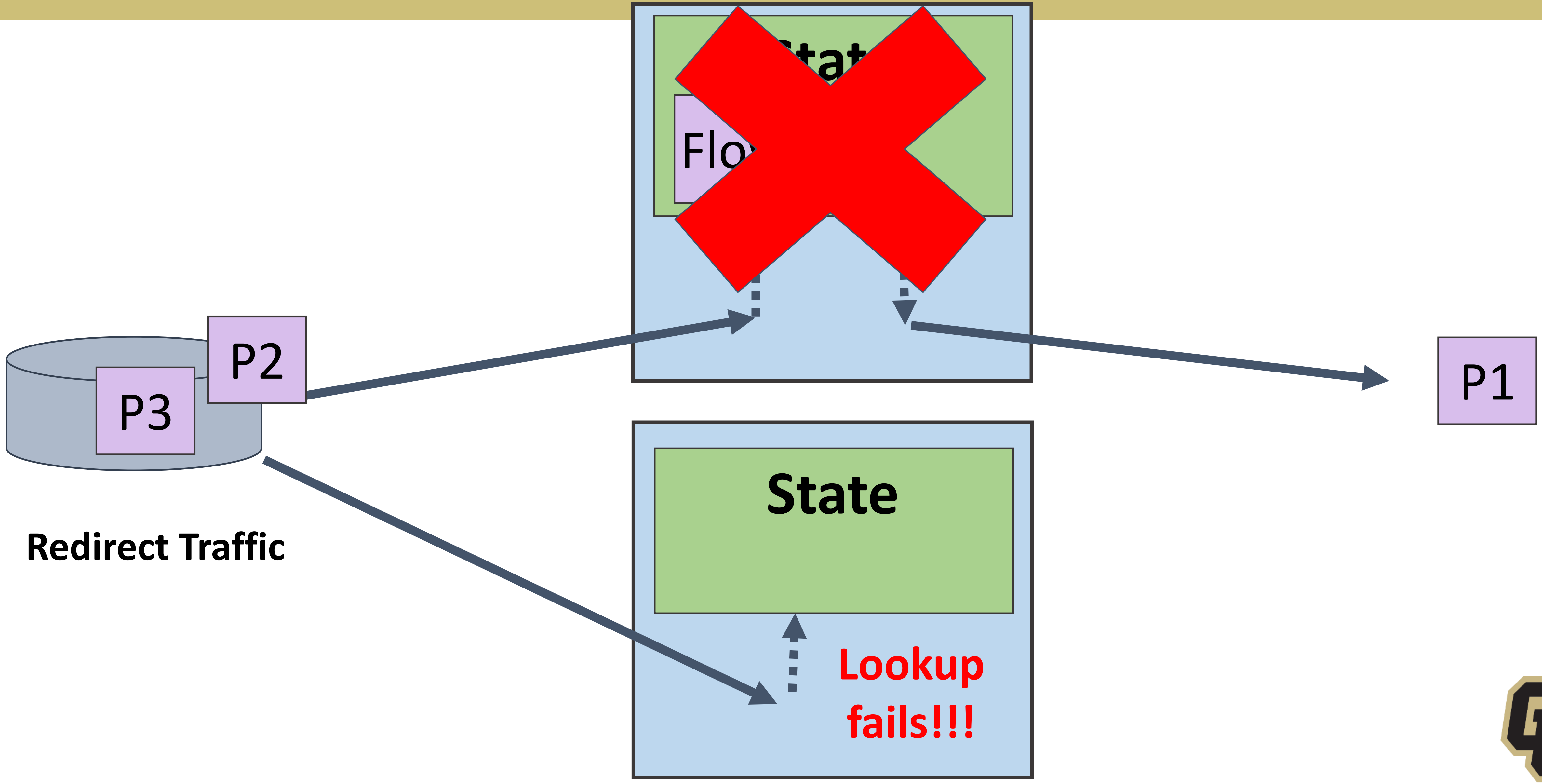


- **Load balancer**: mapping to back end server

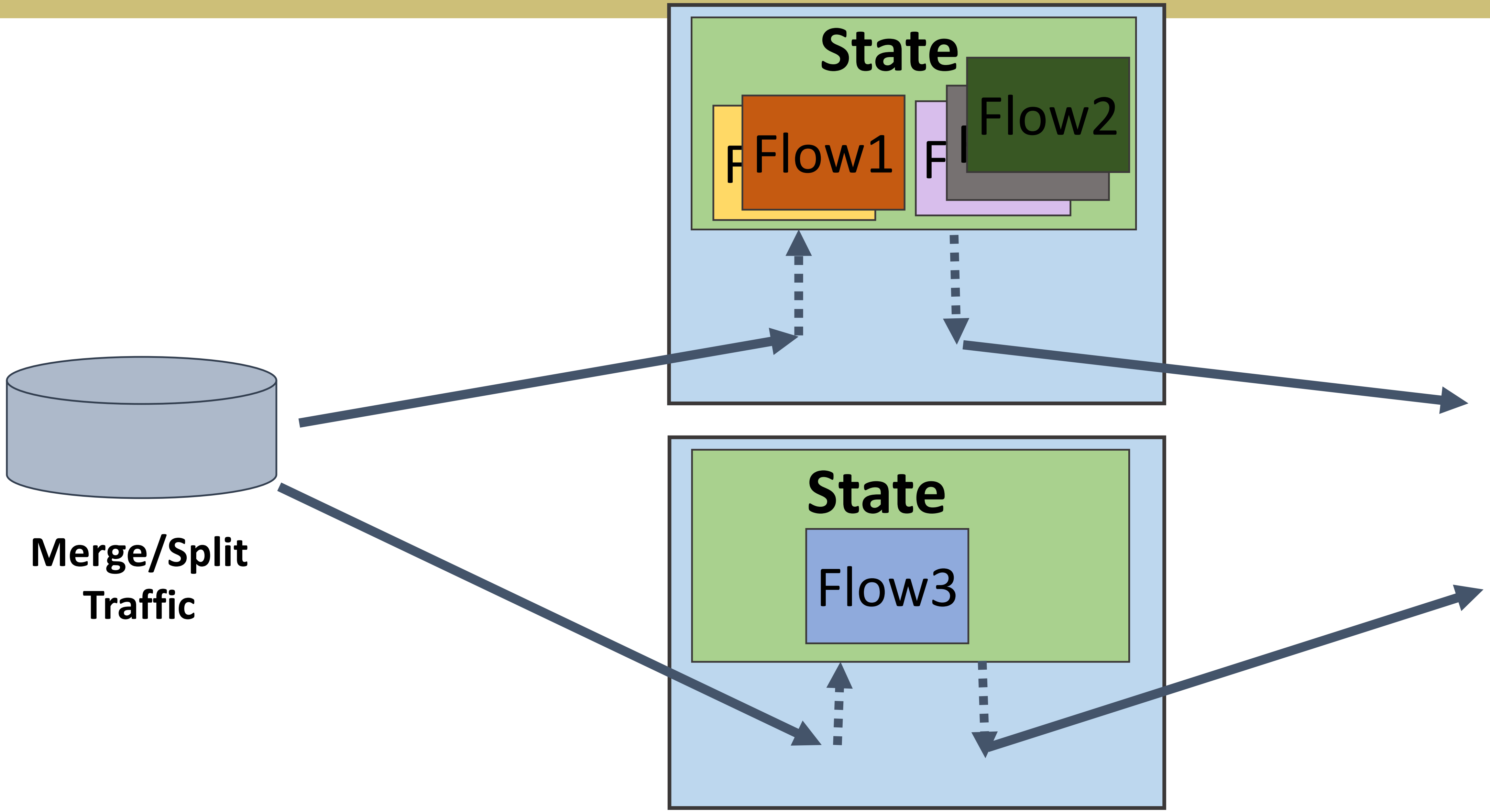
- **Intrusion Prevention**: automata state

- **NAT**: mapping of internal to external addresses

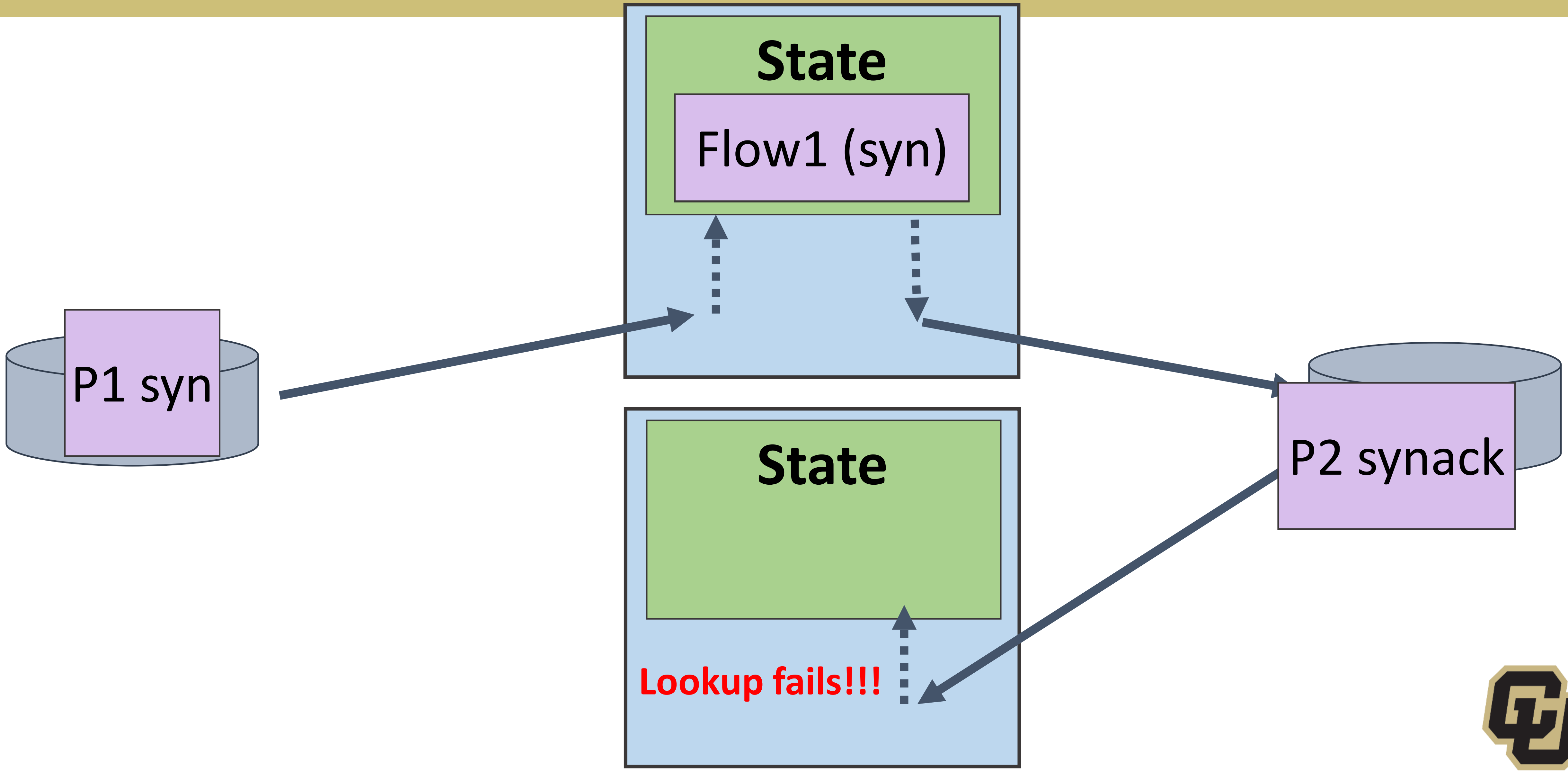
Example Problem 1: Failure



Example Problem 2: Scaling In and Out



Example Problem 3: Asymmetric / Multi-path

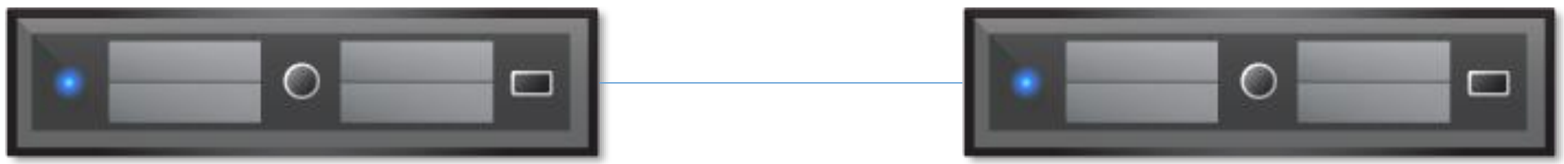


Other Solutions

Industry Approaches to Deal with State

HA Pairs

- Doubles cost, limited scalability, unreliable [Jain2009]

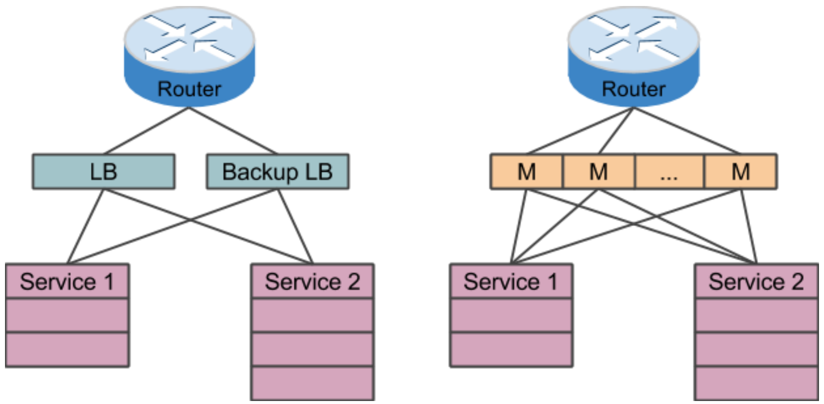


Active

Backup

Don't use state

- e.g., Google Maglev
  - (hash 5-tuple to select backend).
  - Limited applications



Dealing with State: State Migration (for scaling)

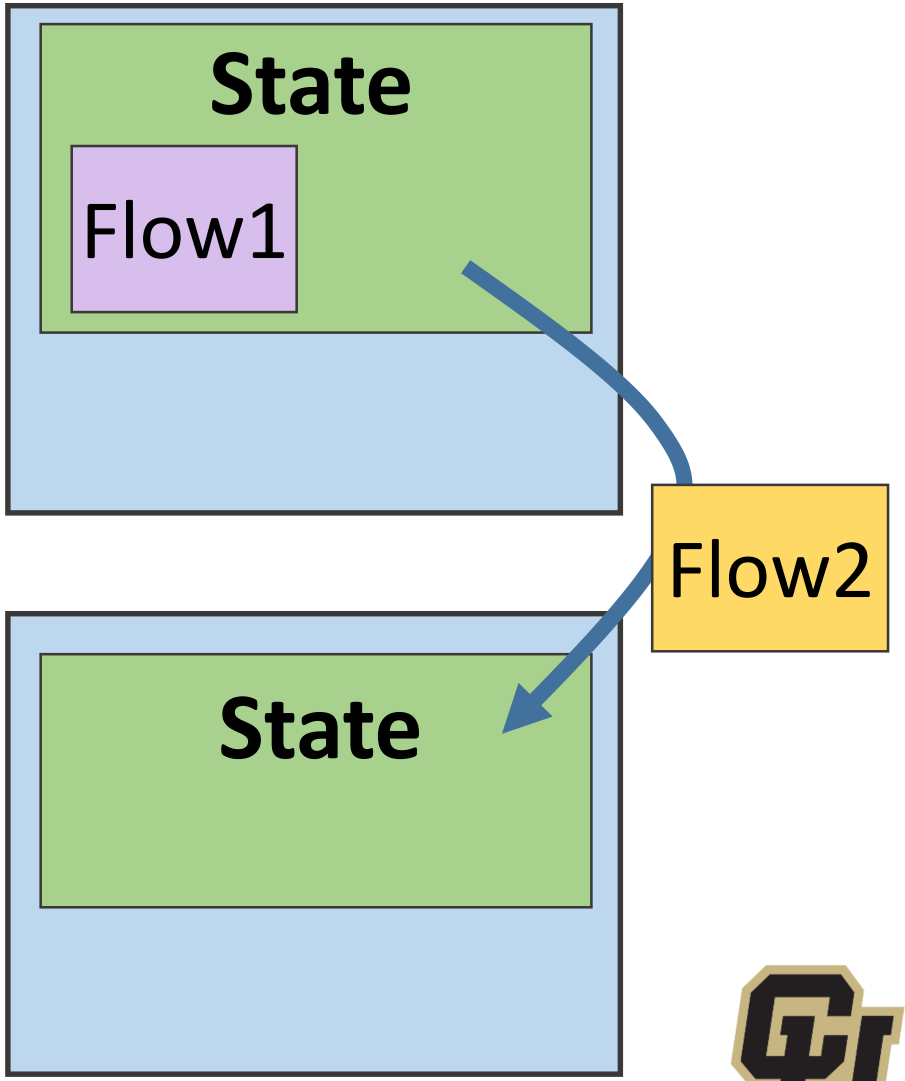
Router Grafting [NSDI 2010],

Split Merge [NSDI 2013],

OpenNF [SIGCOMM 2014]

- When needed, migrate the relevant state

- Only handles pre-planned events
- High overhead to migrate state (e.g., 100 ms)
- Relies on flow affinity



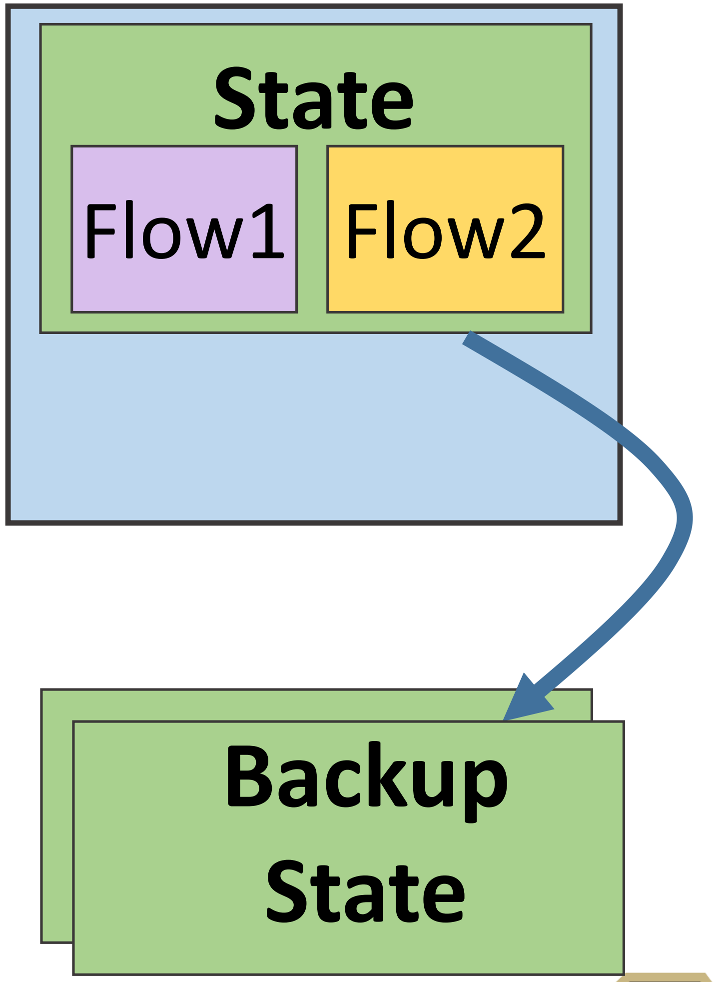
Dealing with State: Check Pointing (for failure)

Pico Replication [SoCC 2013]

- Periodically checkpoint state
  (only diffs, and only network state)

Limitations:

- Quick recovery from failure
- High packet latency
  (can’t release packets until state check pointed)



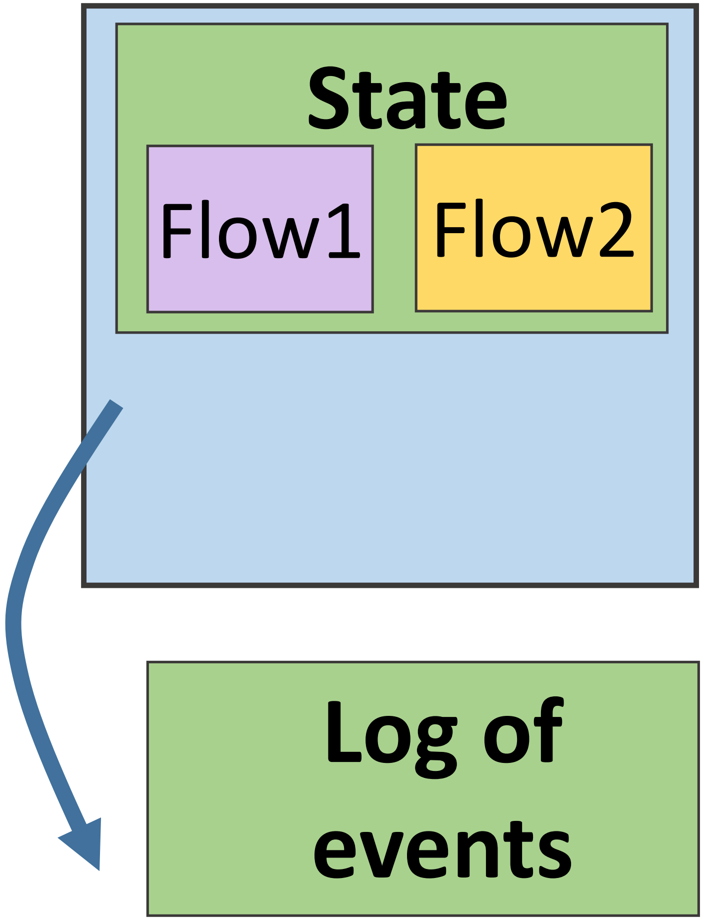
Dealing with State: Deterministic Replay (for failure)

FTMB [SIGCOMM 2015]

- Log events so that upon failure we can re-play those events to rebuild the state
- Use periodic check pointing to limit the replay time
- Improves packet latency

Limitation:

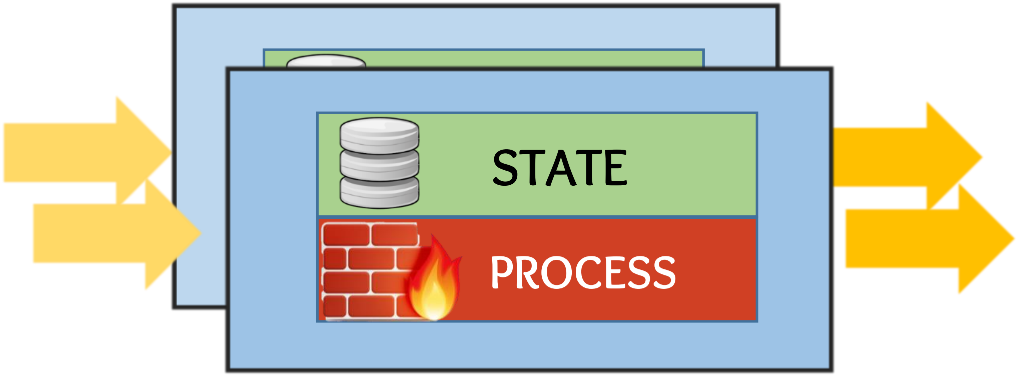
- Long recovery time (time since last check point)



What is the root of the problem?

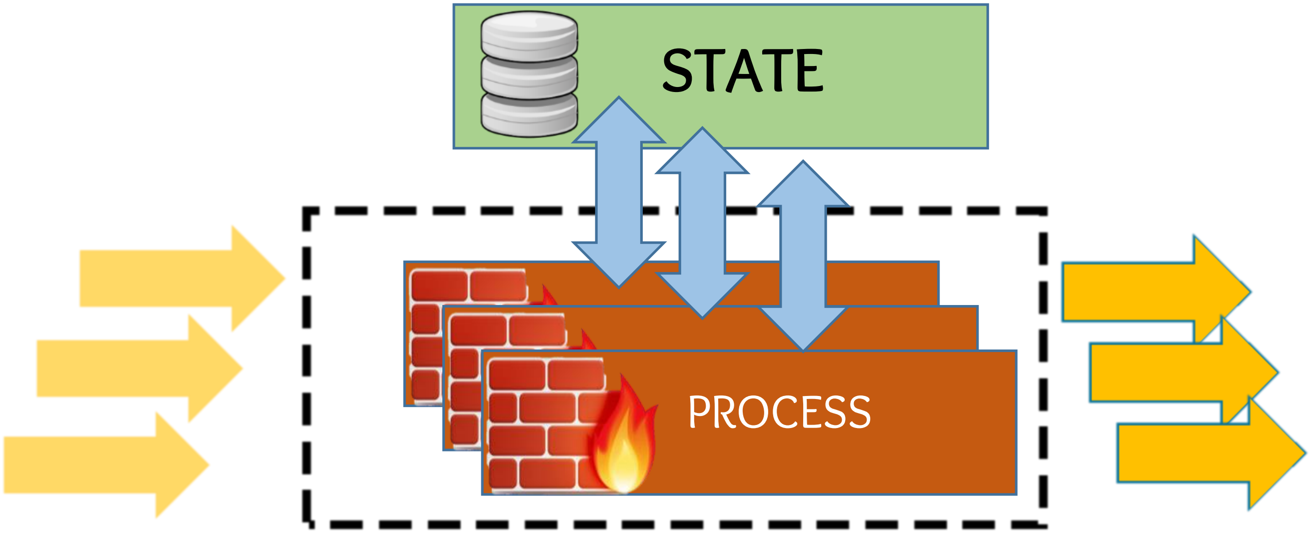
… Appliance mentality

Maintaining the Tight Coupling between State and Processing



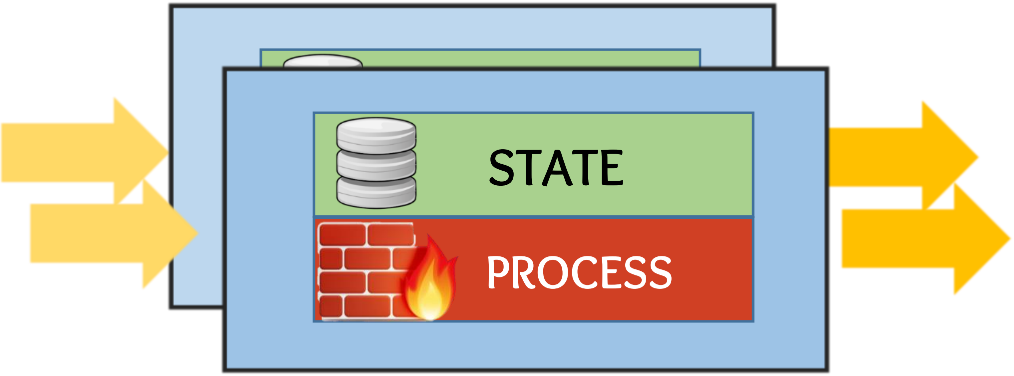
Stateless Network Functions

- Re-designed as a distributed system from the ground up.
- Decoupling the state from the processing



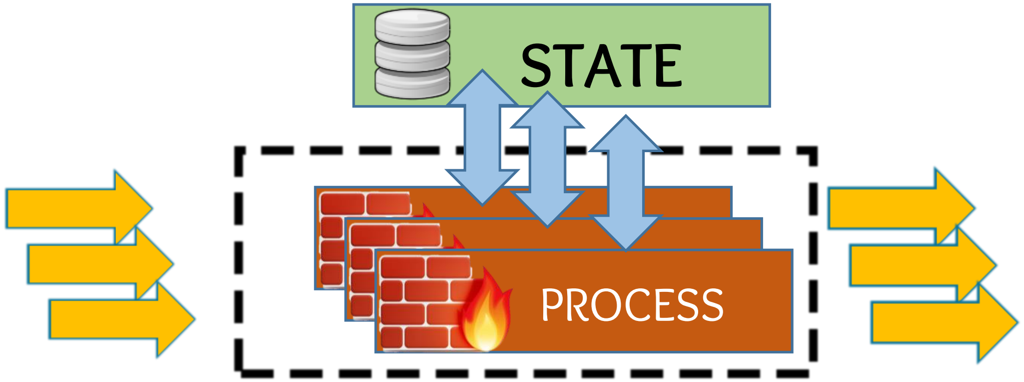
Benefits of Decoupling State from Processing

Traditional Network Function
e.g., Firewall



- High overhead to manage state
- Relies on flow affinity
- Hard to achieve both resiliency and elasticity

Stateless Network Function
e.g., Stateless Firewall



- Seamless elasticity
- No disruption in failure
- Doesn't rely on flow affinity
- Centralized state (simpler to manage)

Is this even possible?

We need to handle millions of packets per second

A Counter-Intuitive Proposal… But it is possible

Why we can do this:

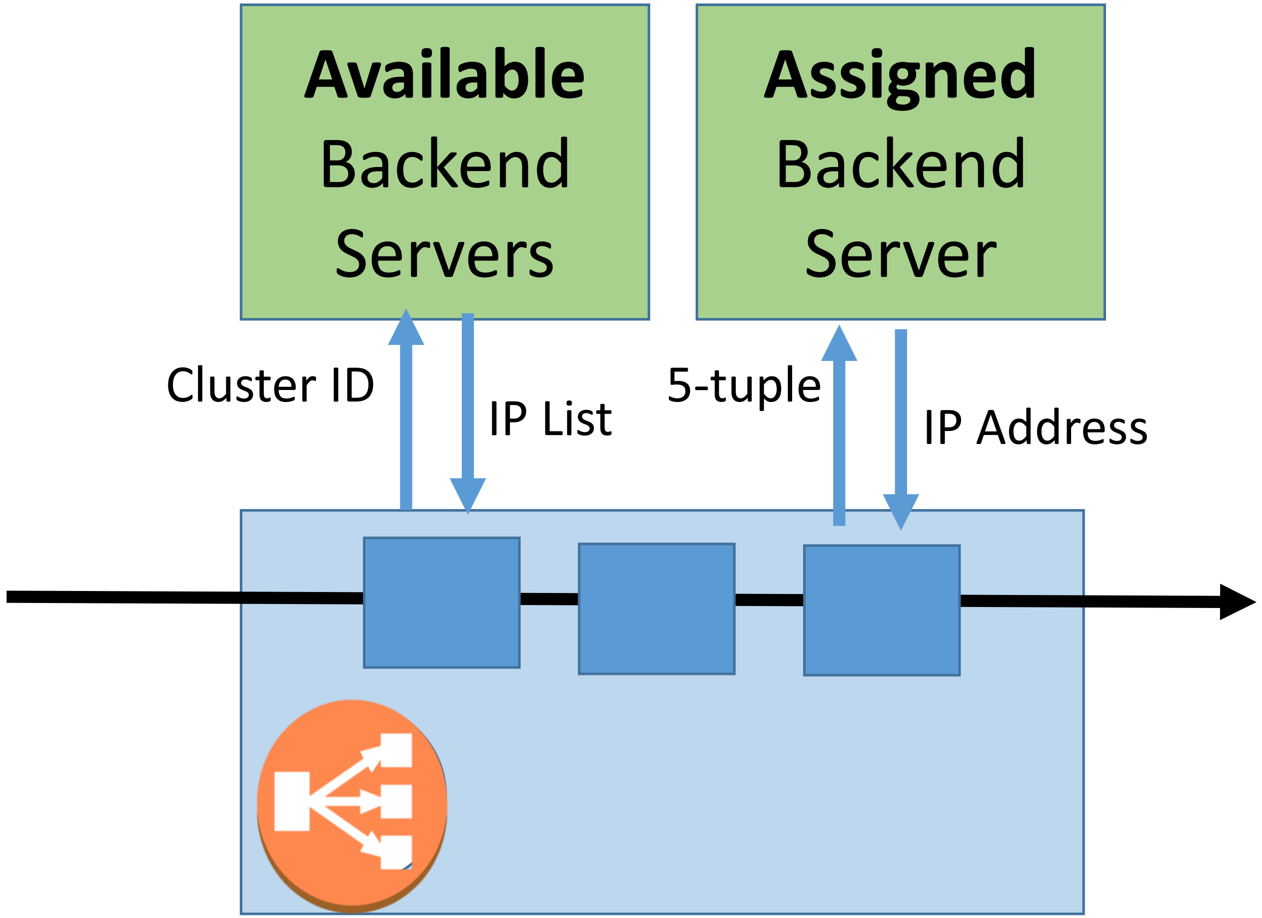
- Common packet processing pipeline has a lookup stage
  (so, per packet request to data store, but not lots of back and forth)

- Requests to data store are much smaller than packets
  (so, scaling traffic rates does not result in same scaling of data store)

- Advances in low-latency technologies
  (data stores, network I/O, etc.)

How State is Accessed

- Example for Load balancer



1st Packet of flow
(Pick an available server)

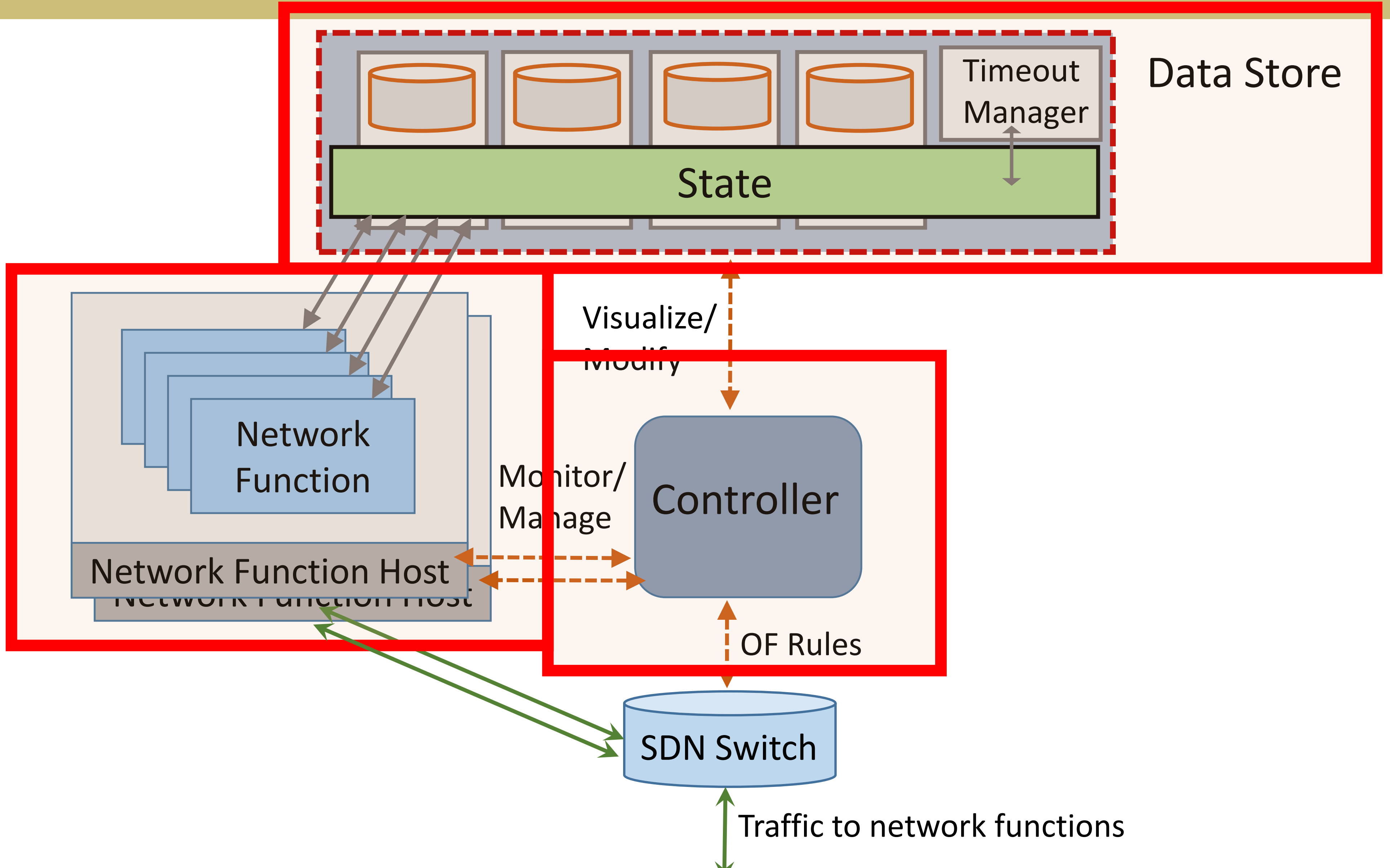
- **1 Read** from Available table,
- **1 Write** to Assigned table

Every other Packet of flow
(look up assigned server)

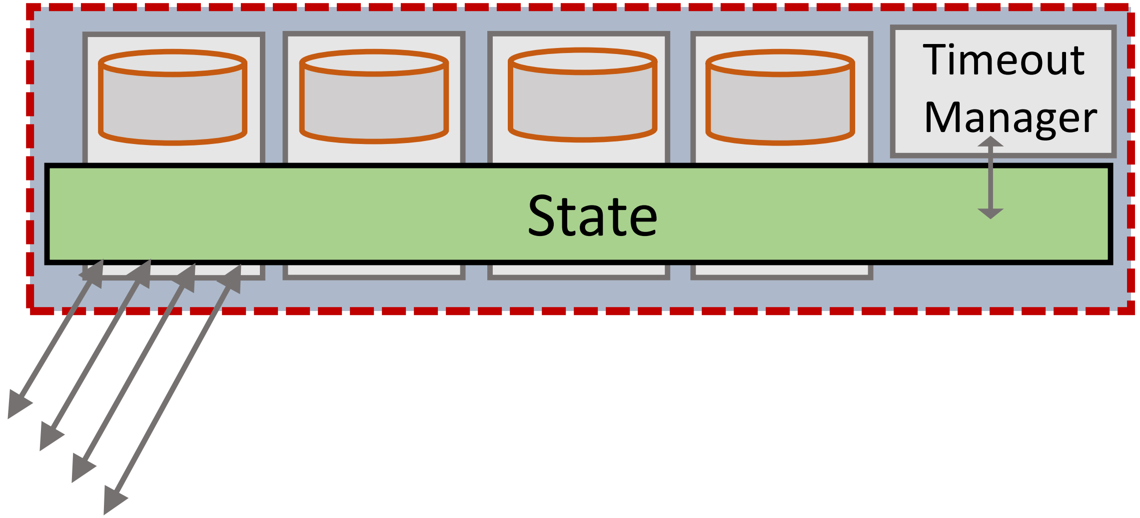
- **1 Read** from Assigned table

System Architecture
StatelessNF

StatelessNF Architecture



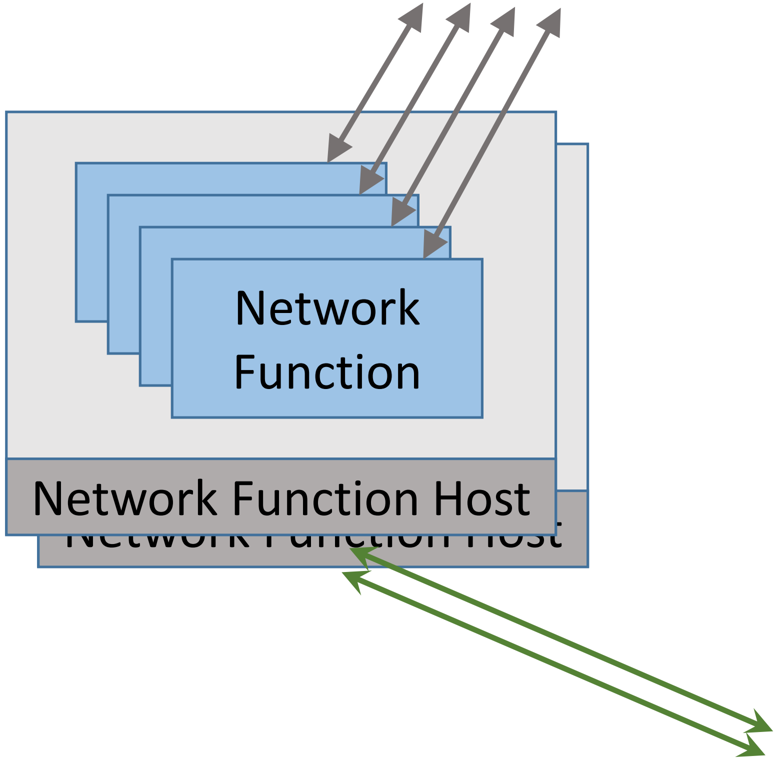
Data Store



Data Store (RAMCloud)

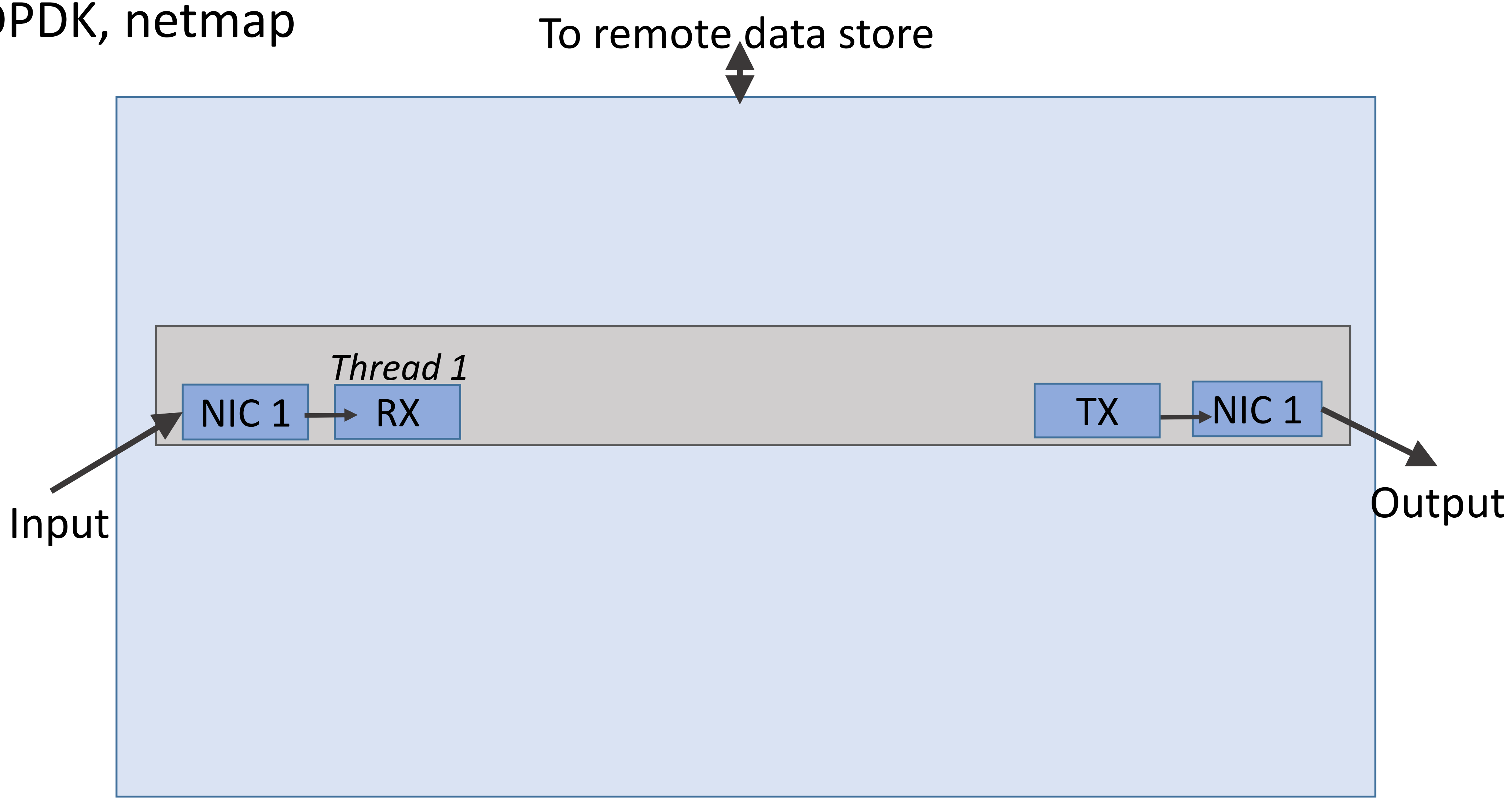
- Low latency, etc.
- Also needs (or could use) support for timers, atomic updates, queues

Network Function Instances



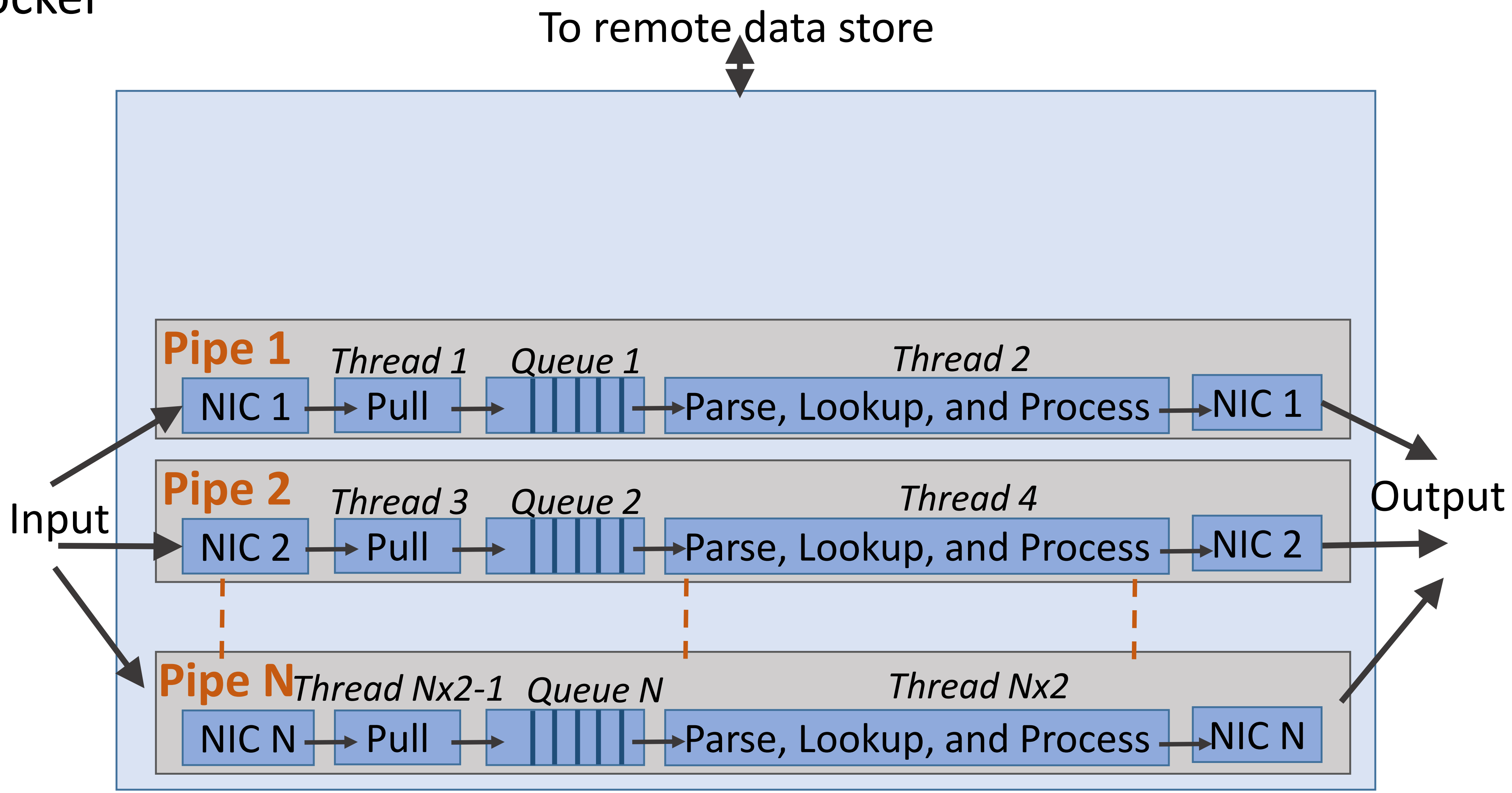
High-Performance Network I/O

e.g., DPDK, netmap



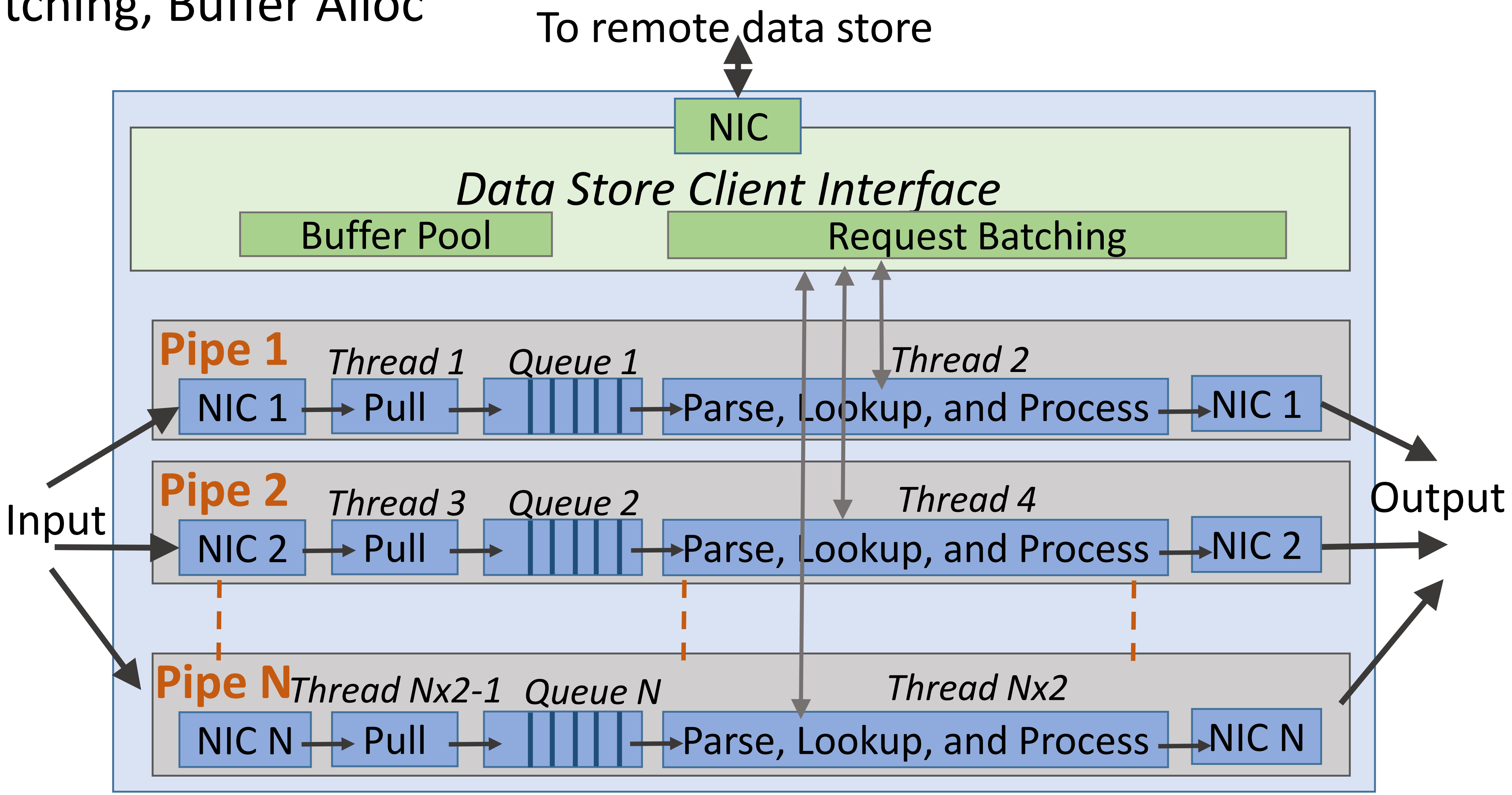
Deployable Packet Processing Container

e.g., Docker



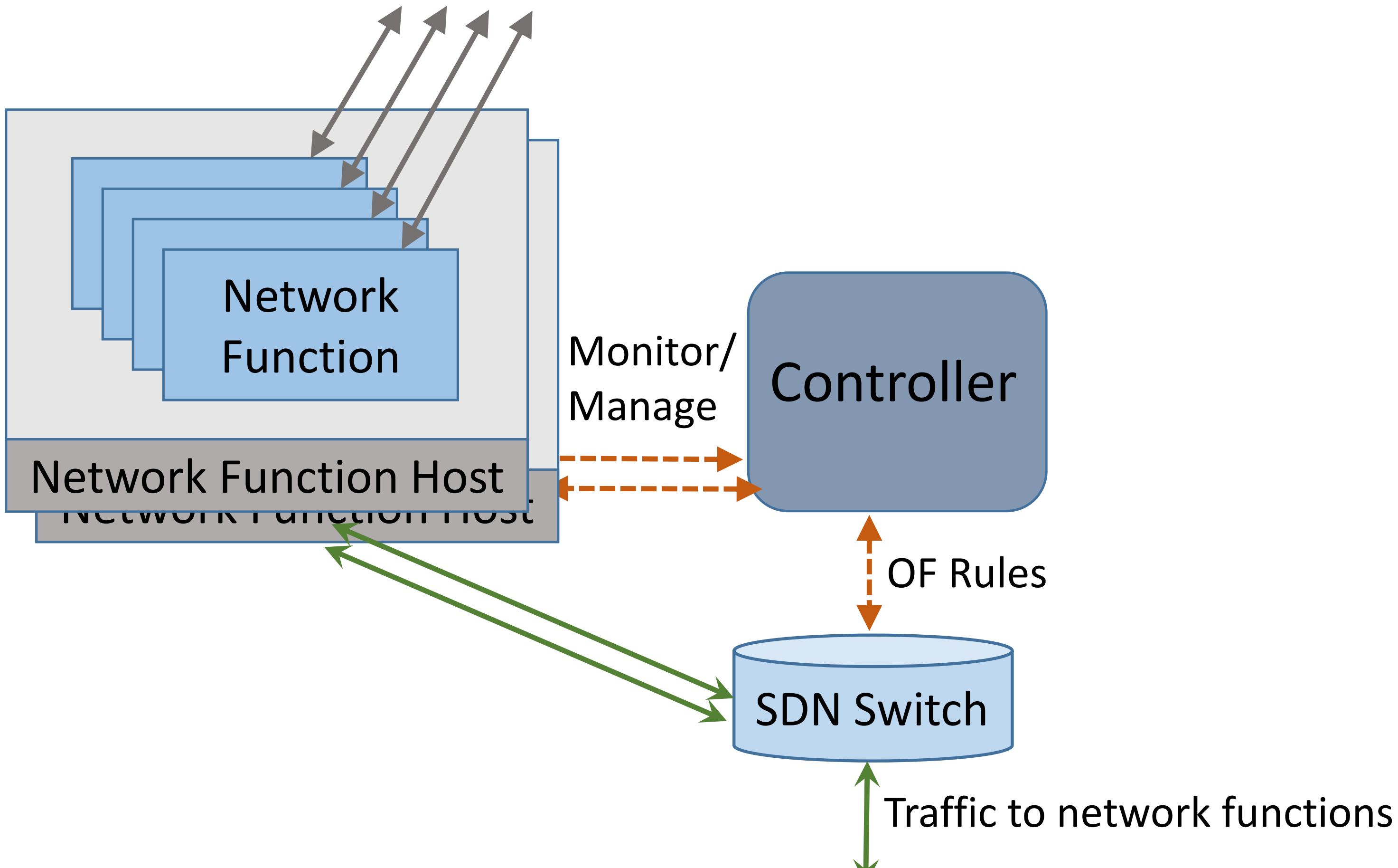
Optimized Data Store Client Interface

e.g., Batching, Buffer Alloc



Orchestration

- Failure handling – speculative failure detection (much faster reactivity)
- Scaling in and out – no need to worry about state when balancing traffic



Implementation

Network Functions (NAT, Firewall, Load balancer)

- DPDK
- SR-IOV
- Docker
- Infiniband to Data store (DPDK since paper)

Data store

- RAMCloud (Redis since paper)
- Extending with timer

Controller

- Extended FloodLight, basic policies for handling scaling and failure.

StatelessNF System Evaluation

Evaluation

Goal: in this extreme case architecture, can we get **similar throughput and latency** as other software solutions,

but with better **handling of resilience and failure**?

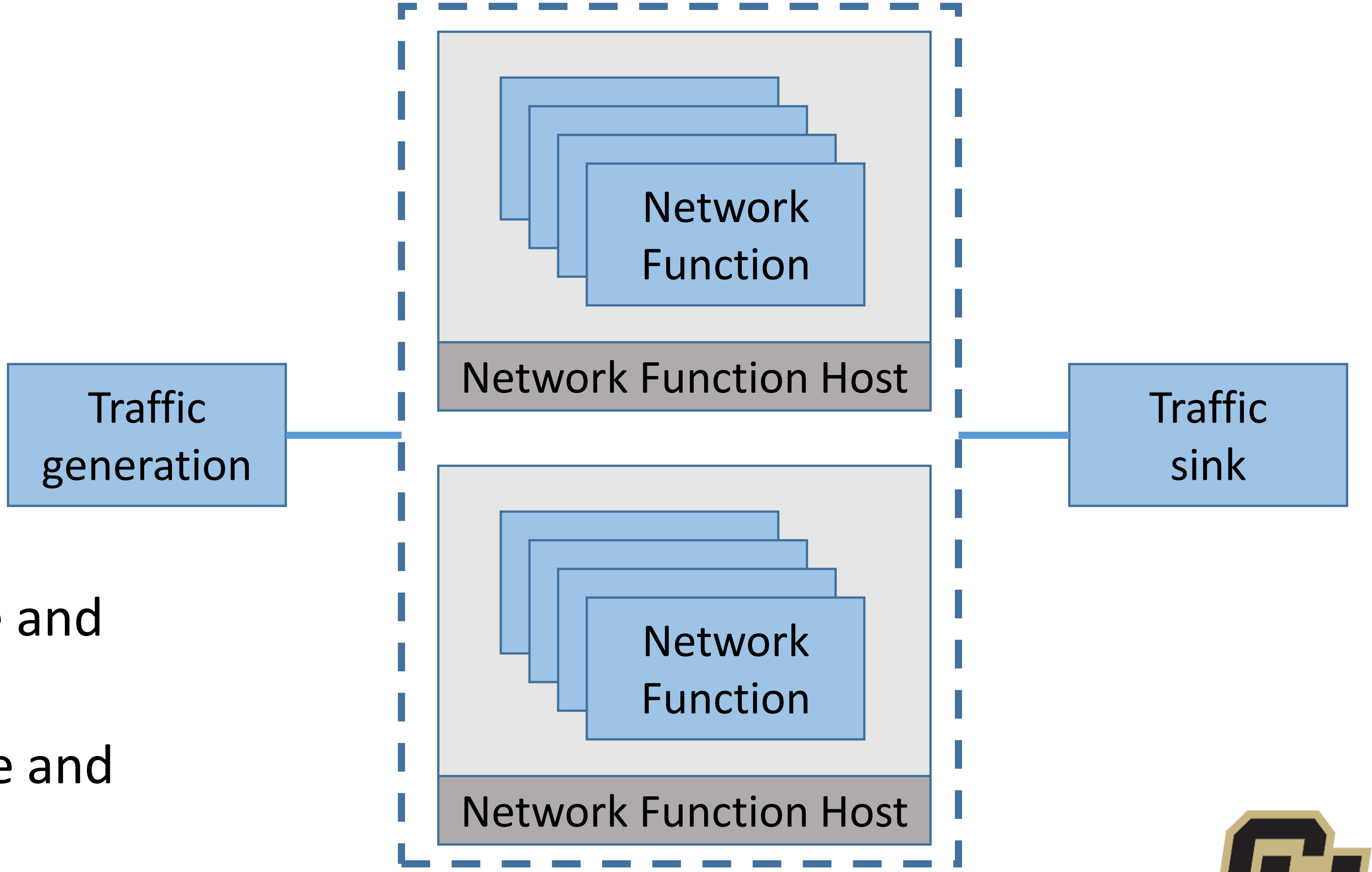
Experiment Setup

Tests:

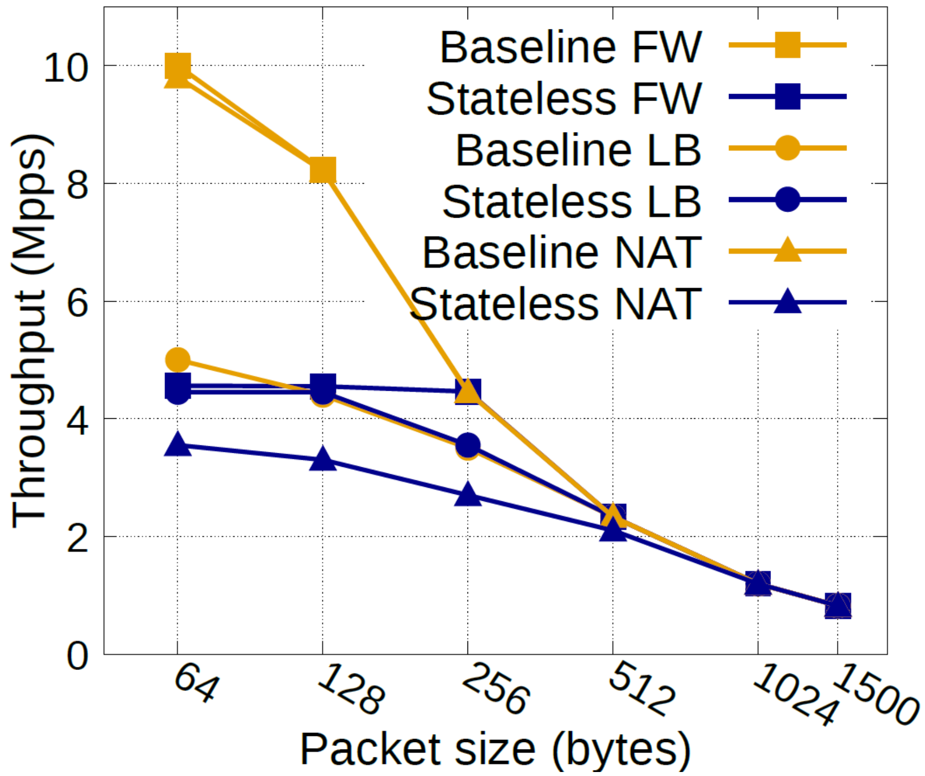
- Raw throughput, latency
- Handling failure
- Handling scaling in-out

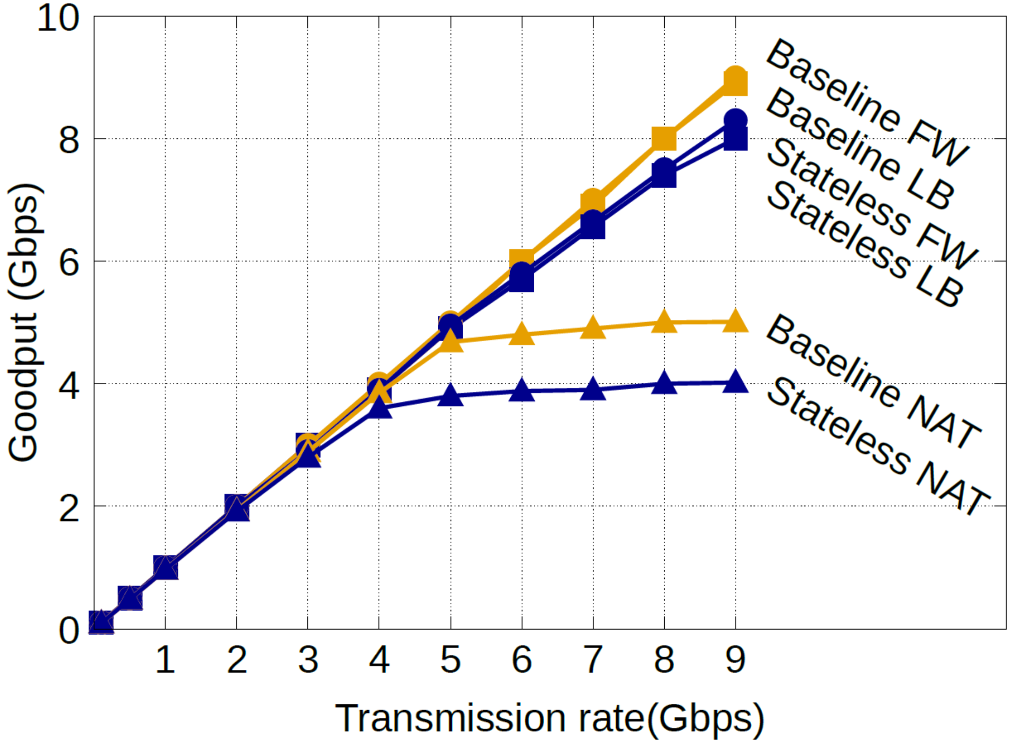
Network Functions:

- Baseline Network Functions (state and processing are coupled)
- Stateless Network Functions (state and processing are decoupled)



Throughput



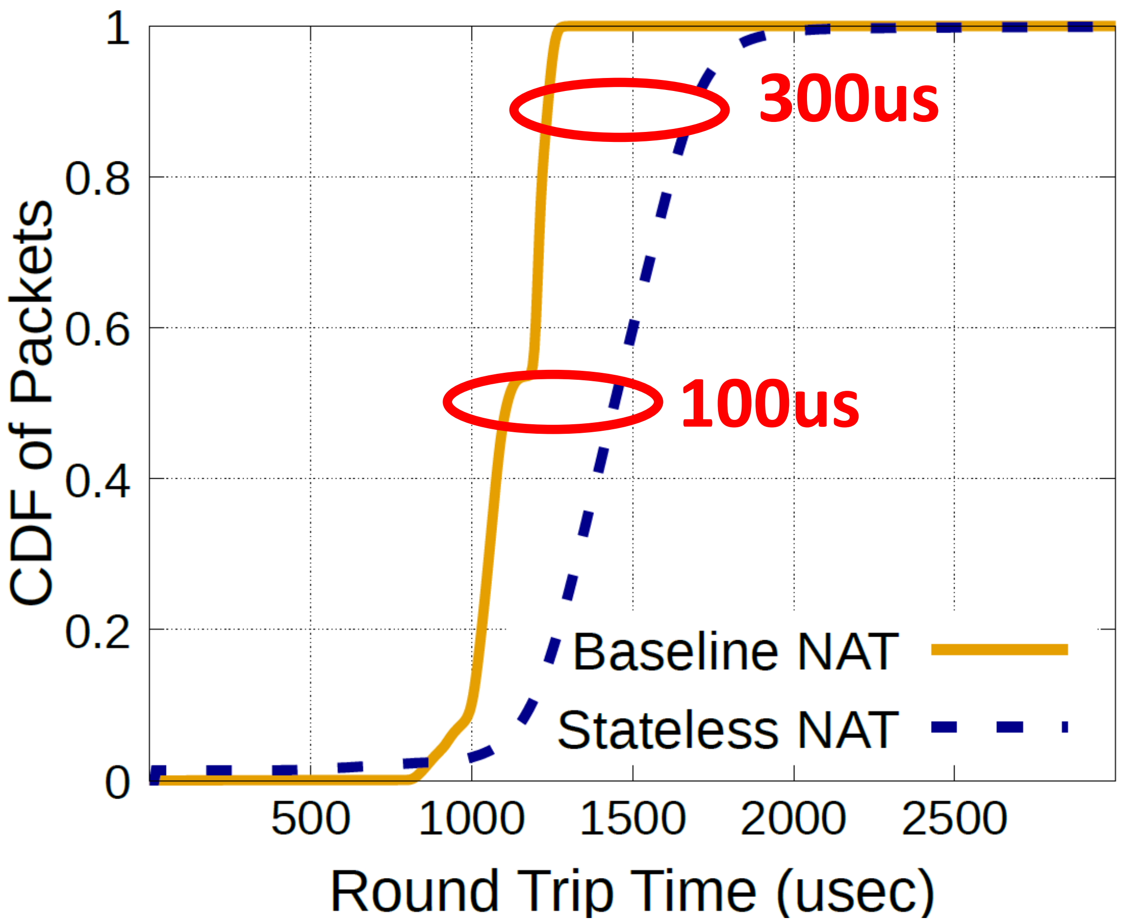


Raw packets per second – lower until about 256 byte packets

Enterprise Trace – Stateless Roughly matches Baseline

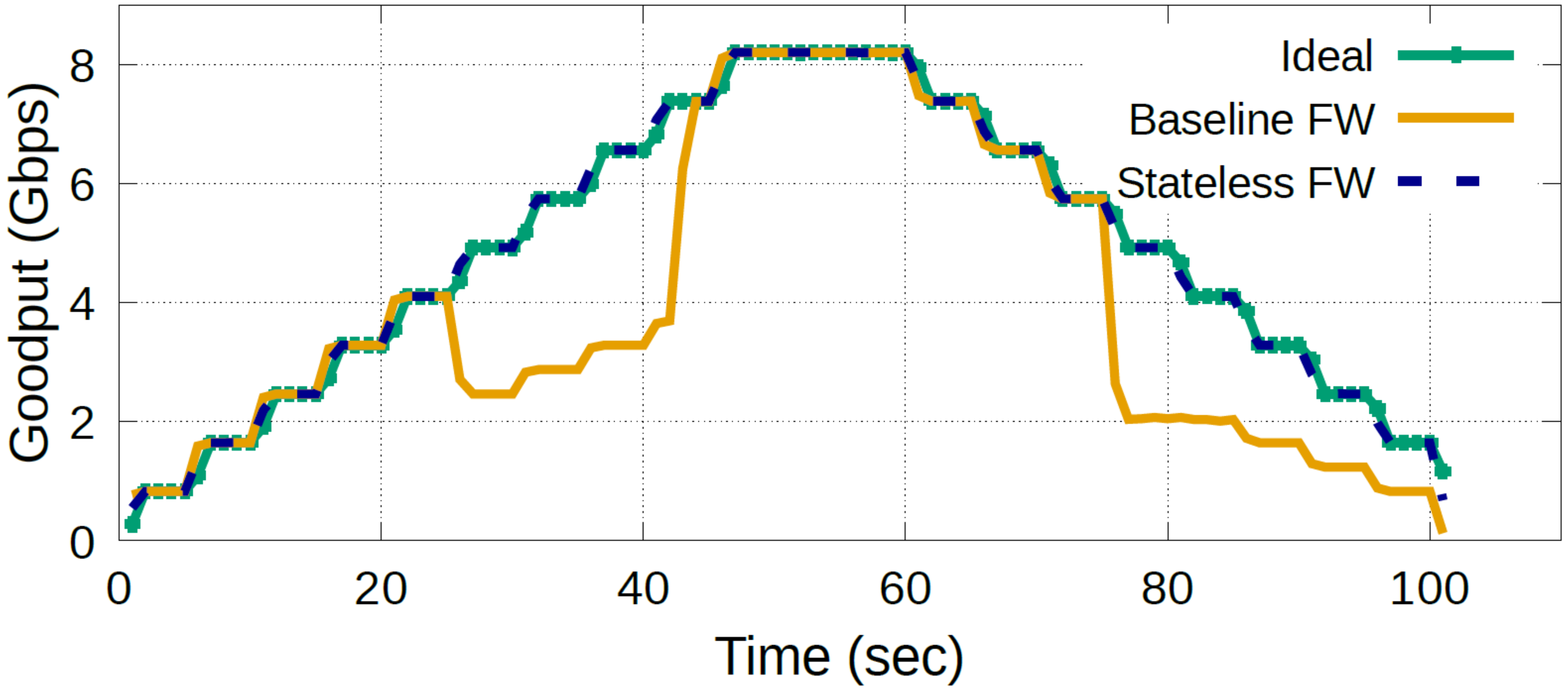
Note: similar to systems which have added support for scaling or failure

Latency

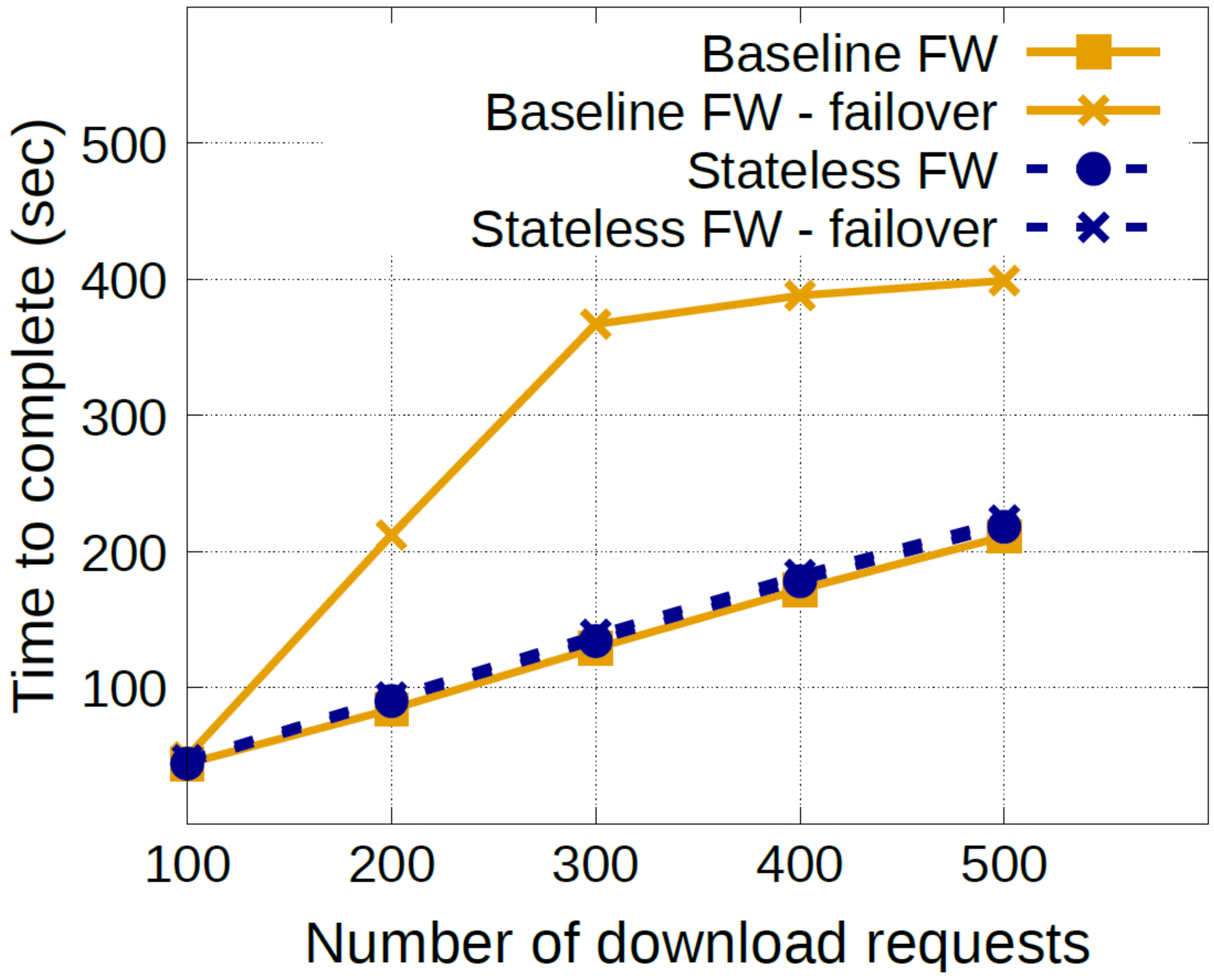


NAT (Firewall and Load balancer has slight less latencies)

Scaling In and Out



Handling Failure



Discussion and Future Work

Discussion

- Date store scalability
  - Replace RAMCloud with other systems that report better throughput and lower latency (e.g., FARM, Algo-Logic)
- Reducing interactions with a remote data store
  - Integrate a set membership structure (e.g., a bloom filter) to reduce the penalty of read misses
  - Explore placement of data store instances (e.g., co-locating with network function instances)

Conclusions and Future Work

- Networks need agile network functions
  - Seamless scalability, failure resiliency, without sacrificing performance
- StatelessNF is a design from the ground up
  - Zero loss scaling, zero loss fail-over
- Main potential drawback… performance, but in this extreme point:
  - Throughput similar to other solutions
  - 100-300us added latency (similar to other solutions)
- Future work: Evolve data store design for network functions

Thanks!