Recent Advances in Network Functions

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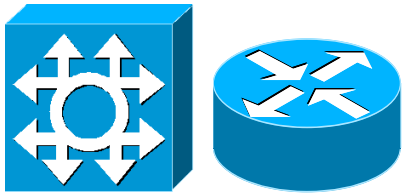
UW-Madison

HotMiddlebox 2016

Network functions

Routing and switching

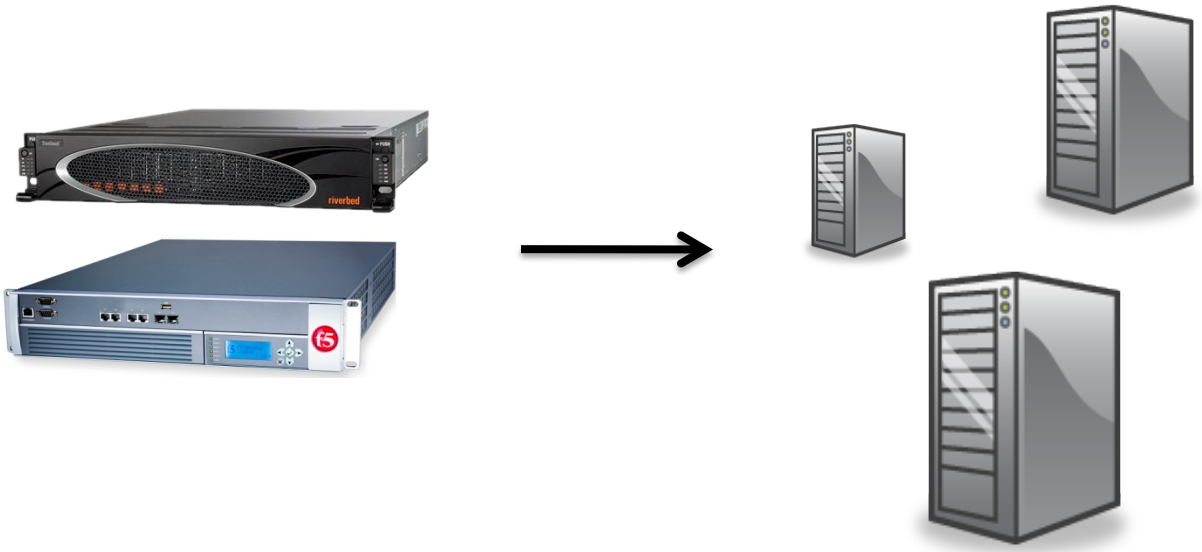


Functionality added to routers

Filtering
Load balancing
Rate limiting

Implemented as custom packet processing boxes

"Middleboxes"
Firewalls, proxies,
intrusion detection systems,
scrubbing, load balancing,
Security, WAN optimization



Network functions virtualization

- VMs
- Containers
- Micro-services (lambas?)

Platforms for implementing, deploying NFs

- CoMB
- NetBricks

Point impl. of specific functions

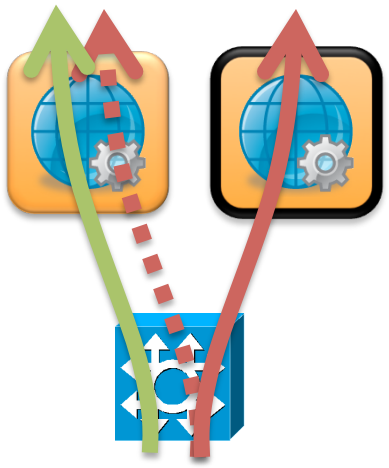
- SDN-based NATs/ filtering
- Software load balancers

This talk

- Some fundamental issues, and systems we built
  - State management
  - Software implementation
  - Composition
- Some interesting open problems

State Management

Dynamic **reallocation** in **distributed** processing



Load balancing

Elastic scaling

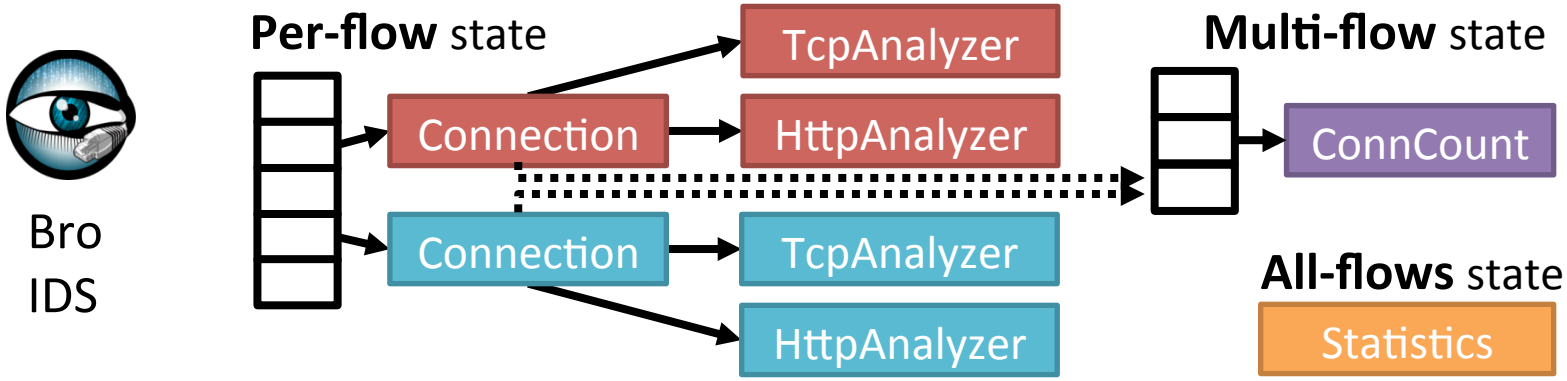
High availability

Network migration

Remote invocation

Always updated NFs

Stateful operation

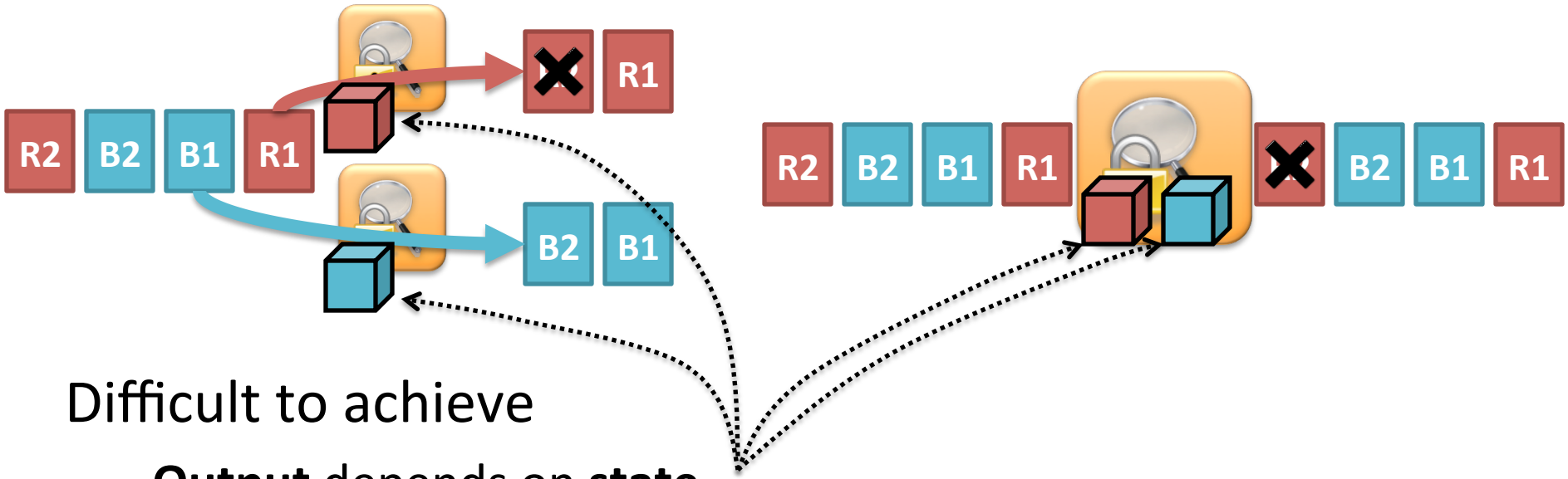


Dynamically updated
per packet

NF's **action** for packet depends on **state**

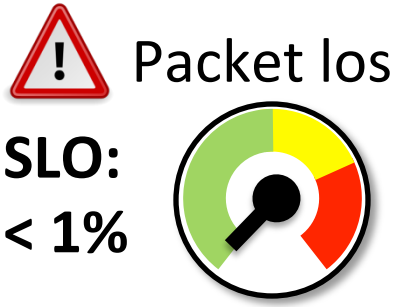
Output equivalence:

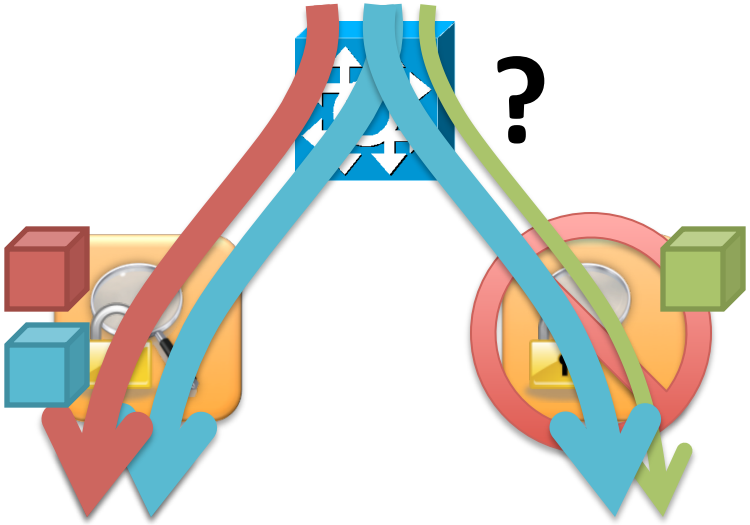
Multiple instances of an NF should collectively produce the **same output** as a **single** instance



Difficult to achieve

- **Output** depends on **state**
- Desire for ↑ **performance** and ↓**resource usage**


Packet loss
SLO:
< 1%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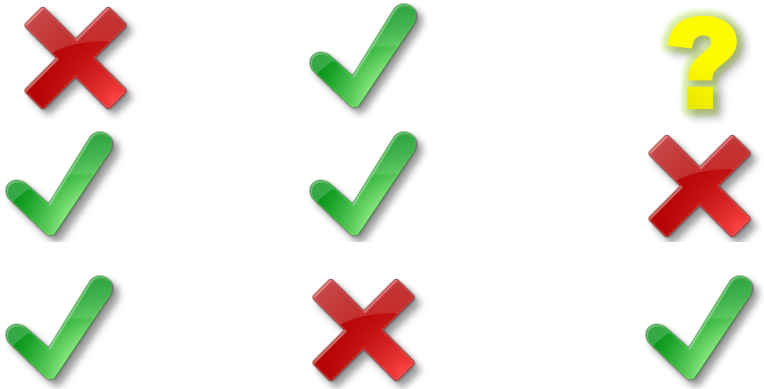
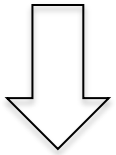
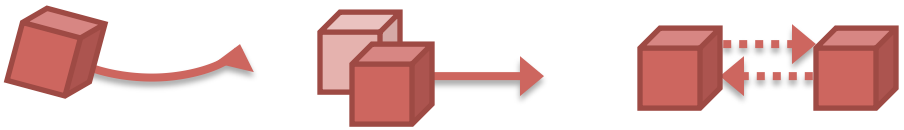

?

The state management problem

Performance + **resource use** + **output equiv.**

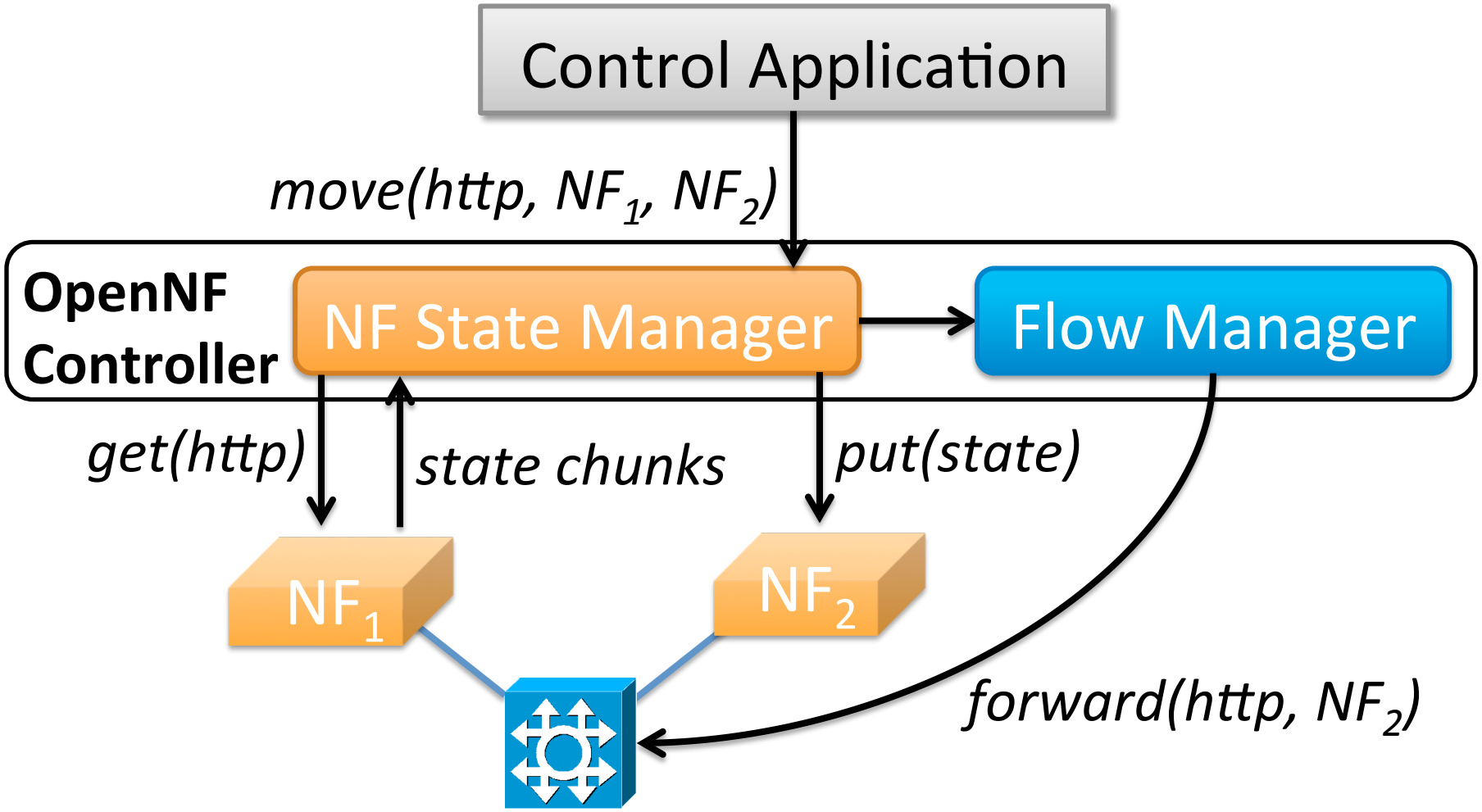


Quickly **move or copy NF state** alongside updates to network forwarding state



Safety guarantees on updates (none lost; no reordering)

OpenNF


Control Application
move(http, NF1, NF2)
OpenNF Controller
NF State Manager
Flow Manager
get(http)
state chunks
put(state)
NF1
NF2
forward(http, NF2)

Events for loss-free move

1. enableEvents(red) on Bro_1
2. get/delete on Bro_1
3. Buffer events at controller
4. put on Bro_2
5. Flush packets in events to Bro_2
6. Update forwarding

Loss free move

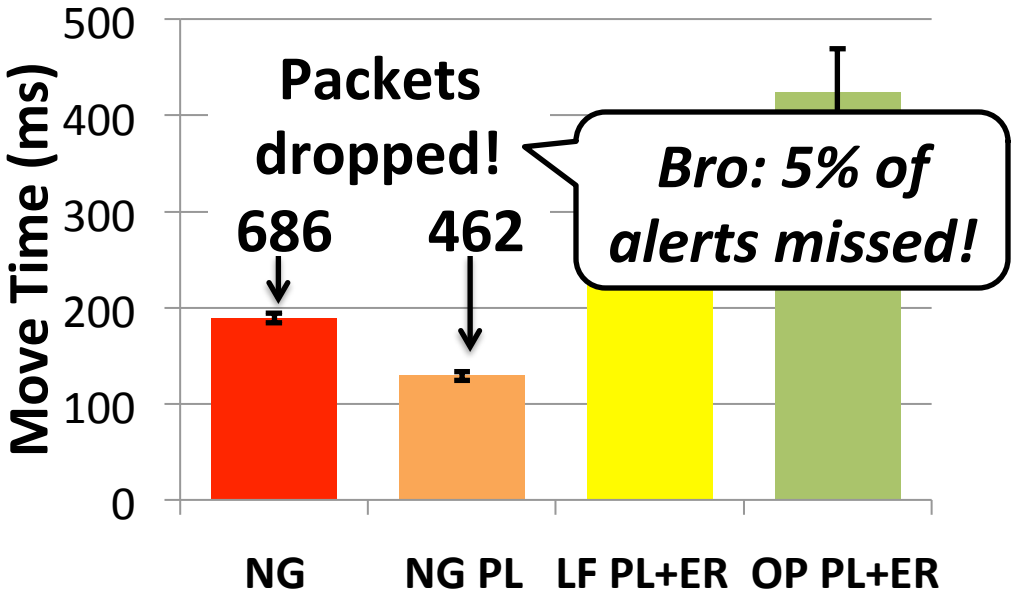
Order-preserving move

Eventual, strict, strong consistency for state sharing

Safety guarantees

PRADS asset detector processing 5K pkts/sec

Move per-flow state for 500 flows



Operations are efficient, but guarantees come at a cost!

Open issues: state

- Better approaches to move/copy state?
  - E.g., FTMB's copy operation is faster, offers stronger consistency; but no support for move
- Other safety guarantees
  - Timing of packets, cross-session ordering?
- What if state is externalized?
  - Copy may be simplified
  - Move is still nuanced
    - Coordinating processing reallocation
    - Local caching of state may complicate matters

Automating Modification Using StateAlyzr

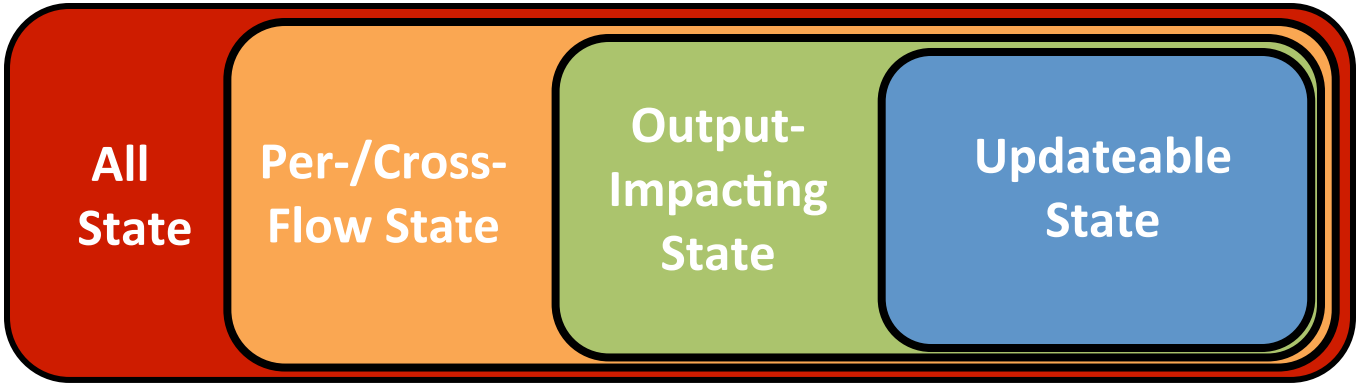
required for **output equivalence**

Soundness means that the system ***must not miss any critical*** types, storage locations, allocations, or uses of state

required for **performant state transfers**

Precision means that the system identifies ***the minimal set of state*** that requires special handling.

StateAlyzr



MB	All variables	Persistent variables	per-/cross-flow	Updateable
PRADS	1529	61	29	10
Snort IDS	18393	507	333	148
HAproxy	7876	272	176	115
OpenVPN	8704	156	131	106

StateAlyzr offers useful ***improvements*** in ***precision***

Theoretically ***proved*** the ***soundness*** of our algorithms

Software Implementation

Host-based functions

Goal: CPU, memory efficiency; speed

Careful allocation of cores
Cache allocation
VM-to-VM copy
…

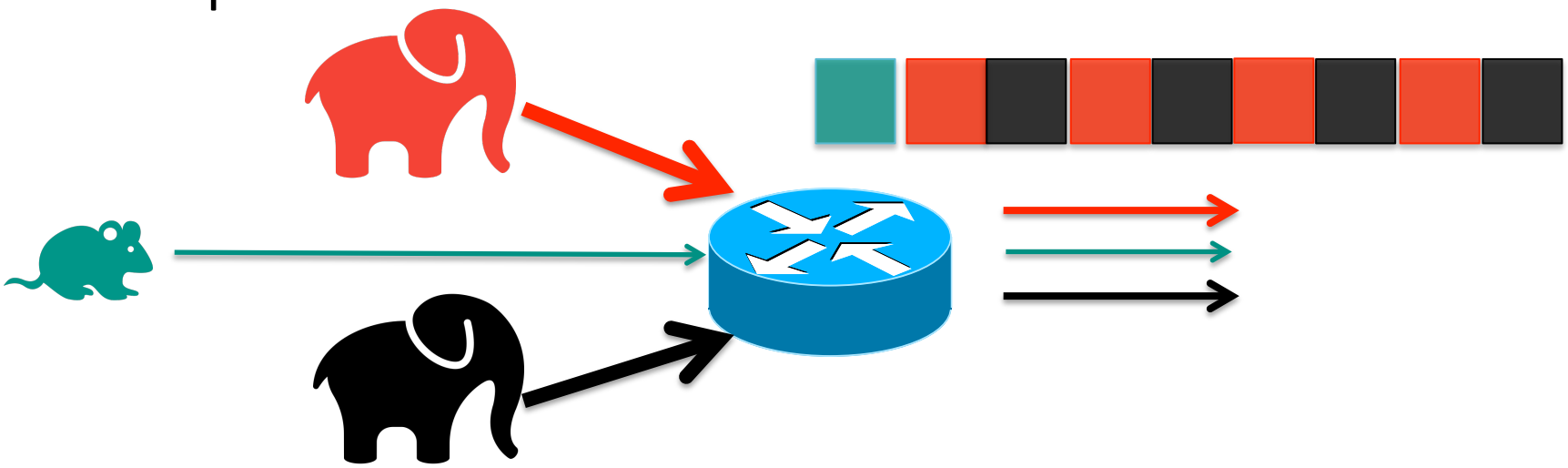
Network-wide functions

Also: meet global goals

Relatively unexplored
E.g., network load balancing

Network Load Balancing

- Network congestion: flows of all types suffer
- Example



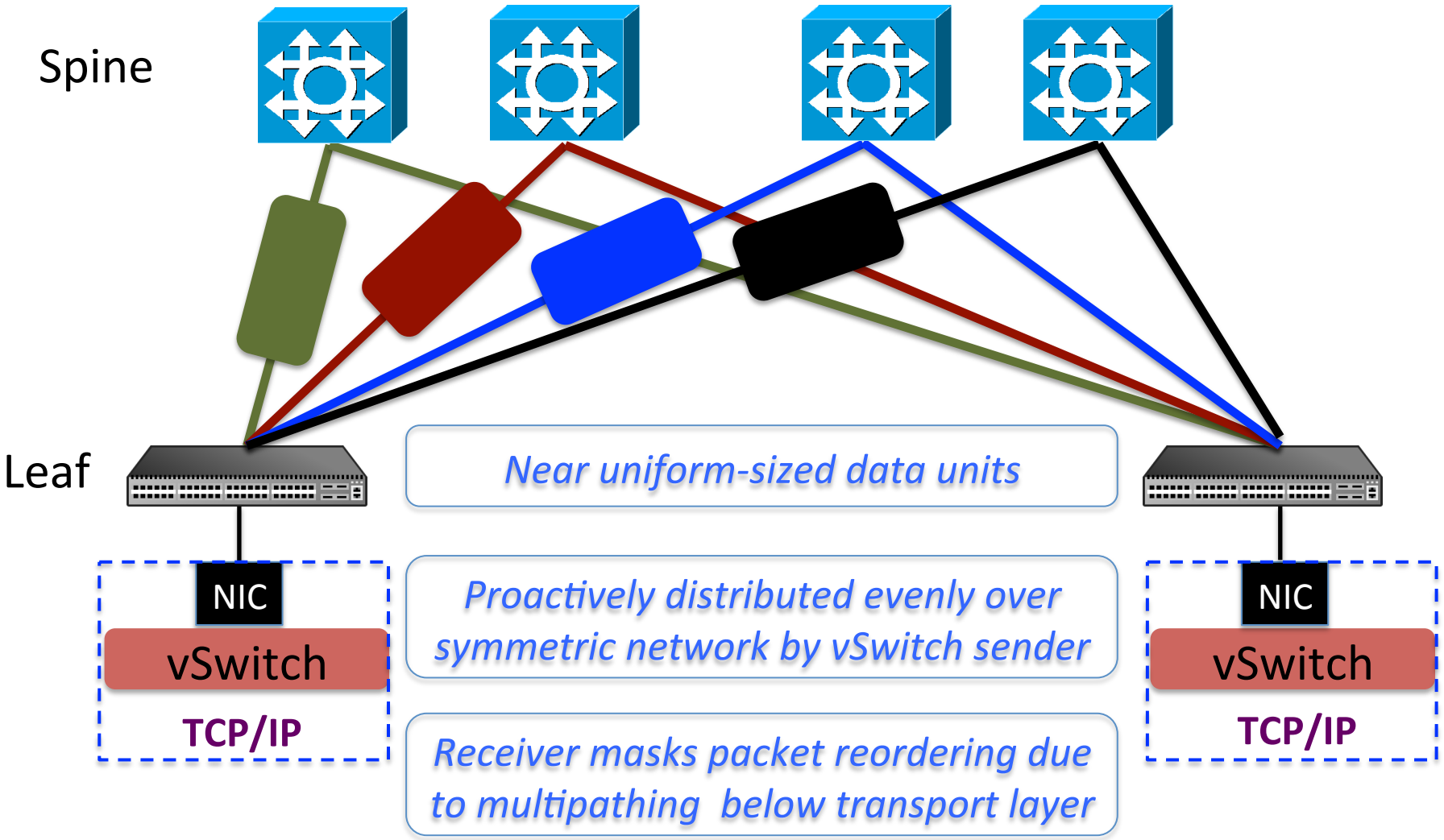
  - Elephant throughput is cut by half
  - TCP RTT is increased by 100X per hop (Rasley, SIGCOMM'14)

Traffic Load Balancing Schemes

Scheme	Hardware changes	Transport changes	Granularity	Pro-/reactive
ECMP	No	No	Coarse-grained	Proactive
Centralized	No	No	Coarse-grained	Reactive (control loop)
CONGA/ Juniper VCF	Yes	No	Fine-grained	Proactive
MPTCP	No	Yes	Fine-grained	Reactive
Presto	No	No	Fine-grained	Proactive

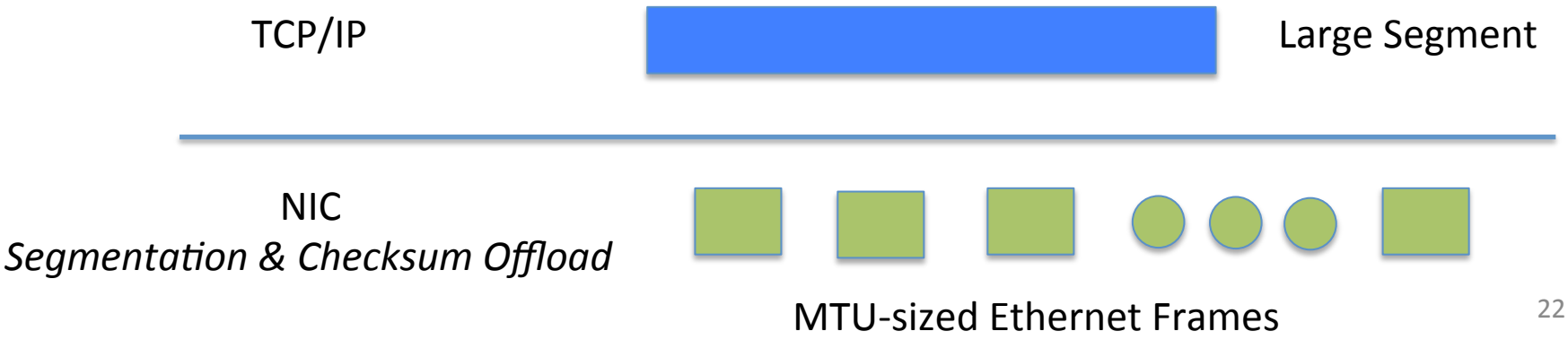
Can we do this purely in software?

Presto at a High Level



Presto LB Granularity

- Presto: load-balance on *flowcells*
- What is flowcell?
  - *A set of TCP segments with bounded byte count*
  - Bound is maximal TCP Segmentation Offload (TSO) size
    - Maximize the benefit of TSO for high speed
    - *64KB* in implementation
- What's TSO?



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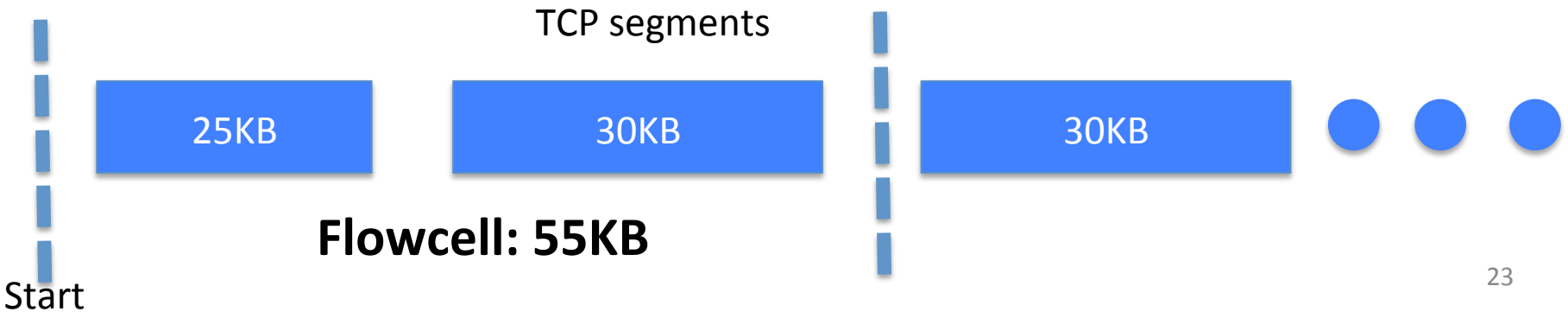

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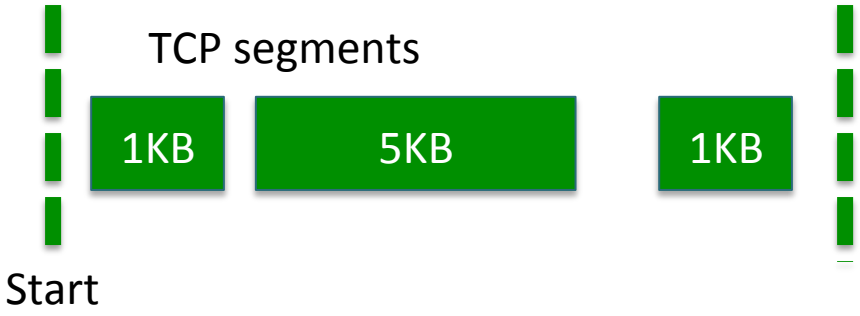
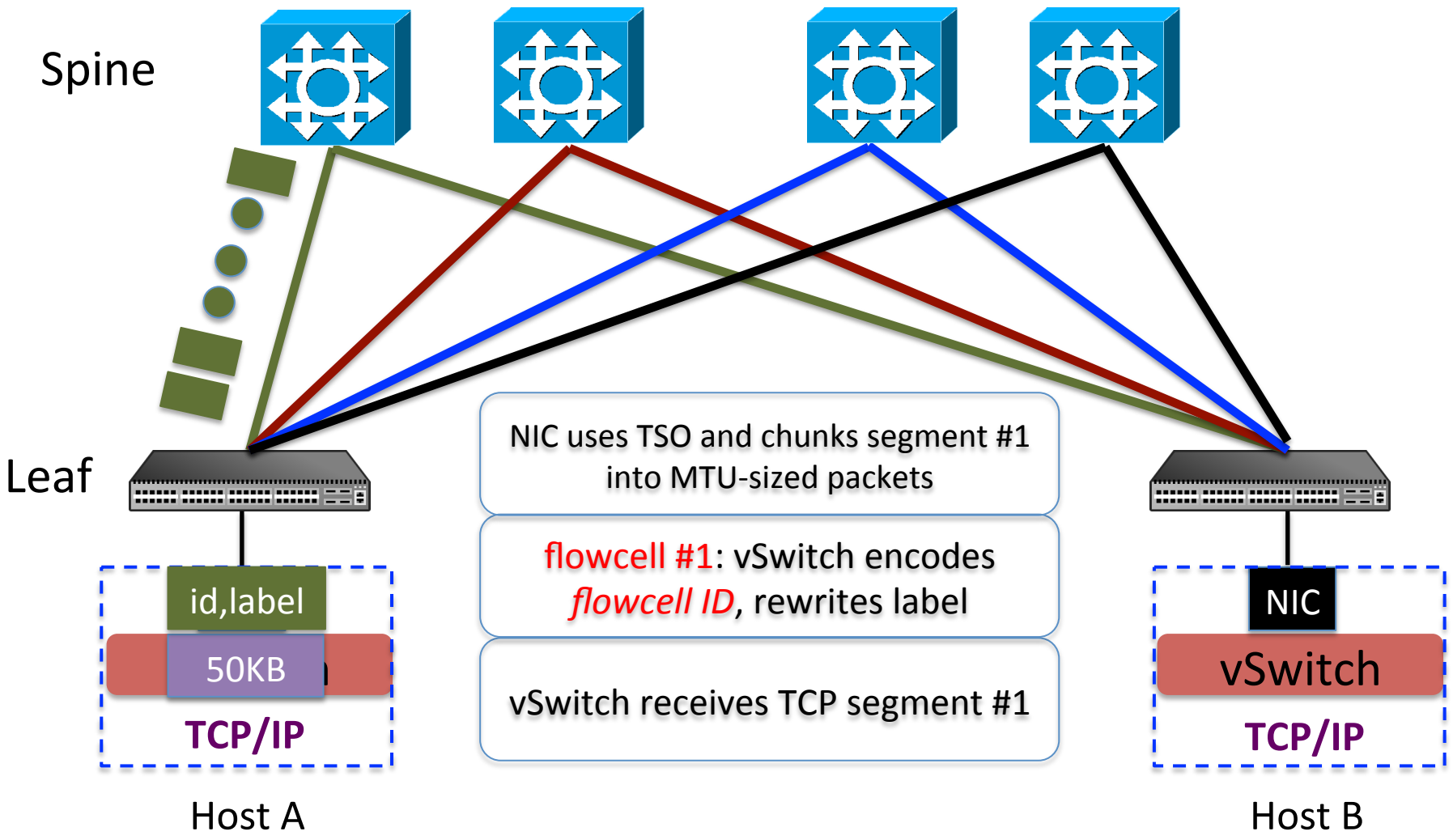


Flowcell: 7KB (the whole flow is 1 flowcell)

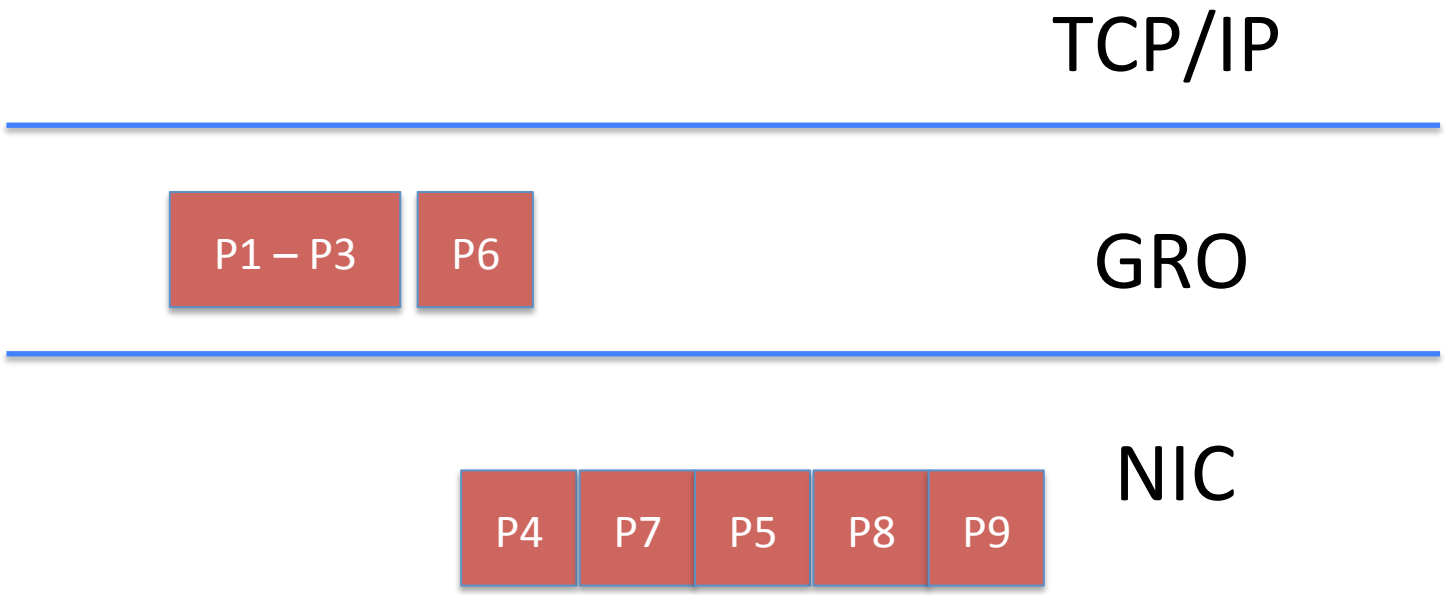
Presto Sender



Benefits

- Many flows smaller than 64KB [Benson, IMC'11]
  - *the majority of mice are not exposed to reordering*
- Most bytes from elephants [Alizadeh, SIGCOMM'10]
  - *traffic routed on uniform sizes*
- Fine-grained and deterministic scheduling over disjoint paths
  - *near optimal load balancing*

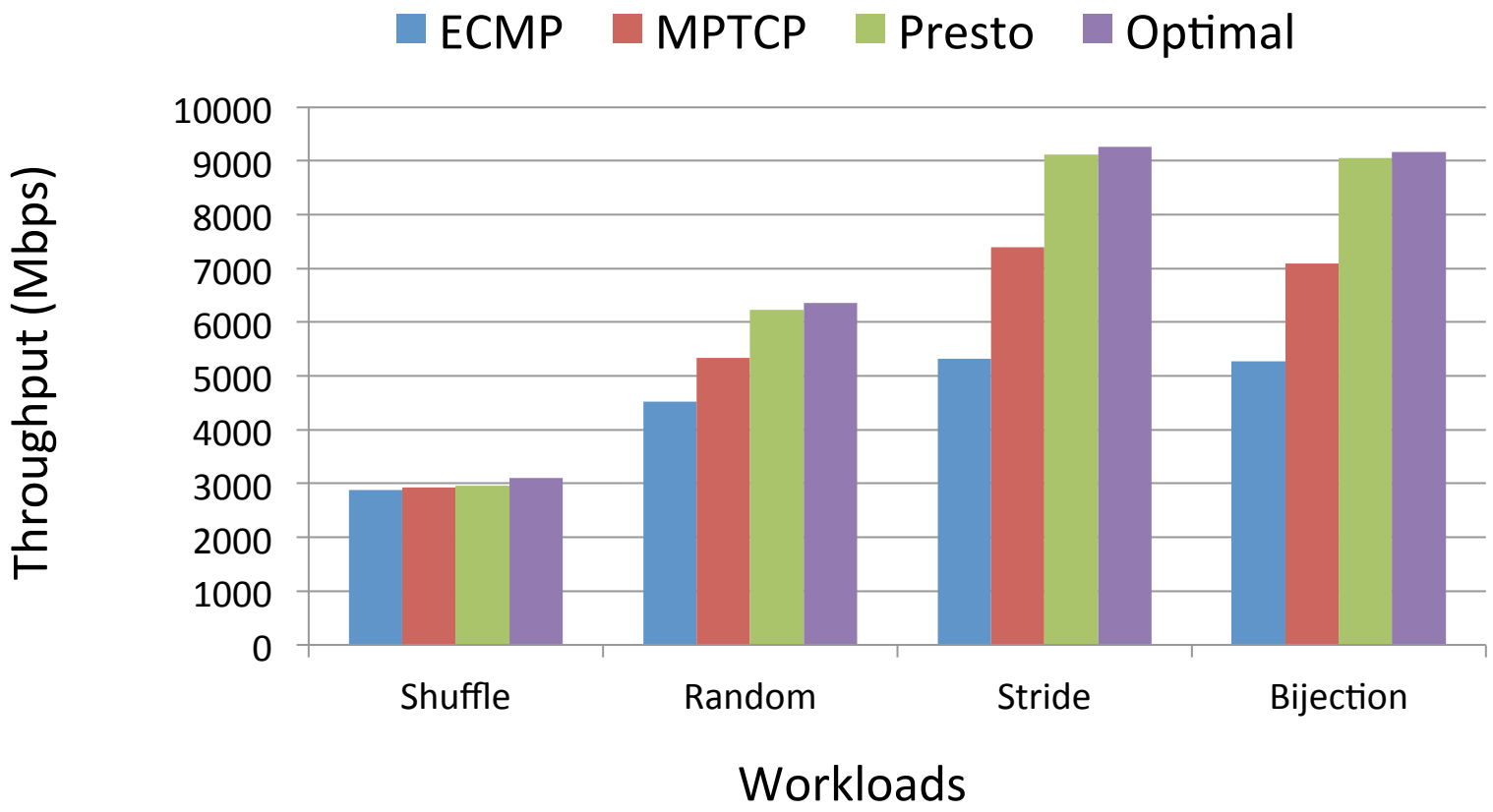
Presto Receiver



- Packet reordering for large flows due to multipath
  - Interferes with GRO – rendering GRO useless
  - Flowcell-aware GRO
- Distinguish loss from reordering
  - Smart heuristic based on flowcell routing properties

Evaluation

Presto's throughput is within 1 – 4% of Optimal, even when the network utilization is near 100%; In non-shuffle workloads, Presto improves upon ECMP by 38-72% and improves upon MPTCP by 17-28%.

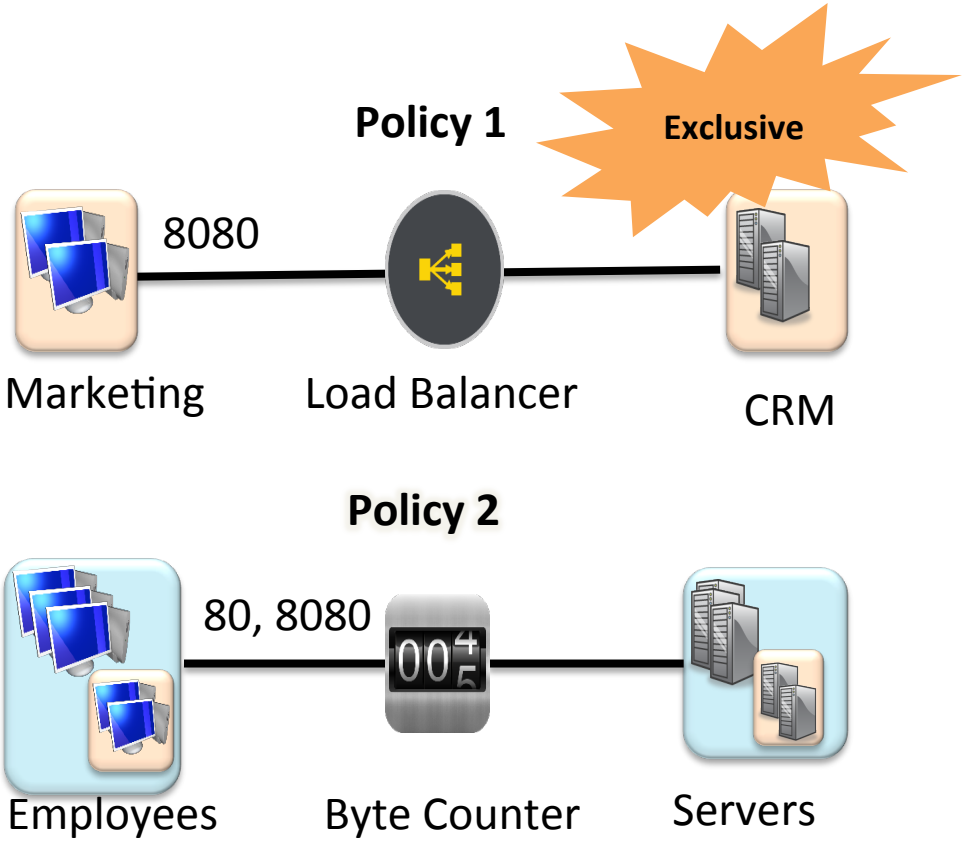


Optimal: all the hosts are attached to one single non-blocking switch

Open issues: implementation

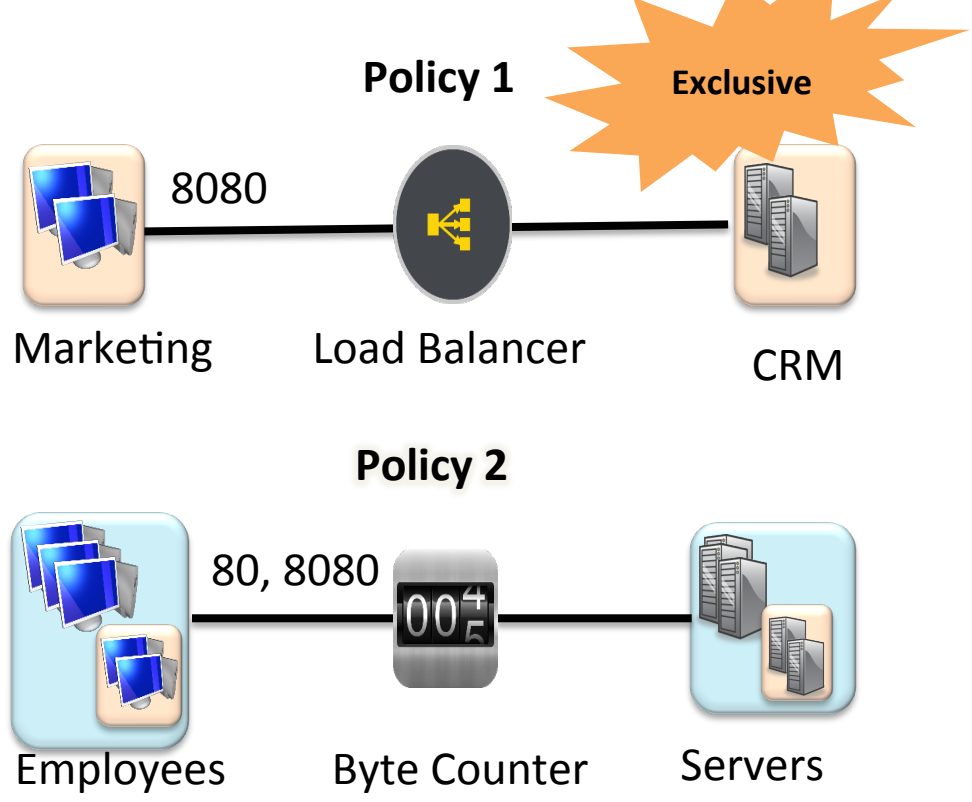
- Leveraging server features and network to accelerate network functions
  - Hashing, checksumming, multiple queues, RDMA
- Data plane programmability, e.g., PIFO, DOMINO, P4
  - Selectively offload to switches for performance or visibility
- Programmatic control over such network functions
- Moving other network-wide functions to the edges
  - Failure recovery, cross-flow caching/analysis, QoS

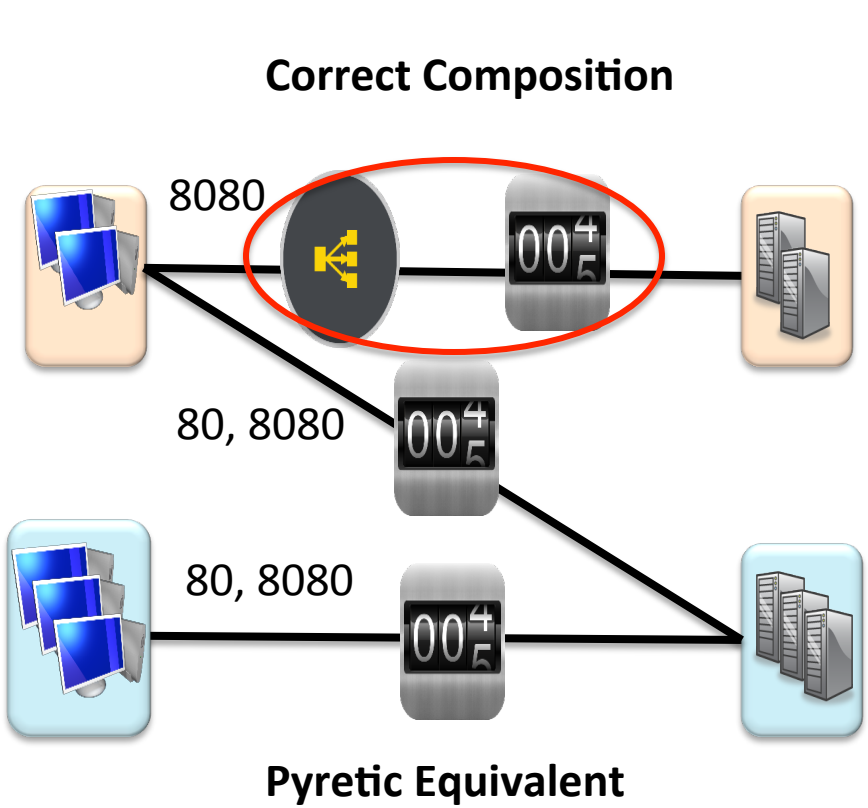
Chain Composition



Compose chains to realize joint intent?

Do NFs compose? NF ordering?





Pyretic Equivalent

Deconstruct P1 and P2 into ACLs, chaining rules

Understand **flow space relations**

Understand **joint intent** of P1 and P2
P1 supersedes P2

Insert a **drop rule**

Understand **NF operation** to order NFs

```
if_(match(srcip=Mktg, tcp, dstport=8080, dstip=CRM),
   LB>>BC>>route,
   if_(match(dstip=CRM),
      drop,
      if_(match(srcip=Empl, tcp,
                dstport=80|8080,
                dstip=Servers),
         BC>>route,
         drop)))
```

Composition challenges

Constructs not rich enough to **encode policy intent**

- In a policy: e.g., an ACL *must* apply
- Across policies: joint intent

Need to know about **NFs actions** to **compose** them

PGA (policy graph abstraction):
A first attempt aimed at **common** cases

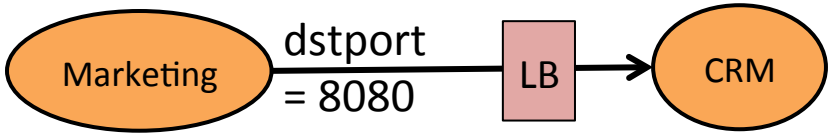
Raises the level of abstraction

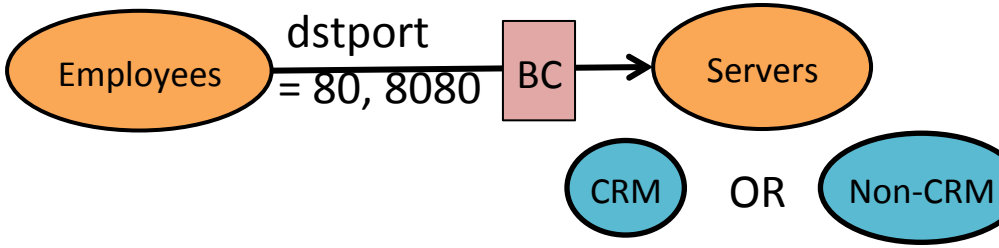
Composition support by
construction

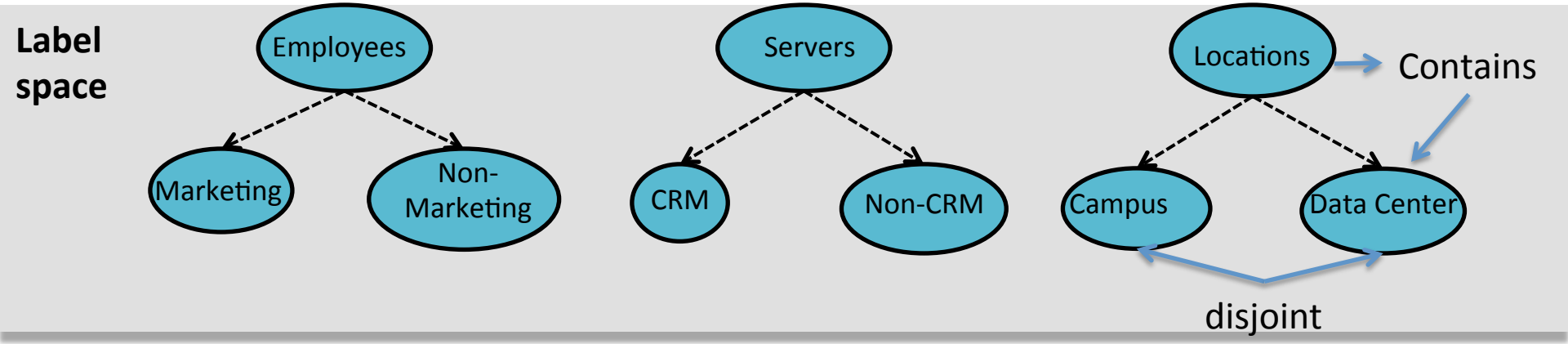
Constructs (1): Policy Graph basics

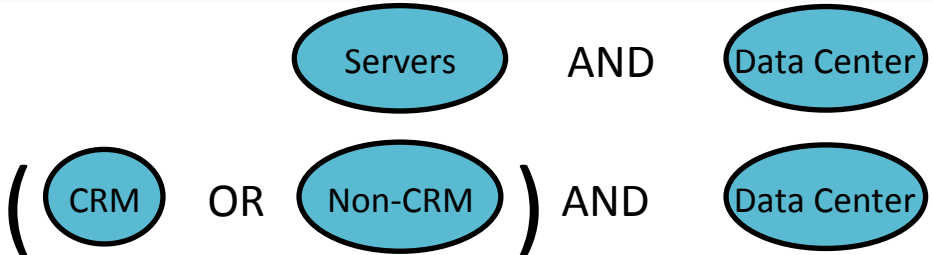
EPG – end-points that satisfy a membership predicate, defined over **labels**

Edge attributes – whitelist and service chain → allowed communication







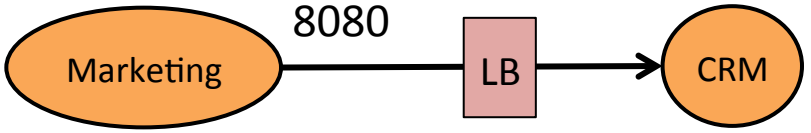


Constructs (2): Composing NFs

Constraints: allowed policy changes when a policy graph is composed with others

No need to specify joint intent, e.g., action precedence

Policy 1



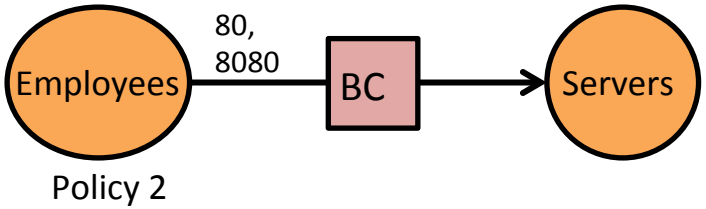
OK to **further constrain** the packet space, but cannot completely disallow

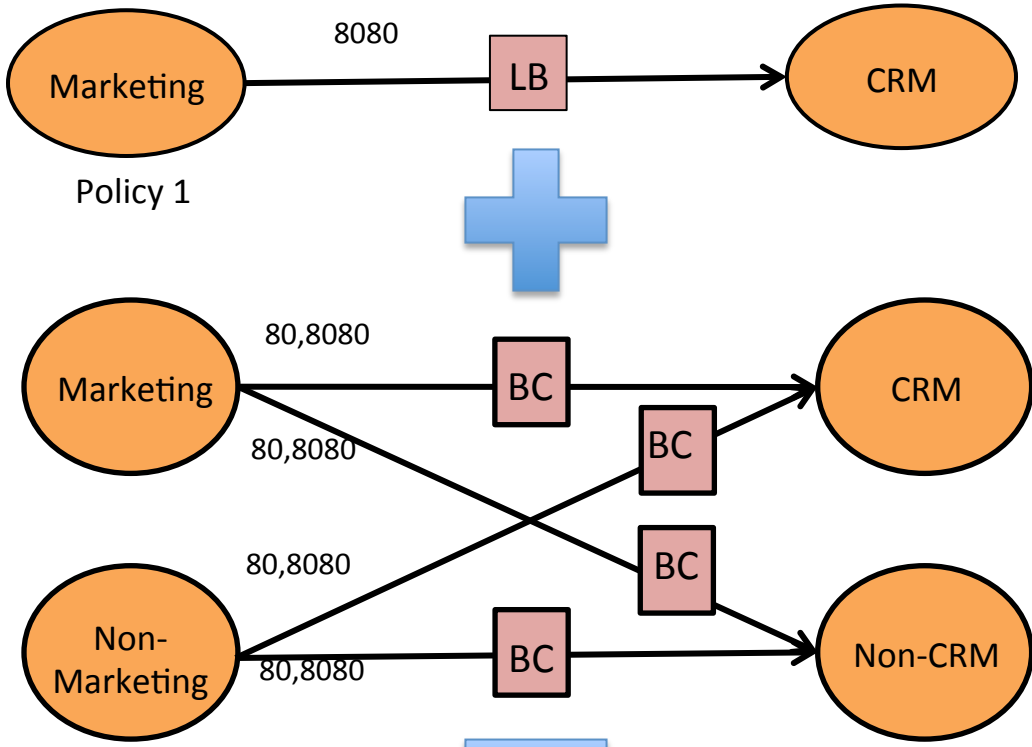
No other communication is allowed

	Classifier		NF	
Match	**Add**	**Remove**	**Drop**	**Modify**
srcIP=Mktg, dstIP=CRM, dstPt=8080	Y	N	N	DSCP= 16, 18,20
dstIP=CRM	N			

Constraints on **NF actions**

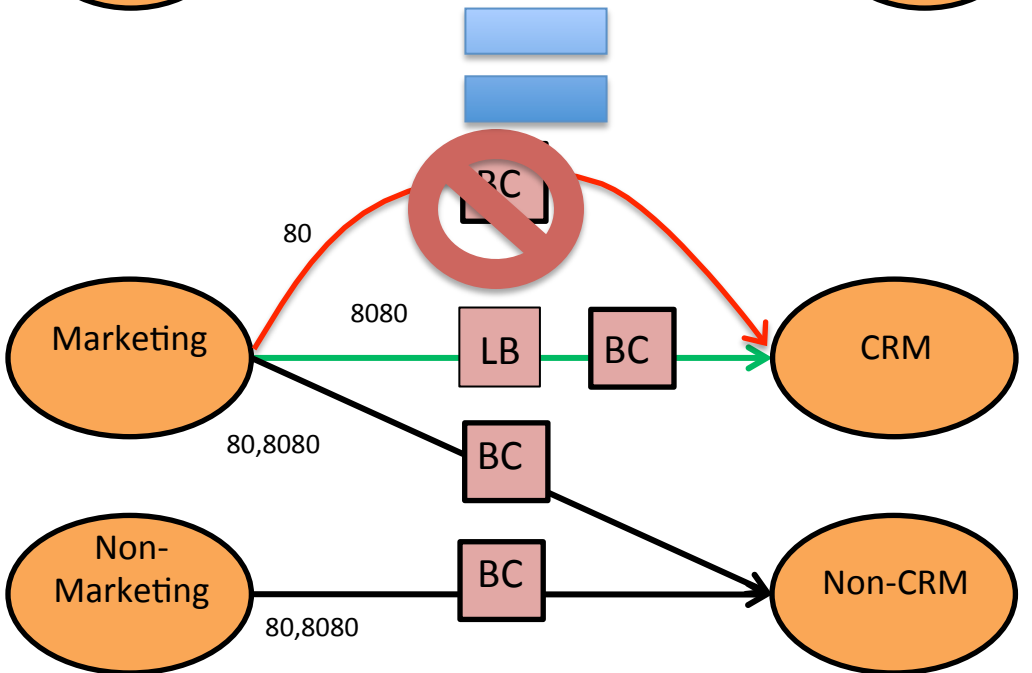
1 **Normalization:** separate input EPG into an equivalent set of disjoint EPGs by rewriting predicate in **positive disjunctive normal form**





2 **Graph union:** merging edges using constraints

	Classifier	
Match	**Add**	**Remove**
srcIP=Mktg, dstIP=CRM, dstPt=8080	Y	N
dstIP=CRM	***N***	



Constructs (3): Grayboxing NFs

match: (dstip=Servers.RIPs) >> count_bytes: {group_by: [dstip]}

Byte Counter

Full specification for some NFs

Grayboxing: specifies the high level **packet processing** behavior of NFs

Input/output packet spaces

match(dstip=CRM.virtIP) >> modify(dstip=CRM.RIPs)

Load Balancer

Not rich enough: necessary but not sufficient

3

NF ordering: dependency analysis

LB

Policy:

match: (dstip=CRM.virtIP) >>
modify: (dstip=CRM.RIPs)

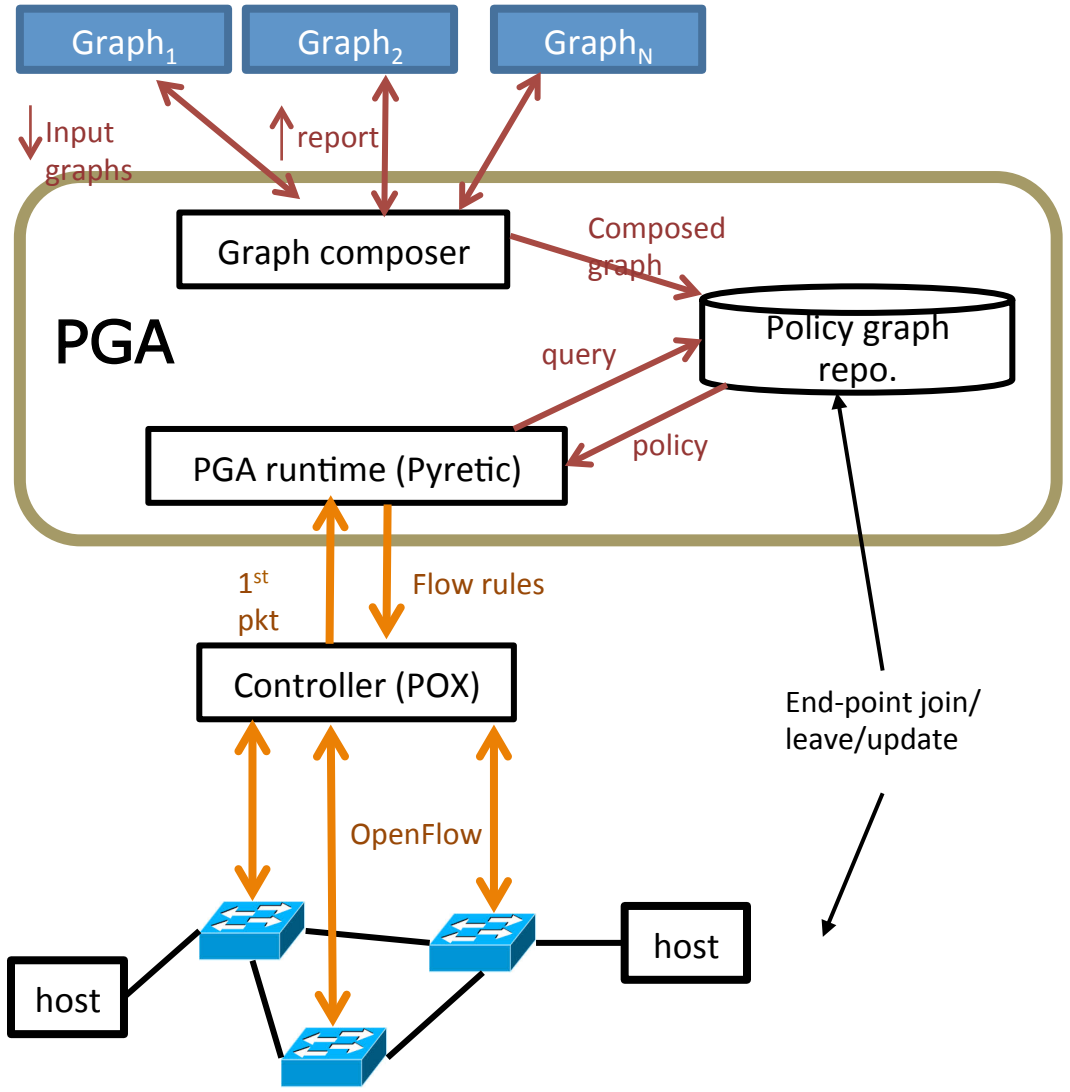
Byte Counter

Policy:

match: (dstip=Servers.RIPs) >>
count_bytes: {group_by: [dstip]}

Topological sort over a dependency graph

PGA Implementation



- Build predicates
- Look up norm. EPGs
- Look up policy

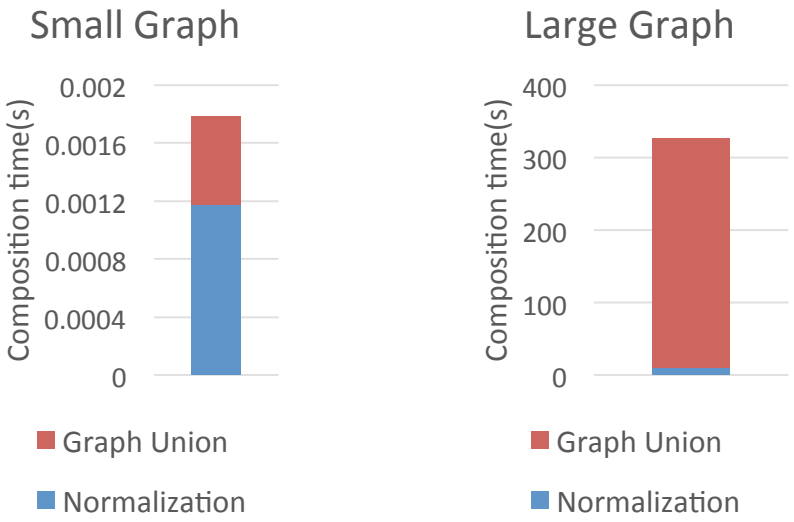
Evaluation

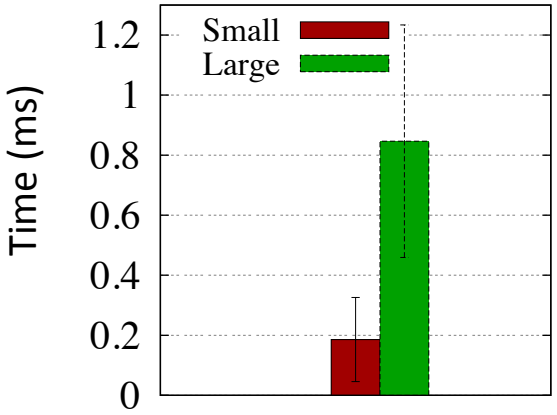
Small synthetic input:
11 EPGs, 4 NFs, 7 EPG-EPG edges

Composed to: **8 EPGs, 20 edges**

Large real input:
137 departments, 4340 subnets, 20K ACLs

Composed to: **3.7K EPGs, 2.1M edges**





Open issues: composition

- Support for richer policies
  - QoS/performance metrics
  - Stateful or event-driven/dynamic policies
- Accommodating other general NFs
- Limitations of graph-based abstractions
  - Network-wide objectives (TE, load balance)

Network functions: rich space!

- Some initial contributions in state management, software implementation and chain composition

- Plenty of ground still to cover