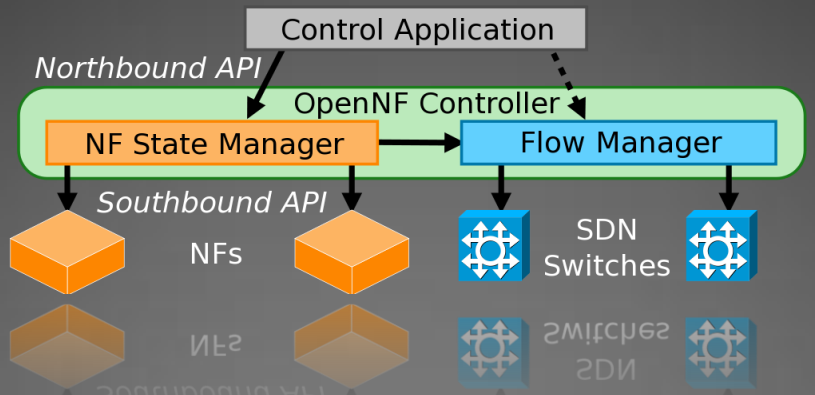

OpenNF: Enabling Innovation in Network Function Control

WISCONSIN
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Network functions (NFs)

- Perform sophisticated *stateful* actions on packets/flows

WAN optimizer

Caching proxy

Intrusion detection system (IDS)

NF trends

- Network Functions Virtualization (NFV)

WAN optimizer

Caching proxy

Intrusion detection system (IDS)

NF trends

- Network Functions Virtualization (NFV)

  → dynamically allocate NF instances

NF trends

- Network Functions Virtualization (NFV)

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- Software-defined Networking

  → dynamically reroute flows

NF trends

- Network Functions Virtualization (NFV)

  → dynamically allocate NF instances

  ✚

- Software-defined Networking

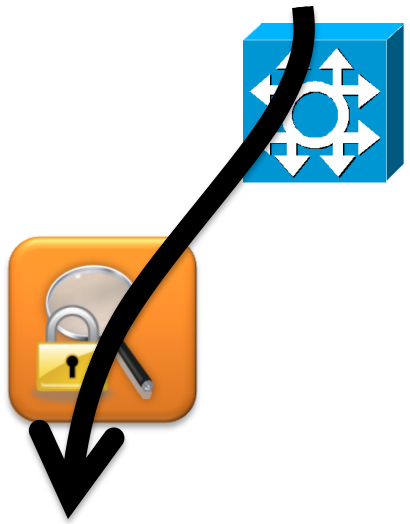
  → dynamically reroute flows

  ⬇

  Dynamic reallocation
  of packet processing

Example: elastic NF scaling

1. Satisfy performance SLAs



Example: elastic NF scaling

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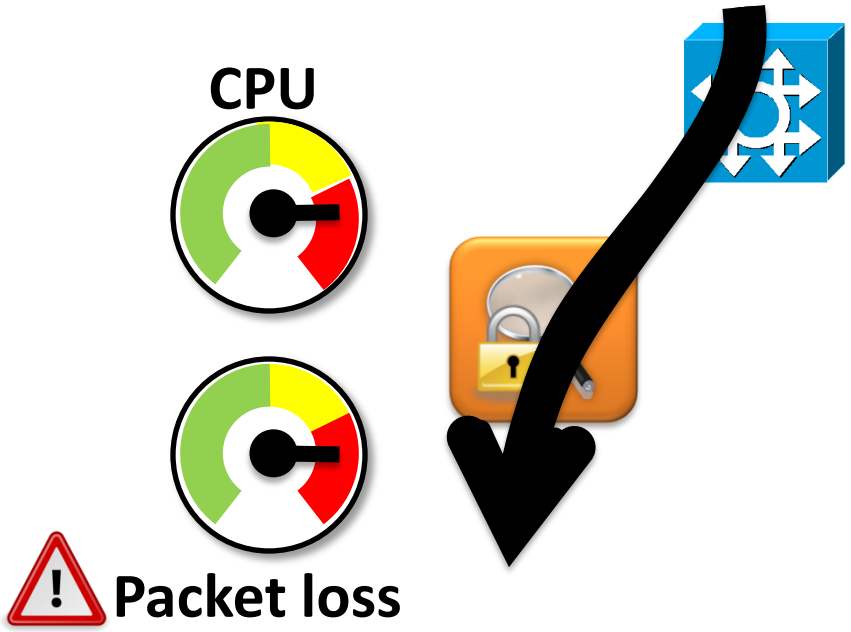

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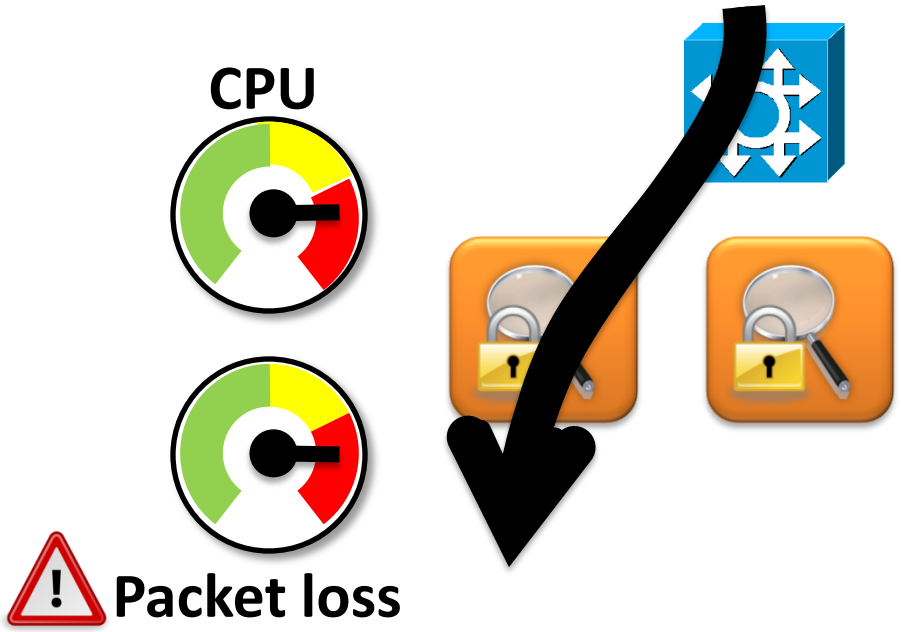

Example: elastic NF scaling

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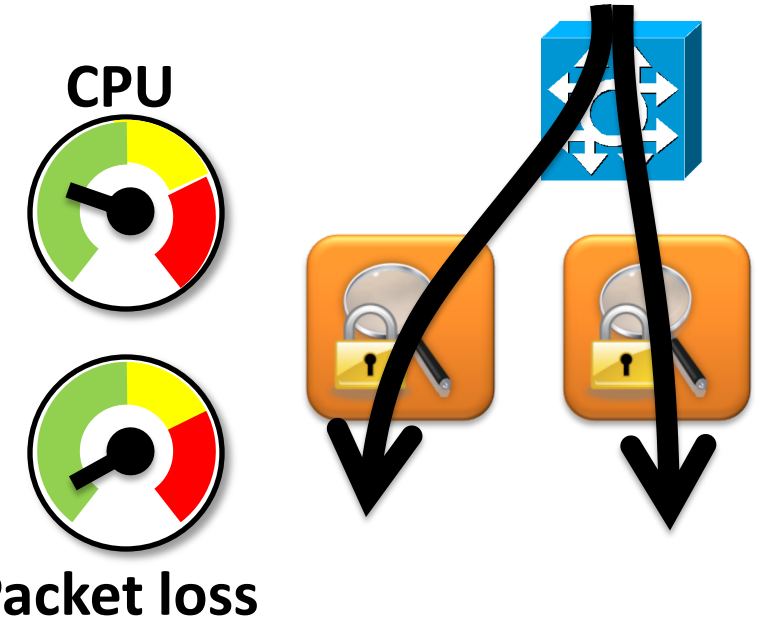
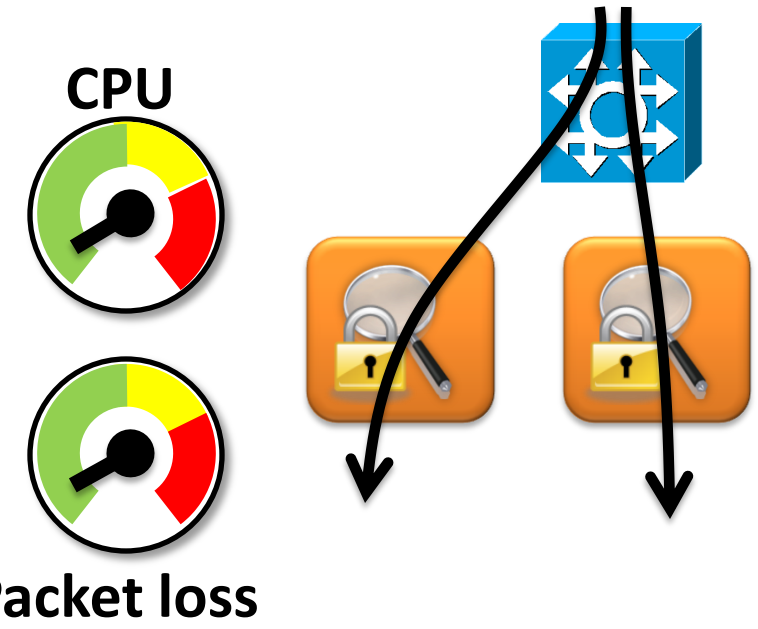


Example: elastic NF scaling

1. Satisfy performance SLAs
2. Minimize operating costs



Example: elastic NF scaling

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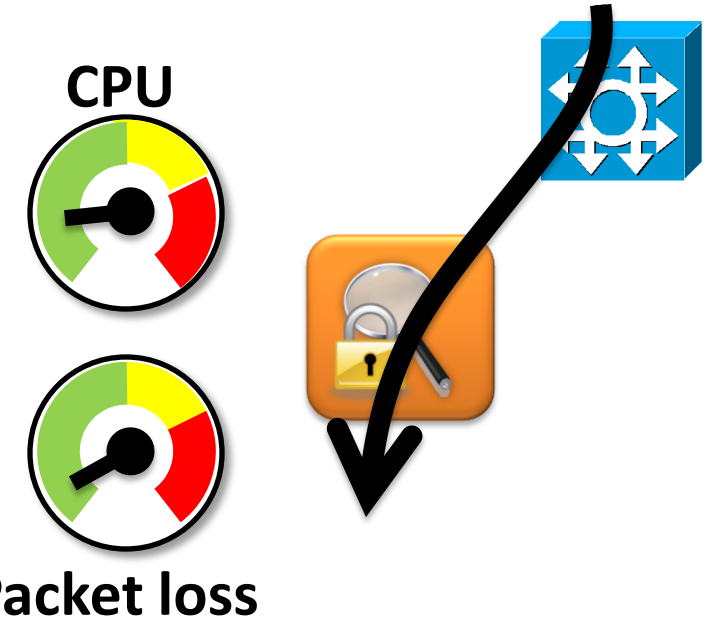
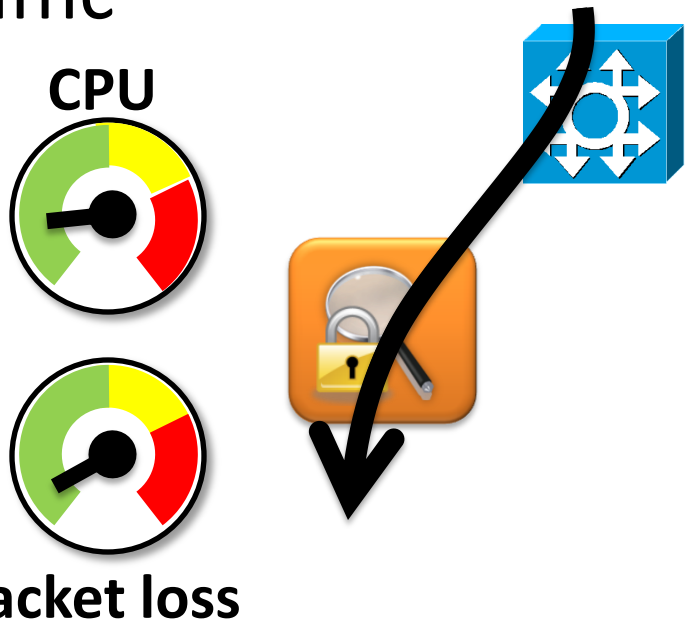


Example: elastic NF scaling

1. Satisfy performance SLAs
2. Minimize operating costs
3. Accurately monitor traffic

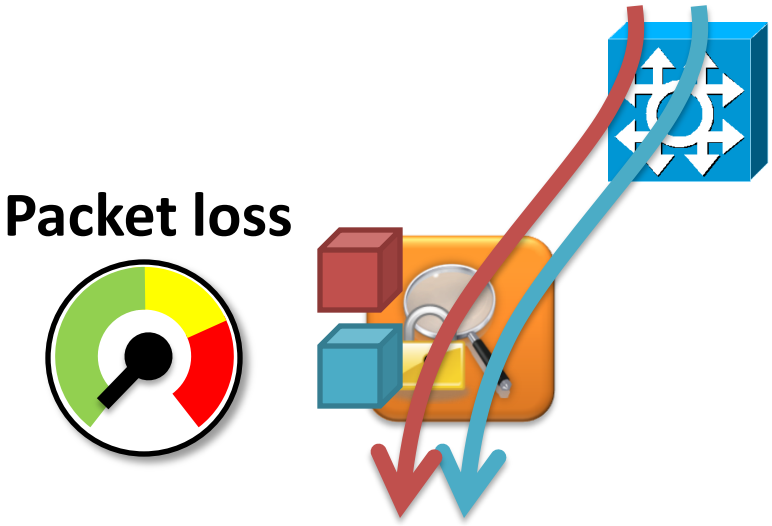


Problem: NFV+SDN is insufficient

To **simultaneously**…

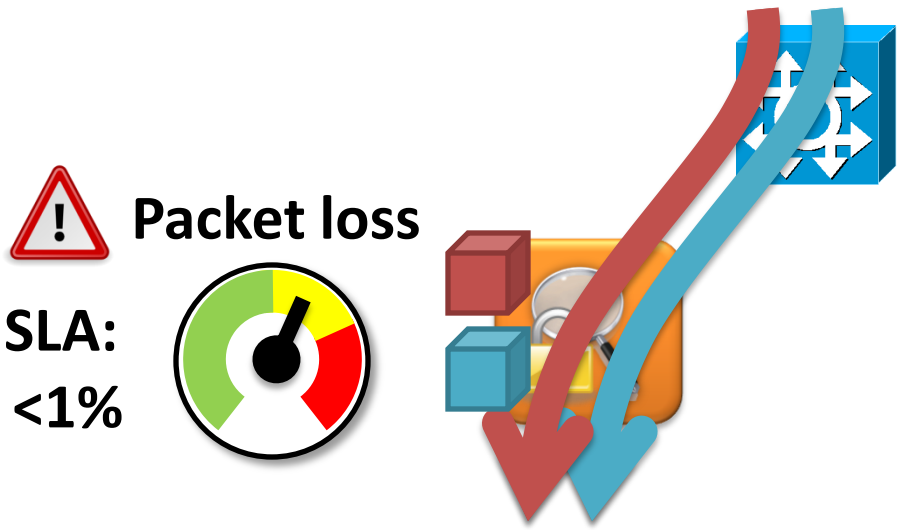
1. Satisfy performance SLAs
2. Minimize operating costs
3. Accurately monitor traffic

Why NFV + SDN falls short



1. SLAs 2. Cost 3. Accuracy

Why NFV + SDN falls short



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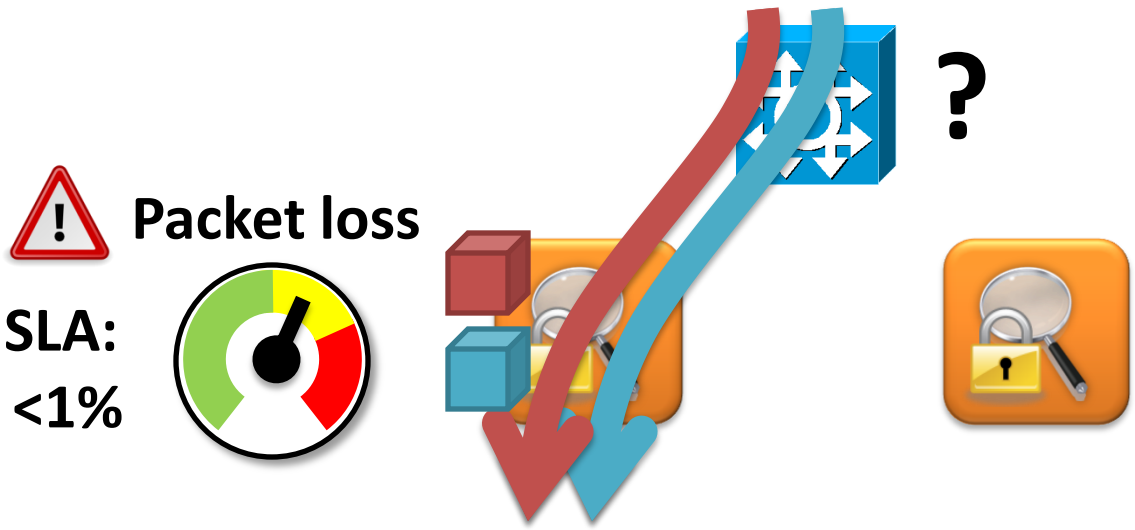

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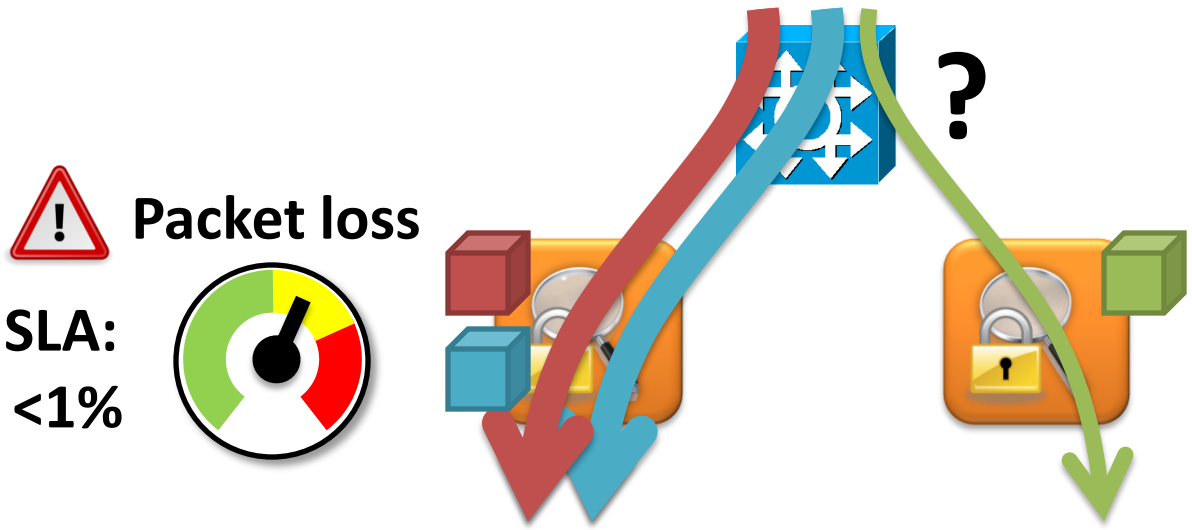
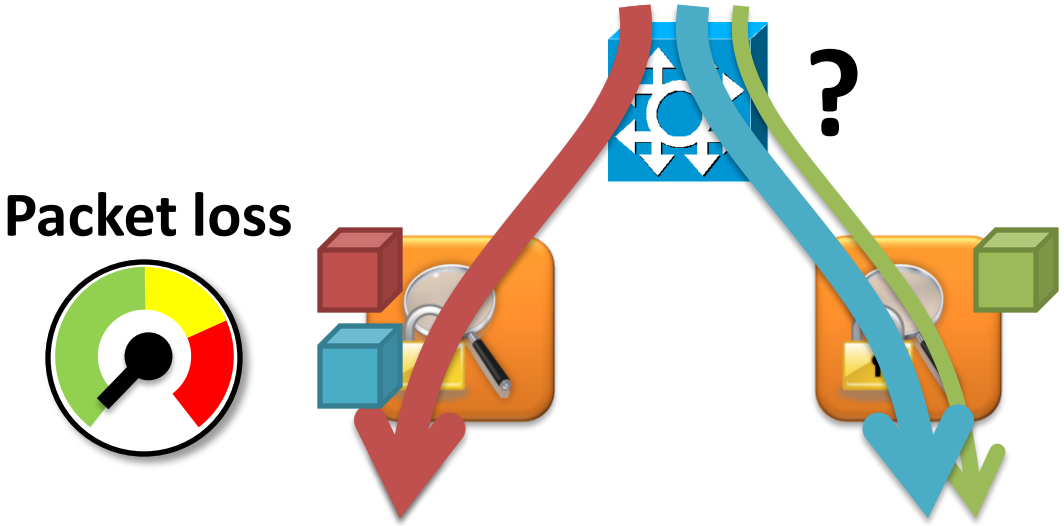


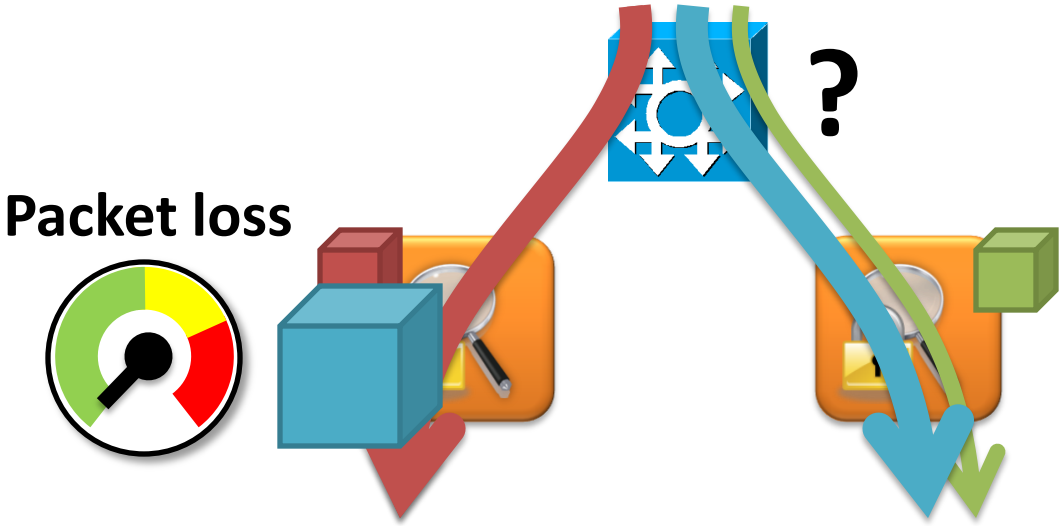
	1. SLAs	2. Cost	3. Accuracy
Reroute new flows	✗	✓	?

Why NFV + SDN falls short



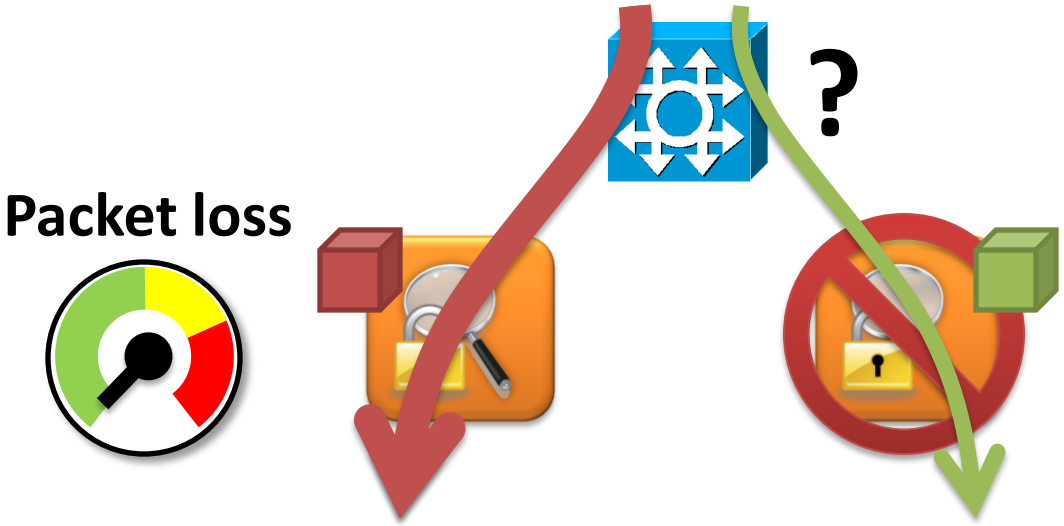
	1. SLAs	2. Cost	3. Accuracy
Reroute new flows	✗	✓	?
Reroute existing flows	✓	✓	

Why NFV + SDN falls short



	1. SLAs	2. Cost	3. Accuracy
Reroute new flows	✗	✓	?
Reroute existing flows	✓	✓	✗

Why NFV + SDN falls short



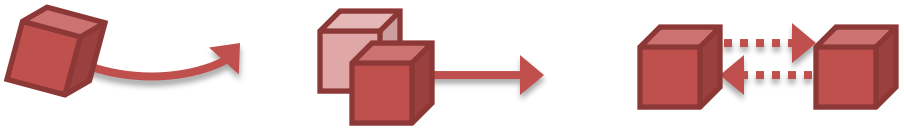
	1. SLAs	2. Cost	3. Accuracy
Reroute new flows	✗	✓	?
Reroute existing flows	✓	✓	✗

Why NFV + SDN falls short

	1. SLAs	2. Cost	3. Accuracy
Reroute new flows	✗	✓	?
Reroute existing flows	✓	✓	✗
Wait for flows to die	✓	✗	✓

SLAs + cost + accuracy: What do we need?

- Quickly move, copy, or share internal NF state alongside updates to network forwarding state



- Guarantees: loss-free, order-preserving, …

Also applies to other scenarios

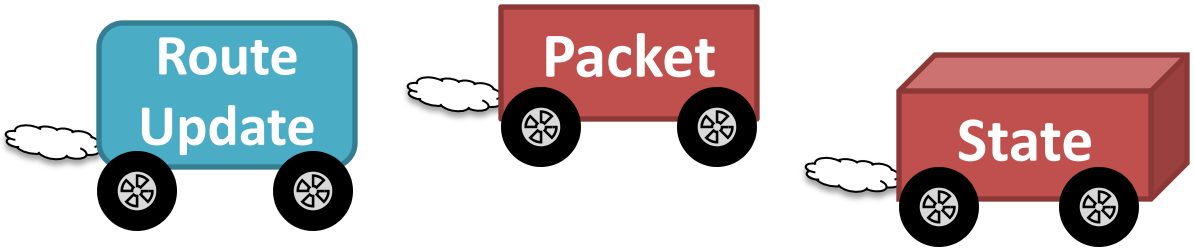
Outline

- Motivation and requirements
- Challenges
- OpenNF architecture
  - State export/import
  - State operations
  - Guarantees
- Evaluation

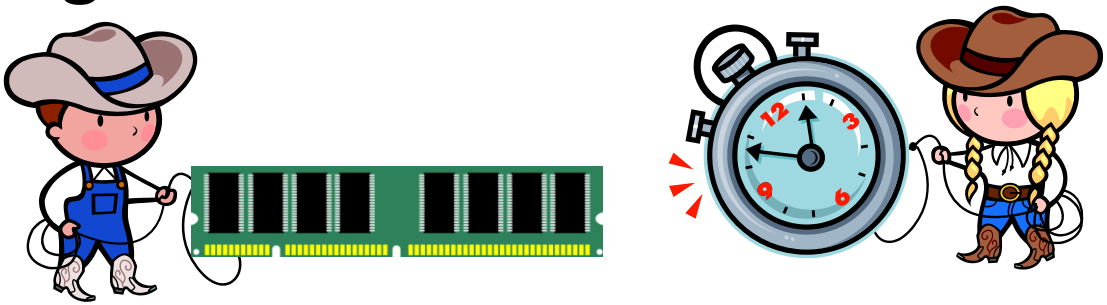
Challenges

1. Supporting many NFs with minimal changes

2. Dealing with race conditions

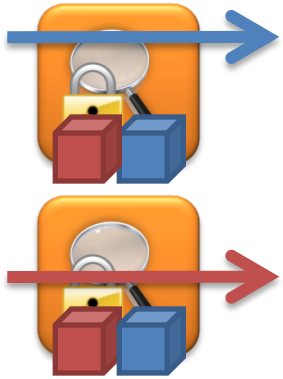


3. Bounding overhead



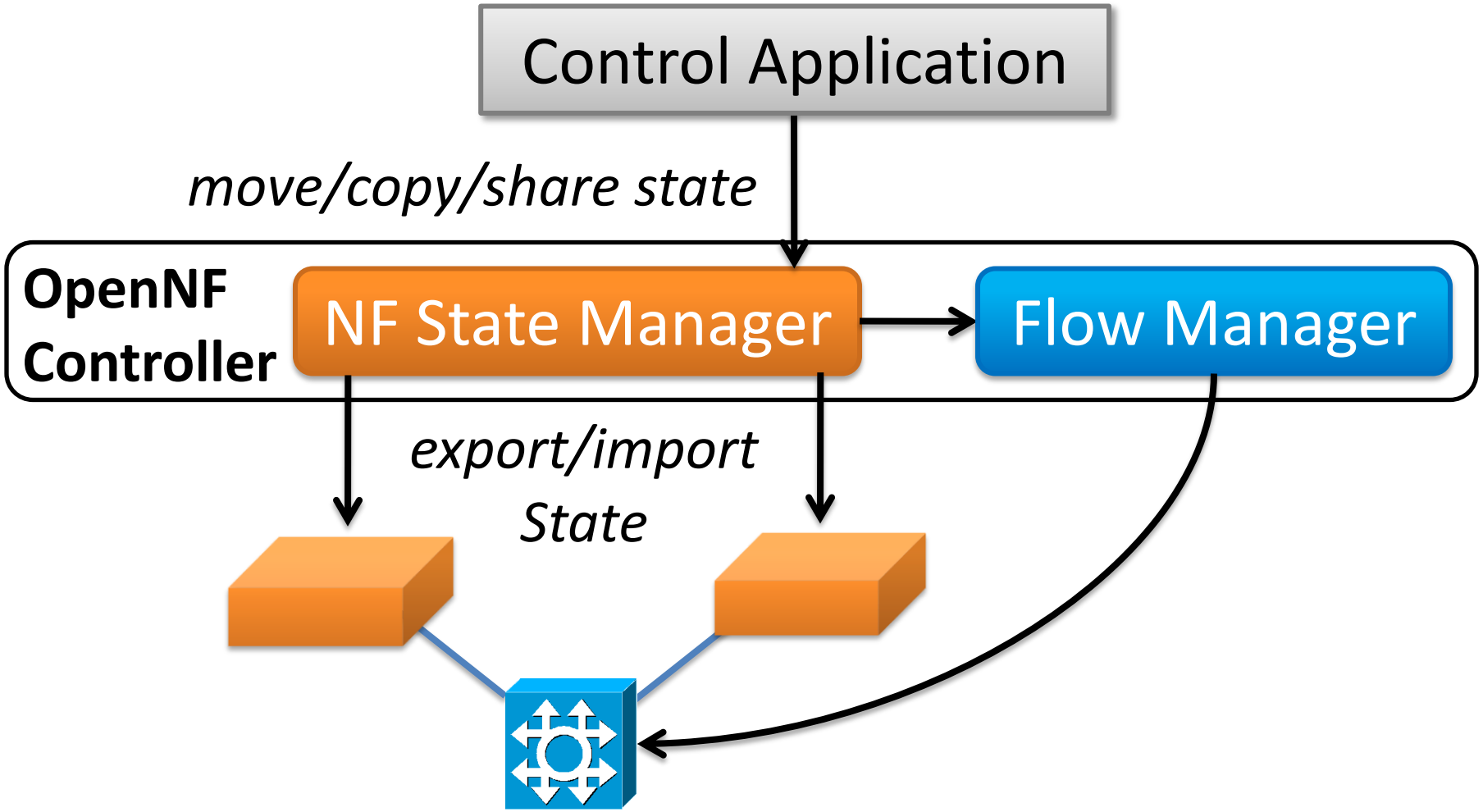
Existing approaches

- ✗ Virtual machine replication
  - Cannot combine → limited rebalancing



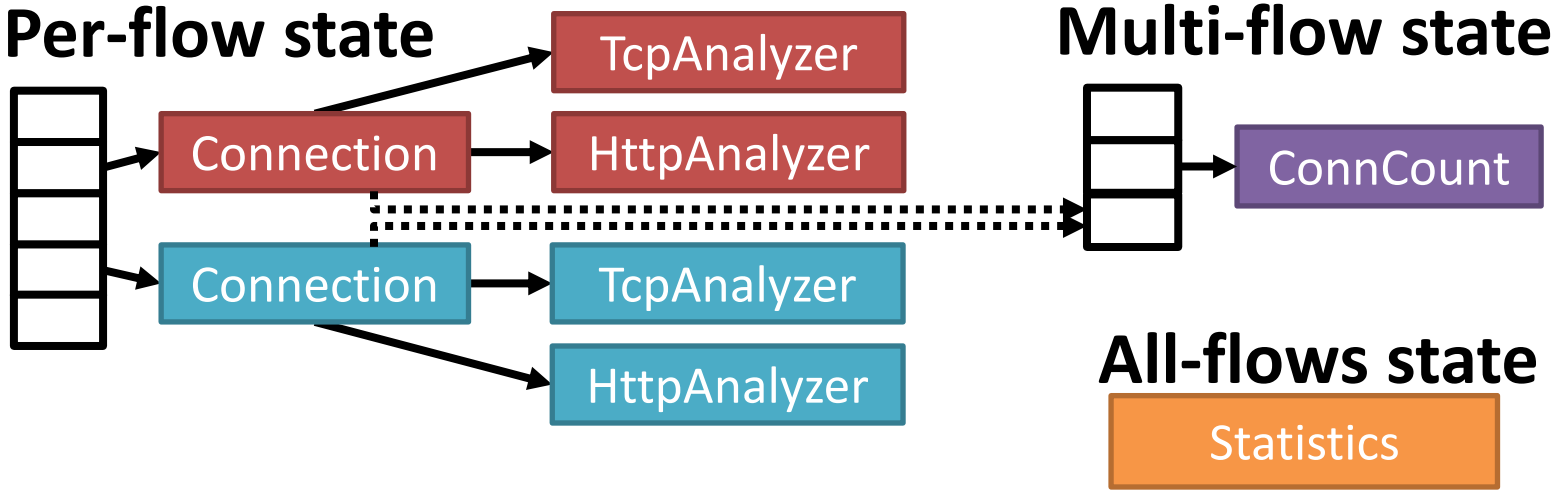
- ✗ Split/Merge *[NSDI'13]*
  - State allocations and accesses occur via library
  - Addresses a specific problem → limited suitability
  - Packets may be dropped or re-ordered → wrong NF behavior

OpenNF overview



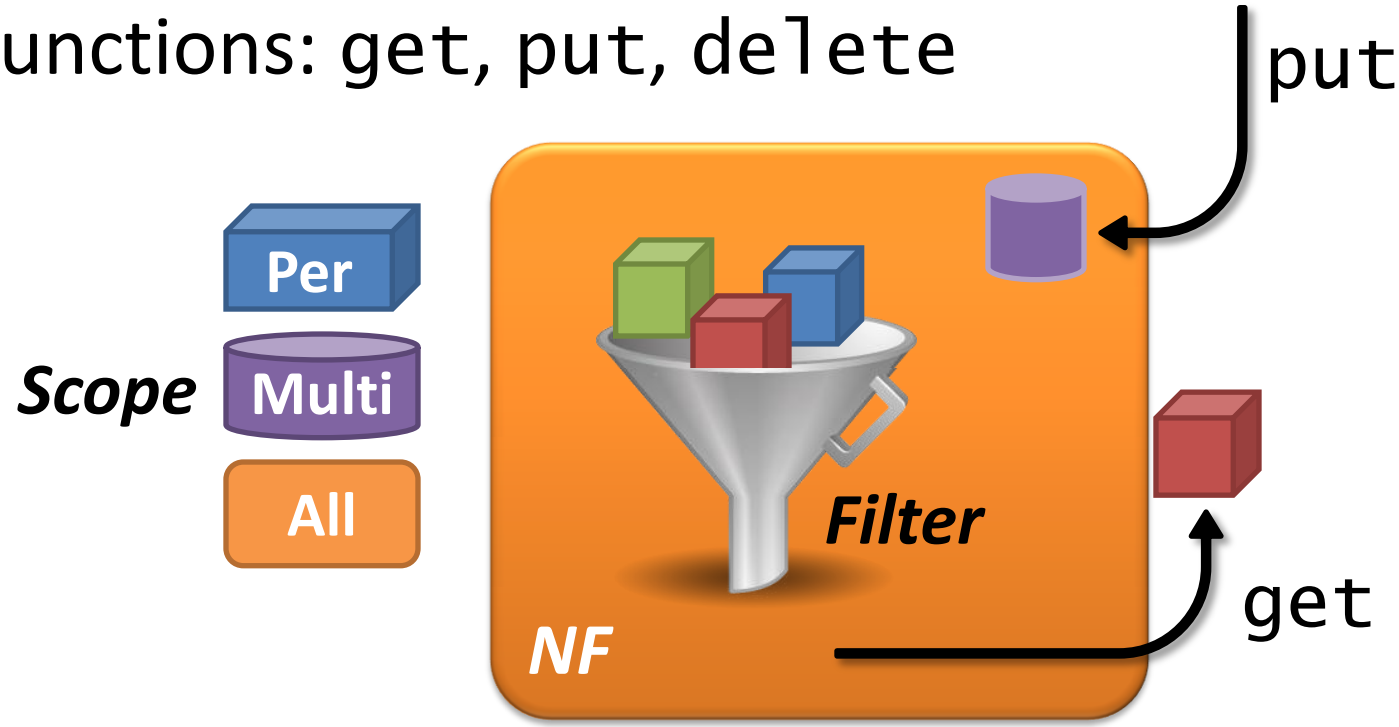
NF state taxonomy

State created or updated by an NF applies to either a **single flow** or a **collection of flows**



NF API: export/import state

- Functions: `get`, `put`, `delete`



No need to expose/change internal state organization!

Control operations: move

Control Application

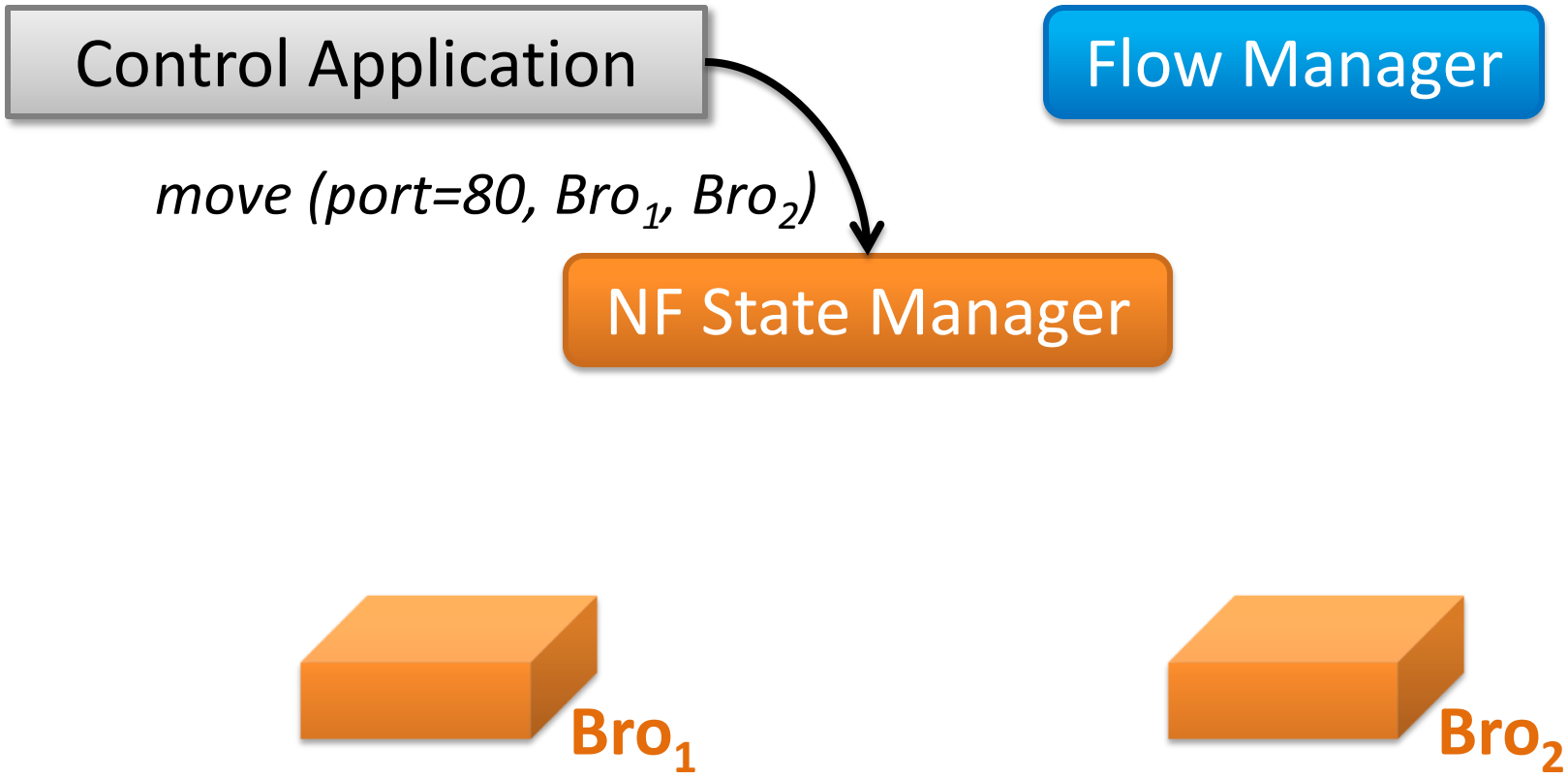
Flow Manager

NF State Manager

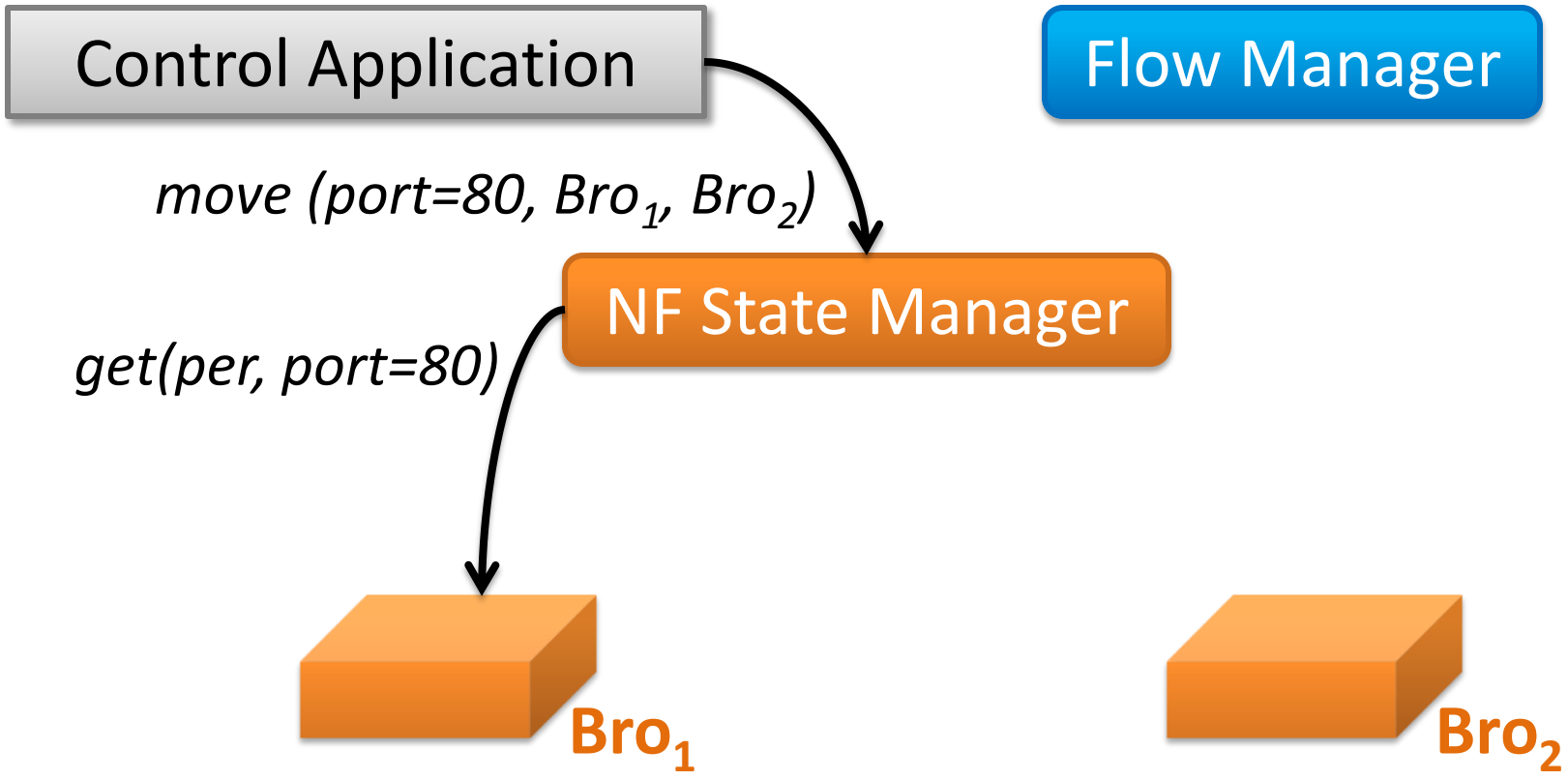
Bro_1

Bro_2

Control operations: move



Control operations: move



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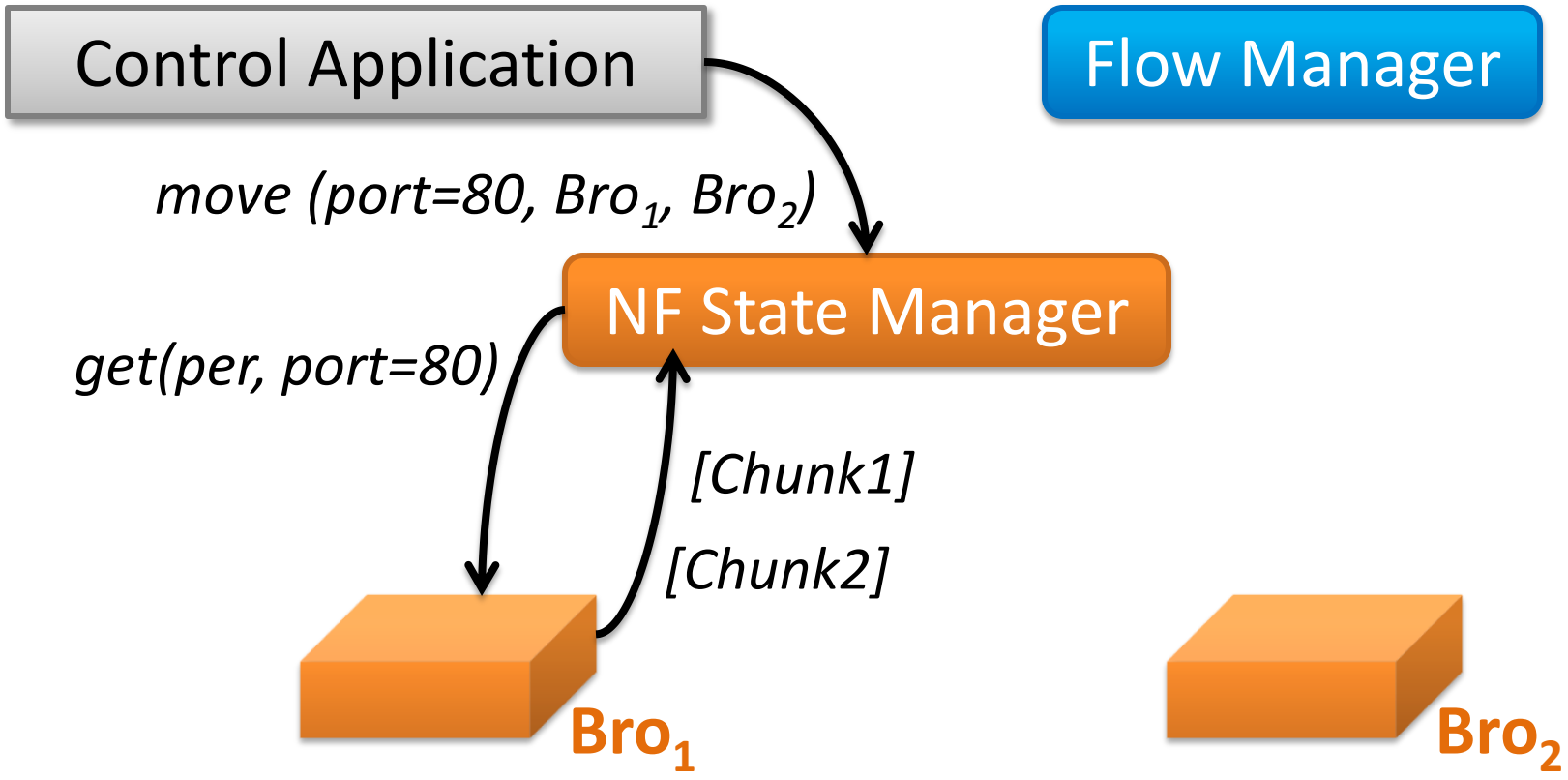
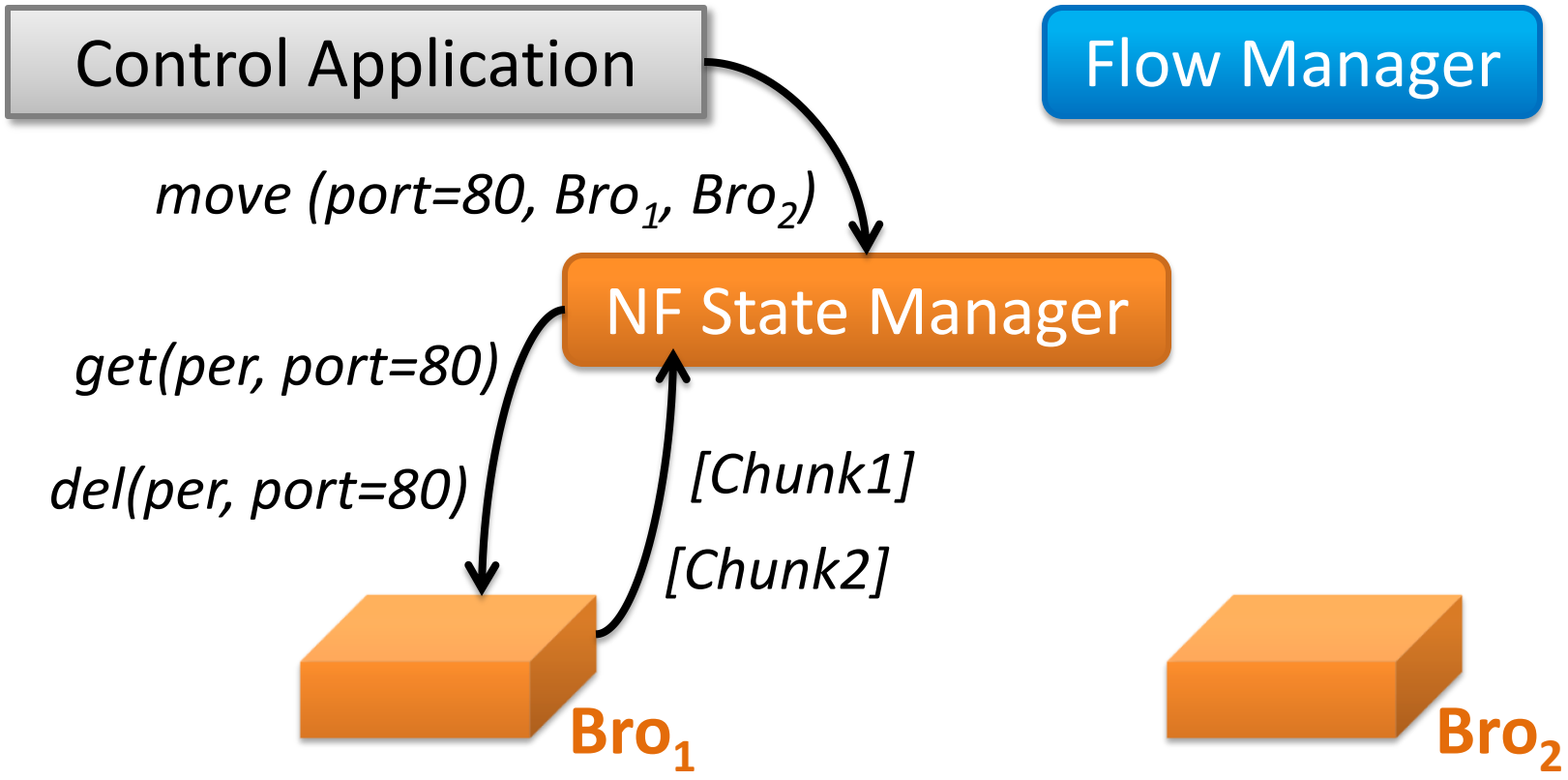
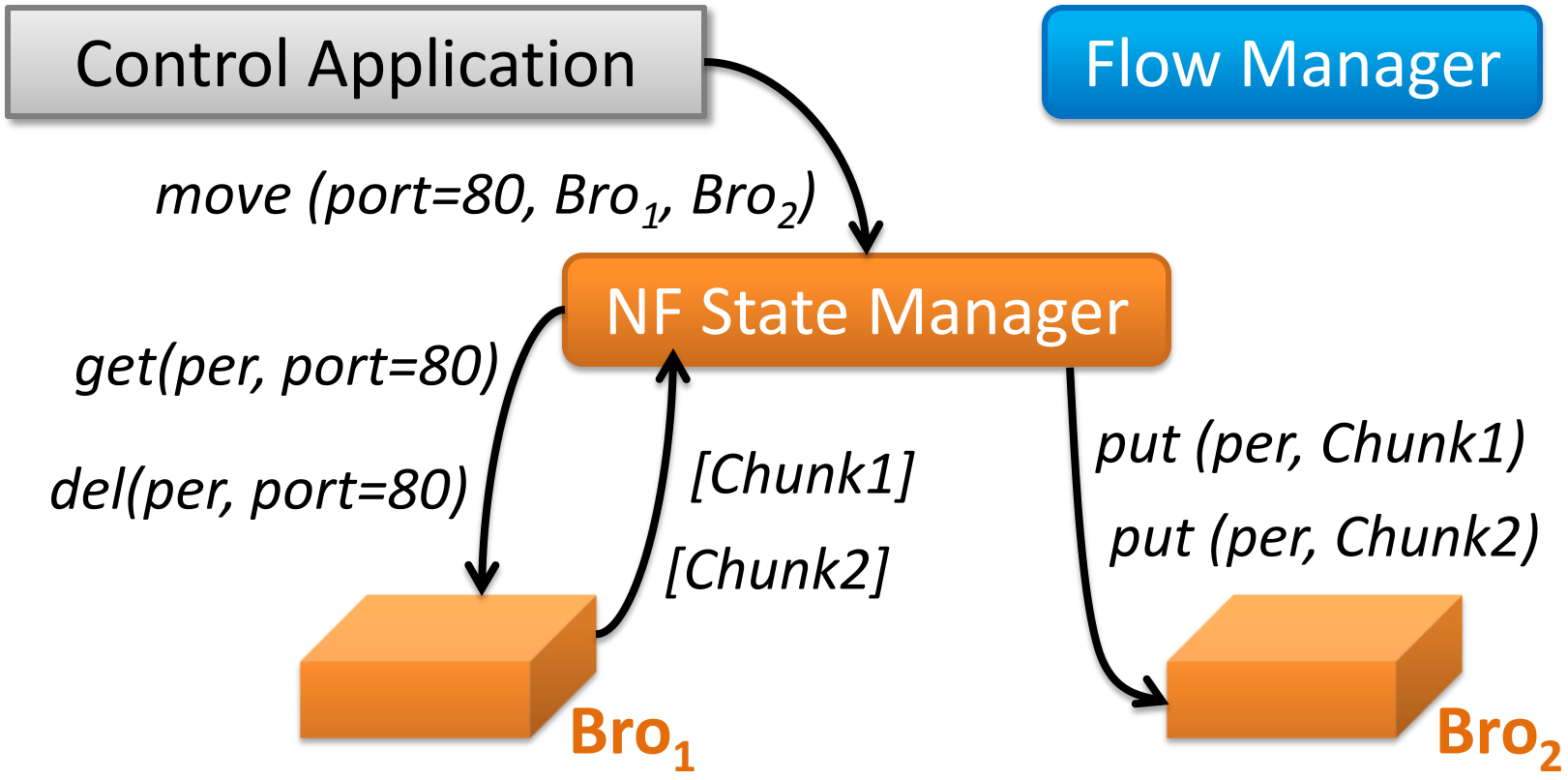


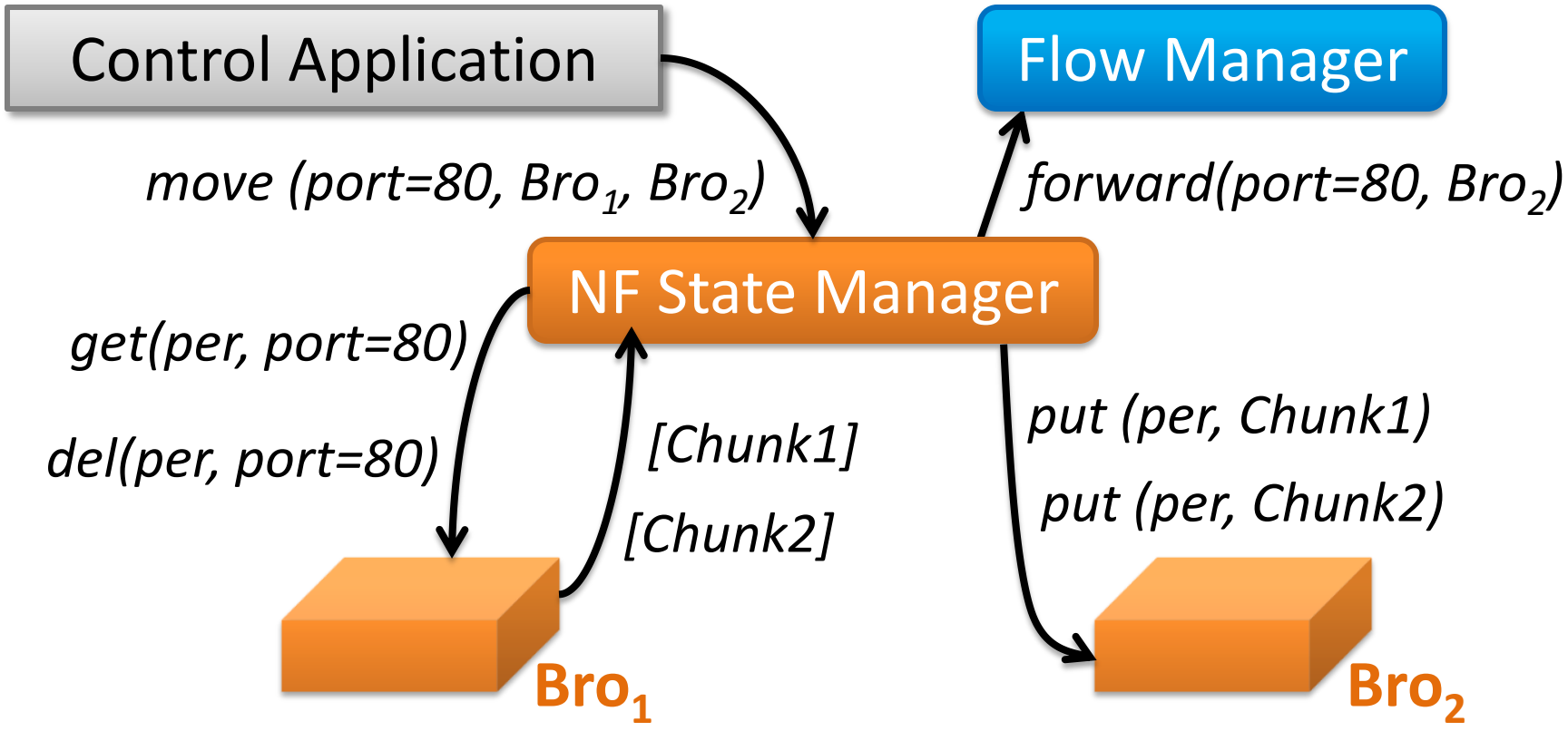
Control operations: move



Control operations: move



Control operations: move



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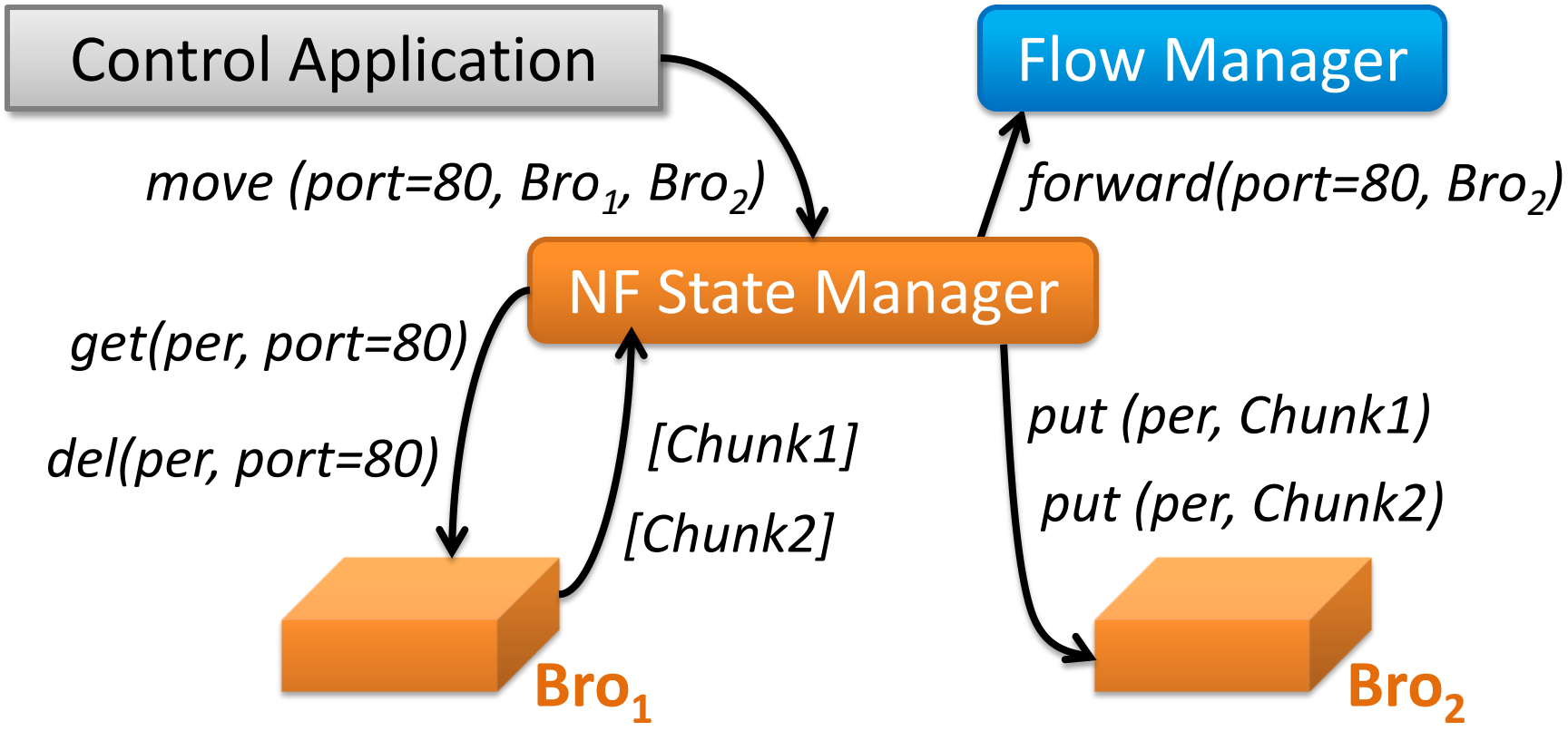

Also provide copy and share

Challenges

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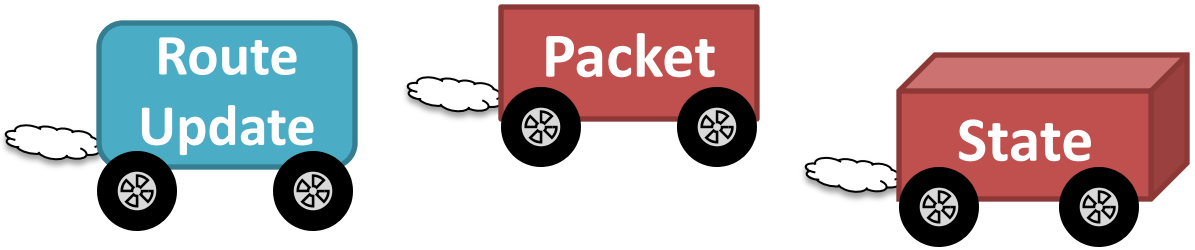

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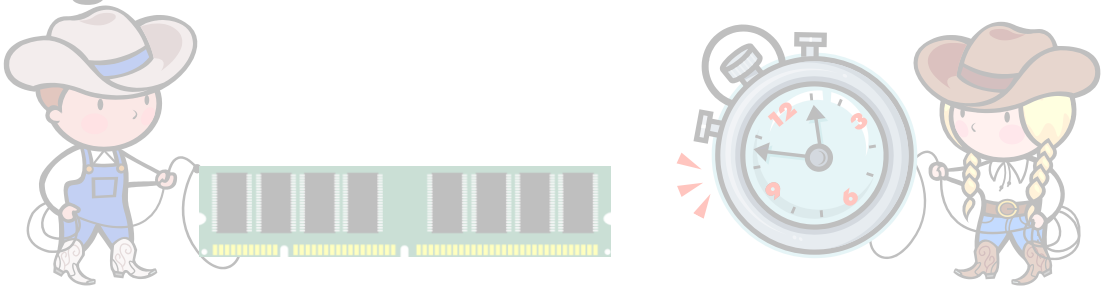
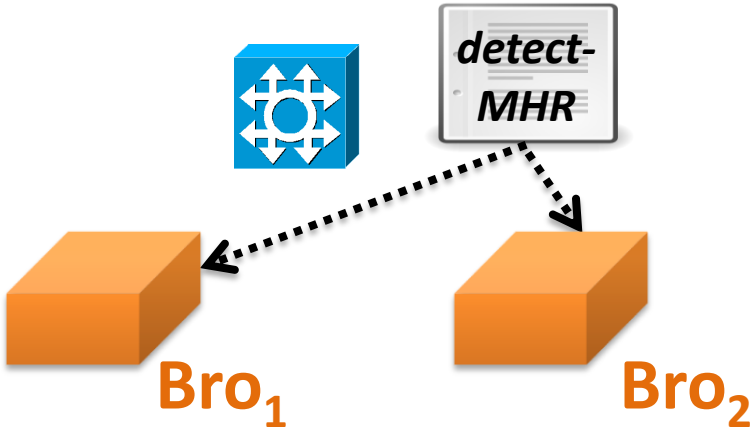


Lost updates during move



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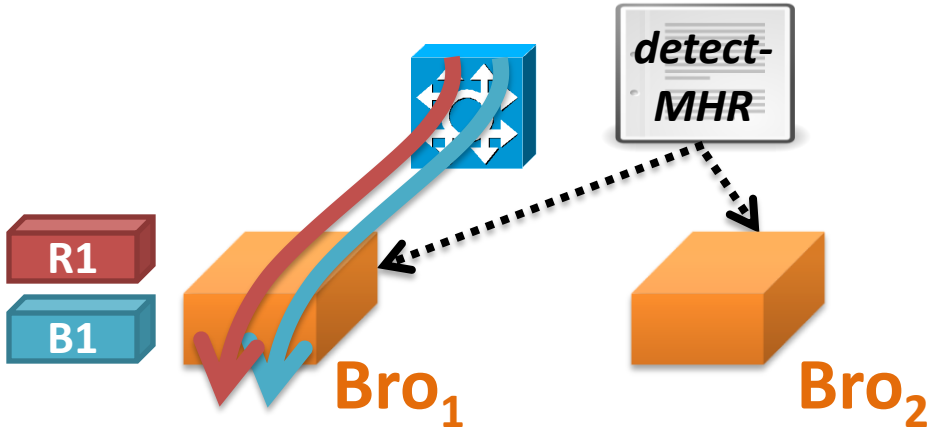
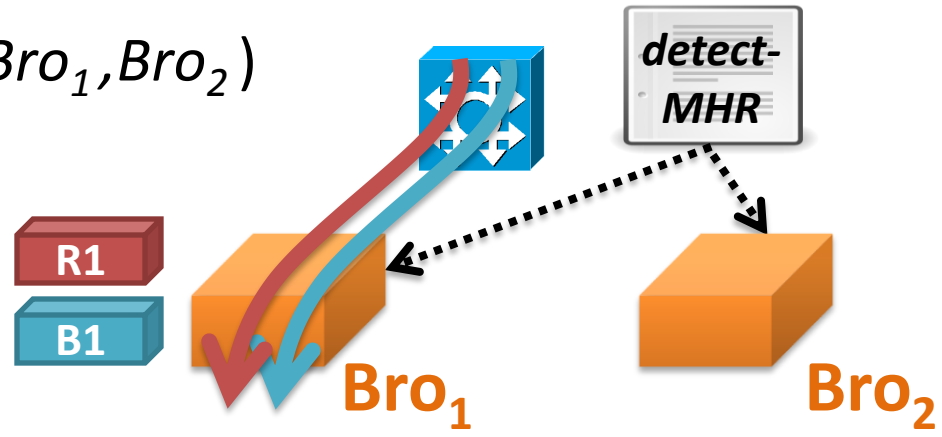


Lost updates during move

move(red,Bro$_1$,Bro$_2$)



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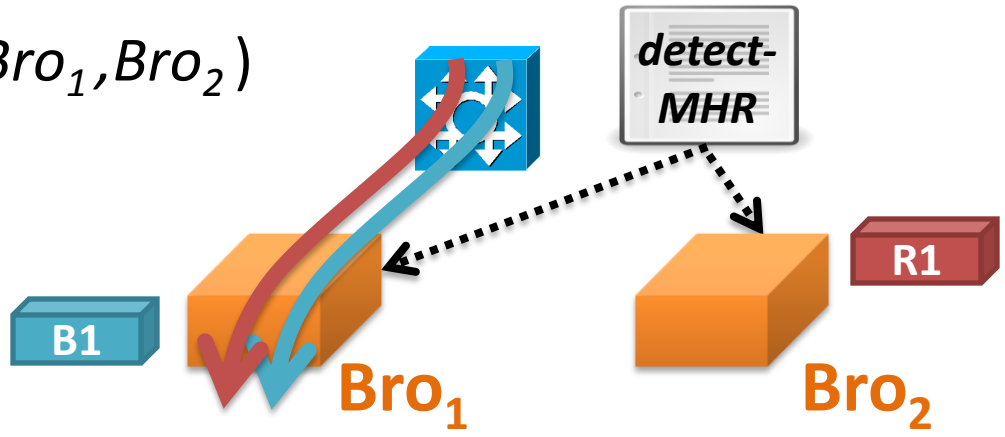
move(red,Bro$_1$,Bro$_2$)



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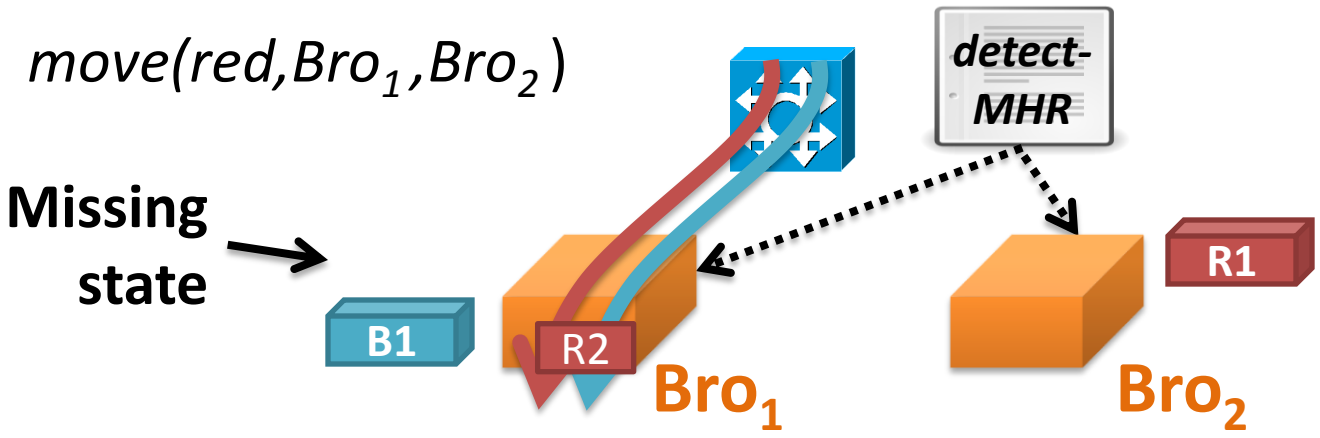

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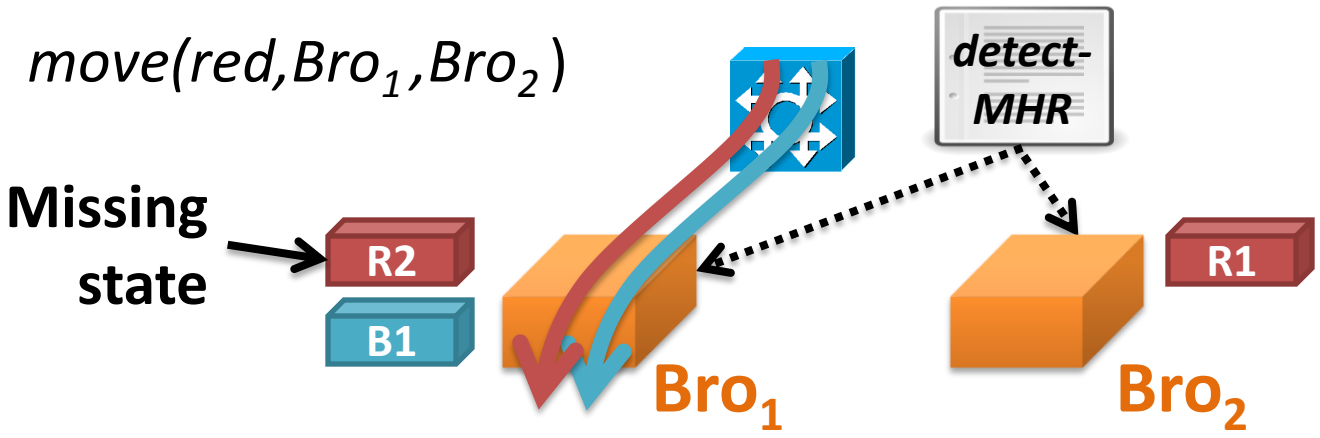

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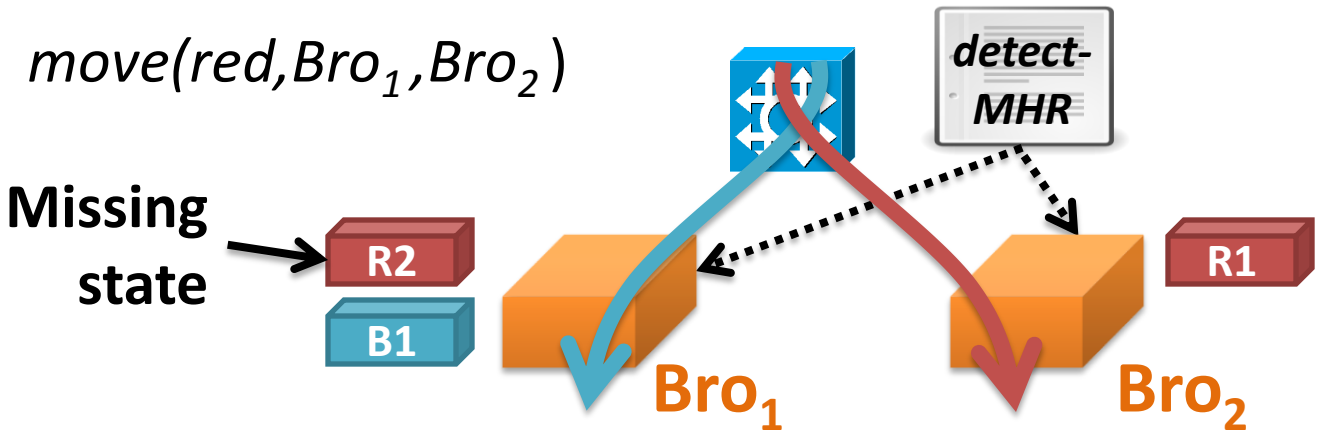

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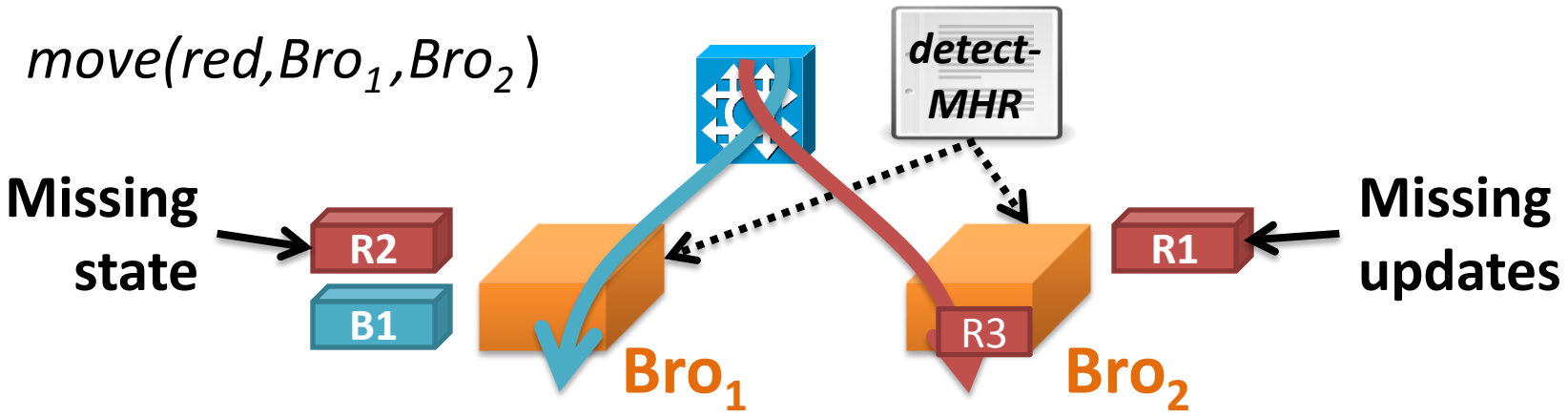

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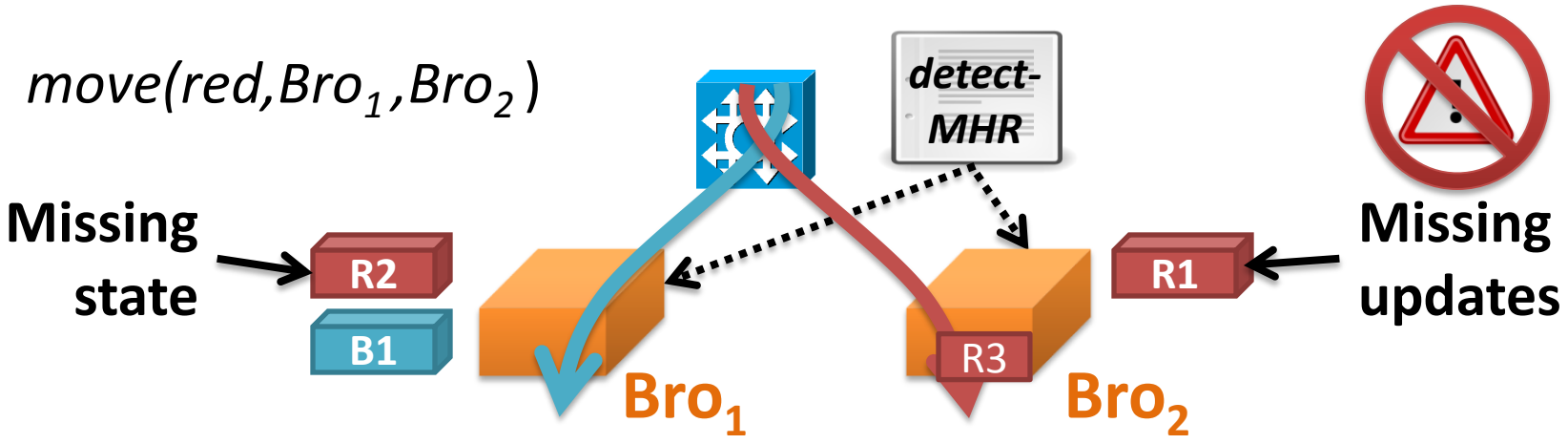

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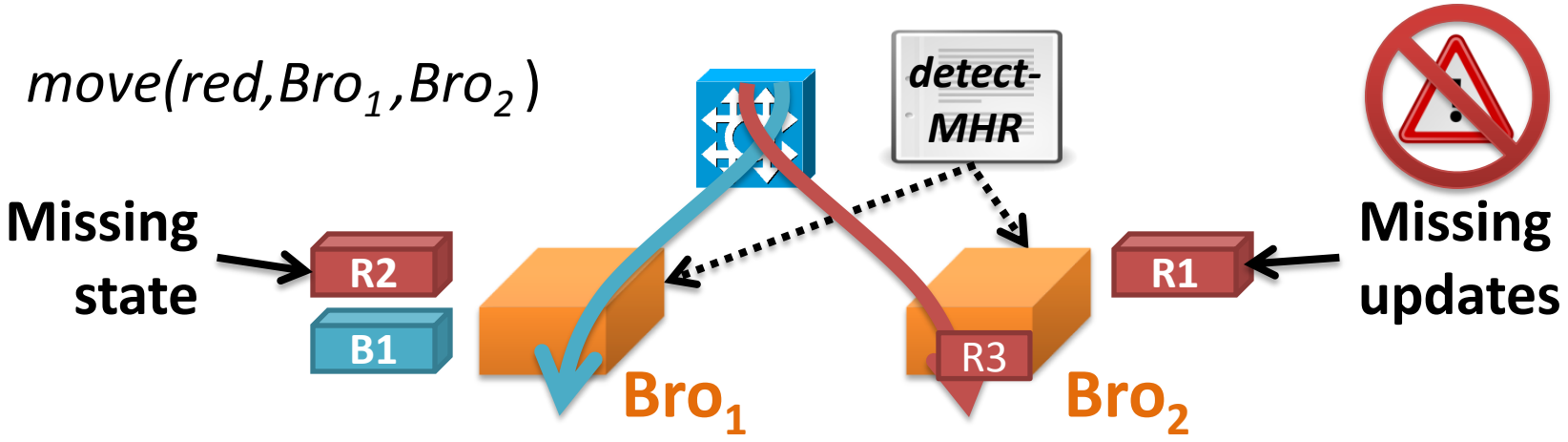
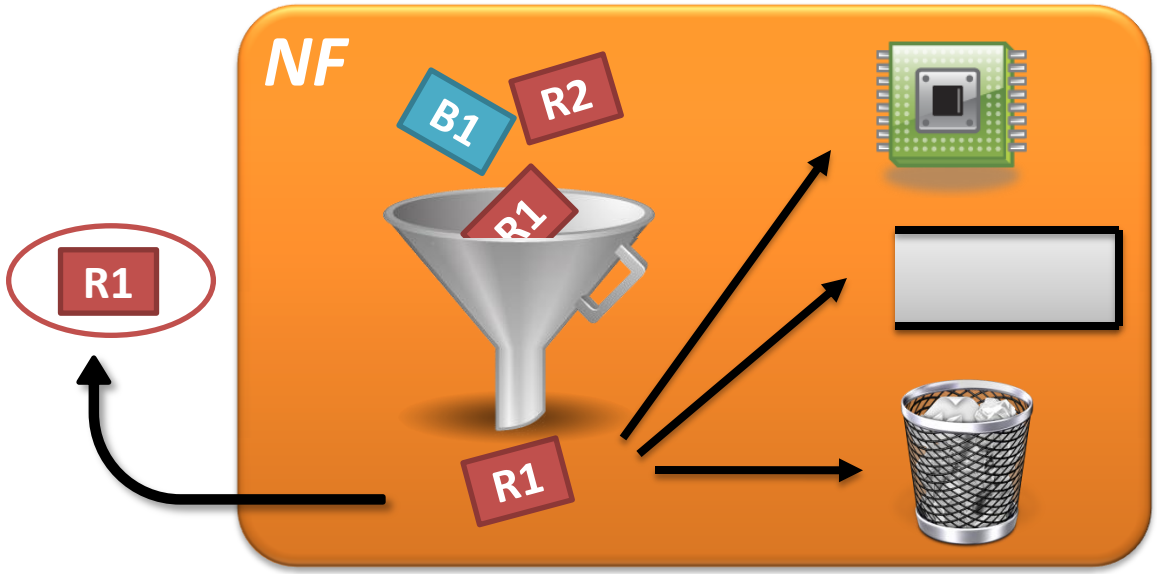


Loss-free: All state updates should be reflected in the transferred state, and all packets should be processed

✗ Split/Merge *[NSDI '13]*: pause traffic, buffer packets

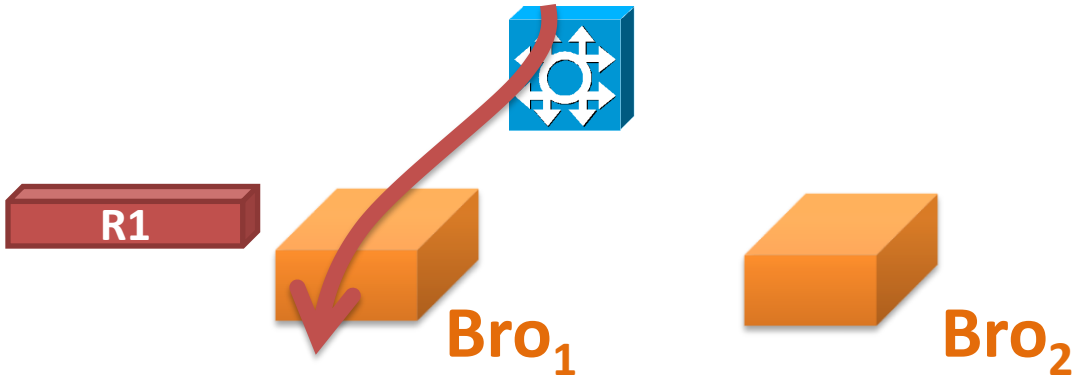
– Packets in-transit when buffering starts are dropped

NF API: observe/prevent updates using events



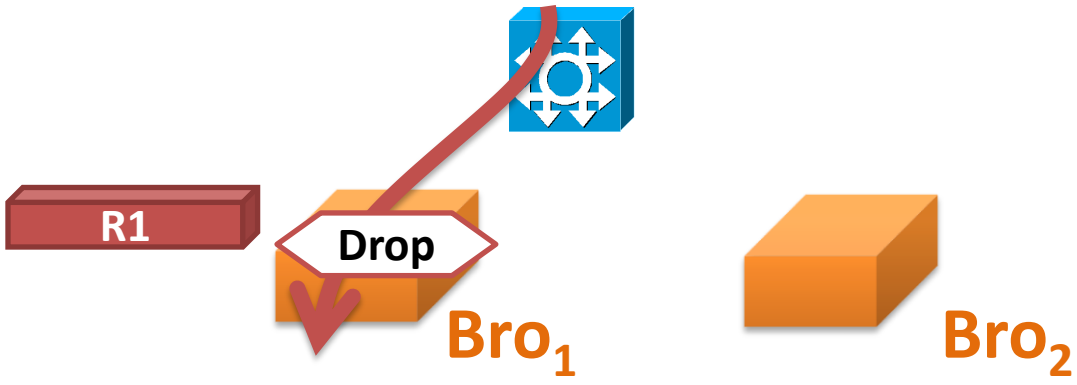
Only need to change an NF's receive packet function!

Use events for loss-free move



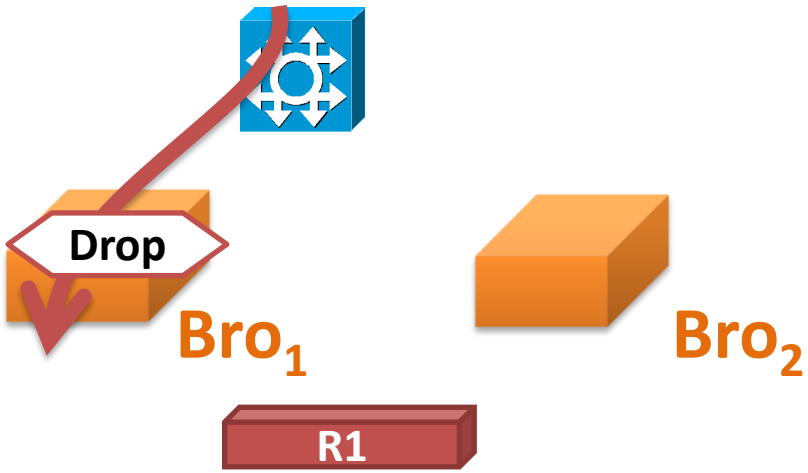
Use events for loss-free move

1. `enableEvents(red,drop)` on Bro_1



Use events for loss-free move

1. `enableEvents(red,drop)` on Bro_1
2. `get/delete` on Bro_1



Use events for loss-free move

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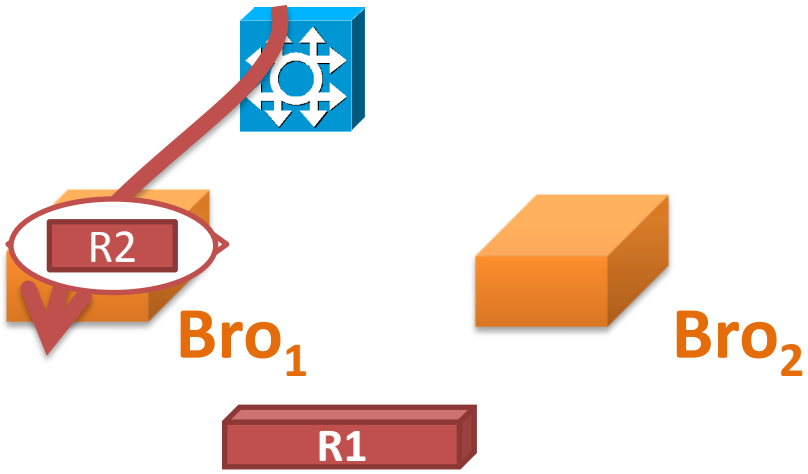
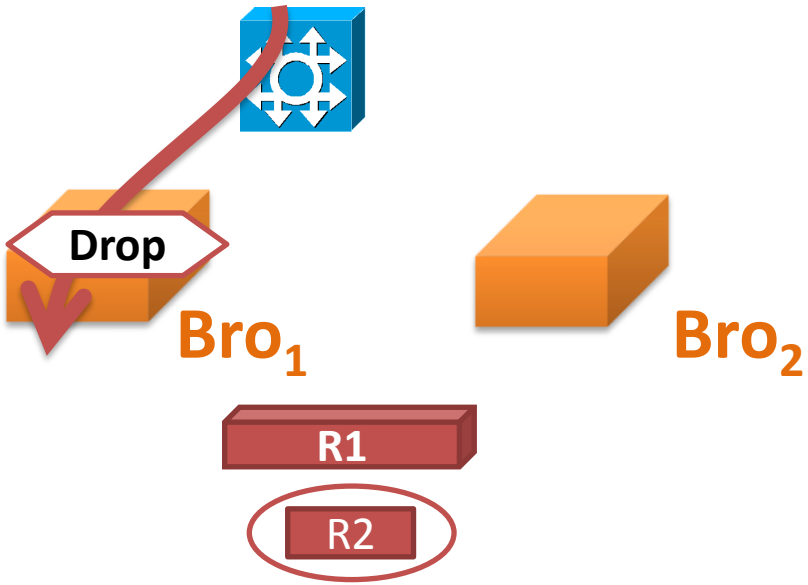


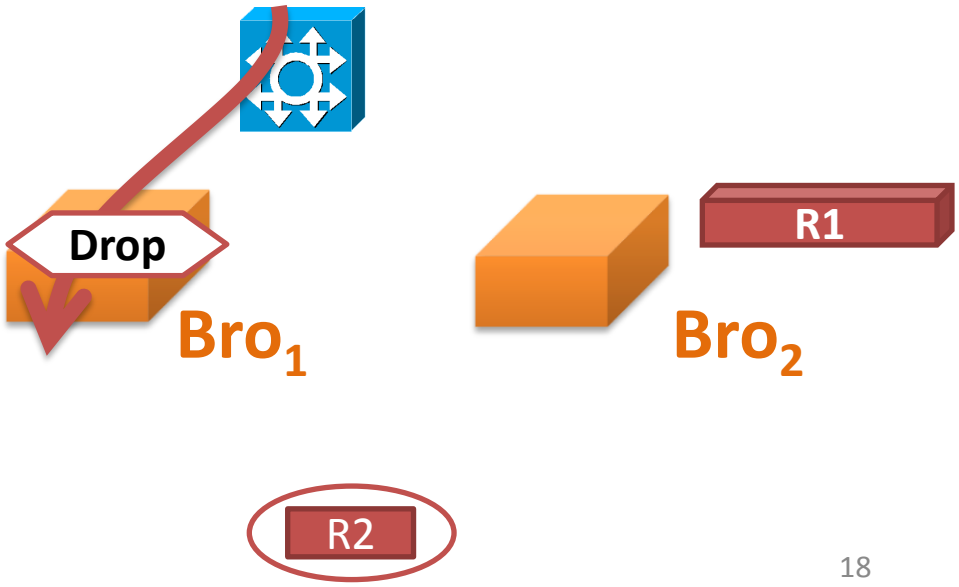
Use events for loss-free move

1. `enableEvents(red,drop)` on Bro_1
2. `get/delete` on Bro_1
3. Buffer events at controller



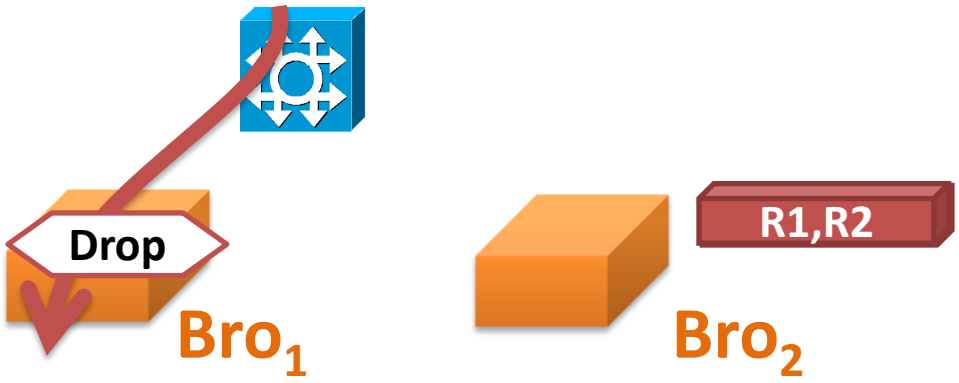
Use events for loss-free move

1. `enableEvents(red,drop)` on Bro_1
2. `get/delete` on Bro_1
3. Buffer events at controller
4. `put` on Bro_2



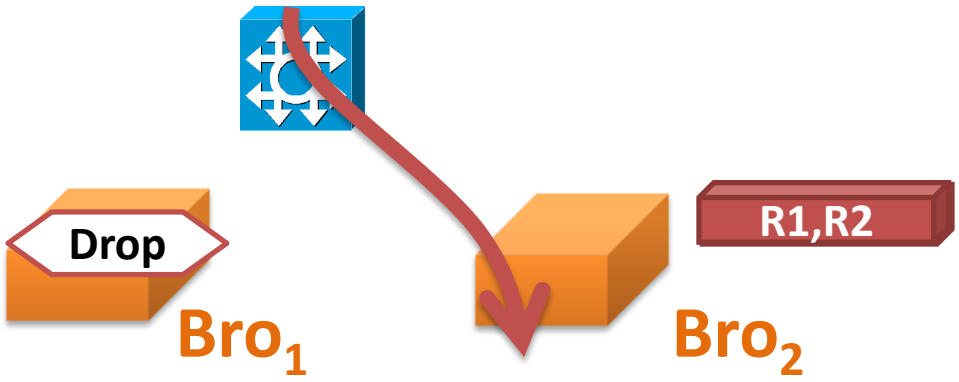
Use events for loss-free move

1. `enableEvents(red,drop)` 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



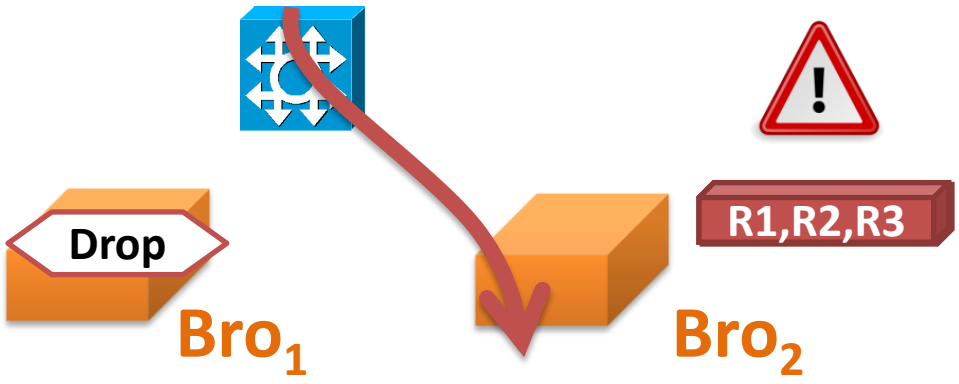
Use events for loss-free move

1. `enableEvents(red,drop)` 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



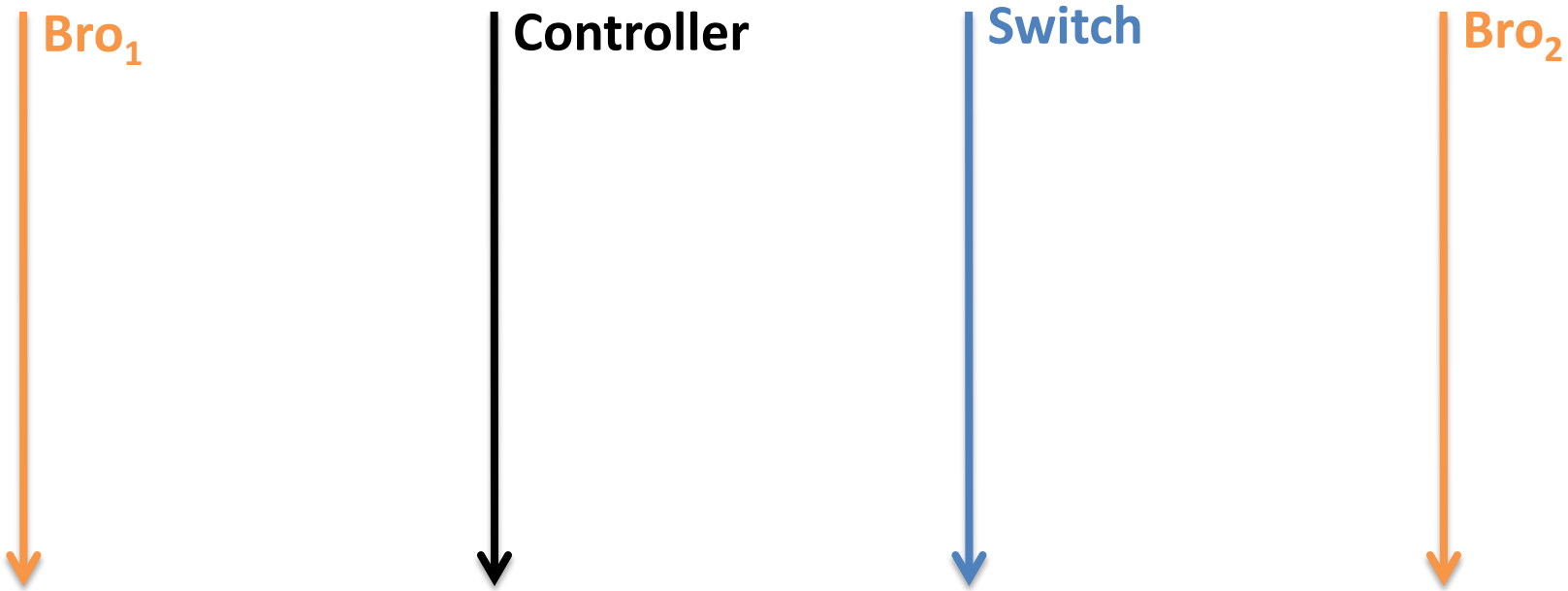
Use events for loss-free move

1. `enableEvents(red,drop)` 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



Re-ordering of packets

- False positives from Bro's `weird` script



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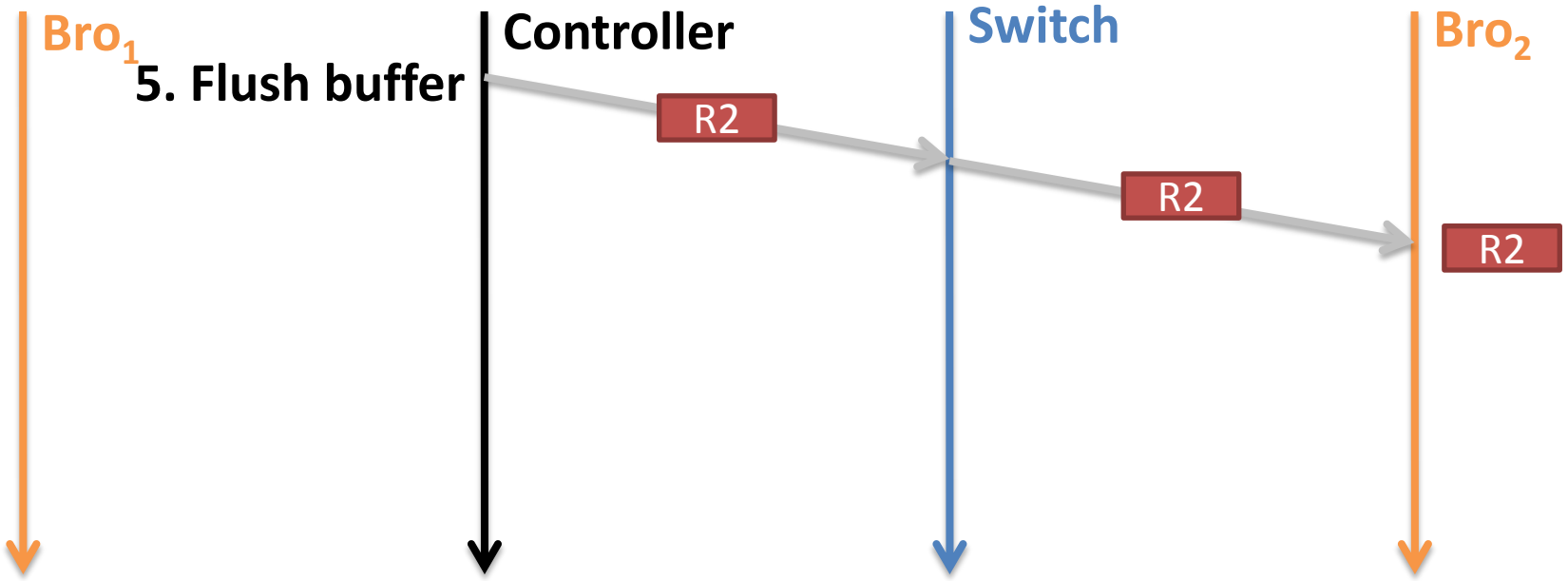

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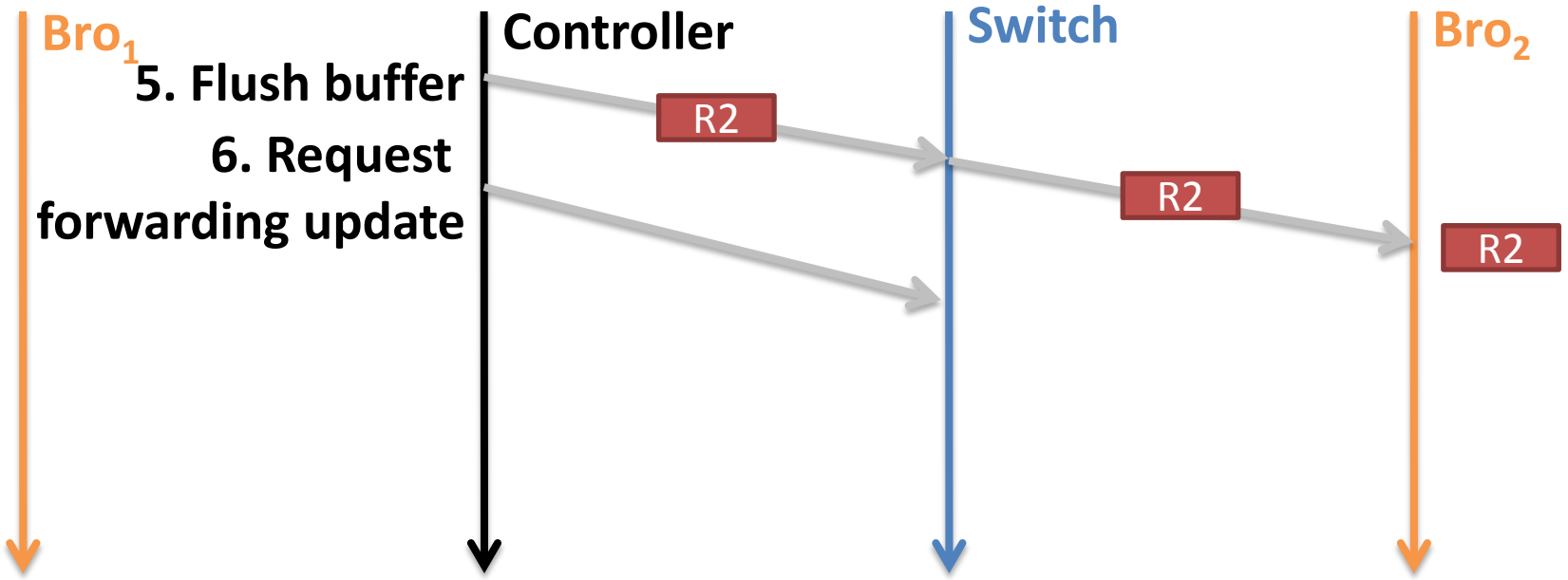

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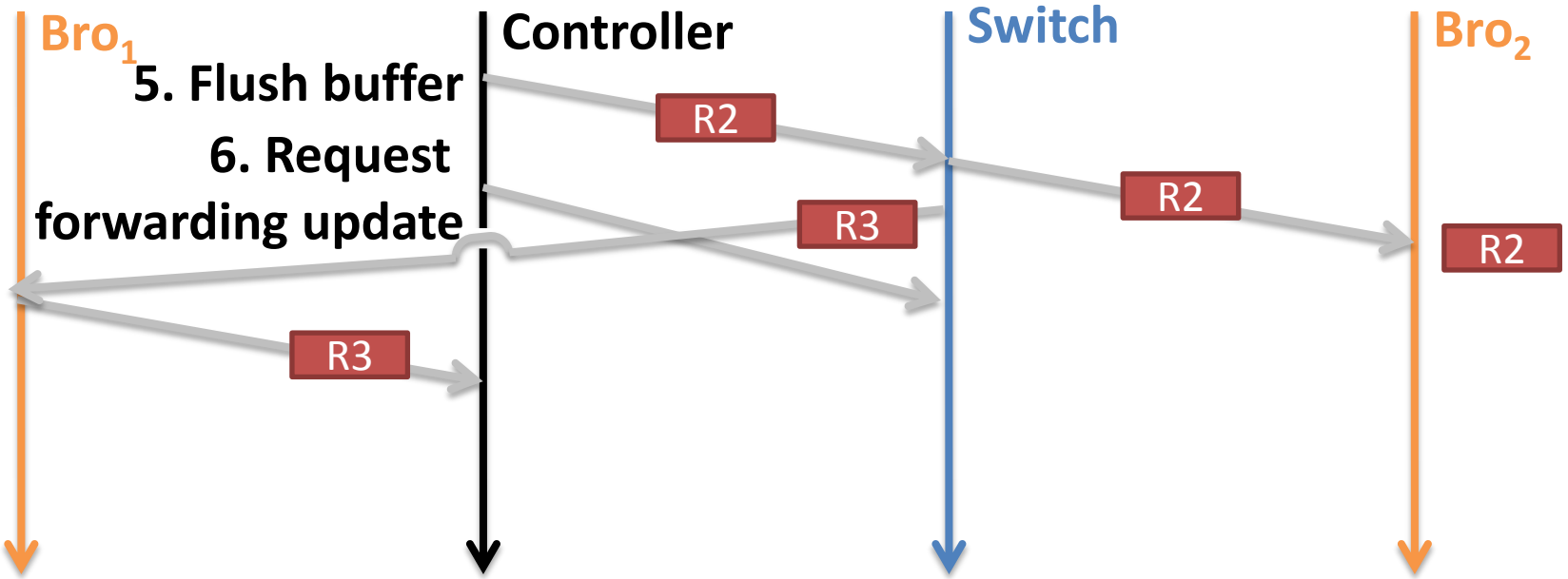

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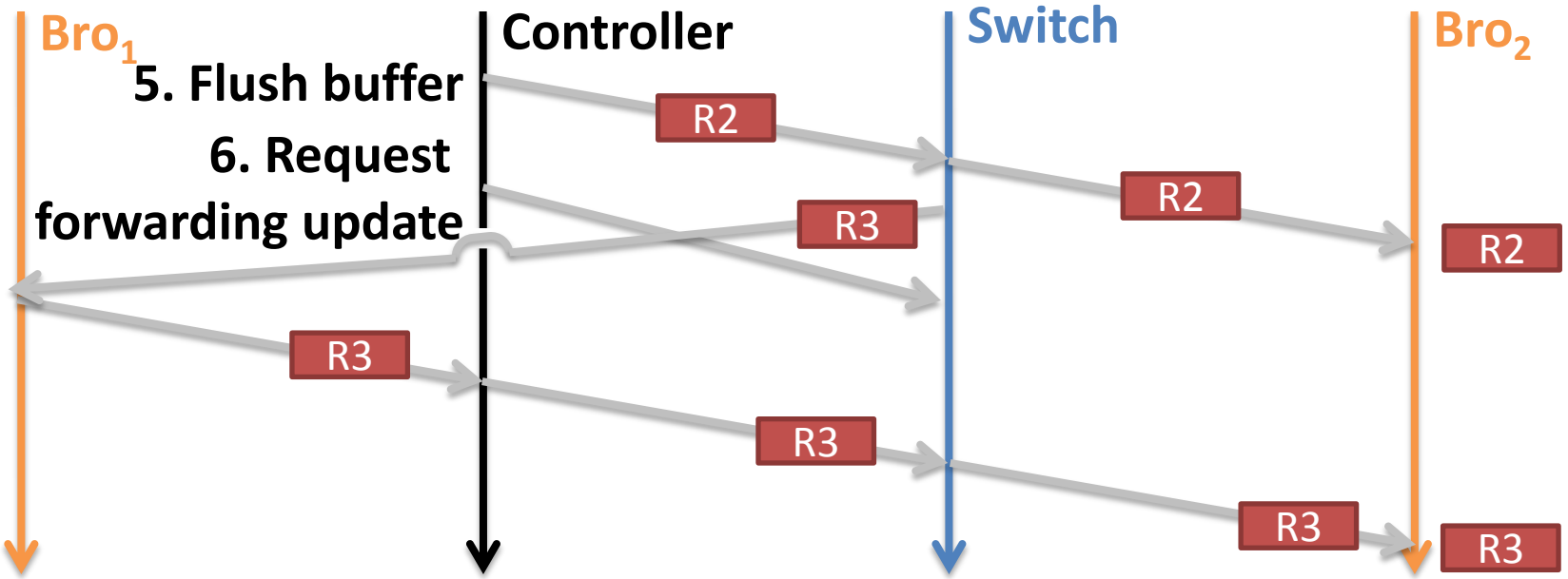

Re-ordering of packets

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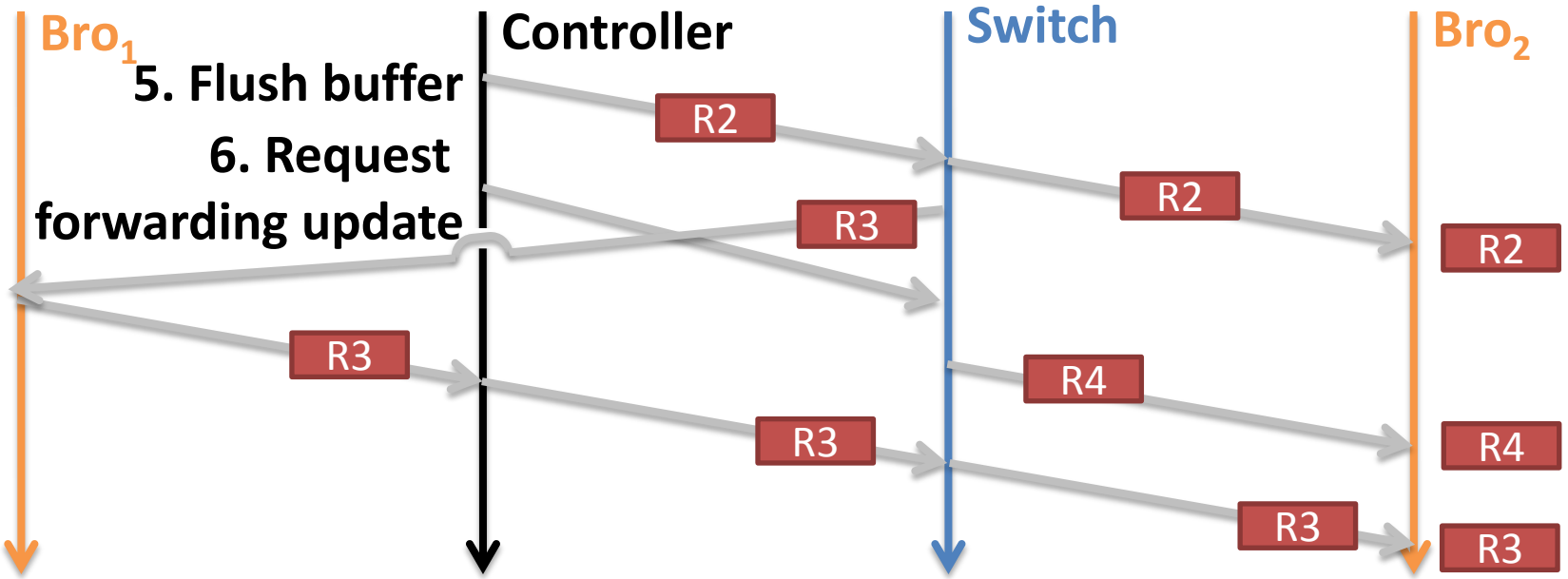

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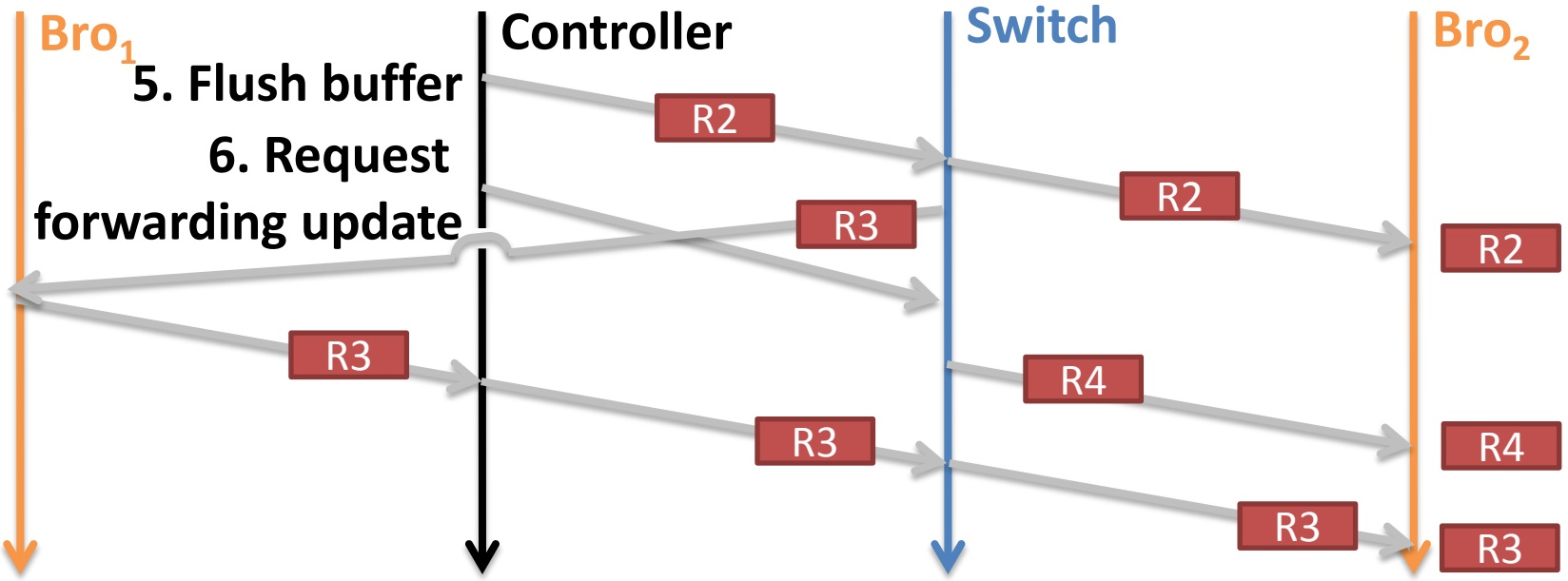
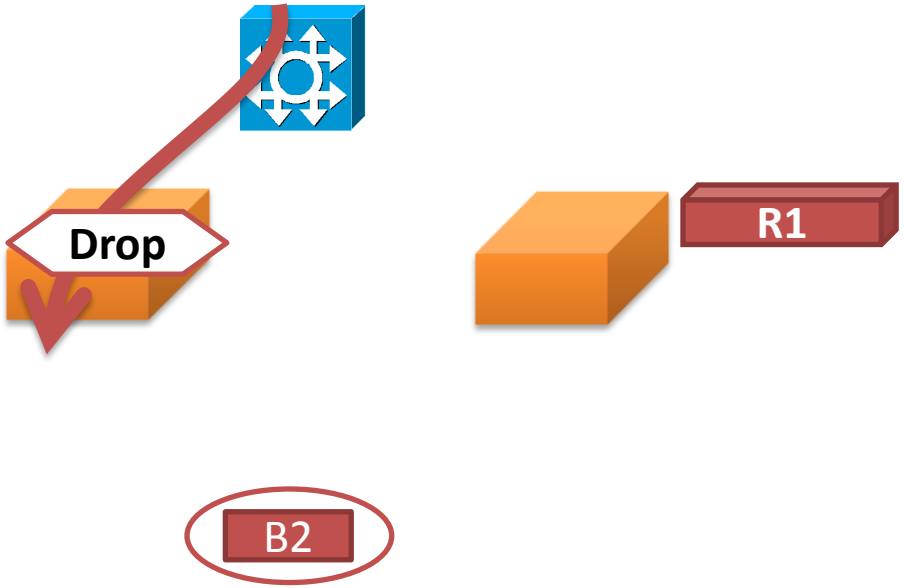
- False positives from Bro's `weird` script



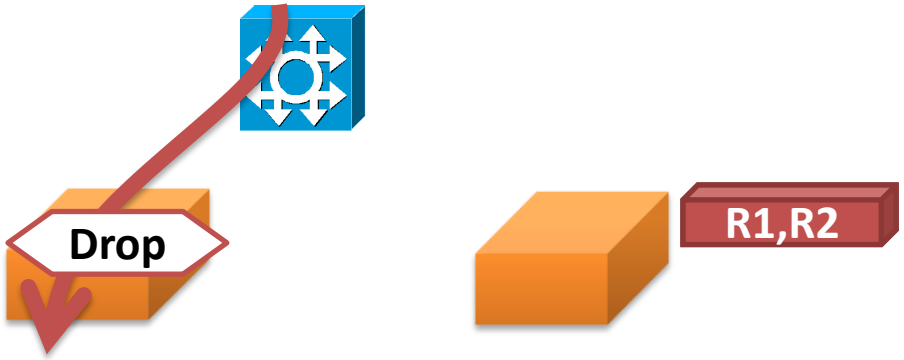
Order-preserving: All packets should be processed in the order they were forwarded by the switch

Order-preserving move



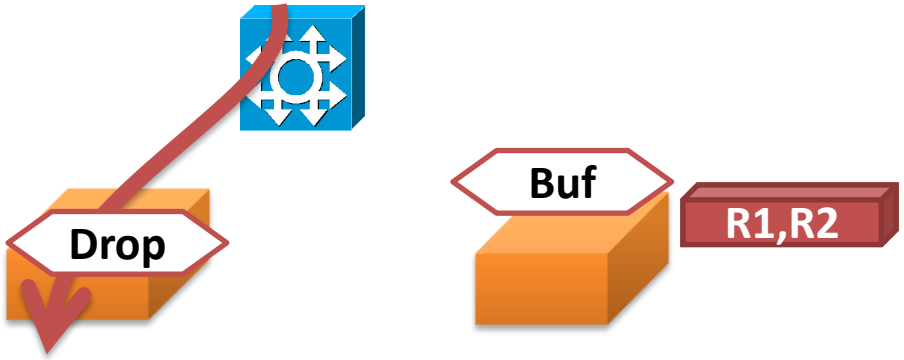
Order-preserving move

- Flush packets in events to $Inst_2$



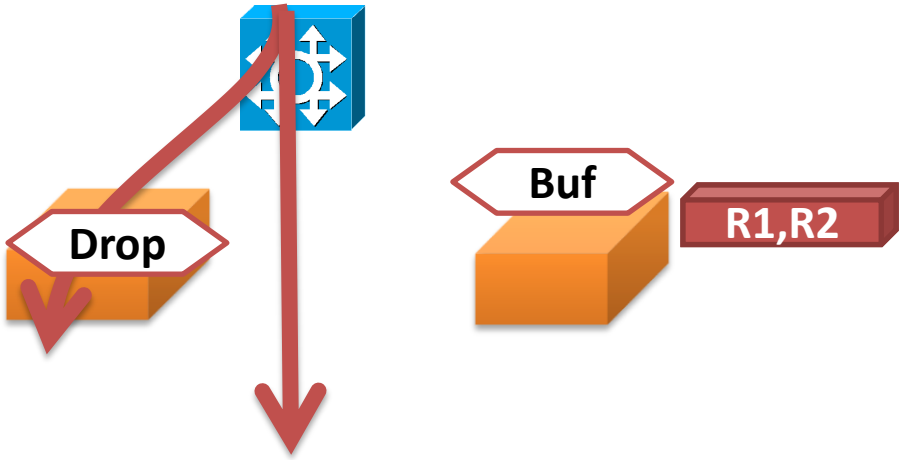
Order-preserving move

- Flush packets in events to $Inst_2$
- `enableEvents(red,buffer)` on $Inst_2$



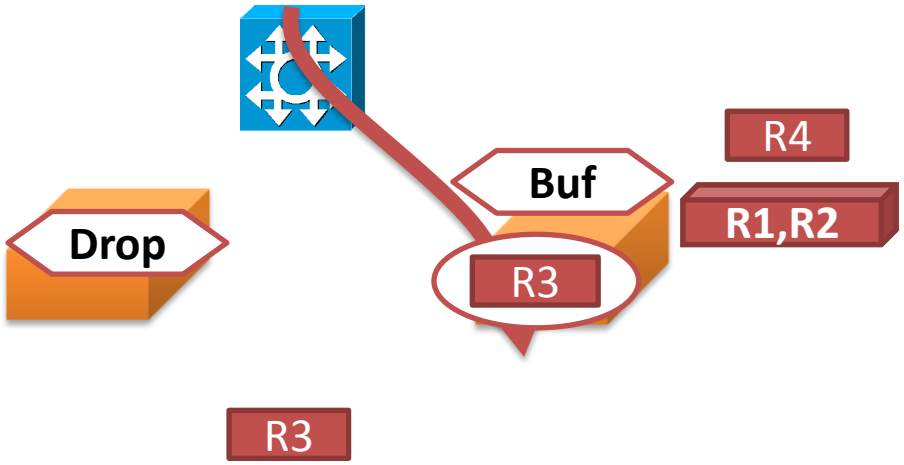
Order-preserving move

- Flush packets in events to $Inst_2$
- `enableEvents(red,buffer)` on $Inst_2$
- ***Forwarding update:*** send to $Inst_1$ & controller



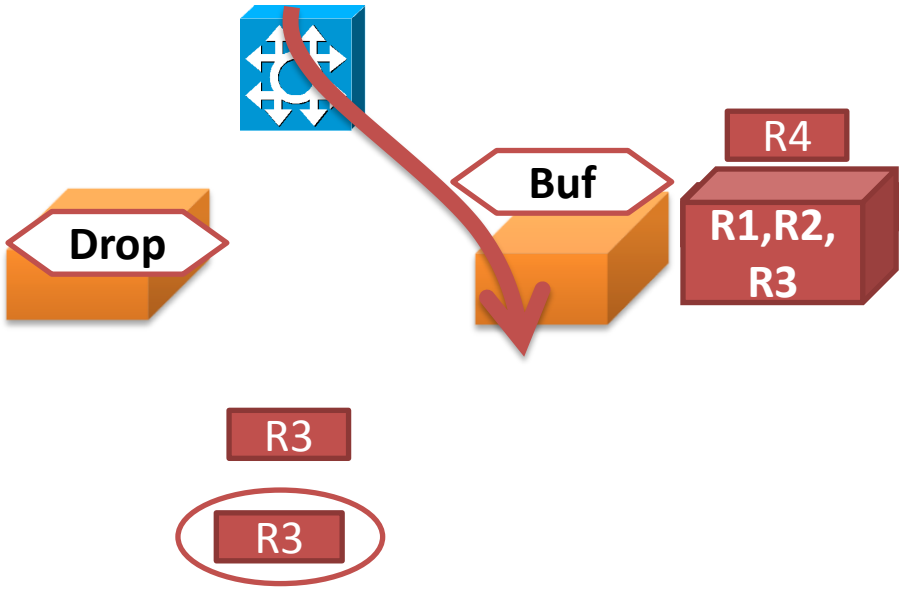
Order-preserving move

- Flush packets in events to $Inst_2$
- `enableEvents(red,buffer)` on $Inst_2$
- ***Forwarding update:*** send to $Inst_1$ & controller
- Wait for packet from switch (remember last)
- ***Forwarding update:*** send to $Inst_2$



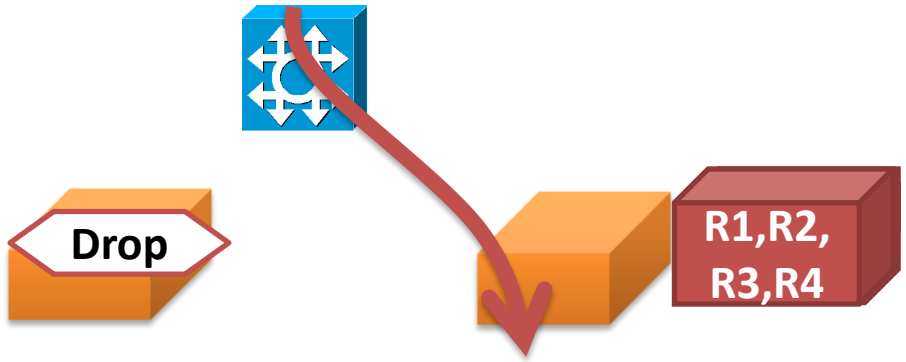
Order-preserving move

- Flush packets in events to $Inst_2$
- `enableEvents(red,buffer)` on $Inst_2$
- ***Forwarding update:*** send to $Inst_1$ & controller
- Wait for packet from switch (remember last)
- ***Forwarding update:*** send to $Inst_2$
- Wait for event for last packet from $Inst_2$



Order-preserving move

- Flush packets in events to $Inst_2$
- `enableEvents(red,buffer)` on $Inst_2$
- ***Forwarding update:*** send to $Inst_1$ & controller
- Wait for packet from switch (remember last)
- ***Forwarding update:*** send to $Inst_2$
- Wait for event for last packet from $Inst_2$
- Release buffer of packets on $Inst_2$



Order-preserving move

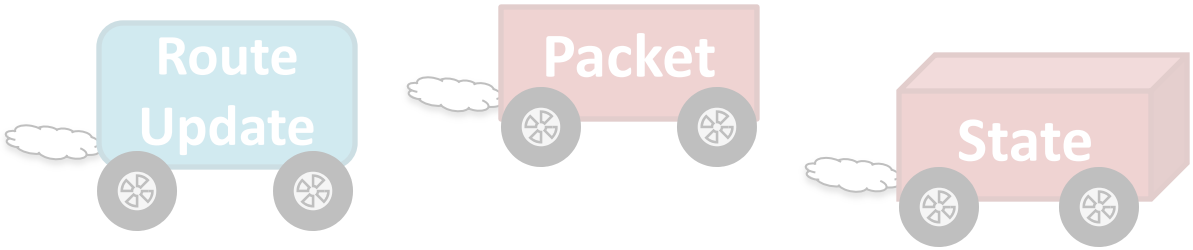
- Flush packets in events to $Inst_2$
- `enableEvents(red,buffer)` on $Inst_2$
- ***Forwarding update:*** send to $Inst_1$ & controller
- Wait for packet from switch (remember last)
- ***Forwarding update:*** send to $Inst_2$
- Wait for event for last packet from $Inst_2$
- Release buffer of packets on $Inst_2$

Assumes no loss or re-ordering on the links from switch to NFs

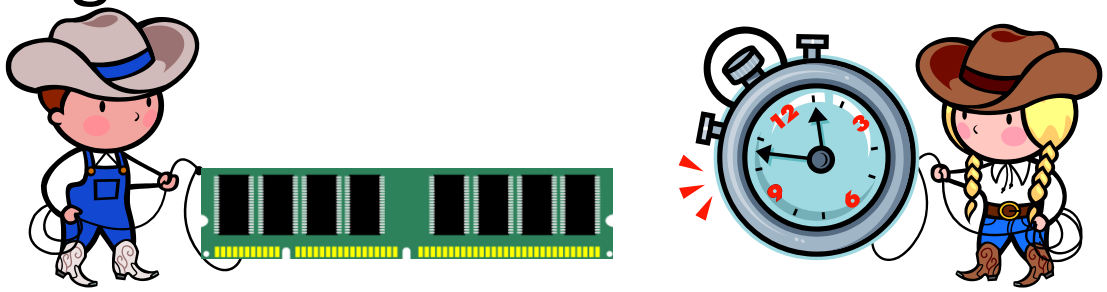
Challenges

1. Supporting many NFs with minimal changes

2. Dealing with race conditions



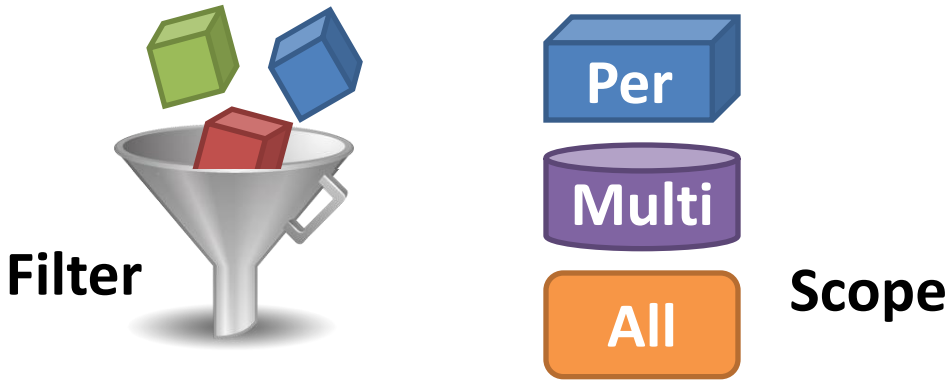
3. Bounding overhead



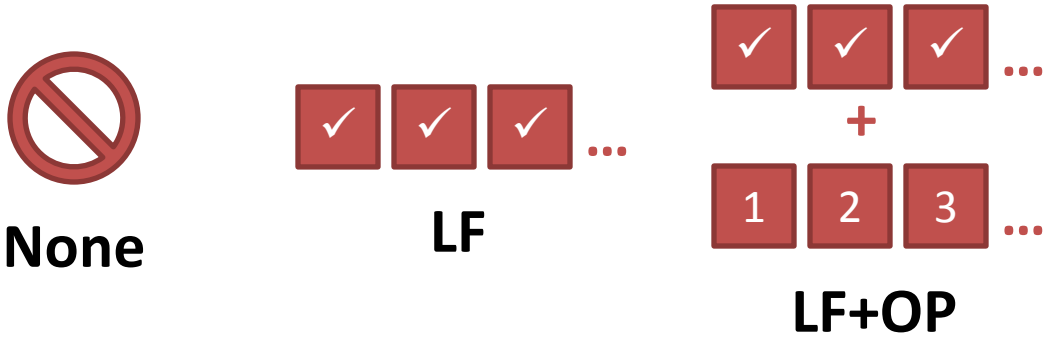
Bounding overhead

Applications decide (based on NF & objectives):

1. Granularity of operations



2. Guarantees desired



OpenNF: SLAs + cost + accuracy

1. Dealing with diversity

   Export/import state based on its association with flows

2. Dealing with race conditions

   Events + Lock-step forwarding updates

3. Bounding overhead

   Applications choose granularity and guarantees

Implementation

- Controller (*3.8K lines of Java*)
- Communication library (2.6K lines of C)
- Modified NFs (3-8% increase in code)

Bro IDS

iptables

Squid Cache

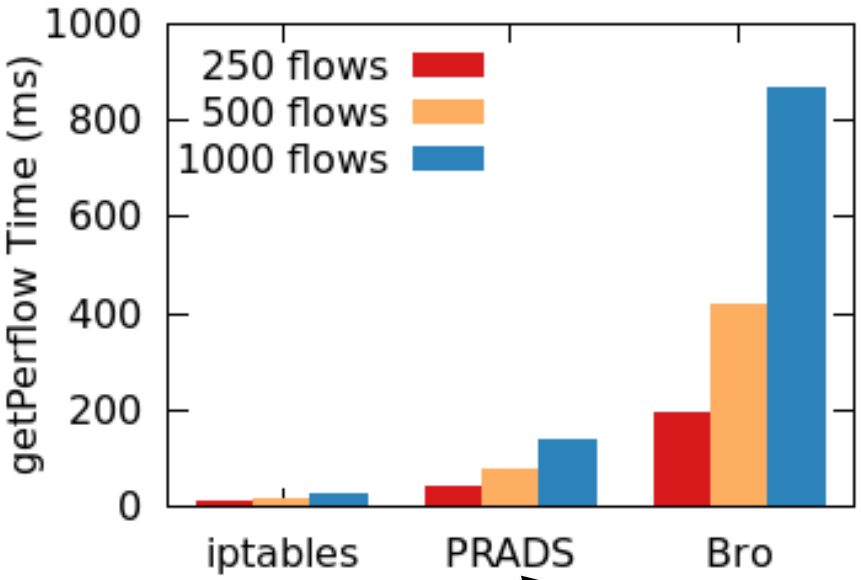
PRADS

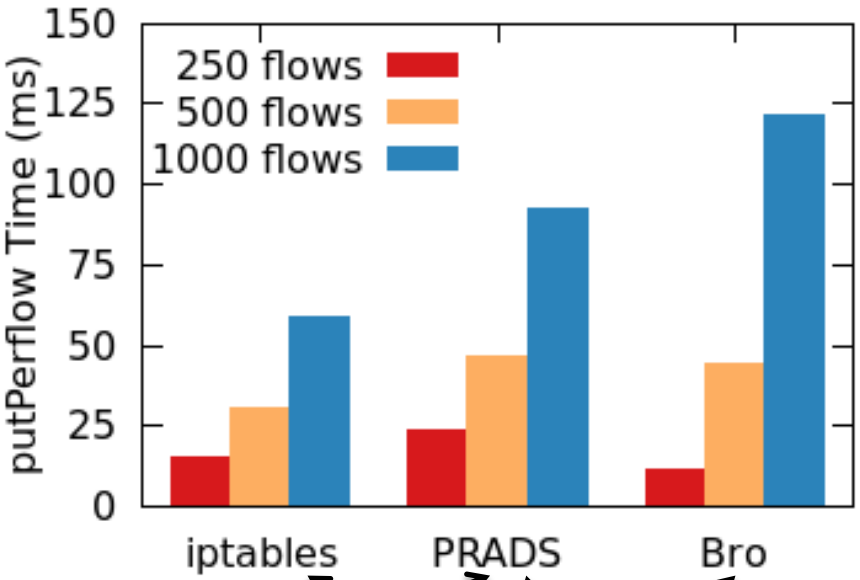
Overall benefits for elastic scaling

- Bro IDS processing 10K pkts/sec
  - *At 180 sec:* move HTTP flows (489) to new IDS
  - *At 360 sec:* move back to old IDS
- SLAs: 260ms to move (loss-free)

- Accuracy: same log entries as using one IDS
  - VM replication: incorrect log entries
- Cost: scale in after state is moved
  - Wait for flows to die: scale in delayed 25+ minutes

Evaluation: state export/import



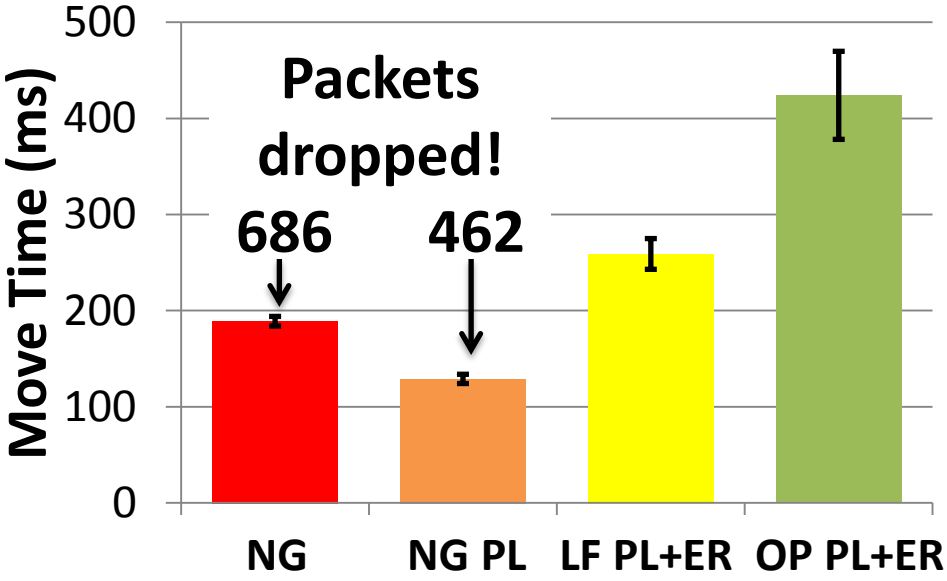


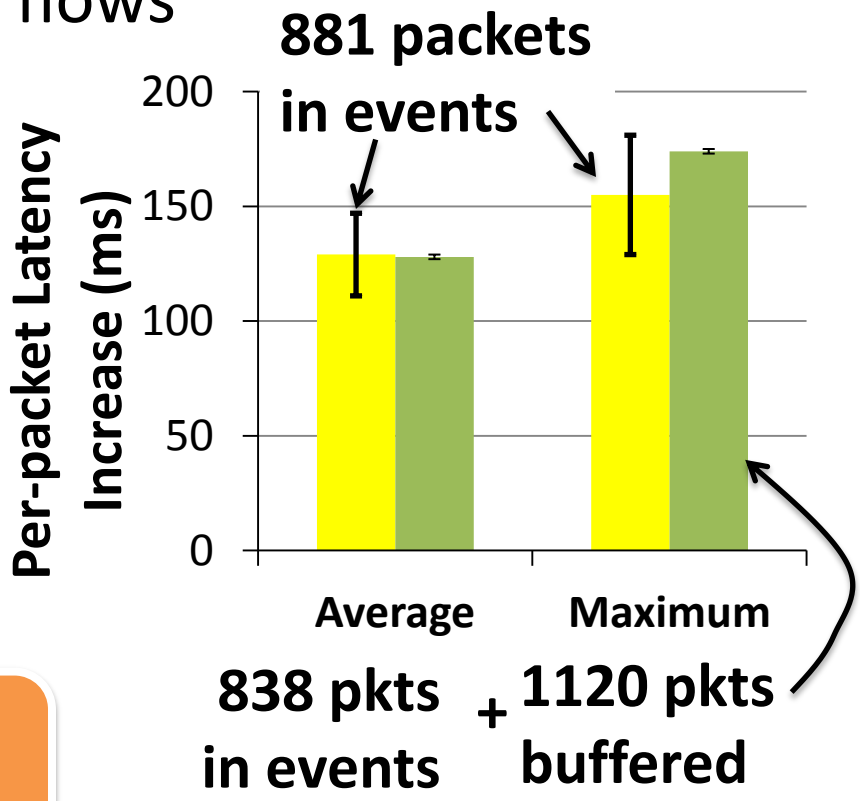
Serialization/deserialization costs dominate

Cost grows with state complexity

Evaluation: operations

- PRADS asset detector processing 5K pkts/sec
- Move per-flow state for 500 flows





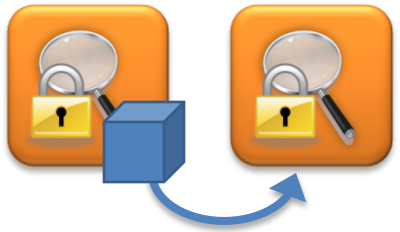
Operations are efficient, but guarantees come at a cost!

Future work

- Reduce buffering
  - Allow packet processing during state transfer, then replay input to bring state "up to speed"
- Improve scalability
  - Peer-to-peer state transfer
- (Semi) automatically modify NFs
  - Static program analysis

Conclusion

- Dynamic reallocation of packet processing enables new services



- Realizing SLAs + cost + accuracy requires quick, safe control of internal NF state
- OpenNF provides flexible and efficient control with few NF modification

Learn more and try it!
http://opennf.cs.wisc.edu

Backup

- Copy and share
- Example app: elastic NF scaling
- Evaluation: controller scalability
- Evaluation: importance of guarantees
- Evaluation: benefits of granular control

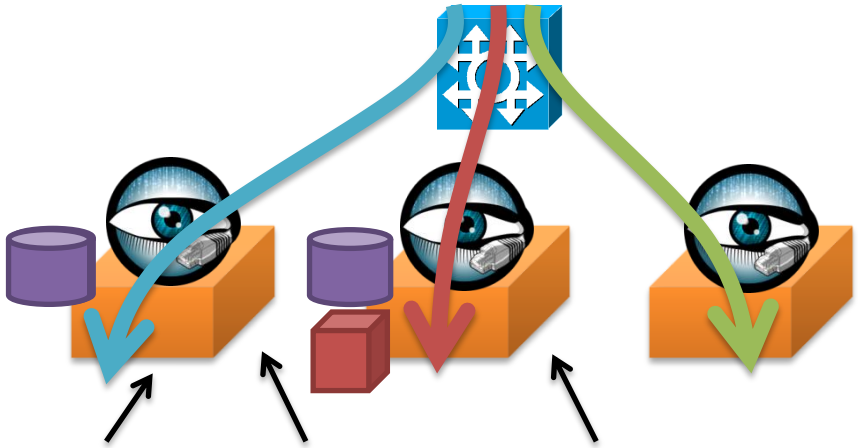
Copy and share operations

- Used when multiple instances need some state
- Copy – no or eventual consistency
  - Once, periodically, based on events, etc.
- Share – strong or strict consistency
  - Events are raised for all packets
  - Events are released one at a time
  - State is copied before releasing the next event

Copy (multi-flow): 111ms
Share (strong): 13ms/packet

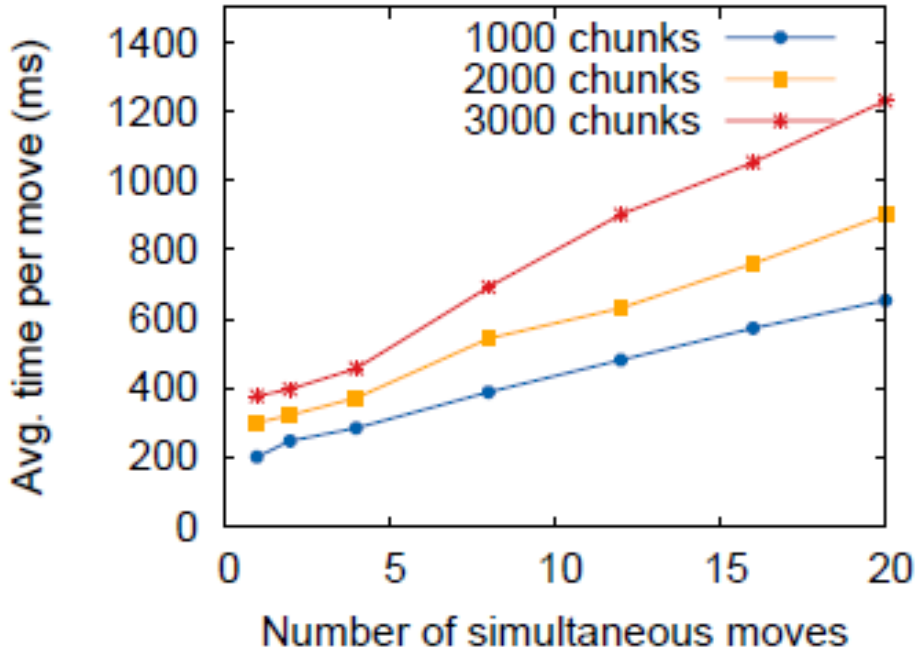
Example app: elastic NF scaling

scan.bro
vulnerable.bro
weird.bro



```
movePrefix(prefix,oldInst,newInst):
  copy(oldInst,newInst,{nw_src:prefix},multi)
  move(oldInst,newInst,{nw_src:prefix},per,LF+OP)
  while (true):
    sleep(60)
    copy(oldInst,newInst,{nw_src:prefix},multi)
    copy(newInst,oldInst,{nw_src:prefix},multi)
```

Evaluation: controller scalability



Improve scalability with P2P state transfers

Evaluation: importance of guarantees

- Bro_1 processing malicious trace @ 1K pkts/sec
- After 14K packets: move active flows to Bro_2

Alert	Baseline	NG	LF	LF+OP
Incorrect file type	26	25	24	26
MHR Match	31	28	27	31
MD5	116	111	106	116
Total	173	164	157	173

Evaluation: benefits of granular control

- HTTP requests from 2 clients (40 unique URLs)
- Initially: both go to $Squid_1$
- 20s later: reassign $Client_1$ to $Squid_2$

	Ignore	**Copy-client**	**Copy-all**
Hits @ $Squid_1$	117	117	117
Hits @ $Squid_2$	Crash!	39	50
State transferred	0 MB	4 MB	54 MB