HotSwap: Correct and Efficient Controller Upgrades for Software-Defined Networks

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HotSDN

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Joint work with

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HotSwap: Correct and Efficient Controller Upgrades for Software-Defined Networks

1 Today's upgrades
disruptive & incorrect

2 The HotSwap system
record, replay, swap

3 Scalability & correctness
filter & specify

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1 Today's upgrades

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As any piece of complex software,
SDN controller must be frequently upgraded

SDN controllers must be upgraded to

- fix bugs
- improve performance
- deploy new features or applications

As any piece of complex software,

SDN controller must be frequently upgraded

SDN controller	# releases	# commits (over 2 years)
Pox	3*	1349
Floodlight	7	2106
Ryu	15	897
Trema	33	2670

source: GitHub

* Pox uses branches instead of releases

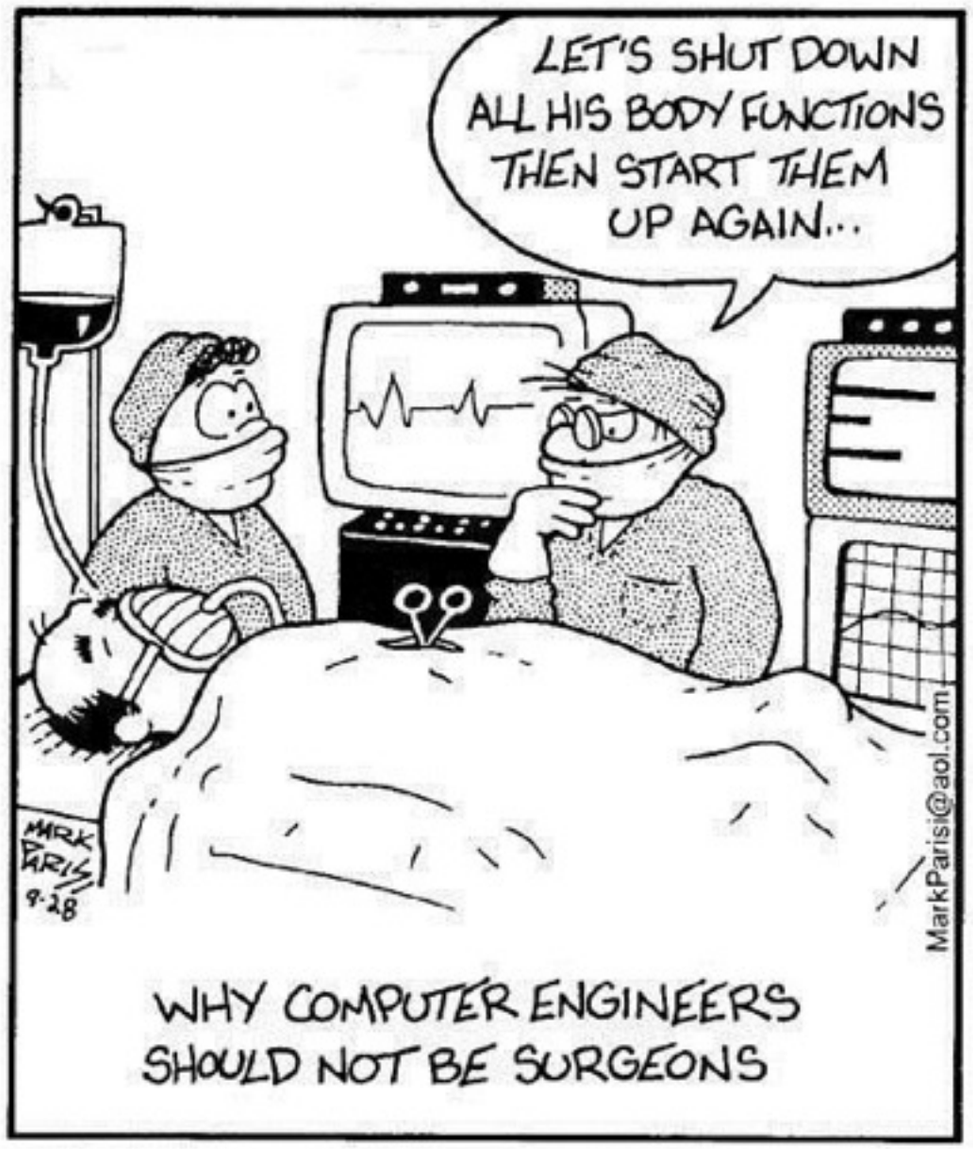
As any piece of complex software,
SDN controller must be frequently upgraded

SDN controller	# releases	# commits	(over 2 years)
Ryu	15	897	
Trema	33	2670	

source: GitHub

How is it done today?

SDN controllers are usually upgraded
by rebooting the controller on the new version



SDN controllers are usually upgraded
by restarting the controller on the new version

During a controller restart, any

- network failure
- rule timeout
- diverted packet

is ignored

SDN controllers are usually upgraded
by restarting the controller on the new version

After a restart, the controller

- resets all network forwarding state to prevent inconsistencies

  leading to **losses** and **delays**

- recreates its state according to the *current* network traffic

  leading to **bugs**

SDN controllers are usually upgraded
by rebooting the controller on the new version

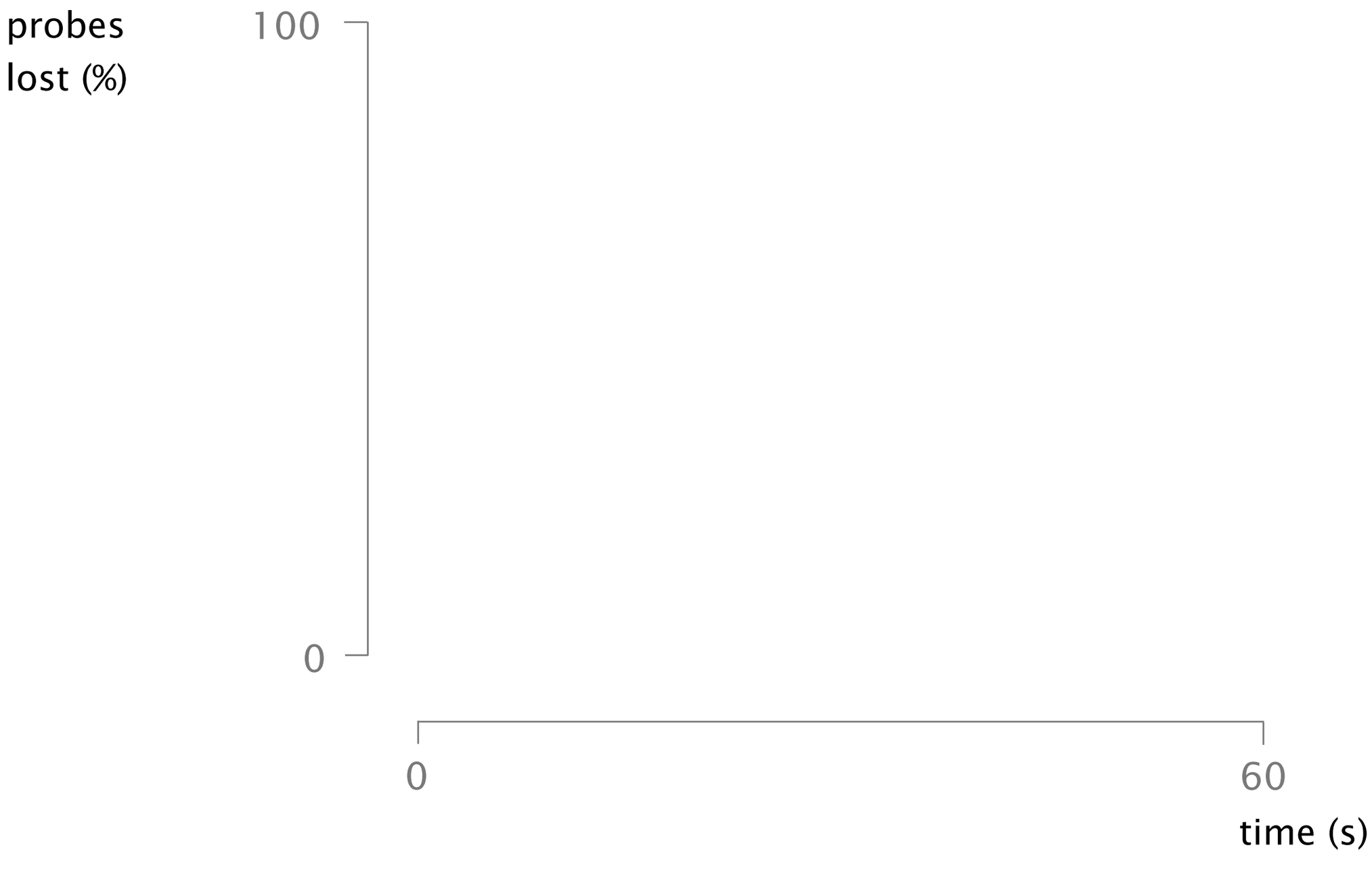
After a reboot, the controller

Is it *really* a problem?

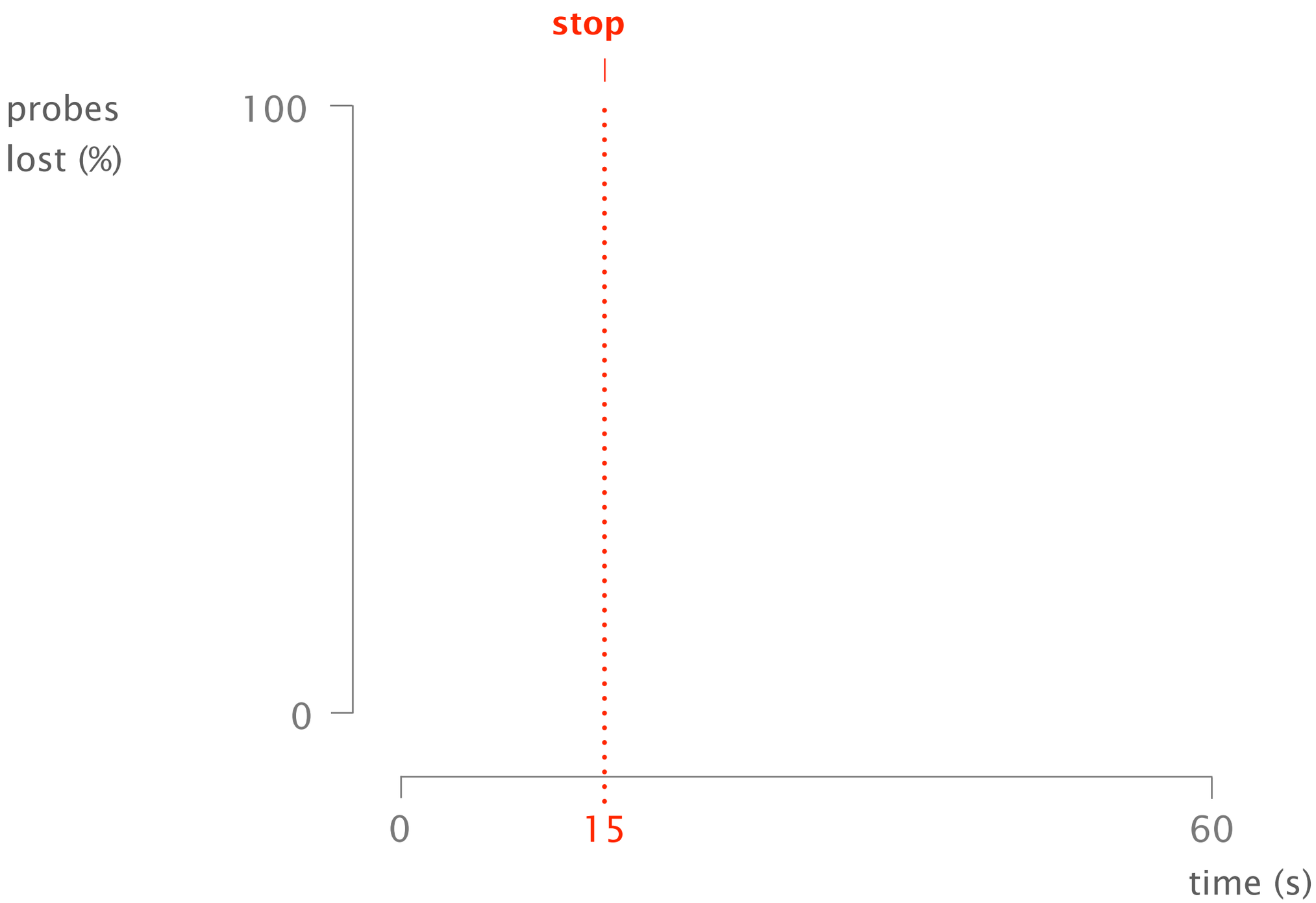
- recreates its state according to the *current* network traffic

leading to **bugs**

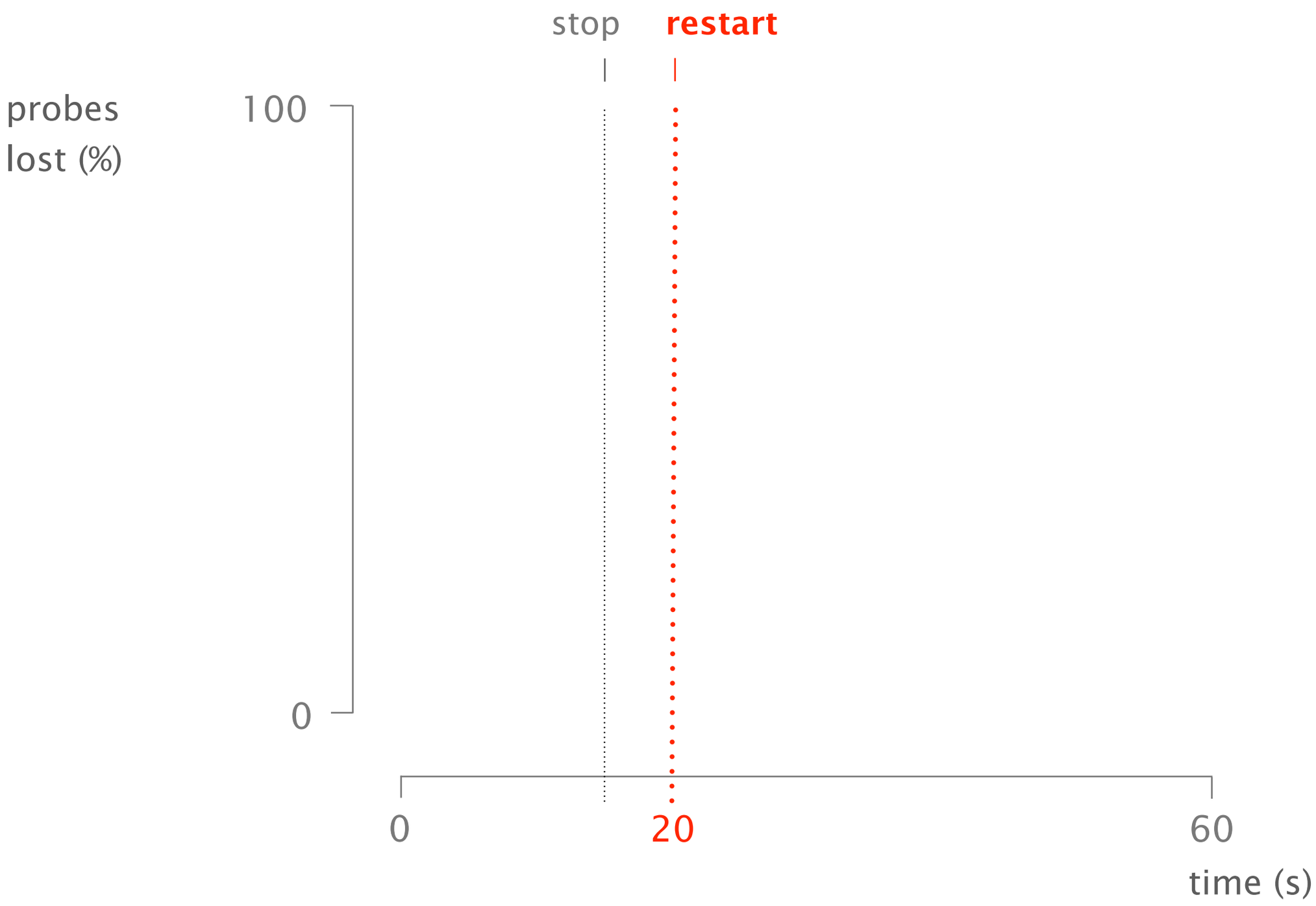
Restarting a controller can create network-wide disruption


probes
lost (%)
100
0
0
60
time (s)

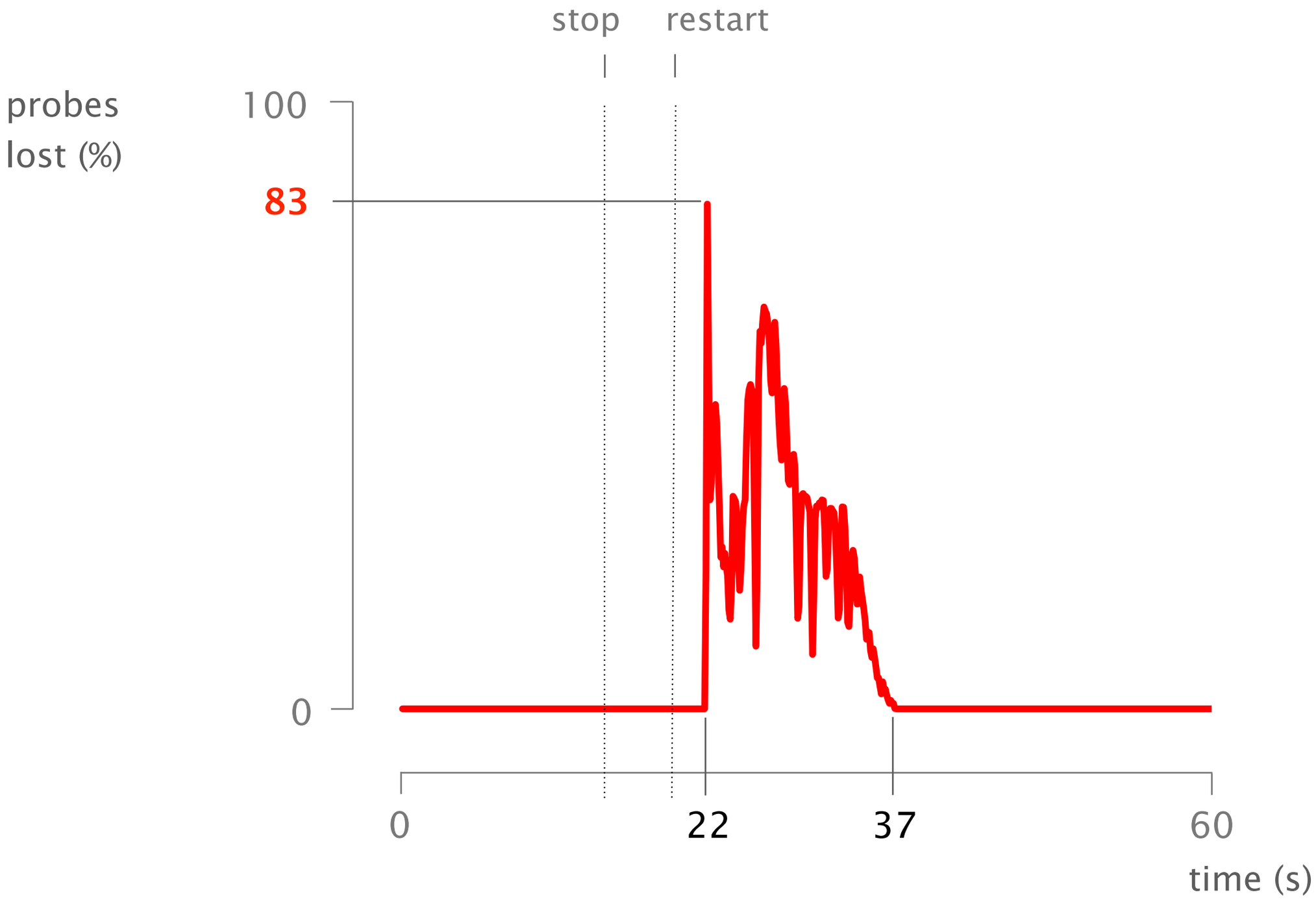
We stop the controller after 15 seconds



We restart it controller after 20 seconds



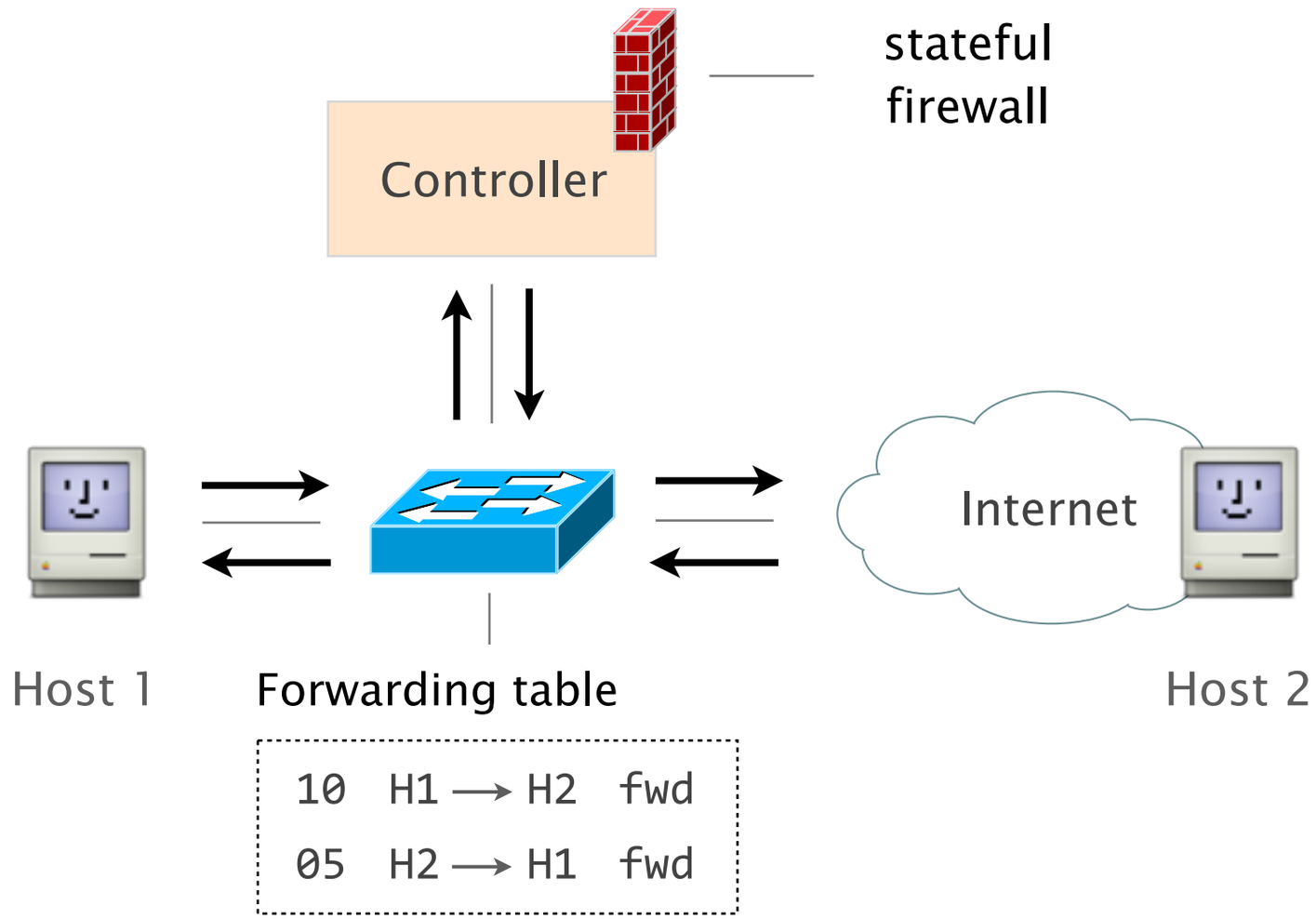
Soon after the controller restart, the network suffered from important *network-wide* losses



Restarting a controller can create bugs

Let's restart a controller running a stateful firewall

which only allows connection initiated from the inside



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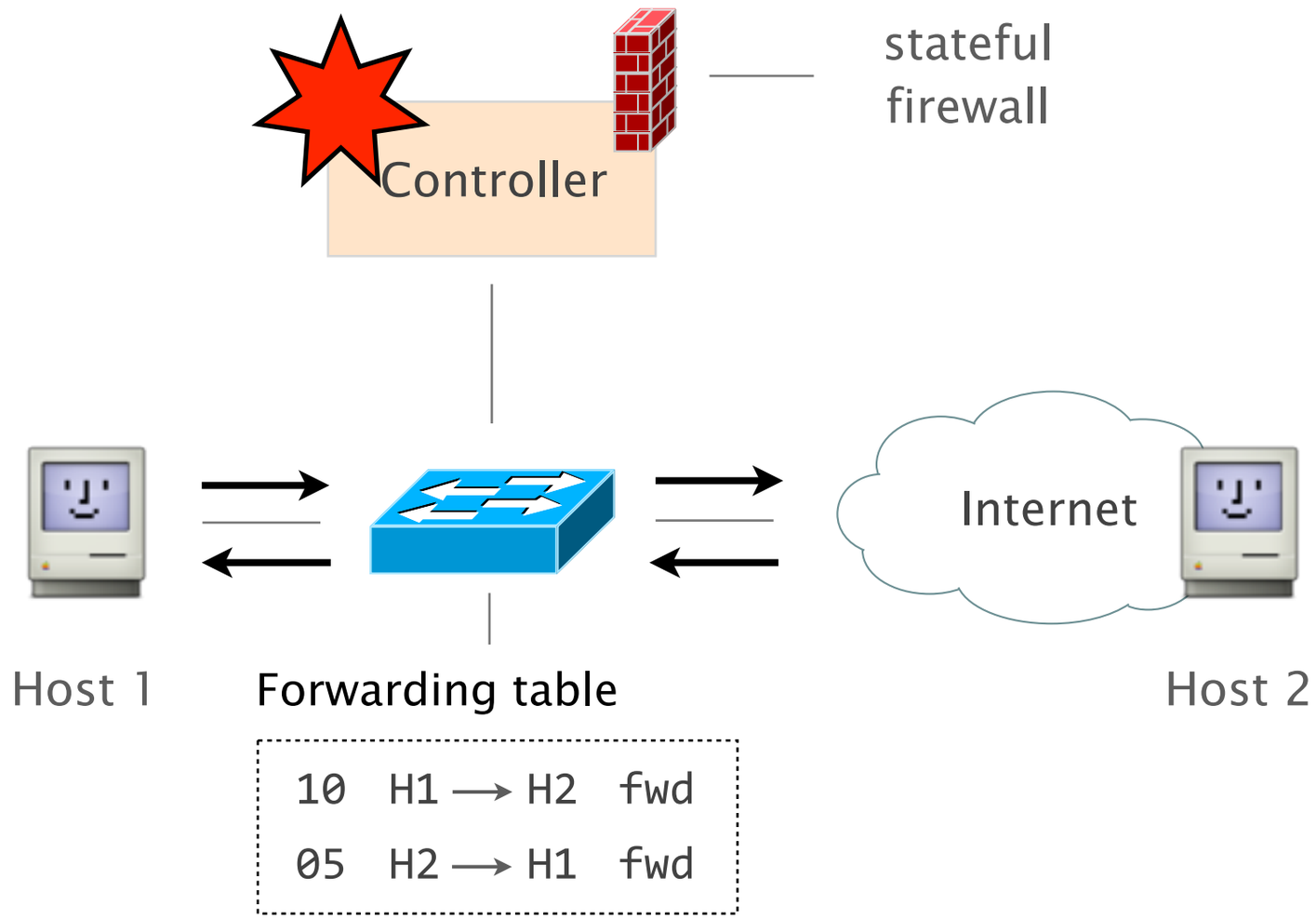
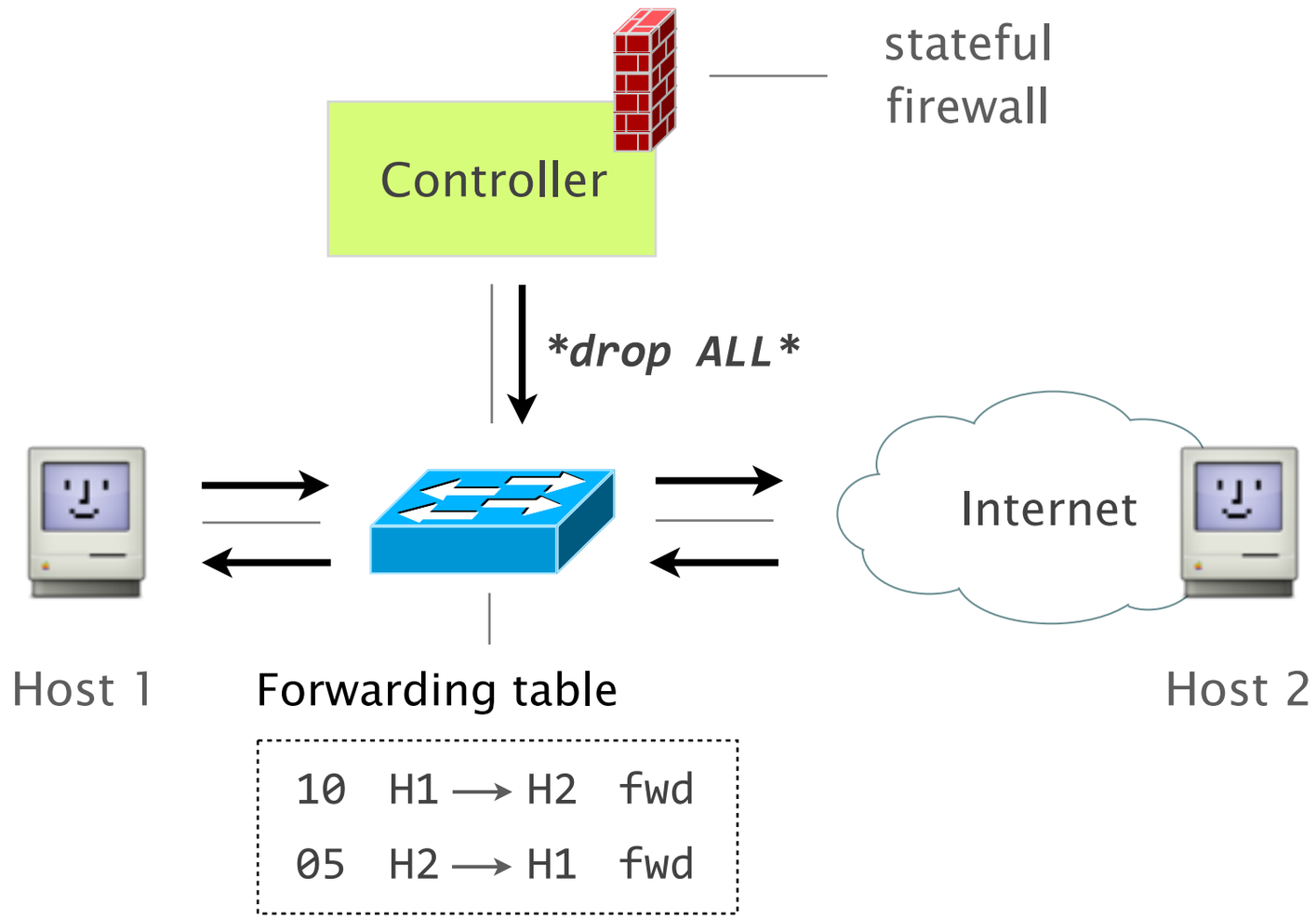


Upon restart, the controller
wipes out all the forwarding entries



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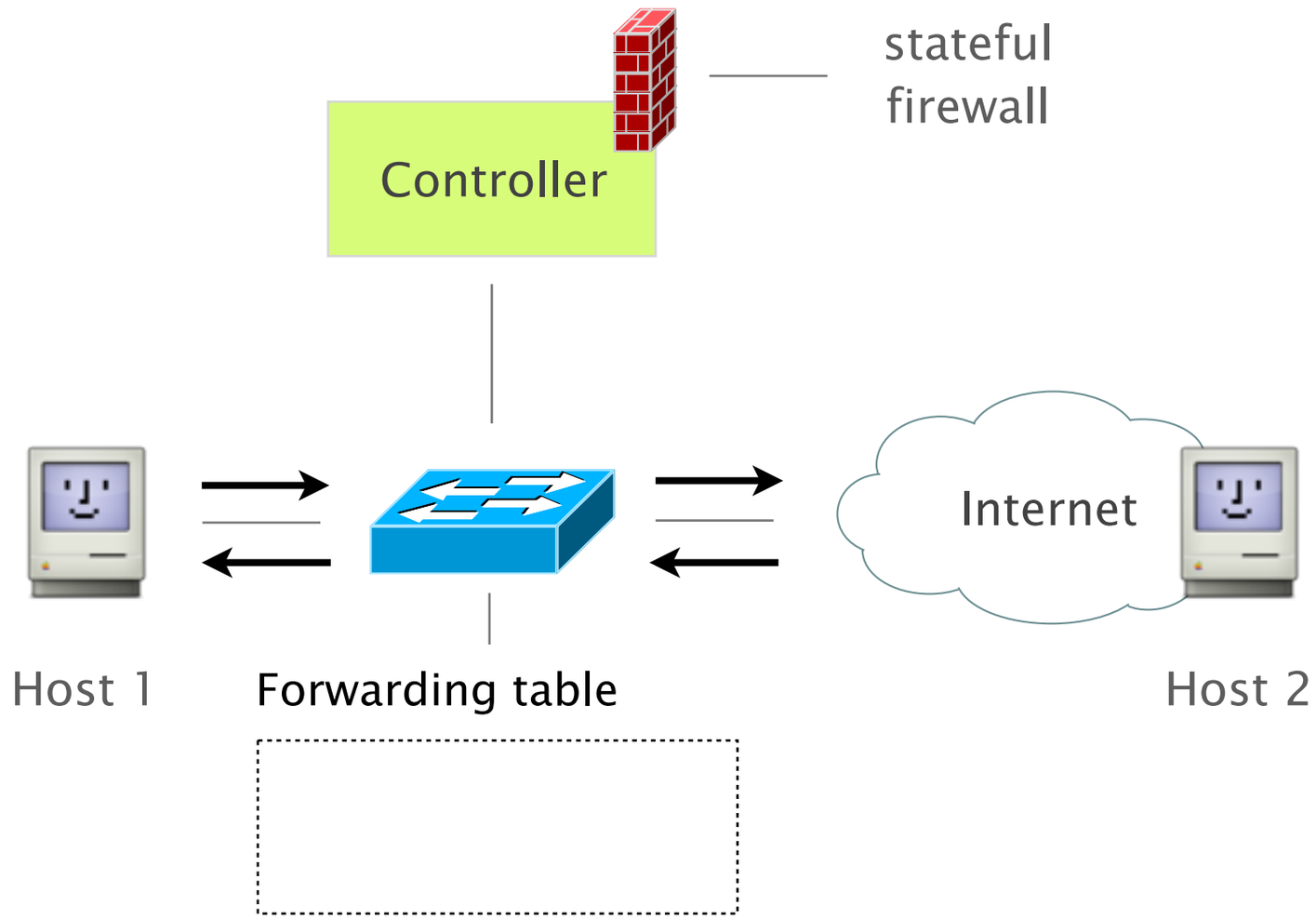
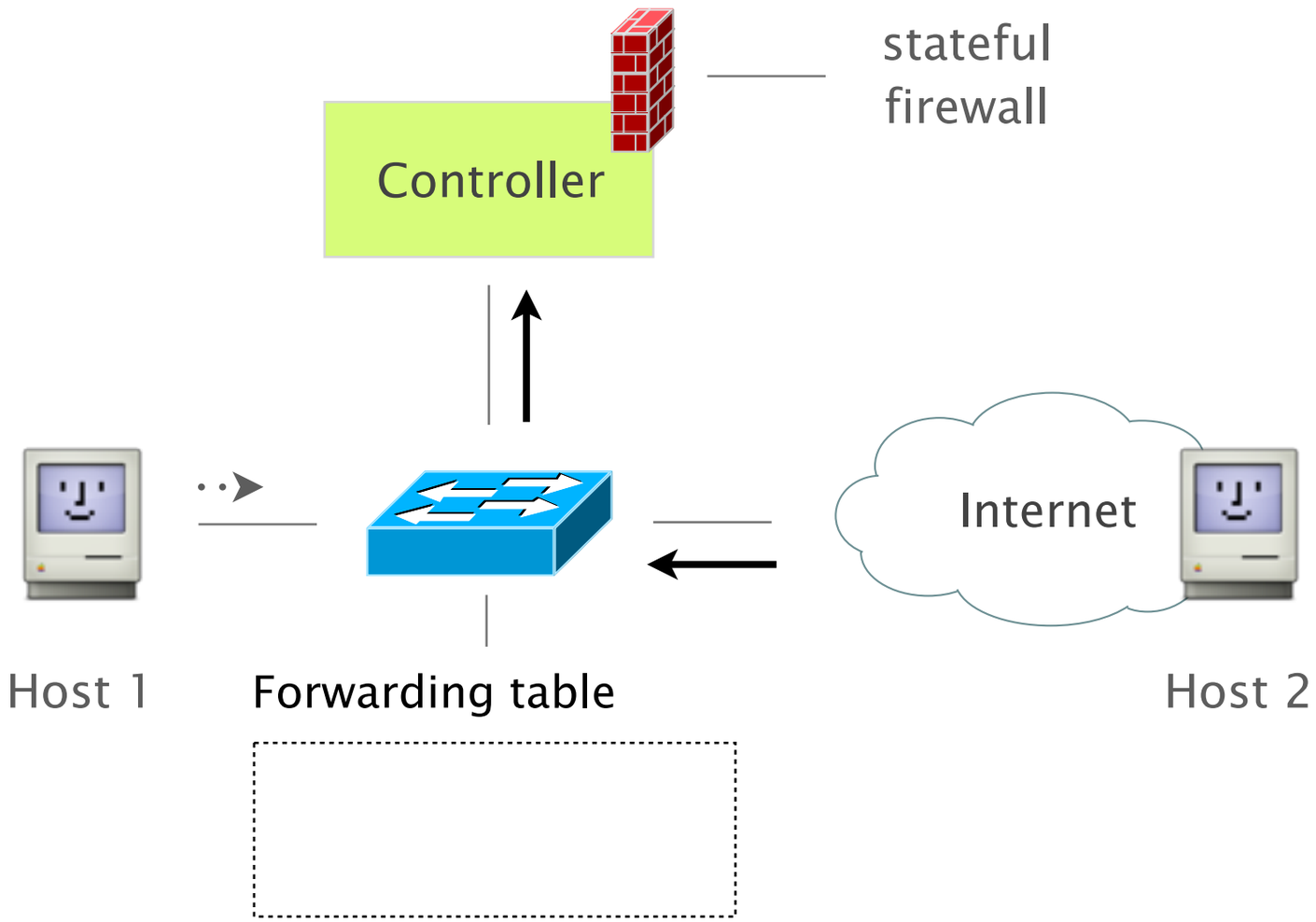


Ongoing flows for which externally originated packets are received first will get dropped by the controller



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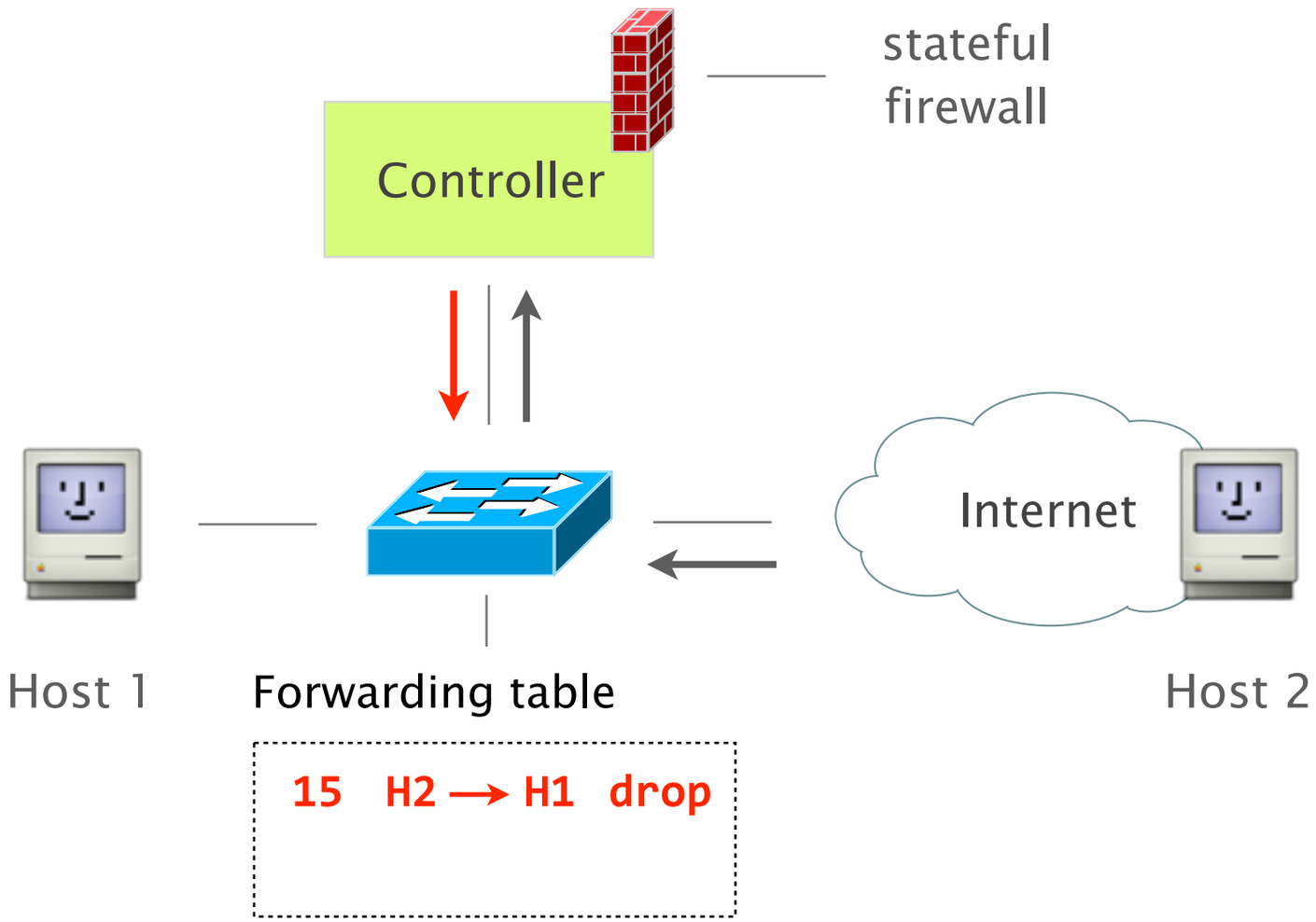
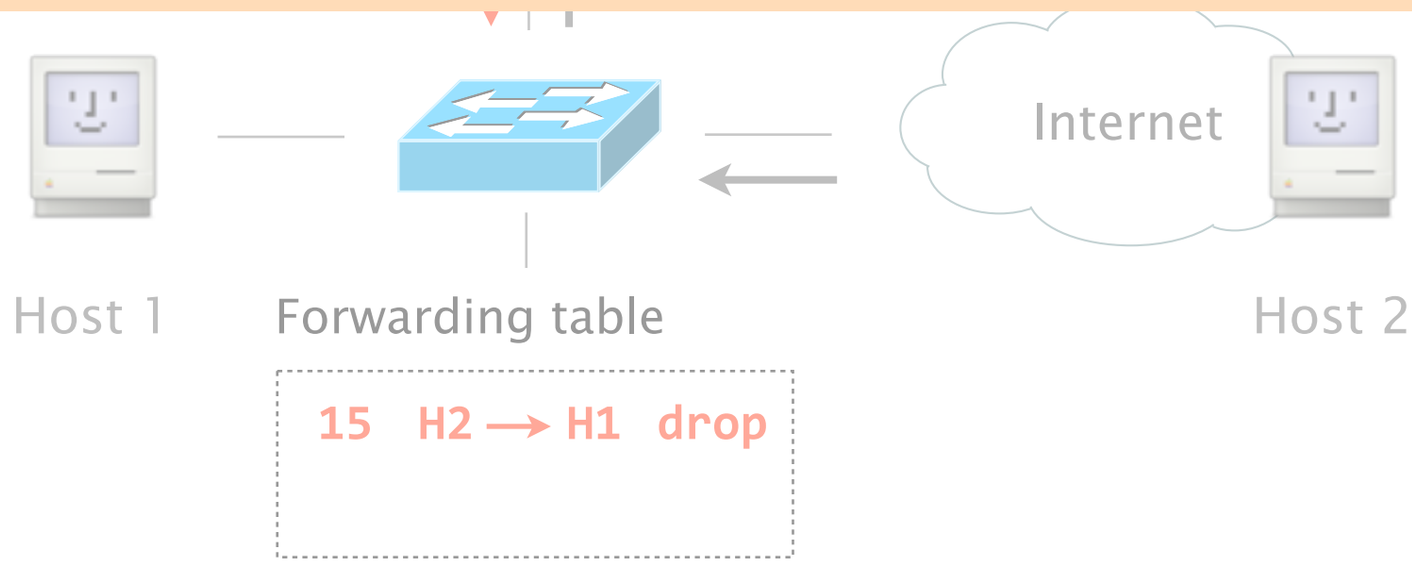


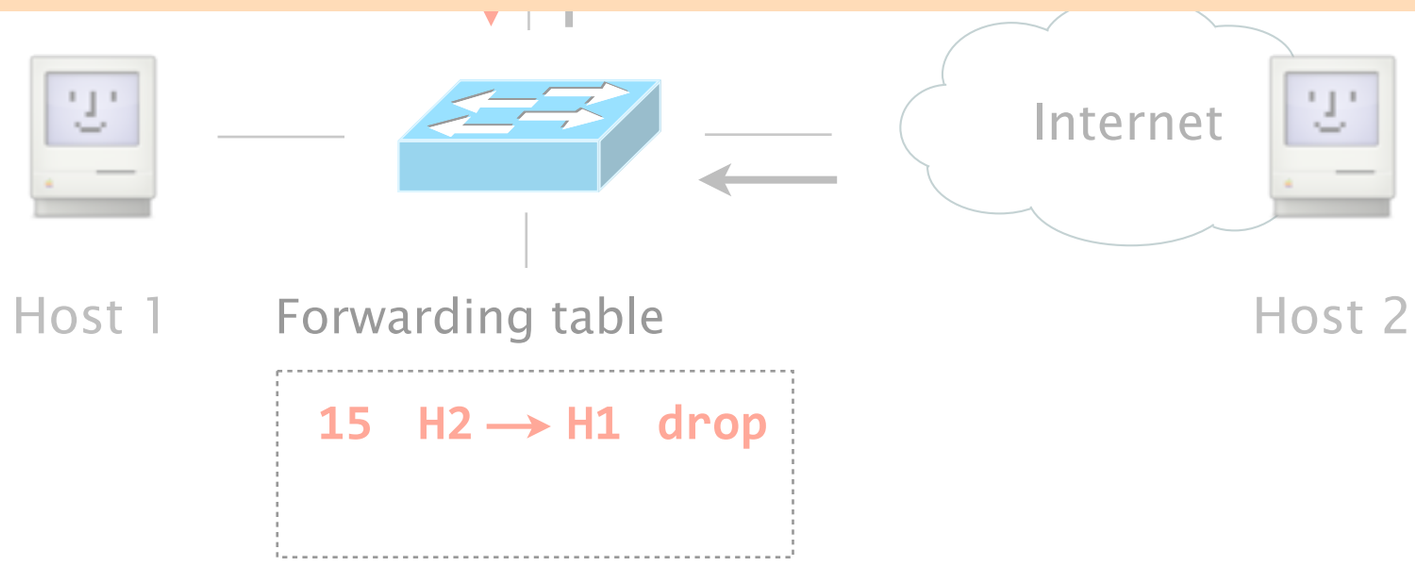
Ongoing flows for which externally originated packets are received first will get dropped by the controller

Restarting the controller can cause **allowed** traffic to be **blocked**



Ongoing flows for which externally originated packets are received first will get dropped by the controller

Restarting the controller can also cause **forbidden** traffic to be **allowed**



HotSwap: Correct and Efficient Controller Upgrades for Software-Defined Networks

Today's upgrades

disruptive & incorrect

2 The HotSwap system

record, replay, swap

Scalability & correctness

filter & specify

HotSwap warms up the upgraded controller before giving it control over the network

Recreate state in the upgraded controller

in a controlled fashion, guaranteeing correctness

Keeping as much traffic in the network

avoiding network-wide disruptions

Tolerating different control and forwarding behavior

between the new and old controller

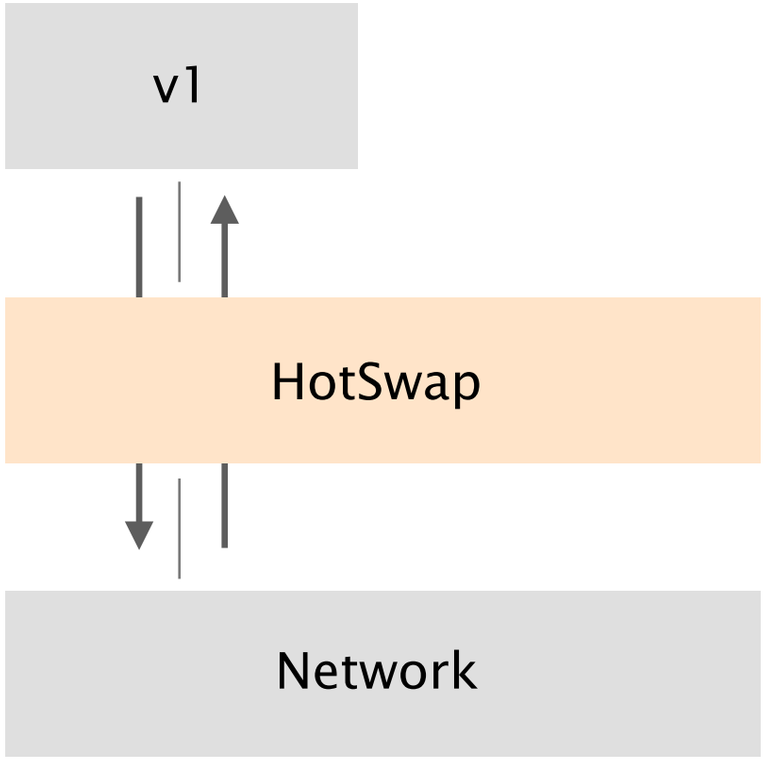
v1

SDN Controller

OpenFlow messages

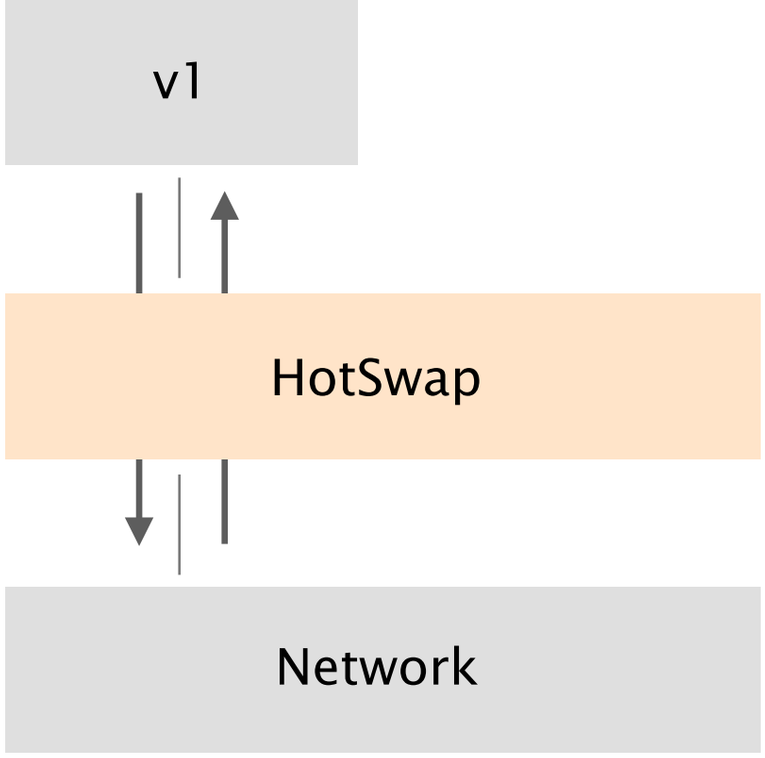
Network

HotSwap is a hypervisor that sits
between the network and the controller



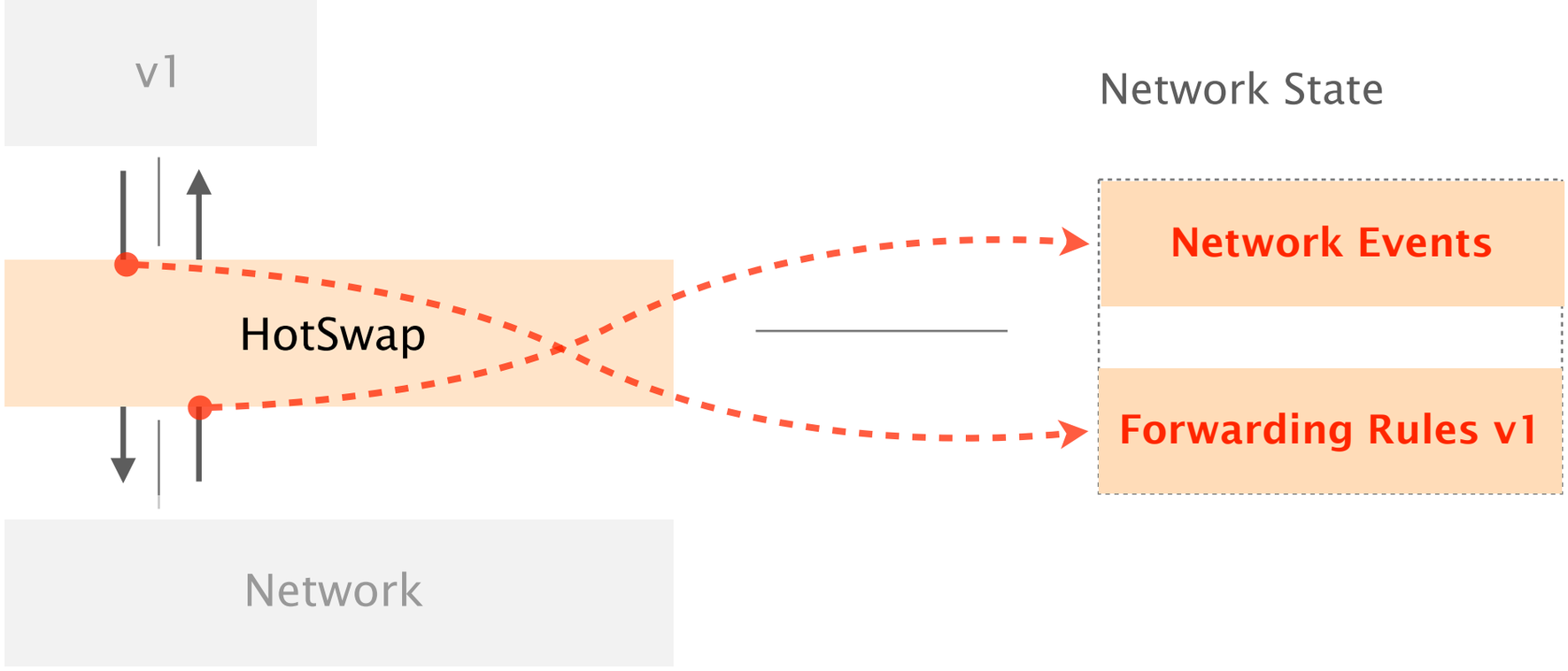
HotSwap proceeds in four stages:

record, *replay*, *compare* & *replace*



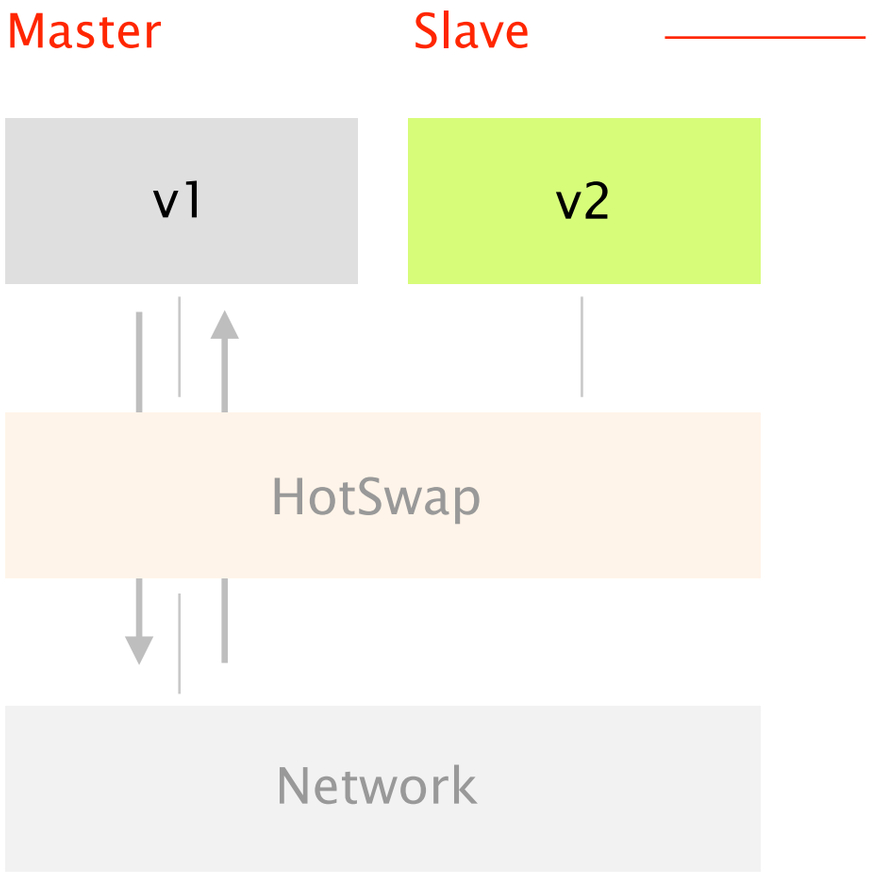
In the *record* stage,

HotSwap maintains a copy of the network state



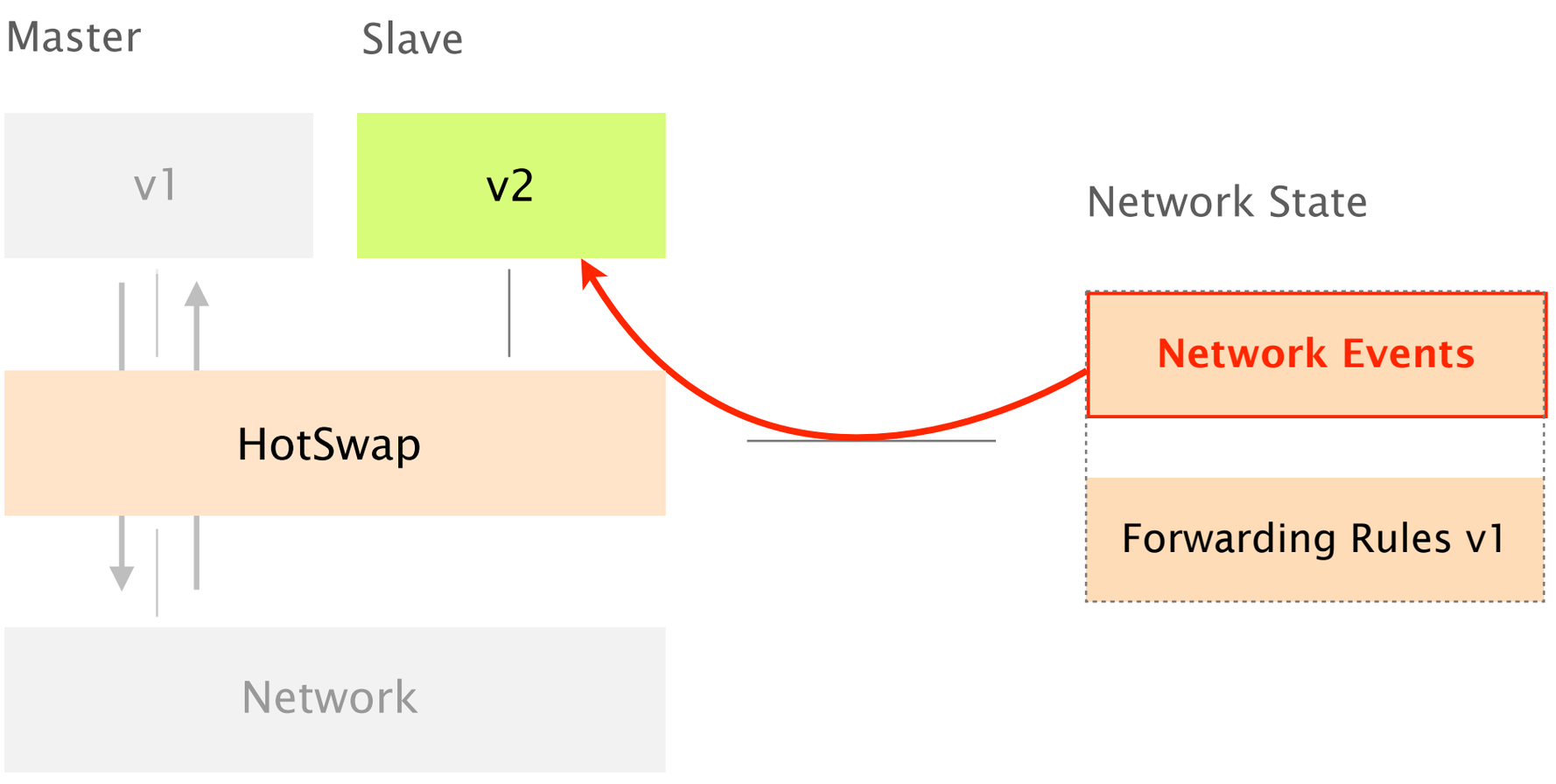
When an upgrade is initiated,

HotSwap sets the upgraded controller as slave

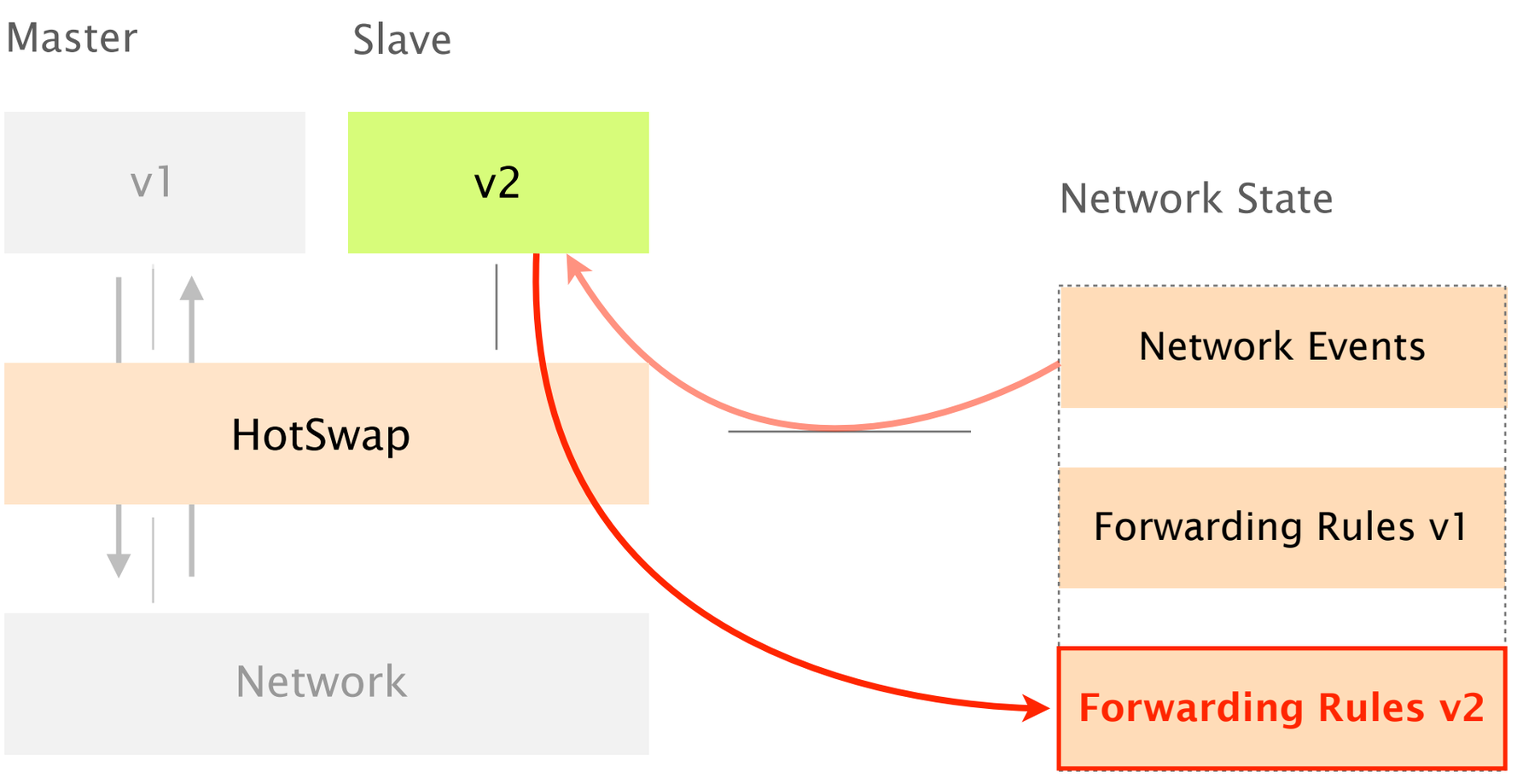


Only the master controller can write to the network

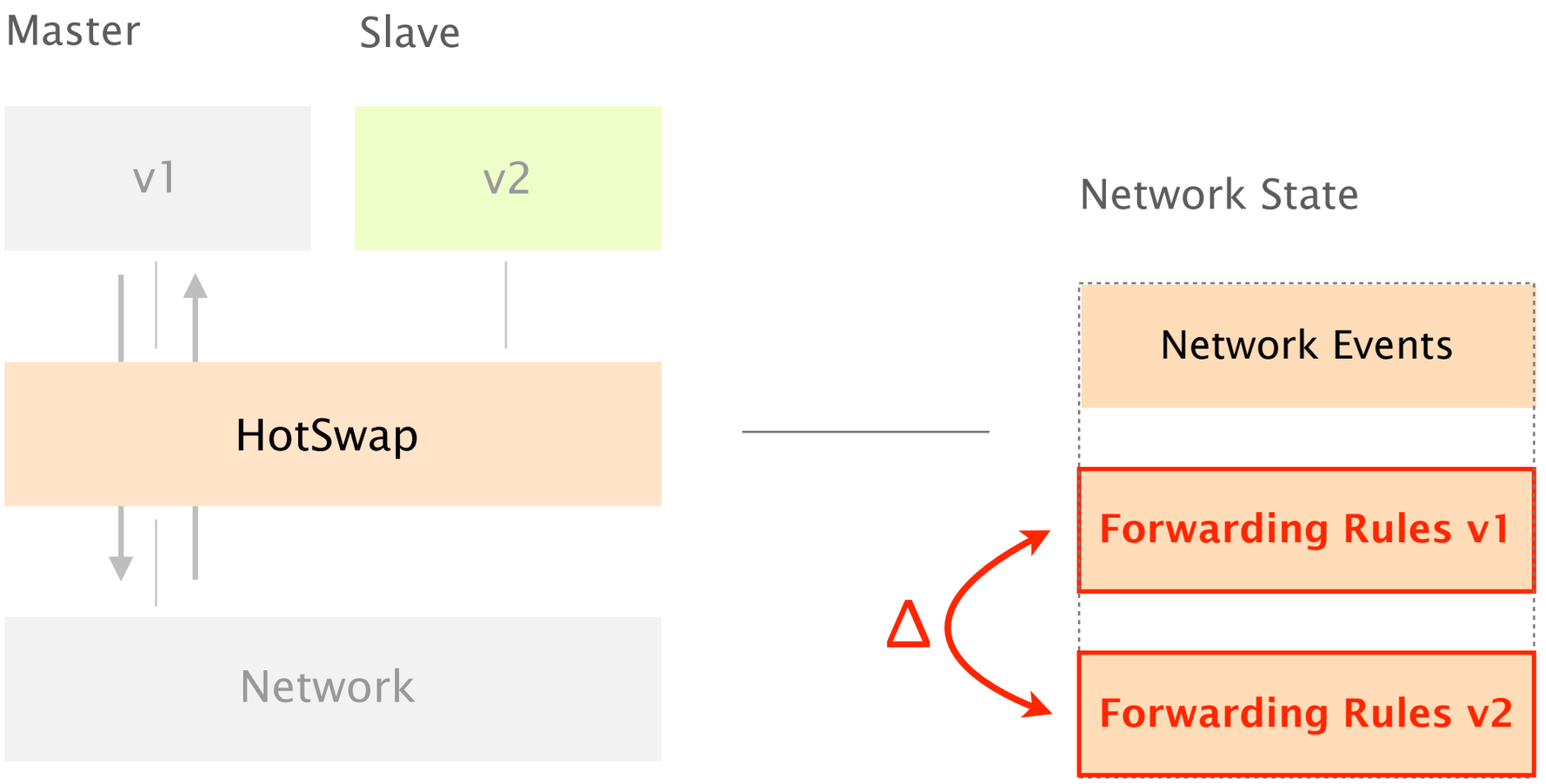
HotSwap then *replays* the recorded network events against the upgraded controller



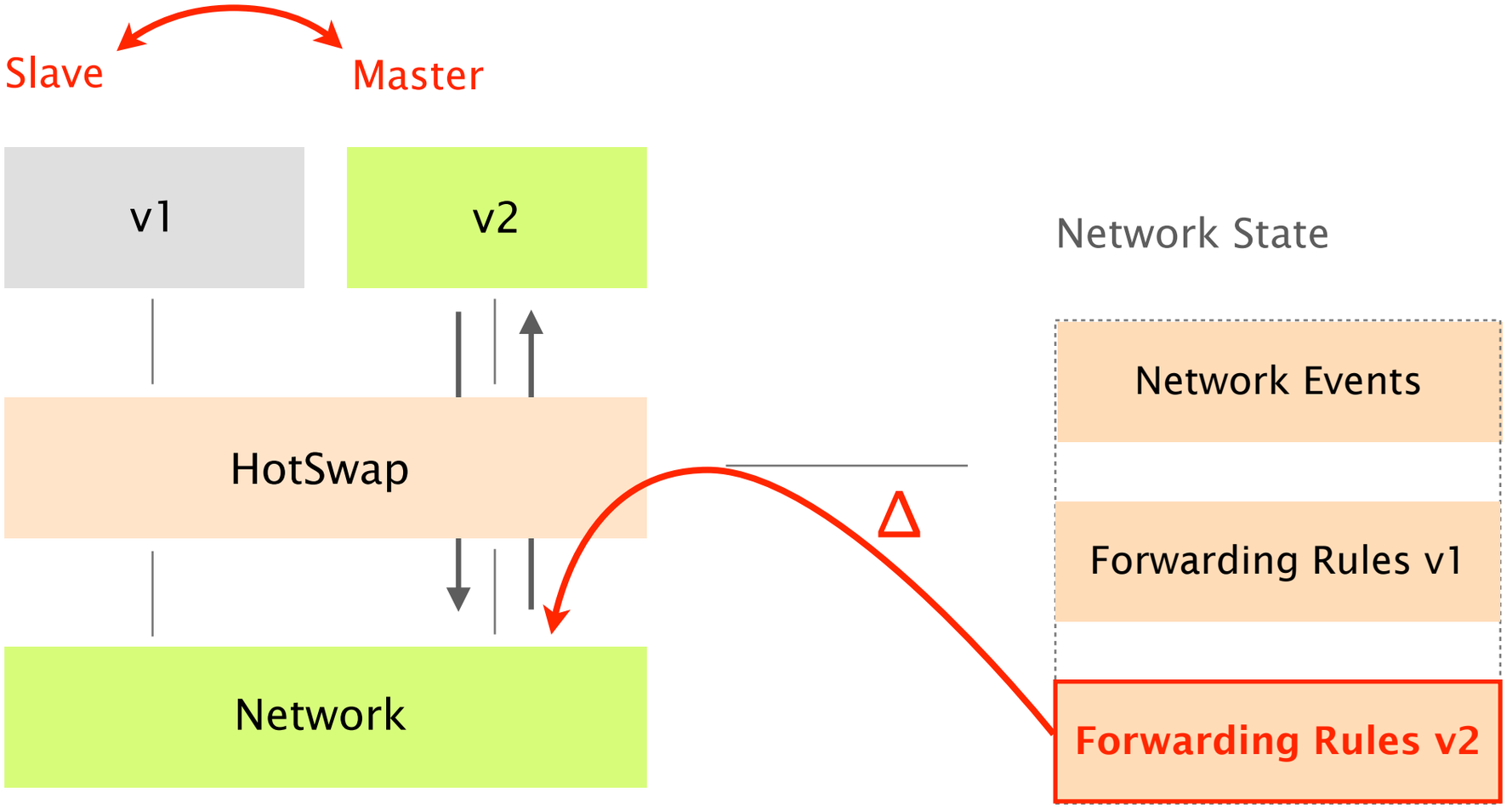
During the *replay*, HotSwap records the forwarding rules generated by the upgraded controller



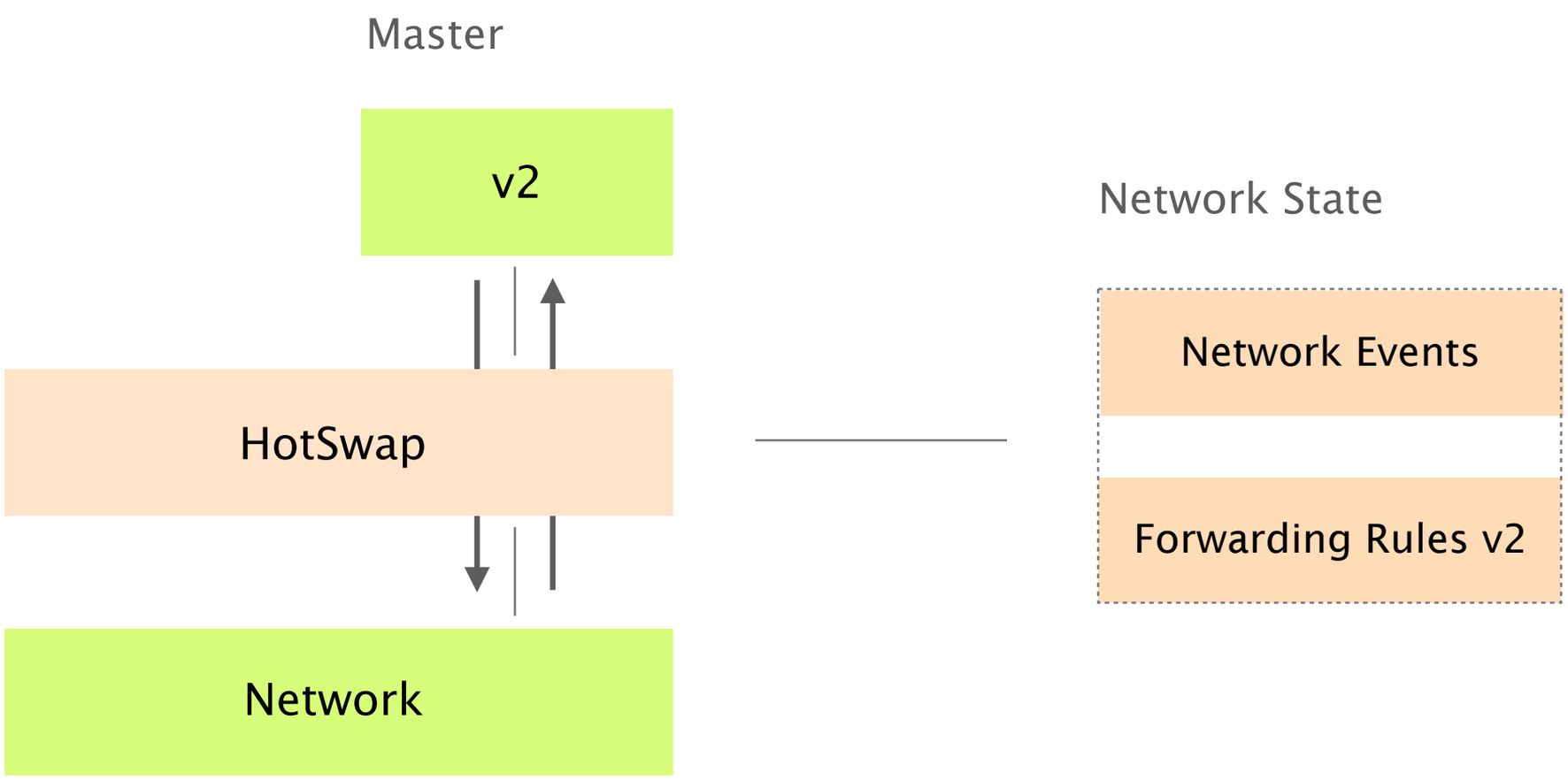
Once the *replay* is completed, HotSwap computes the deltas between the initial and upgraded rules



In the *replace* stage, HotSwap sets the upgraded controller as master and installs the deltas



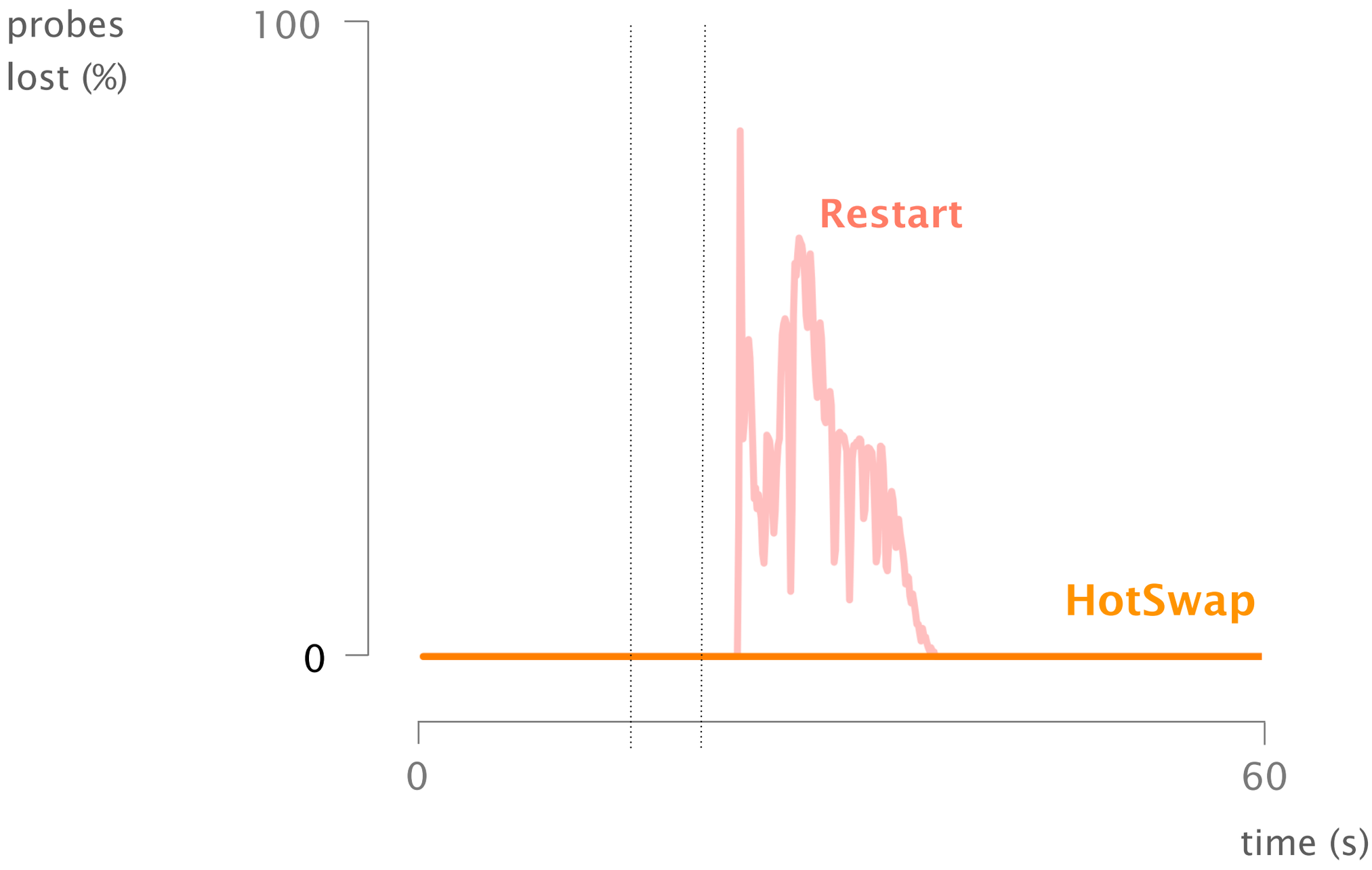
HotSwap finally removes the initial controller and re-enters the *record* stage



HotSwap performs upgrade
in a disruption-free manner

Using HotSwap,

not a single packet is lost during the upgrade



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Recording all network events does not scale

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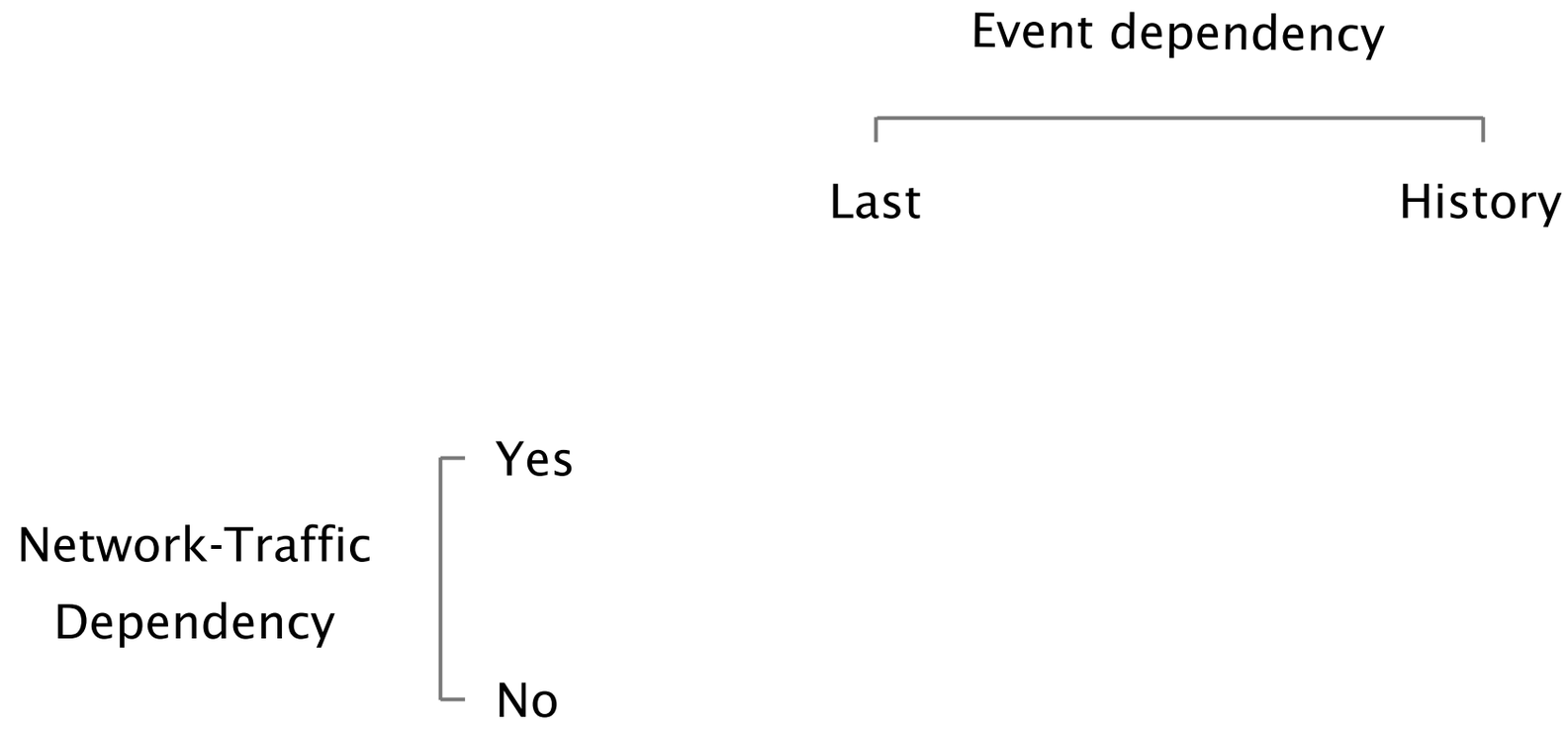
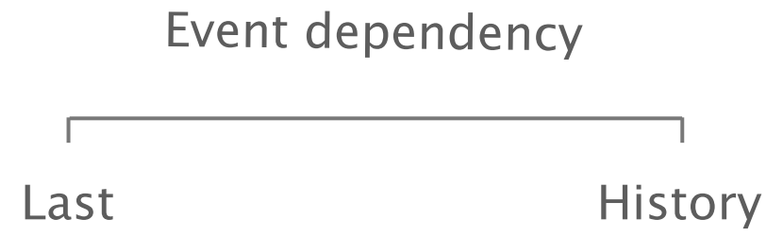
... but is not needed!

Most stateful controllers only
require *some* events to be replayed

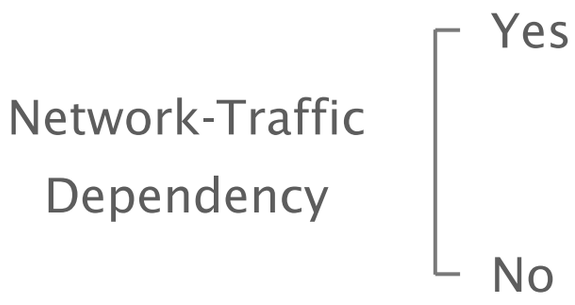
The number and type of events to be recorded depend on the controller category ...



... whether their state depend on
the actual traffic being exchanged



... whether their state depend on
the last network event or on an history of events



Network-Traffic Dependency	Event dependency: Last	Event dependency: History
Yes	Learning-Switch	Stateful Firewall
No	Shortest-Path Routing	Reliable Routing

Event dependency

HotSwap provides a query language to filter stream of events at record *and* replay time

Dependent

No

Shortest-Path Routing

Reliable Routing

What does it mean for an upgrade to be correct?

When we upgrade from v1 to v2,

We would like the network to behave as if v2 had been running since the beginning

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- What does it mean?

When we upgrade from v1 to v2,

We would like the network to behave as if v2 had been running since the beginning

What does it mean?

same forwarding rules?

same forwarding semantic?

eventual semantic consistency?

It depends ...

same forwarding rules?

same forwarding semantic?

eventual semantic consistency?

HotSwap verifies if the desired correctness criteria is met before swapping controllers

The operator defines a relation that captures the *acceptable* differences on the controller outputs

|

$=$ same forwarding rules?

$\cong$ same forwarding semantic?

$\diamond$ eventual semantic consistency?

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query language

HotSwap enables disruption-free and correct SDN controller upgrade

HotSwap

- works in practice

  first implementation on top of FlowVisor

- is highly general

  no assumption on the controller or on the application

- is easy to use

  minimum input from the network operator

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