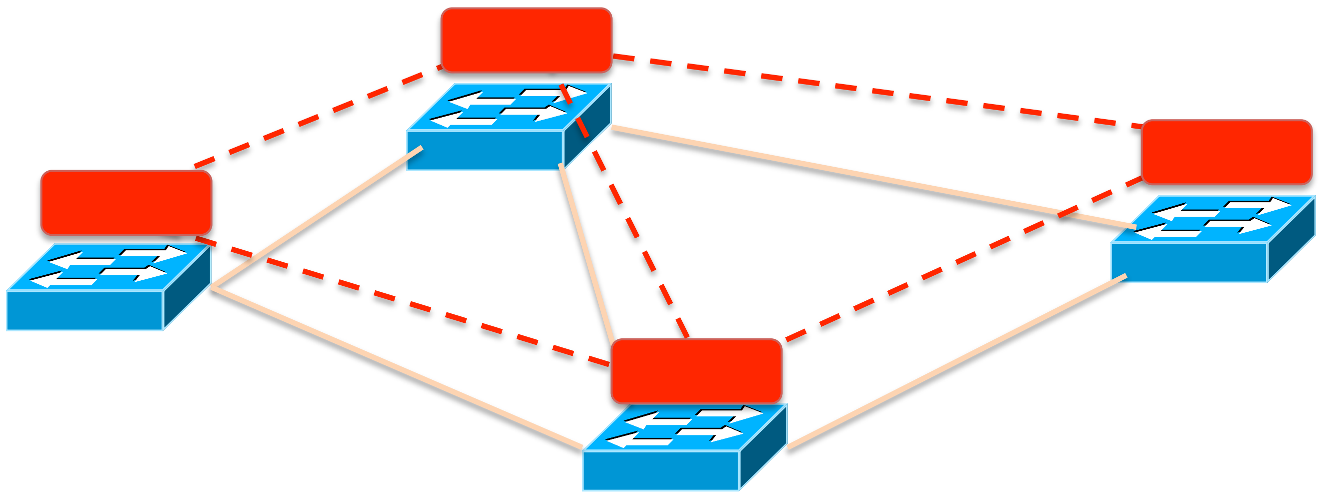
Flog : Logic Programming for Software Defined Networks

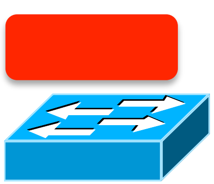
Naga Praveen Katta,
Jennifer Rexford, David Walker
Princeton University

Traditional networks

- Traditional network elements - special purpose devices running distributed algorithms.

Operator:
- Monitors traffic
- Identifies threats
- Indirectly configures policy





Control Plane – Complex Distributed algorithms

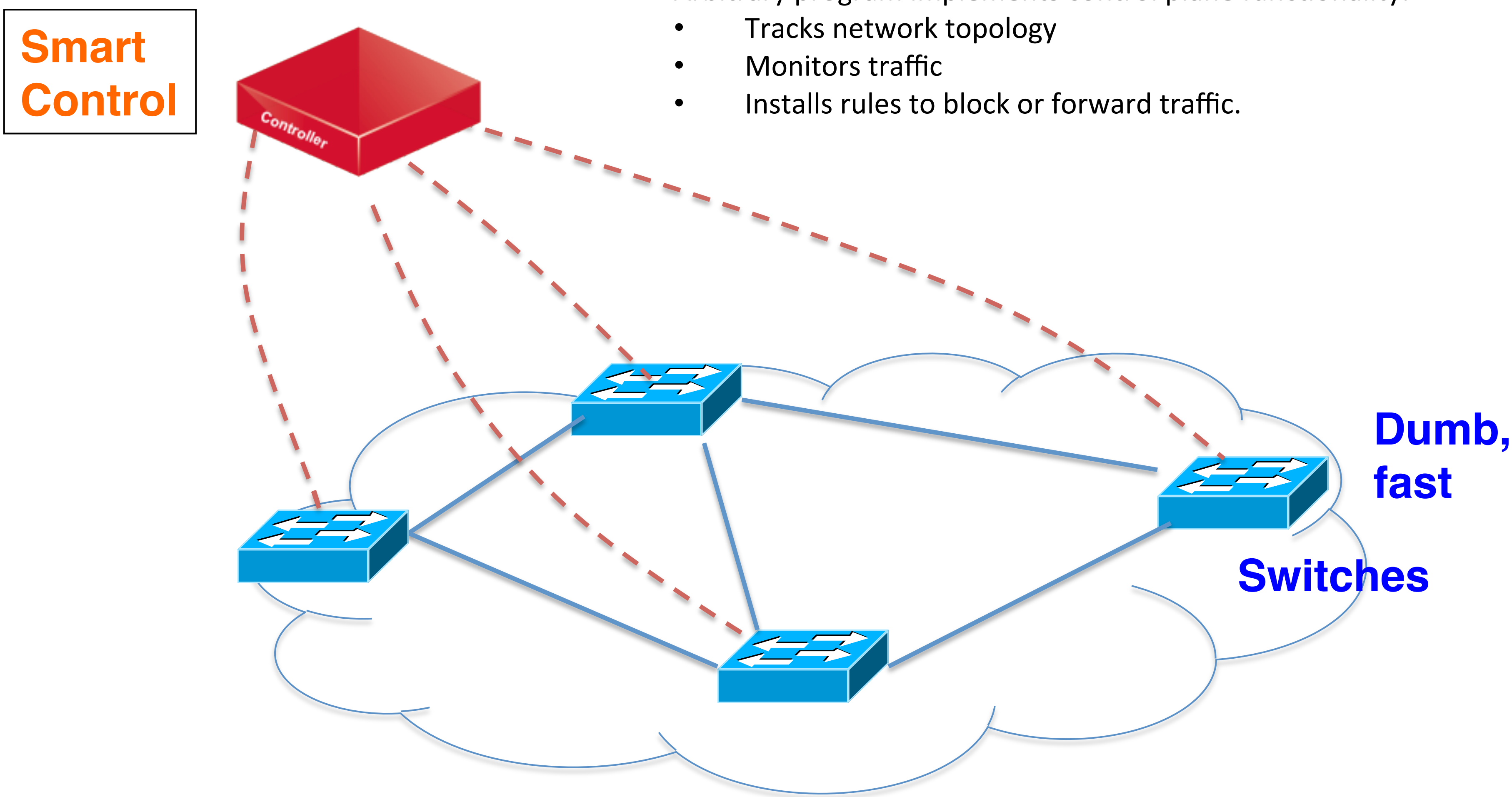
Data Plane – Simple packet forwarding

Traditional networks

- Managing a network is hard
  - Routers with millions of lines of code
  - Running complex distributed protocols
  - Connected to a diverse set of middleboxes
- Operating a network is expensive
  - More than half the cost of a network
  - Manual operator errors cause most outages
- Traditionally hard to innovate
  - Closed equipment with vendor specific interfaces
  - Ossified evolution
  - Few people can make changes (say, CISCO certified)

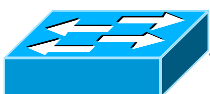
What is a Software-Defined Network?

Controller Machine
Arbitrary program implements control plane functionality:
- Tracks network topology
- Monitors traffic
- Installs rules to block or forward traffic.



Openflow Switches

- Switch packet-handling rules : **<pattern, action, priority>**
  - **Pattern**: match packet header bits
  - **Action**: drop, forward, modify, send to controller
  - **Priority**: disambiguate overlapping patterns
  - Counters: #bytes and #packets



Flow Table

Pattern	Action	Bytes	Packets
01010	Drop	200	10
010*	Forward(n)	100	3
011*	Controller	0	0

priority

Industry Thrust

OPEN NETWORKING FOUNDATION

- Everyone has signed on
  - Google, Facebook, Microsoft, Yahoo, Verizon, Deutsche Telekom
- New applications
  - Host mobility
  - Server load balancing
  - Network virtualization
  - Dynamic access control
  - Energy-efficiency
- Real deployments
  - Google's usage in a Wide Area Network
  - Nicira, acquired by VMWare

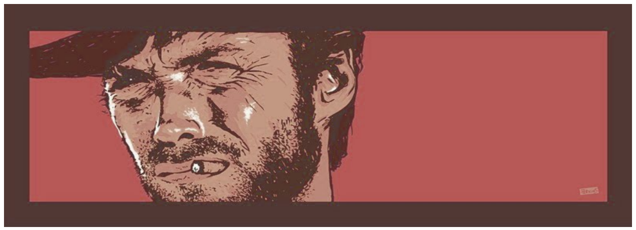
OpenFlow

ONS

OPEN NETWORKING SUMMIT

nicira

Software-Defined Networks



The Good

- Simple data plane abstraction
- Logically-centralized controller
- Direct control over switch policies

The Bad

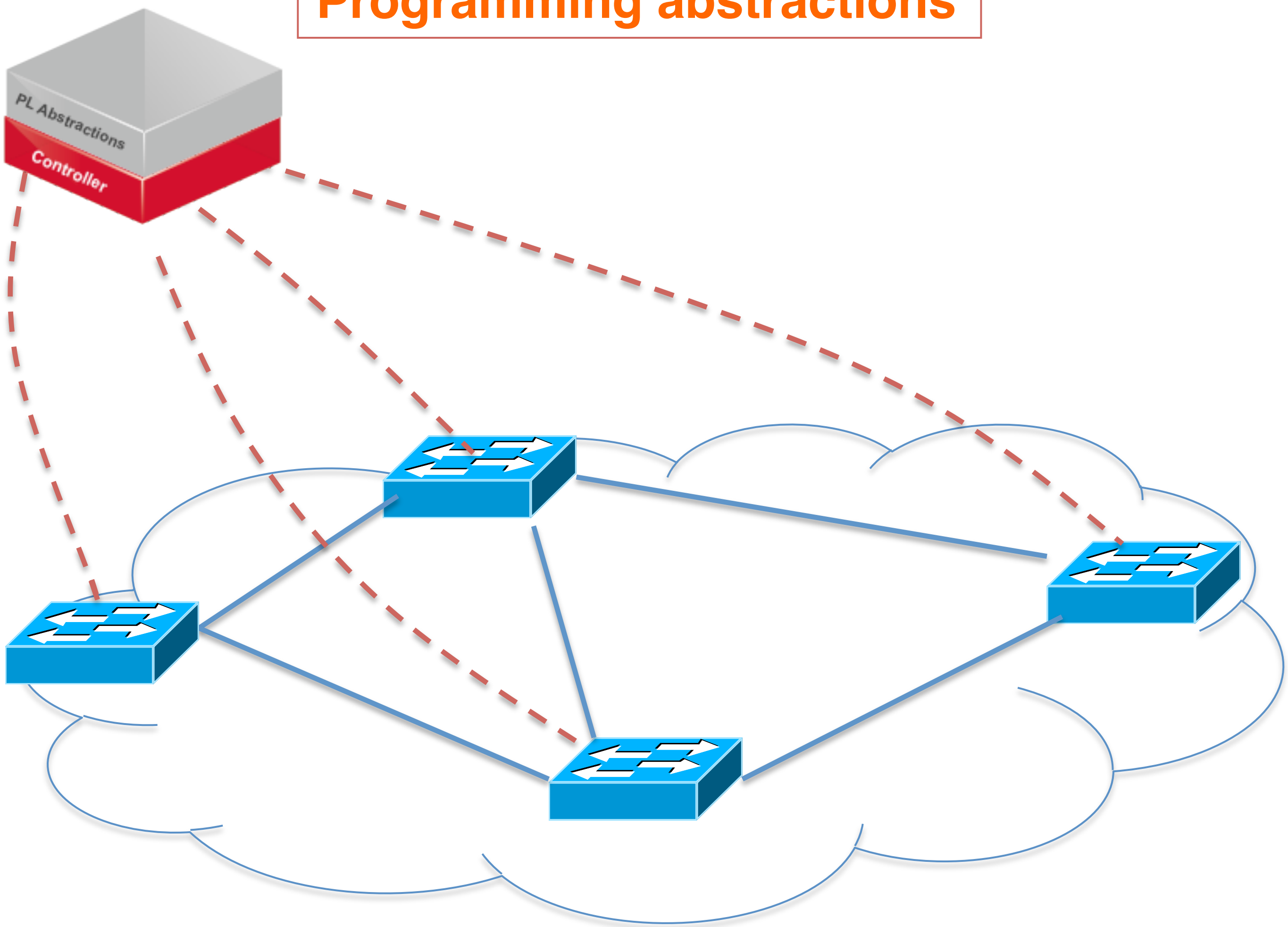
- Low-level programming interface
- Functionality tied to hardware
- Explicit resource control

The Ugly

- Non-modular, non-compositional
- Programmer faced with challenging distributed programming problem

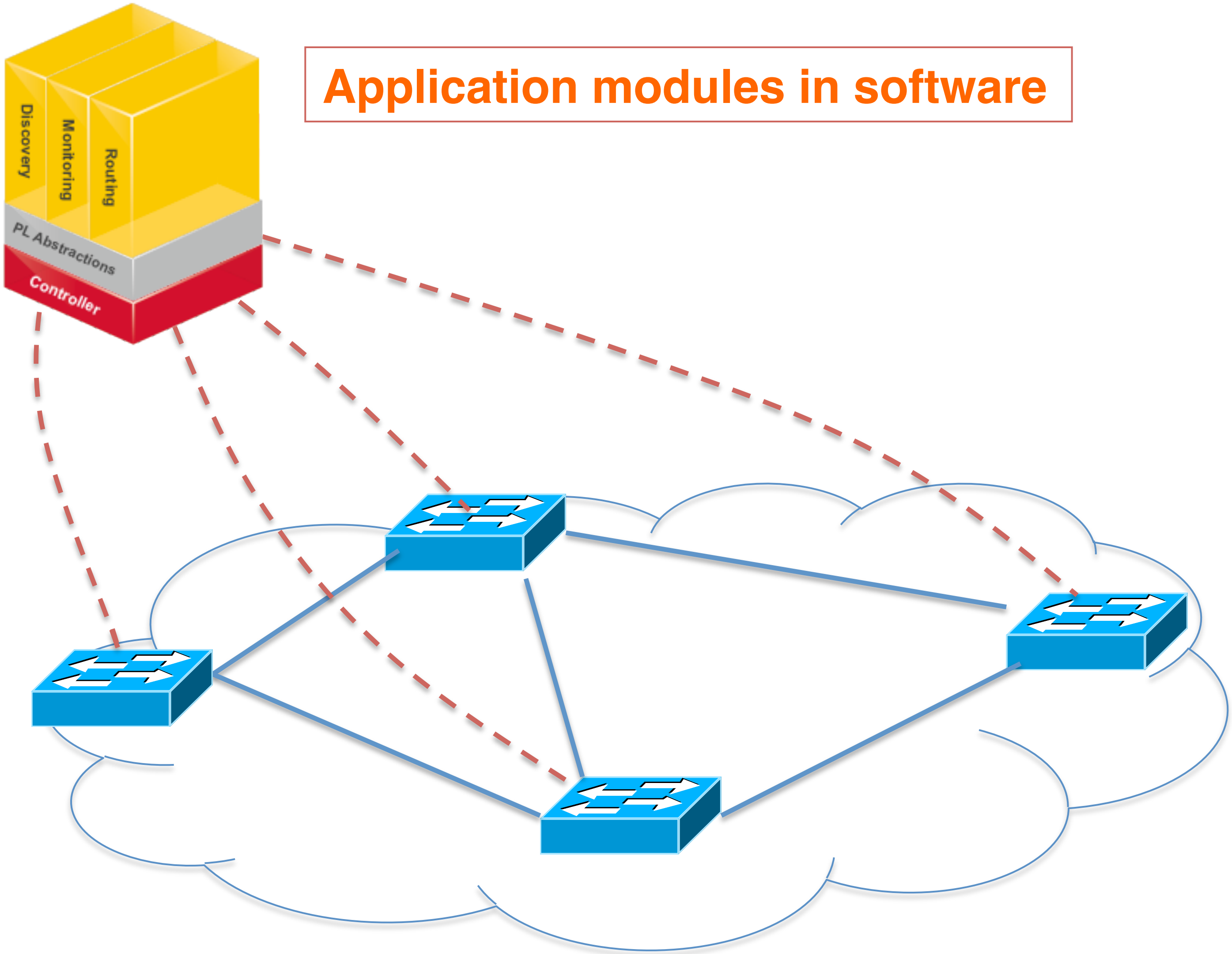
Programming the controller

Programming abstractions

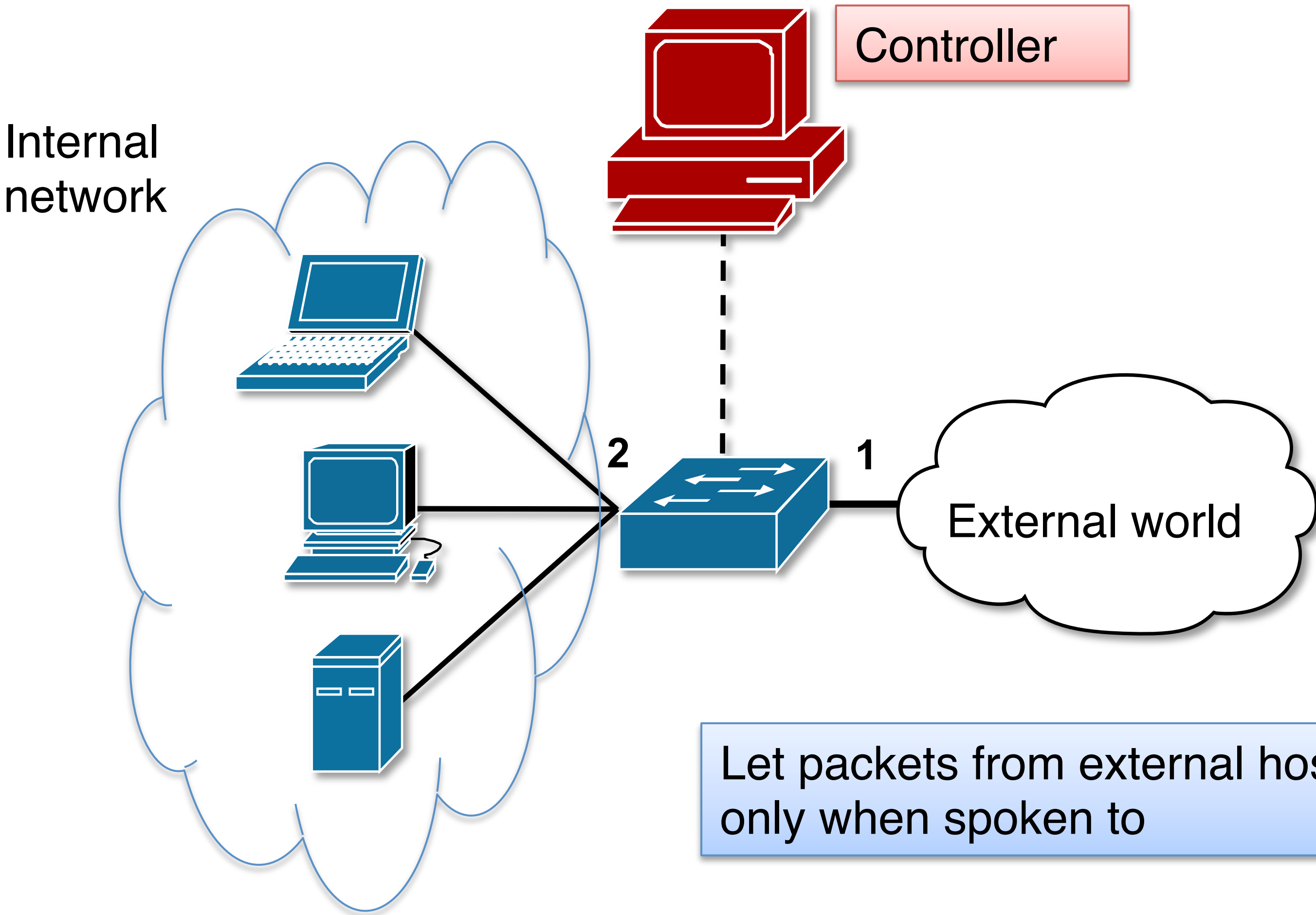


Programming the controller

Application modules in software

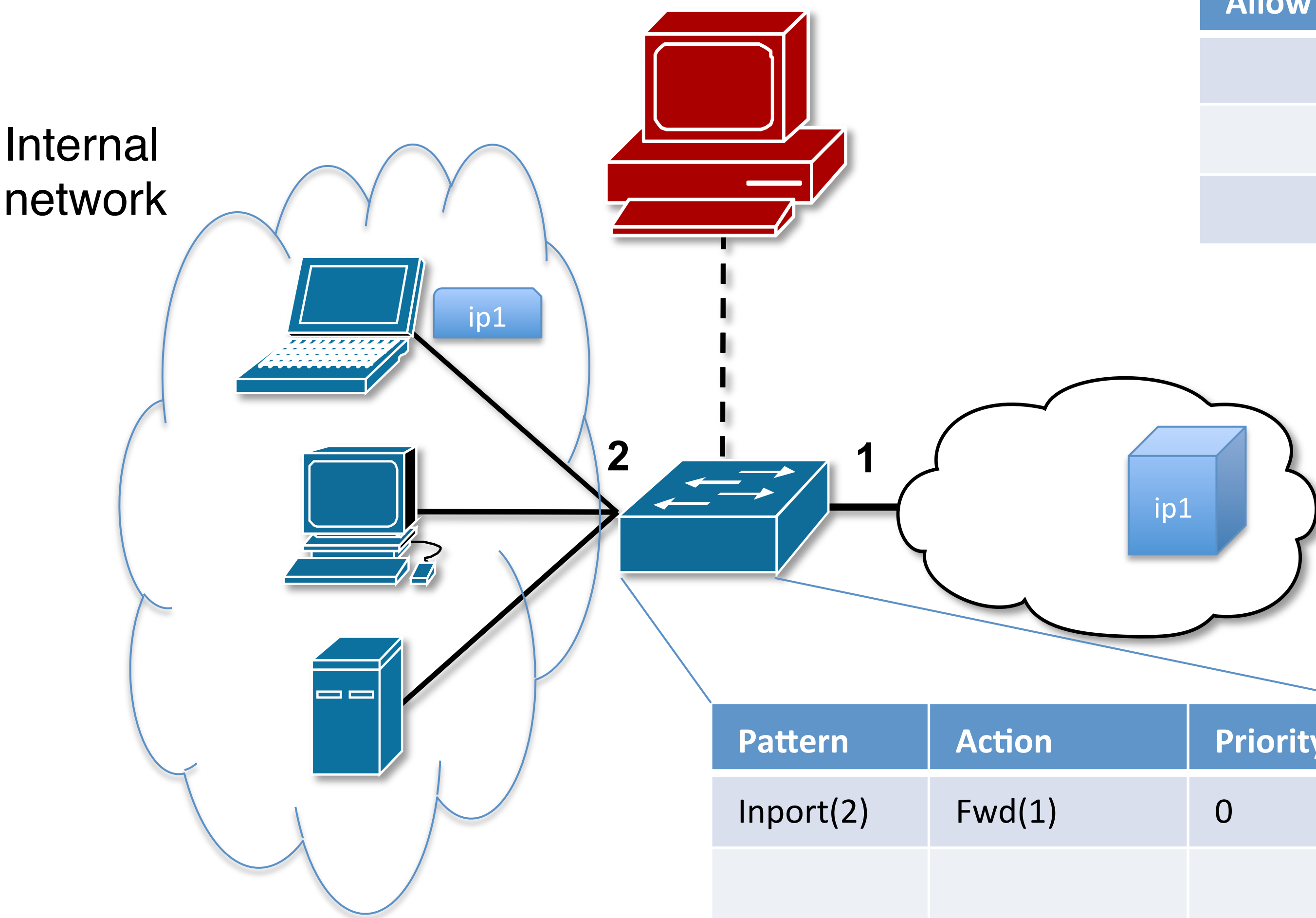


Stateful Firewall



Let packets from external hosts in, only when spoken to

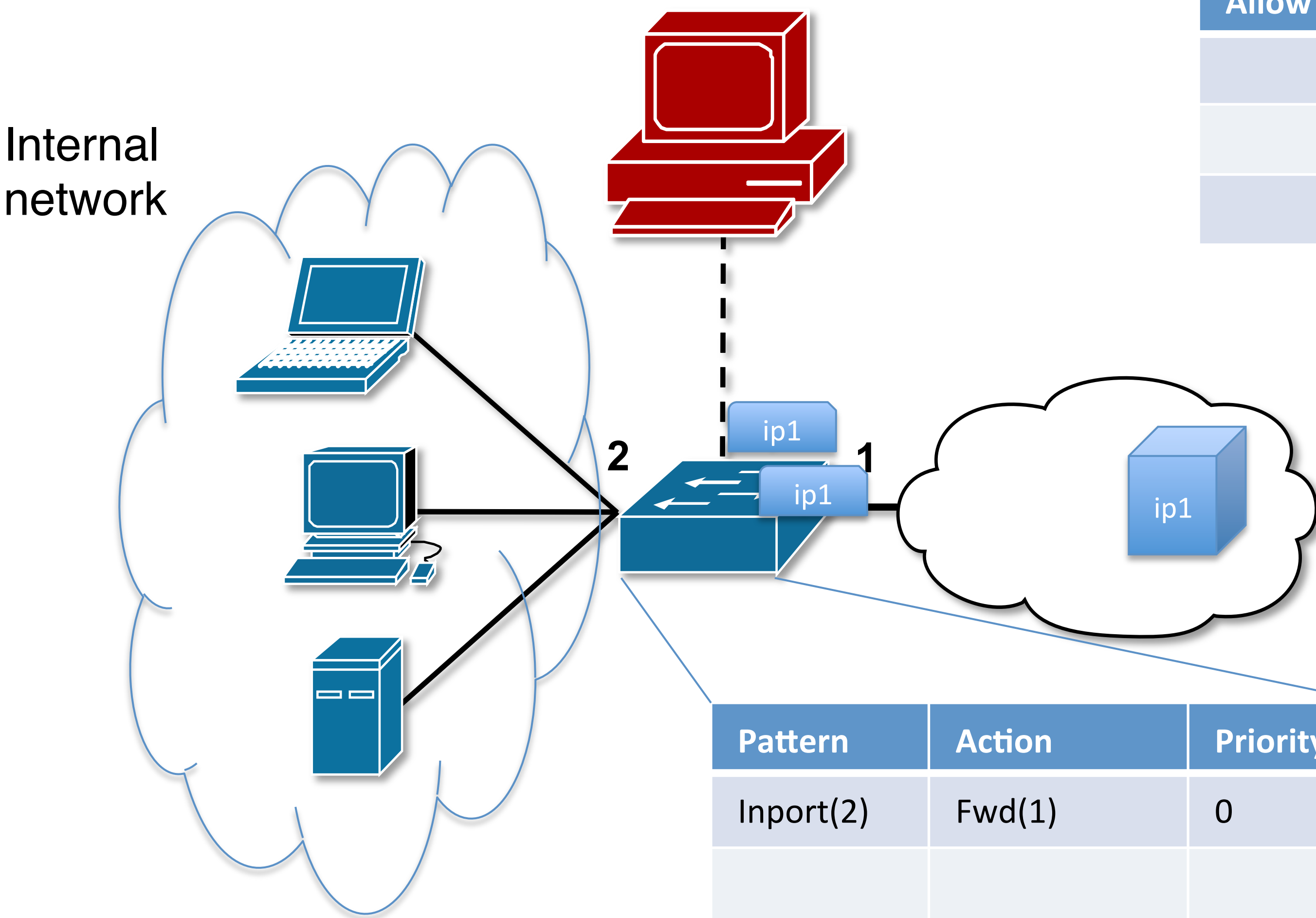
Stateful Firewall



Allow

Pattern	Action	Priority
Inport(2)	Fwd(1)	0

Stateful Firewall

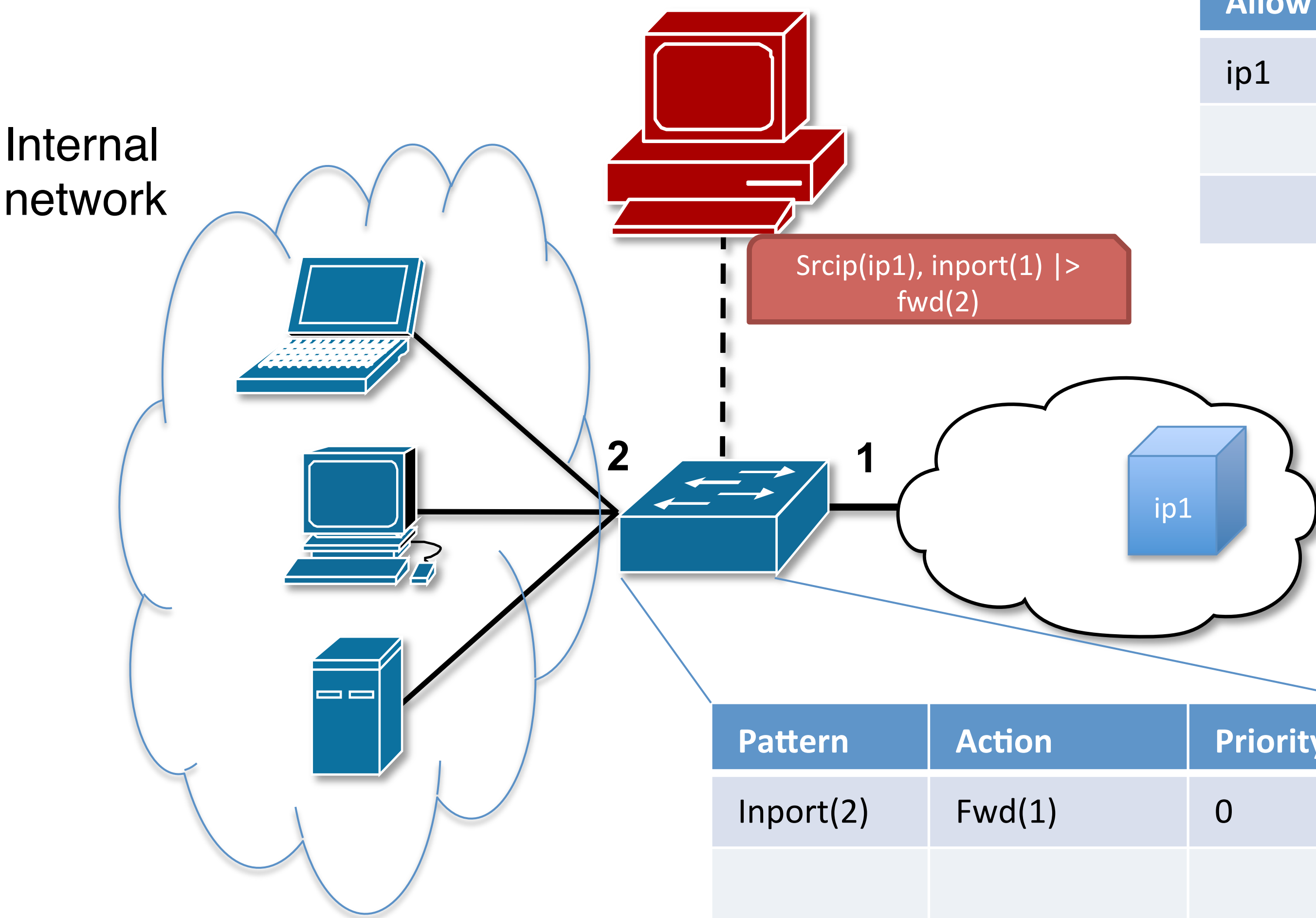


Allow

Pattern	Action	Priority
Inport(2)	Fwd(1)	0

Stateful Firewall

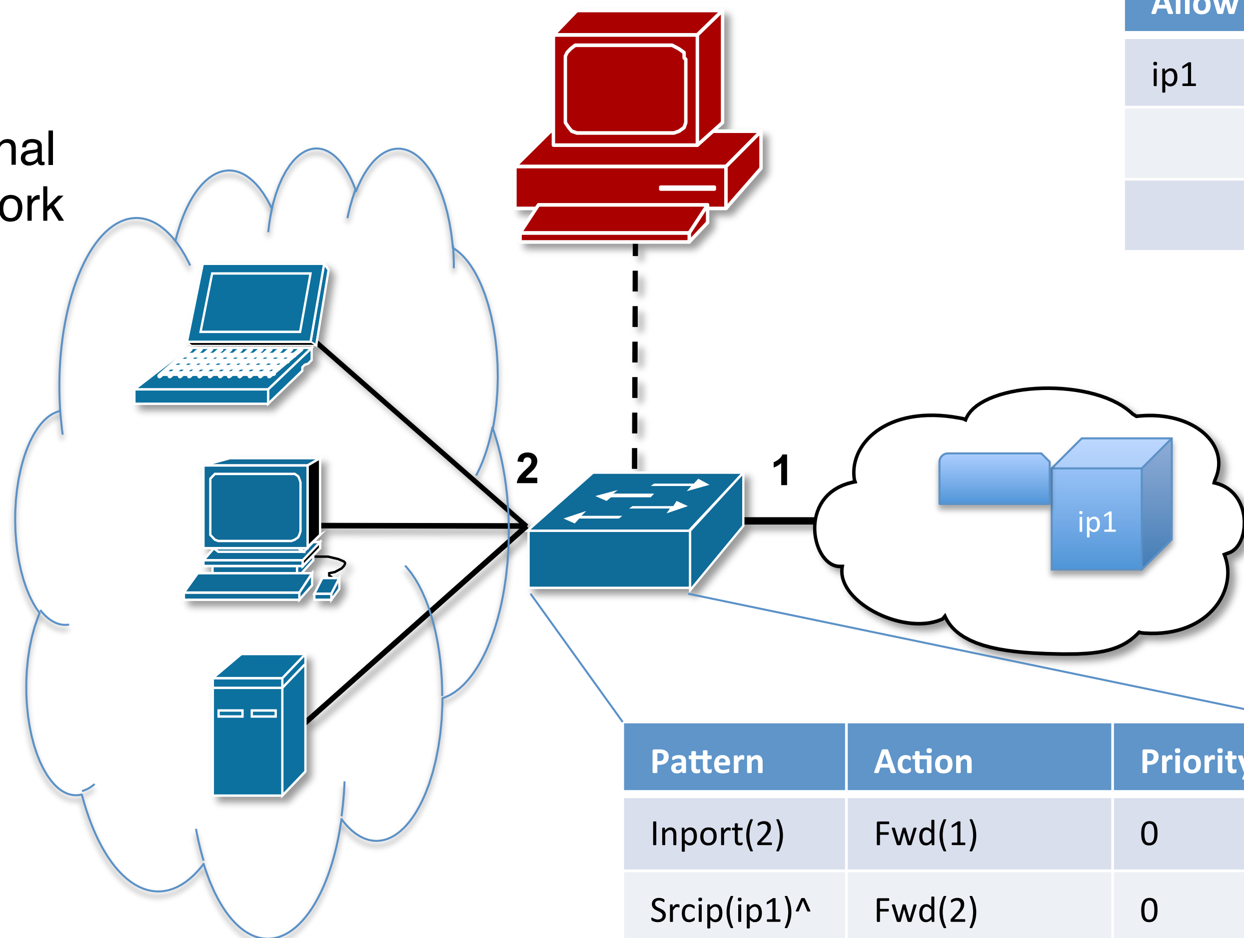
Allow
ip1



Pattern	Action	Priority
Inport(2)	Fwd(1)	0

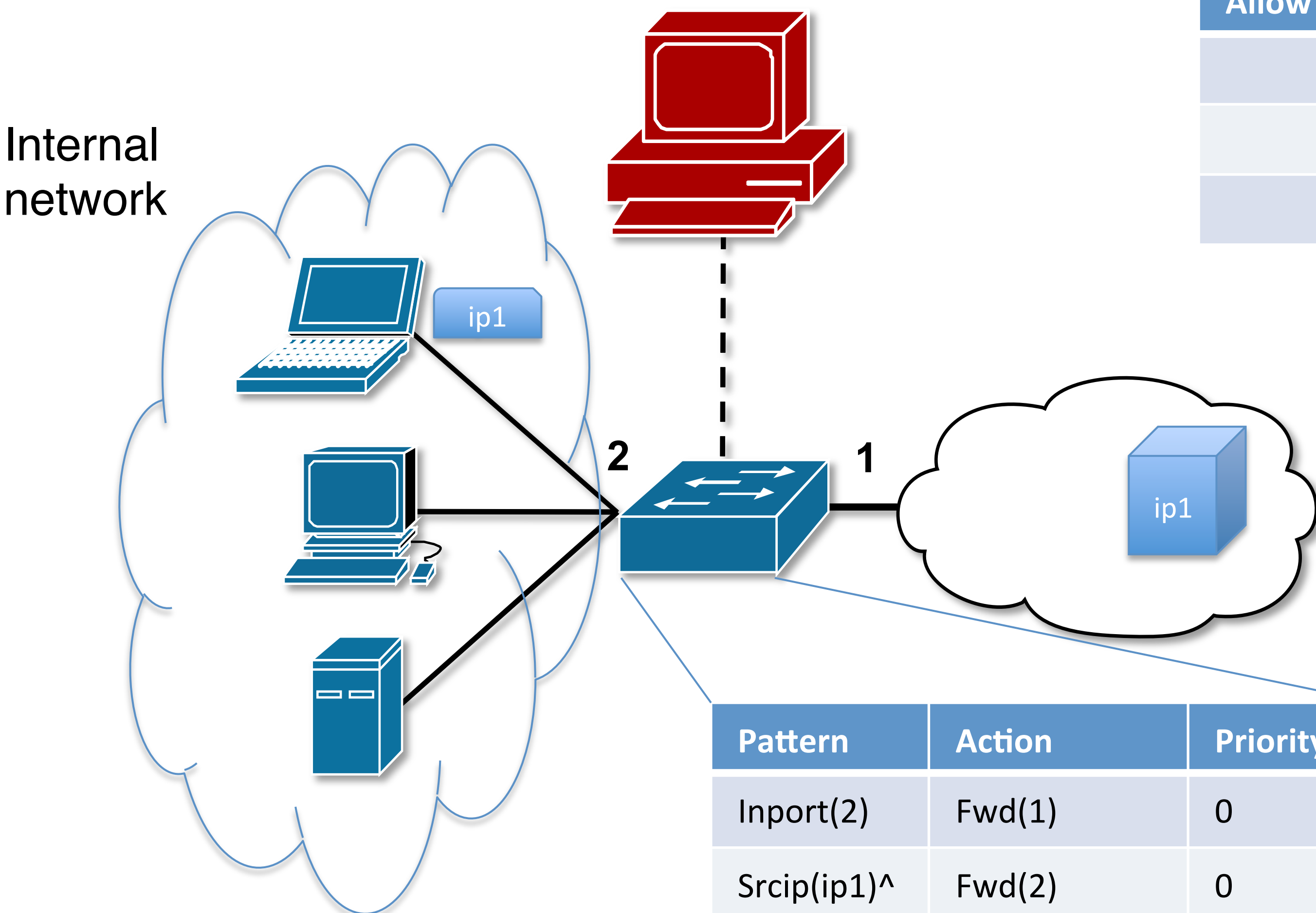
Stateful Firewall

Allow
ip1



Pattern	Action	Priority
Inport(2)	Fwd(1)	0
Srcip(ip1)^ inport(1)	Fwd(2)	0

Stateful Firewall



Allow

Pattern	Action	Priority
Inport(2)	Fwd(1)	0
Srcip(ip1)^ inport(1)	Fwd(2)	0

1. Flow Identification

```
# Network Events
flow(dstip=IP), inport=2 --> seen(IP).
```

- Events : packet-ins, switches and ports go online/offline.
- Flow identification rule

```
flow(h1=X1,h2=X2,...), constraints --> rel(X1,X2,...)
```

- Example :

```
flow(srcip=IP, vlan=V), V > 0 --> myvlans(IP,V)
```

2. Update Controller State

```
# Information Processing
seen(IP) +-> allow(IP).
allow(IP) +-> allow(IP).
```

- A logic program to process the monitored network-events (base facts)
- Has multiple inference rules for deriving new facts
- Two kinds of inference rules

`fact1, fact2, ... --> factn`
<**`factn`** generated and added to current database>

`fact1, fact2, ...  +-> factn`
<**`factn`** added to a database which is used in the next epoch>

3. Specifying Policy

```
# Policy Generation
inport(2) |> fwd(1), level(0).

allow(IP) -->
  srcip(IP), inport(1) |> fwd(2), level(0).
```

- Generate a forwarding policy for the switches

```
fact(V1, V2 …) -> pattern(V1,V2…)|> action, level(i)
```

- Gives the pattern, action and the priority for the switch rules

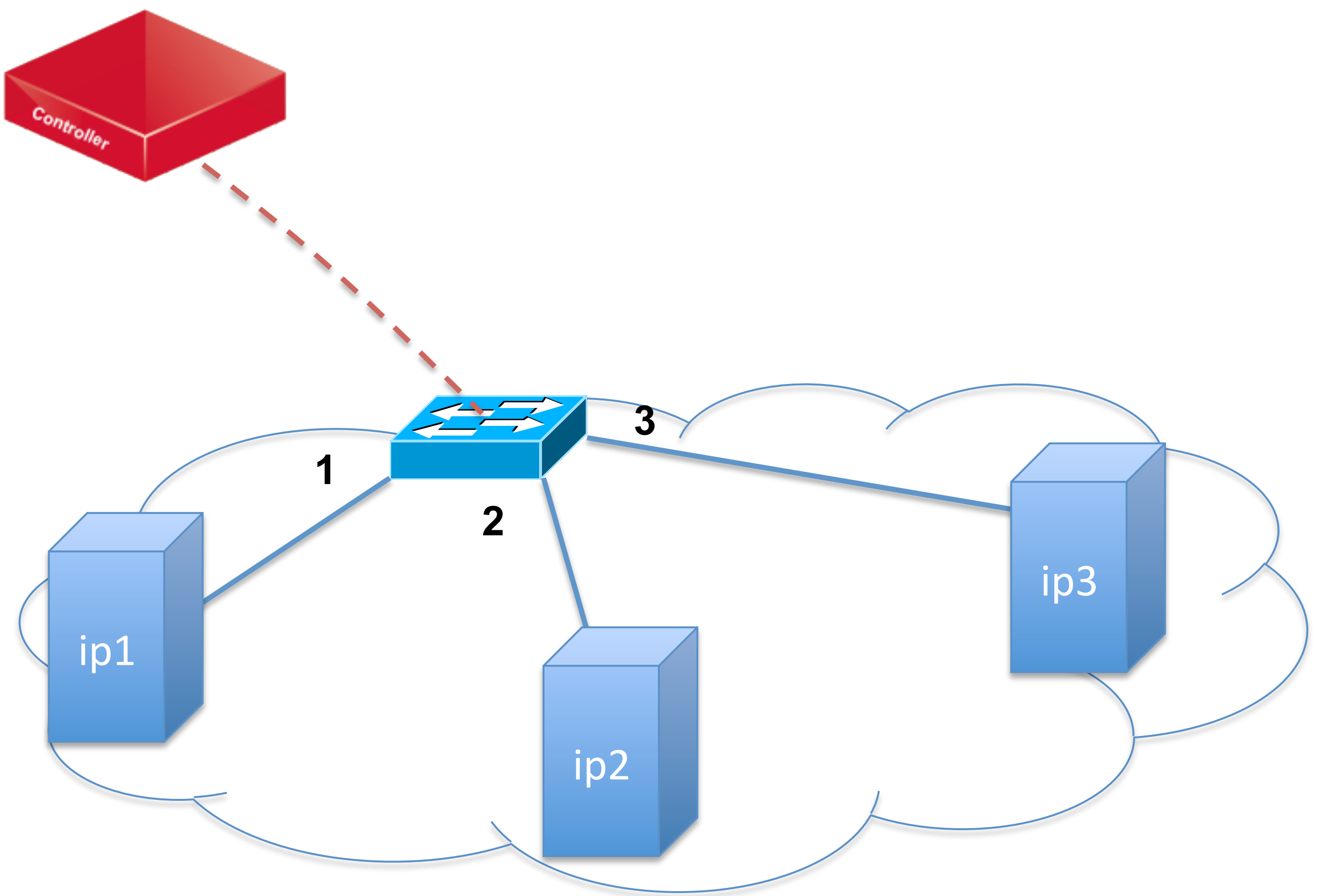
Stateful Firewall

```
# Network Events
flow(dstip=IP), inport=2 --> seen(IP).

# Information Processing
seen(IP) +-> allow(IP).
allow(IP) +-> allow(IP).

# Policy Generation
inport(2) |> fwd(1), level(0).

allow(IP) -->
  srcip(IP), inport(1) |> fwd(2), level(0).
```

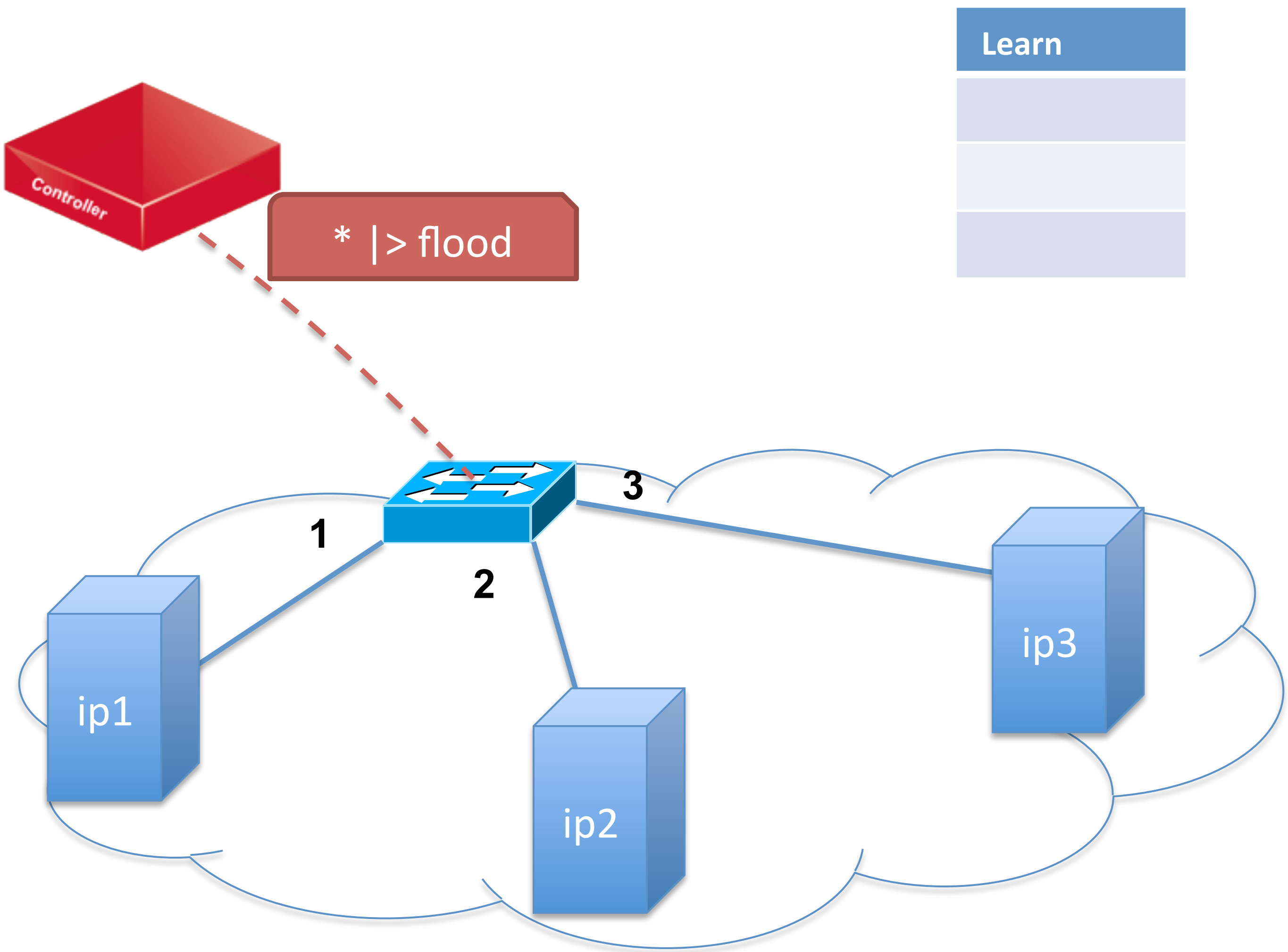
What is Flog?

- An event-driven, forward chaining logic programming language
- Has three effects
  - Executed every time a specific network event occurs (***epoch***)
  - Updates the state (tables) at the controller.
  - Generates a forwarding policy based on the controller state.
- Why logic programming?
  - Good for table-driven collection and processing of network statistics
  - Inspired by success of NDlog, Overlog, Dedalus, Bloom
  - Good for incremental updates to state.
- Specialized Logic Programming in the context of SDNs

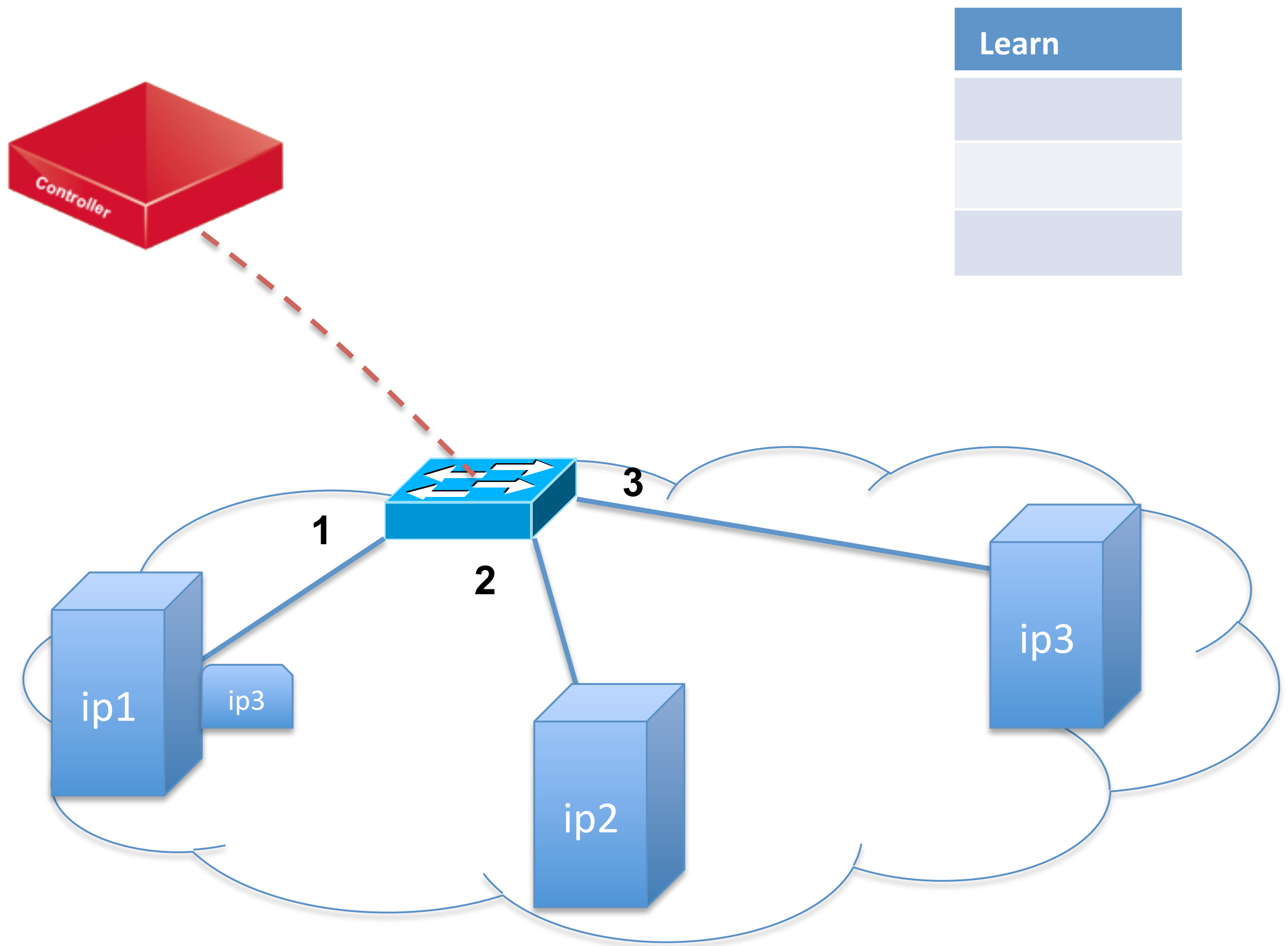
Simple Learning Switch



Simple Learning Switch

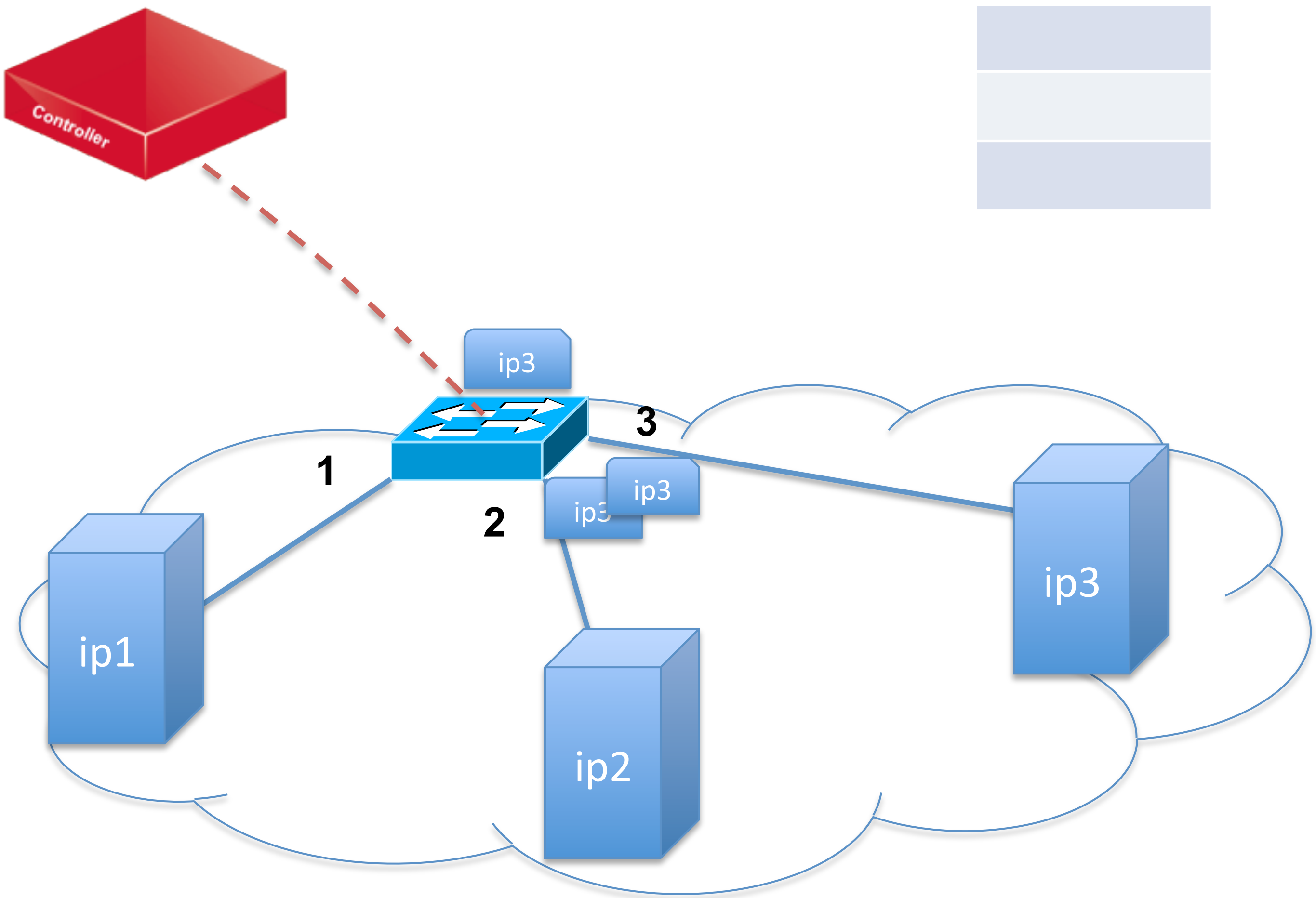


Simple Learning Switch



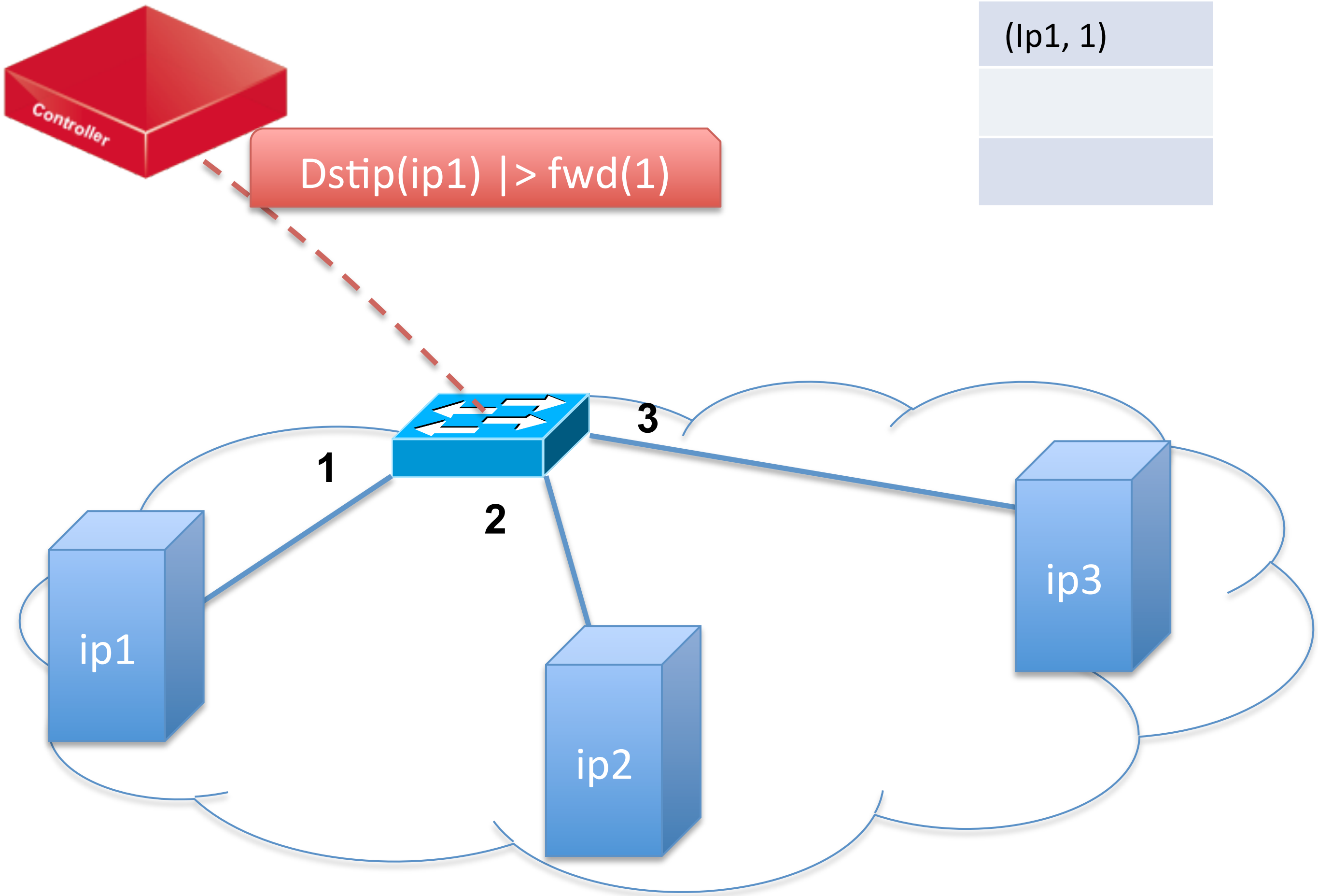
Simple Learning Switch

Learn



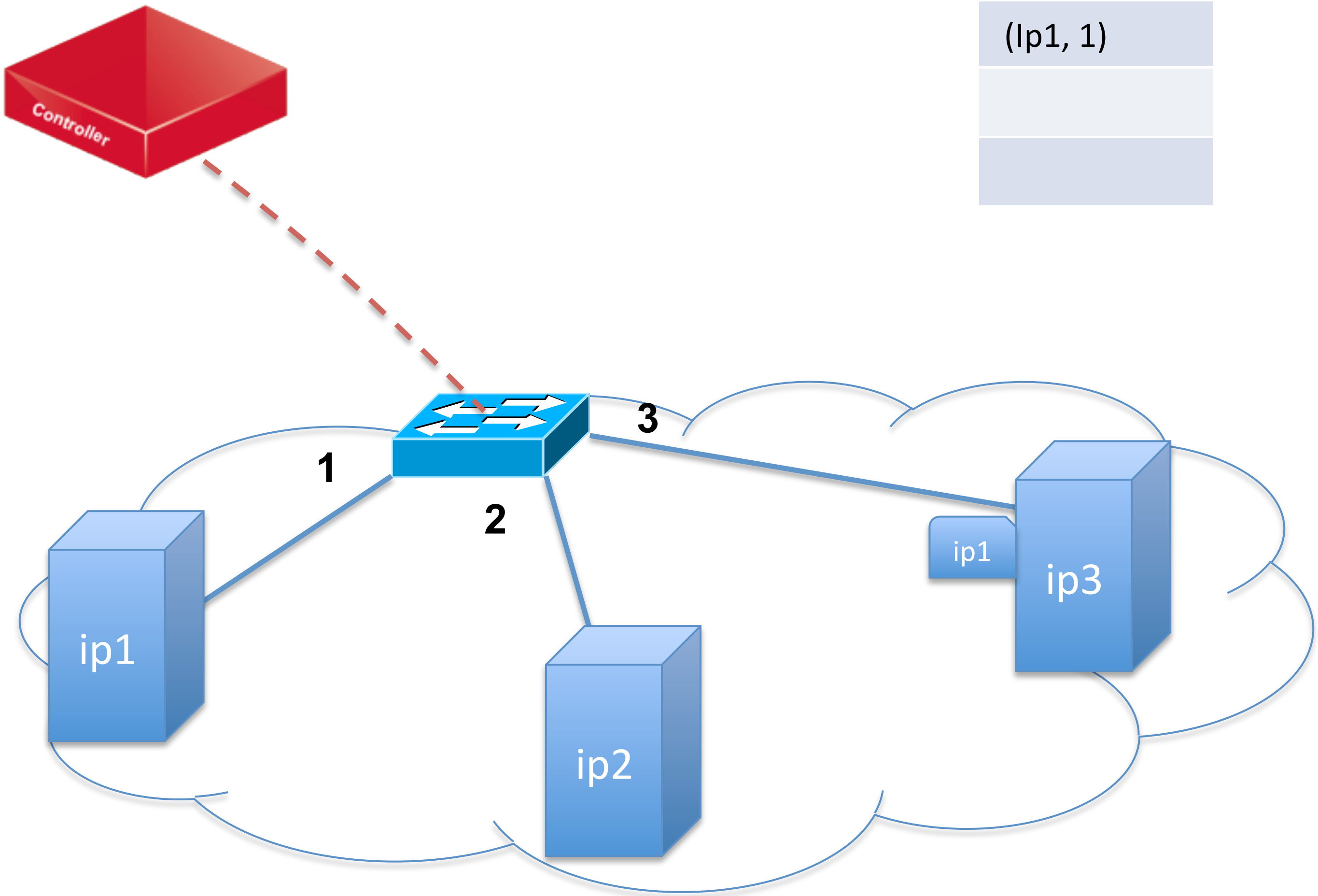
Simple Learning Switch

Learn
(Ip1, 1)



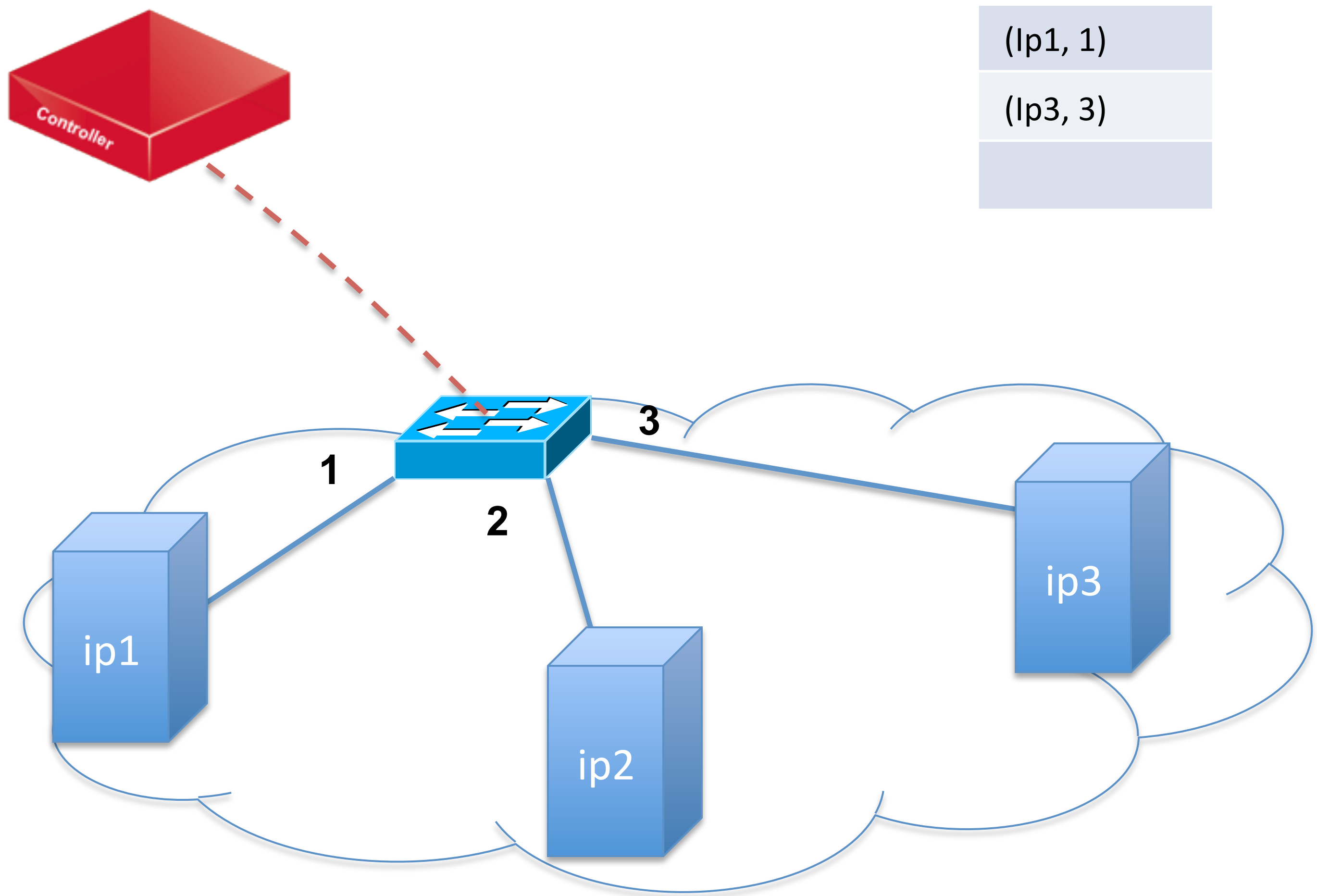
Simple Learning Switch

Learn
(Ip1, 1)



Simple Learning Switch

Learn
(Ip1, 1)
(Ip3, 3)



Simple Learning Switch

```
# Network Events
flow(scrip=IP, inport=P) --> seen(IP, P)

# Information Processing
seen(IP, P) +-> learn(IP, P).
learn(IP, P) +-> learn(IP, P).

# Policy Generation
|> flood, level(0).

learn(IP, P) --> dstip(IP) |> fwd(P), level(1)
```

Learning Switch With Mobility

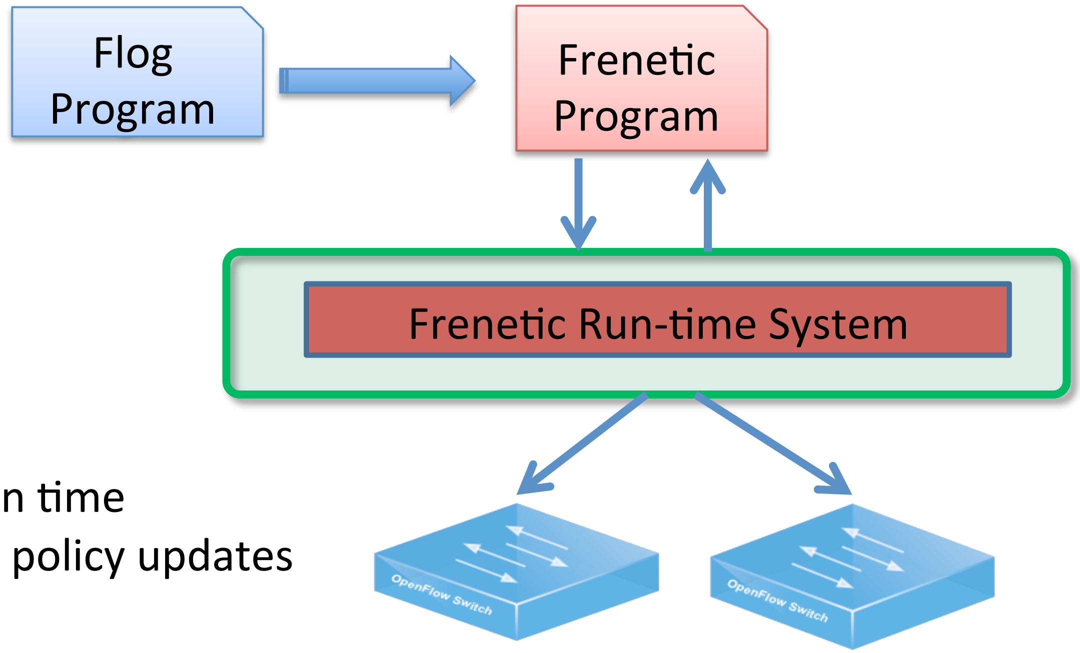
```
# Network Events
flow(scrip=IP, inport=P), split(inport) --> seen(IP, P)

# Information Processing
seen(IP, P) +-> learn(IP, P).
seen(IP, P), learn(IP', P'), IP!=IP' +-> learn(IP',P').

# Policy Generation
* |> flood, level(0).

seen(IP, P) -->
  dst(IP) |> fwd(P), level(1).

seen(IP, P), learn(IP', P'), IP!=IP' -->
  dst(IP') |> fwd(P'), level(1).
```

Related Work

- NOX, Beacon : low-level, imperative, event driven
- install, uninstall forwarding rules directly on the switch
- FML : high-level language for SDN based on Datalog
  - Can mention the kinds of flows to be allowed/denied.
  - not flexible, need to use other languages for stateful computation
- Frenetic provides a combination of
  - (1) a declarative query language with an SQL-like syntax for monitoring packets
  - (2) a functional packet stream-processing language, and
  - (3) a specification language for describing packet forwarding
- Flog - Best of both worlds from FML and Frenetic

Conclusion

- Programming abstractions for Software-Defined Networking
- FLOG - Logic Programming based language for programming SDN controllers
- A Flog program has three important components
  - Network events
  - Information processing
  - Policy generation



- Future Work
  - Full fledged compiler/run time
  - Support for incremental policy updates