ΕΛΛΗΝΙΚΗ ΔΗΜΟΚΡΑΤΙΑ
ΠΑΝΕΠΙΣΤΗΜΙΟ ΚΡΗΤΗΣ

Δίκτυα Καθοριζόμενα από Λογισμικό

Ενότητα 2.2: Modular Network Programming with Pyretic

Ξενοφώντας Δημητρόπουλος
Τμήμα Επιστήμης Υπολογιστών

HY436: Modular Network Programming with Pyretic

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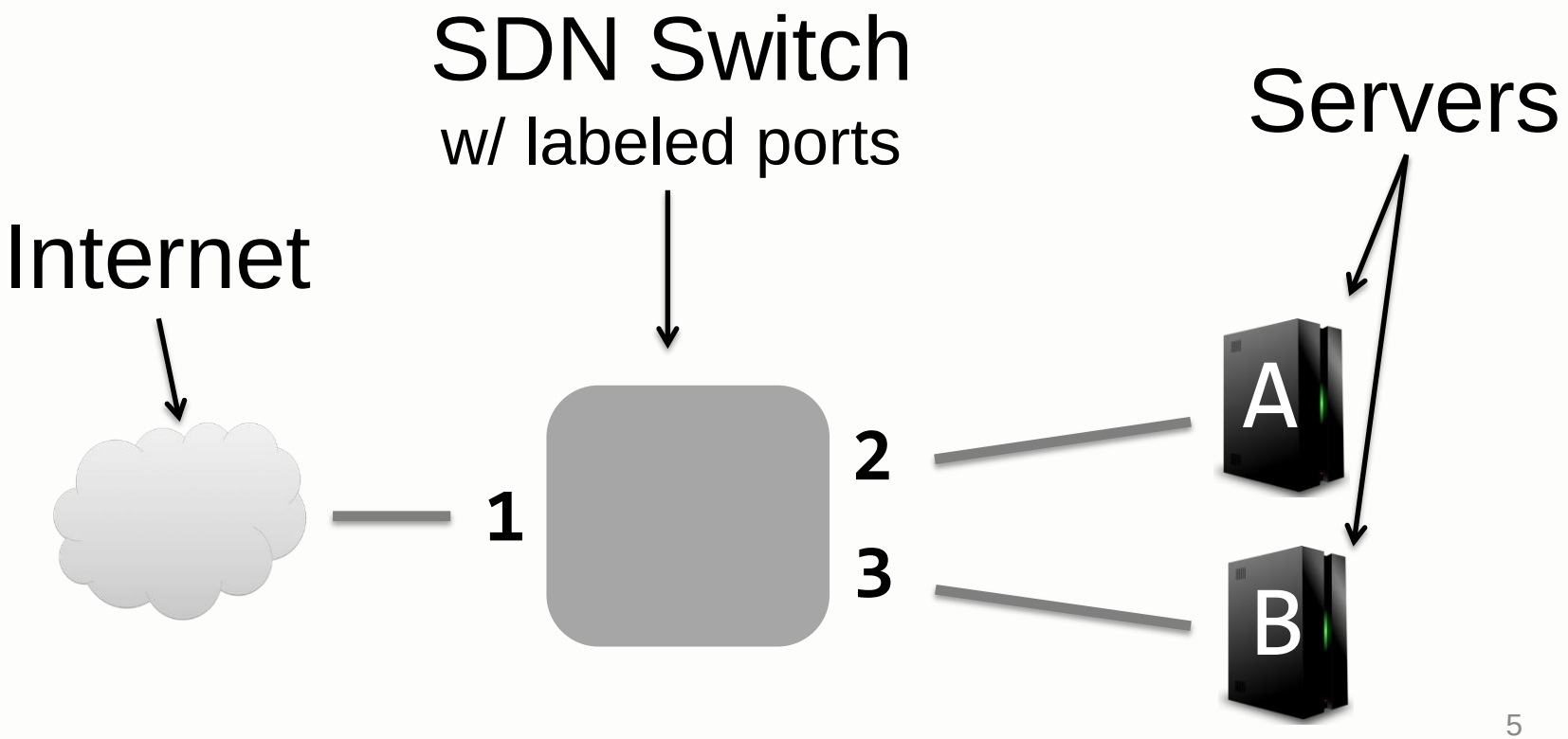
27/10/2014

Credits: Slides modified from Joshua Reich's (Princeton) NSDI 13 talk on "Composing Software Defined Networks"

Running Example Network



Programming in OpenFlow

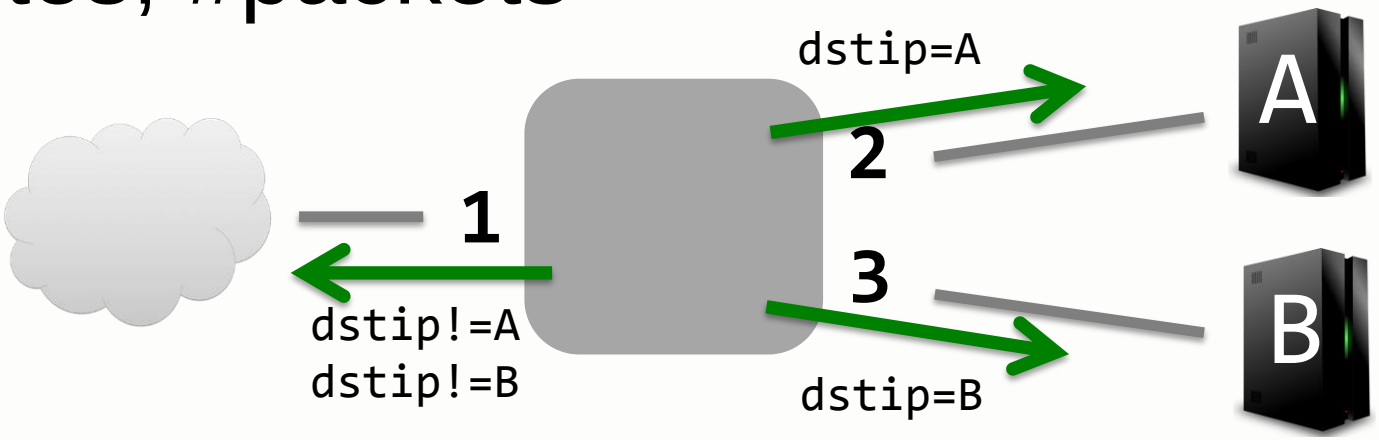
OpenFlow Priority Program

```
2:match(dstip=A)[fwd(2)]
1:match(*       )[fwd(1)]
2:match(dstip=B)[fwd(3)]
```

Pattern Action

Counters for each rule
- #bytes, #packets

Route: IP/fwd



One API, Many Uses

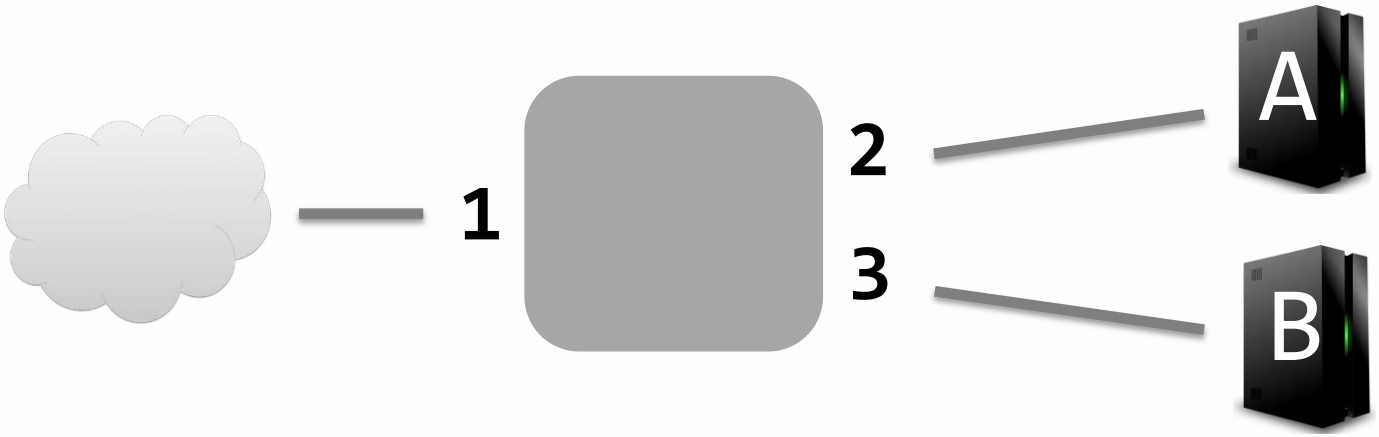
Priority Ordered

```
match(dstmac=A)[fwd(2)]
match(dstmac=B)[fwd(3)]
match(*       )[fwd(1)]
```

Pattern

Action

***Switch*: MAC/fwd**



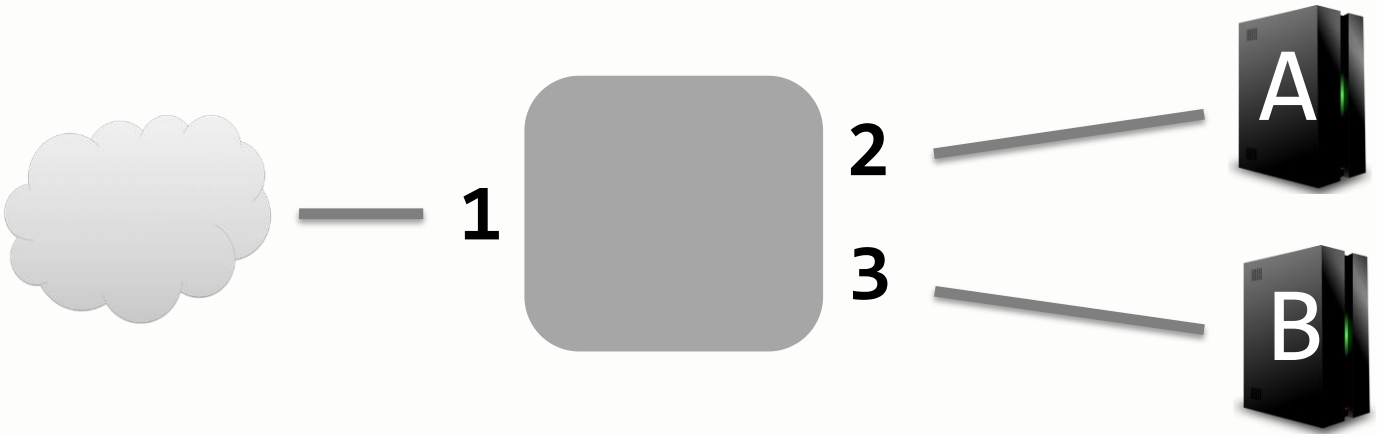
One API, Many Uses

```
match(srcip=0*,dstip=P)[mod(dstip=A)]
match(srcip=1*,dstip=P)[mod(dstip=B)]
```

Pattern

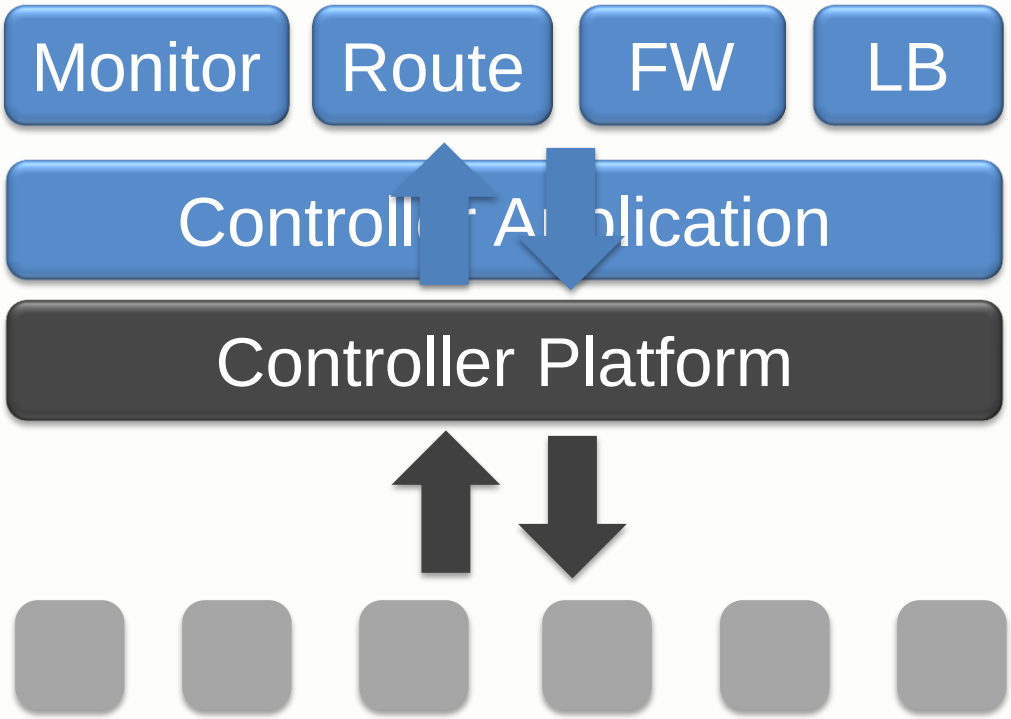
Action

***Load Balancer*: IP/mod**



But Only Half of the Story

Modular & Intuitive



Programmer Interface

?

Hardware Interface

OpenFlow (assembly)

Hardware Flow-Table Rules (Machine Language)

OpenFlow Isn't Modular

Balance then **Route**

```
match(srcip=0*,dstip=P)[mod(dstip=A)]
match(srcip=1*,dstip=P)[mod(dstip=B)]
```

```
match(dstip=A)[fwd(2)]
match(dstip=B)[fwd(3)]
match(*      )[fwd(1)]
```

Combined Rules?
(only one match)

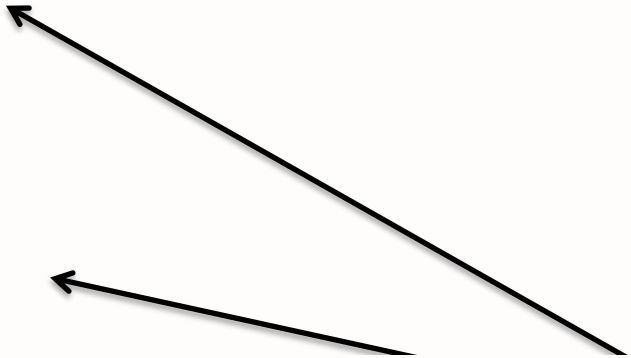
```
match(srcip=0*,dstip=A)[fwd(2)]
match(         dstip=B)[fwd(3)]
match(*                )[fwd(1)]
match(srcip=1*,dstip=A)[fwd(2)]
match(         dstip=B)[fwd(3)]
match(*                )[fwd(1)]
match(srcip=0*,dstip=P)[mod(dstip=A)]
match(srcip=1*,dstip=P)[mod(dstip=B)]
```

Balances w/o Forwards!

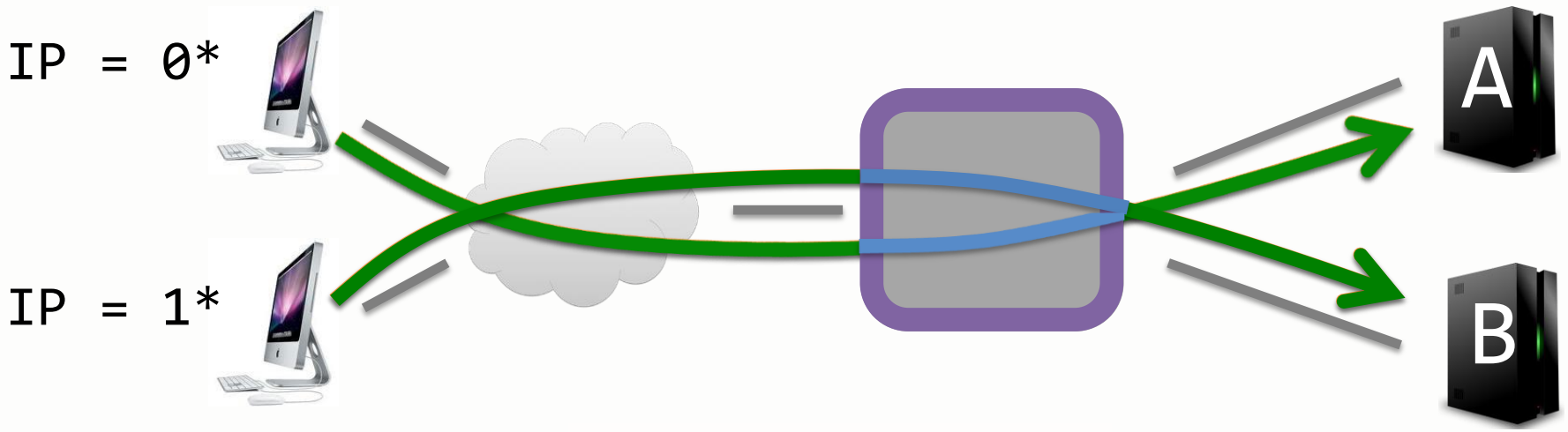
Balancing!

Pyretic (Contributions)

Abstracts	Providing	Supporting



Compositional Operators:
A Monitoring Load Balancer



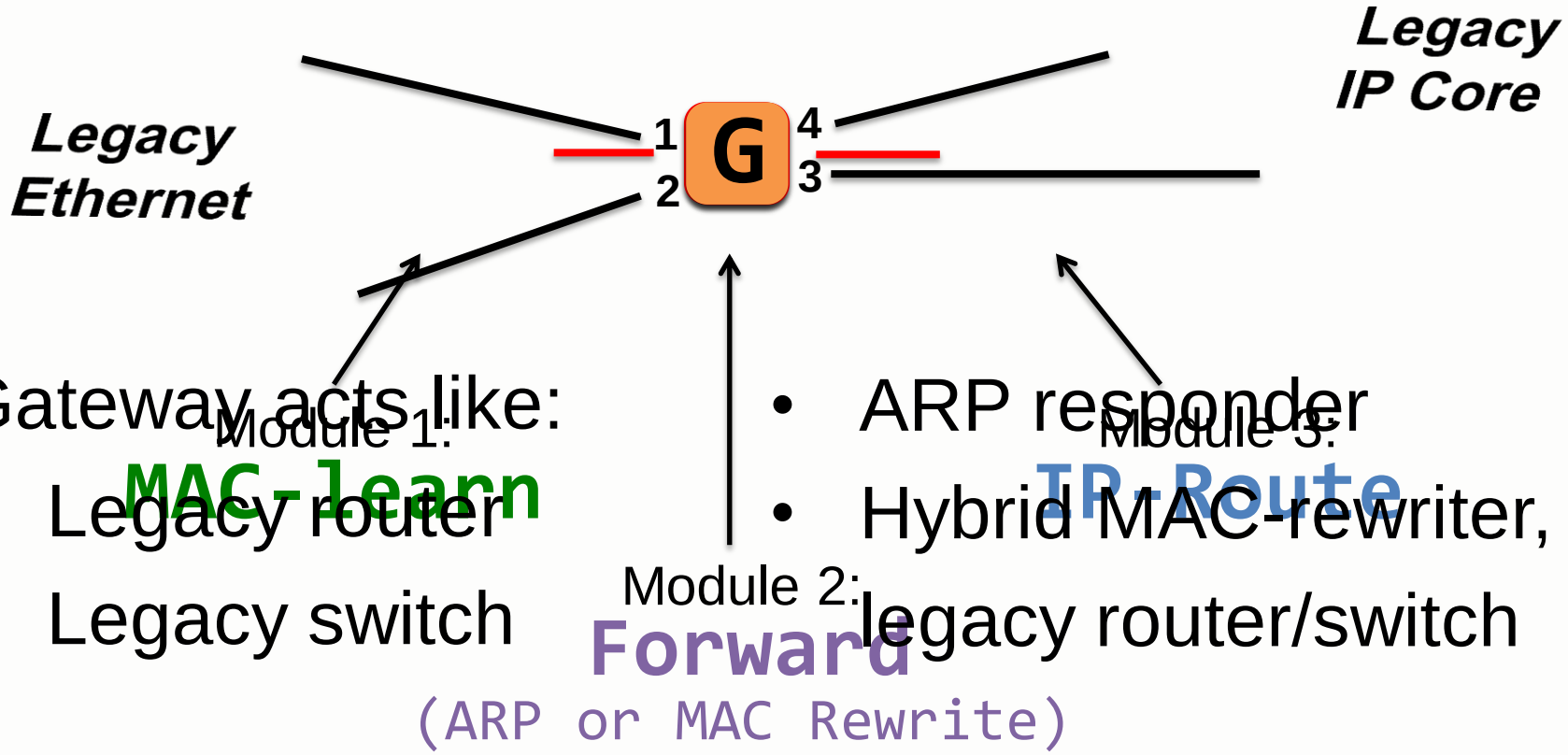
Module 1:

Balance `P` **then** `A, B`

Rewrite `dstip` `P` to
`A`, if `srcip=0*`
`B`, if `srcip=1*`

- Traffic to `P` re-addressed and fowarded to either `A` or `B`, based on source
- Counted if from source `X`

Topology Abstraction:
A Legacy Gateway Replacement



Gateway acts like:

- Legacy router
- Legacy switch
- ARP responder
- Hybrid MAC-rewriter, legacy router/switch

Pyretic's Design

- Monitoring Load Balancer
  - Encode policies as functions
  - Compositional operators
  - Queries as forwarding policies
- MAC-Learning Module
  - Dynamic Policies
- "One Big Switch" Topology Abstraction
  - Extensible packet model

`Pyretic` Drop Policy

Goal: Drop packets (i.e., `OpenFlow` drop)

Write: `drop`

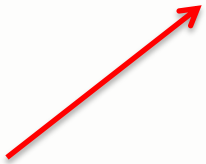
Means: `eval(drop,p) = {}`

`Pyretic` Forward Policy

Goal: Forward packets out port `a`

Write: `fwd(a)`

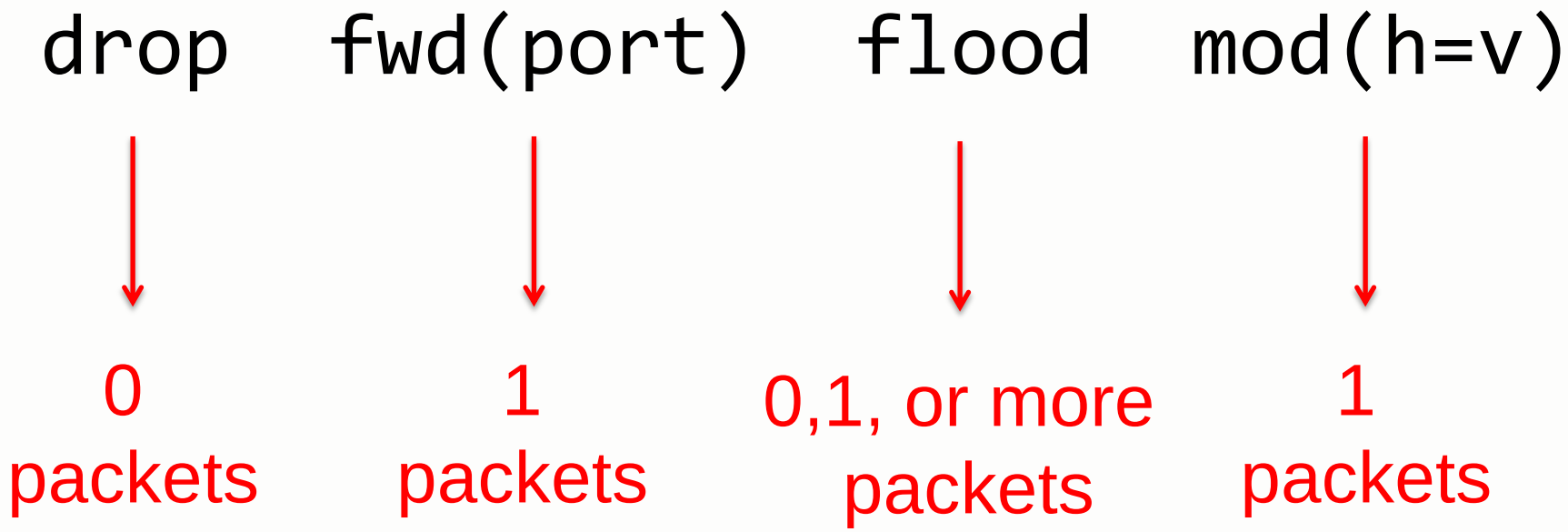
Means: `eval(fwd(a),p) = {p[outport:=a]}`



located packet w/ fields for

- `switch`
- `inport`
- `outport`

One Pyretic Policy For Each OpenFlow Action



Pyretic Policy

A function mapping a located packet to a set of located packets

```
eval(policy,packet) = {packet}
```

Puts focus on ***meaning*** instead of ***mechanics***

Enabling Compositional Operators

Parallel '+': *Do both C1 and C2 simultaneously*

```
eval(C1 + C2,p) =  eval(C1,p) U eval(C2,p)
```

Sequential '>>': *First do C1 and then do C2*

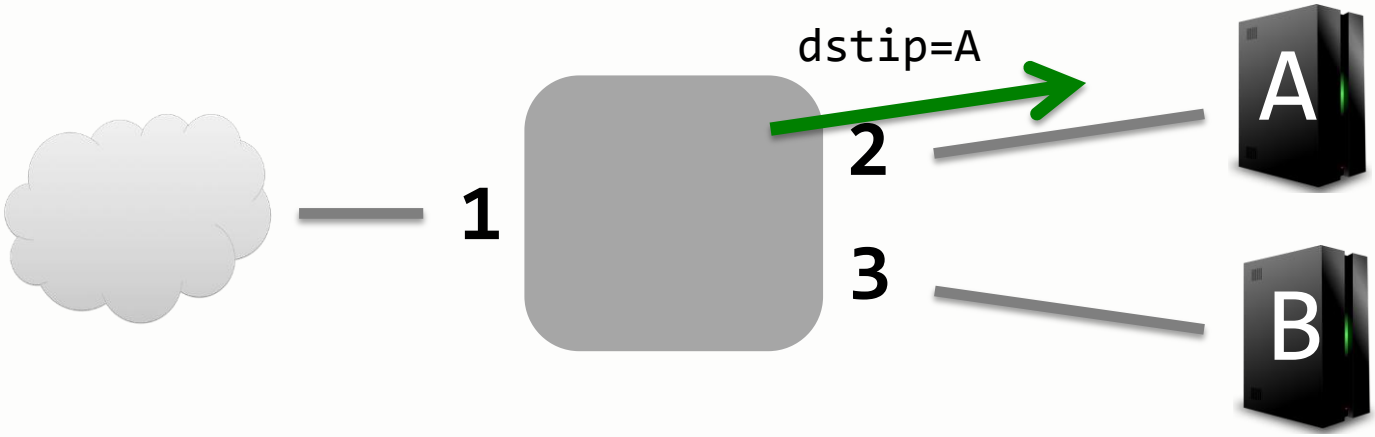
```
eval(C1 >> C2,p) =  U {eval(C2,p')
                       for p' in eval(C1,p)}
```

Sequential Composition Example

- Code to forward to A ?

```
match(dstip=A) >> fwd(2)
```

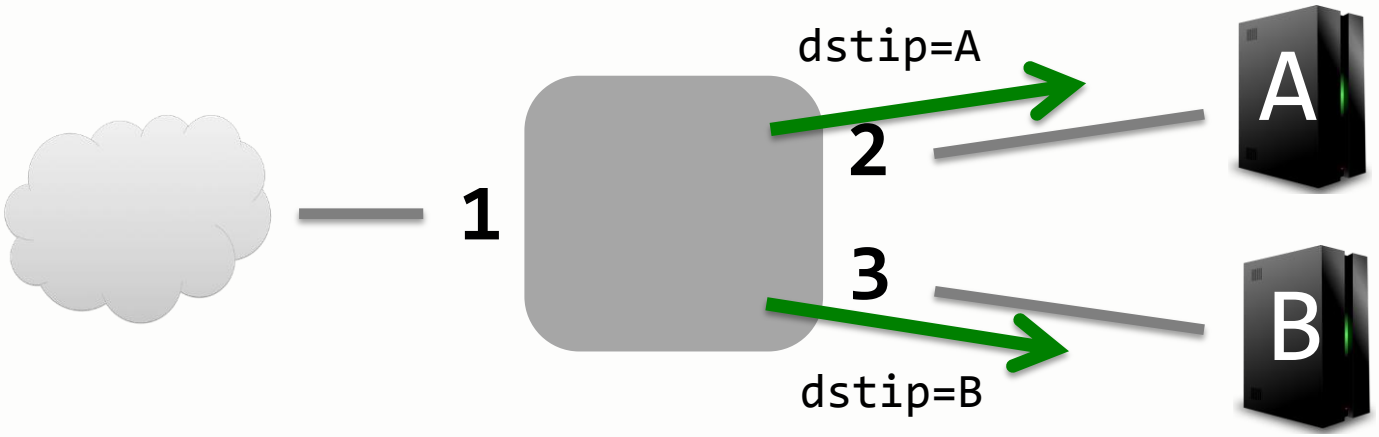
- **The old syntax has been depricated:**
  `match(dstip=A)[fwd(2)]`



Parallel Composition Example

- Code to forward to A or B?

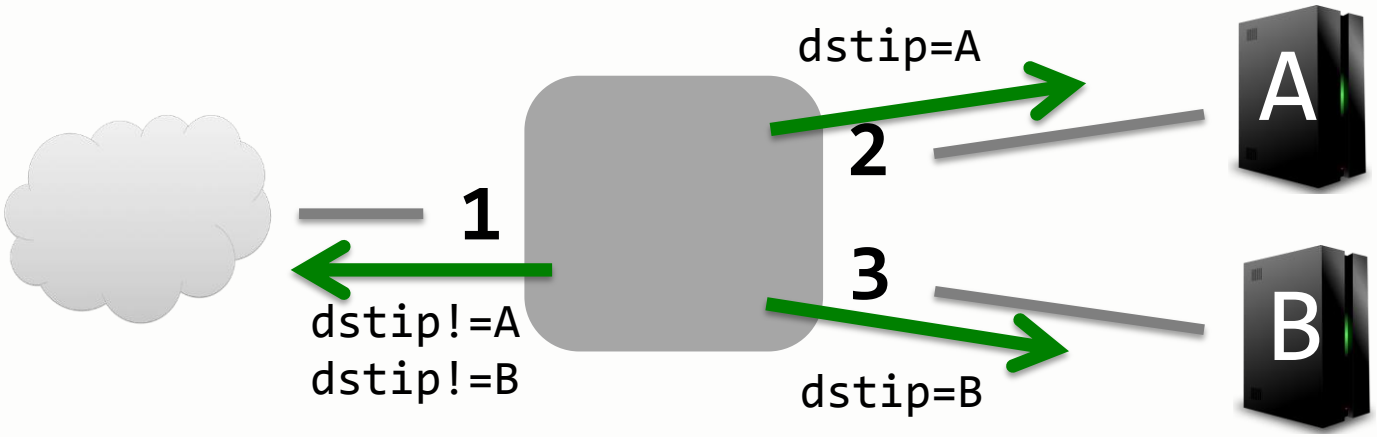
```
(match(dstip=A) >> fwd(2)) +
(match(dstip=B) >> fwd(3))
```



Pyretic program for routing?

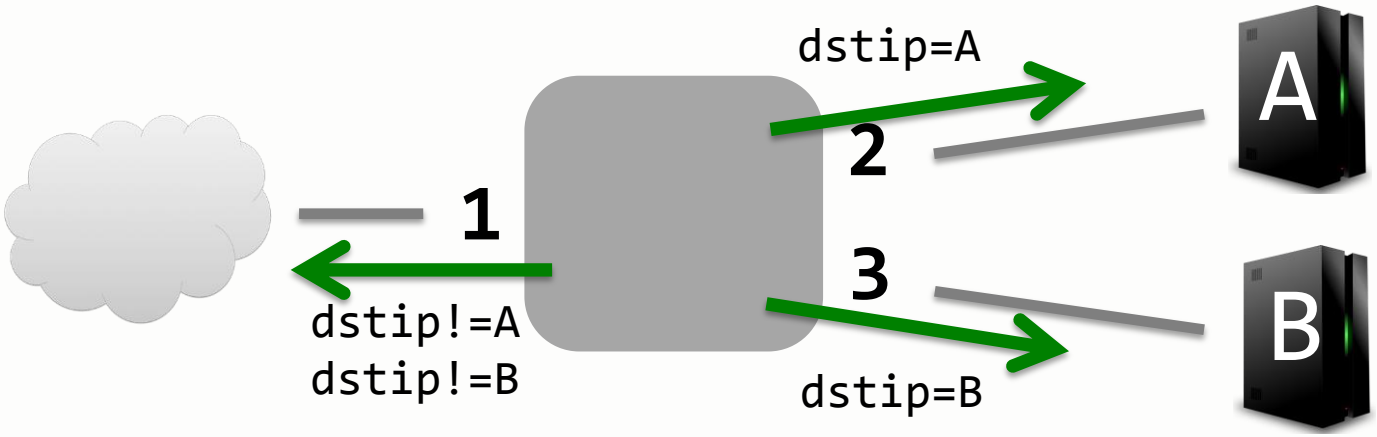
No priorities needed!

```
( match(dstip=A) >> fwd(2) ) +
( match(dstip=B) >> fwd(3) ) +
~(match(dstip=A) | match(dstip=B)) >> fwd(1)
```



if_ abbreviation

```
if_( match(dstip=A), fwd(2),
      if_( match(dstip=B), fwd(3) , fwd(1) )
   )
```



Examples

- `flood`

  ➔Broadcasts every single packet on any inport of any switch

- `match(switch=s1,inport=2,srcip='1.2.3.4') >> flood`

  ➔Only broadcasts packets on switch s1 input 2 from srcip 1.2.3.4

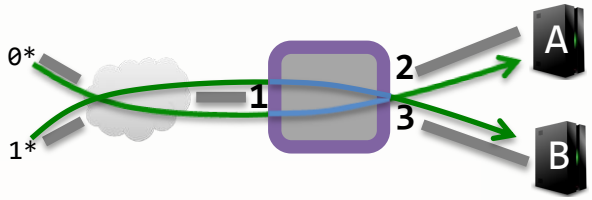
Querying as Forwarding

`packets(limit,[h])` `count_packets(every,[h])`

Abstract location corresponding to a data-structure that store packet-data and callback processing routines

```
b = count_packets(every=1)
b.register_callback(print)
match(srcip=X) >> fwd(b)
```

Monitoring Load Balancer




```
                                    eval(id,p) = {p}
route =
  ( match(dstip=A) >> fwd(2) ) +
  ( match(dstip=B) >> fwd(3) ) +
  ~(match(dstip=A) | match(dstip=B)) >> fwd(1)
```

```
b = count_packets(every=1)
b.register_callback(print)
monitor = match(srcip=X) >> fwd(b)
```

Compared to

```
install_flowmod(5,srcip=X &  dstip=P,[mod(dstip=A), fwd(2)])
install_flowmod(4,srcip=0* & dstip=P,[mod(dstip=A), fwd(2)])
install_flowmod(4,srcip=1* & dstip=P,[mod(dstip=B), fwd(3)])
install_flowmod(4,srcip=X & dstip=A ,[              fwd(2)])
install_flowmod(4,srcip=X &  dstip=B,[              fwd(3)])
install_flowmod(3,                dstip=A,[         fwd(2)])
install_flowmod(3,                dstip=B,[         fwd(3)])
install_flowmod(2,srcip=X                 ,[        fwd(1)])
install_flowmod(1,*                       ,[        fwd(3)])
```

Summary: Pyretic Policy Syntax

Check also Assignment for syntax changes

8 Actions

```
A ::= drop | fwd(port) | flood | mod(h=v) |
      id | push(h=v) | pop(h) | move(h1=h2)
```

6 Predicates

```
P ::= all_packets | no_packets | match(h=v) |
    | P & P | (P|P) | ~P
```

2 Query Buckets

```
B ::= packets(limit,[h])|count_packets(every,[h])
```

5 Policies

```
C ::= A | fwd(B) | P[C] | (C|C) | C >> C
```

New Actions Explained

- `passthrough`
  identity function (changed to `id`)
- `push(h=v)`
  pushes value v to field h
- `pop(h)`
  pops value out of field h
- `move(h1=h2)`
  pops top value from h2 and pushes it to h1

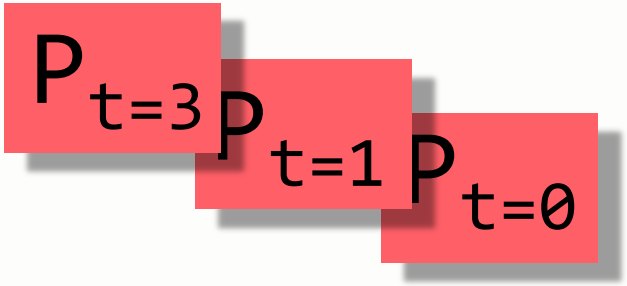
Pyretic's Design

- Monitoring Load Balancer
  - Encode Policies as Functions
  - Compositional Operators
  - Queries as Forwarding Policies
- MAC-Learning Module
  - Dynamic Policies
- "One Big Switch" Topology Abstraction
  - Extensible packet model

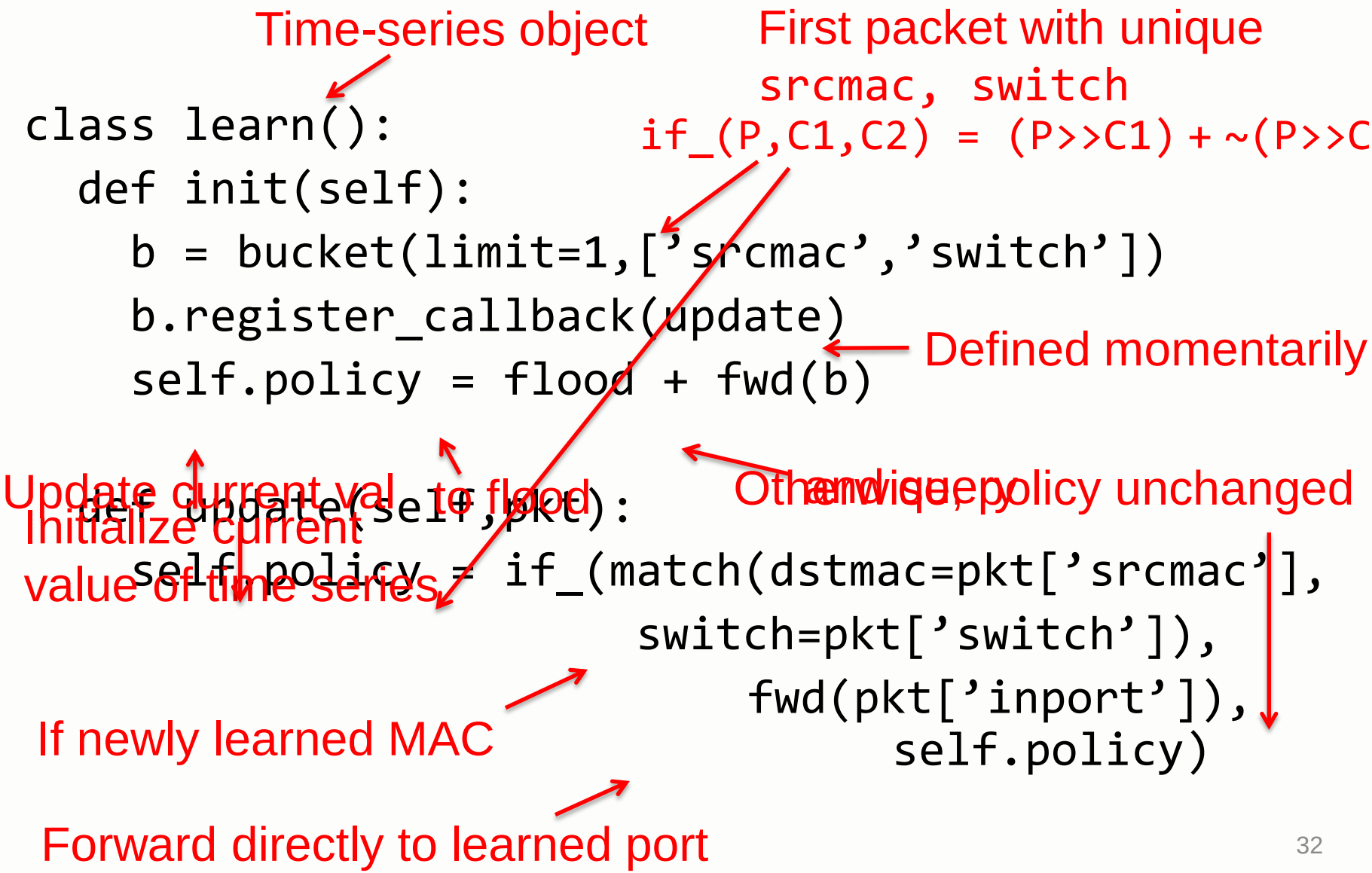
How Do We Change Policies?

Dynamic policy

a time-series of policies



MAC-Learning Module



Pyretic's Design

- Monitoring Load Balancer
  - Encode Policies as Functions
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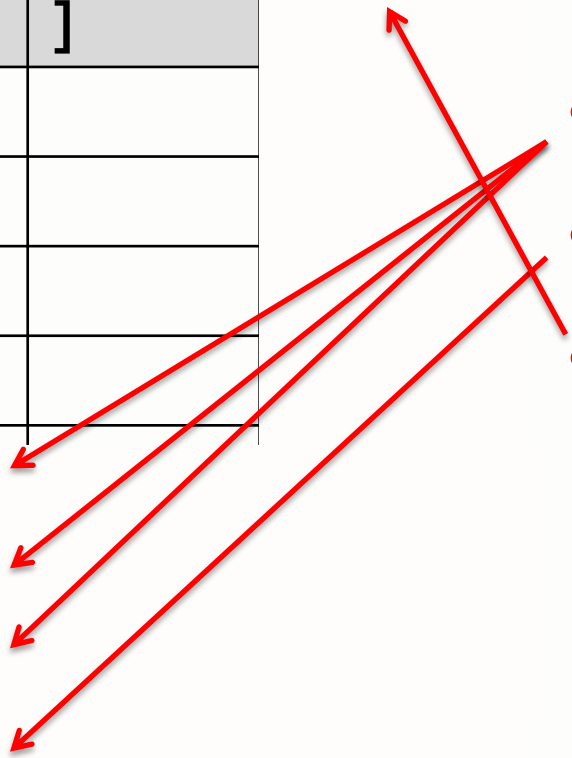
Extensible Pyretic Packet Model

Field	Val[0]
srcmac	
dstmac	
proto	
srcip	

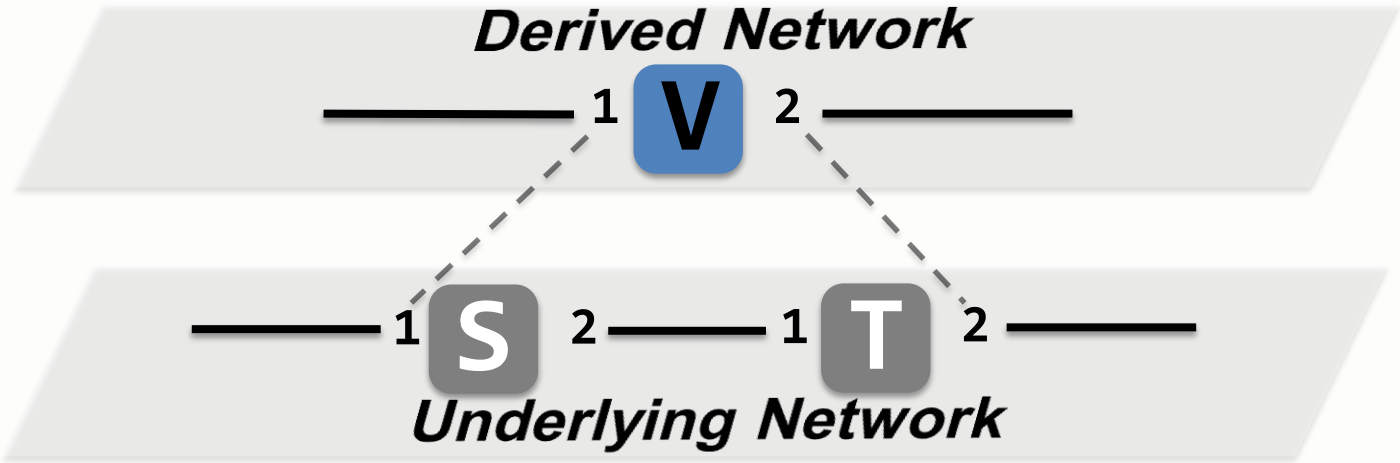


- All OpenFlow fields
- Location fields
- Virtual fields
- Stacks of values
  - push(h=v)
  - pop(h)
  - Actions and matches use (currently) top value

vswitch		

Implemented on OpenFlow by mapping extended field values to VLAN tags/MPLS labels

“One Big Switch” Topology Abstraction



- Simplest of topology abstraction examples
- Build a distributed middlebox
  by running centralized middlebox app on V!

Topology Virtualization

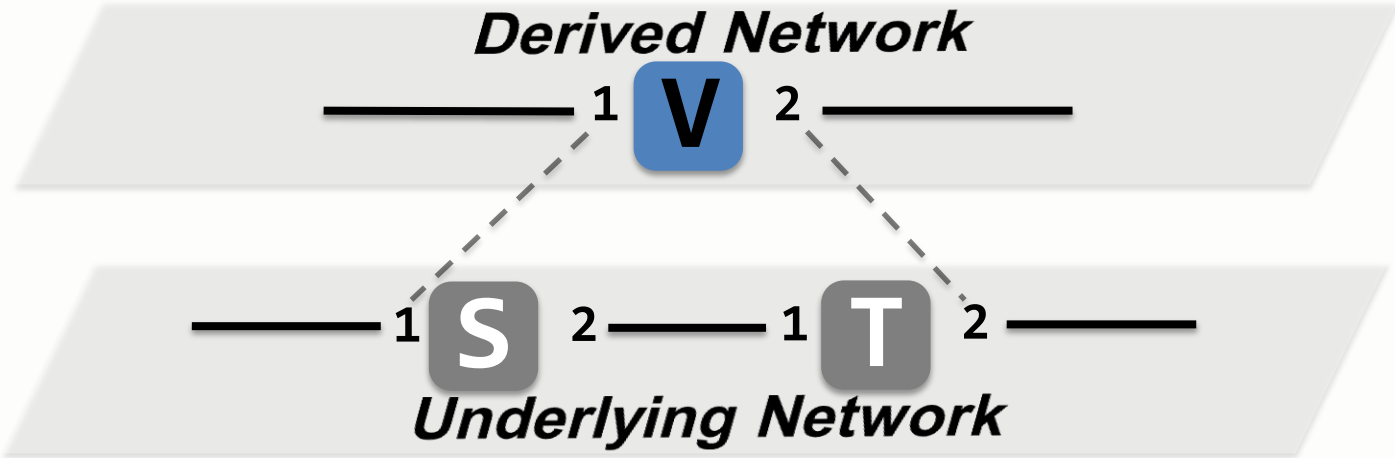
```
def virtualize(derived,transformation)
```

that "does" the `derived` policy on the abstract topology (i.e., on node V)

Returns a new policy for the underlying network (i.e., on nodes S and T)

Defines transformation policies:

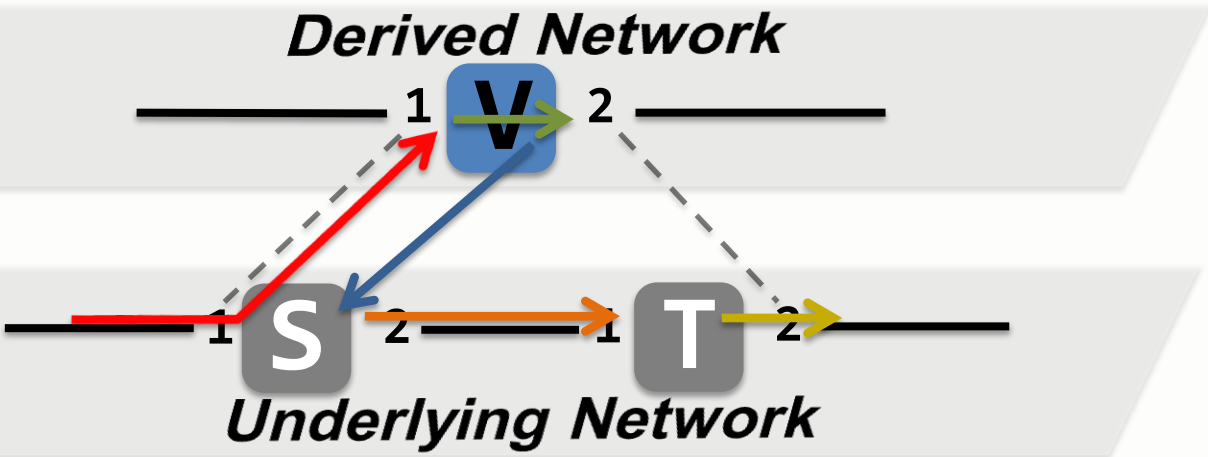
- `ingress_policy` handles packets entering abstract switch
- `fabric_policy` moves packets through abstract switch
- `egress_policy` handles packets exiting abstract switch



Simplified implementation of `virtualize(derived,transformation)`

```
return ingress_policy >> # defines part of transform
       derived        >> # app run on abstract topo
       lower_packet   >> # built-in
       fabric_policy  >> # defines part of transform
       egress_policy     # defines part of transform
```

Field	V0	V1
switch	S	V
inport	1	1
outport	2	2
vinport	1	
voutport	2	



Summary: Abstractions

Pyretic	Current APIs

Related Work:

[Frenetic, Maestro, FRESCO] / [Click]

	Pyretic	**Current APIs**
Policy	Rich Composition	**Some / Full** Composition
Network	Layered Abstract Topologies	Concrete Network
Packet	Extensible Headers	Fixed OpenFlow Headers

But only for a single software switch
not multiple hardware switches

Related Work:

[FlowVisor] / [Nicira NVP, OpenStack Quantum]

	`Pyretic`	**Current APIs**
Policy	Rich Composition	Little Composition
Network	Layered Abstract Topologies	**Disjoint Slices / Topology Hiding**
Packet	Extensible Headers	Fixed OpenFlow Headers

Both approaches support multi-tenancy,
but not topological decomposition
(or functional composition)

`Pyretic` Interpreter and Suite of Apps

Available at www.frenetic-lang.org/pyretic

- Monitoring & DPI
- Load Balancers
- Hub
- ARP
- Firewalls
- MAC learner

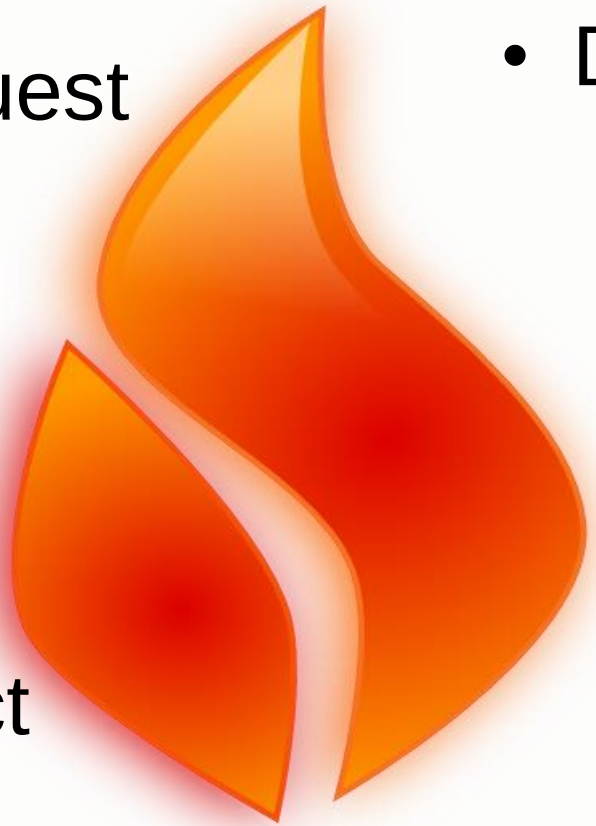
- Abstractions
  - Big switch (one-to-many)
  - Spanning tree (many-to-many)
  - Gateway (many-to-one)

And bigger applications built by combining these.

And More!

Available at www.frenetic-lang.org/pyretic

- Features Request
- Bug reporting
- Link to github
- Discuss list
- Join the project



- Dev Roadmap
  - Reactive (microflow) runtime
  - Proactive (compilation) runtime
  - Optimizations
  - Caching

Further Reading

- Pyretic description (login article): http://www.cs.princeton.edu/~jrex/papers/pyretic-login13.pdf

- Pyretic tutorial: http://youtu.be/hq7L4davQy8

- Nick Feamster's course: http://youtu.be/oa2KQ-b1SV4 http://youtu.be/UKxjitMqn88

Τέλος Ενότητας

Χρηματοδότηση

- Το παρόν εκπαιδευτικό υλικό έχει αναπτυχθεί στα πλαίσια του εκπαιδευτικού έργου του διδάσκοντα.
- Το έργο «**Ανοικτά Ακαδημαϊκά Μαθήματα στο Πανεπιστήμιο Κρήτης**» έχει χρηματοδοτήσει μόνο τη αναδιαμόρφωση του εκπαιδευτικού υλικού.
- Το έργο υλοποιείται στο πλαίσιο του Επιχειρησιακού Προγράμματος «Εκπαίδευση και Δια Βίου Μάθηση» και συγχρηματοδοτείται από την Ευρωπαϊκή Ένωση (Ευρωπαϊκό Κοινωνικό Ταμείο) και από εθνικούς πόρους.

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ΕΣΠΑ 2007-2013
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης

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