Bringing SDN to the Internet, one exchange point at the time

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	BGP	SDN
Fwd paradigm		
Fwd control		
Fwd influence		

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	BGP	SDN
Fwd paradigm	destination-based	
Fwd control	indirect configuration	
Fwd influence	local BGP session	

SDN can enable fine-grained, flexible and direct expression of interdomain policies

	BGP	SDN
Fwd paradigm	destination-based	any source addr, ports,…
Fwd control	indirect configuration	direct open API (e.g., OpenFlow)
Fwd influence	local BGP session	global remote controller control

How do you deploy SDN in a network composed of 50,000 subnetworks?

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Well, you don't …

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Deploy SDN in locations that

- connect a large number of networks
- carry a large amount of traffic
- are opened to innovation

Internet eXchange Points (IXP) meet all the criteria

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AMS-IX

675 networks

3.2 Tb/s (peak)

BGP Route Server

Mobile peering

Open peering…

https://www.ams-ix.net

A single deployment can have a large impact

Deploy SDN in locations that

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SDX = SDN + IXP

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Augment the IXP data-plane with SDN capabilities

keeping default forwarding and routing behavior

Enable fine-grained inter-domain policies

bringing new features & simplifying operations

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Augment the IXP data-plane with SDN capabilities

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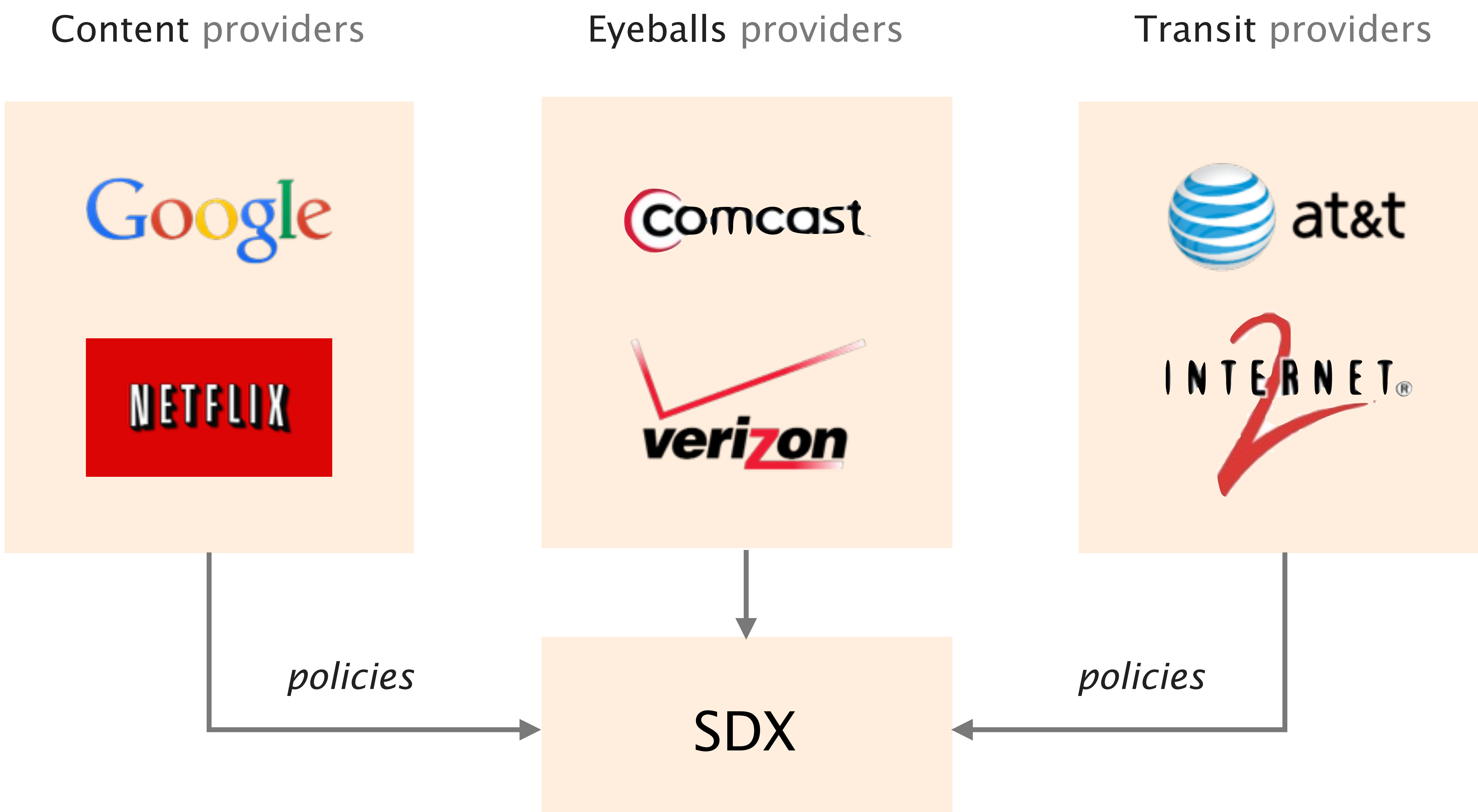
Enable fine-grained inter-domain policies

bringing new features & simplifying operations

… with scalability and correctness in mind

supporting large IXP load and resolving conflicts

SDX enables multiple stakeholders to implement policies and apps over a shared infrastructure



Bringing SDN to the Internet, one exchange point at the time

1 **Architecture**
programming model

2 **Scalability**
control- & data-plane

3 **Applications**
inter domain bonanza

Bringing SDN to the Internet, one exchange point at the time

1 **Architecture**

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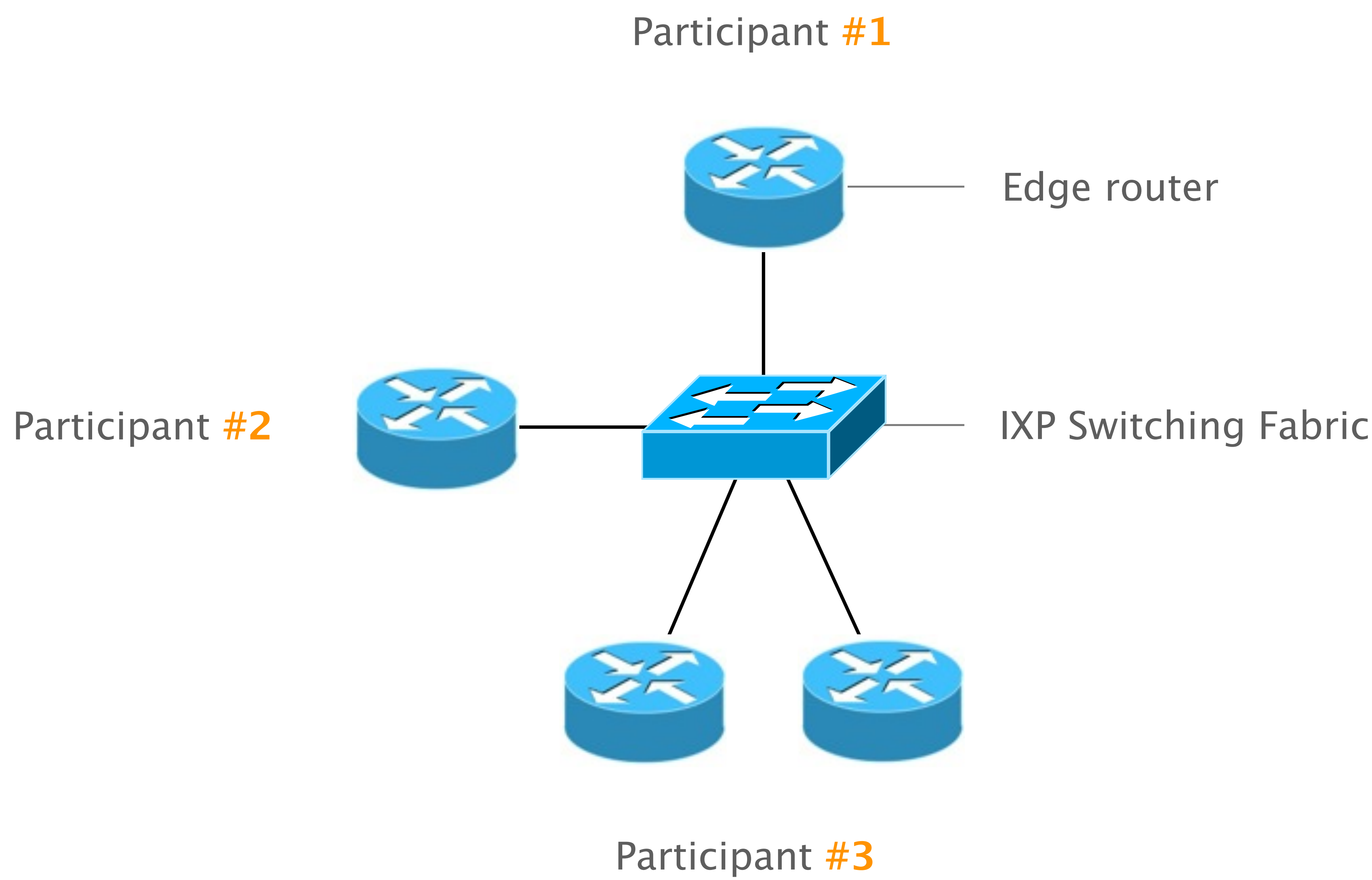
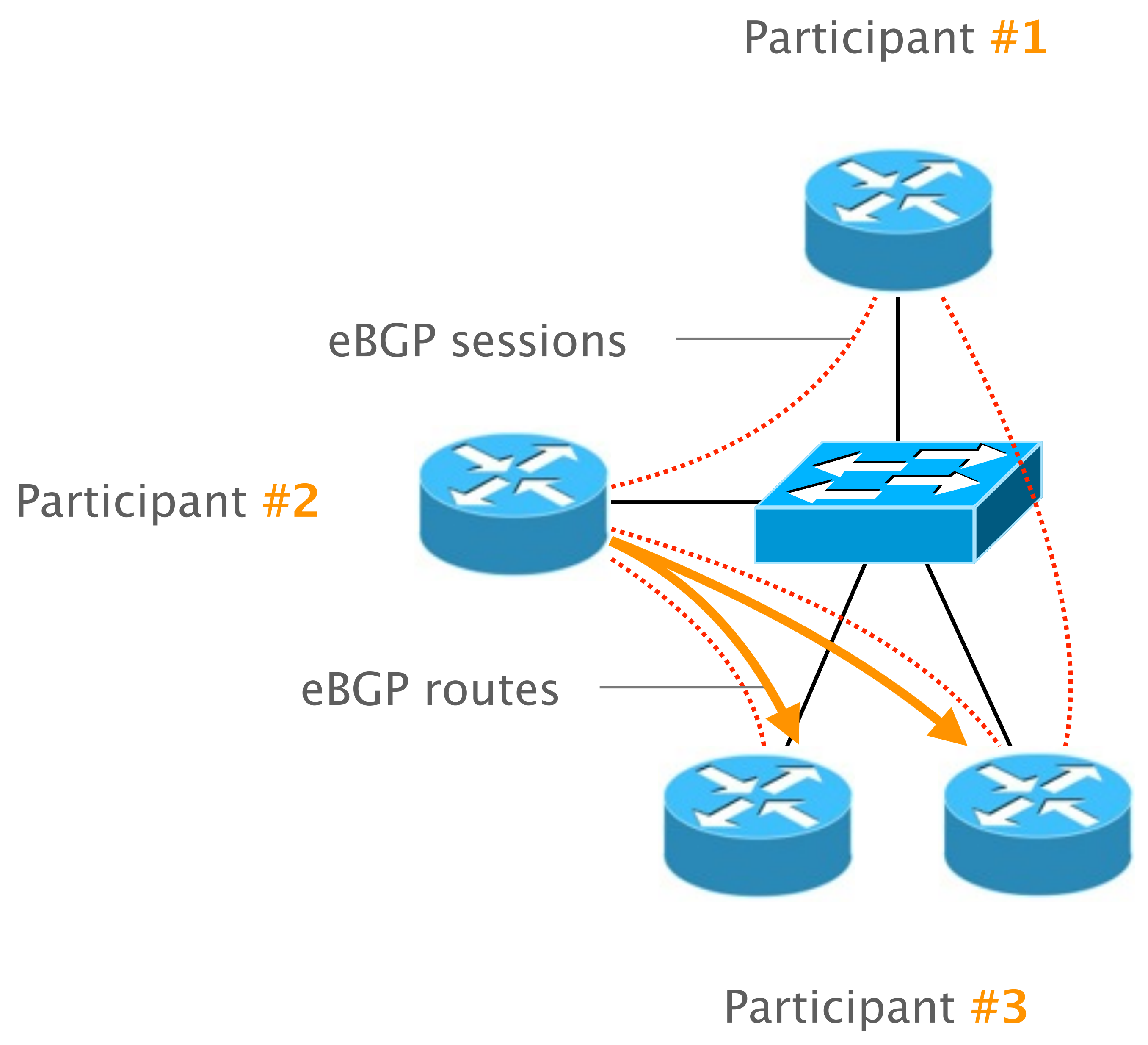
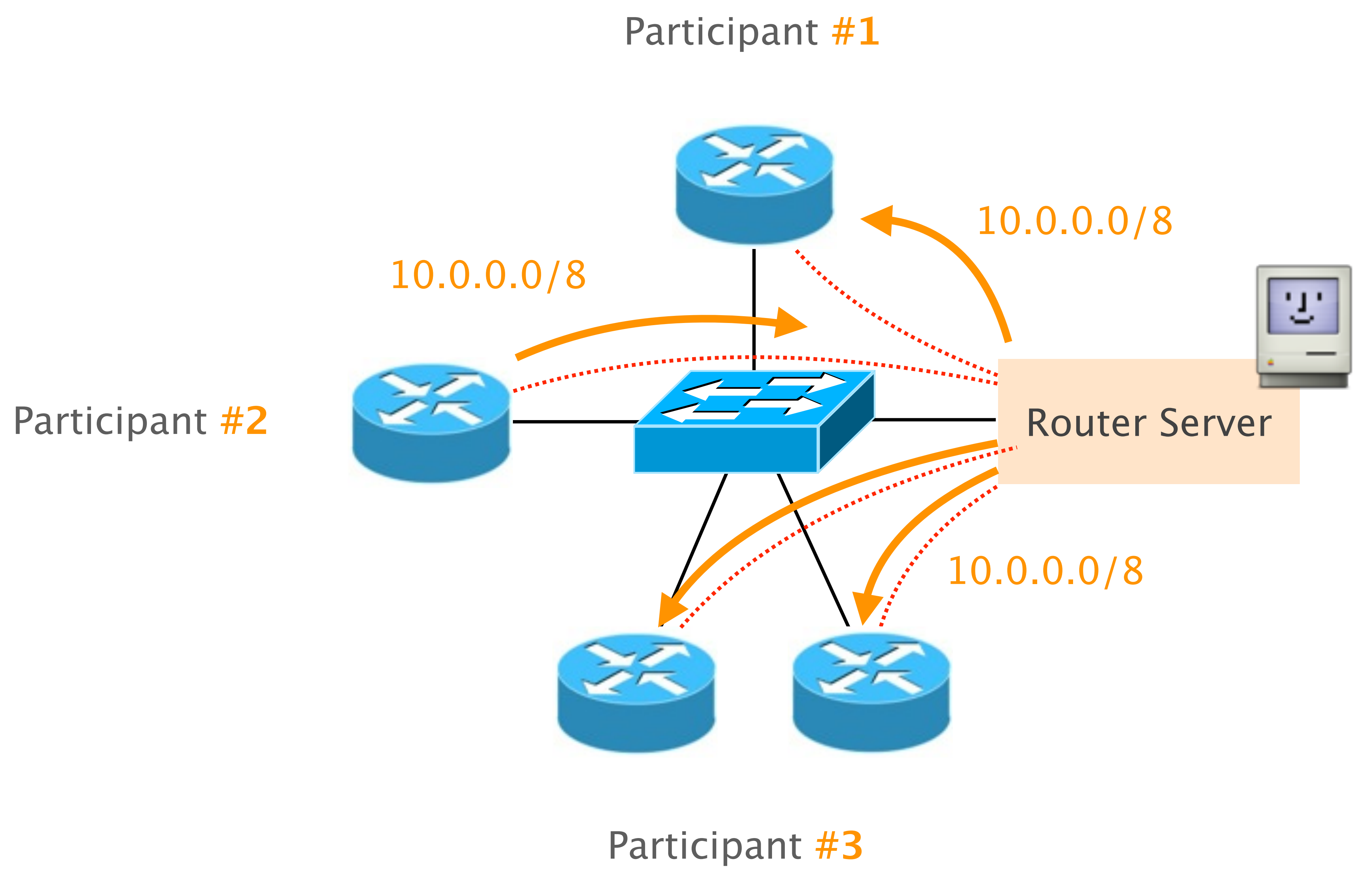
An IXP is a large layer-2 domain



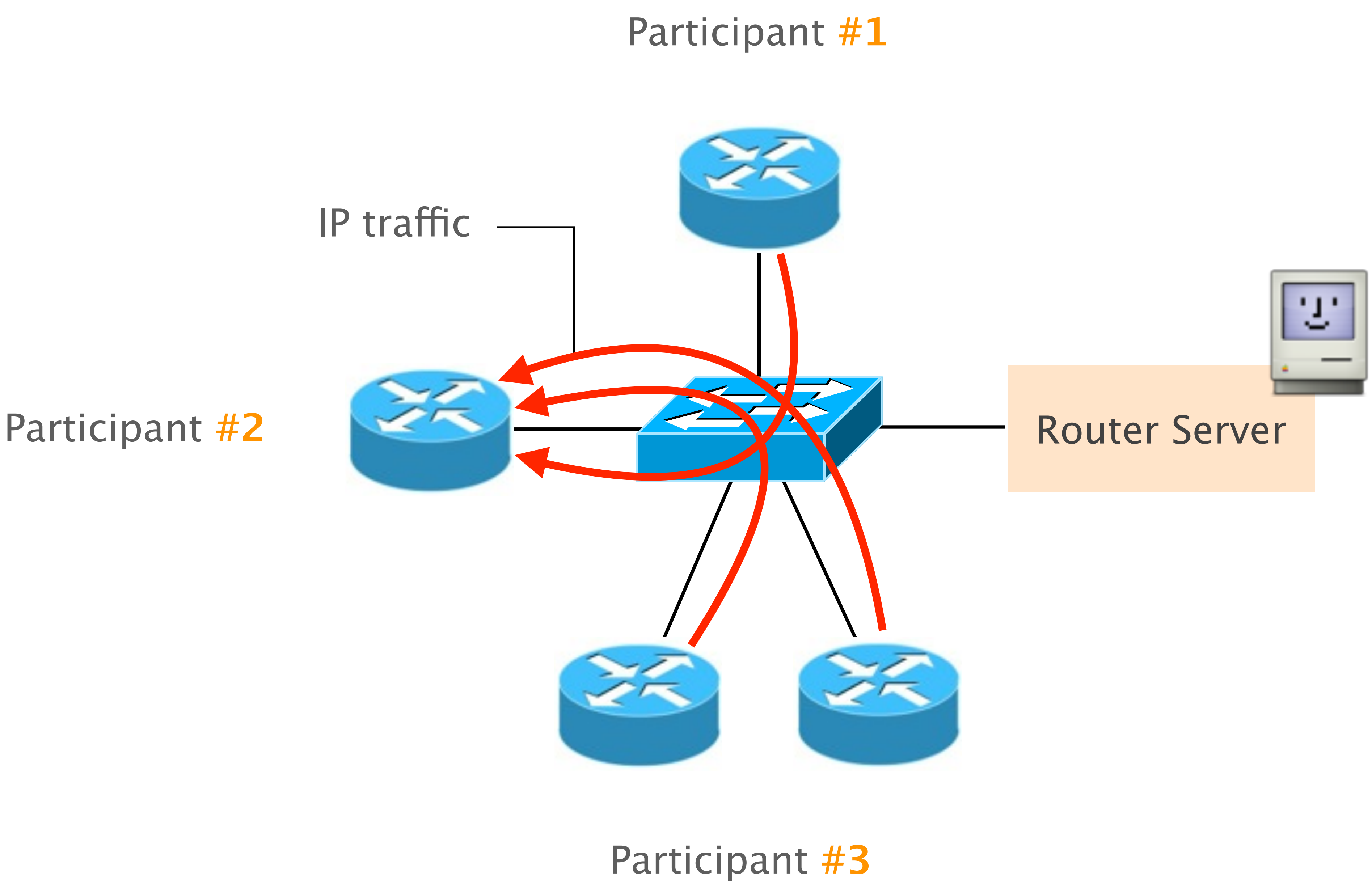
An IXP is a large layer-2 domain where participant routers exchange routes using BGP



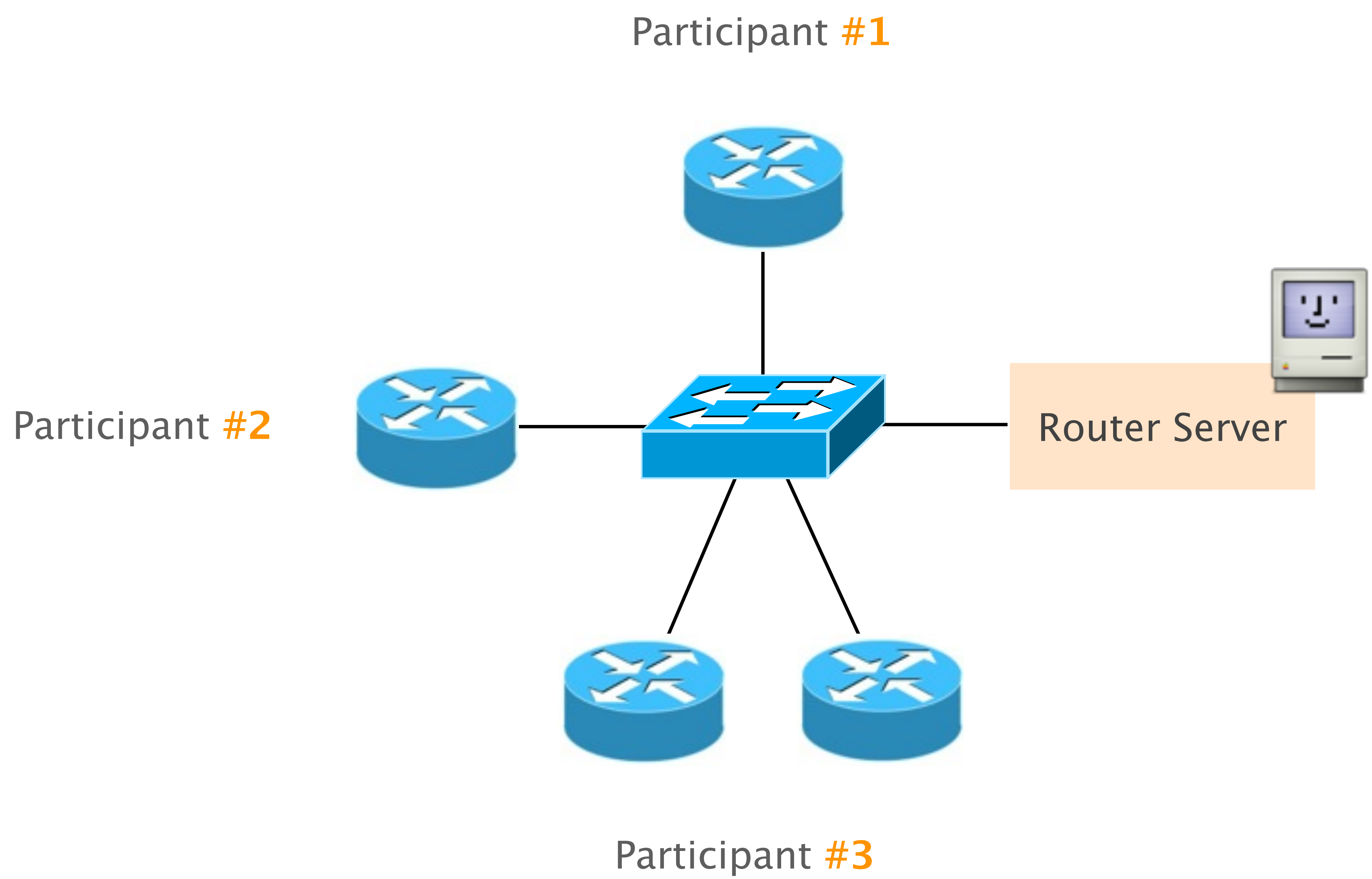
To alleviate the need of establishing eBGP sessions, IXP often provides a Route Server (route multiplexer)



IP traffic is exchanged directly between participants

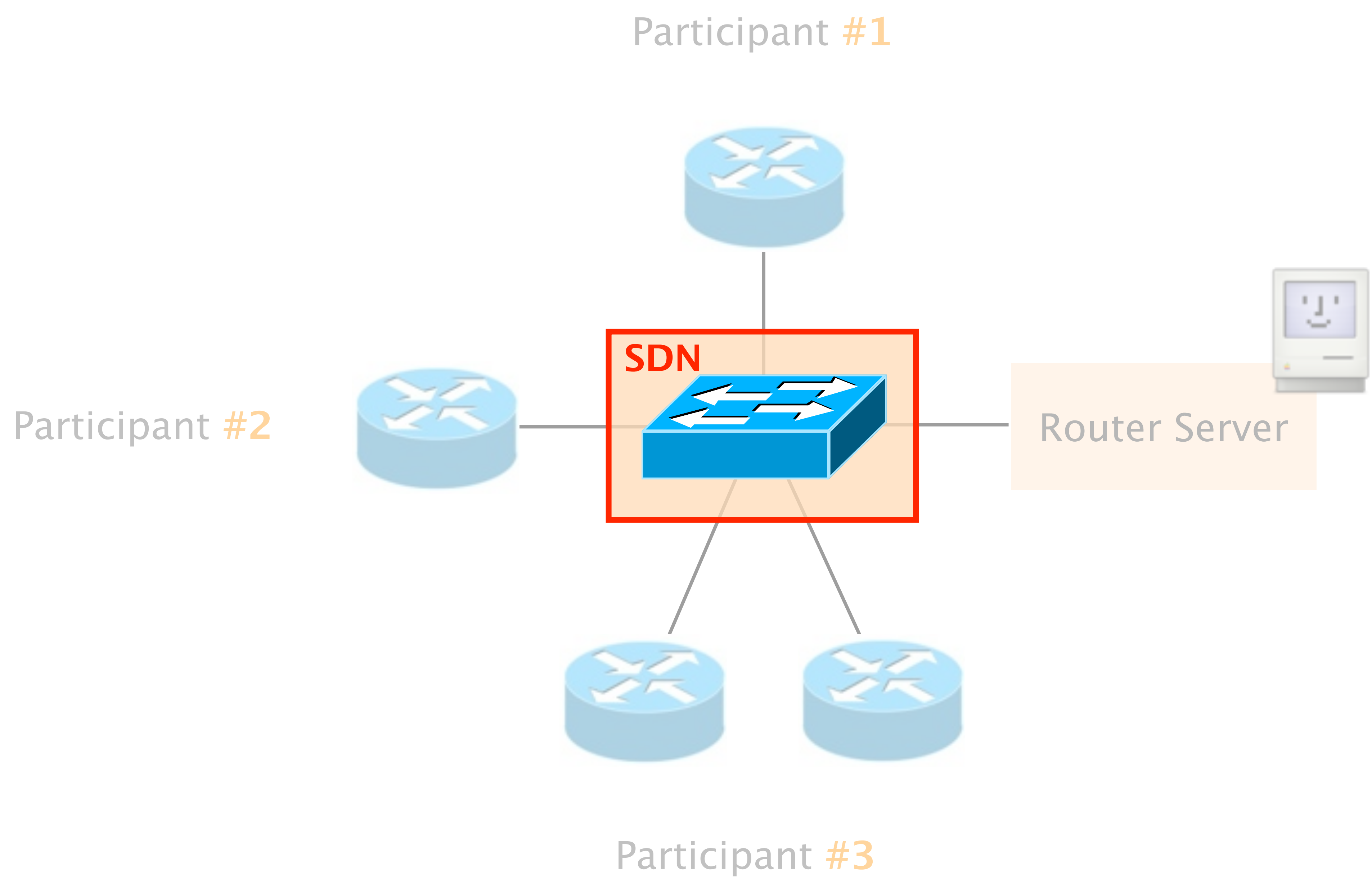


With respect to a traditional IXP,



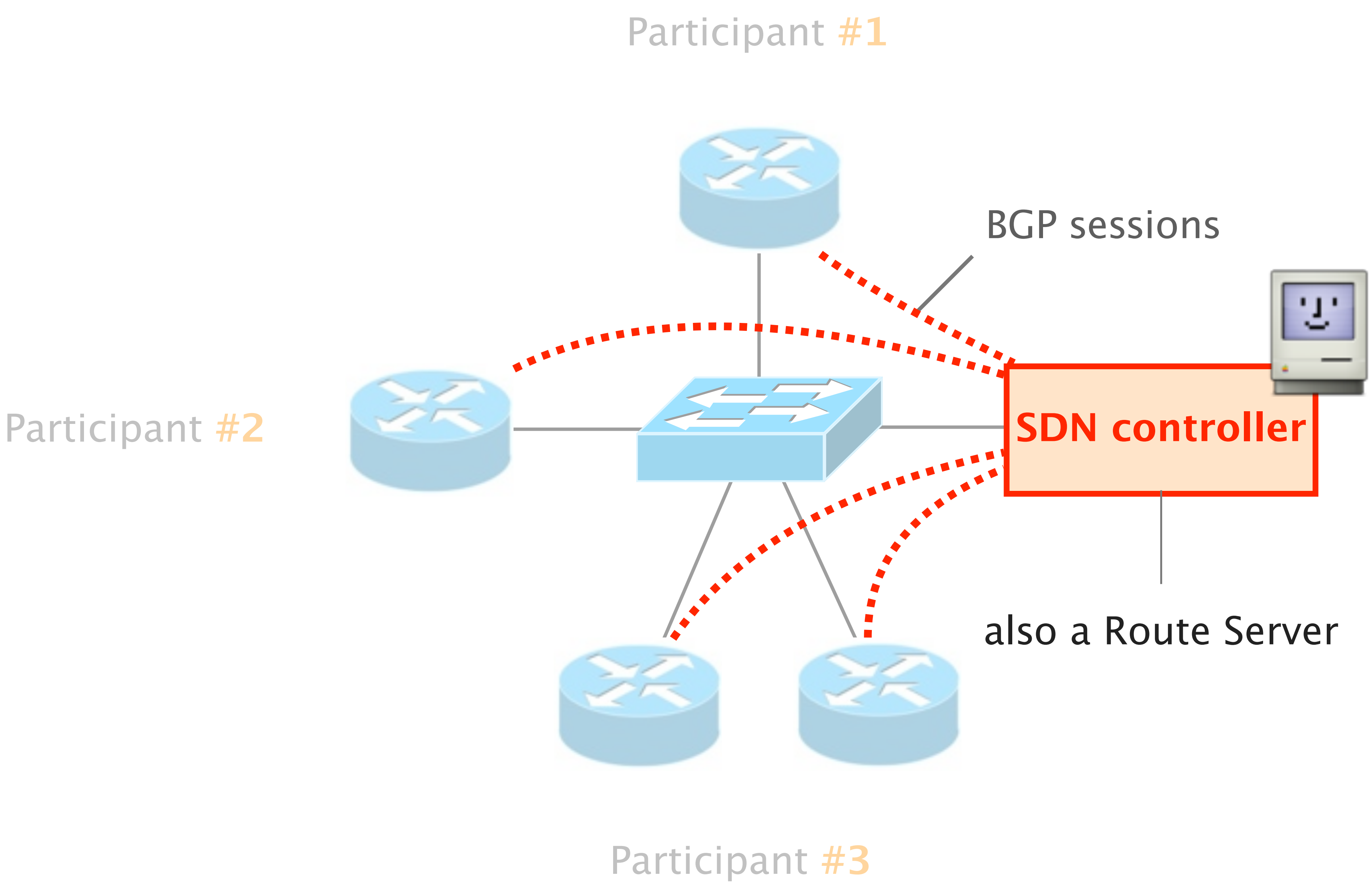
With respect to a traditional IXP,

SDX data-plane relies on SDN-capable devices



With respect to a traditional IXP,

SDX control-plane relies on a SDN controller



SDX participants express their forwarding policies in a high-level language, built on top of Pyretic (*)

(*) http://frenetic-lang.org/pyretic/

SDX policies are composed of a pattern and some actions

match (Pattern), then (Actions)

Pattern selects packets based on any header fields,

Pattern

match (eth_type, vlan_id, srcmac, dstmac, protocol, dstip, tos, srcip, srcport, dstport , &&, ||), then (Actions)

Pattern selects packets based on any header fields,
while actions forward or modify the selected packets

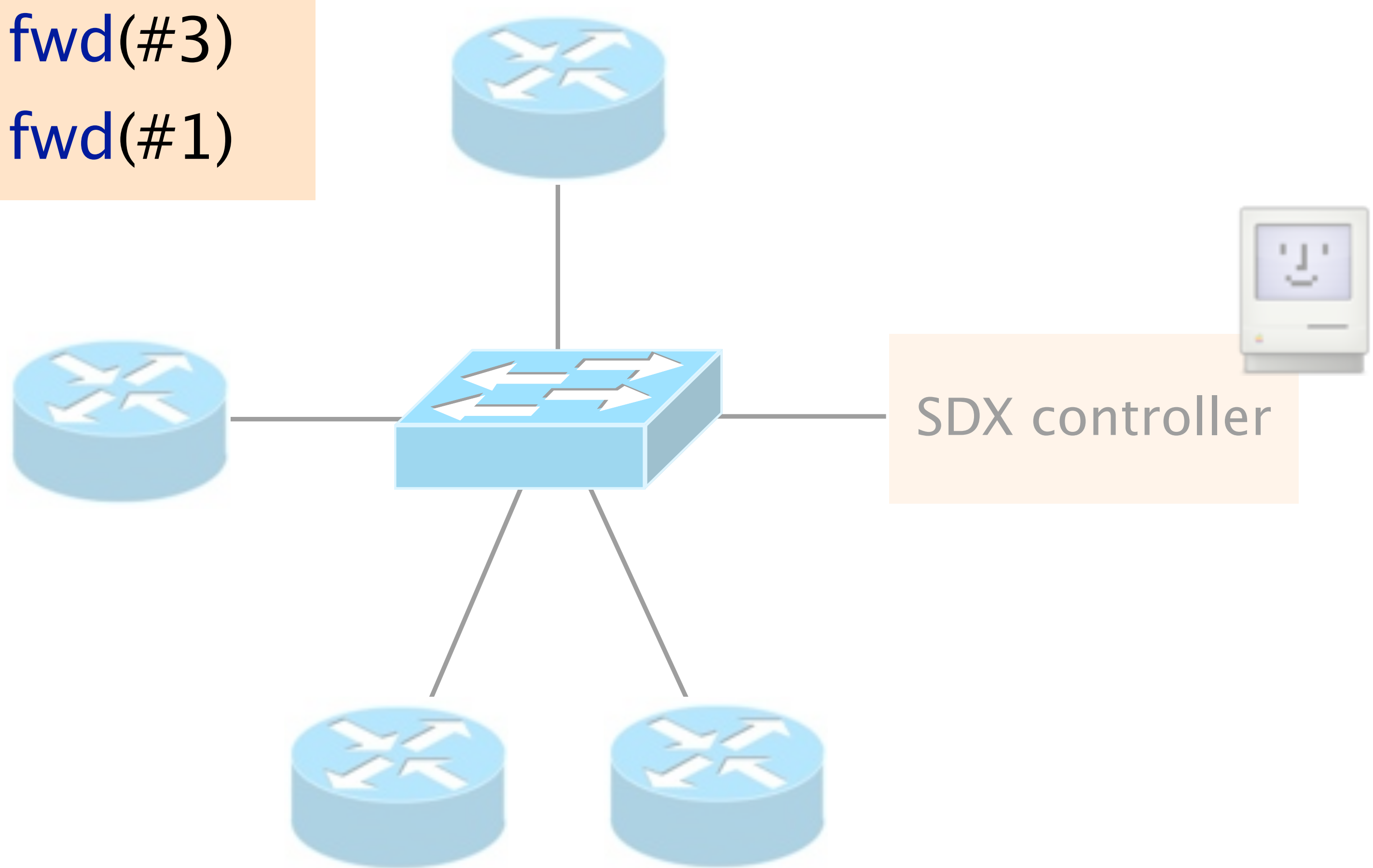
Actions

match (Pattern), then (drop / forward / rewrite)

Each SDX participant writes her policies independently

Participant **#2** policy

```
match(dstport=80), fwd(#3)
match(dstport=22), fwd(#1)
```



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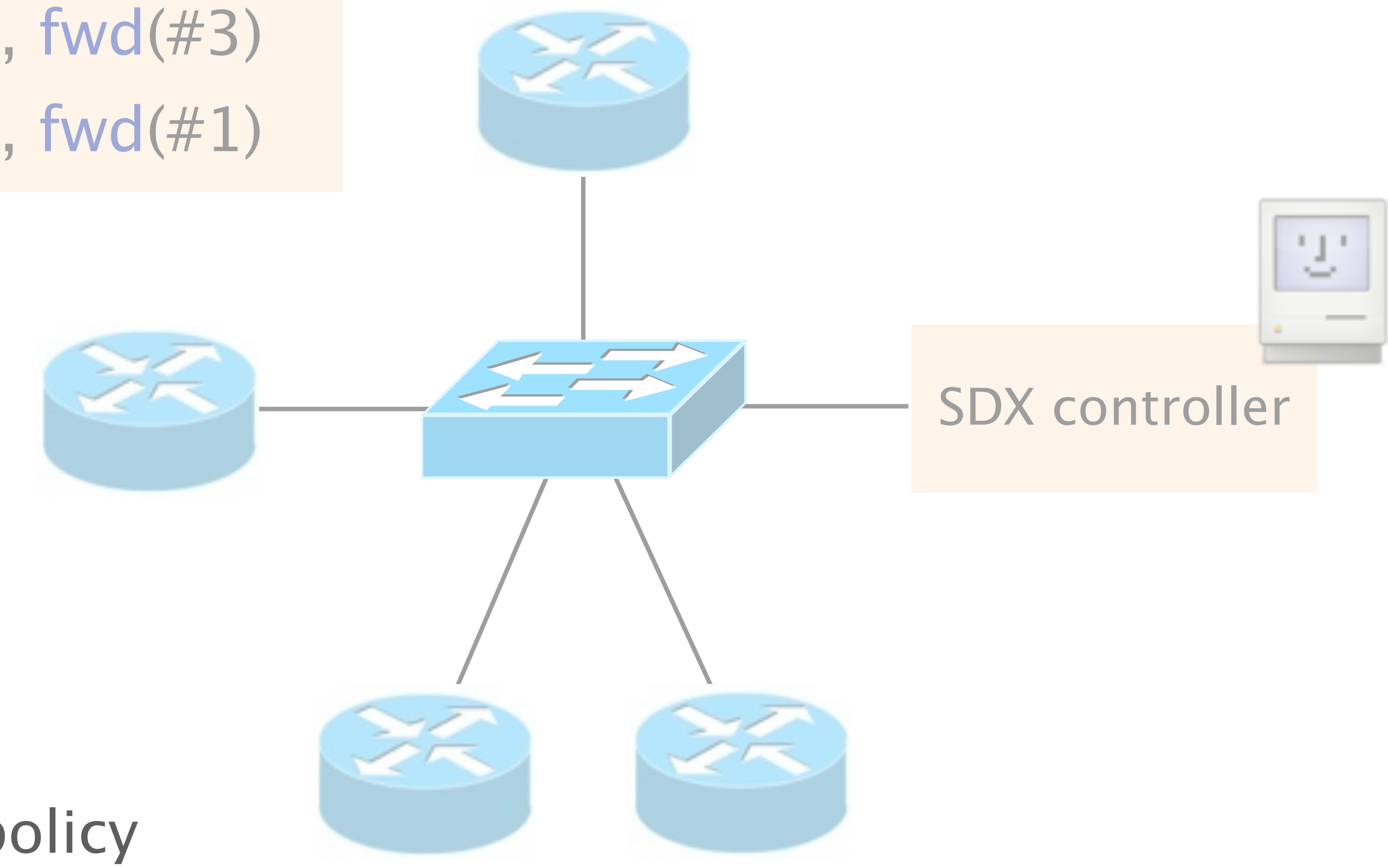


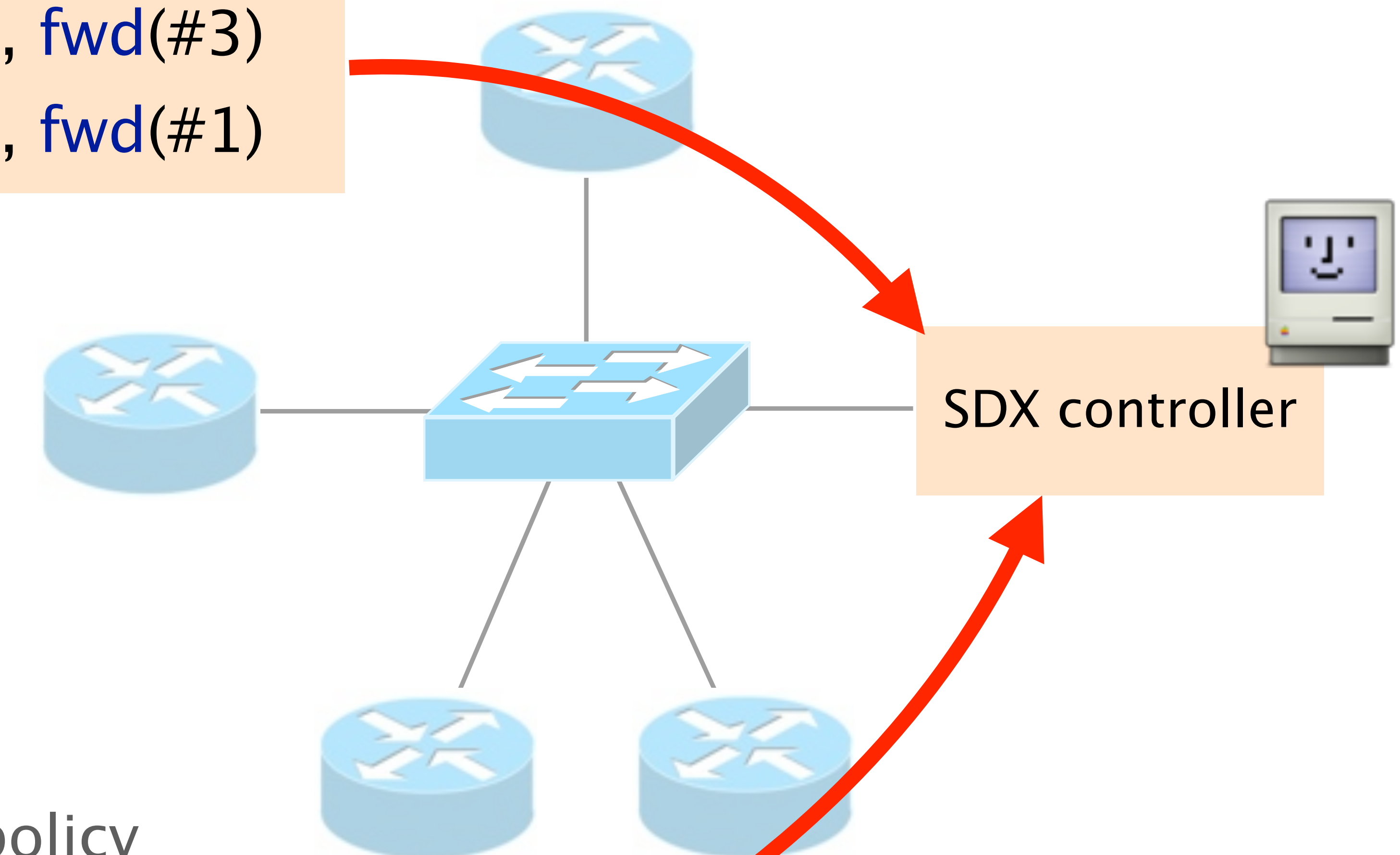
Participant #3 policy

match(srcip=0*), fwd(left)
match(srcip=1*), fwd(right)

… and transmit them to the SDX controller

Participant #2 policy

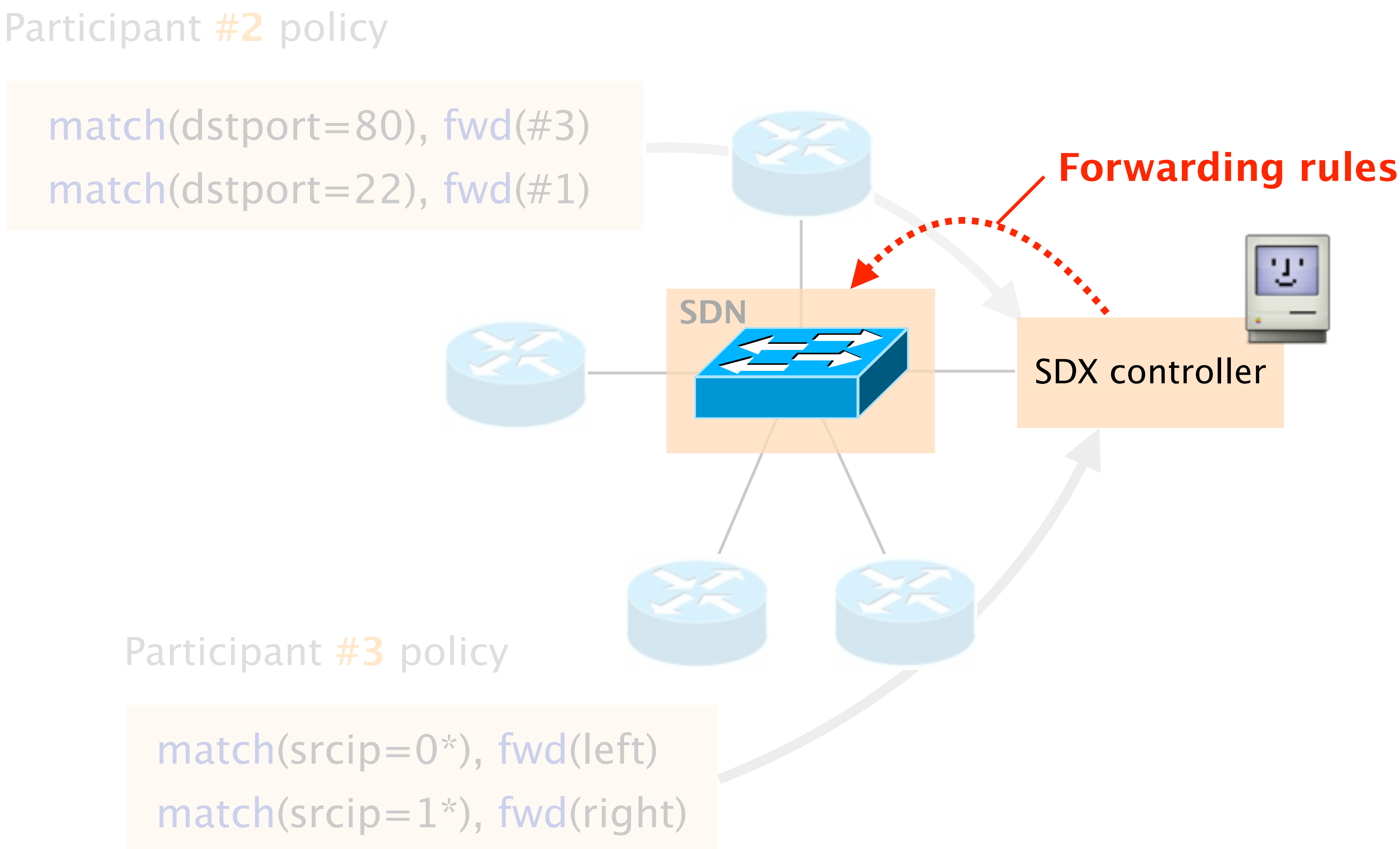
match(dstport=80), fwd(#3)
match(dstport=22), fwd(#1)



Participant #3 policy

match(srcip=0*), fwd(left)
match(srcip=1*), fwd(right)

The controller compiles all the policies into SDN forwarding rules



SDX compilation stage implements *each* participant policy in the data-plane

Ensuring isolation

Resolving conflict

Considering BGP

SDX compilation stage implements *each* participant policy in the data-plane

Ensuring isolation

Each participant controls one “virtual” switch

connected to participants it can communicate with

Resolving conflict

Considering BGP

SDX compilation stage implements *each* participant policy in the data-plane

Ensuring isolation

Resolving conflict

Policies are composed

according to BGP
business relationships

Considering BGP

SDX compilation stage implements *each* participant policy in the data-plane

Ensuring isolation

Resolving conflict

Considering BGP

Policies are augmented with BGP information

guarantee correctness and reachability

Bringing SDN to the Internet, one exchange point at the time

Architecture

programming model

2 Scalability

control- & data-plane

Applications

inter domain bonanza

The SDX platform faces scalability challenges in both the data- and in the control-plane

data-plane

space

control-plane

time

data-plane

space

512k prefixes, 500+ participants,
potentially 10^9 of forwarding rules

control-plane

time

forwarding rules must be updated
dynamically according to BGP

To scale, the SDX platform leverages existing infrastructure & domain-specific knowledge

data-plane

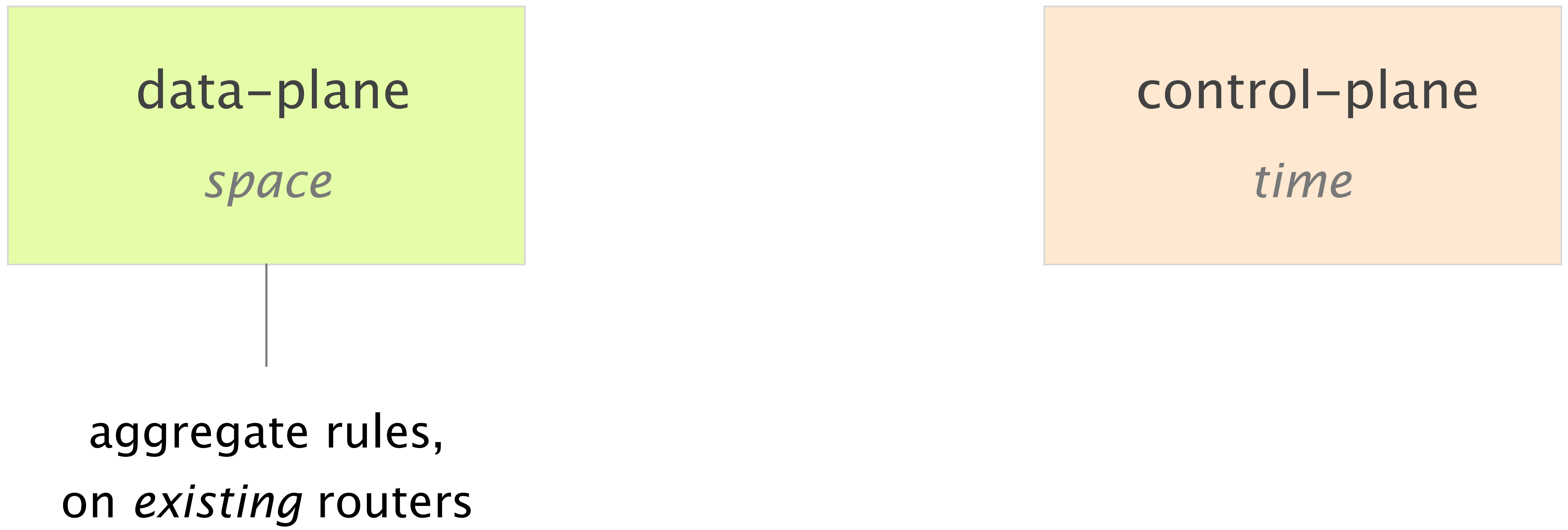
space

aggregate rules,
on *existing* routers

control-plane

time

leverage
policy structure


data-plane
space
control-plane
time
aggregate rules,
on existing routers

SDX groups IP prefixes according to their behavior through the fabric

- policies are prefix-based

  just the way the Internet works

- forwarding actions are shared for a lot of prefixes

  e.g., all prefixes advertised by X

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- policies are prefix-based

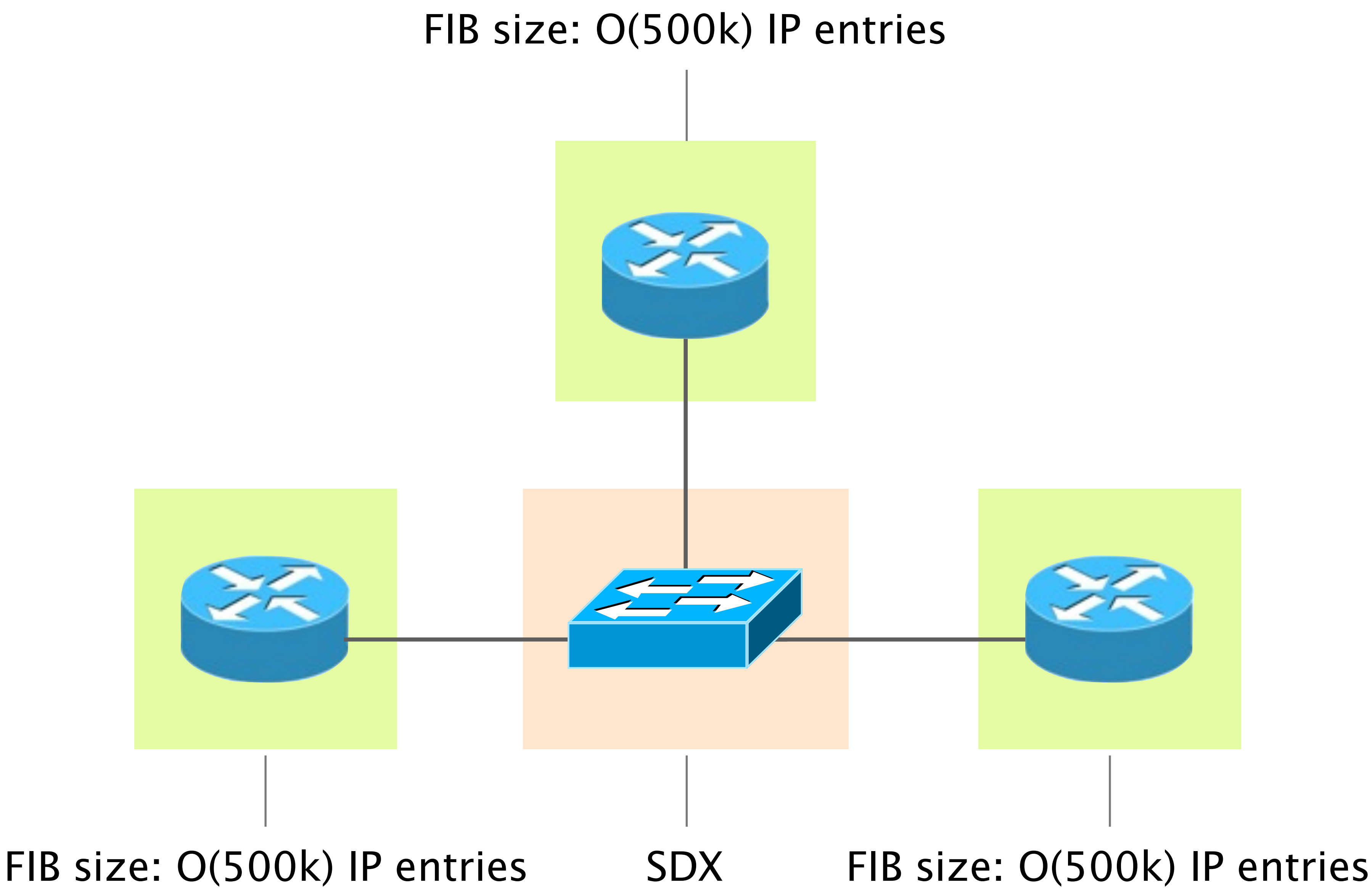
  just the way the Internet works

- forwarding actions are shared for a lot of prefixes

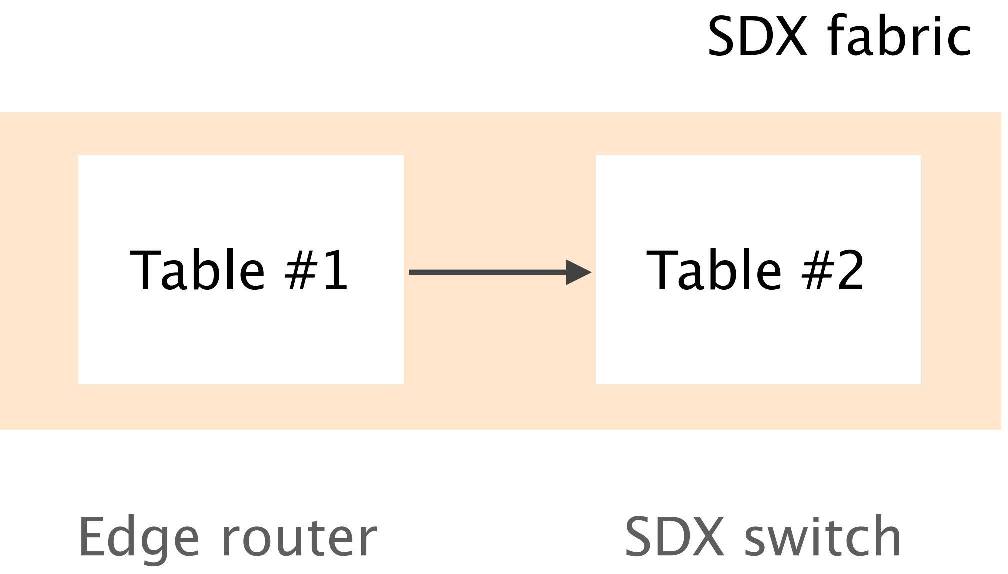
  e.g., all prefixes advertised by X

- group prefixes by equivalence class

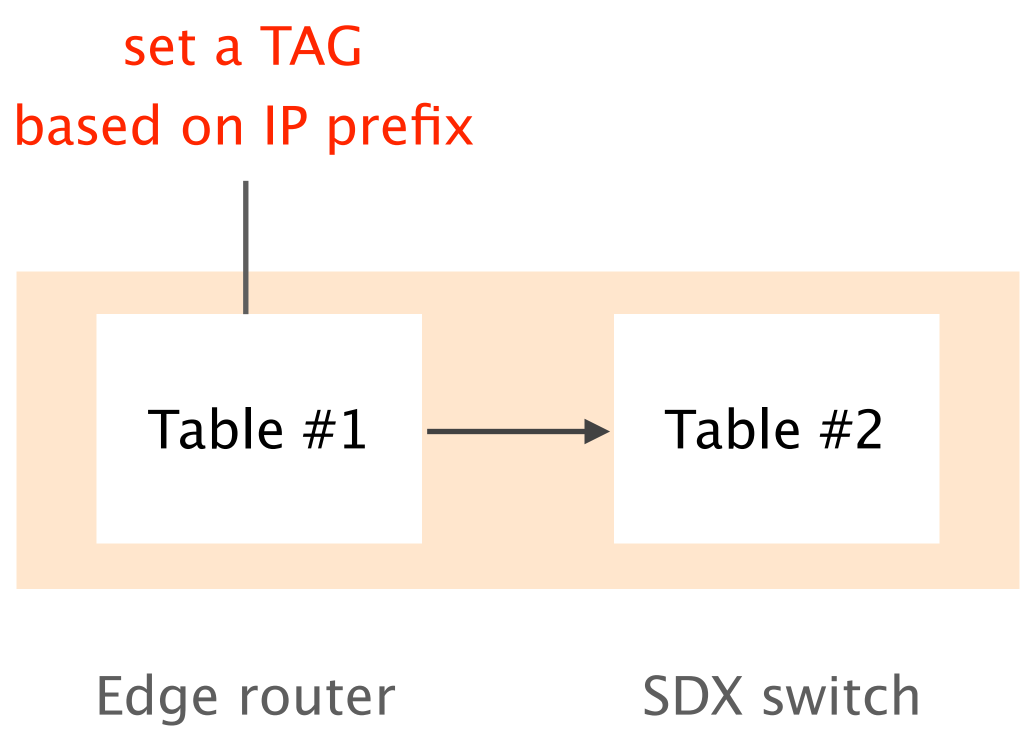
SDX leverages edge routers to map packets to their equivalence class



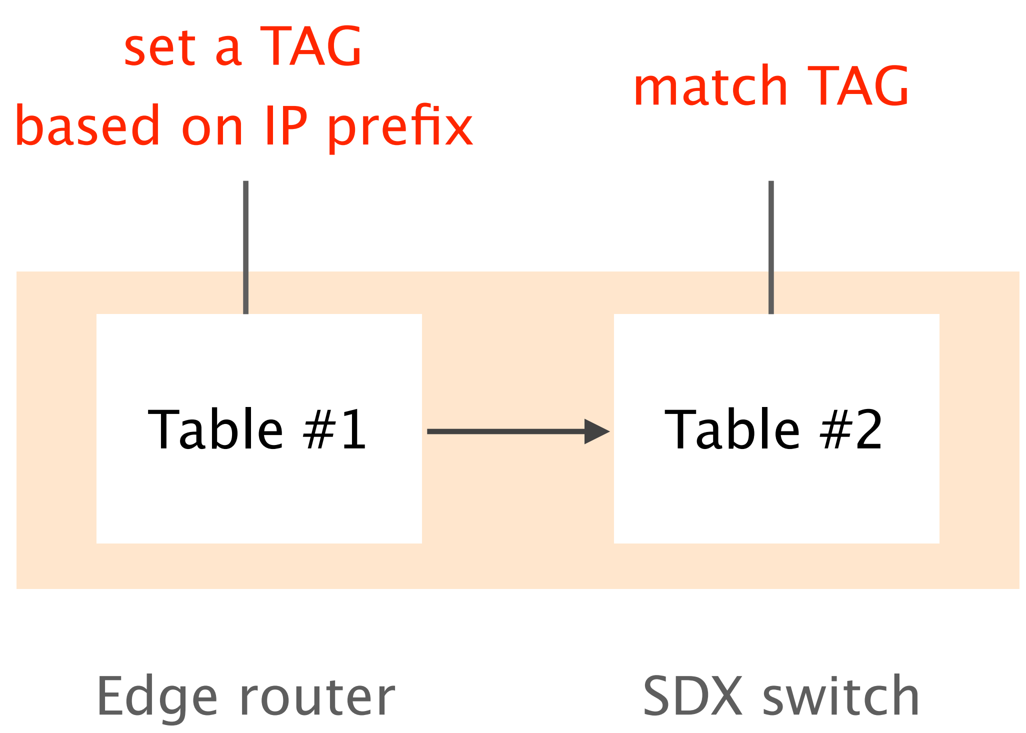
SDX considers edge routers' FIB as the first stage of a multi-stage FIB



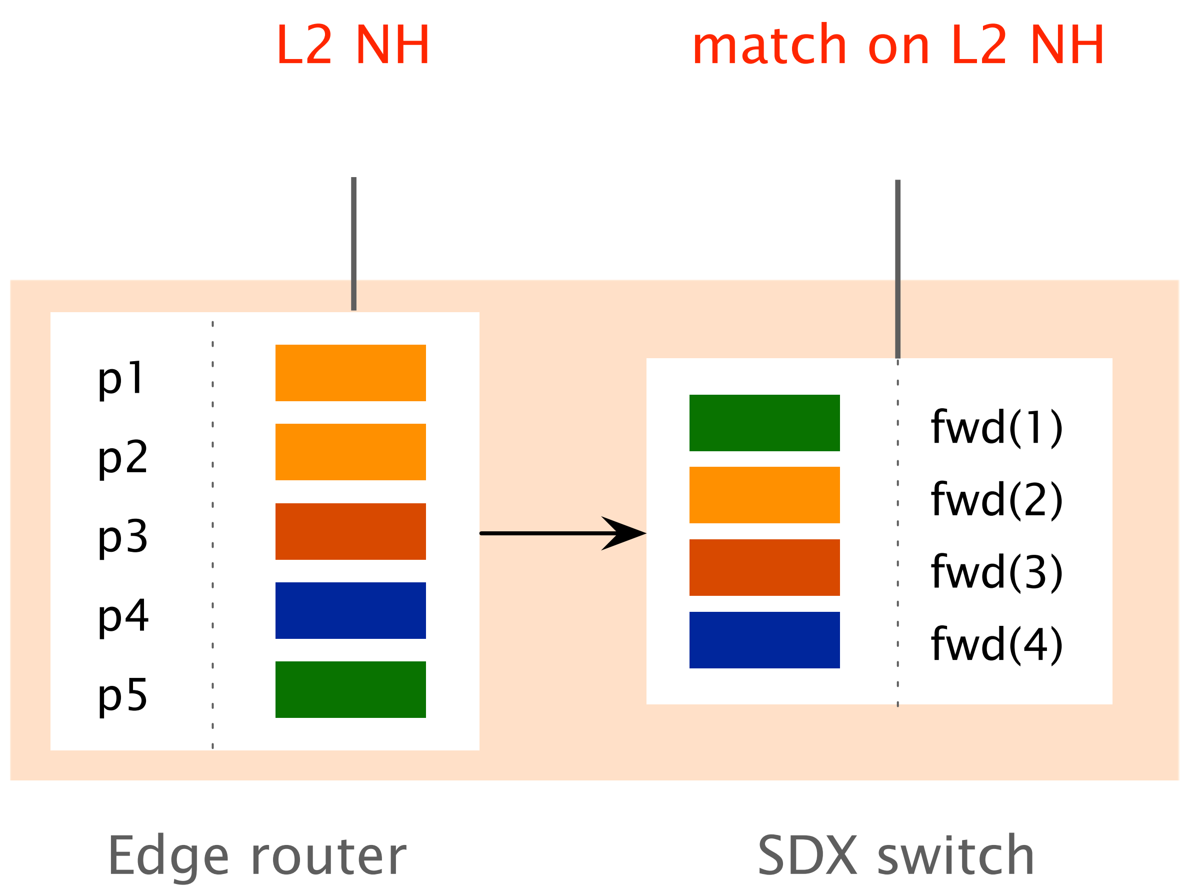
Routers FIB match on the destination prefix and set a tag accordingly



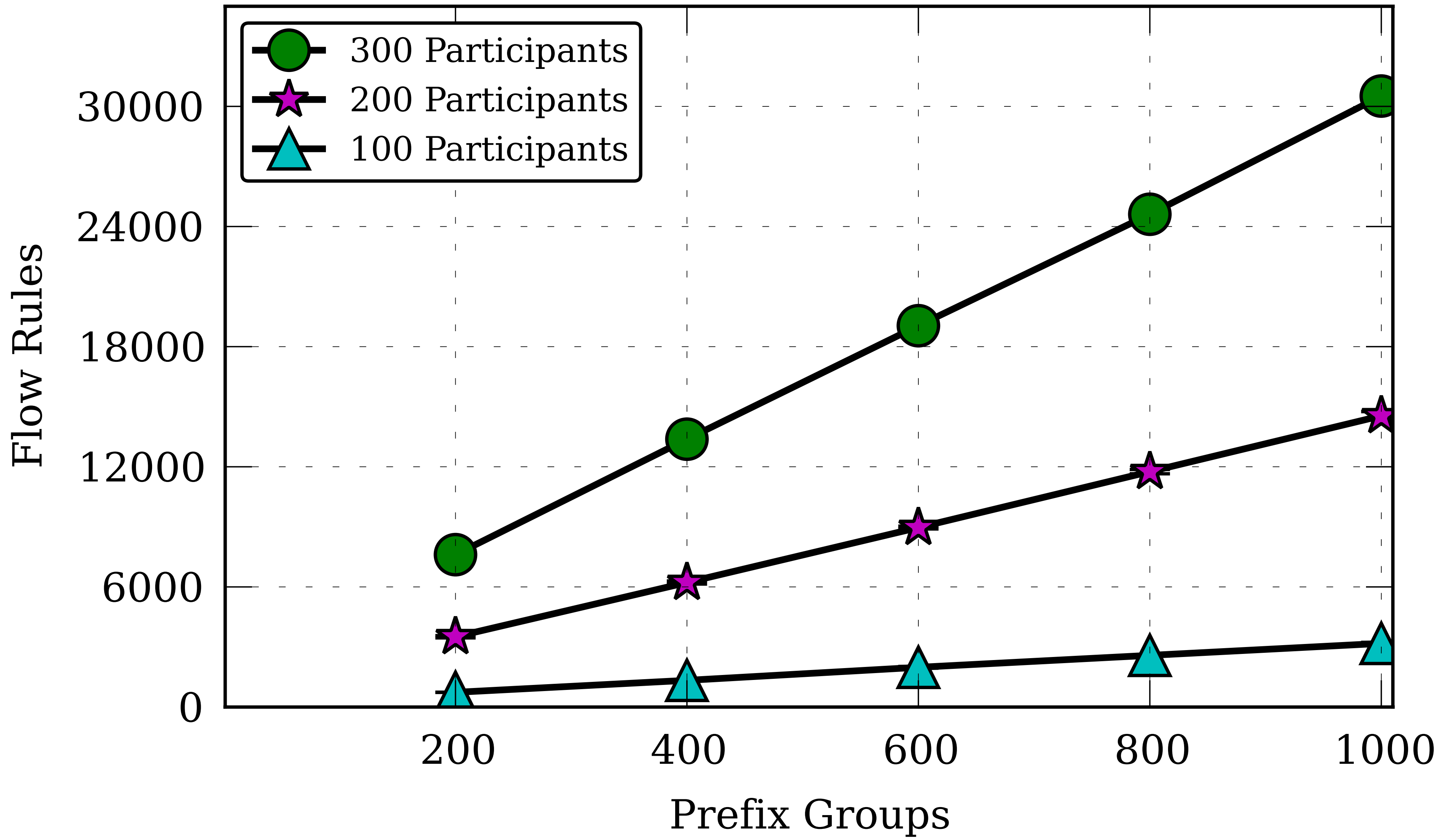
SDX FIB matches on the tag



SDX uses BGP NH as a provisioning interface and MAC addresses as tag in the data-plane



SDX accommodates policies
for 100+ participants, with less than 30k rules



data-plane

space

control-plane

time

leverage
policy structure

SDX policies share key characteristics

Static	disjointness
Dynamic	locality
	burstiness

SDX policies share key characteristics

Static **disjointness**

disjoint policies don't need to be composed

significant gain as composition is costly

Dynamic locality

burstiness

SDX policies share key characteristics

Static — disjointness

Dynamic — **locality**

policy updates usually impact few prefixes

75% of the updates affect no more than 3 prefixes

burstiness

SDX policies share key characteristics

Static disjointness

Dynamic locality

burstiness

policy updates are separated by large periods of inactivity

In 75% of the case, updates are separated by 10s or more

These characteristics enable an efficient, 2-stage compilation algorithm

Stage 1	*Fast*, non-optimal algorithm upon updates can install more forwarding rules than required
Stage 2	*Slow*, but optimal algorithm in background regroup rules according to forwarding behavior

These characteristics enable an efficient, 2-stage compilation algorithm

Fast, non-optimal algorithm upon updates

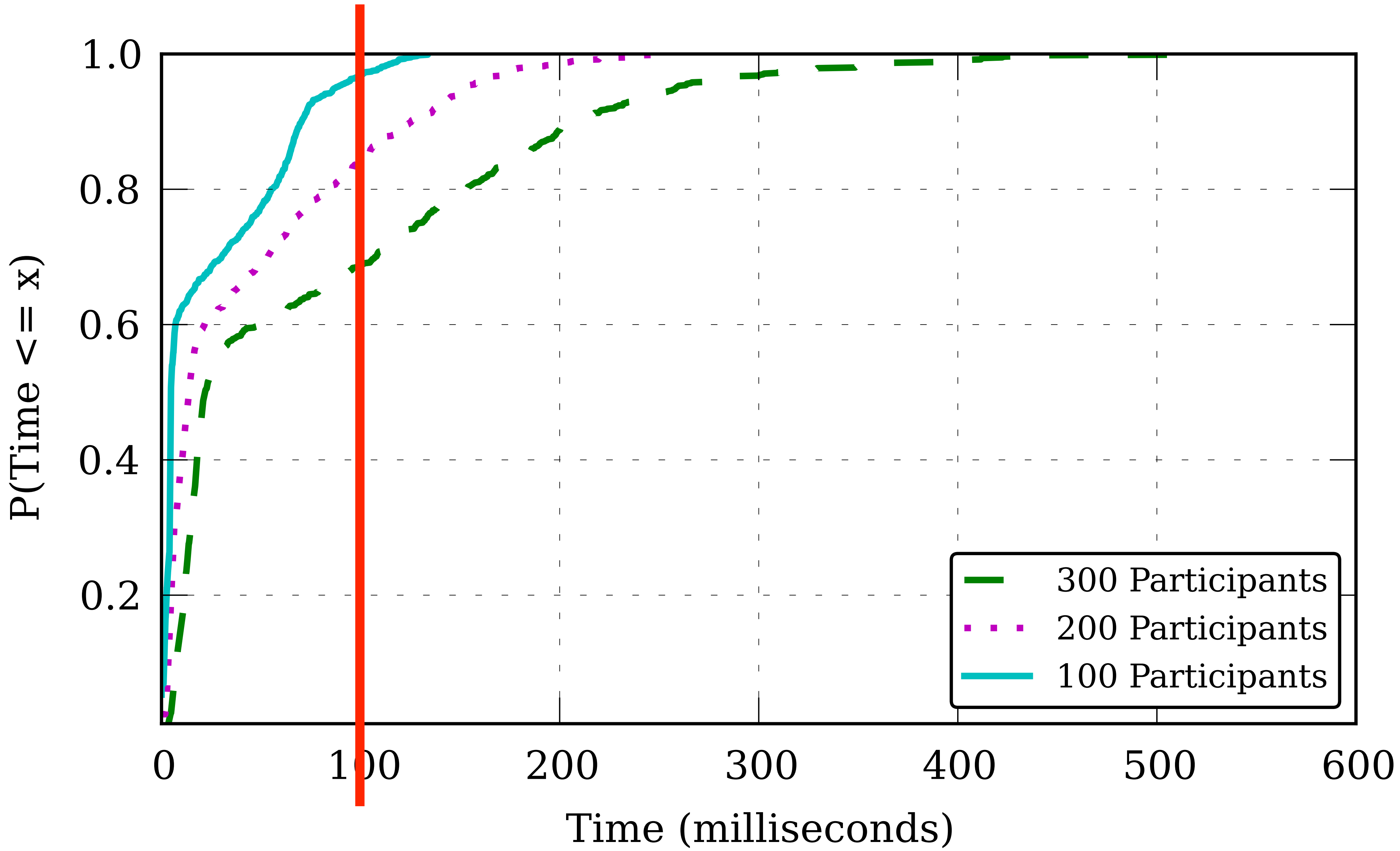
can install more forwarding rules than required

Slow, but optimal algorithm in background

regroup rules according to forwarding behavior

Time vs Space trade-off

In most cases, the SDX takes <100 ms
to recompute the entire policy



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inter domain bonanza

SDX enables a wide range of novel applications

security	Prevent/block policy violation Prevent participants communication Upstream blocking of DoS attacks
forwarding optimization	Middlebox traffic steering Traffic offloading Inbound Traffic Engineering Fast convergence
peering	Application-specific peering
remote-control	Influence BGP path selection Wide-area load balancing

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forwarding optimization	Middlebox traffic steering Traffic offloading **Inbound Traffic Engineering** Fast convergence
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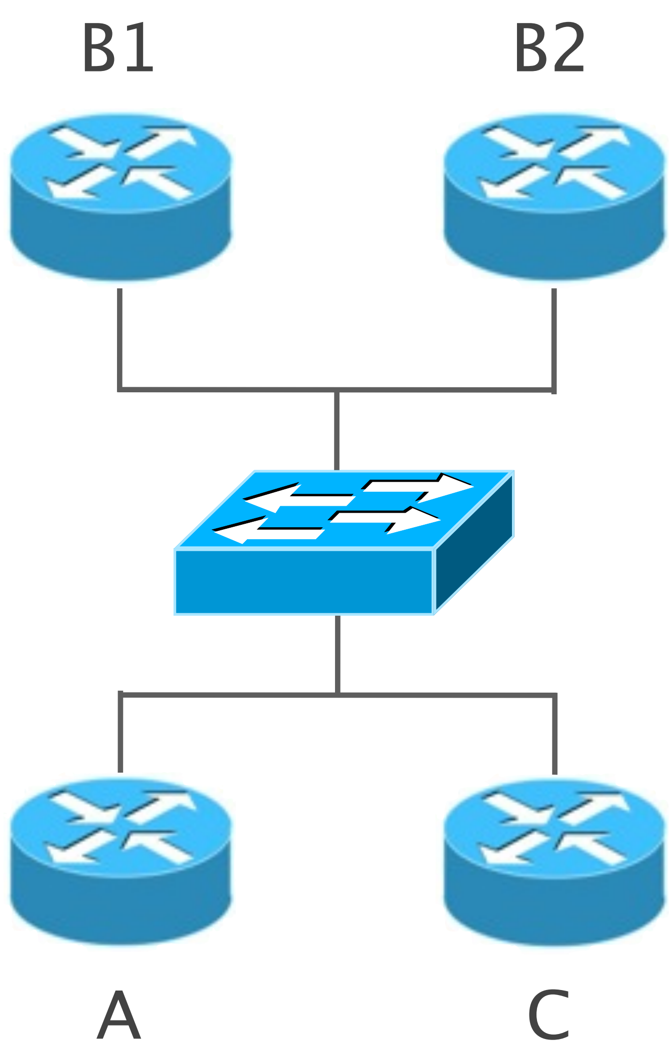
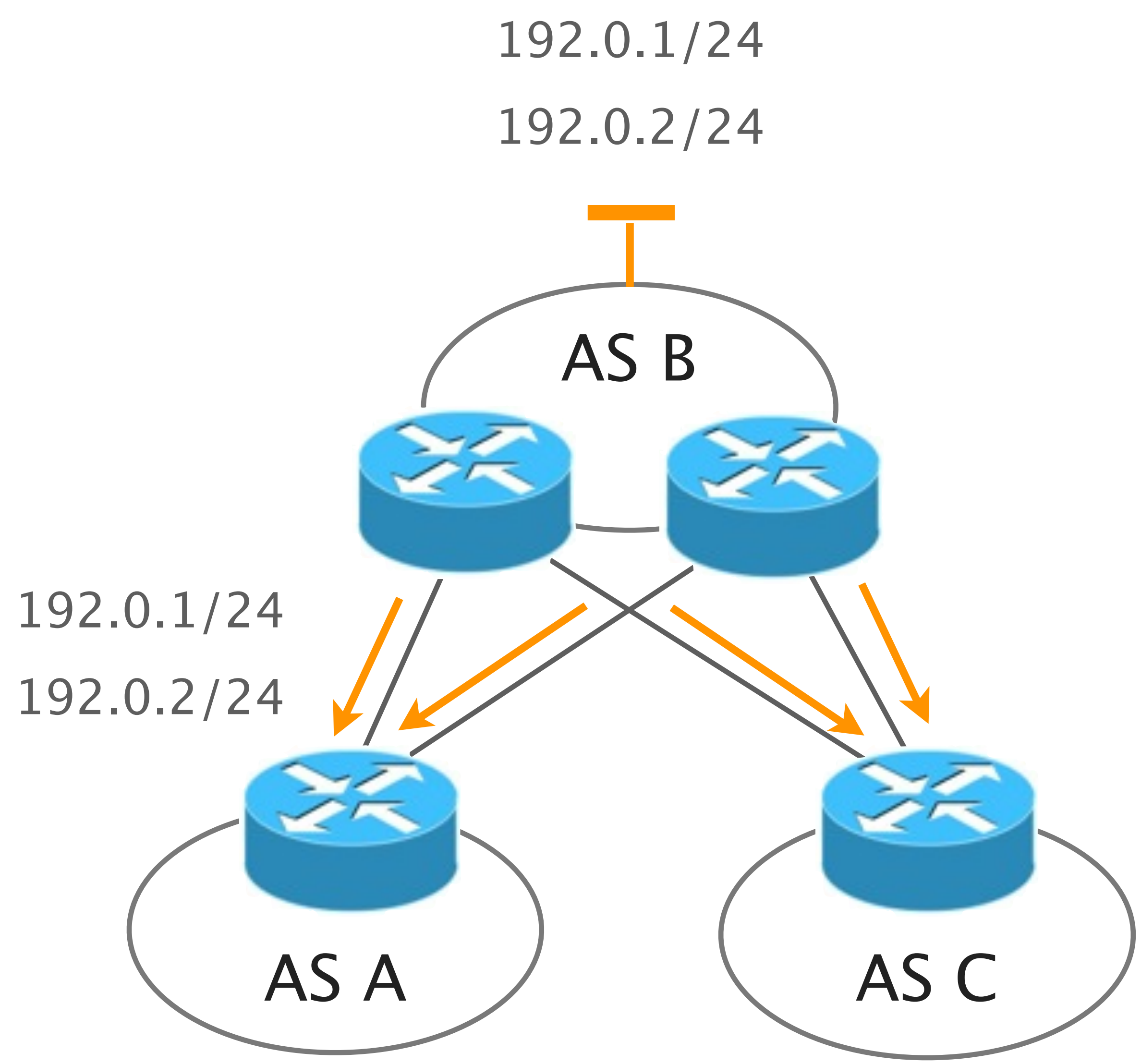
SDX can improve inbound traffic engineering

Given an IXP Physical Topology and a BGP topology,



IXP Fabric

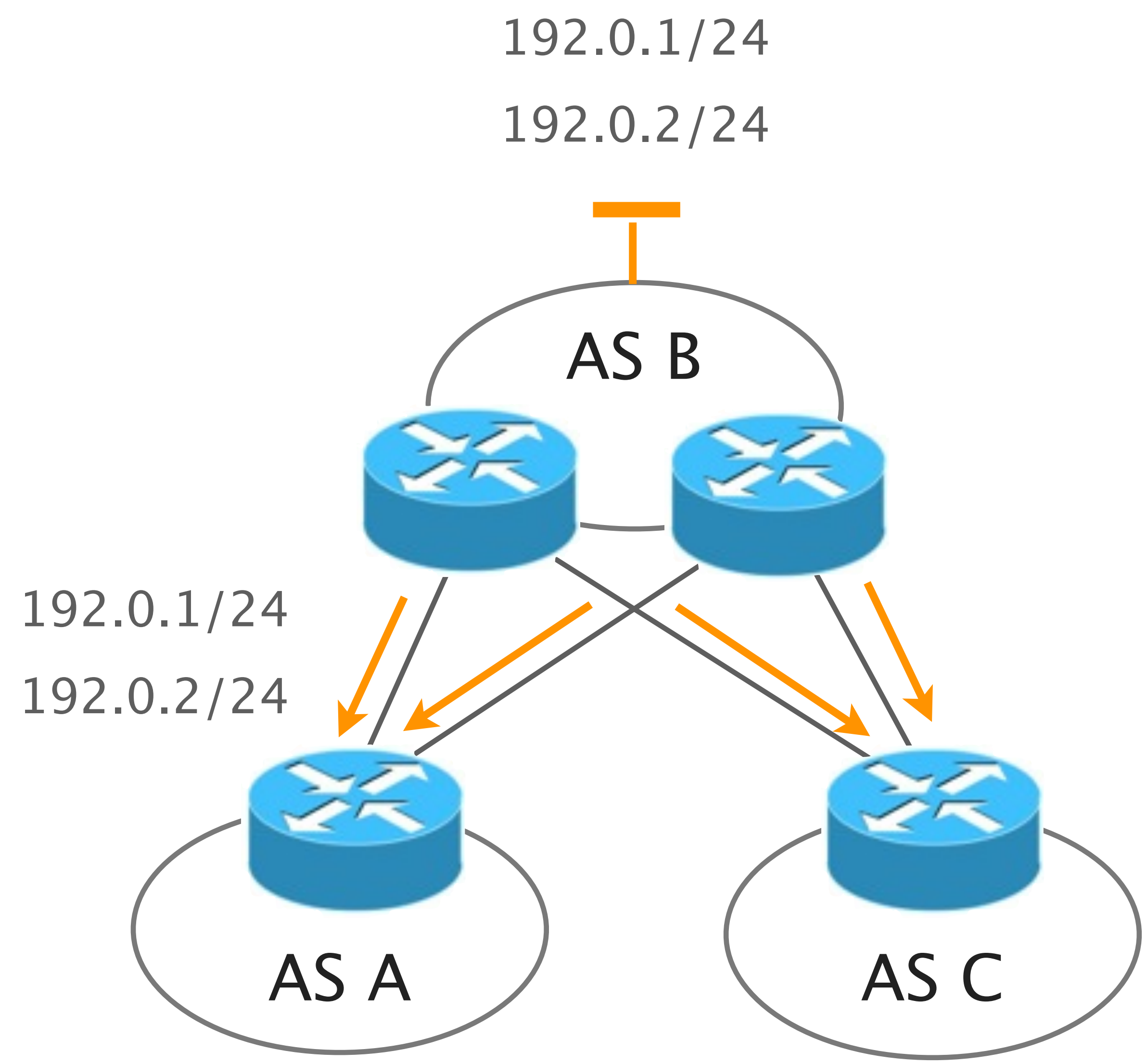


BGP topology

Given an IXP Physical Topology and a BGP topology, Implement B's inbound policies

B's inbound policies

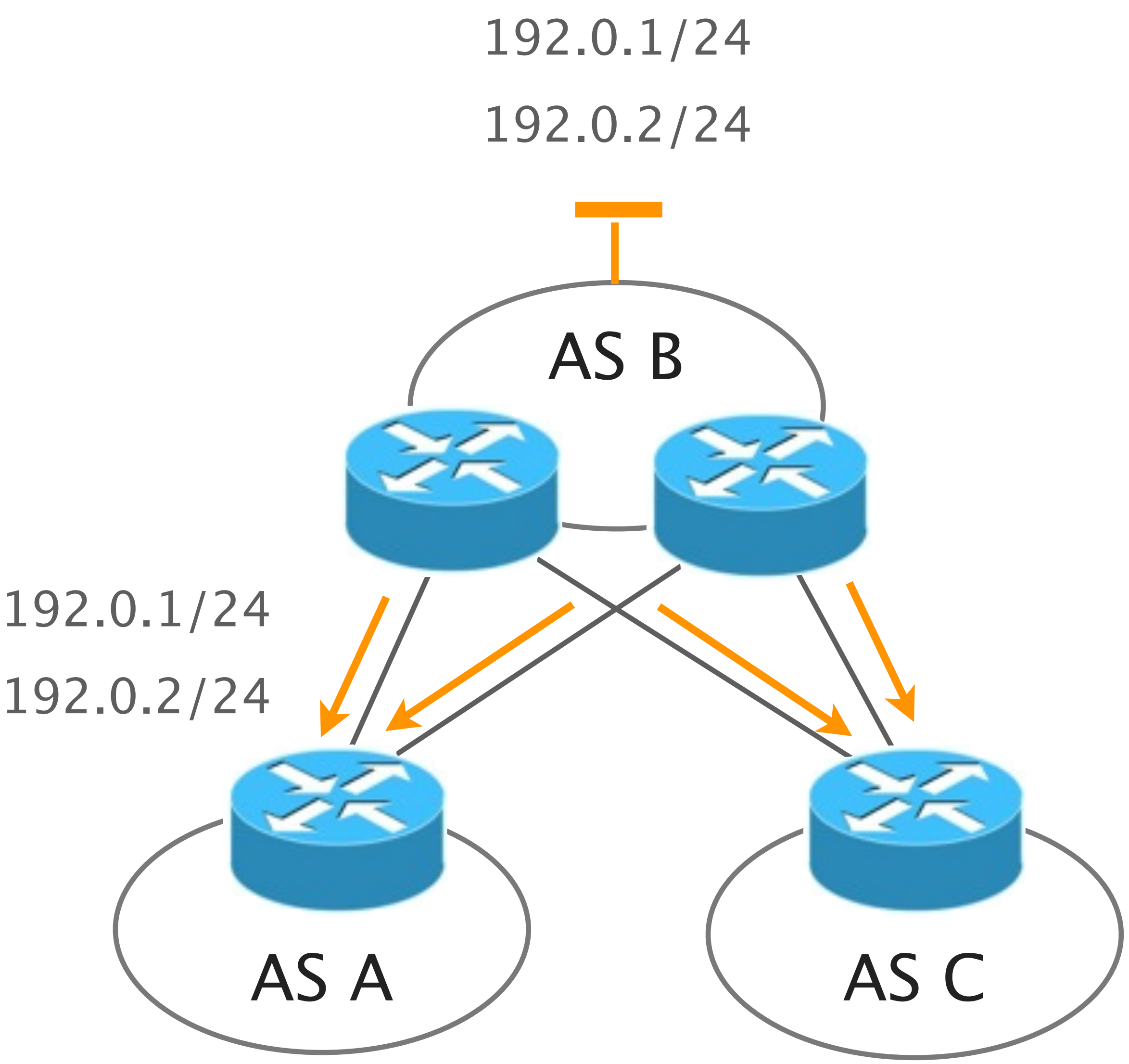
to	from	receive on
192.0.1/24	A	left
192.0.2/24	C	right
192.0.2/24	ATT_IP	right
192.0.1/24	*	right
192.0.2/24	*	left



How do you that with BGP?

B's inbound policies

to	from	receive on
192.0.1/24	A	left
192.0.2/24	C	right
192.0.2/24	ATT_IP	right
192.0.1/24	*	right
192.0.2/24	*	left



It is hard.

BGP provides few knobs to influence remote decisions

Implementing such a policy is configuration-intensive

using AS-Path prepend, MED, community tagging, etc.

It is even impossible for some requirements

BGP policies **cannot** influence remote decisions based on source addresses

to	**from**	receive on
192.0.2.0/24	**ATT_IP**	right

In any case, the outcome is unpredictable

There is no guarantee that remote parties will comply

one can only “influence” remote decisions

Networks engineers have no choice but to “try and see”

which makes it impossible to adapt to traffic pattern

With SDX, implement B's inbound policy is easy

SDX policies give any participant direct control on its forwarding paths

to	from	fwd
192.0.1/24	A	left
192.0.2/24	B	right
192.0.2/24	ATT_IP	right
192.0.1/24	*	right
192.0.2/24	*	left

B's SDX Policy

```
match(dstip=192.0.1/24, srcmac=A), fwd(L)
match(dstip=192.0.2/24, srcmac=B), fwd(R)
match(dstip=192.0.2/24, srcip=ATT), fwd(R)
match(dstip=192.0.1/24), fwd(R)
match(dstip=192.0.2/24), fwd(L)
```

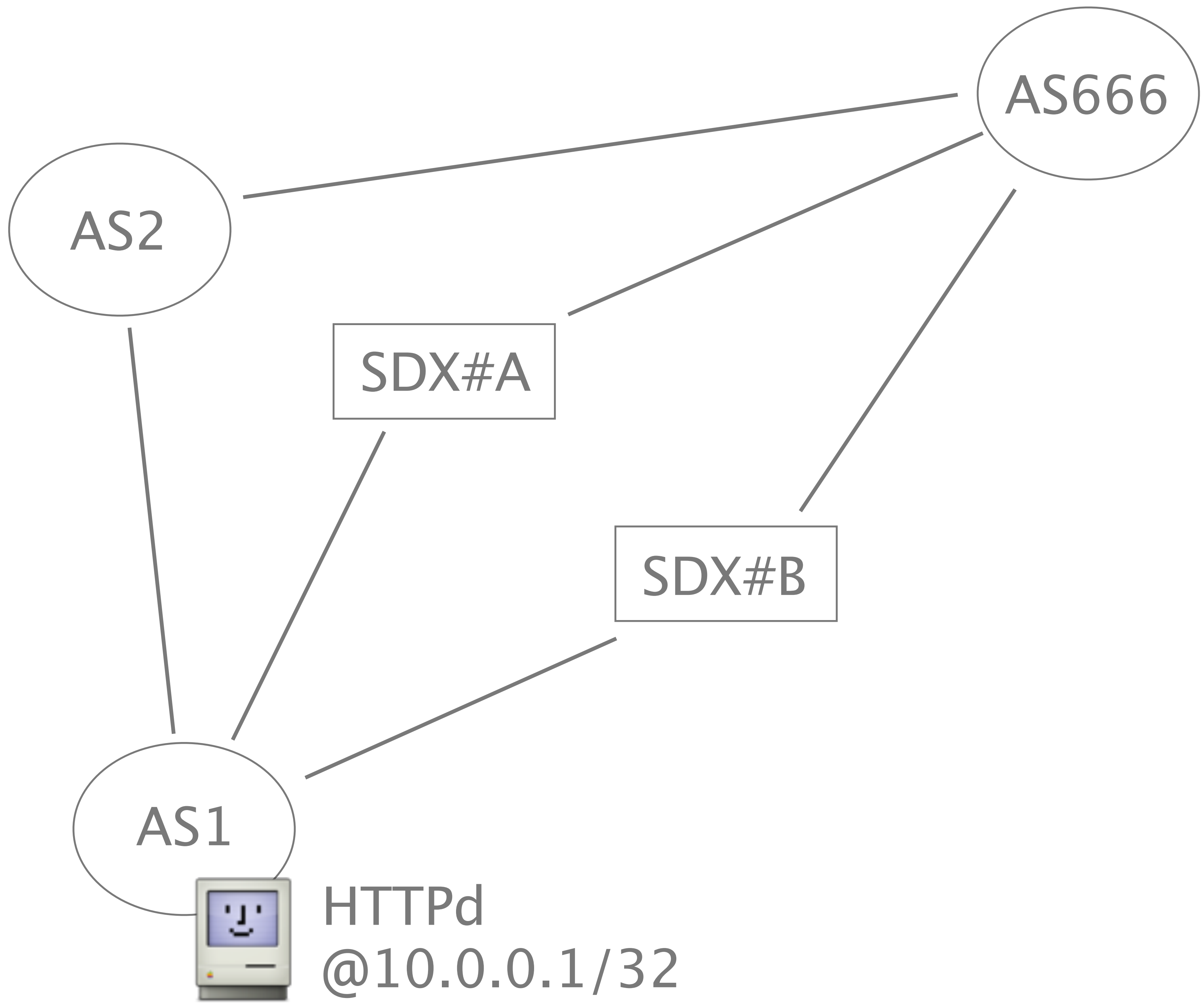
SDX enables a wide range of novel applications

security	Prevent/block policy violation
	Prevent participants communication
	Upstream blocking of DoS attacks
forwarding optimization	Middlebox traffic steering
	Traffic offloading
	Inbound Traffic Engineering
	Fast convergence
peering	Application-specific peering
remote-control	Influence BGP path selection
	Wide-area load balancing

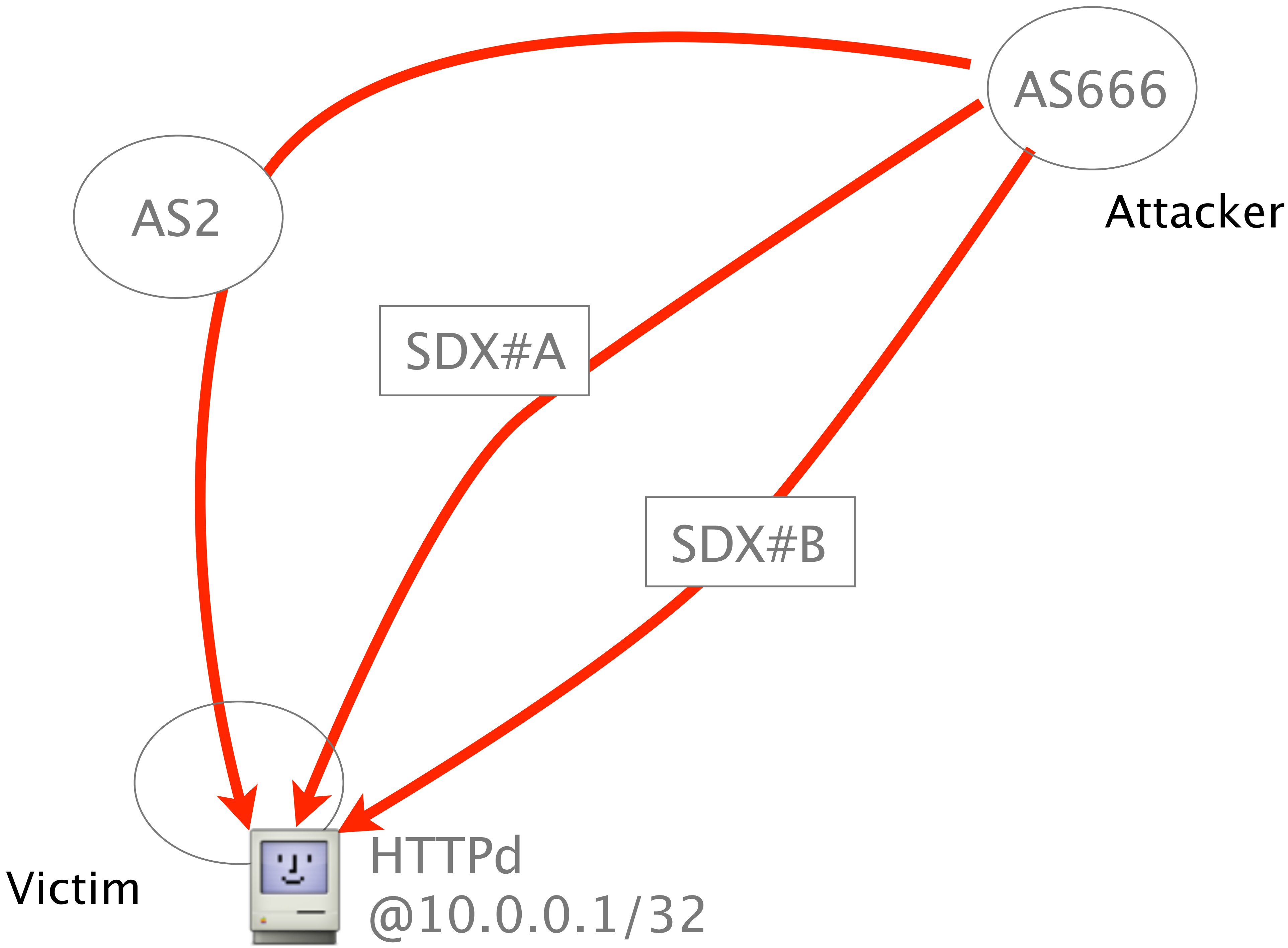
SDX enables a wide range of novel applications

security	Prevent/block policy violation Prevent participants communication **Upstream blocking of DoS attacks**
forwarding optimization	Middlebox traffic steering Traffic offloading Inbound Traffic Engineering Fast convergence
peering	Application-specific peering
remote-control	Influence BGP path selection Wide-area load balancing

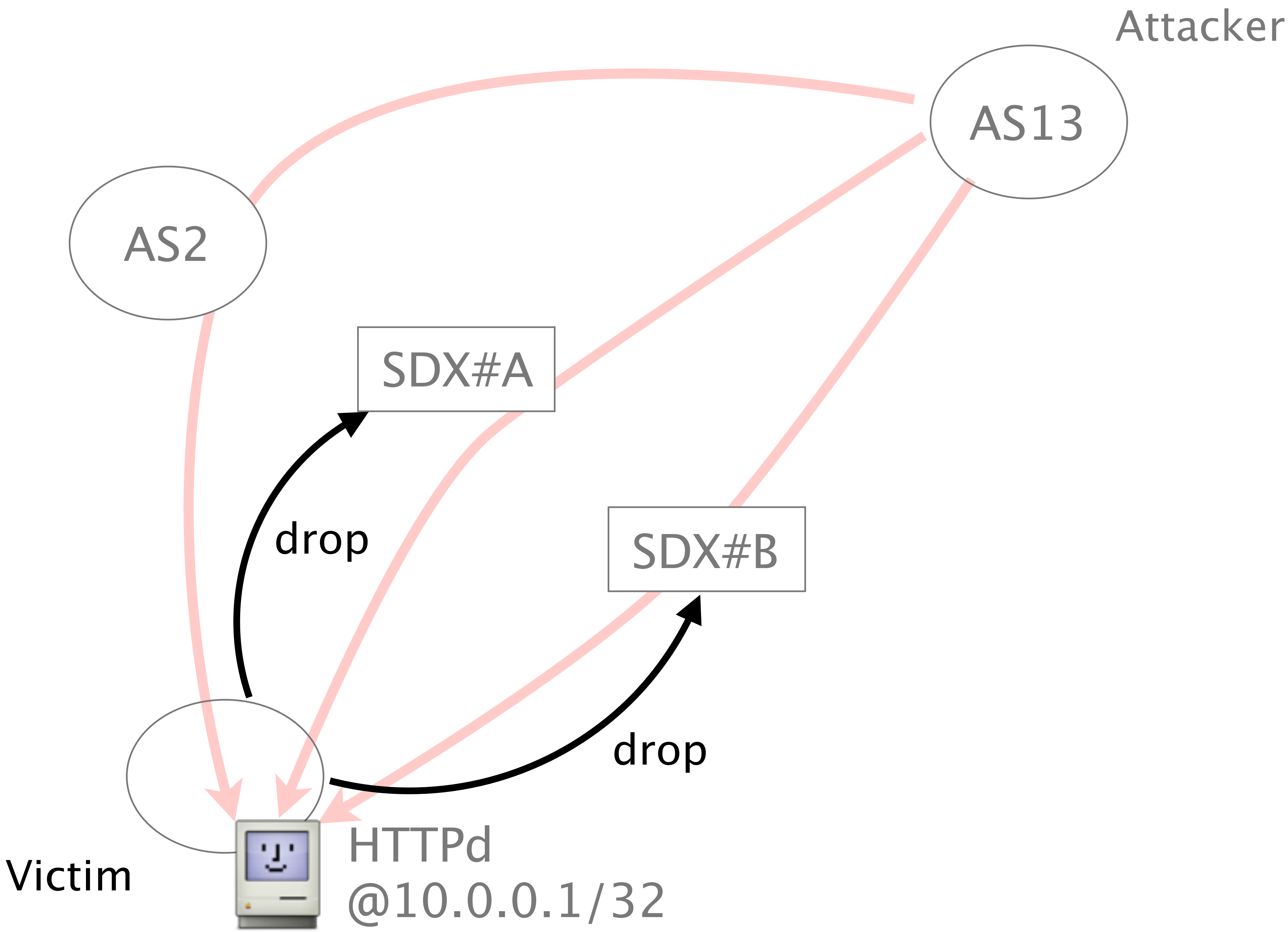
SDX can help mitigating DDoS attacks, closer to the source



AS1 is victim of a DDoS attack targeting its web server



AS1 remotely installs drop policies in all SDXes



AS1 remotely installs drop policies in all SDXes

AS1 policy

```
match(srcip=*, dstip=10.0.01/32, dstport=80) >> drop()
```

SDX policies are targeted, hence other services stay reachable

AS1 policy

```
match(srcip=*, dstip=10.0.01/32, dstport=80) >> drop()
```

single IP — *single* service

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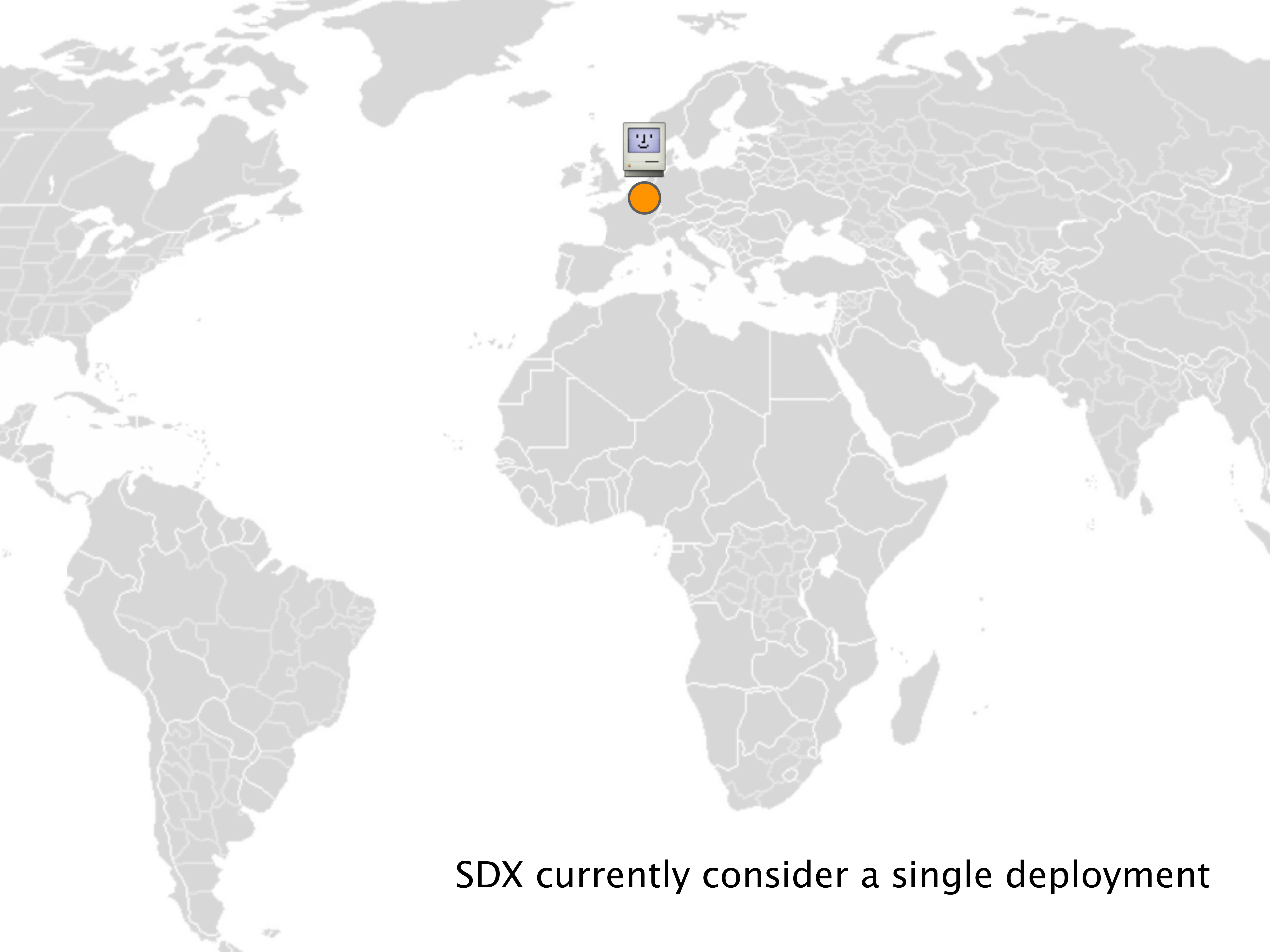
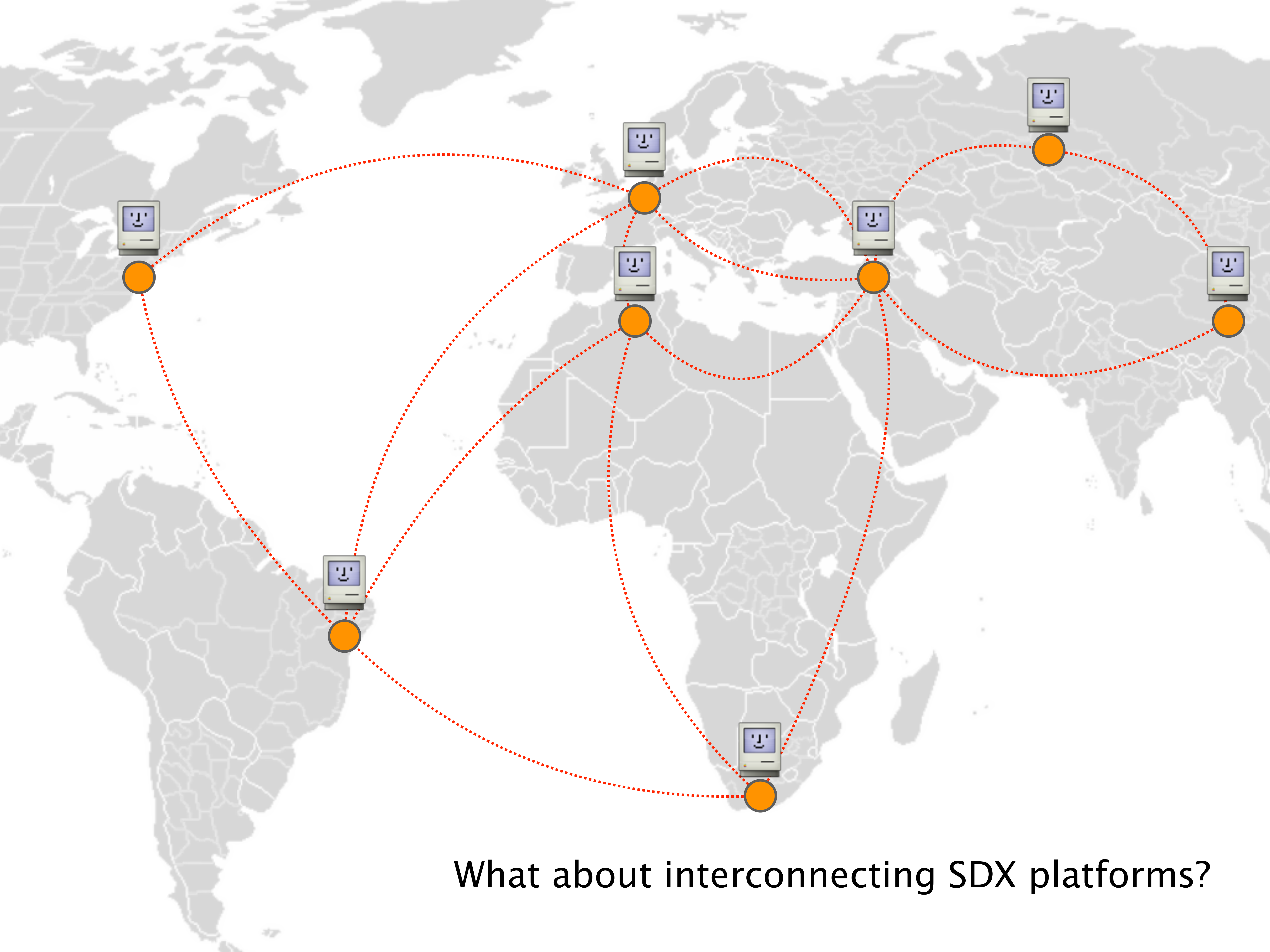
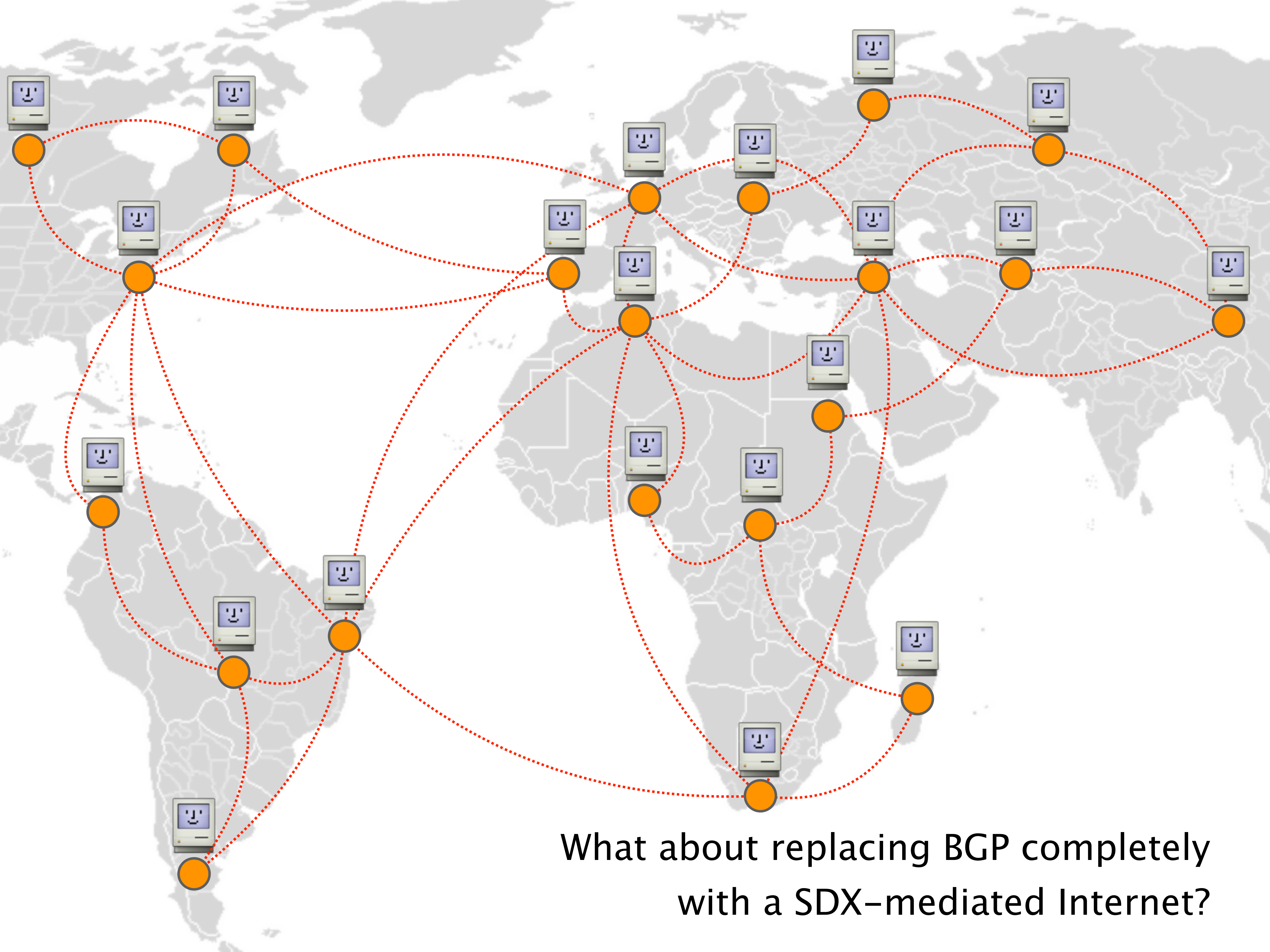
What's next?



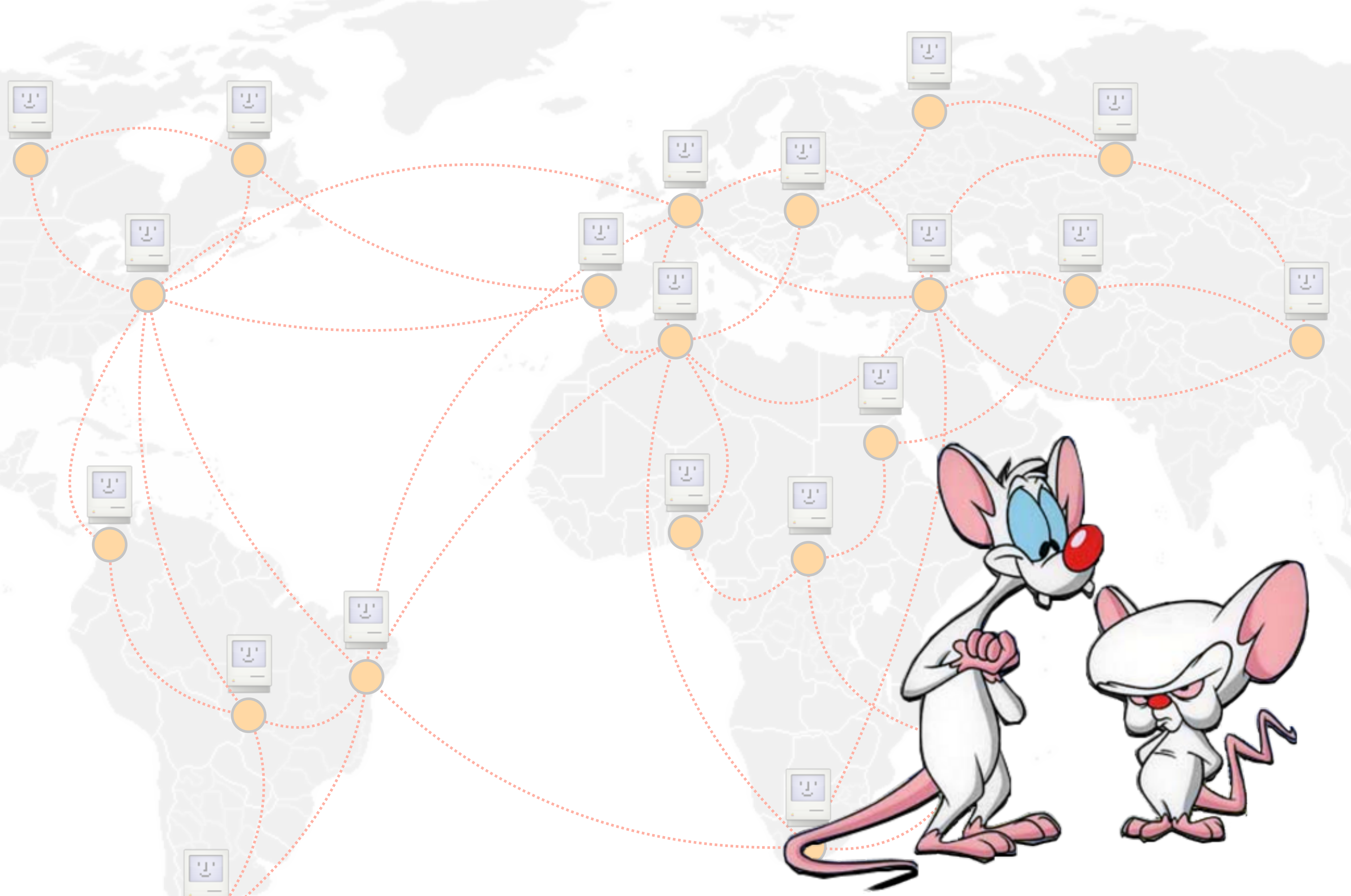
SDX currently consider a single deployment



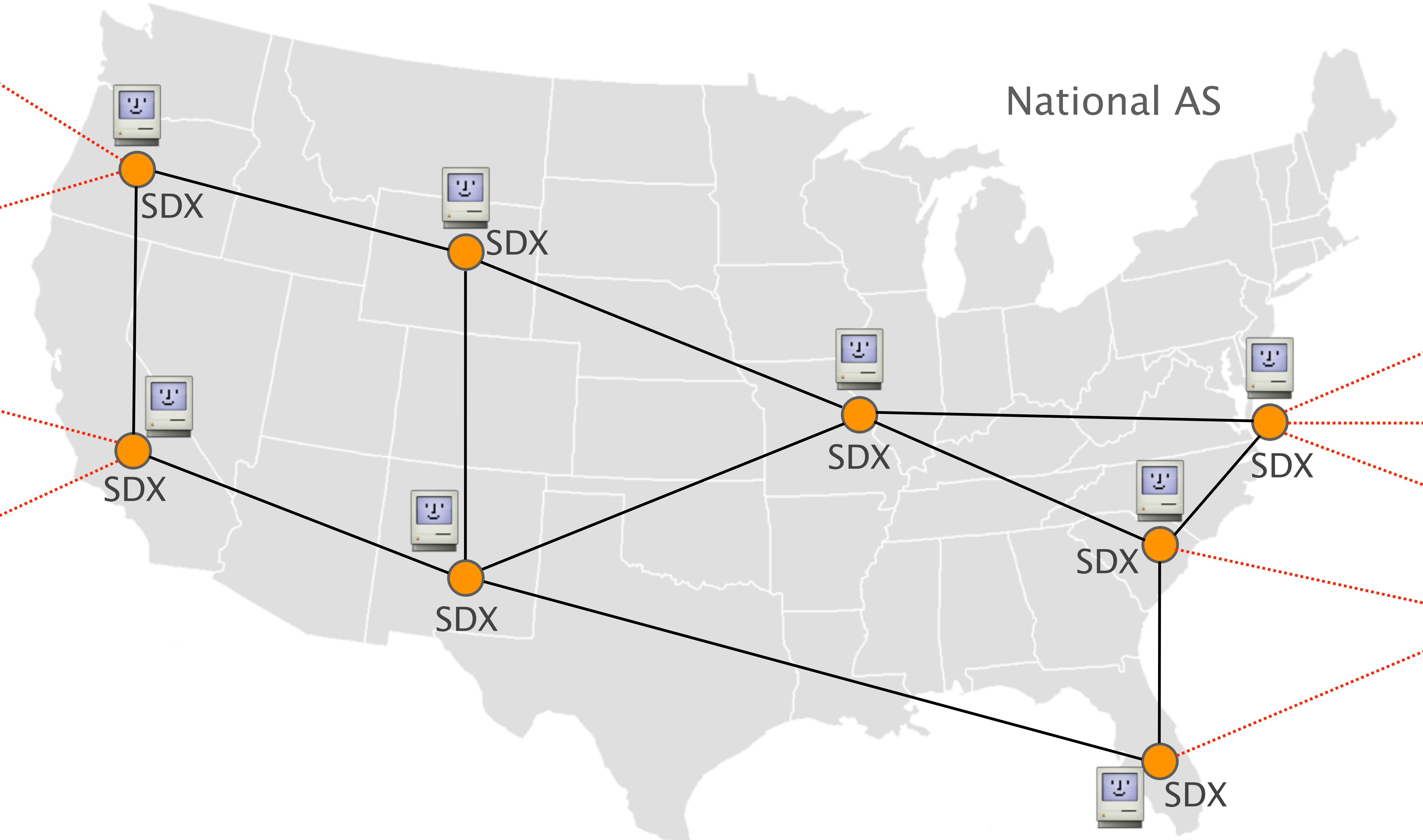
What about interconnecting SDX platforms?



What about replacing BGP completely
with a SDX-mediated Internet?



“Let’s take over the world”



Not only for eBGP. Multi-site SDX can be used within an AS to implement iBGP policies

SDX is a promising first step towards fixing Internet routing

Enable declarative, fine-grained inter-domain policies

many of which are not possible Today

Scale to hundreds of participants

both in the control- and in the data-plane

Running code (*) and deployment under way

important potential for impact

(*) https://github.com/sdn-ixp/sdx-platform

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Internet ❤ SDN

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