ONOS Developer Workshop

for ONOS 1.2.0 (Cardinal)

Open Networking Summit
June 15, 2015

Developer Workshop Sessions

- ONOS Fundamentals
  - architecture, checking out, building & running ONOS
- ONOS Distributed Core
  - OSGi, anatomy of a core subsystem, distributed stores & primitives
- ONOS App Development
  - background, Maven archetypes, app deployment on ONOS cluster
- ONOS Interfaces
  - component config service, flow objective service, intent service
  - CLI, REST and GUI overview
- Wrap-up

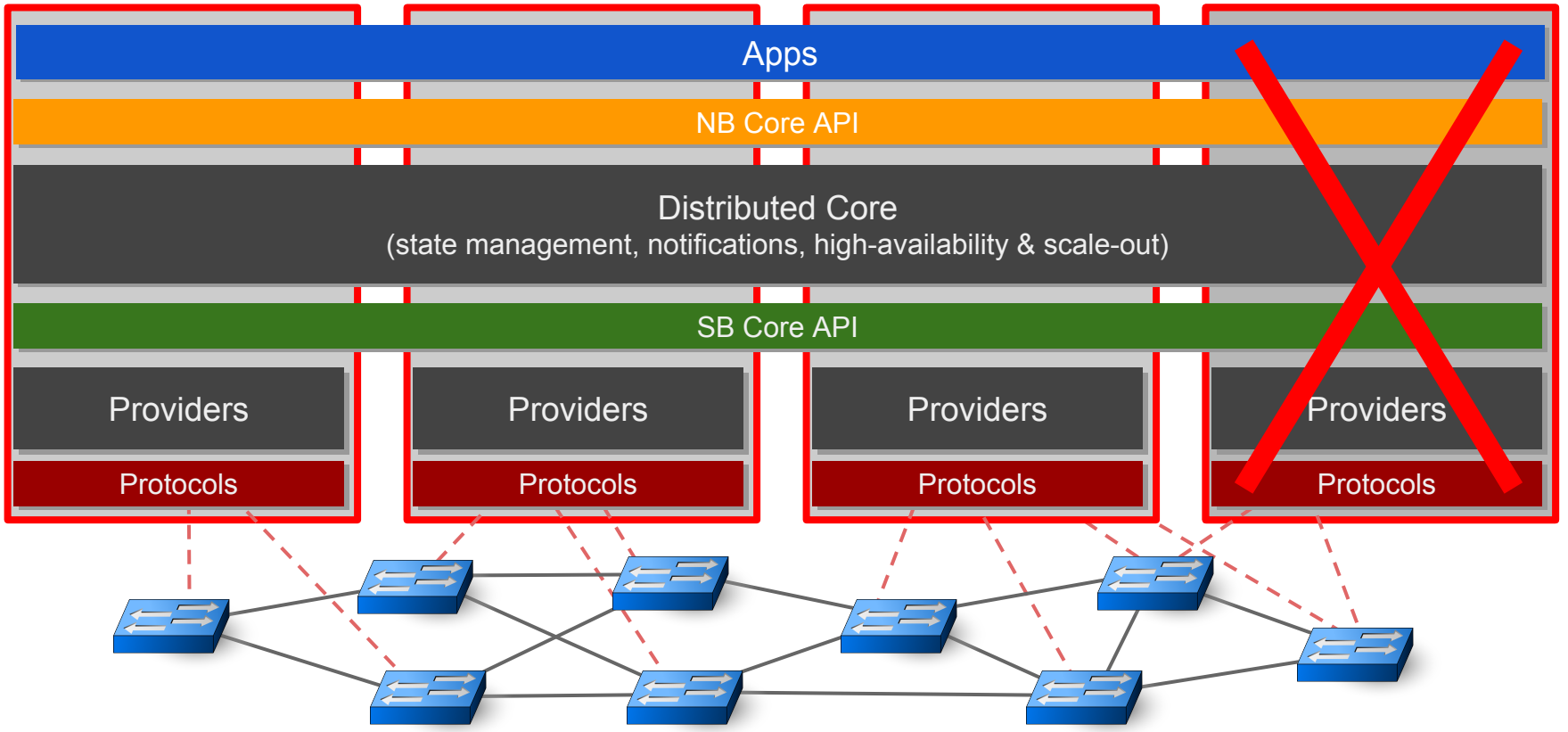
ONOS Fundamentals 8:30-10:00

- ONOS Overview (~30)
  - tenets, architecture, tiers, subsystems
  - general subsystem structure
- Getting started with ONOS (~30)
  - check-out code, environment customization and build
  - describe Maven, hierarchical POM structure
  - run ONOS locally on developer machine
  - CLI & GUI demo with a simple mininet topology (torus,8,8,2)
- Code organization (~30)
  - importing ONOS source into IDE (demo with IntelliJ)
  - core (api, net, stores), web (gui, rest), providers (openflow, netconf)

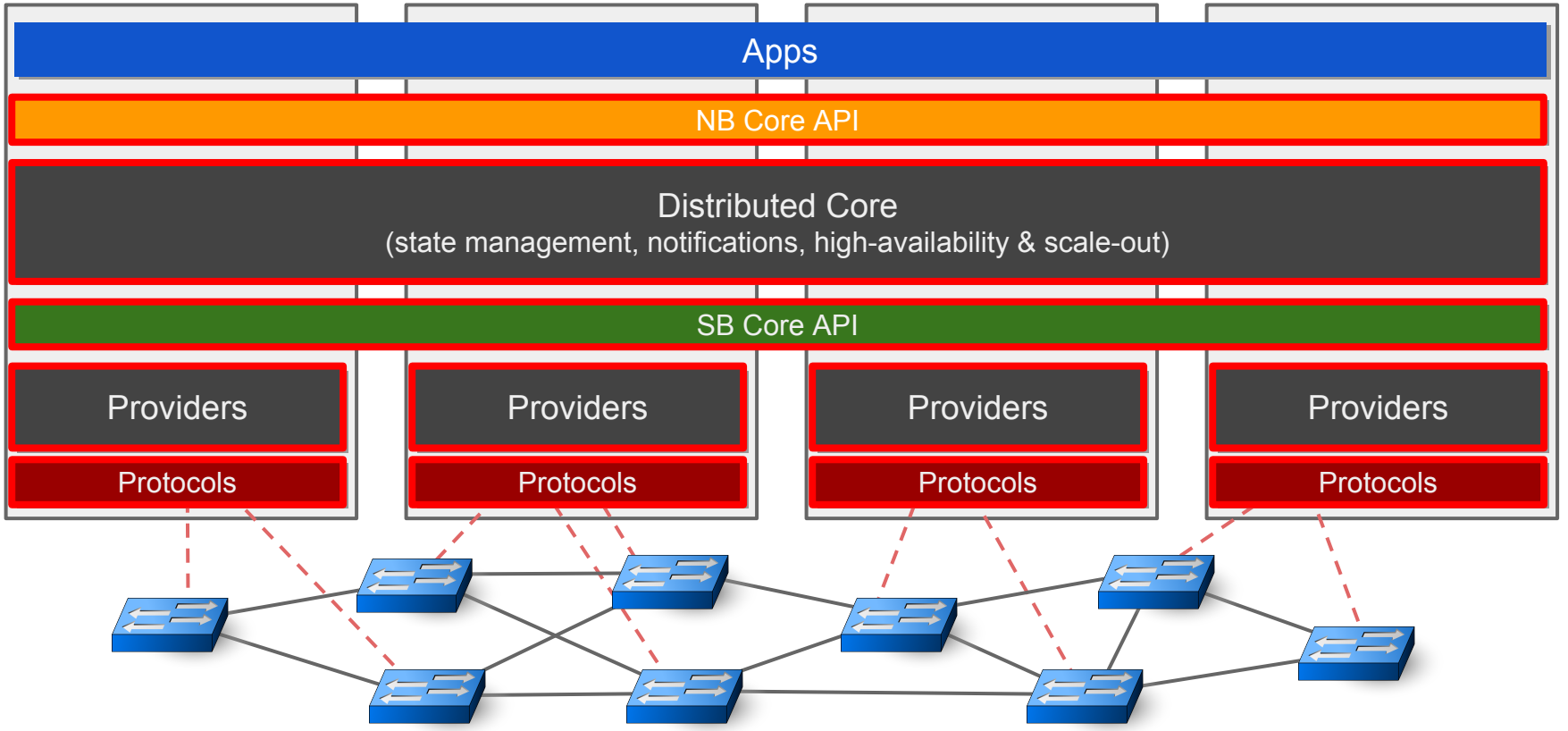
Architectural Tenets

- High-availability, scalability and performance
  - required to sustain demands of service provider & enterprise networks
- Strong abstractions and simplicity
  - required for development of apps and solutions
- Protocol and device behaviour independence
  - avoid contouring and deformation due to protocol specifics
- Separation of concerns and modularity
  - allow tailoring and customization without speciating the code-base

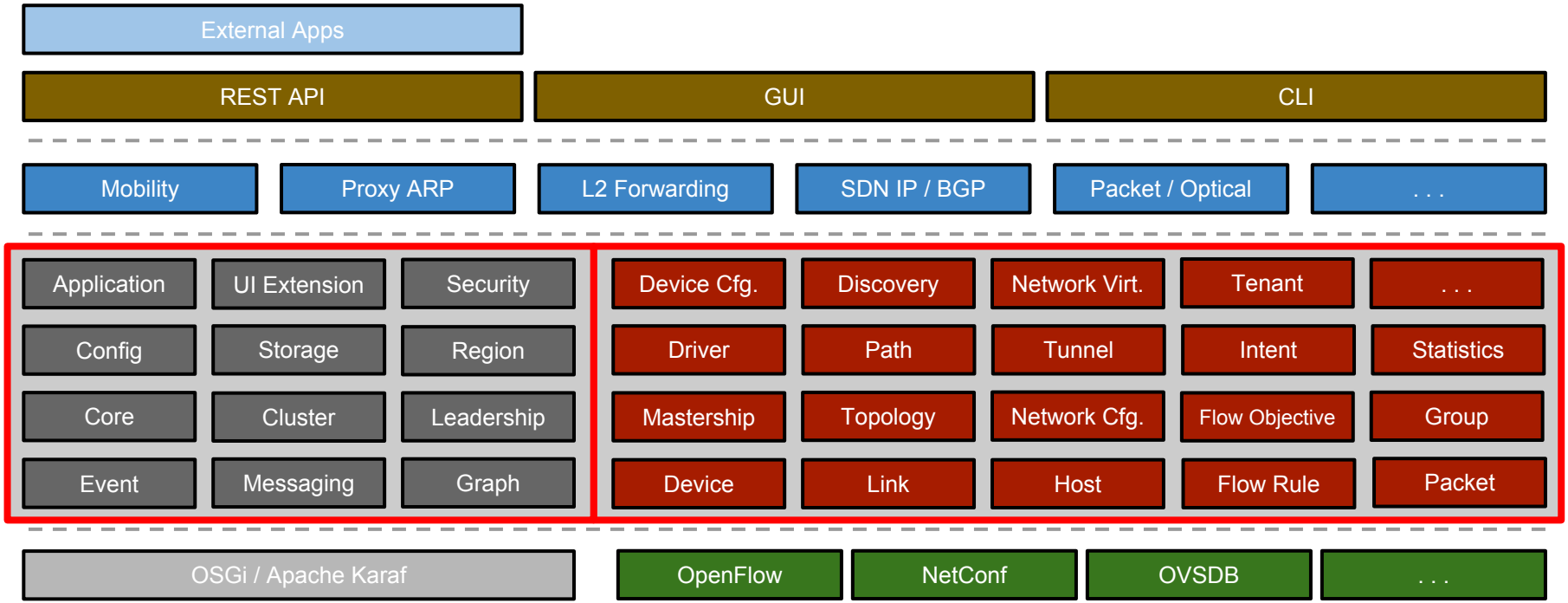
ONOS Distributed Architecture



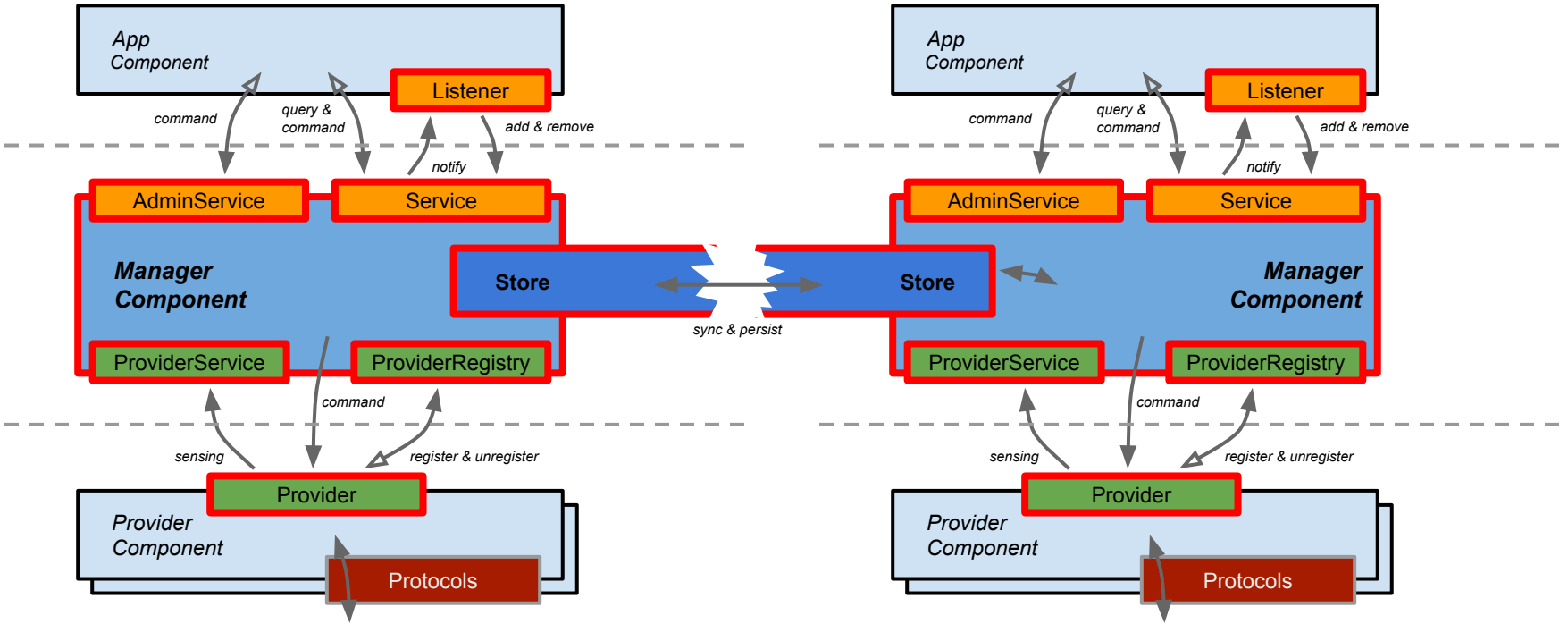
ONOS Distributed Architecture



ONOS Core Subsystems



ONOS Core Subsystem Structure



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Development Pre-Requisites

- Bash (or similar shell)
- Oracle Java Development Kit 8+
  `http://www.oracle.com/technetwork/java/javase/downloads`
- Apache Maven 3.3.x+
  `https://maven.apache.org/download.html`
- Apache Karaf 3.0.3+ (for local development)
  `http://karaf.apache.org/index/community/download.html`
- IDE of your choice (IntelliJ, Eclipse, …)

Getting started with ONOS

- Check-out ONOS code via git
- Tailor bash environment for ONOS development
- Build ONOS via Maven
- Run ONOS locally on developer machine
- Activate pre-installed reactive forwarding application
- Test ONOS via a mininet simulated network
- Explore ONOS GUI & CLI

Check-out ONOS code

- Open a new terminal shell and clone ONOS repo:

```
$ git clone https://gerrit.onosproject.org/onos
```

Tailor shell for ONOS development

- Edit the shell profile:

```
$ vi ~/.bash_profile
```

- Add the following lines at the top:

```
export ONOS_ROOT=~/onos
source $ONOS_ROOT/tools/dev/bash_profile
```

- Source the modified shell profile

```
$ source ~/.bash_profile
```

Build ONOS via Maven

- Change directory to your ONOS root and invoke Maven

```
$ cd ~/onos
$ mvn clean install
```

- Alternatively, use `onos-build` command or `ob` alias from anywhere

```
$ onos-build
```

Run ONOS locally

- Use `onos-karaf` command or `ok` alias to setup and run ONOS via Apache Karaf

```
$ onos-karaf clean
```

- Use ONOS shell commands to explore

```
onos> summary
onos> nodes
onos> apps -s
```

Activate reactive forwarding app

- Use app command to activate a pre-installed app:

```
onos> app activate org.onosproject.fwd
```

Test ONOS via mininet

- Start ONOS gui via `onos-gui` command or `gui` alias:

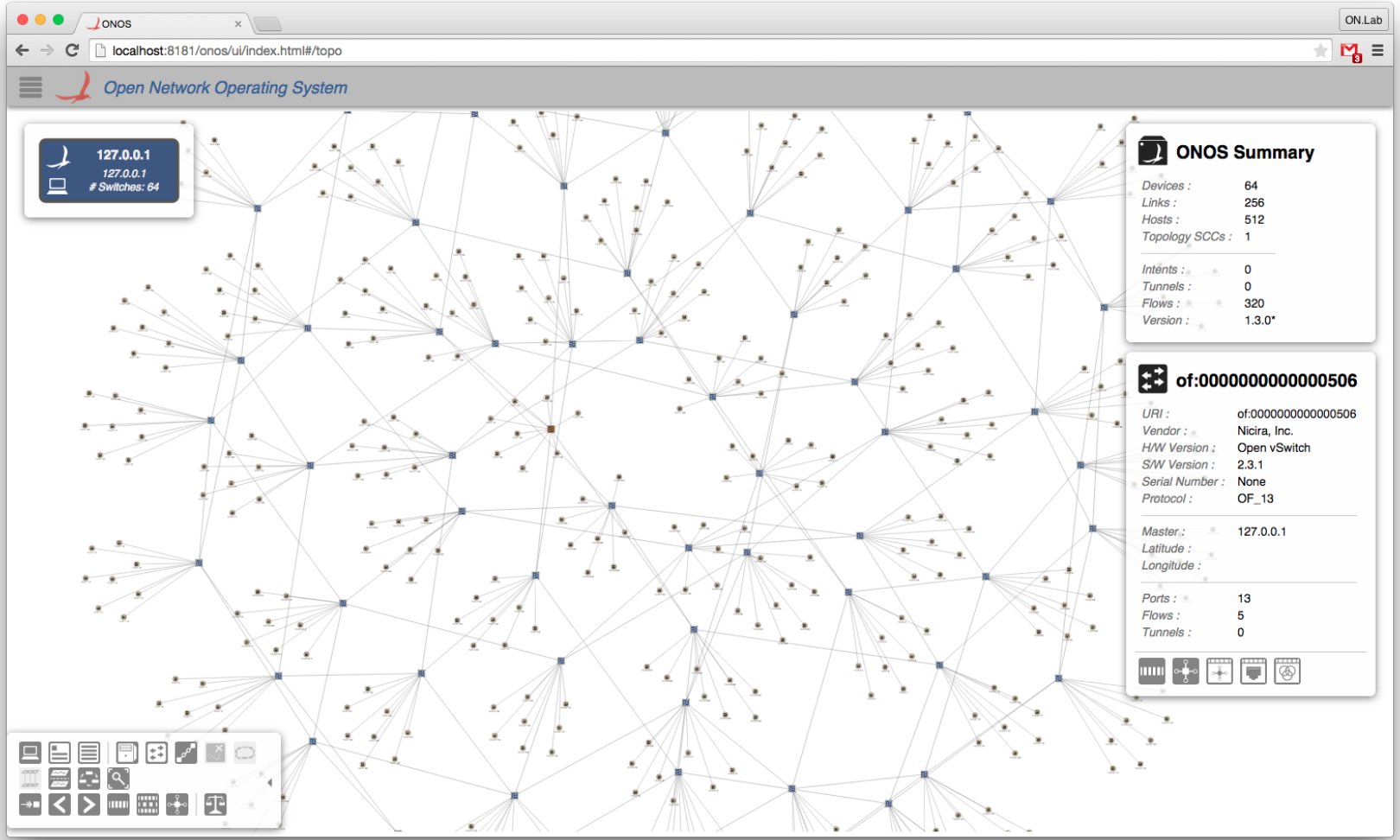
```
$ onos-gui
```

- Start 8x8 torus topology with 2 hosts per switch:

```
$ sudo mn --topo torus,8,8,2 \
    --controller remote,ip=192.168.56.1
```

- Ping all hosts in mininet

```
mininet> pingall
```


ONOS
ON.Lab
localhost:8181/onos/ui/index.html#/topo
Open Network Operating System
127.0.0.1
127.0.0.1
Switches: 64
ONOS Summary
Devices : 64
Links : 256
Hosts : 512
Topology SCCs : 1
Intents : 0
Tunnels : 0
Flows : 320
Version : 1.3.0*
of:0000000000000506
URI : of:0000000000000506
Vendor : Nicira, Inc.
H/W Version : Open vSwitch
S/W Version : 2.3.1
Serial Number : None
Protocol : OF_13
Master : 127.0.0.1
Latitude :
Longitude :
Ports : 13
Flows : 5
Tunnels : 0

Explore ONOS GUI & CLI

- Enable host display via tool icon or `H` key
- Explore Devices, Links and Hosts views, etc.

- Explore ONOS CLI via the following shell commands:

```
onos> summary
onos> devices
onos> links
onos> hosts
onos> flows
onos> onos:*
```

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Tour of ONOS code-base

- Import ONOS into IDE
- Tour of ONOS core (api, net, stores, etc.)
- Tour of other areas (apps, providers, web, etc.)

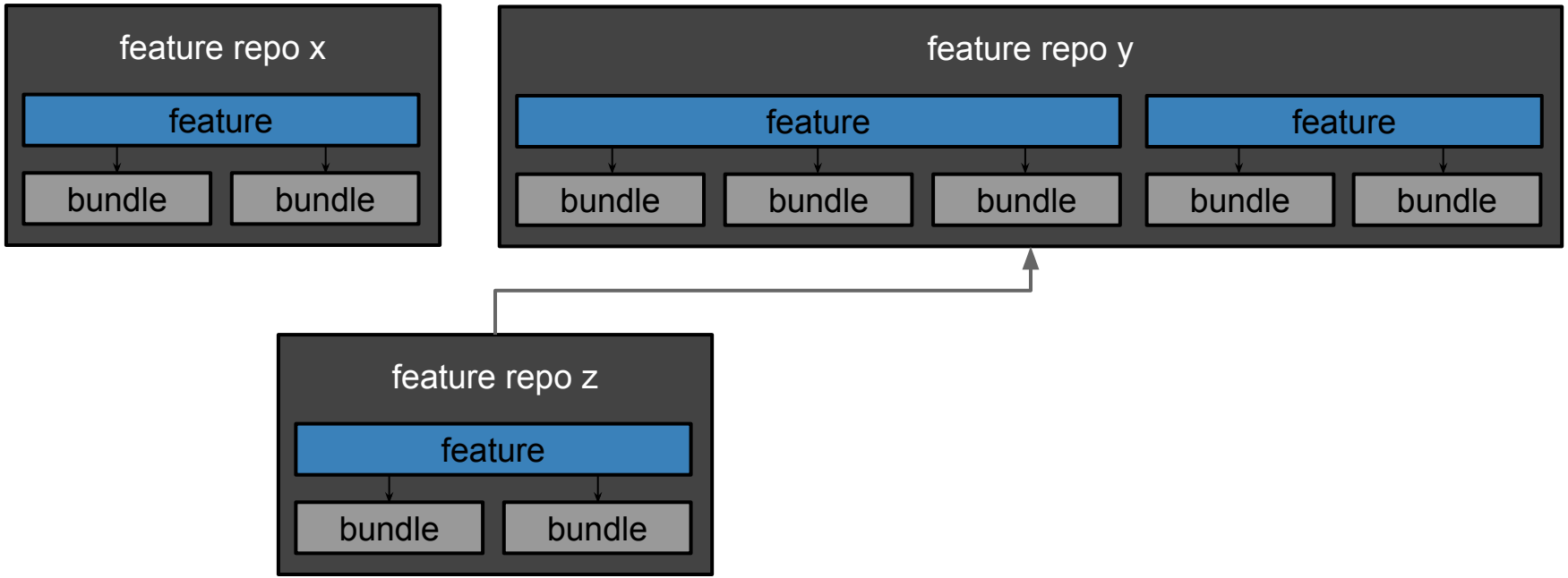
Break

xkcd.com

ONOS Distributed Core 10:30-12:00

- ONOS, OSGi & Apache Karaf (~15)
  - OSGi bundles, Karaf features & SCR components
  - use `bundle:*`, `feature:*`, `scr:*` commands & webconsole
- Anatomy of an ONOS Core Subsystem (~15)
  - use device subsystem as an example
- Distributed stores & primitives (~60)
  - physically distributed & logically centralized
  - deep dive on distributed topology stores (devices, links, hosts)
  - other types of state treatment for other types of state
  - primitives, e.g. eventually consistent/strongly consistent map, leadership, distributed set, distributed queue, atomic counter

OSGi Bundles & Karaf Features



OSGi Bundles & Karaf Features

- OSGi bundles are Java JAR files with an enhanced Manifest
  - bundles have name and version
  - bundles explicitly require/import other Java packages
  - bundles explicit provide/export Java packages for others
- Karaf features are means to install or uninstall a set of bundles as a group
  - features are defined via an XML artifact - a feature repository
  - features reference, but do not deliver the bundle JAR artifacts
- Karaf uses Maven repos as OSGi Bundle Repositories for retrieval of feature and bundle artifacts

Service Component Runtime

- Components are effectively stateful singletons whose life-cycle is controlled by the framework
  - components defined by `OSGI-INF/*.xml` files at run-time
  - ONOS uses `maven-scr-plugin` to convert Java annotations to `OSGI-INF/*.xml` files at compile-time
- Components can provide `@Services` to others
- Components can `@Reference` services from others
- `@Activate`, `@Modified` and `@Deactivate` methods serve as component life-cycle hooks

Bundle & Feature Shell Commands

- Bundle related commands

```
onos> bundle:*
```

- Feature related commands

```
onos> feature:*
```

- Service Component Runtime related commands

```
onos> scr:*
```

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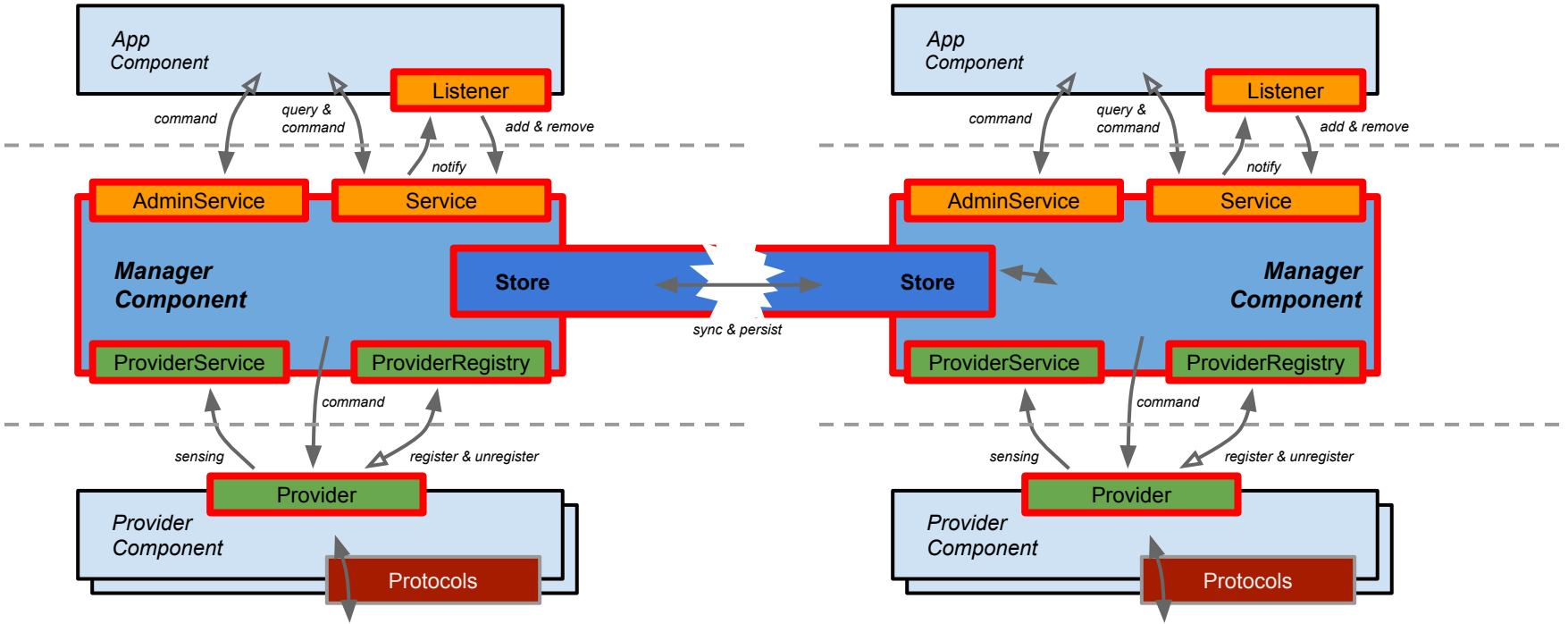
Anatomy of an ONOS subsystem



Device Subsystem - Northbound

- `DeviceManager` component exposes `DeviceService` to apps and other services
  - note the `@Component` and `@Service` annotations
- Apps can subscribe to asynchronous `DeviceEvent` notifications via `DeviceListener` mechanism
- `DeviceManager` also exposes `DeviceAdminService` to privileged apps for select administrative actions

Device Subsystem - Southbound

- `DeviceManager` offers `DeviceProviderRegistry` service
- `DeviceProvider` entities can register and acquire a reference to `DeviceProviderService`
- Core uses registered `DeviceProvider` for sending edicts and queries down to the environment in a protocol-agnostic manner
- Provider uses issued `DeviceProviderService` for sending device and port sensory data up to the core in a protocol-agnostic manner

Device Subsystem - East / West

- `DeviceManager` delegates to peer `DeviceStore` all cluster-related tasks
  - manager becomes `DeviceStoreDelegate` to the `DeviceStore`
- `DeviceStore` is responsible for indexing, persisting and synchronizing the global device and port state with all cluster peers
- `DeviceStore` delegates incoming `DeviceEvents` to its `DeviceStoreDelegate` for local actions and for local event dispatching

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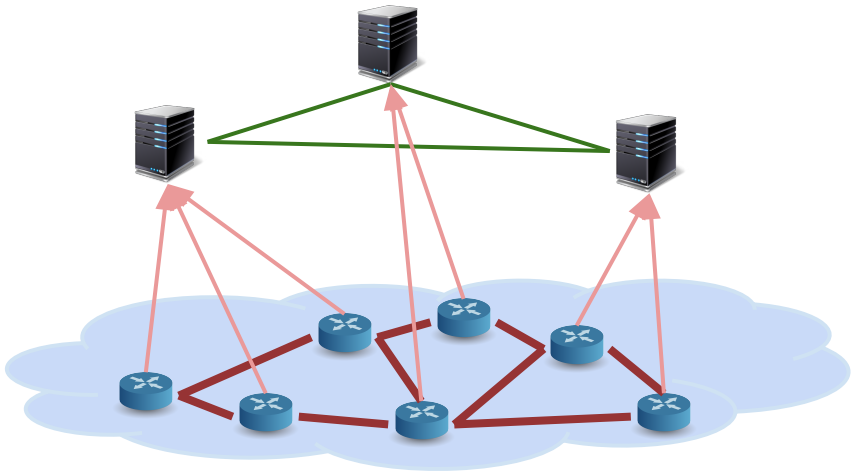
Distributed Stores & Primitives



“The unavoidable price of reliability is simplicity.”

— C.A.R. Hoare

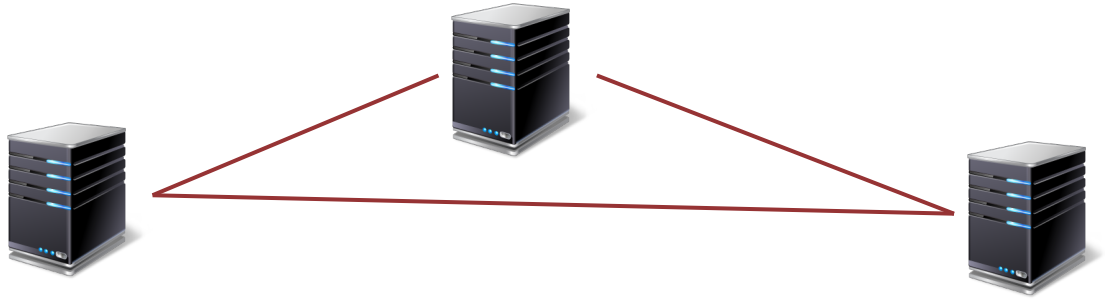
“Simplicity is prerequisite for reliability.”

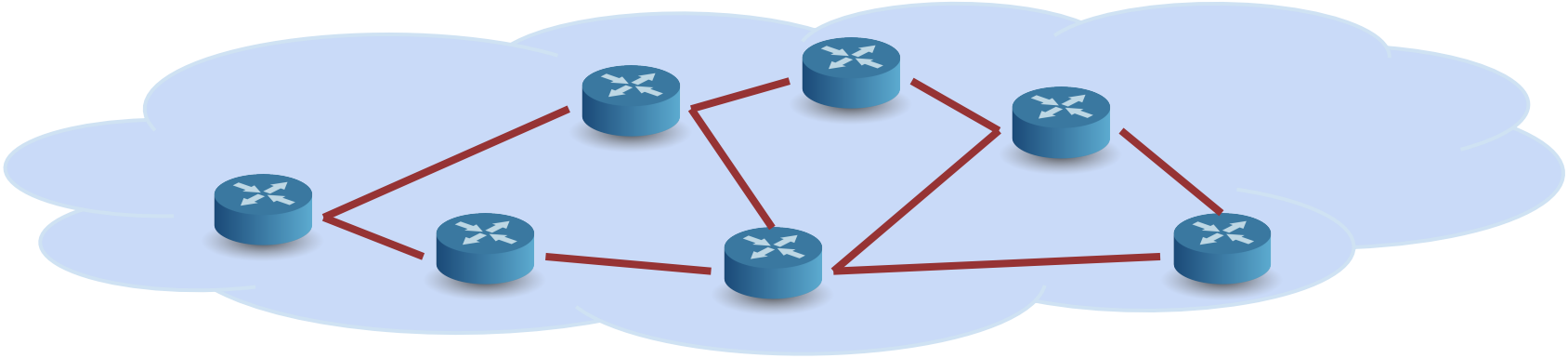
— E. W. Dijkstra

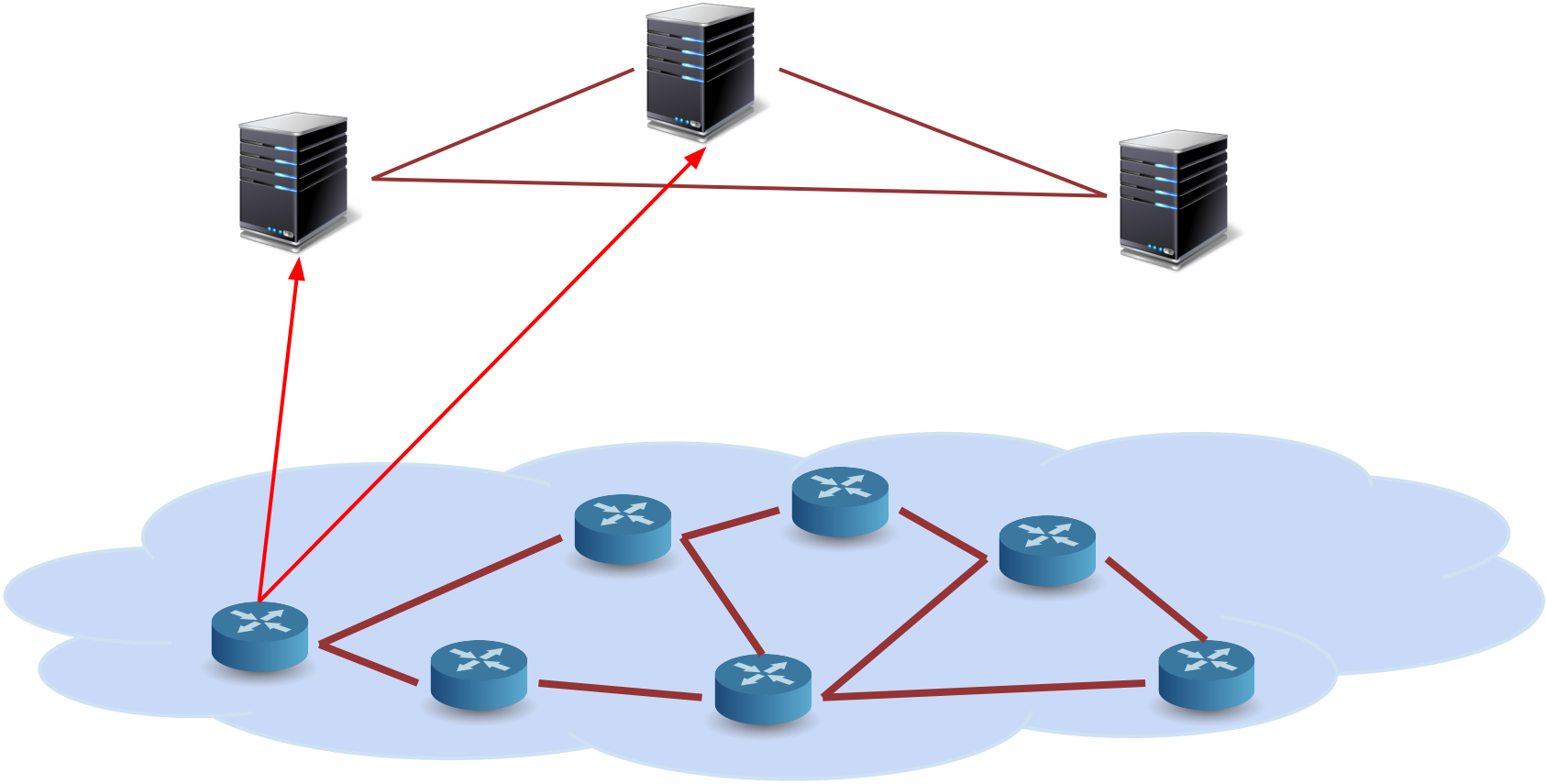
Distributed State Management

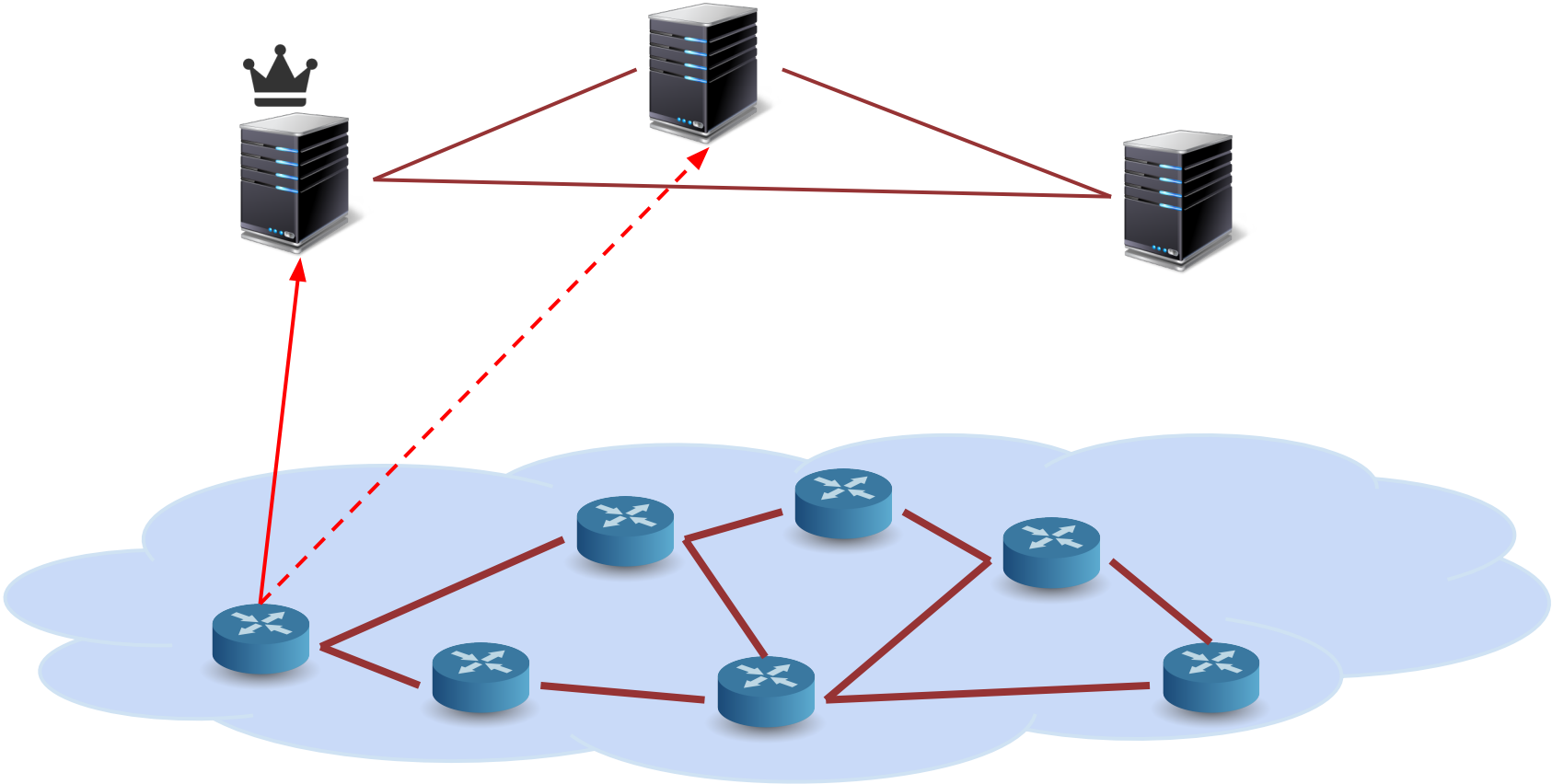
- Using specific examples - introduce various distributed state management primitives ONOS provides

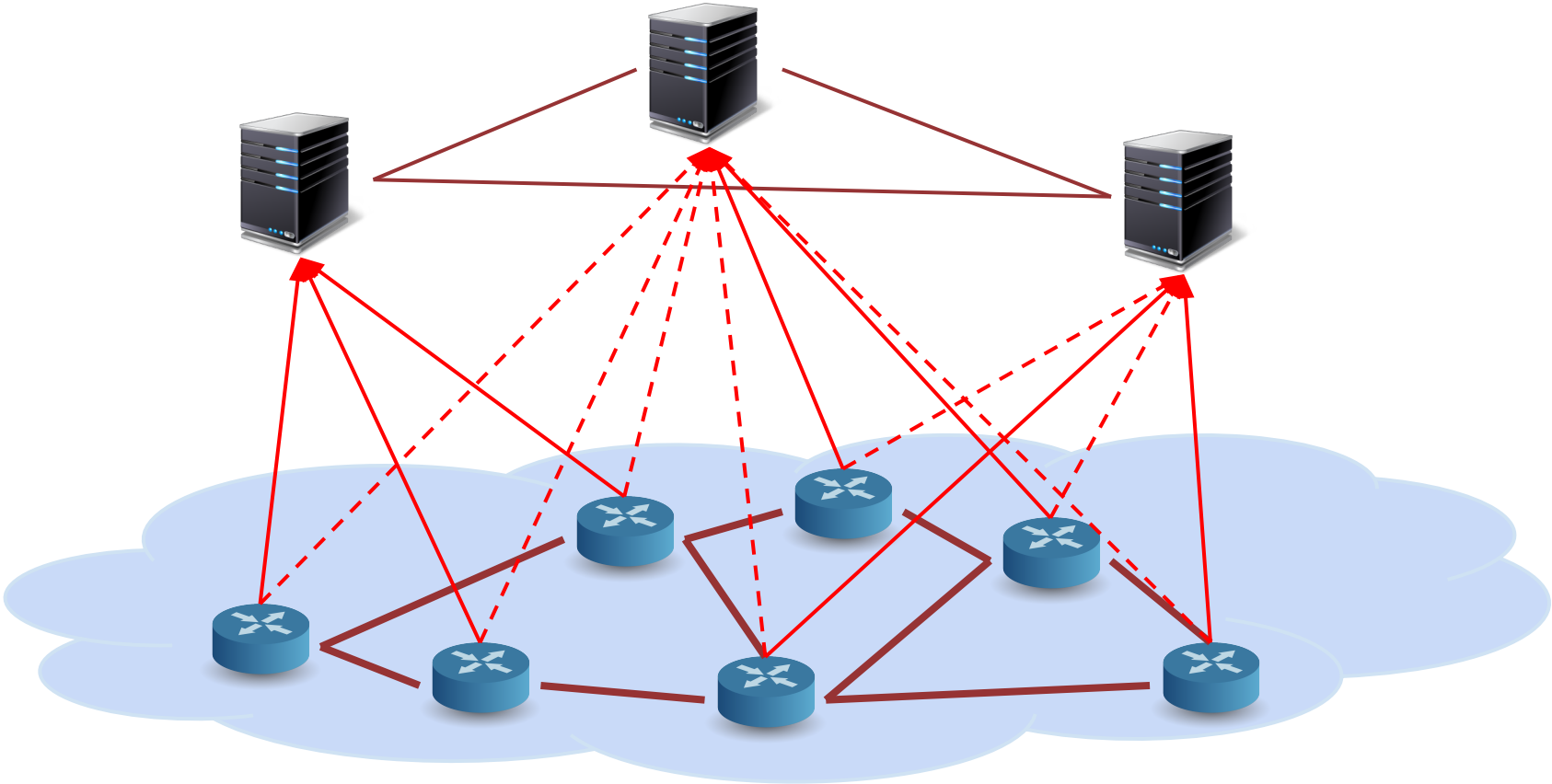
Distributed Control Plane

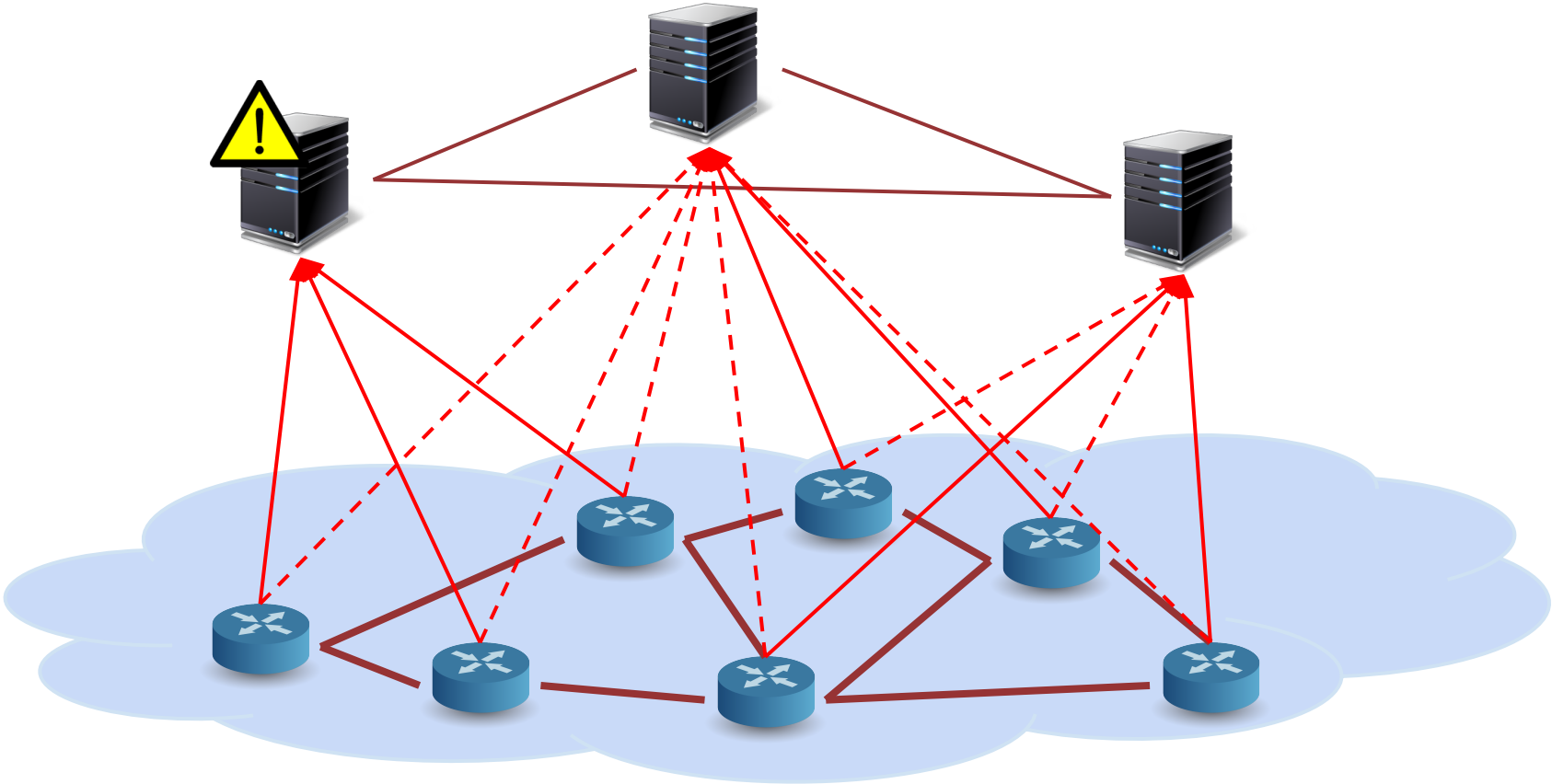


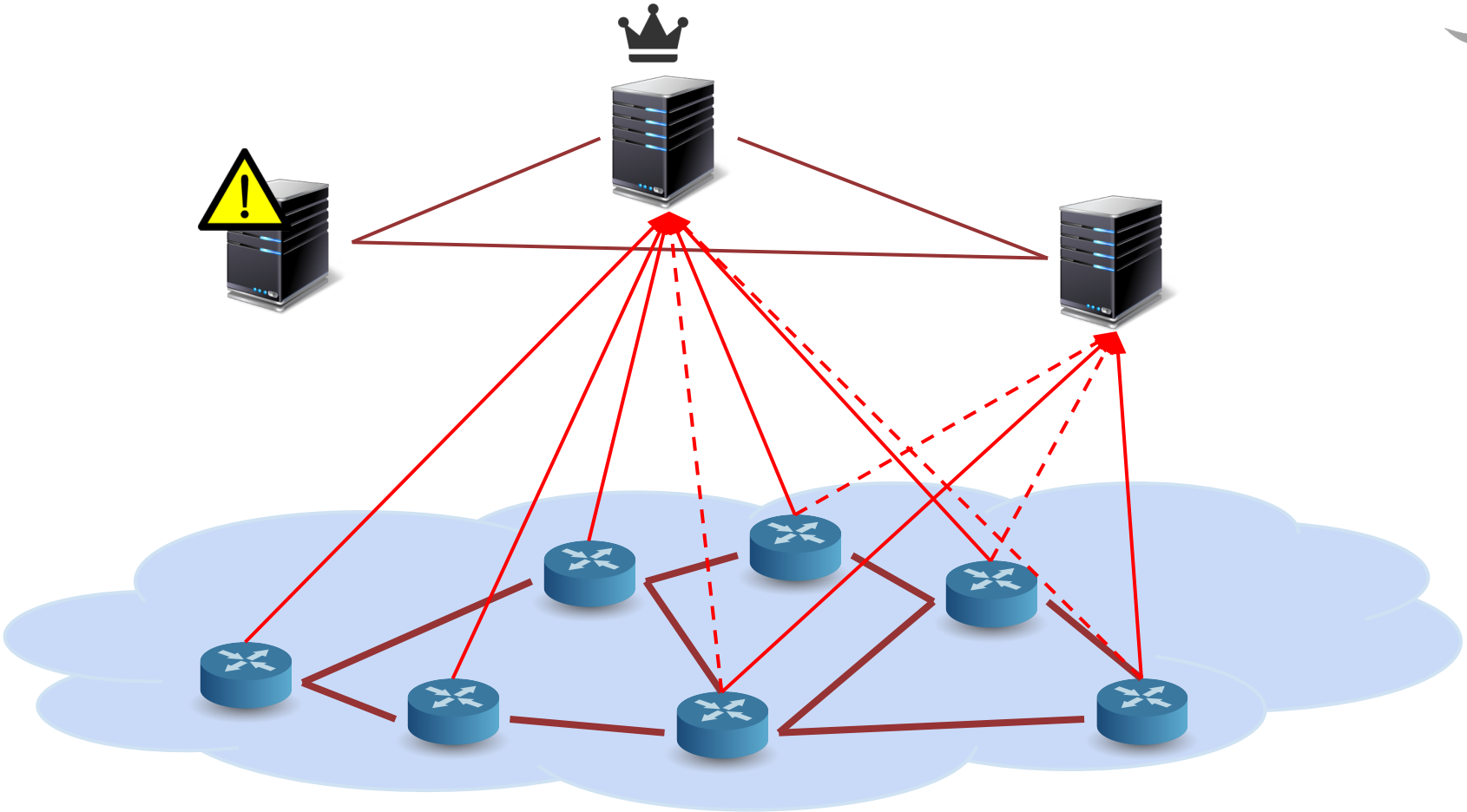










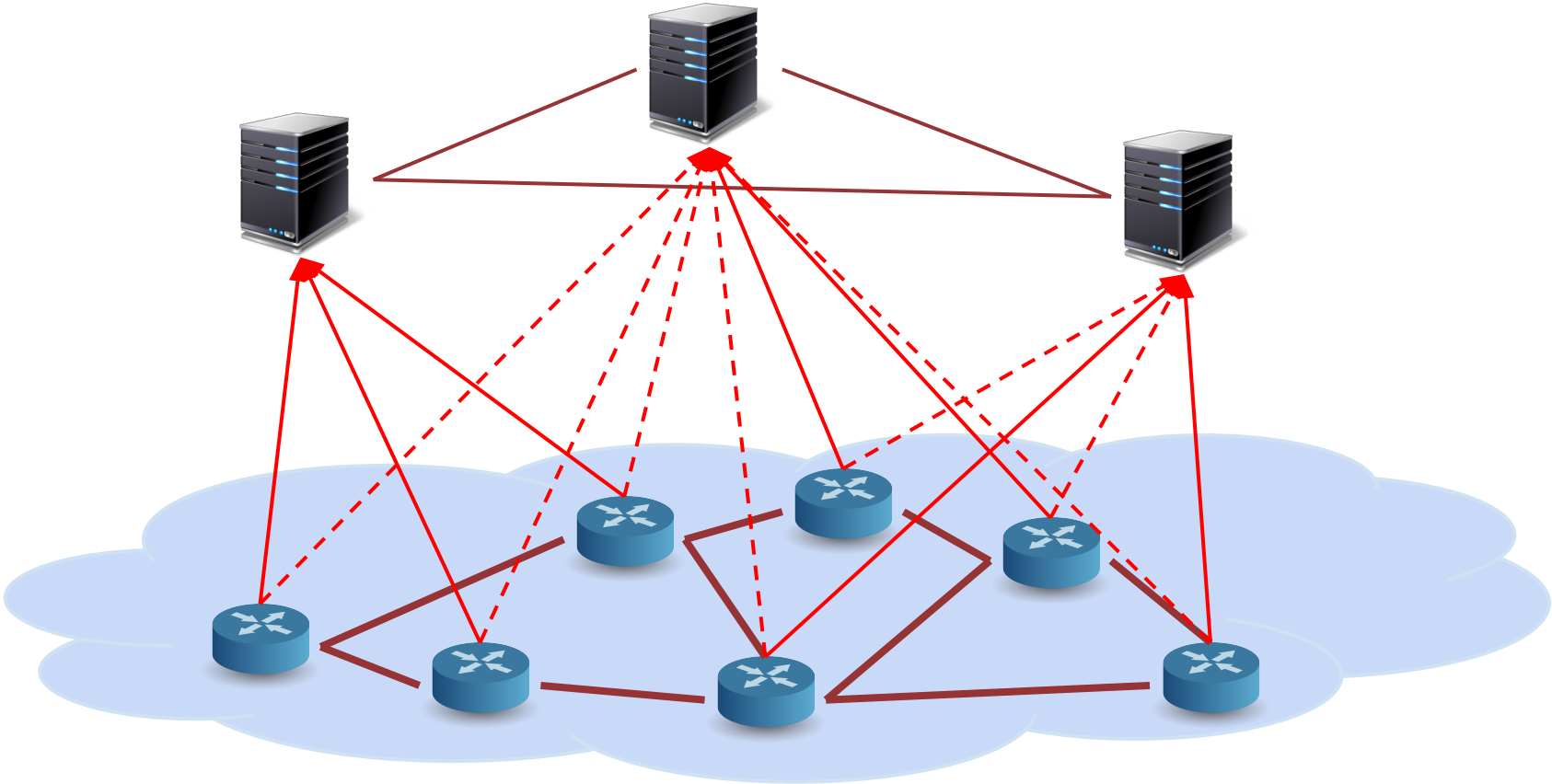


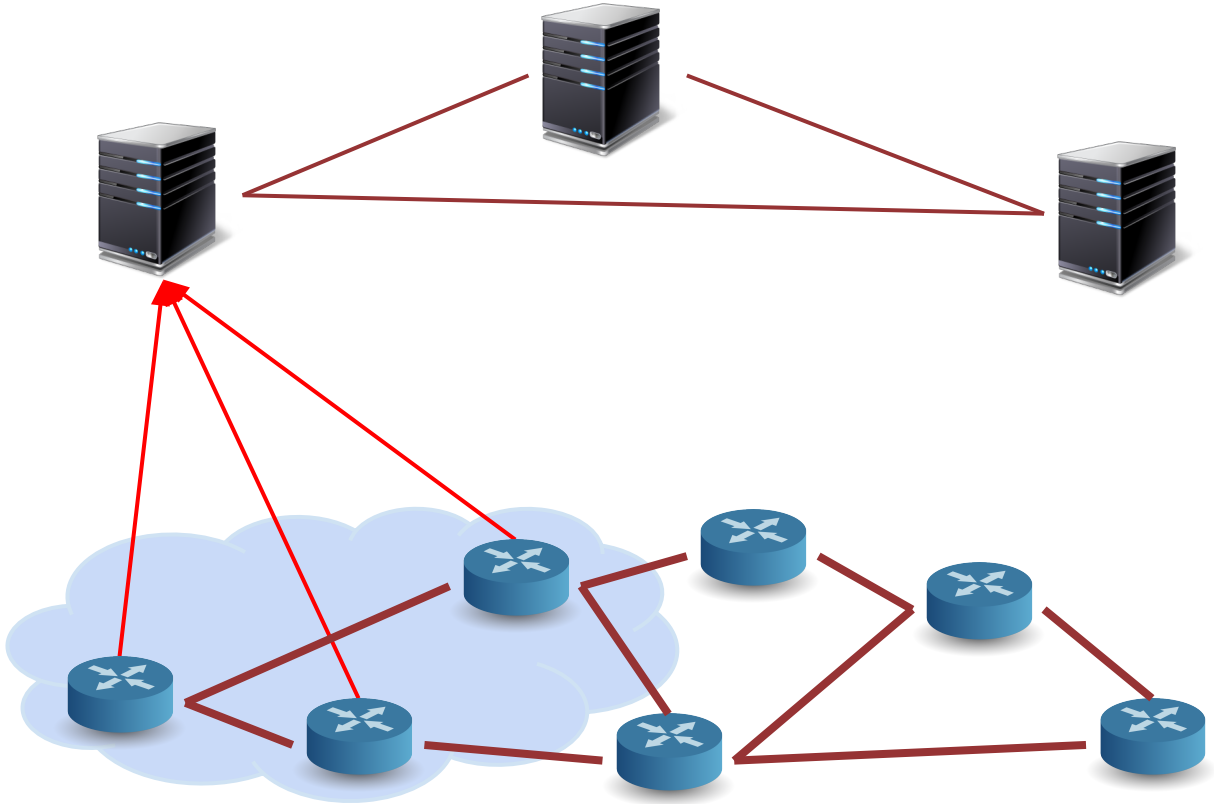
Distributed Primitive: Leadership

- Support for **mutual exclusion** in a distributed setting
- Available as a primitive for applications to consume
- Implemented via the **Raft consensus** protocol
- Cluster **majority** is needed to reach consensus

Deep dive into Topology state

- Formulate the problem
- Evaluate solution space
- Description of ONOS' approach
- Performance evaluation

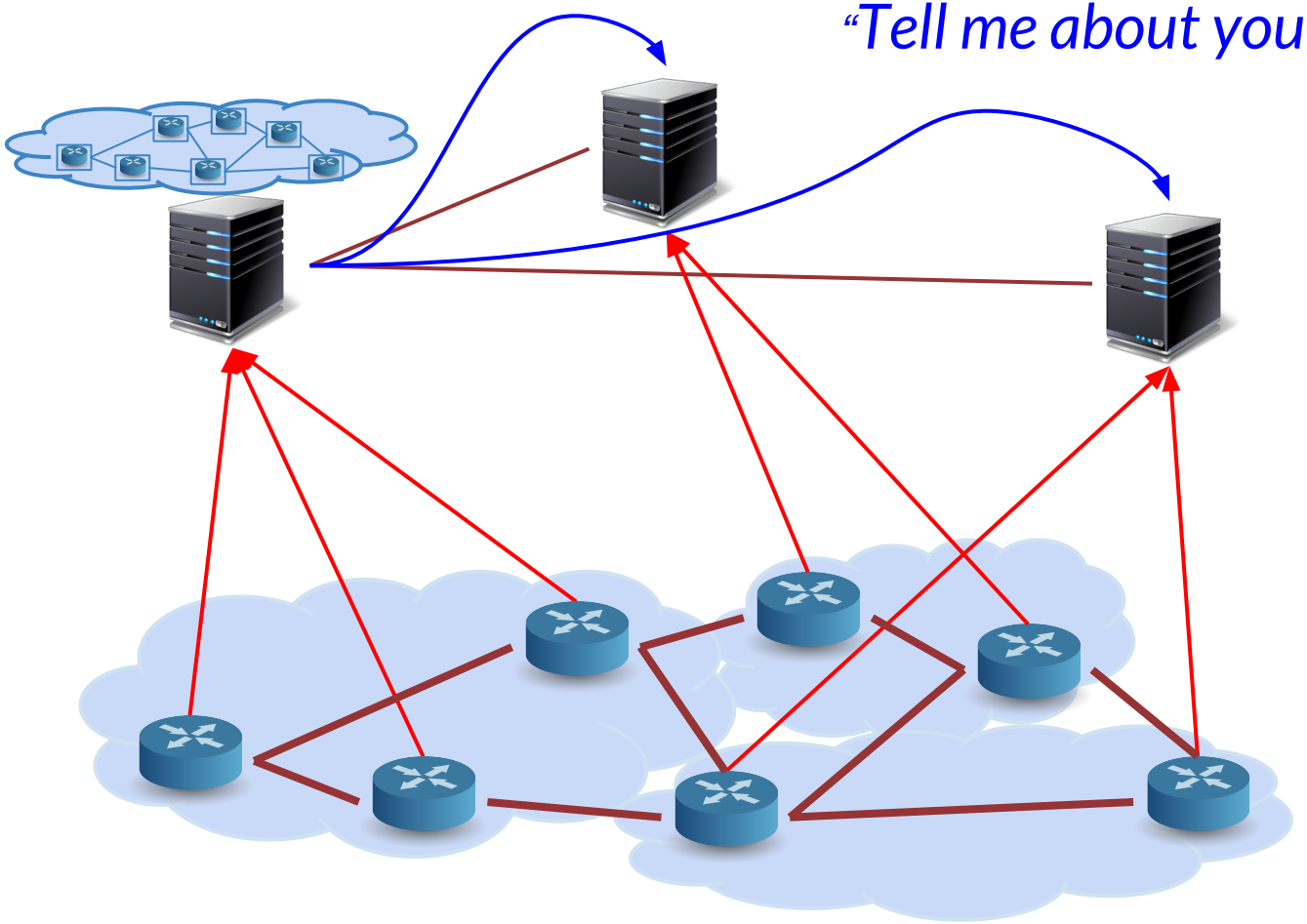




Solution space

- Partitioned by mastership
- Logically centralized data store
- ONOS approach

“Tell me about your slice?”



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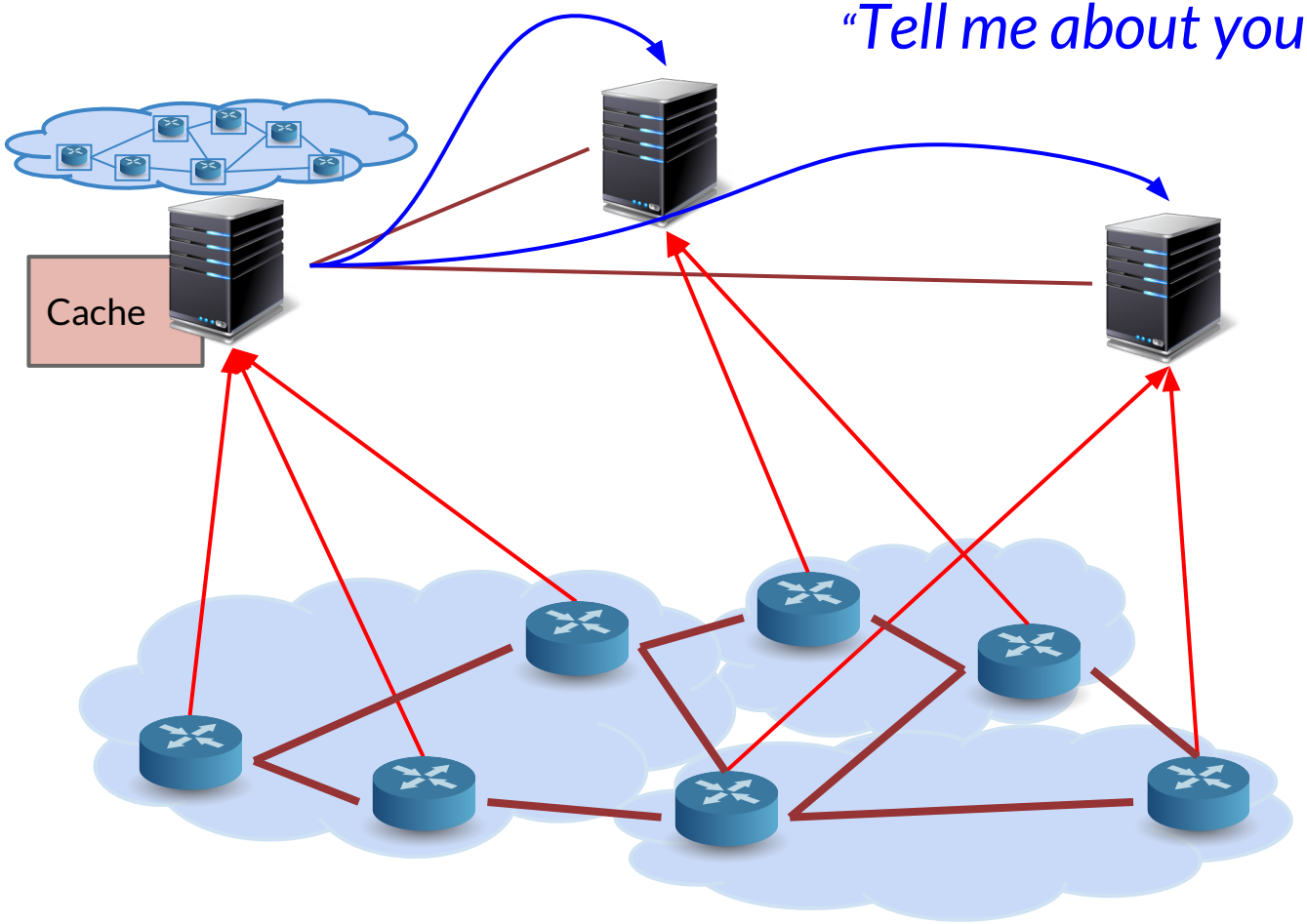
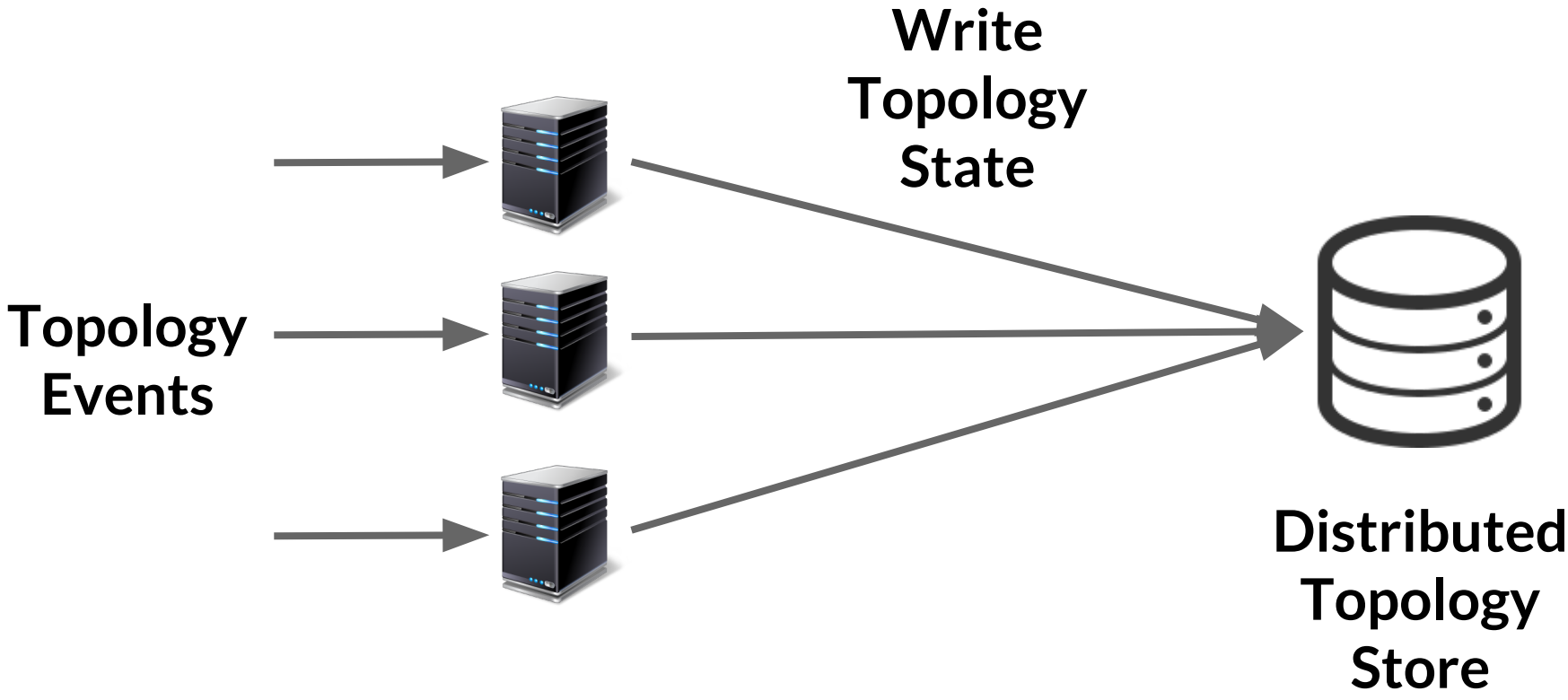
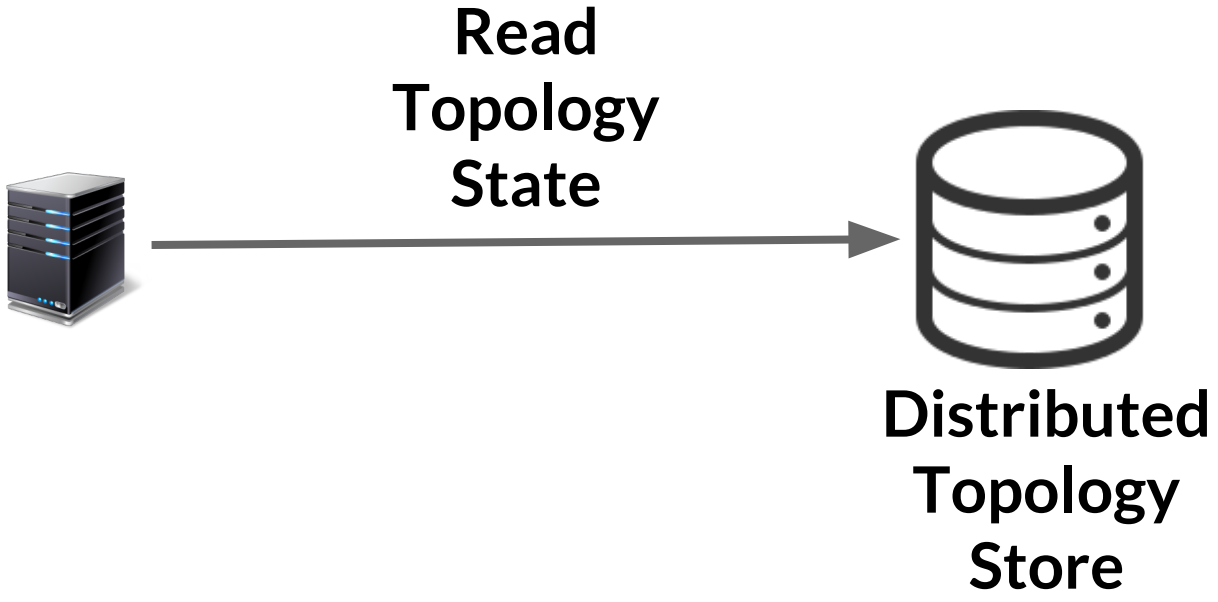



Write
Topology
State
Topology
Events
Distributed
Topology
Store


Read
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State
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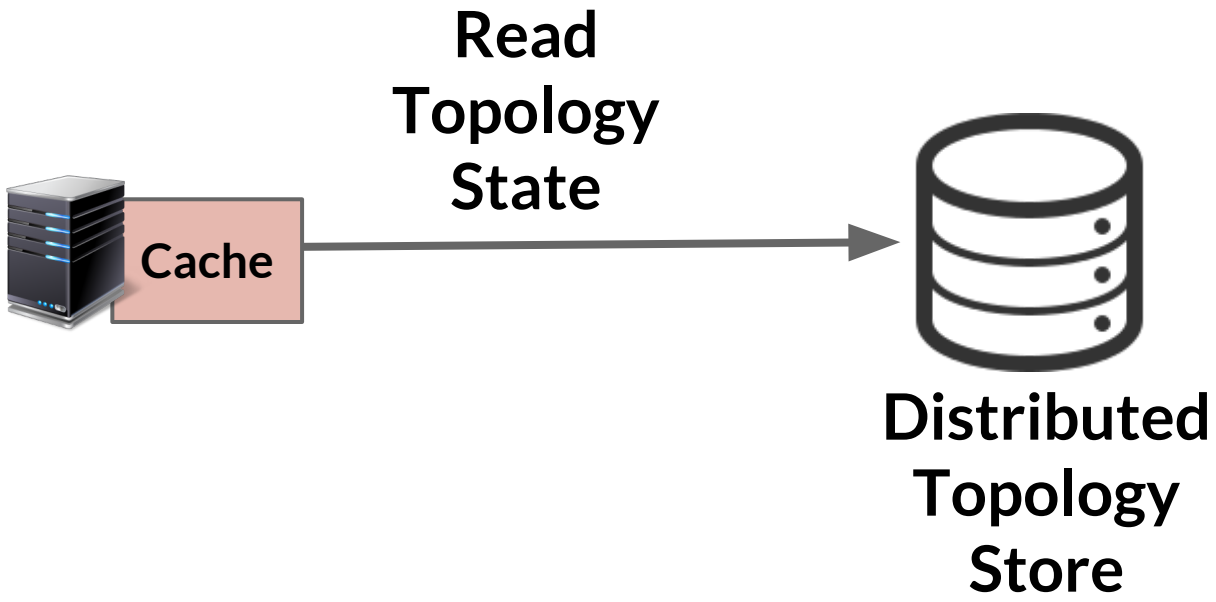
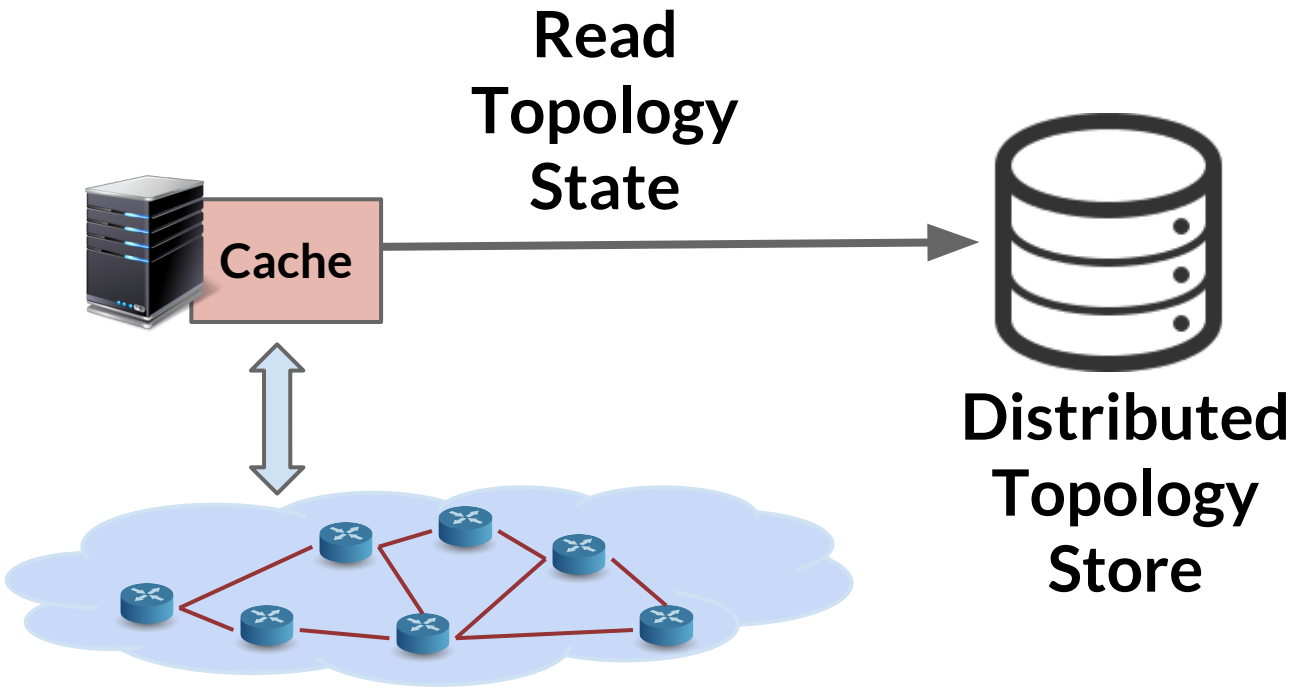
Store


Read
Topology
State
Cache
Distributed
Topology
Store


Read
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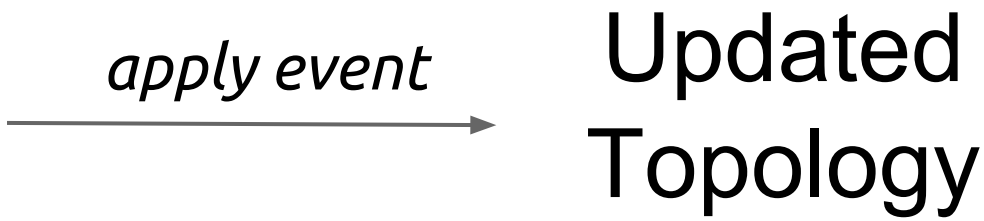
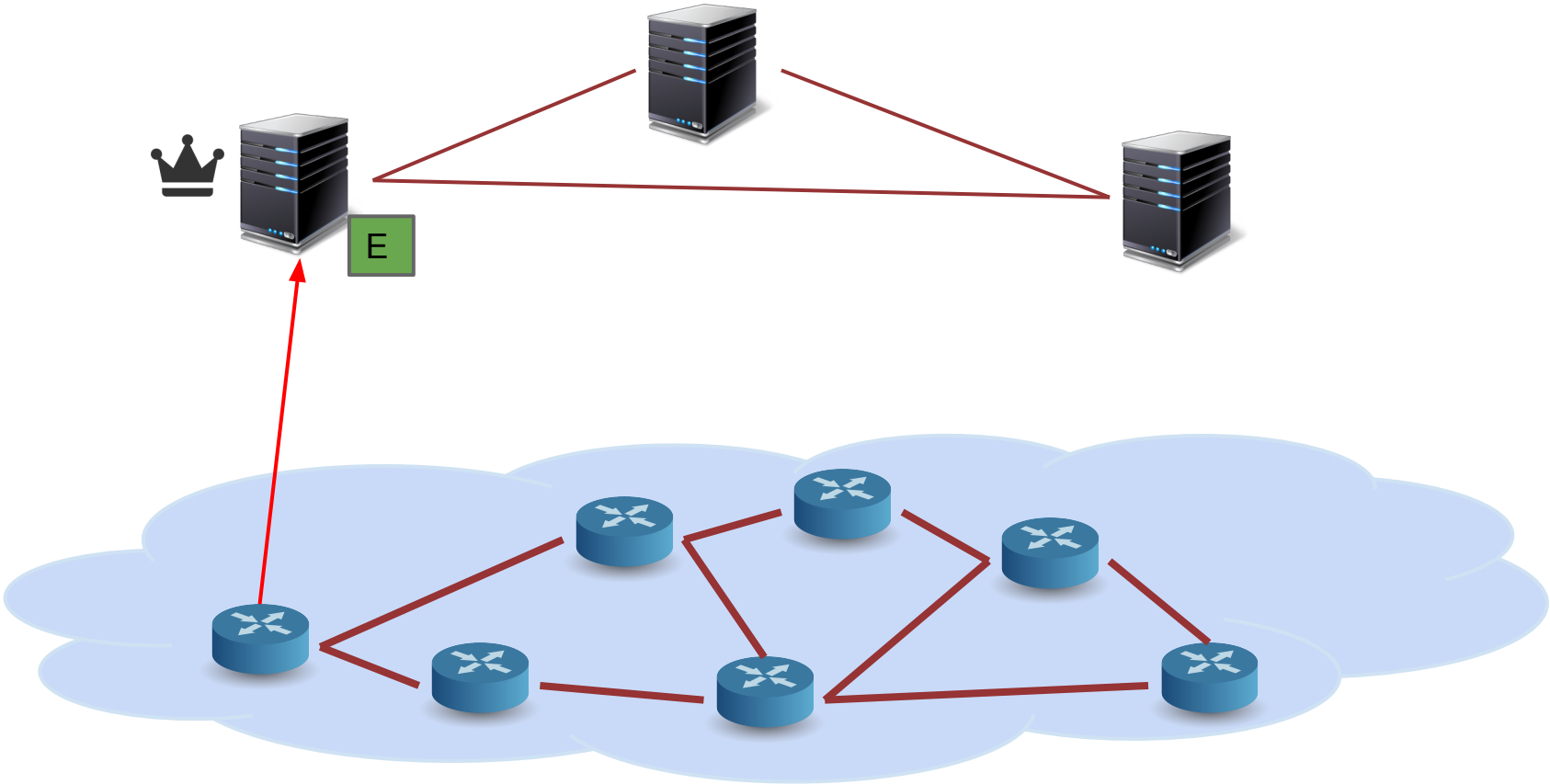
Store

Topology as a State Machine



Events are Switch/Port/Link up/down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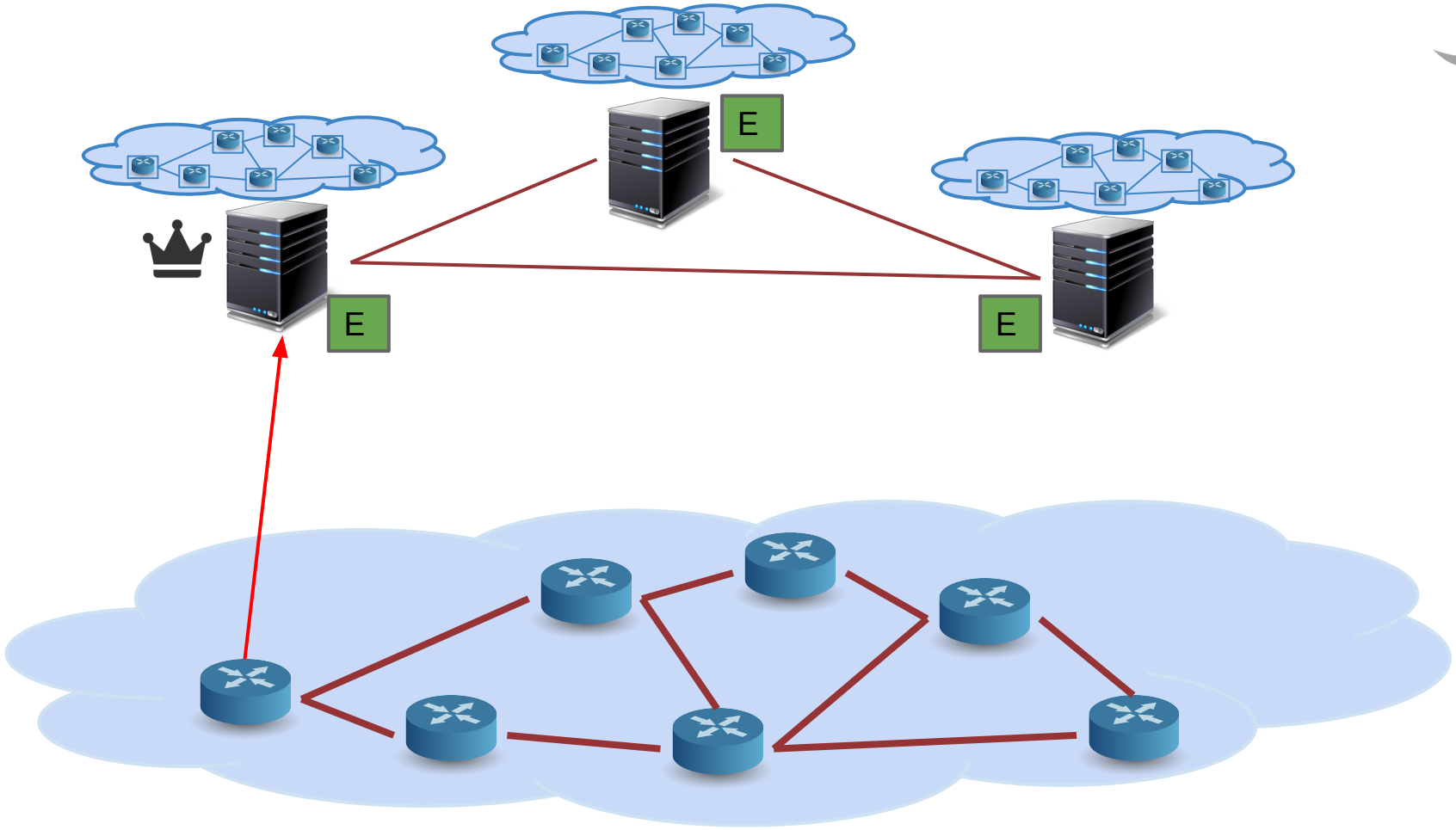
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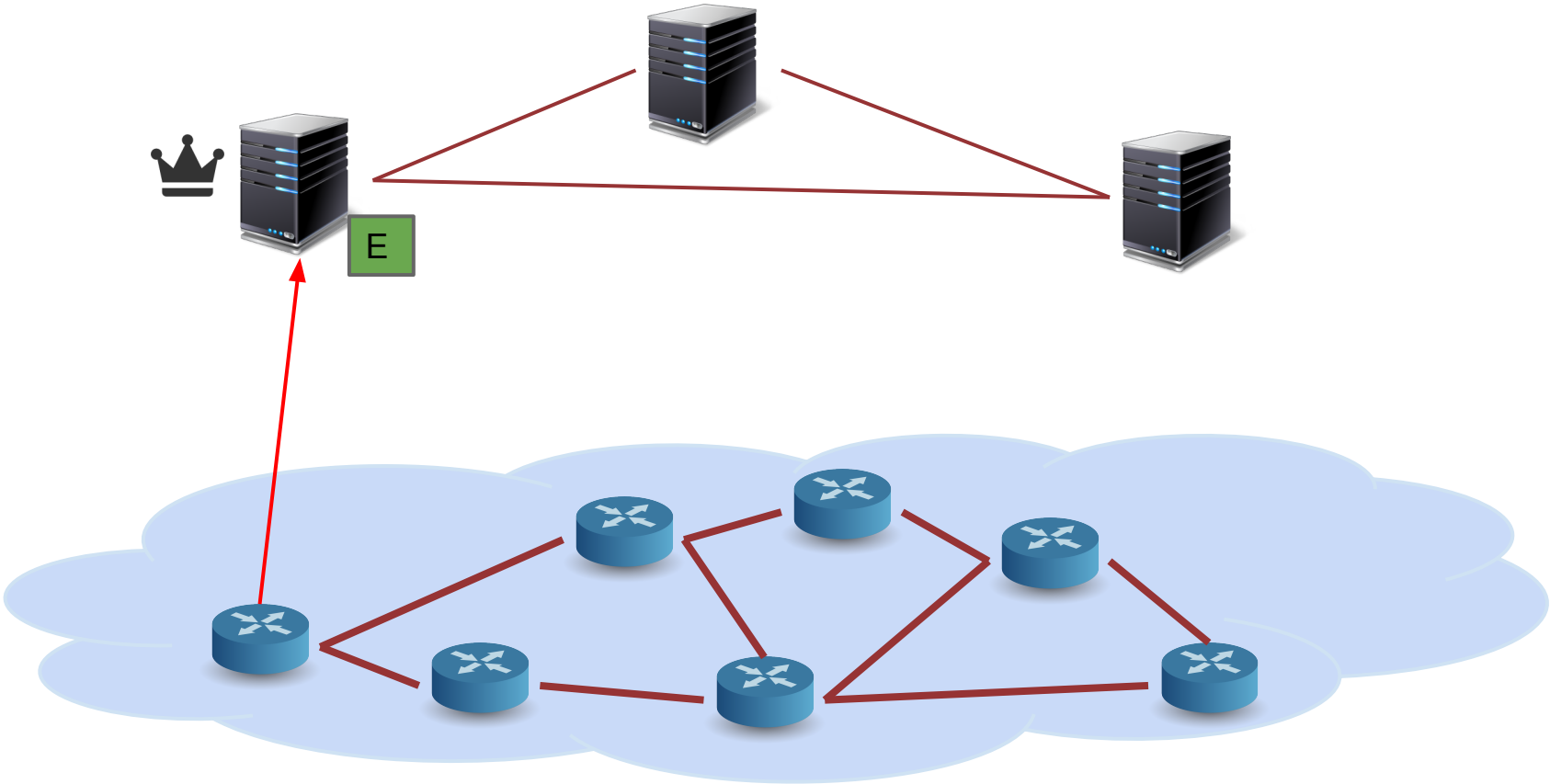
Pros
● Simple ● Fast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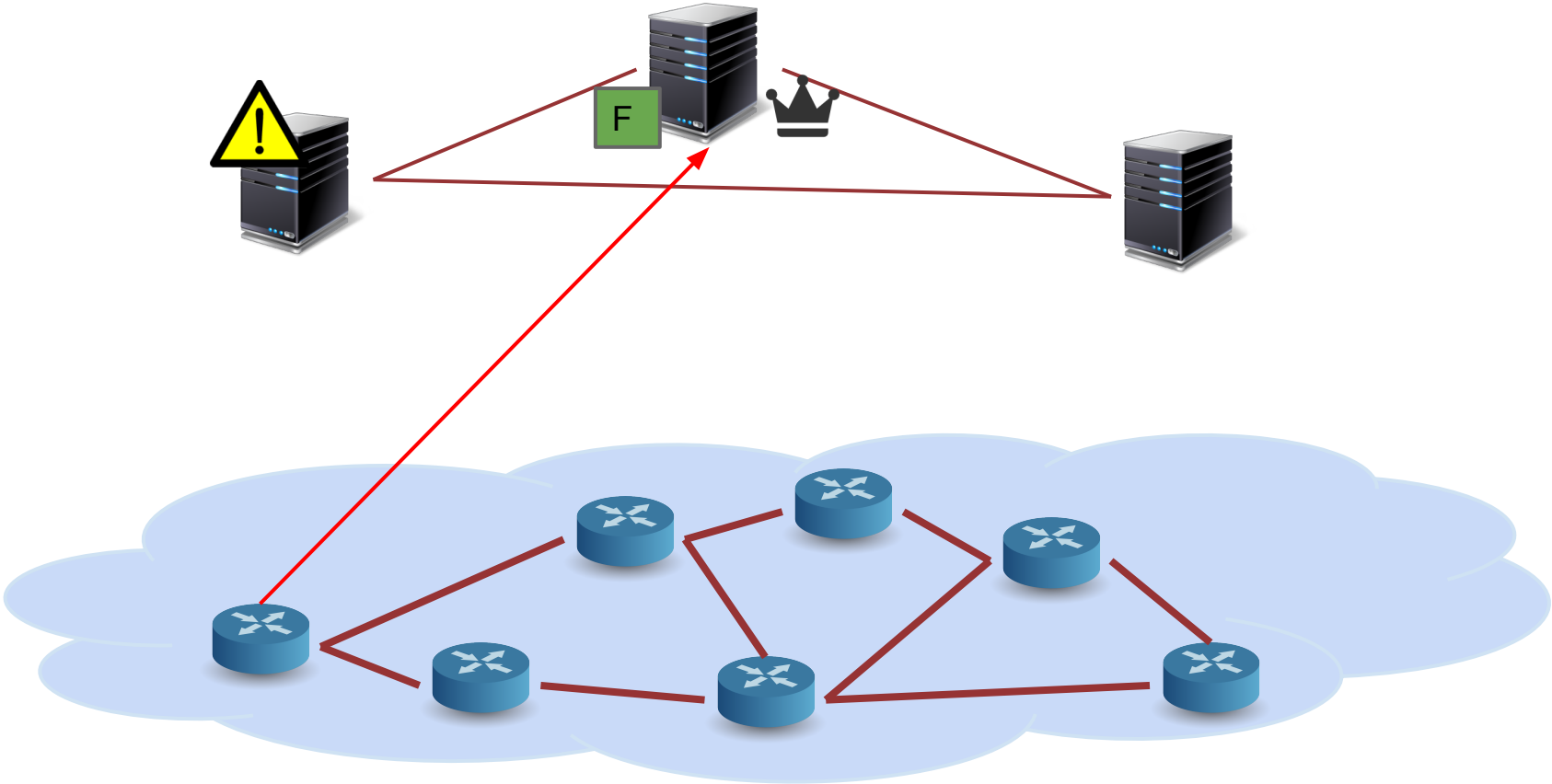
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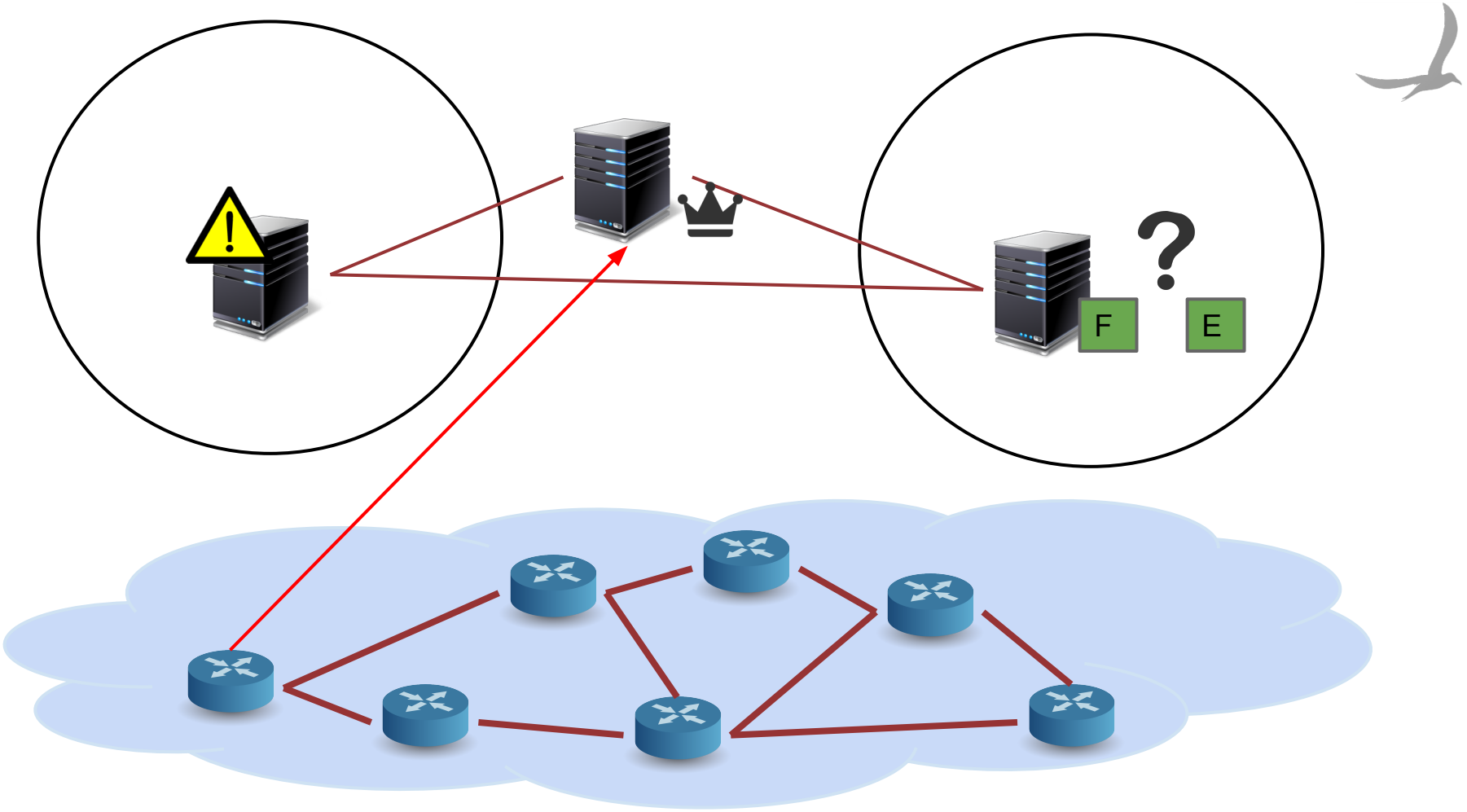
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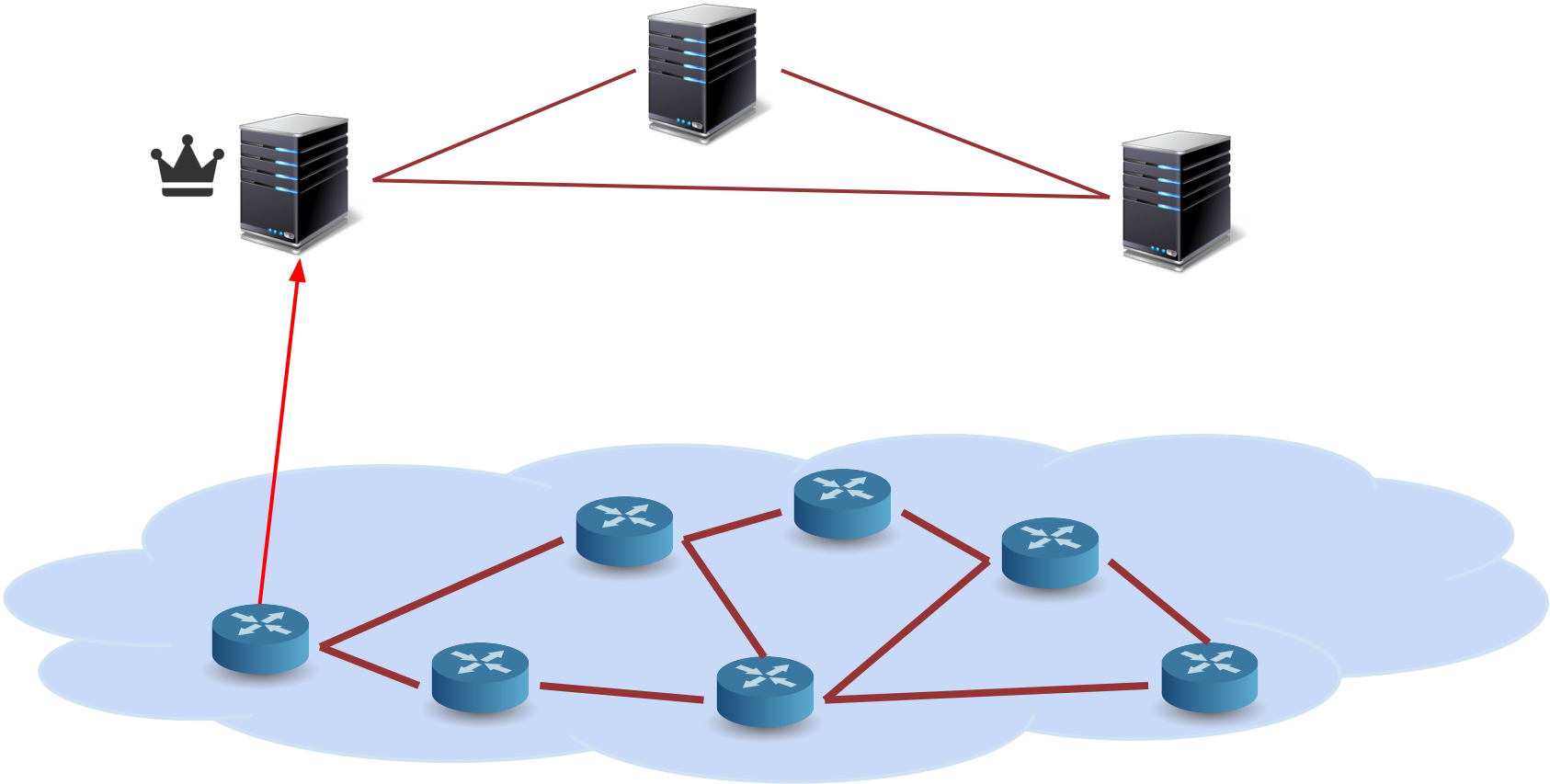
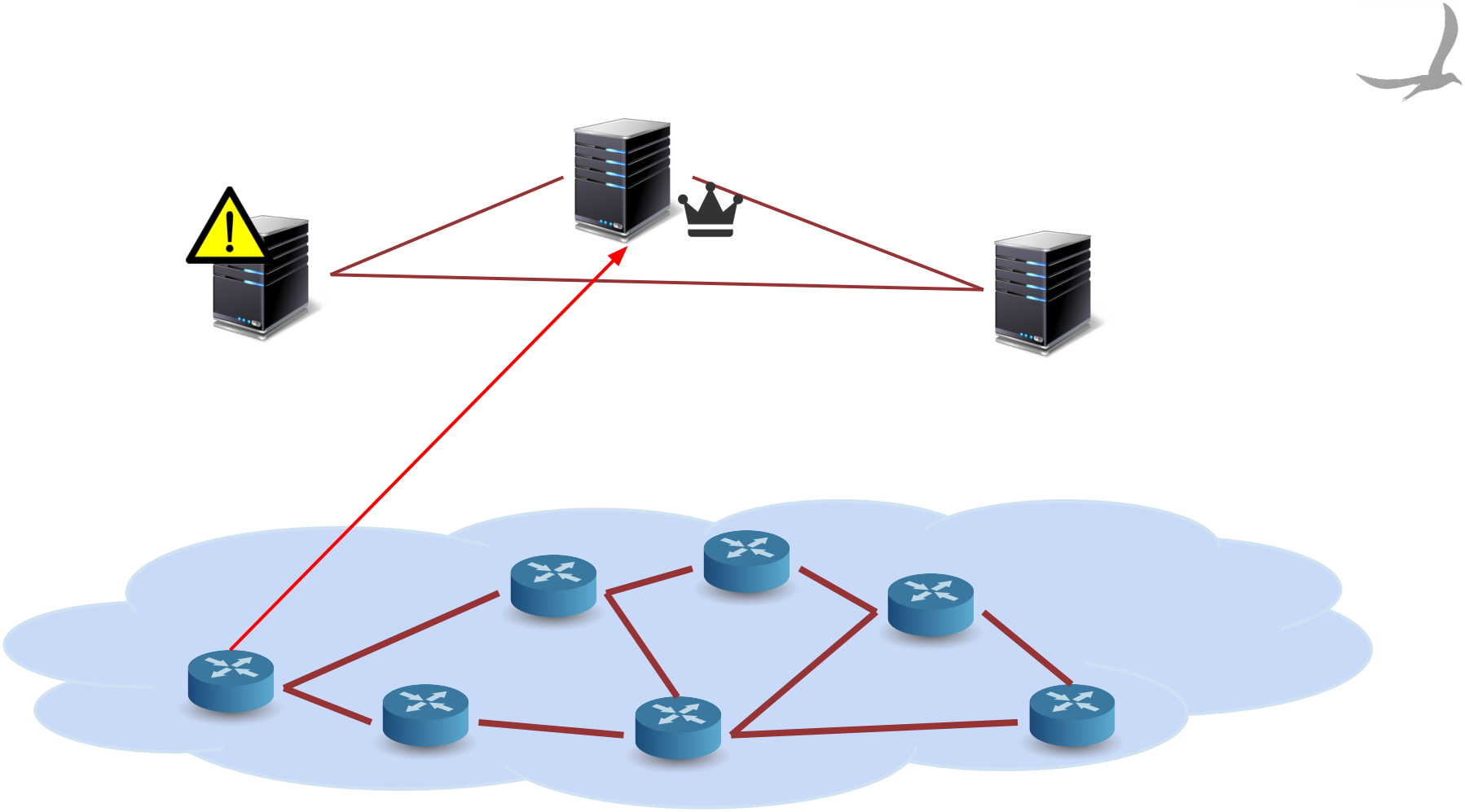
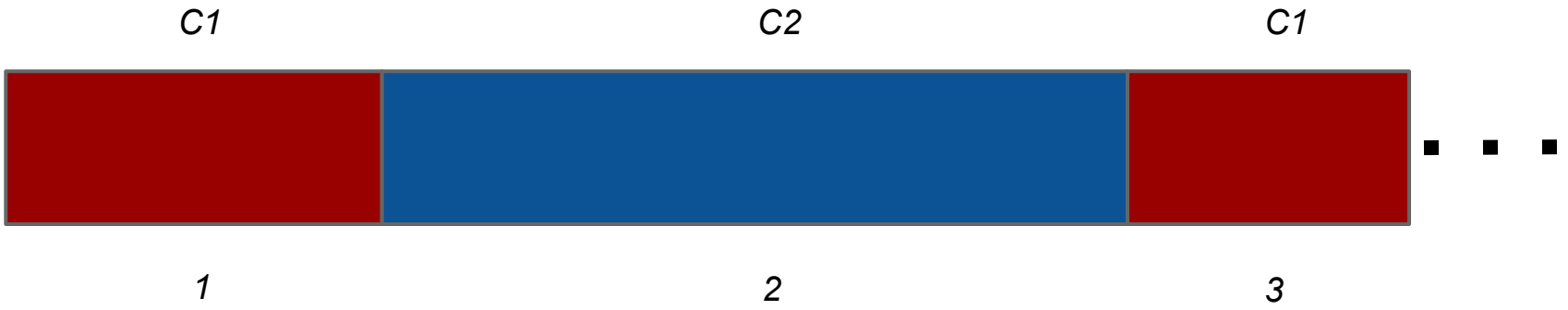
Pros	Cons
● Simple ● Fast	● Dropped messages ● Reordered messages

How to address the cons without sacrificing the pros?



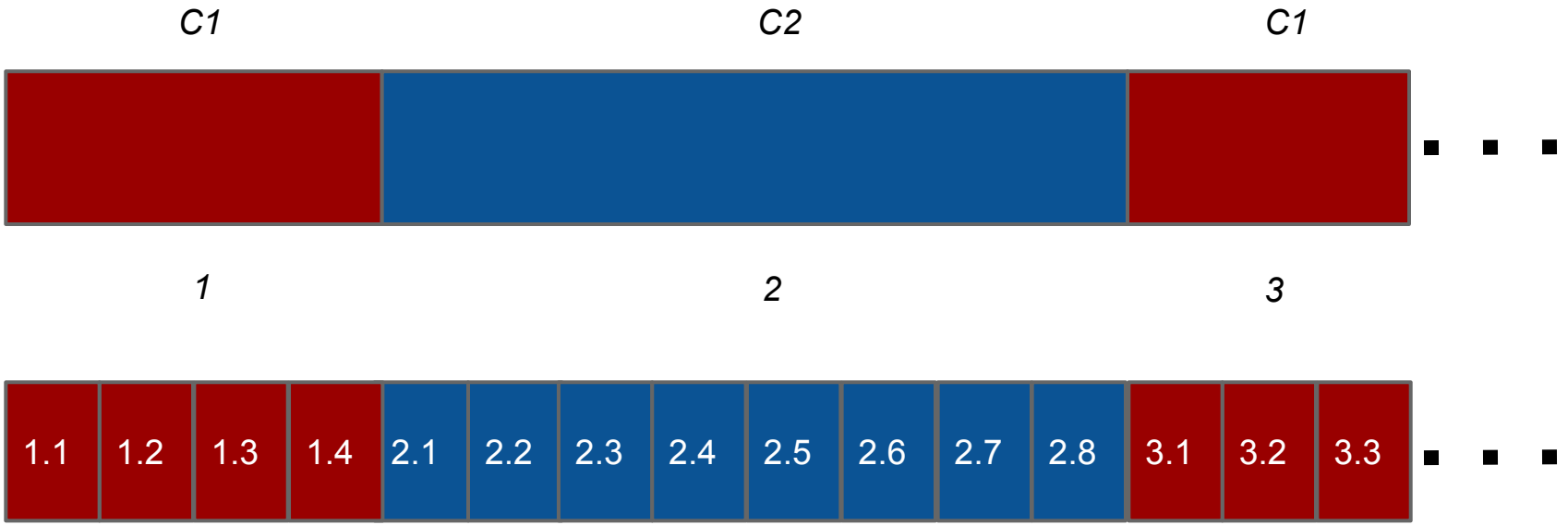


Switch Mastership Terms



We track this in a strongly consistent store

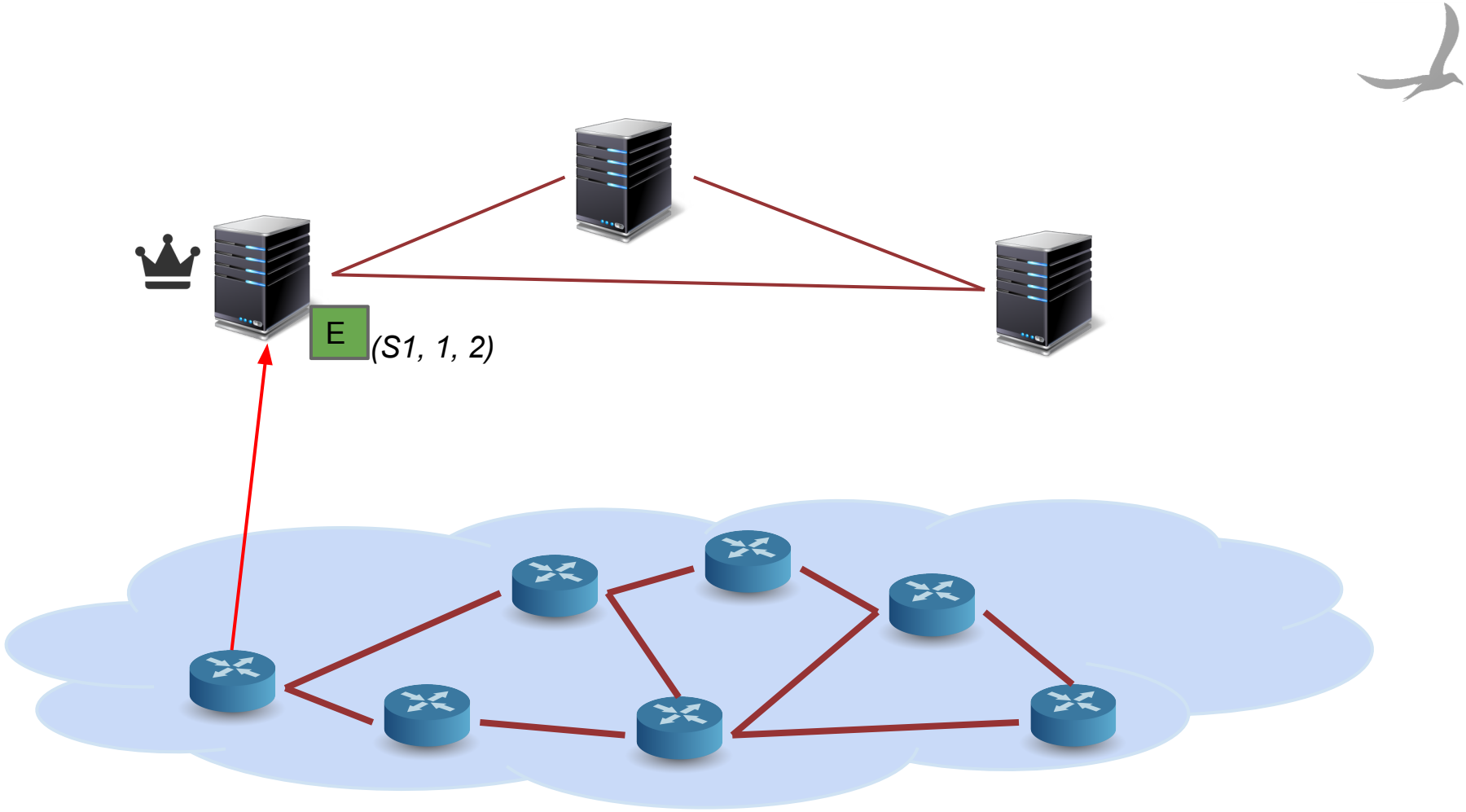
Switch Event Numbers

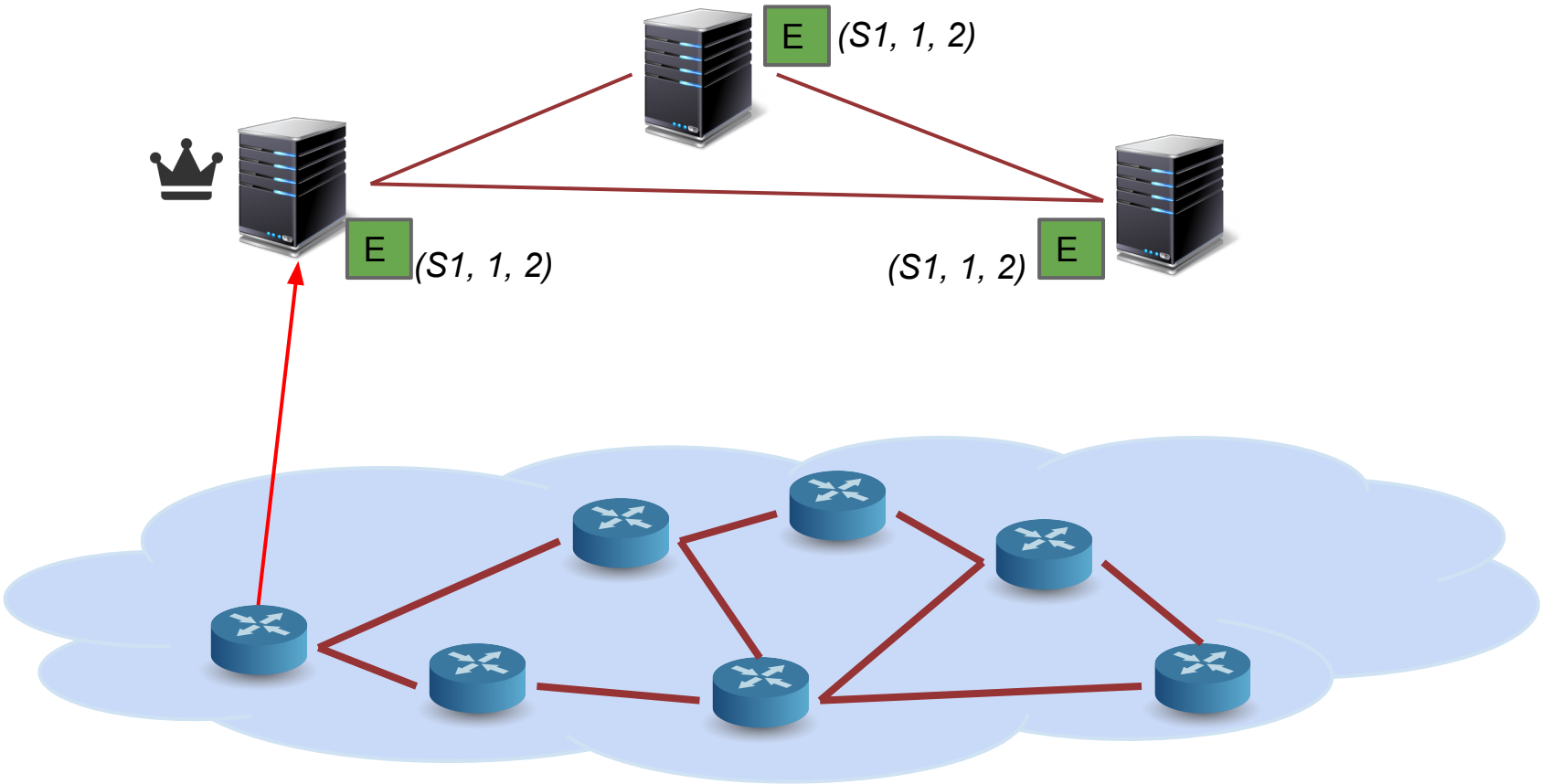


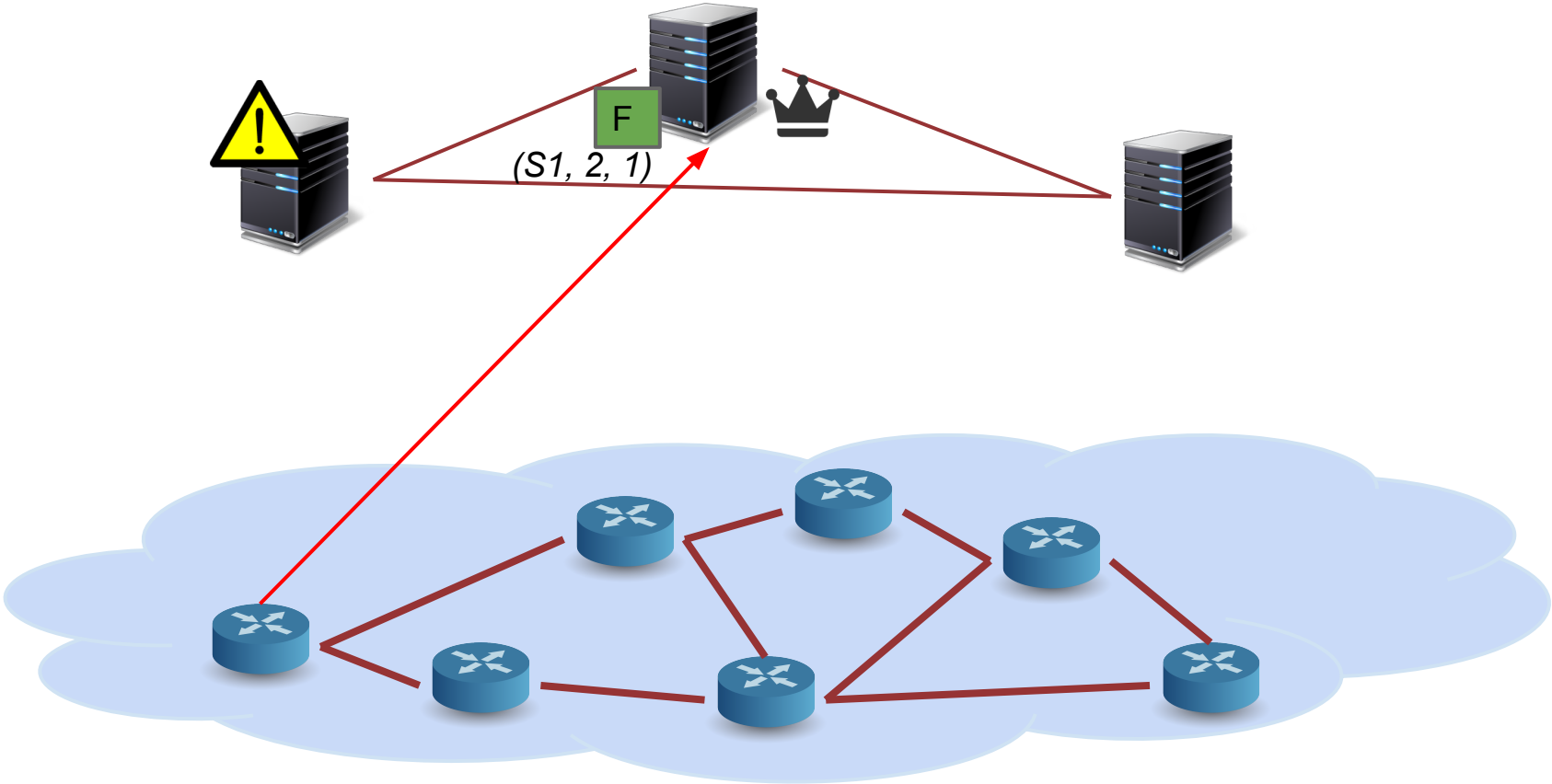
Partial Ordering of Events

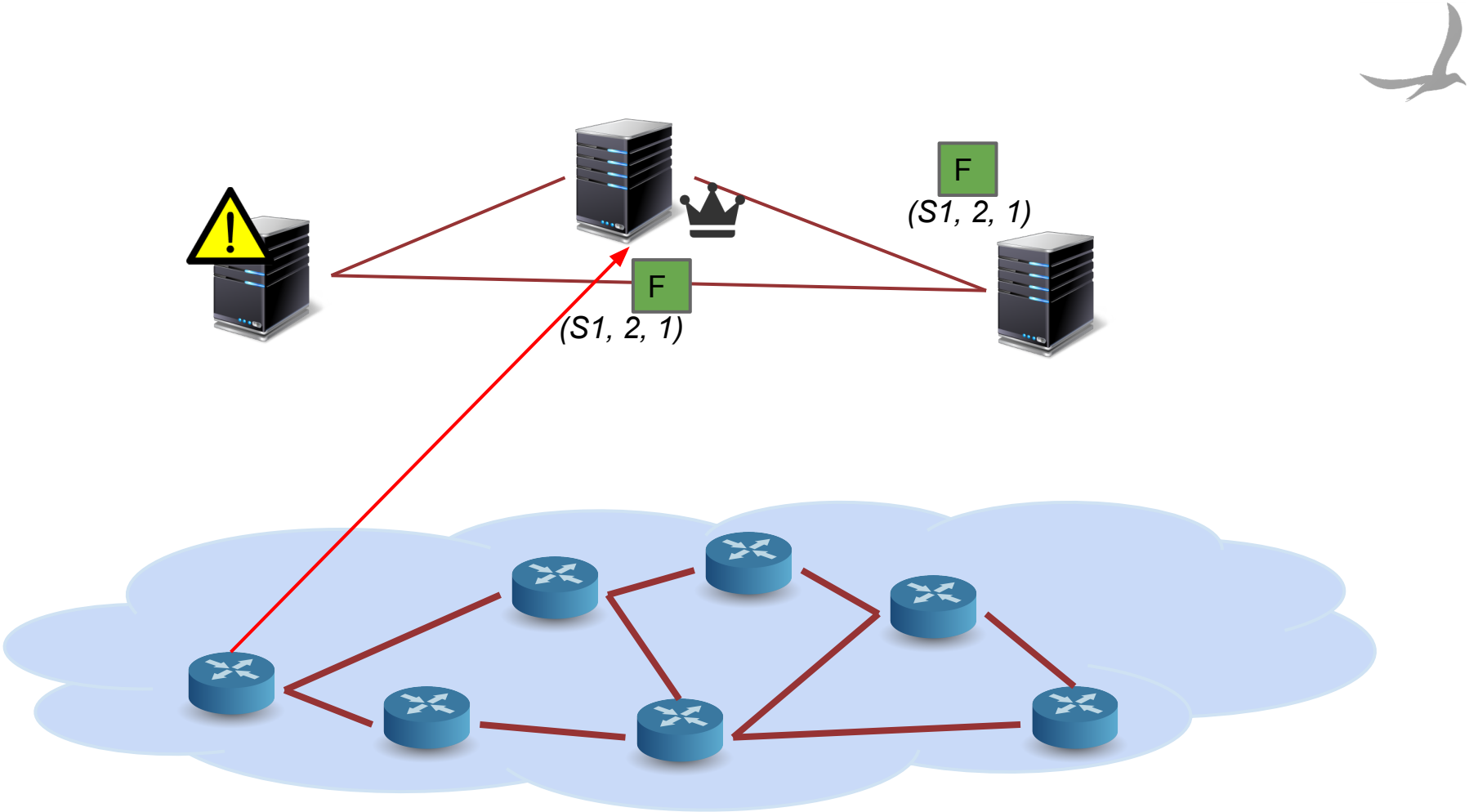
Each event has a unique logical timestamp

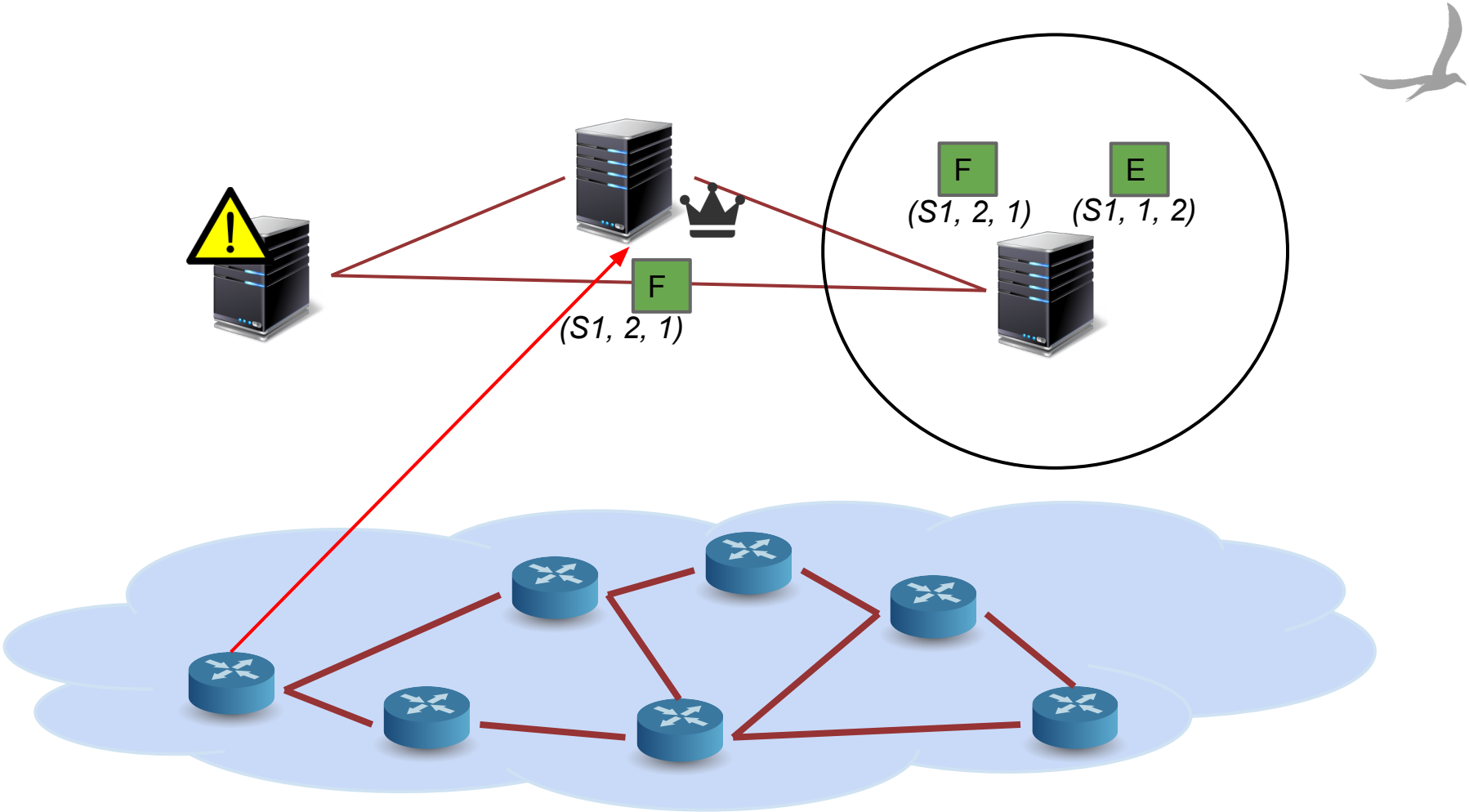
(Switch ID, Term Number, Event Number)

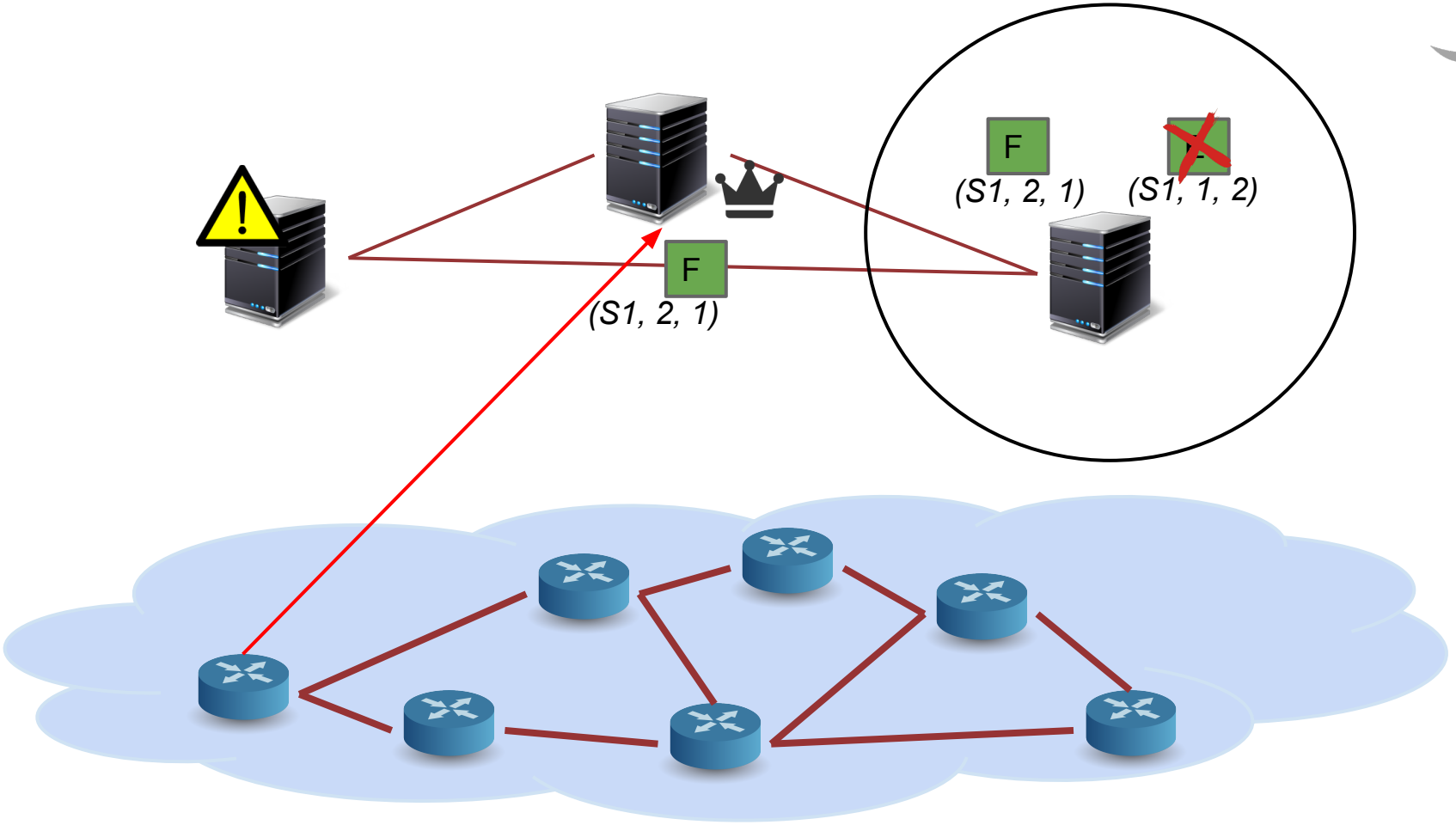

E
(S1, 1, 2)


E
(S1, 1, 2)
E
(S1, 1, 2)
(S1, 1, 2)
E


F
(S1, 2, 1)


F
(S1, 2, 1)
F
(S1, 2, 1)


F
(S1, 2, 1)
E
(S1, 1, 2)
F
(S1, 2, 1)


F
(S1, 2, 1)
F
(S1, 1, 2)
F
(S1, 2, 1)

To Summarize

- Each instance has a full copy of network topology
- Events are timestamped on arrival and broadcasted
- Stale events are dropped on receipt

To Summarize

- Each instance has a full copy of network topology
- Events are timestamped on arrival and broadcasted
- Stale events are dropped on receipt

What about dropped messages?


Did you hear about the port that went offline?
© Angie Brown

Anti-Entropy

Gossip-style

Lightweight

Decentralized

A model for state tracking

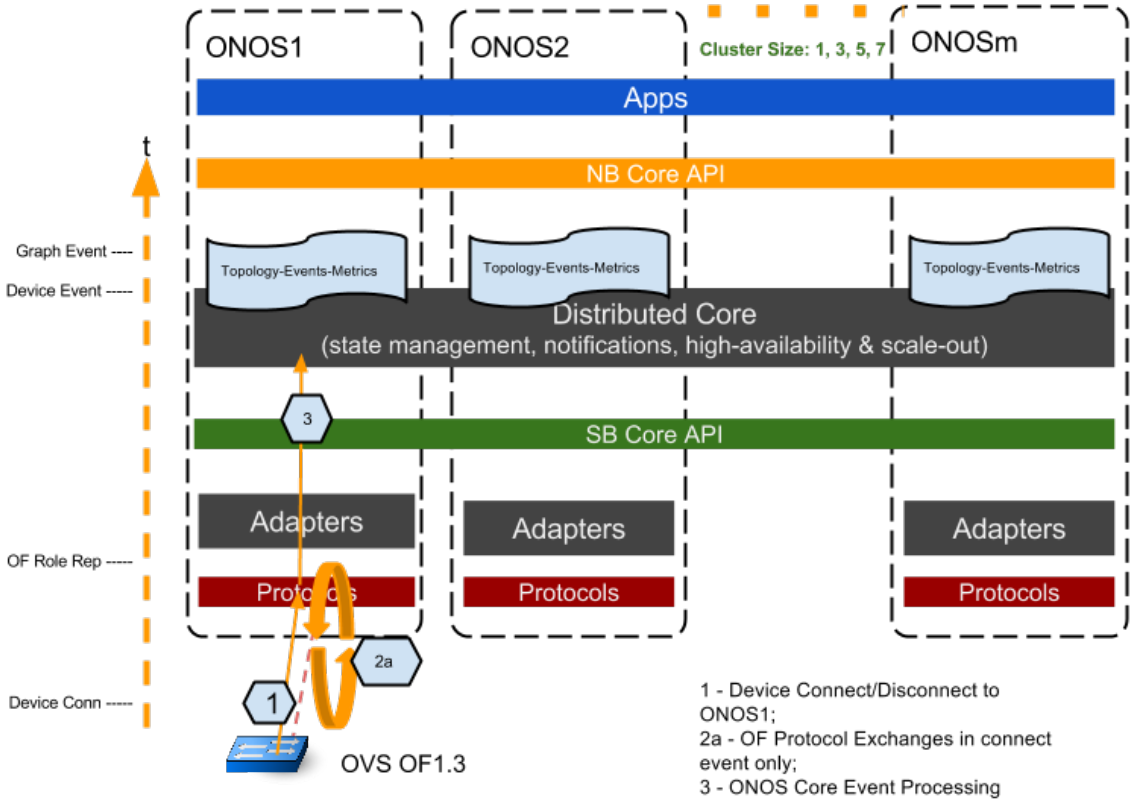
- If you are the observer, **Eventual Consistency** is the best option
- For topology state, ONOS provides **monotonic read consistency**
- View should be consistent with the network, not with other views

Distributed Primitive

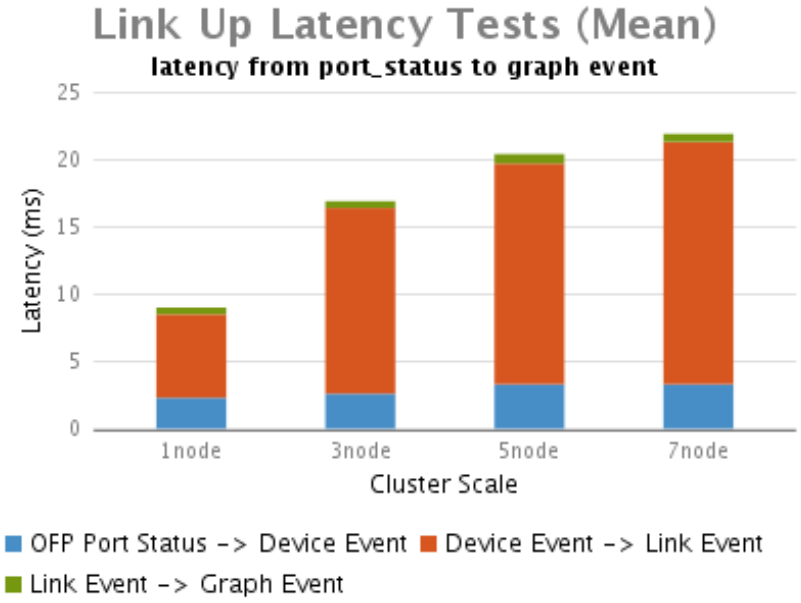
EventuallyConsistentMap<K, V>

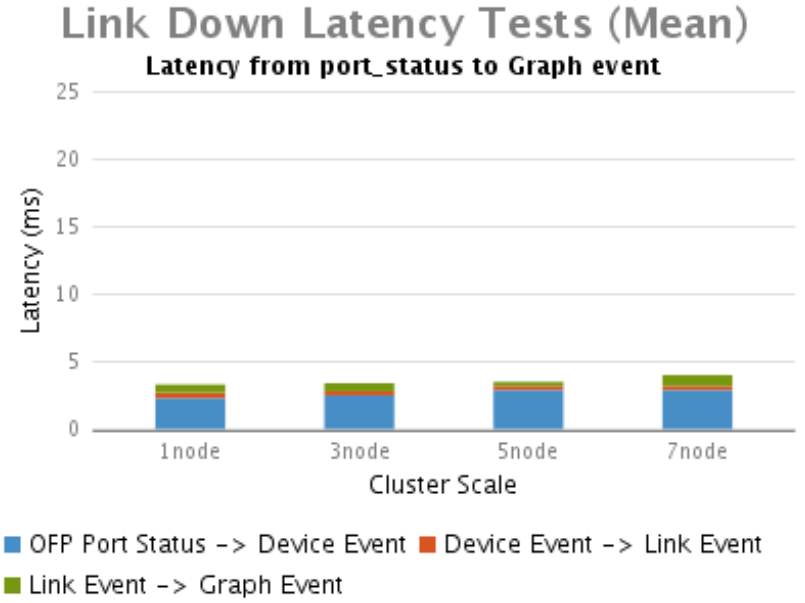
- Allows plugging in custom timestamp mechanism

Device & Link Sensing Latency



Link Up/Down Latency





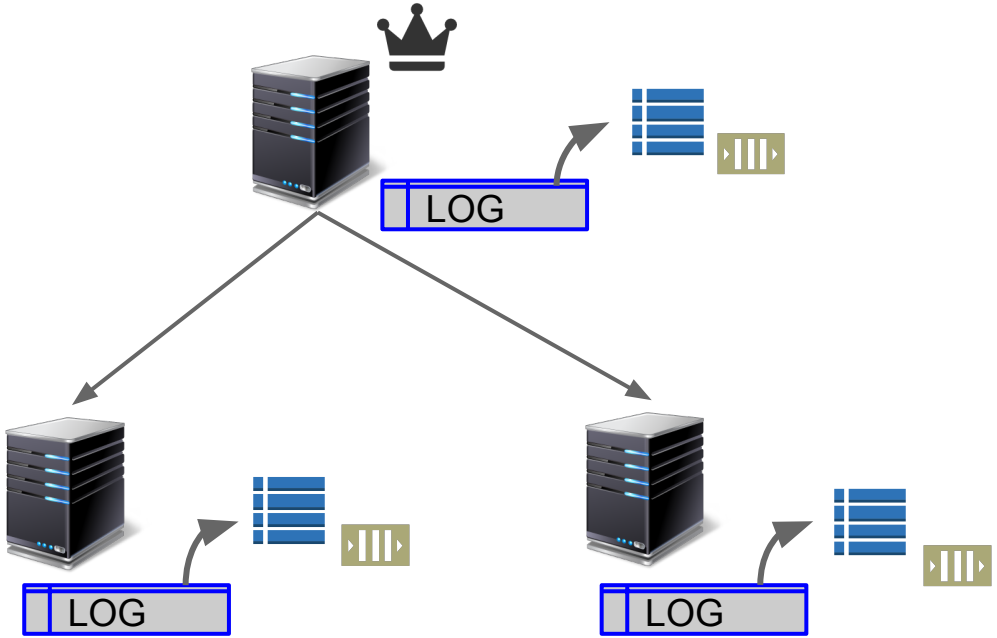
- Since we use LLDP & BDDP to discover links, it takes longer to discover a link coming up than going down

- Port down event trigger immediate teardown of the link.

Next topic: Strong consistency

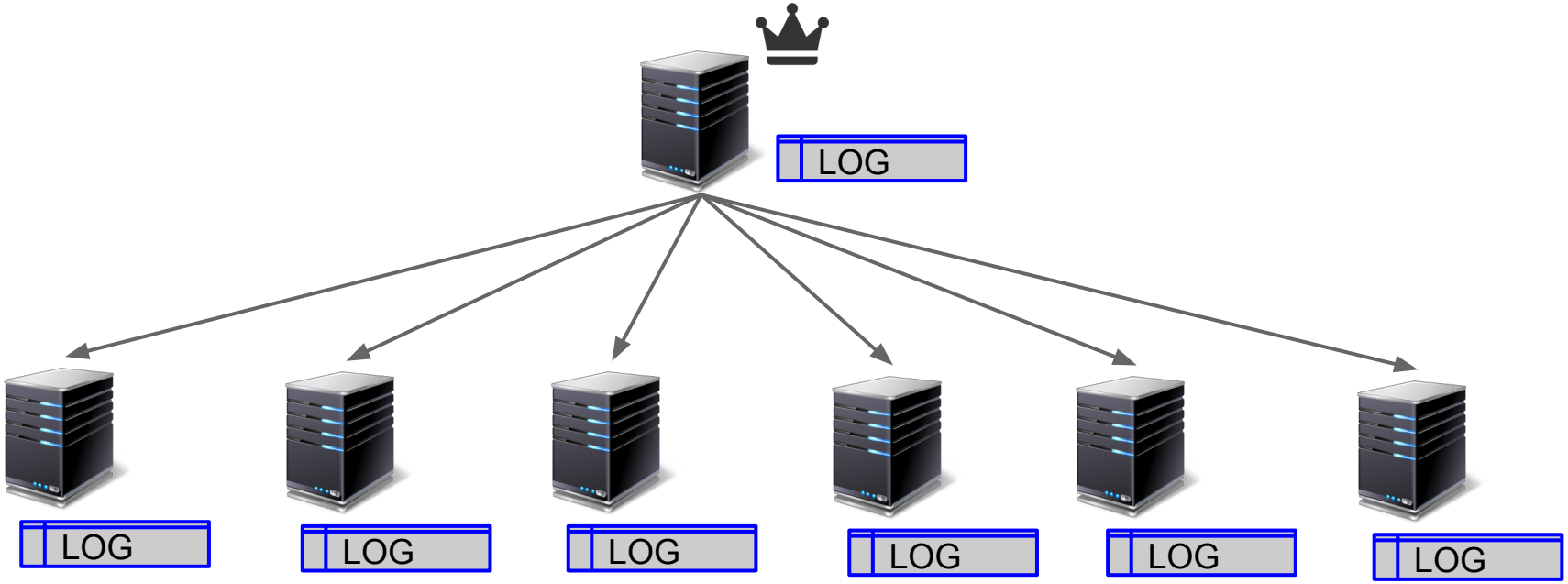
- **EventualConsistency** is necessary but not sufficient
- Some state requires stronger guarantees
  - Reservations is a prime example
- Hard to layer abstractions when you a have a store that only provides weak guarantees

Strong Consistency via Consensus

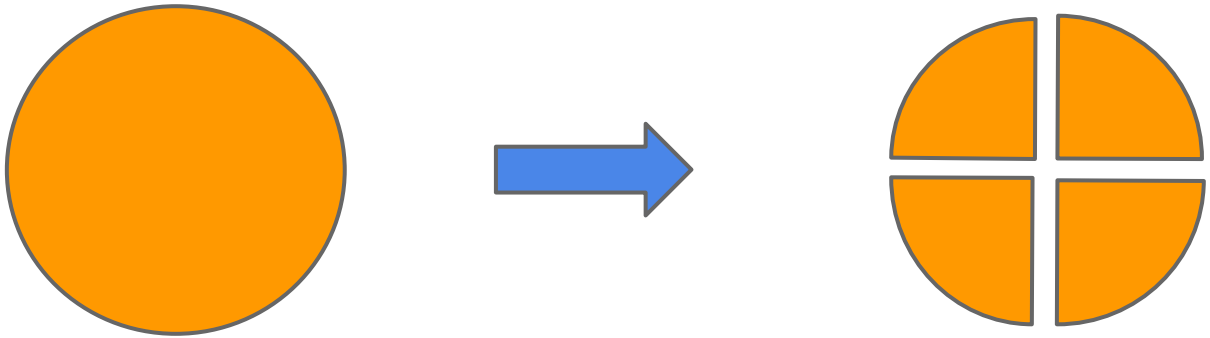


Replicated State Machine

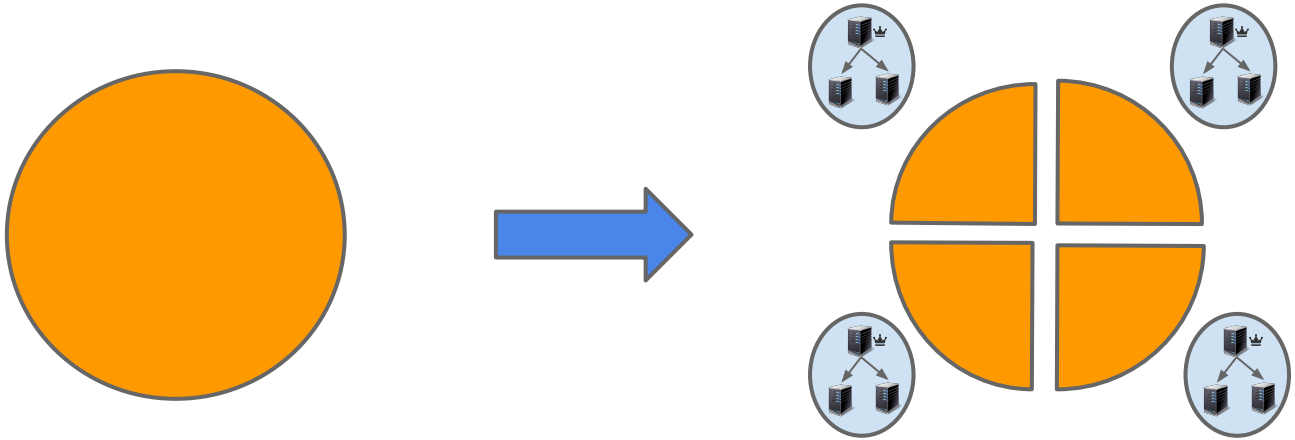
Strong Consistency via Consensus



Scaling Strong Consistency via Partitioning



Scaling Strong Consistency via Partitioning



Distributed Primitives

- ConsistentMap<K, V>
- TransactionalMap<K, V>

Provides transactional semantics for single and group updates

Other Distributed Primitives

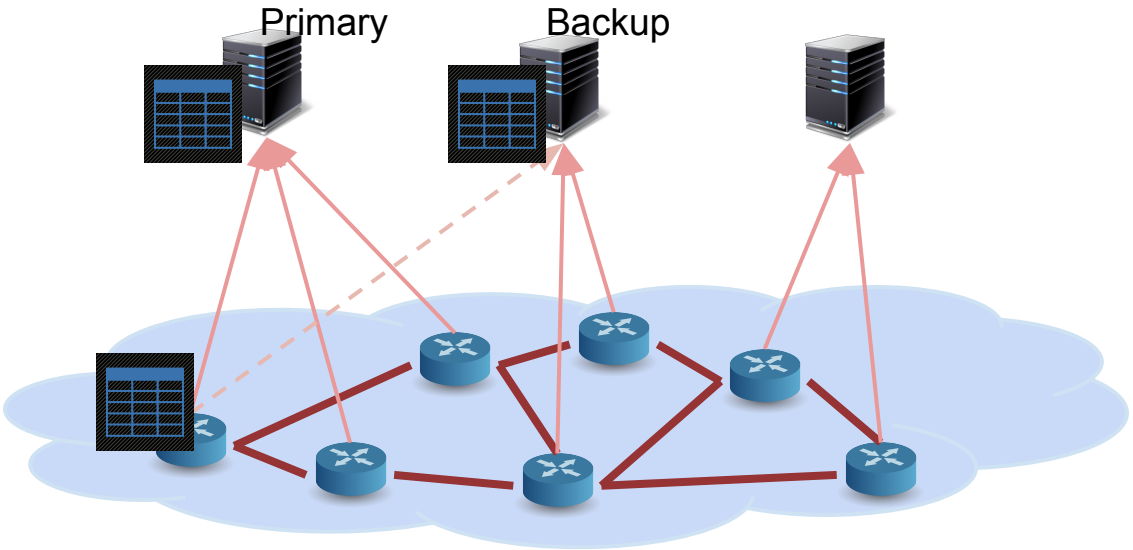
- DistributedSet<E>
- DistributedQueue<E>
- AtomicCounter

Final example: Flows

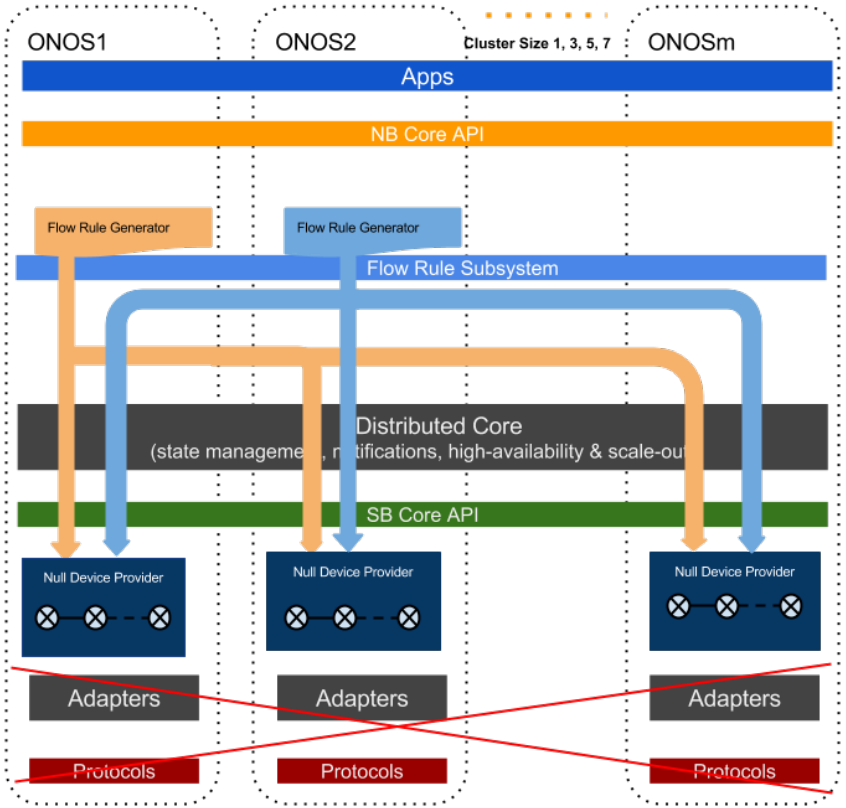
- Forwarding plane rules
- Programmed onto individual switches
- Control plane is the arbiter of truth

Flows

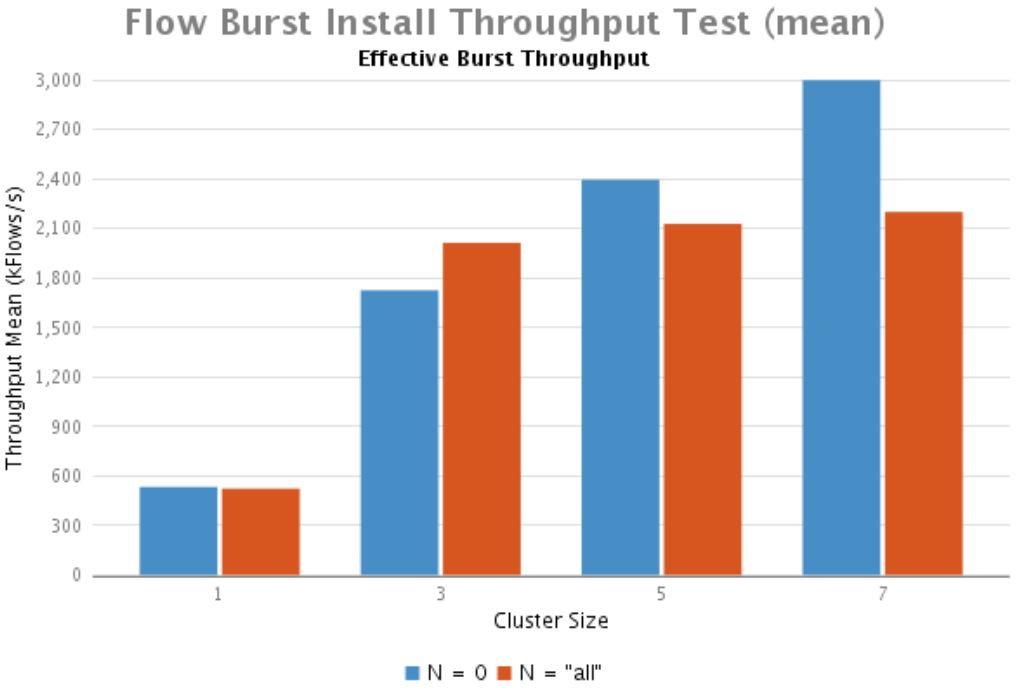
- Primary-backup replication
- Switch master is *primary* and **next** master is *backup*
- Fast read/write access
- Minimal overhead on failover



Flow Rule Operations Throughput

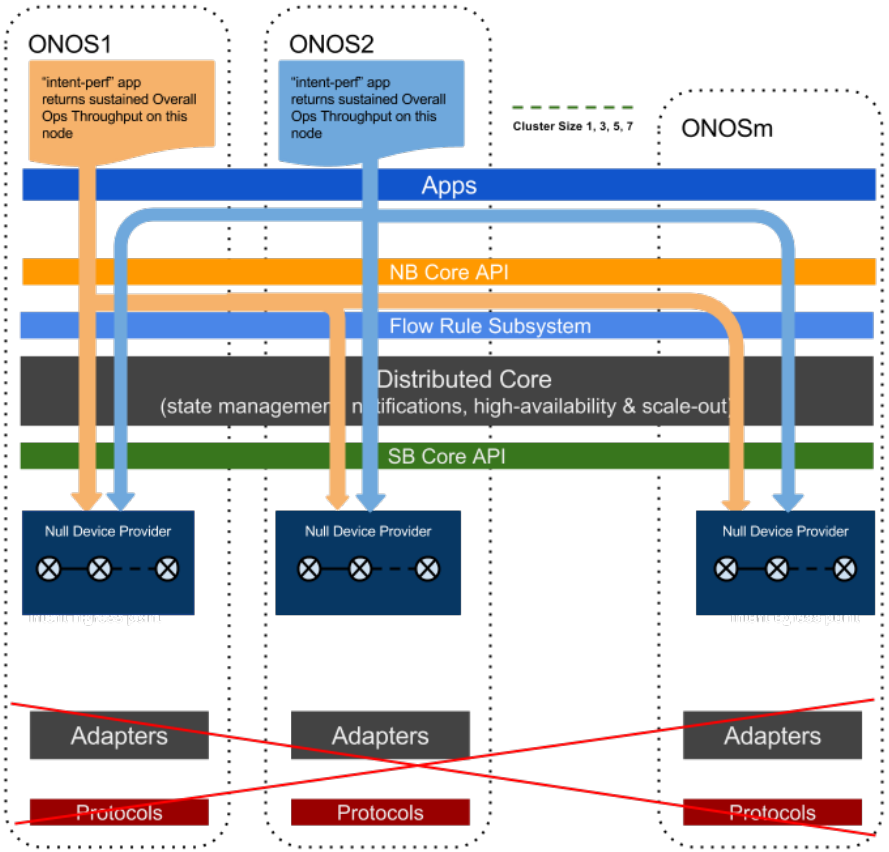


Flow Throughput results

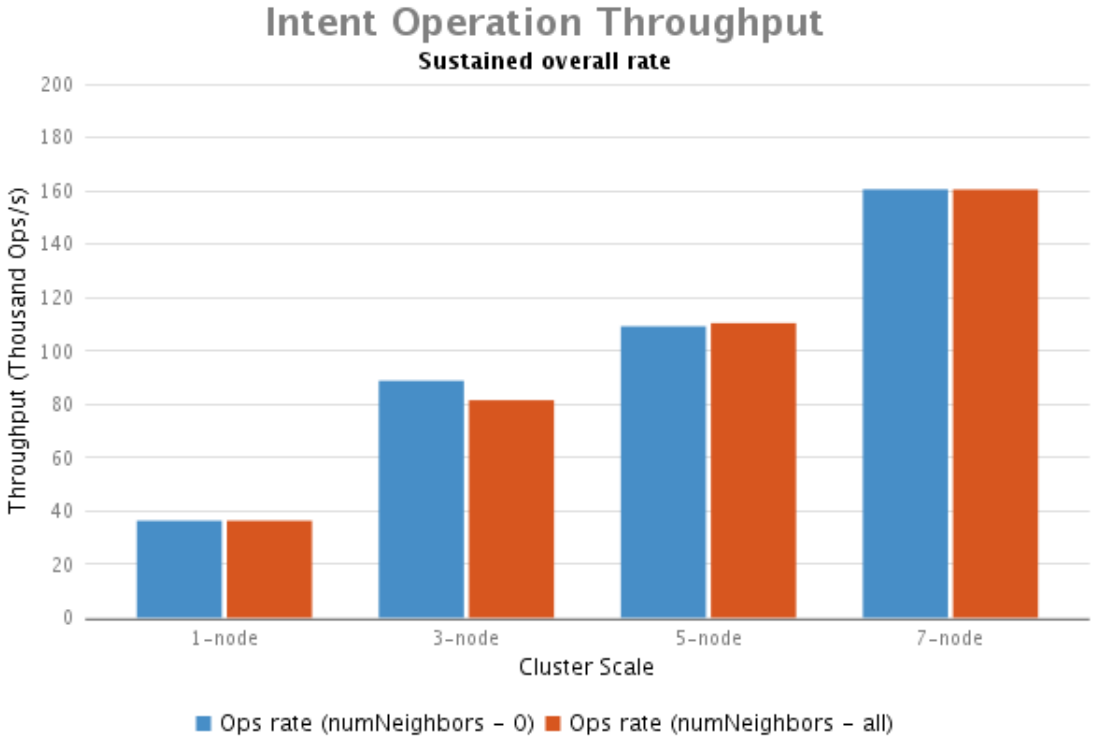


- Single instance can install over 500K flows per second
- ONOS can handle 3M local and 2M non local flow installations
- With 1-3 ONOS instances, the flow setup rate remains constant no matter how many neighbours are involved
- With more than 3 instances injecting load the flow performance drops off due to extra coordination requires.

Intent Throughput Experiment

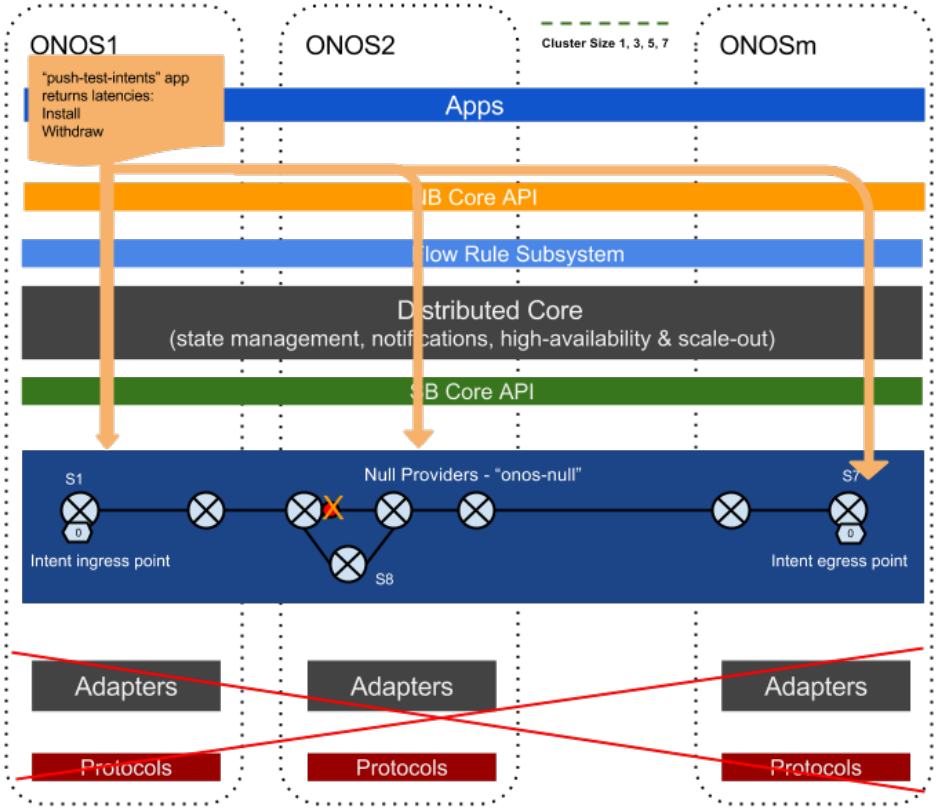


Intent Throughput Results

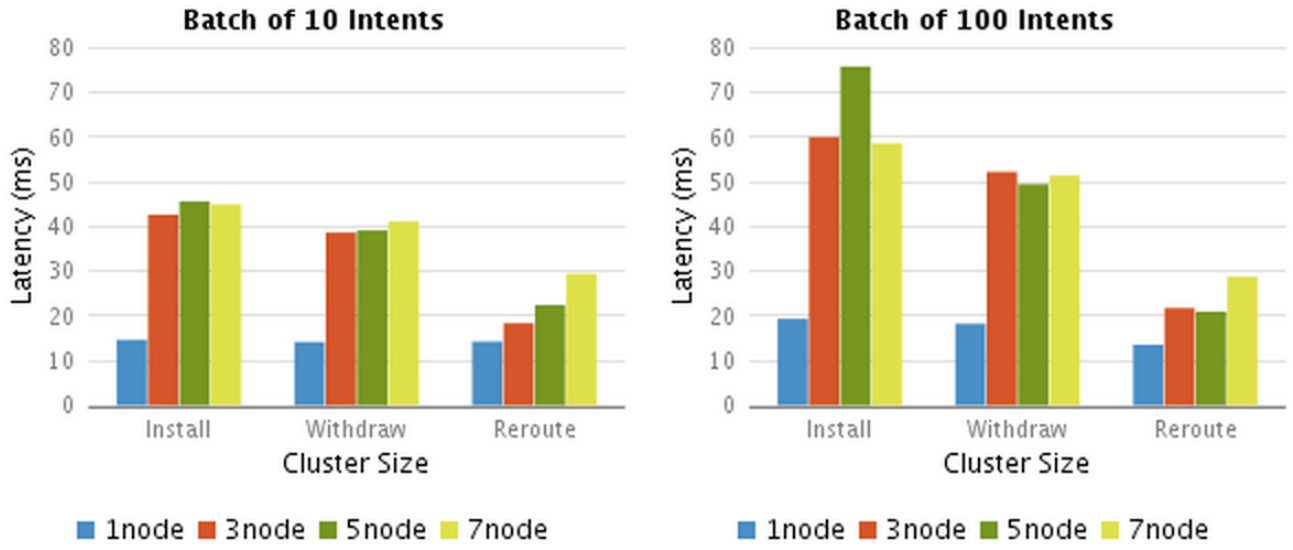


- Processing clearly scales as cluster size increases

Intent Latency Experiment

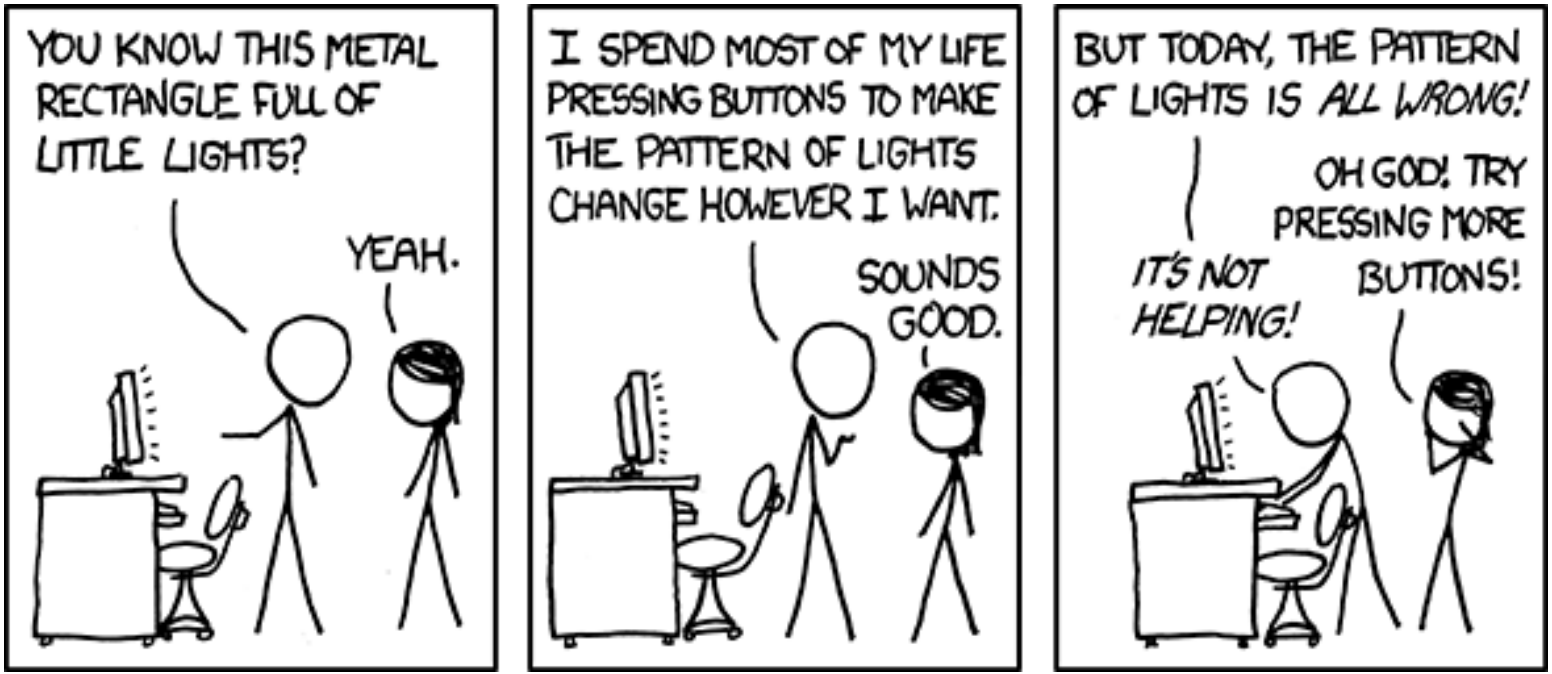


Intent Latency Results



- Less than 100ms to install or withdraw a batch of intents
- Less than 50ms to process and react to network events
  - Slightly faster because intent objects are already replicated

Lunch Break



xkcd.com

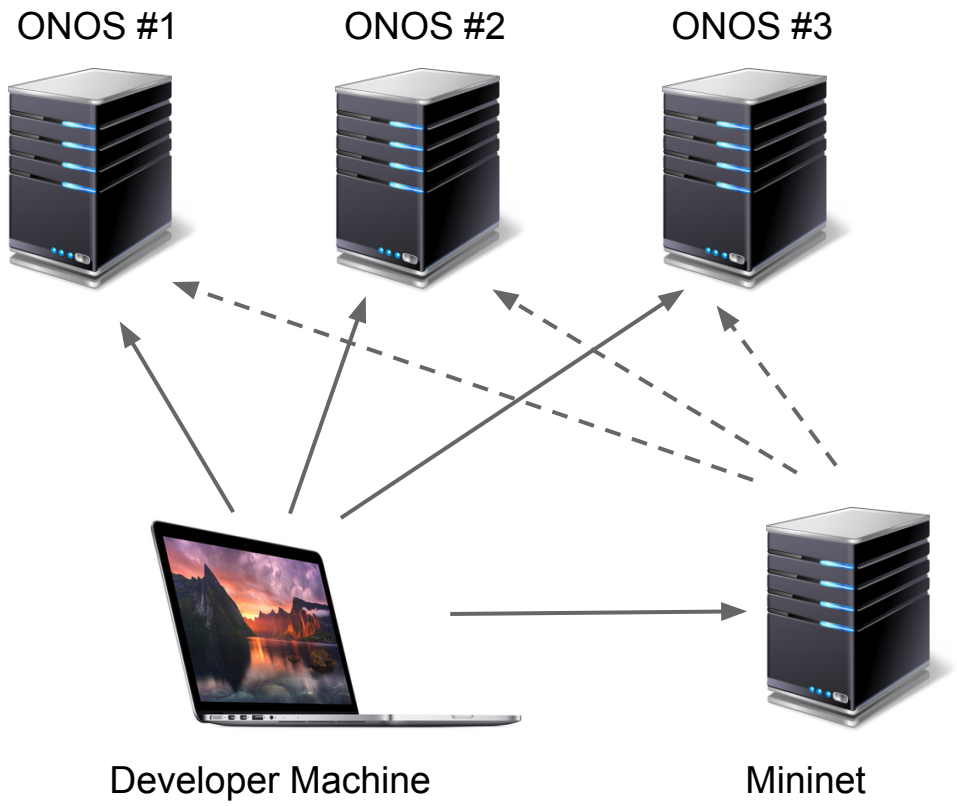
ONOS Dev Workshop Outline

- *ONOS Fundamentals*
  - *architecture, checking out, building & running ONOS*
- *ONOS Distributed Core*
  - *OSGi, anatomy of a core subsystem, distributed stores & primitives*
- ONOS App Development
  - background, Maven archetypes, app deployment on ONOS cluster
- ONOS Interfaces
  - component config service, flow objective service, intent service
  - CLI, REST and GUI overview
- Wrap-up

ONOS App Development 13:15-14:45

- Installing ONOS cluster from onos.tar.gz (~10)
  - untar, `onos-service`, `onos-form-cluster`
- ONOS Applications (~10)
  - OSGi bundles, Karaf features, ONOS apps & OAR files
  - application lifecycle - install, activate, deactivate, uninstall
  - ONOS CLI & GUI
- Developing ONOS apps (~50)
  - use `mvn archetype:generate` and `onos-create-app`
  - archetype overlays for CLI and UI - generated & pre-canned
  - iterative and demonstrating use of `onos-app` tool or GUI

Working with ONOS cluster



Install ONOS cluster from tar.gz

- Install ONOS on all three instances
  - we will use iTerm to do so simultaneously

```
$ onos-cell demo && onos-iterm-cli
```

- Fetch ONOS bits via wget

```
$ wget http://downloads.onosproject.org/onos-1.3.0.dev.tar.gz
```

- Untar bits

```
$ tar zxf onos-1.3.0.dev.tar.gz
```

Start ONOS instances

- Start ONOS

```
$ cd onos-1.3.0.dev
$ bin/onos-service server &
```

- Verify install as individual instances

```
$ bin/onos
onos> nodes
```

- Check logs

```
$ tail -f log/karaf.log
```

Form ONOS cluster

- Form ONOS cluster from individual instances

```
$ bin/onos-form-cluster 10.128.11.1 10.128.11.2 10.128.11.3
```

- Verify install as a cluster

```
$ bin/onos
onos> nodes
```

- Check logs

```
$ tail -f log/karaf.log
```

Setup test network

- Connect mininet to cluster machines

```
$ sudo mn --topo tree,3,4 --controller remote,...
```

- Activate proxy ARP and reactive forwarding apps

```
onos> app activate org.onosproject.proxyarp
onos> app activate org.onosproject.fwd
```

- Issue pingall a few times to show unencumbered flow

```
mininet> pingall
mininet> pingall
```

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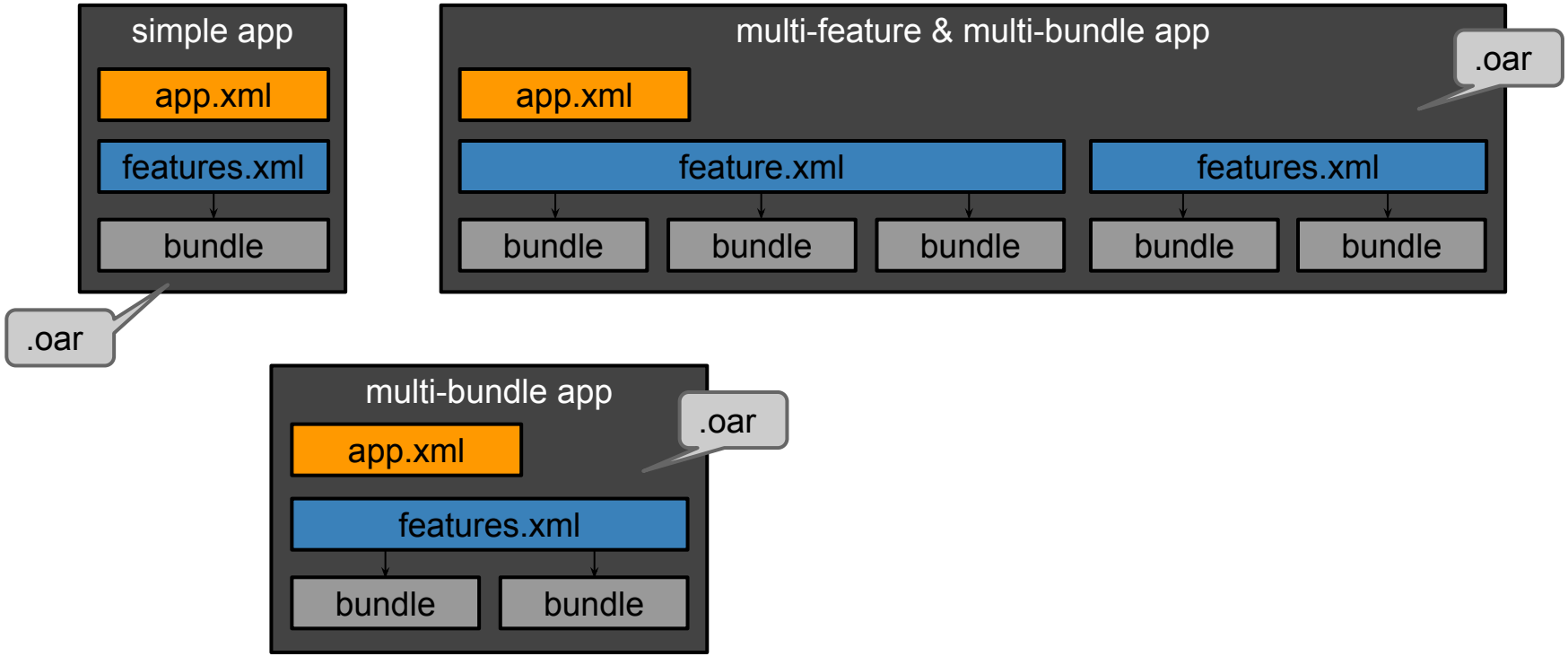
Bundles, Features & ONOS Apps



Bundles, Features & ONOS Apps

- Apps are delivered via ONOS App aRchive (`.oar`) files
  - OAR is a JAR with `app.xml`, `features.xml` and bundle artifacts
  - `onos-maven-plugin` generates an `*.oar` file as part of Maven build
- Apps are managed on the entire ONOS cluster
  - via REST API: `GET|POST|DELETE /onos/v1/applications`
  - via shell tool: `onos-app {install|activate|deactivate|uninstall}`
  - via CLI: `onos:app {install|activate|deactivate|uninstall}`
  - via GUI Applications view
- Back-end installation and activation is done via normal feature & bundle services

Developing ONOS apps

- Maven archetypes
  - `onos-bundle-archetype` - basis for an ONOS bundle or an app
  - `onos-cli-archetype` - overlay for apps with CLI extensions
  - `onos-ui-archetype` - overlay for apps with GUI extensions
  - `onos-api-archetype` - basis for an app Java API bundle
- Run `mvn archetype:generate` to create a working minimal project module
- For simpler usage run `onos-create-app` shell tool
  - simply a convenience wrapper for `mvn`

ONOS App Development 13:15-14:45

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One Ping Only ONOS app

One Ping Only ONOS app

Minimal ONOS app project

- Create minimal app project via `onos-create-app` tool

```
$ onos-create-app app org.oneping oneping 1.0-SNAPSHOT
```

- Build the app via Maven

```
$ cd oneping
$ mvn clean install
```

- Deploy the app to ONOS cluster via `onos-app` tool

```
$ onos-app 10.128.11.1 install! target/oneping*.oar
```

Code & deploy OnePingOnly app

- *“Code”* our app as `OnePing.java`

- Rebuild the app via Maven and redeploy it

```
$ mvn clean install
$ onos-app 10.128.11.1 reinstall! target/oneping*.oar
```

Show one-ping-only enforcement

- Issue one ping between two hosts

```
mininet> h1 ping -c1 h2
mininet> h1 ping -c1 h3
```

- Issue another ping between the same two hosts

```
mininet> h1 ping -c1 h2
```

- Show failed second ping and messages in the logs

ONOS app overlay archetypes

- Some ONOS archetypes can be used to enhance an existing project with additional capabilities
  - add CLI extensions
  - add GUI extensions
  - others in future

- Simply run `onos-create-app` tool in the same project

- First show that sample command does not exist

```
onos> sample
```

Overlay CLI archetype

- Overlay CLI additions via `onos-create-app`

```
$ onos-create-app cli org.oneping oneping 1.0-SNAPSHOT
```

- Rebuild and redeploy the enhanced app

```
$ mvn clean install
$ onos-app 10.128.11.1 reinstall! target/oneping*.oar
```

- Show that sample command now exists

```
onos> sample
```

Overlay GUI archetype

- Show existing GUI navigation menu
- Overlay GUI additions via `onos-create-app` and rebuild

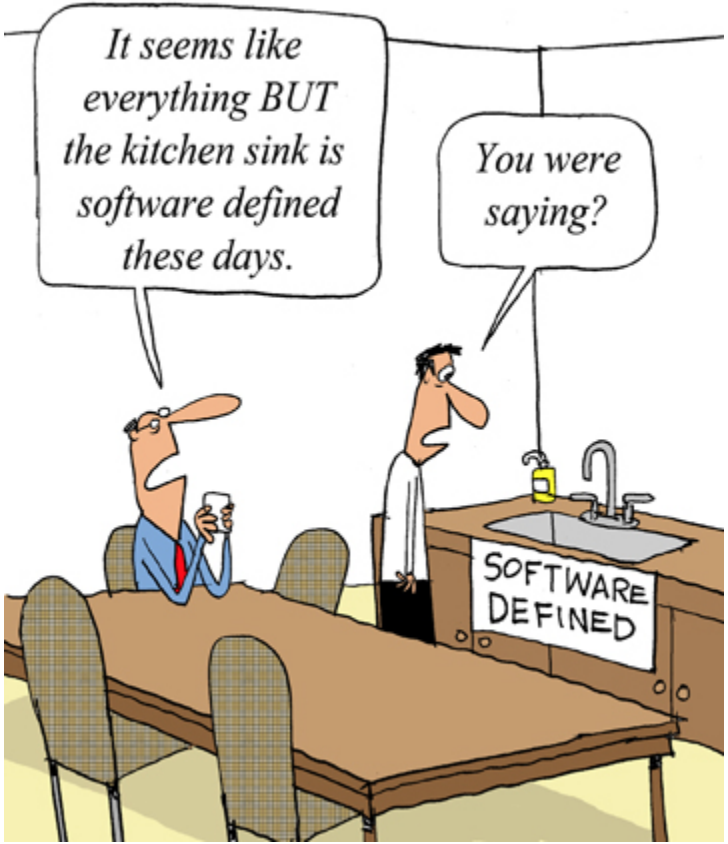
```
$ onos-create-app ui org.oneping oneping 1.0-SNAPSHOT
```

- Rebuild and redeploy the enhanced app

```
$ mvn clean install
$ onos-app 10.128.11.1 reinstall! target/oneping*.oar
```

- Refresh GUI and show enhanced GUI navigation menu

Break

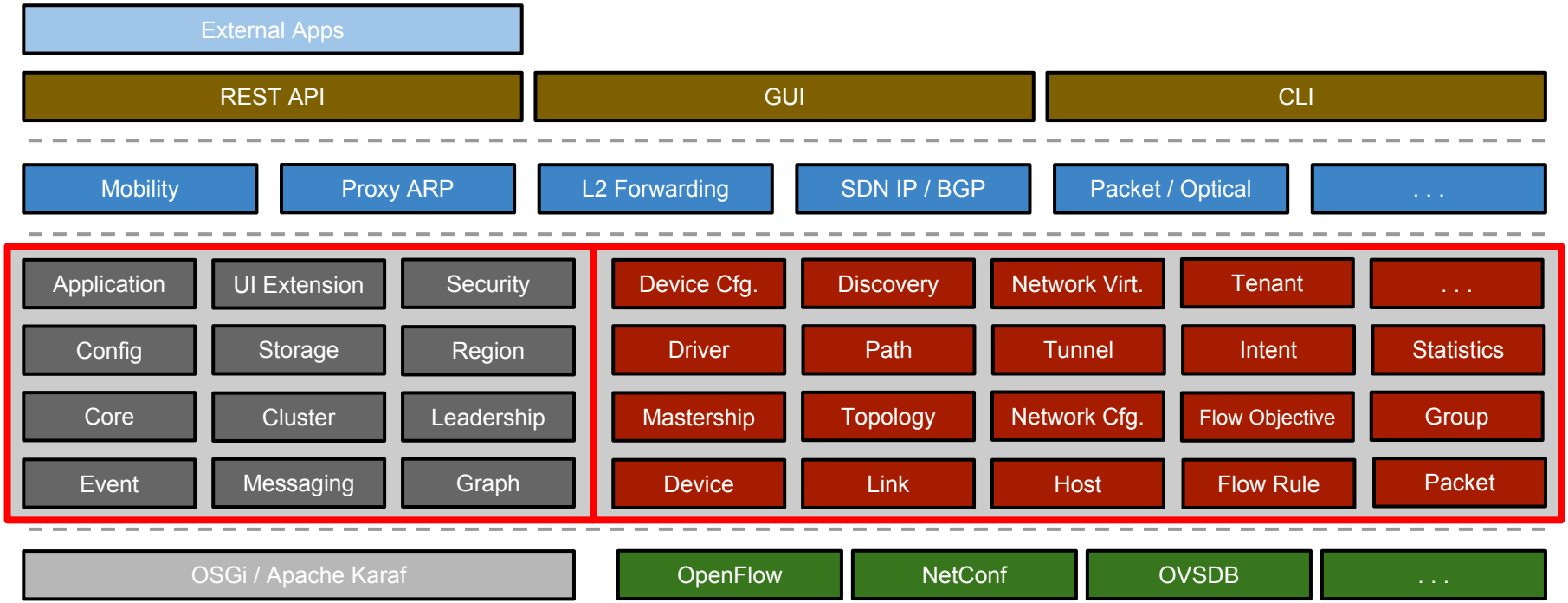

It seems like everything BUT the kitchen sink is software defined these days.
You were saying?
SOFTWARE DEFINED

ONOS Interfaces

15:15-17:00

- Component Config Service (~10)
- Device Drivers Service (~10)
- Flow Objective Service (~15)
- Intent Service (~15)
- GUI overview (~15)
- CLI overview (~5)
- REST API overview (~5)
- Wrap-up & Final QA (~15)

ONOS Core Subsystems



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Component Config Subsystem

- Provide centralized and cluster-wide component configuration
- Avoid drift between configurations on cluster instances
- Built atop the OSGi `ConfigurationAdmin` service
- Components accept configuration via standard OSGi `@Modified` hook
- Catalogue of config properties for each component generated at build-time via `onos-maven-plugin`

Component Config Subsystem

- Component registers its properties on activation

```
void registerProperties(getClass());
```

- Component unregisters its properties on deactivation

```
void unregisterProperties(getClass(), false);
```

- Component provides configuration method hook

```
@Modified
public void modified(ComponentContext context) { … }
```

ONOS Interfaces

15:15-17:00

- Component Config Service (~10)
- Device Drivers Service (~10)
- Flow Objective Service (~15)
- Intent Service (~15)
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- CLI overview (~5)
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Device Driver Subsystem

- Isolate device-specific code
- Allow asynchronous delivery & dynamic loading
  - by ON.Lab, vendors or others
- Allow abstracting of how to interact with devices
  - via Java API (`Behaviour` interfaces)
- Avoid a monolithic driver approach
  - different facets of behaviour can come from different sources
- Facilitate specialization via inheritance
  - families of devices share many similar characteristics

Driver

- Representation of a specific family of devices or a specific device
  - has a unique name, e.g. `ciena-6500`
  - supports set of `Behaviour` classes
  - may *inherit* behaviours from another `Driver`

- `DefaultDriver` is a default implementation class

DriverAdminService

- Service for tracking driver providers

  ```
  Set<DriverProvider> getProviders()
  registerProvider(DriverProvider)
  unregisterProvider(DriverProvider)
  ```

- `DriverProvider` provides a set of driver definitions

  ```
  Set<Driver> getDrivers()
  ```

DriverService

Service for locating appropriate drivers for the device

- by driver name
- by manufacturer, H/W version & S/W version patterns
- by supported behaviour
- by device ID

Behaviour & HandlerBehaviour

- `Behaviour` is an interface for talking about a device

- `HandlerBehaviour` is an interface for interacting with a device
  - `OpenFlowController`
  - `OpenFlowPipeliner`
  - `...`

DriverData & DriverHandler

- `DriverData` is a container for data about a device
  - provides behaviours for talking about a device
  - has parent driver

- `DriverHandler` is a context for interacting with a device
  - provides behaviours for interacting with a device
  - has `DriverData`
  - has parent driver

ONOS Interfaces

15:15-17:00

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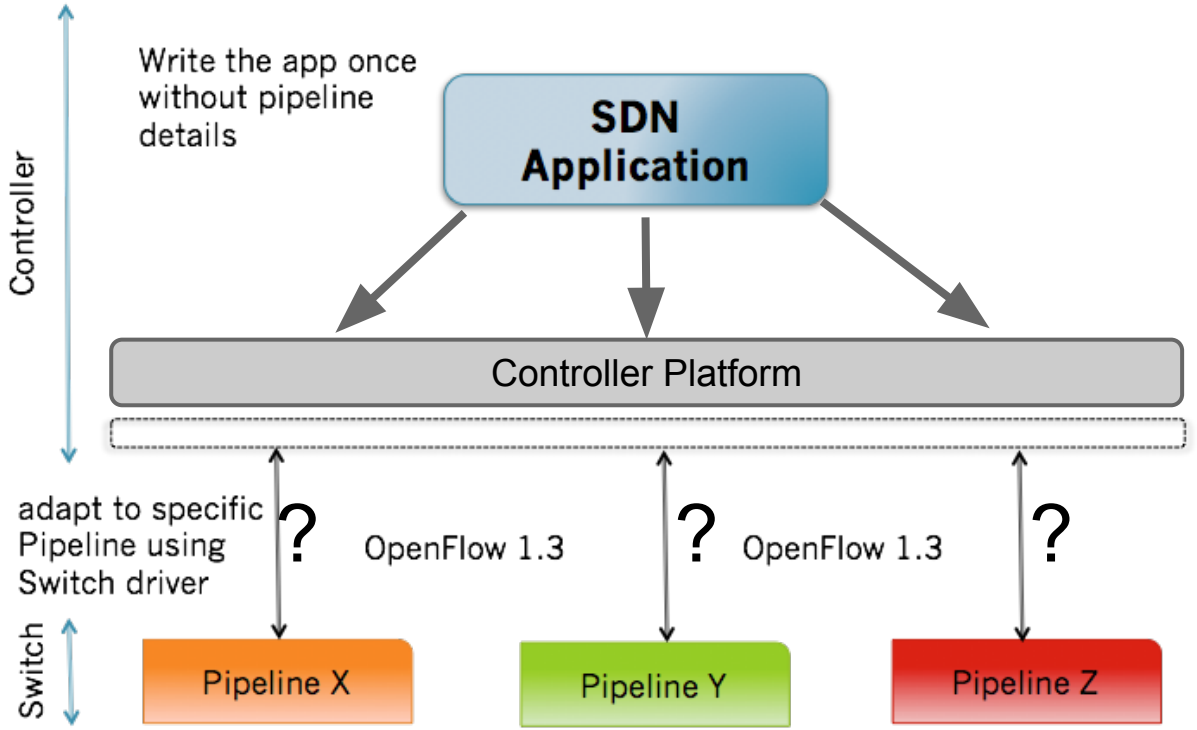
Flow Objective Subsystem

- **Problem:** Applications today must be pipeline aware, effectively making them applicable to specific HW.



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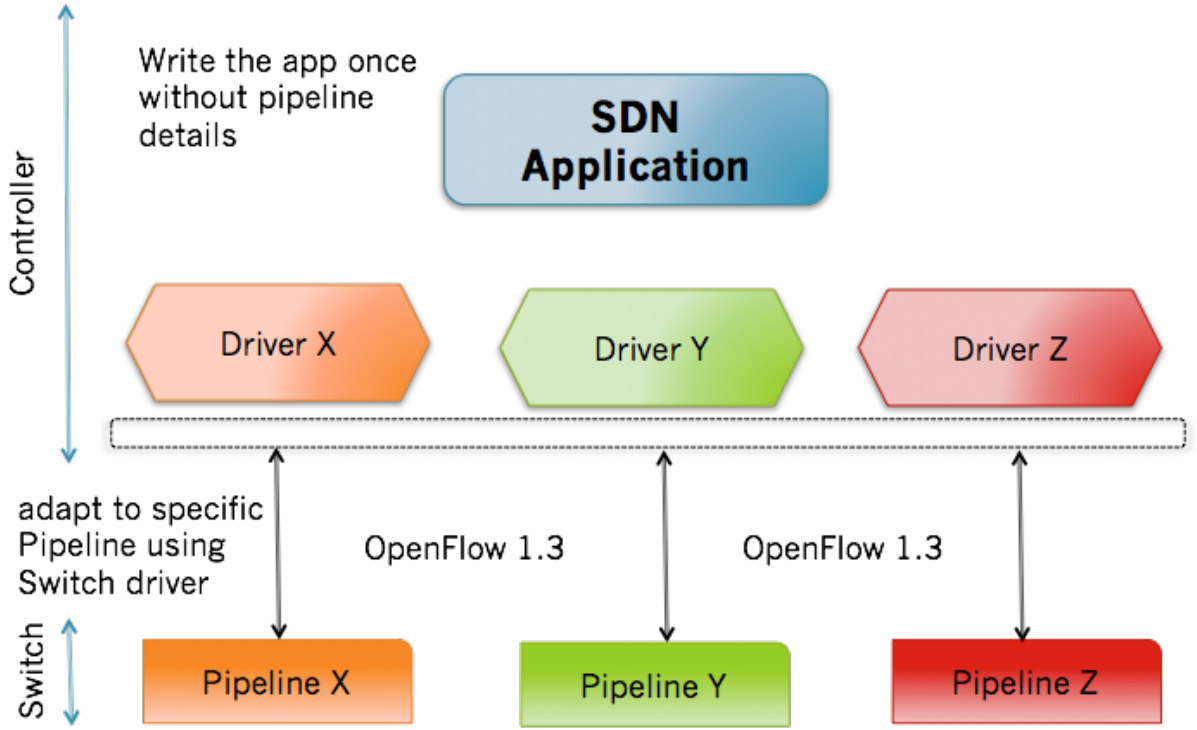
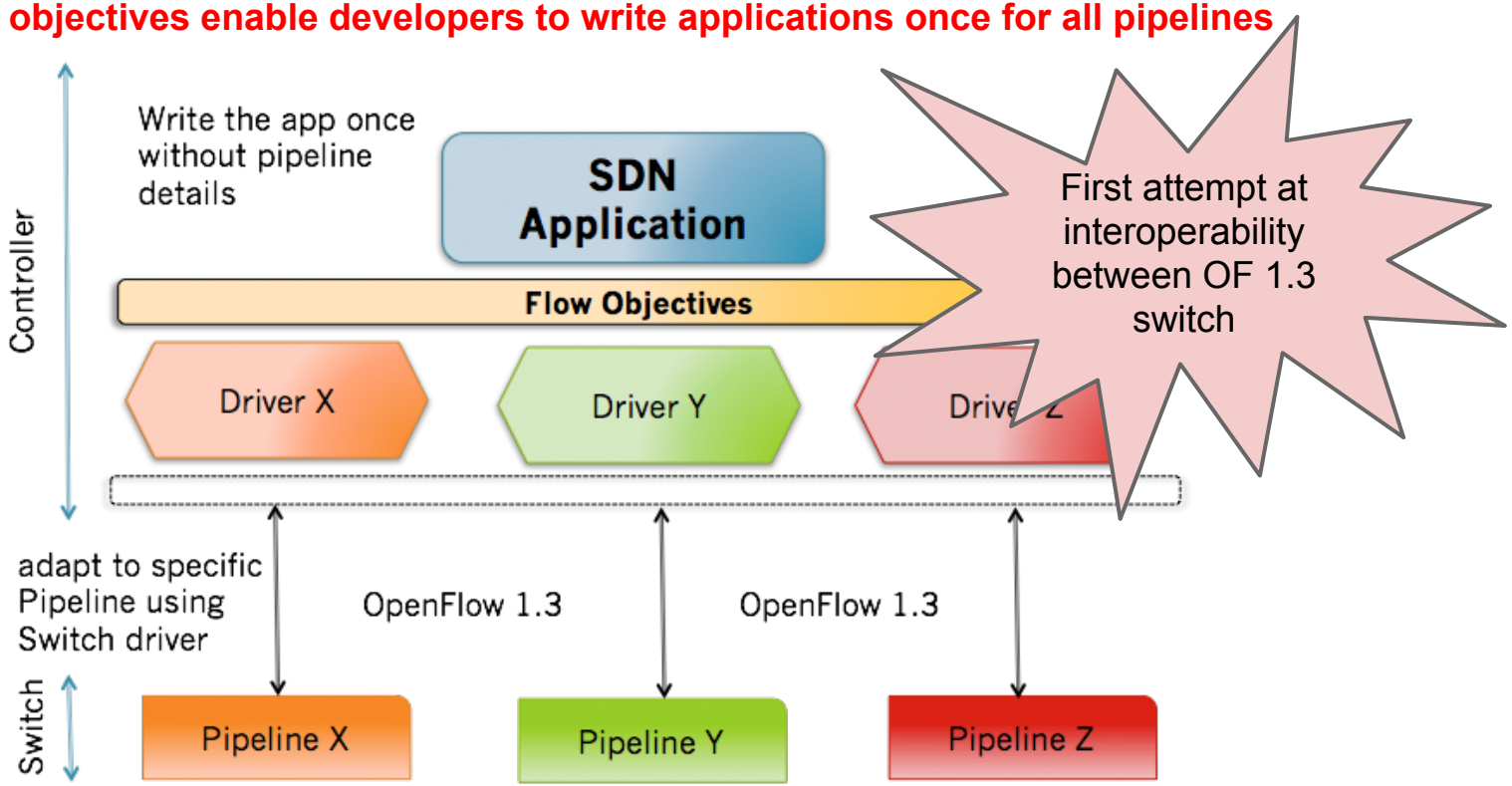


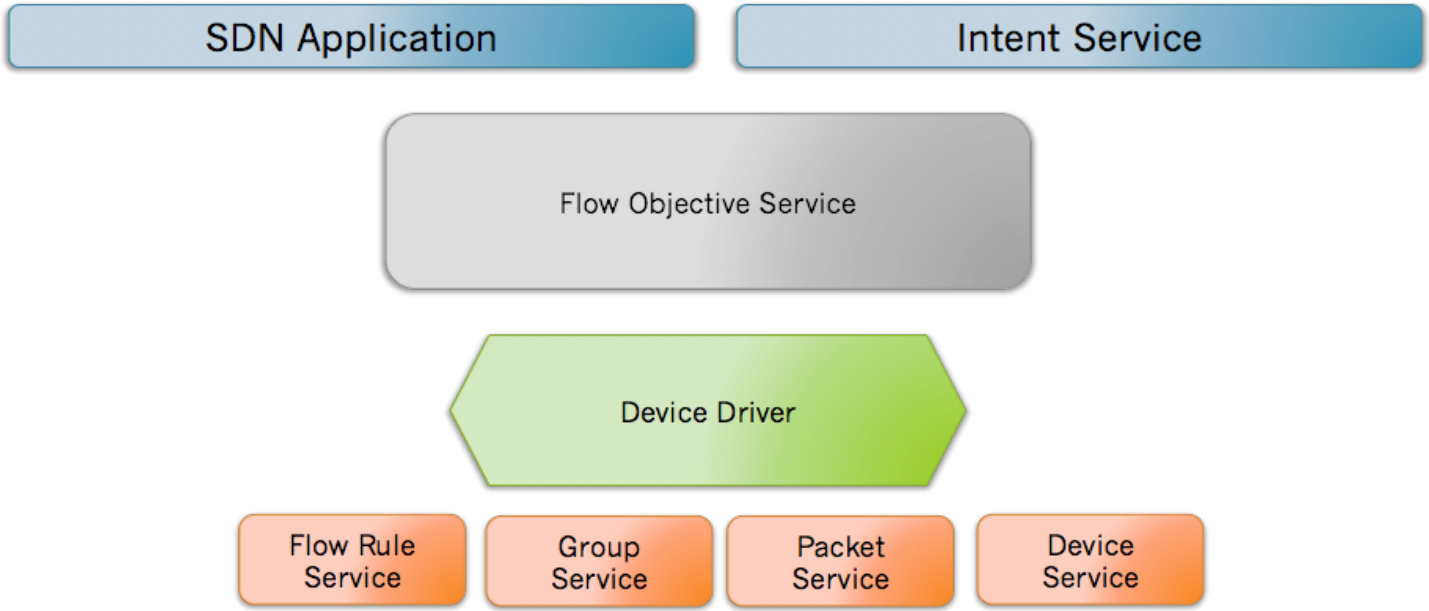
Flow Objective Abstraction

- **Problem:** Applications currently must be pipeline aware, effectively making applicable on specific HW.

Flow objectives enable developers to write applications once for all pipelines



Flow Objective Service



- Applications use Objective to take advantage multi-table architectures
- Other services also make use of the Objective service (eg. Intent Service)
- Device driver translates objectives to the specific flow rules for a given device

Flow Objectives

- Flow Objectives describe a SDN application's objective behind a **flow** it is sending to a **device**

- We currently only have three types of objectives:
  1. Filtering Objective
  2. Forwarding Objective
  3. Next Objective

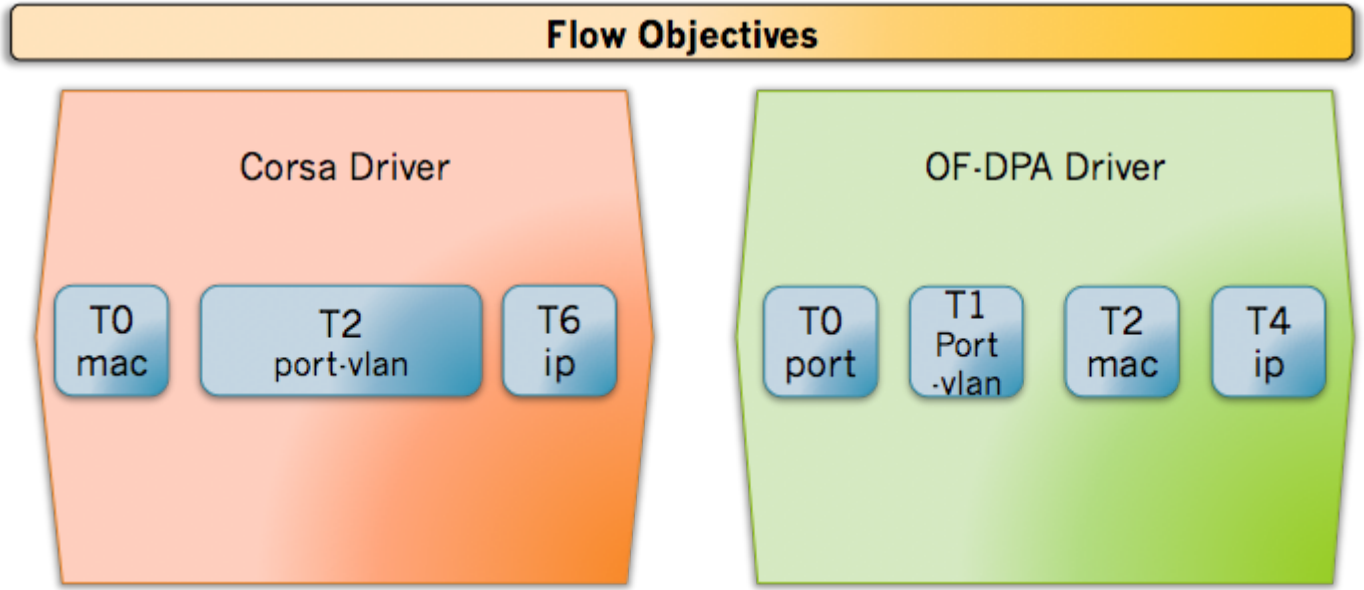
Filtering Objective

- Filter -> only Permit or Deny options
- On criteria (match fields)

Example:
Peering Router

Switch Port : **X**

Permit: MAC 1, VLAN 1, IP 1, 2, 3
Permit: MAC 1, VLAN 2, IP 4, 5



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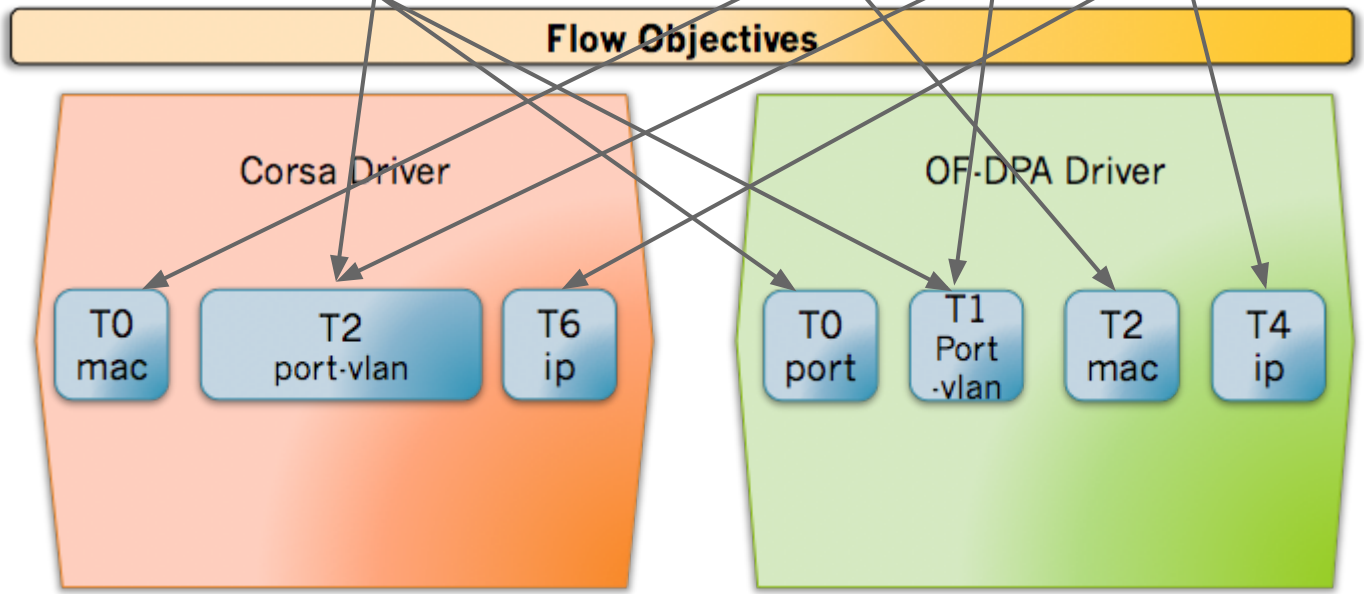
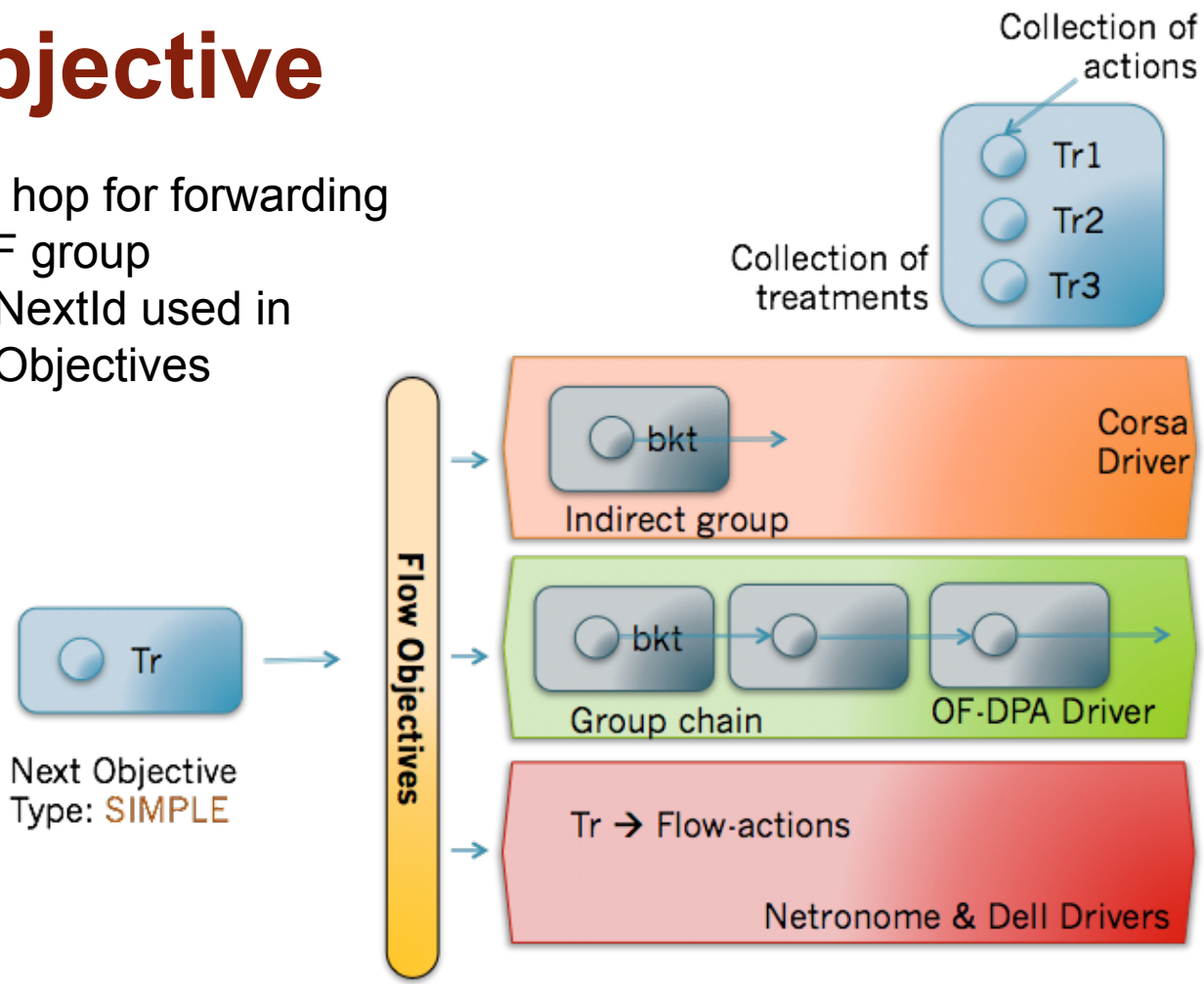


Next Objective

- Next -> next hop for forwarding
- Similar to OF group
- Keyed by a NextId used in Forwarding Objectives



Forwarding Objective

- Forwarding: { Selector -> Next Id }
- Forwarding Types: Specific or Versatile
  - Specific -> MAC, IP, MPLS forwarding tables
  - Versatile -> ACL table
- NextId is resolved to whatever the driver previously built for the corresponding Next Objective

Objectives - Simpler applications

```
for (InterfaceIpAddress ipAddr : intfIps) {
    log.debug("adding rule for IPs: {}", ipAddr.ipAddress());
    selector = DefaultTrafficSelector.builder();
    treatment = DefaultTrafficTreatment.builder();

    selector.matchEthType(Ethernet.TYPE_IPV4);
    selector.matchIPDst(IpPrefix.valueOf(ipAddr.ipAddress(), 32));
    treatment.transition(Type.ACL);

    rule = new DefaultFlowRule(deviceId, selector.build(),
                               treatment.build(), HIGHEST_PRIORITY, appId,
                               0, true, FlowRule.Type.IP);

    ops = install ? ops.add(rule) : ops.remove(rule);
}
```

```
for (MacAddress mac : intfMacs) {
    log.debug("adding rule for MAC: {}", mac);
    selector = DefaultTrafficSelector.builder();
    treatment = DefaultTrafficTreatment.builder();

    selector.matchEthDst(mac);
    treatment.transition(FlowRule.Type.VLAN_MPLS);

    rule = new DefaultFlowRule(deviceId, selector.build(),
                               treatment.build(),
                               CONTROLLER_PRIORITY, appId, 0,
                               true, FlowRule.Type.FIRST);

    ops = install ? ops.add(rule) : ops.remove(rule);
}
```

```
for (Map.Entry<PortNumber, VlanId> portVlan : portVlanPair.entrySet()) {
    log.debug("adding rule for VLAN: {}", portVlan);
    selector = DefaultTrafficSelector.builder();
    treatment = DefaultTrafficTreatment.builder();

    selector.matchVlanId(portVlan.getValue());
    selector.matchInPort(portVlan.getKey());
    treatment.transition(Type.ETHER);
    treatment.deferred().popVlan();

    rule = new DefaultFlowRule(deviceId, selector.build(),
                               treatment.build(), CONTROLLER_PRIORITY, appId,
                               0, true, FlowRule.Type.VLAN);

    ops = install ? ops.add(rule) : ops.remove(rule);
}
```

```
private void processIntfFilters(boolean install, Set<Interface> intfs) {
    log.info("Processing {} router interfaces", intfs.size());
    for (Interface intf : intfs) {
        FilteringObjective.Builder fob = DefaultFilteringObjective.builder();
        fob.withKey(Criteria.matchInPort(intf.connectPoint().port()))
           .addCondition(Criteria.matchEthDst(intf.mac()))
           .addCondition(Criteria.matchVlanId(intf.vlan()));
        intf.ipAddresses().stream()
            .forEach(ipaddr -> fob.addCondition(
                               Criteria.matchIPDst(ipaddr.subnetAddress())));
        fob.permit().fromApp(appId);
        flowObjectiveService.filter(deviceId,
                            Collections.singletonList(fob.add()));
    }
}
```

Flow Objective Summary

- *Flow Objective Service:* **Abstraction** for applications to be **pipeline unaware** while **benefiting** from scalable, multi-table architectures
- Aims to make it **simple** to write apps
- First attempt at achieving **interoperability** between OF 1.3 implementations

ONOS Interfaces

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Building Network Applications

Objective: Connect Host 1 and Host 2

Host 1

Host 2

Building Network Applications

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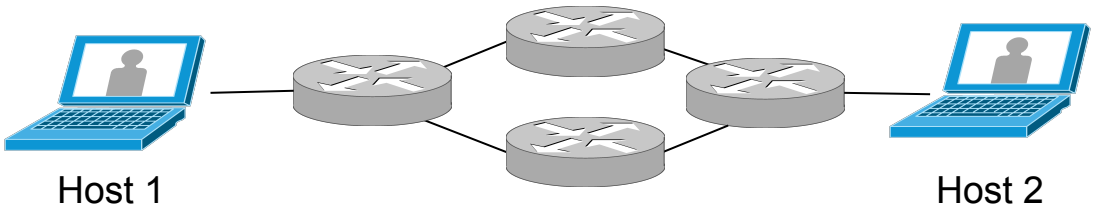
1. Read/discover the topology



Building Network Applications

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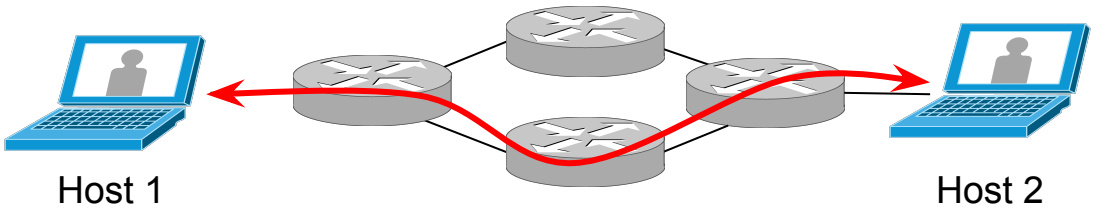
1. Read/discover the topology
2. Compute a path



Building Network Applications

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1. Read/discover the topology
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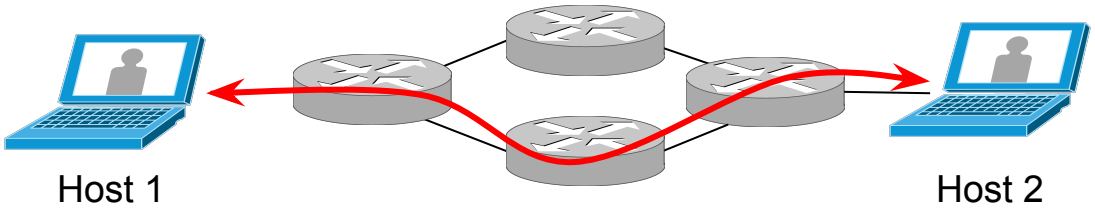
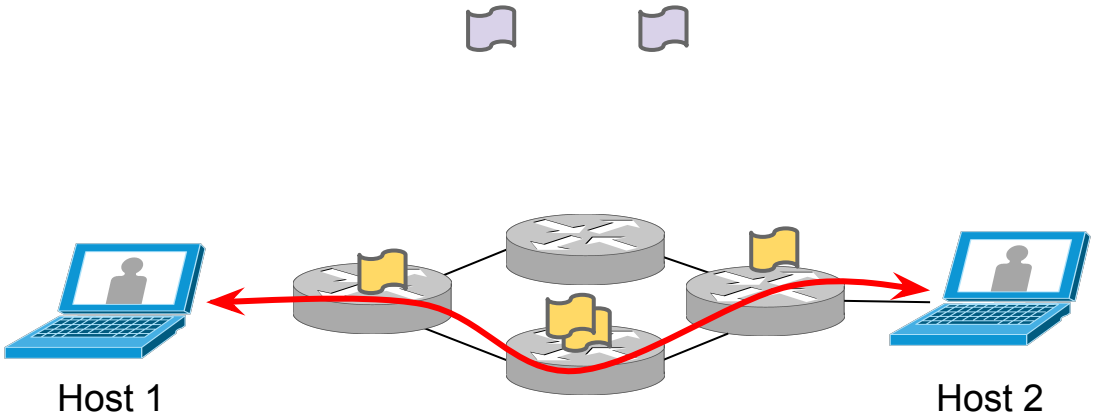
3. Build flow objectives for each device



Building Network Applications

Objective: Connect Host 1 and Host 2

1. Read/discover the topology
2. Compute a path
3. Build flow objectives for each device
4. Install rules in consistent way



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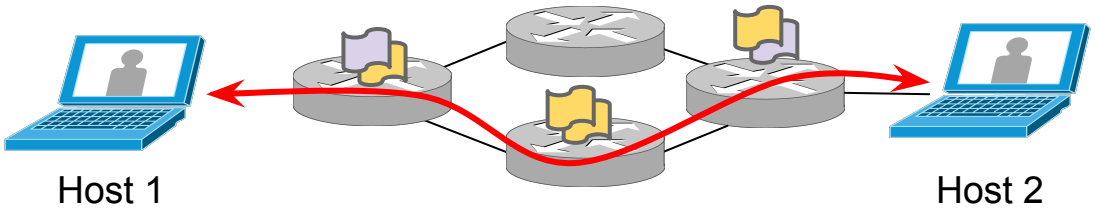
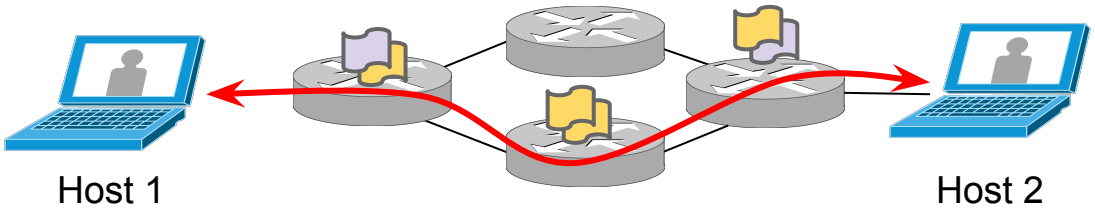


Building Network Applications

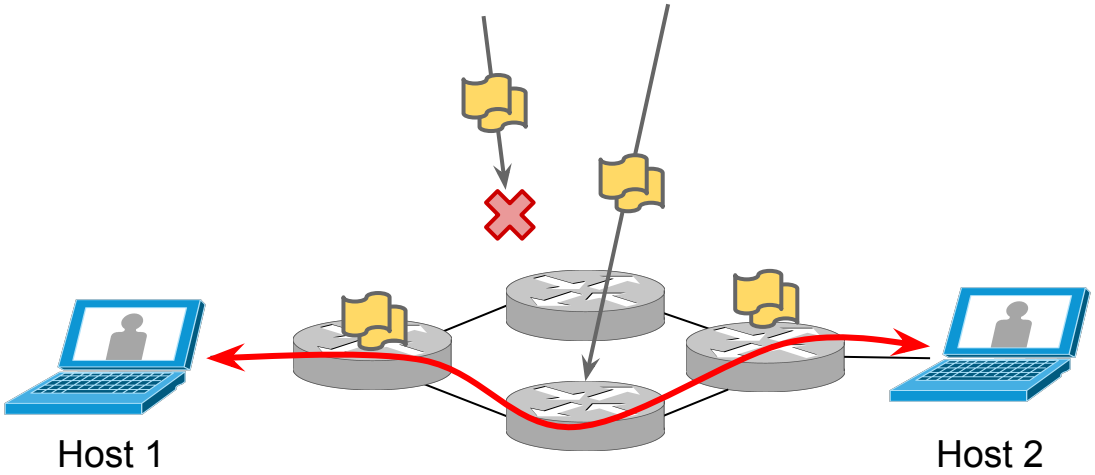
What can go wrong?



Building Network Applications

What can go wrong?

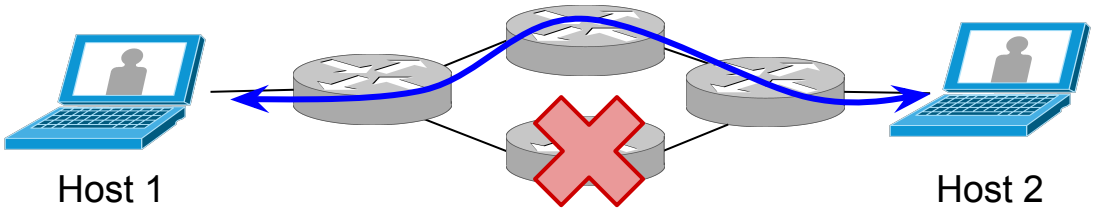
- Missing / rejected / dropped rules
  - Monitor devices connections
  - Send barriers between rule updates
  - Poll flow state



Building Network Applications

What can go wrong?

- Missing / rejected / dropped rules
  - Monitor devices connections
  - Send barriers between rule updates
  - Poll flow state
- Topology changes
  - Listen to switch, port, link and host events
  - Compute new path that leverage or remove old flows



Building Network Applications

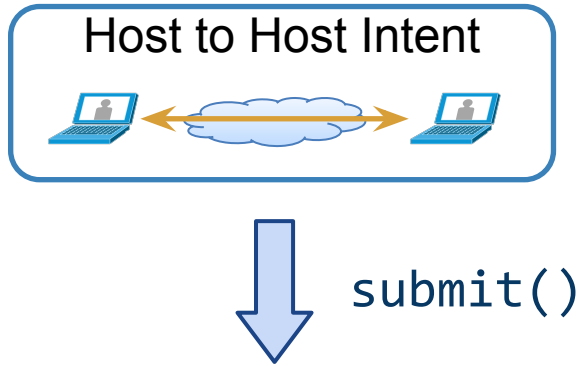
- Each application requires complex path computation and rule installation engines and state machines
- Inconsistent behavior in the face of failures
  - Failures may be handled in different ways (or not at all)
- Bugs need to fixed in multiple places (applications)
- Expensive to upgrade/refactor behavior across all applications; e.g.
  - Improve performance
  - Support new types of devices
  - Implement better algorithms
- Difficult or impossible to resolve conflicts with other applications

Intent Subsystem

- Provides high-level, network-centric interface that focuses on what should be done rather than how it is specifically programmed
- Abstracts unnecessary network complexity from applications
- Maintains requested semantics as network changes
- High availability, scalability and high performance

Intent Example

Intent Example



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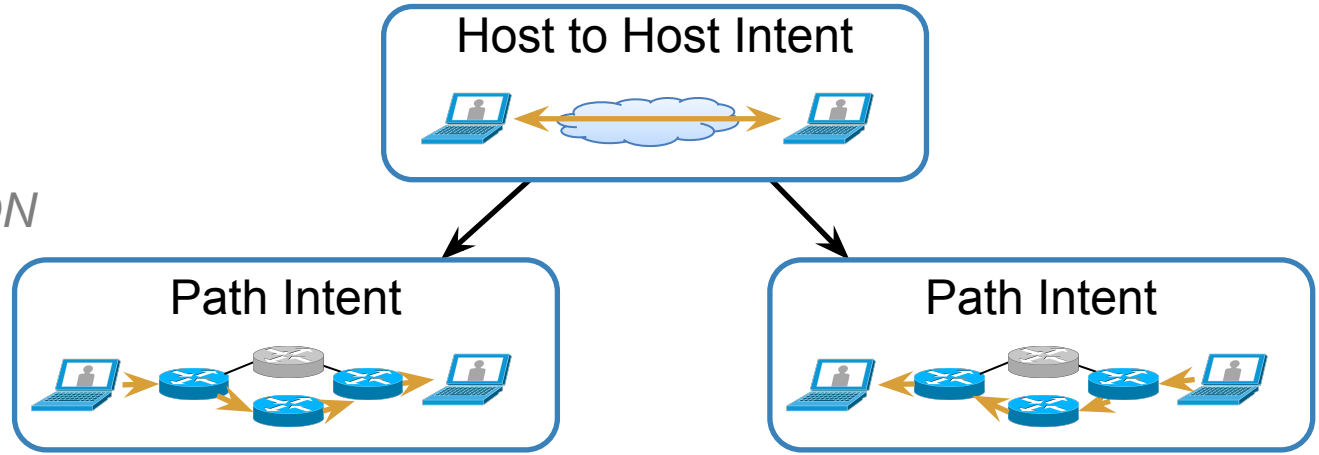

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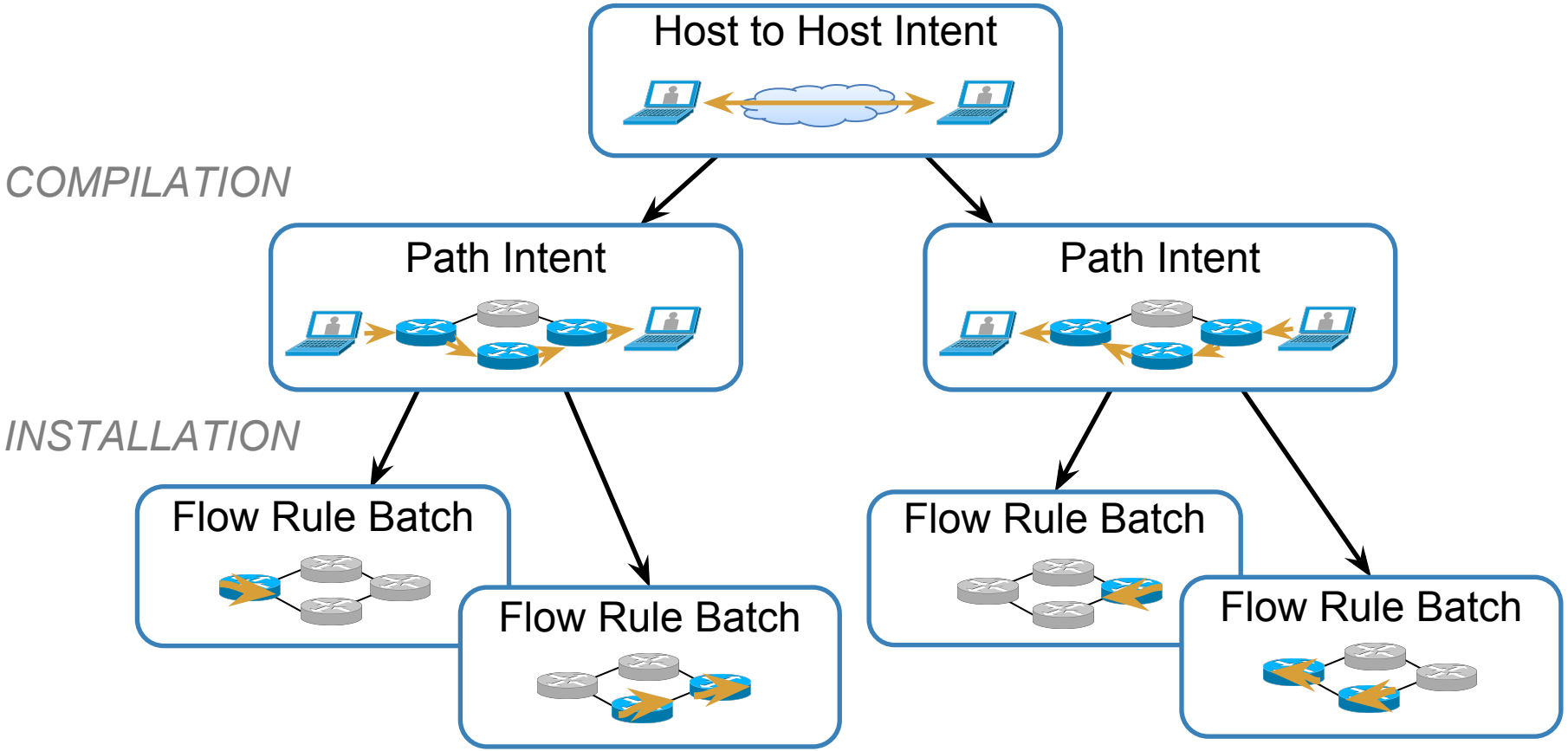


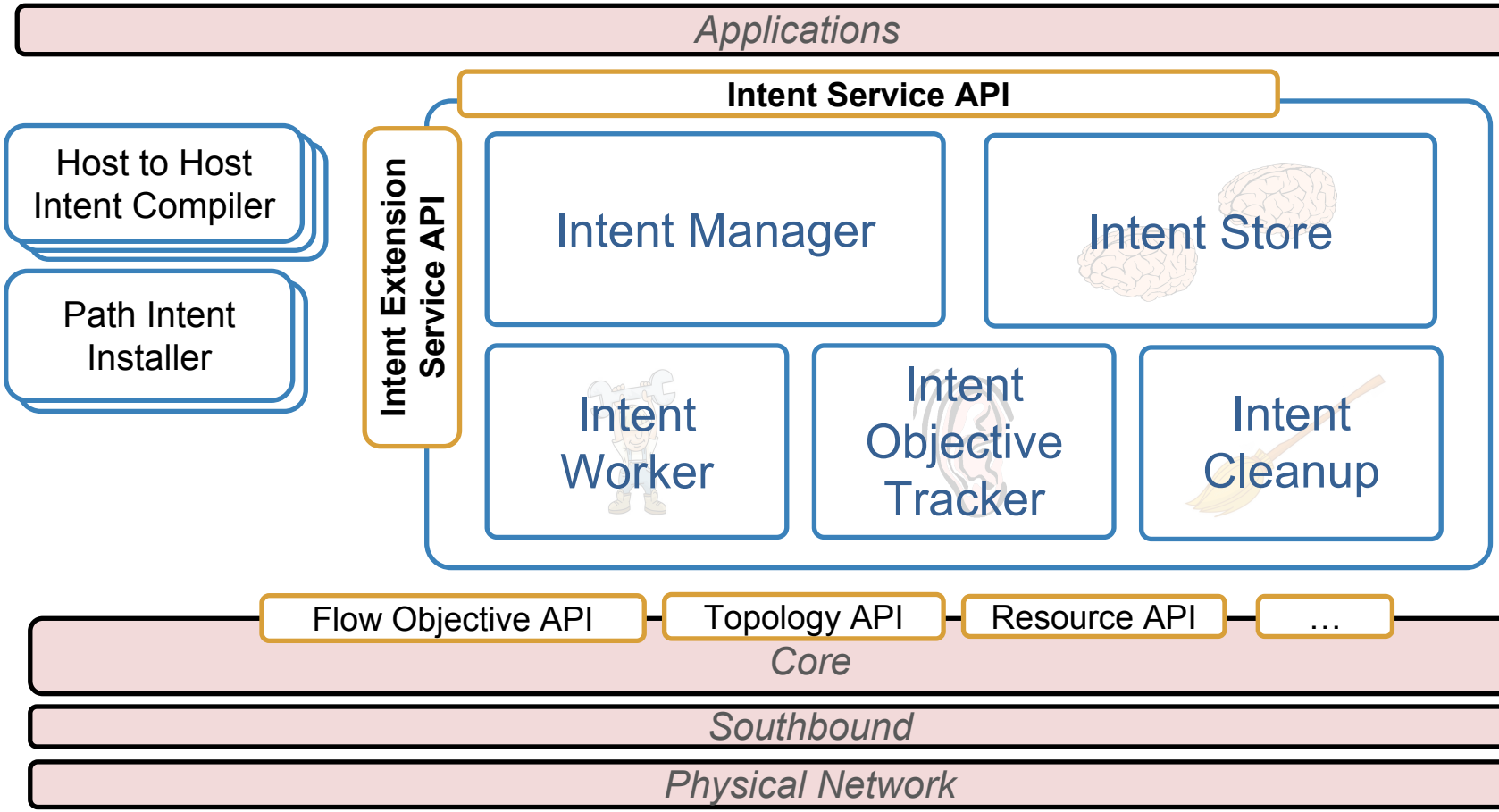
Intent Compilers

- Produce more specific Intents given the environment
- Works on high-level network objects, rather than device specifics
- “Stateless” – free from HA / distribution concerns

Intent Installers

- Transform Intents into device commands
- Allocate / deallocate network resources
- Define scheduling dependencies for workers
- “Stateless”

Intent Framework Design



ONOS Interfaces

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GUI Overview

- Single page application at `/onos/ui`
  - AngularJS
  - d3.js (Data-Driven Documents)
  - SVG
  - Web-Socket
- Shared web-socket for asynchronous & bidirectional exchange
- REST also used for select few interactions
- Dynamically extensible navigation & views
  - apps can contribute new views at run-time

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CLI Overview

- Built using Apache Karaf shell mechanism
  - `ssh -p8101` …
  - `onos` shell tool provided for convenience
- All commands in `onos:` namespace
- Most arguments support TAB-completion
- Plain-text output format for human readability
- JSON output format for easy scripting via `--json` option
- Noun oriented
  - a few verb-oriented exceptions will be addressed

REST API Overview

- Core REST APIs available under path `/onos/v1`
  - all resources support read (get)
  - not all resources support write (post/put/delete) yet
- Resources available today:

`/topology`
`/devices`
`/links`
`/hosts`
`/paths`
`/flows`
`/intents`
`/cluster`
`/applications`
`/configuration`
`/config`

ONOS Dev Workshop Outline

- *ONOS Fundamentals*
  - *architecture, checking out, building & running ONOS*
- *ONOS Distributed Core*
  - *OSGi, anatomy of a core subsystem, distributed stores & primitives*
- *ONOS App Development*
  - *background, Maven archetypes, app deployment on ONOS cluster*
- *ONOS Interfaces*
  - *component config service, flow objective service, intent service*
  - *CLI, REST and GUI overview*
- Wrap-up

Wrap-Up

- Browse ONOS Wiki
  `https://wiki.onosproject.org/`
- Watch ONOS how-to screencasts on YouTube
  `https://goo.gl/8Druv0`
- Browse ONOS Java API
  `http://api.onosproject.org/`

- Join ONOS `onos-dev@onosproject.org` mailing list
  `https://wiki.onosproject.org/display/ONOS/ONOS+Mailing+Lists`

- Engage with ONOS developers & community