Cloud Networking (VITMMA02)
Software Defined Networking (SDN) in the Cloud

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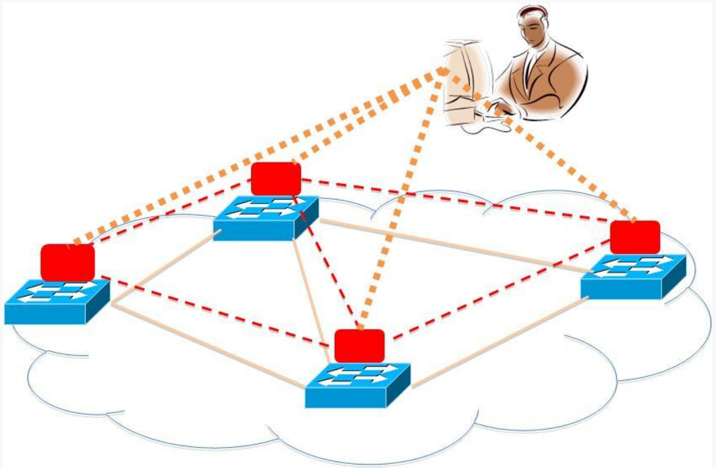
Traditional Computer Network

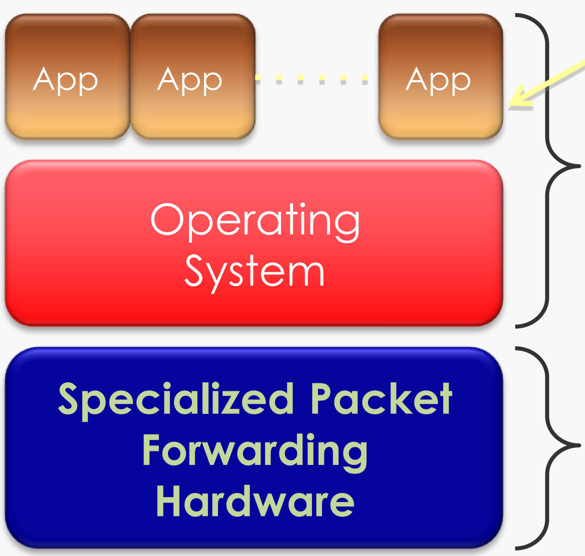
- Data plane: wire-speed time scale (fast)
  - packet handling: Forward, filter, buffer, mark, rate-limit, and measure packets
- Control plane: slower time scale (per control event)
  - distributed algorithms
  - tracking topology changes, computing routes, installing forwarding rules
- Management plane: human time scale
  - centralized
  - collecting measurements and configuring the equipment



Traditional Network (Device) Architecture

- Networks used to be simple: Ethernet, IP, TCP….
- New **control** requirements led to great complexity
  - Isolation → VLANs, ACLs
  - Traffic engineering → MPLS, ECMP, Weights
  - Packet processing → Firewalls, NATs, middleboxes
  - Payload analysis → Deep packet inspection (DPI)
  - …..
- Many complex functions built into the infrastructure
  - OSPF, BGP, multicast, differentiated services, Traffic Engineering, NAT, firewalls, MPLS, …
- An industry with a “mainframe-mentality” – monolithic

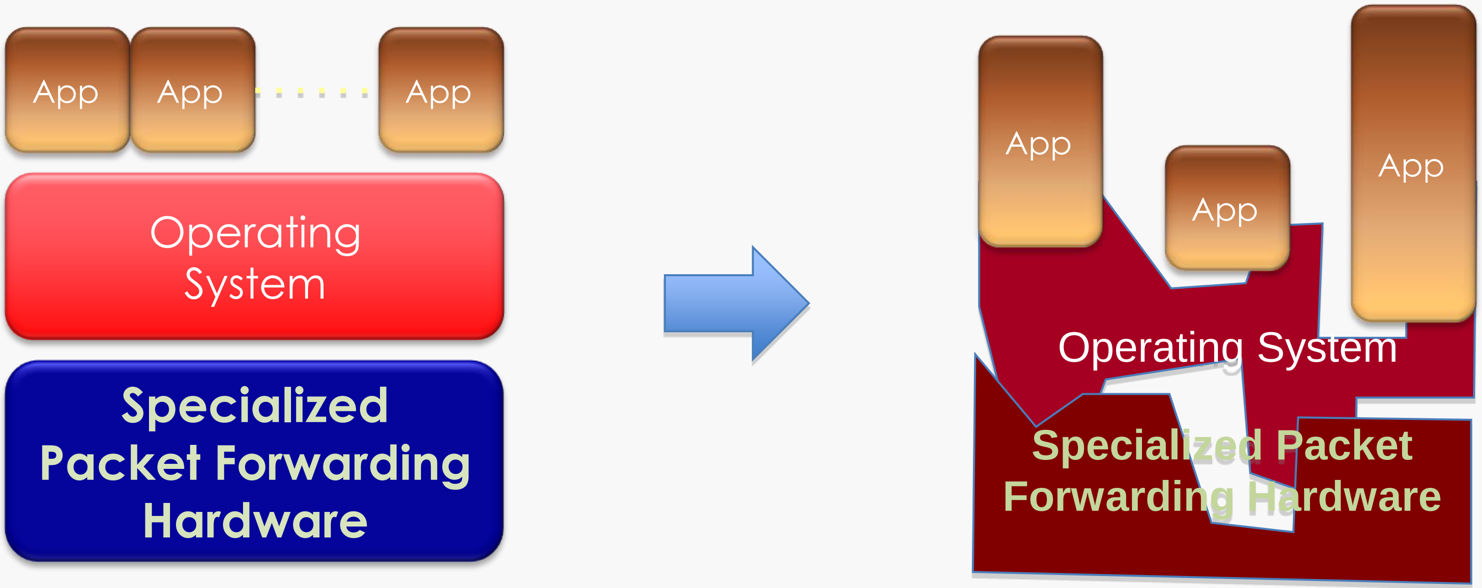
Routing, management, mobility management, access control, VPNs, …



Million of lines of source code | 5400 RFCs | Barrier to entry

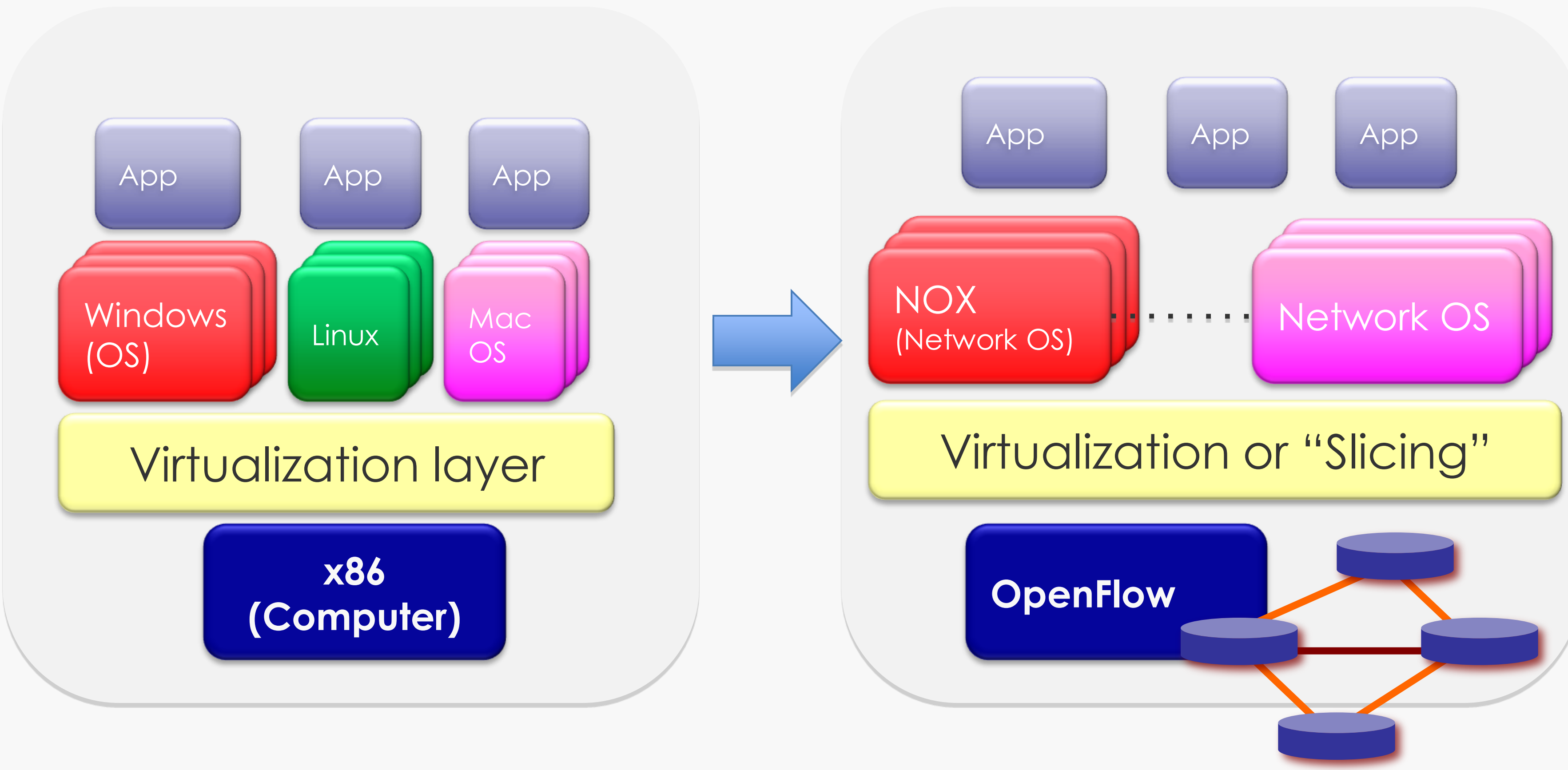
500M gates 10Gbytes RAM | Complex | Power Hungry

Ideal vs. Real Architecture



- Lack of competition hinders innovation
  - few people can innovate
  - slow standardization process
- Closed architecture means blurry, closed interfaces
  - software bundled with hardware
- Vertically integrated, complex, closed, proprietary
  - vendor specific interfaces
- Not suitable for experimental ideas
- Not good for network owners & users, researchers

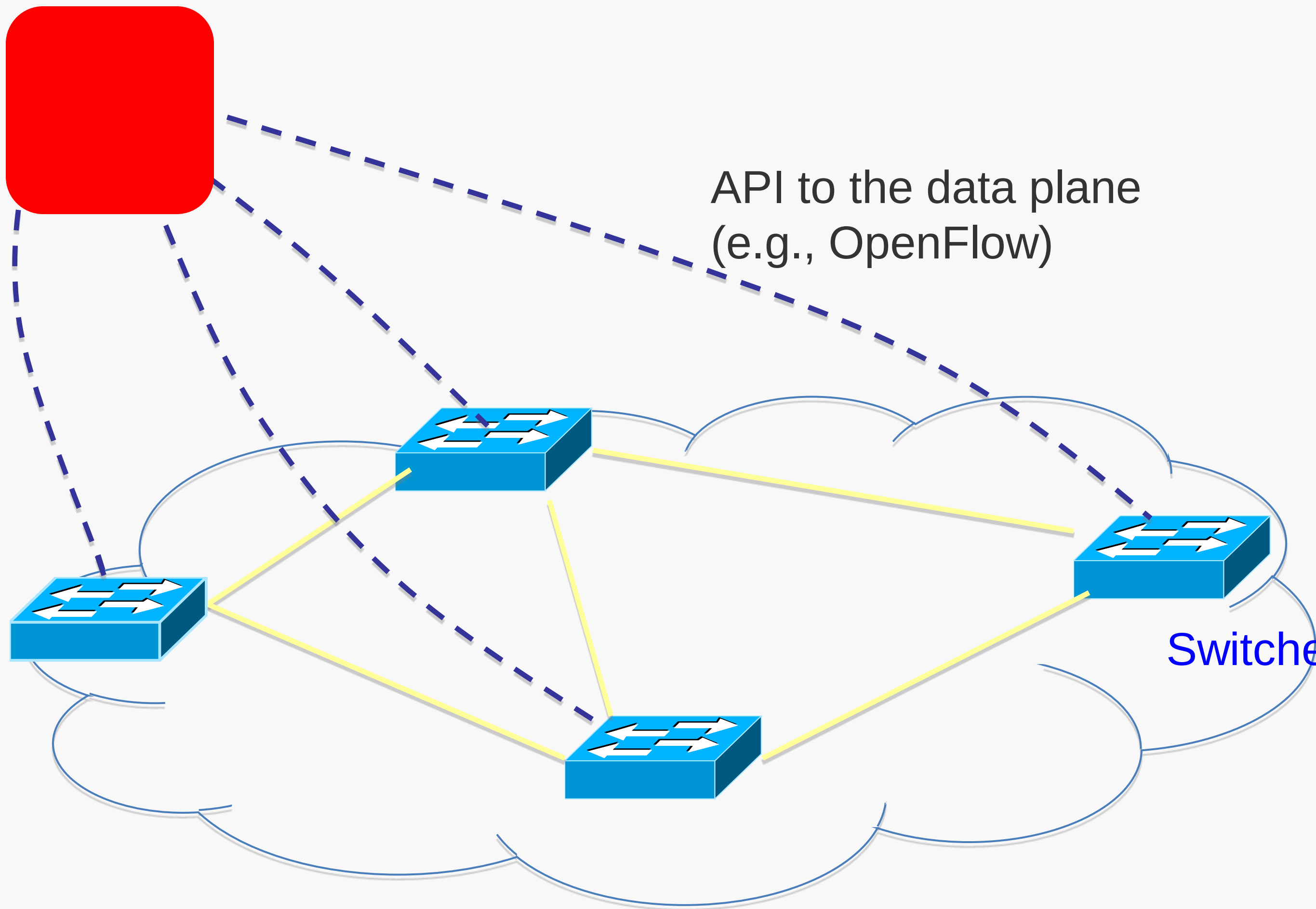
Similarities



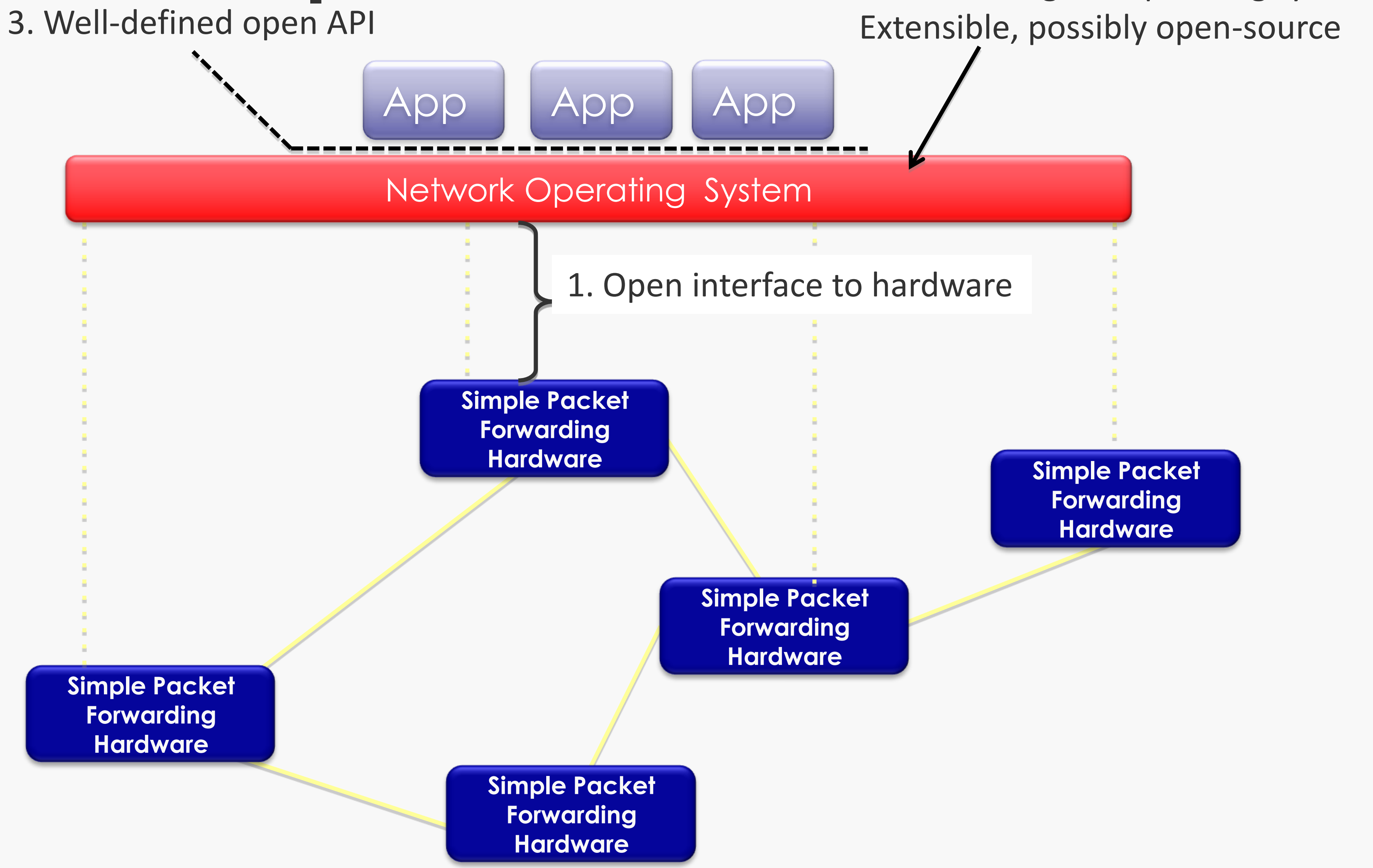
Computer Industry

Network Industry

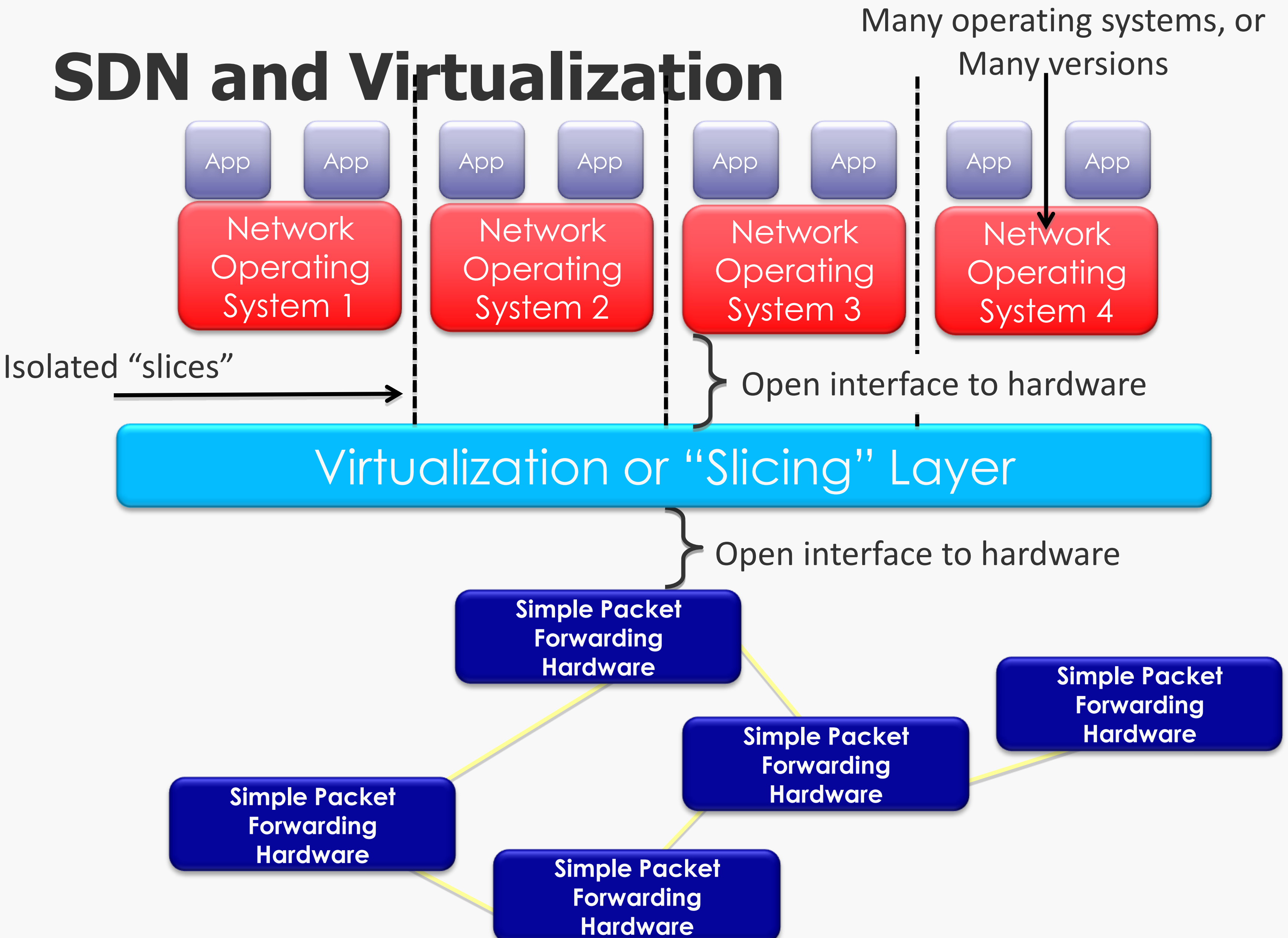
Software Defined Networking (SDN)



SDN Components

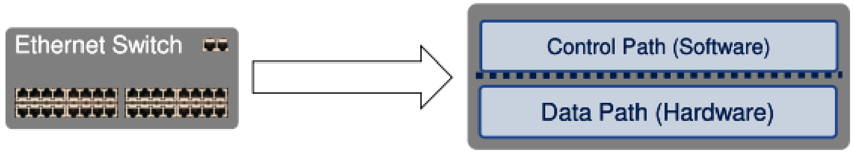


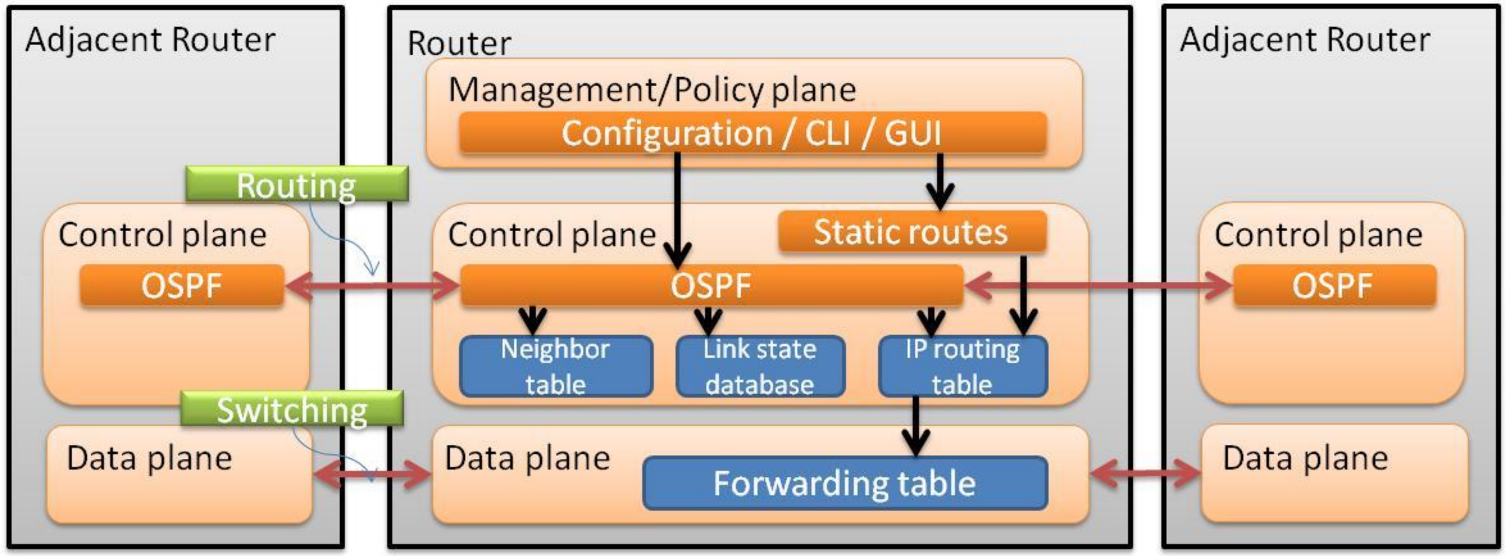
SDN and Virtualization



Traditional Switch/Router

- Operations can be partitioned into planes
  - Management plane / Configuration
  - Control plane / Decisions
  - Data plane / Forwarding





Concept of SDN

- Separate Control plane and Data plane entities
  - Network intelligence and state are logically centralized
  - The underlying network infrastructure is *abstracted* from the applications
- Execute or run Control plane software on general purpose hardware
  - Decouple from specific networking hardware
  - Use commodity servers
- Have programmable data planes
  - Maintain, control and program data plane state from a central entity
- An architecture to control not just a networking device but an entire network

Control Software Program

Control program operates on view of network

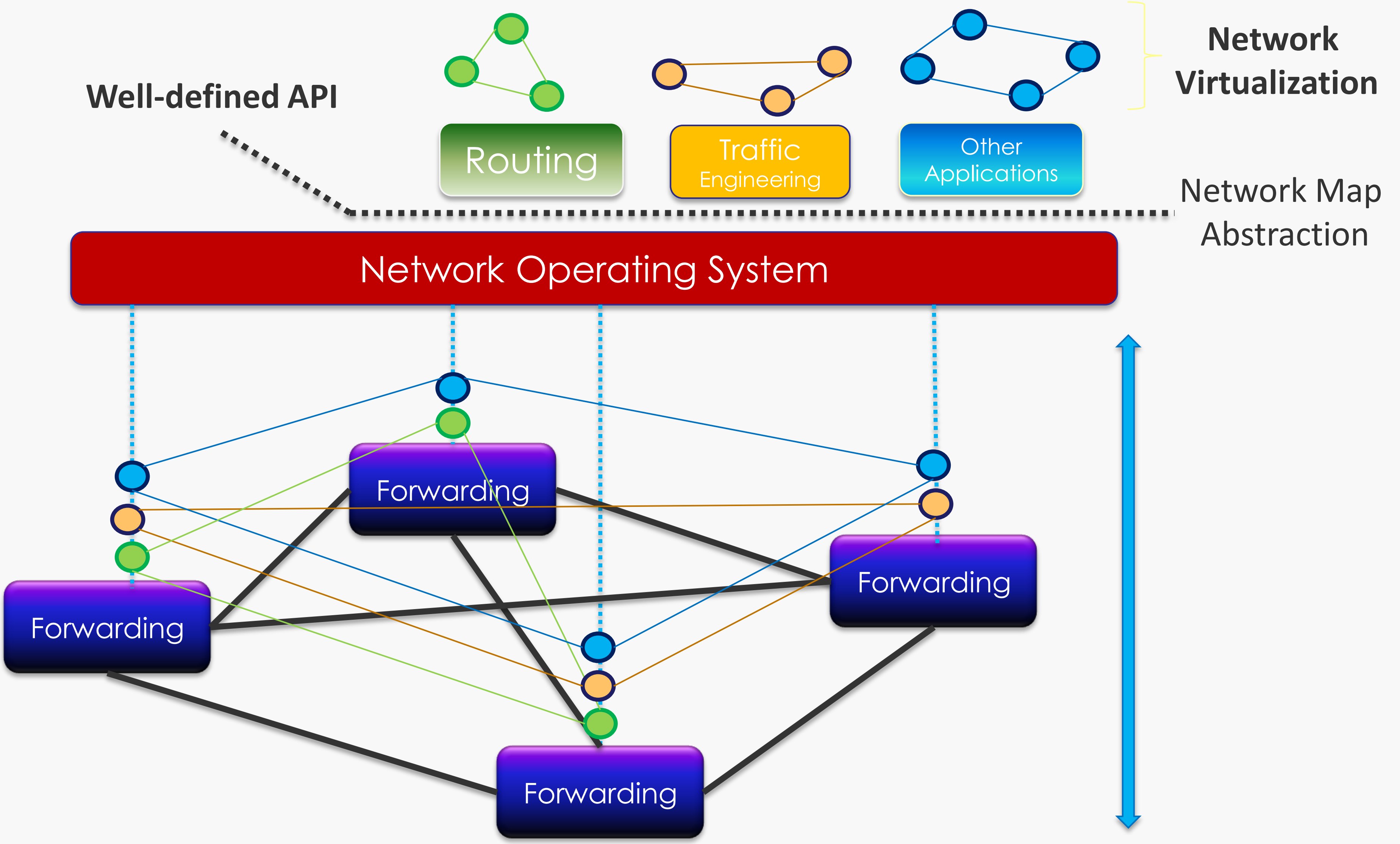
- **Input**: global network view (graph/database)
  - Annotated network graph provided through an API
  - Receives events from switches
    - Topology changes
    - Traffic statistics
    - Arriving packets

- **Output**: configuration of each network device
  - Control mechanism is a program, implementing e.g. a graph algorithm
  - Sends commands to switches
    - (Un)install rules
    - Query statistics
    - Send packets

Control program is **not** a distributed system

- Abstraction hides details of distributed state

SDN with Abstractions in the Control Plane



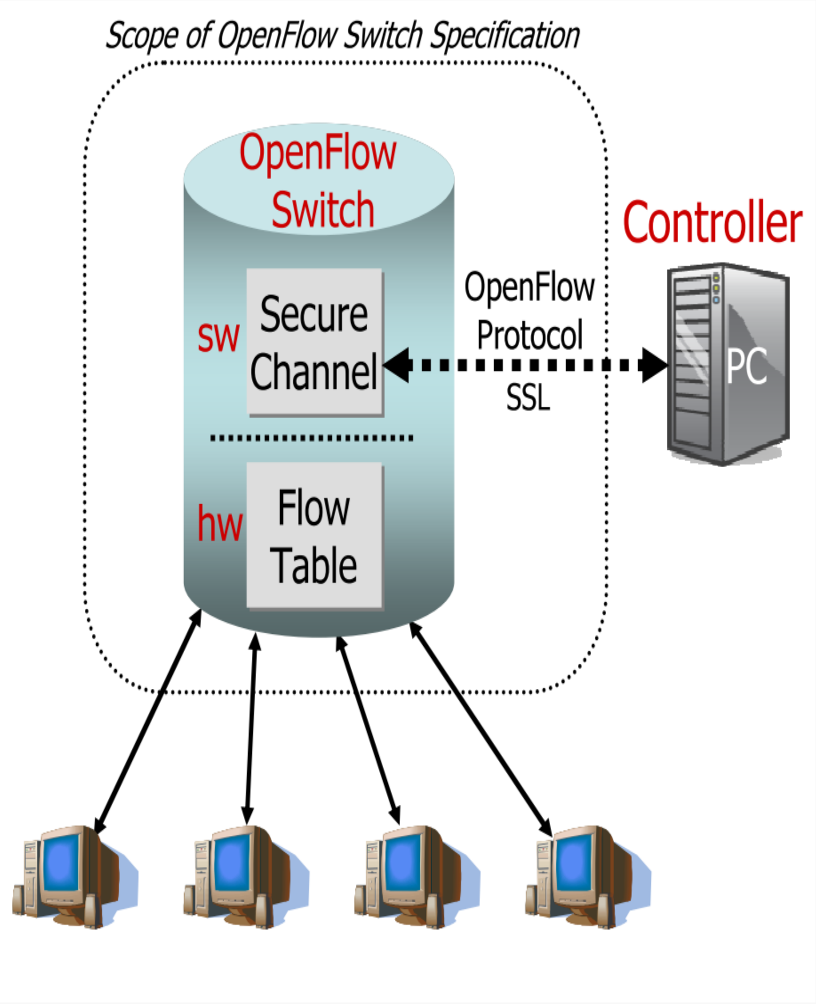
Forwarding Abstraction

- Purpose: Abstract away forwarding hardware
- Flexible
  - Behavior specified by control plane
  - Built from basic set of forwarding primitives
- Minimal
  - Streamlined for speed and low-power
  - Control program not vendor-specific

- OpenFlow is an example way of such an abstraction

What is OpenFlow?

- Provides open interface to “black box” networking node
  - (i.e. Routers, L2/L3 switch) to enable visibility and openness in network
- Separation of control plane and data plane
  - The datapath of an OpenFlow Switch consists of a Flow Table, and an action associated with each flow entry
  - The control path consists of a controller which programs the flow entry in the flow table
- OpenFlow is based on an Ethernet switch, with an internal flow-table, and a standardized interface to add and remove flow entries



OpenFlow Devices

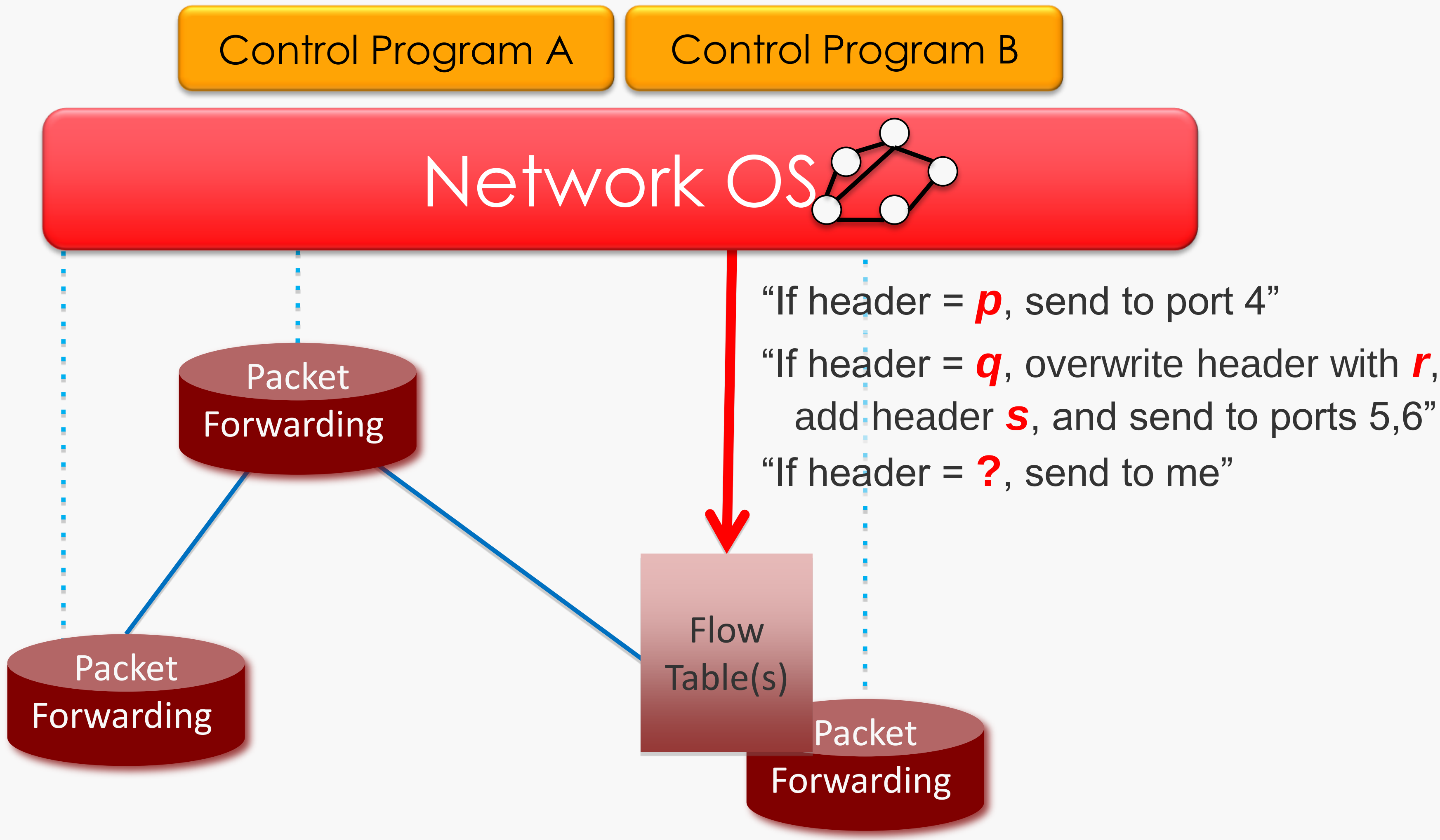
Controller/NOS

- POX: (Python)
  - general SDN controller
  - features: queriable topology graph and support for virtualization
- NOX: (C++)
  - was the first OpenFlow controller
- IRIS: (Java)
  - features : Horizontal Scalability for carrier-grade network; High Availability with transparent failover from failure; (Multi-domain support with recursive network abstraction based on Openflow
- Beacon: (Java)
  - event-based and threaded operation
- Floodlight: (Java)
  - enterprise level
- OpenDaylight (Java)
  - NFV
- Ryu: (Python)
  - an open-sourced Network Operating System (NOS)
- NodeFlow (JavaScript)
  - an OpenFlow controller written in pure JavaScript for Node.JS
- ovs-controller (C)
  - Trivial reference controller packaged with Open vSwitch

Switches

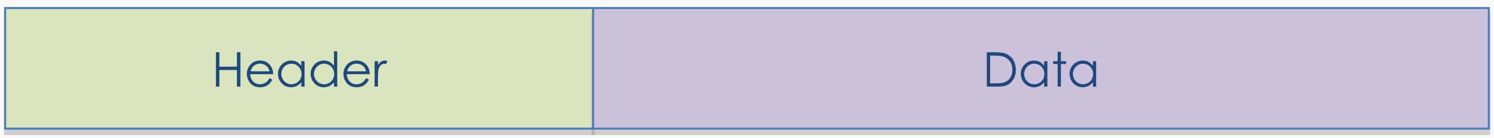
- Software Switches
  - Stanford Reference Implementation v1.0
  - Ericsson implementation v1.1 & v1.2
    - Linux-based Software Switch running in User Space
  - Open vSwitch
    - Linux-based Software Switch running in Kernel Space
    - Not just an OF switch, widely used by virtual machines (VirtualBox, XEN)
    - Firmware of some devices based on Open vSwitch
  - OpenFlow 1.3 Software Switch
    - CPqD in technical collaboration with Ericsson Research, Brazil
- Software → Hardware
  - Commercial off-the-shelf (COTS) devices
    - running OpenWRT
    - software switches can be ported
    - run by CPU
    - in user-space
  - NetFPGA-based implementation
- Hardware vendors
  - HP, Cisco, Juniper, IBM, Arista, NEC, Netgear, Pronto, …

OpenFlow Basics



OF Primitives: <Header match, Action>

- Simple packet-handling rules
- Match arbitrary bits in headers:



Match: 1000x01xx0101001x

  - Match on any header, or new header
  - Allows any flow granularity
- Action
  - Forward to port(s), drop, send to controller
  - Overwrite header with mask, push or pop
  - Forward at specific bit-rate

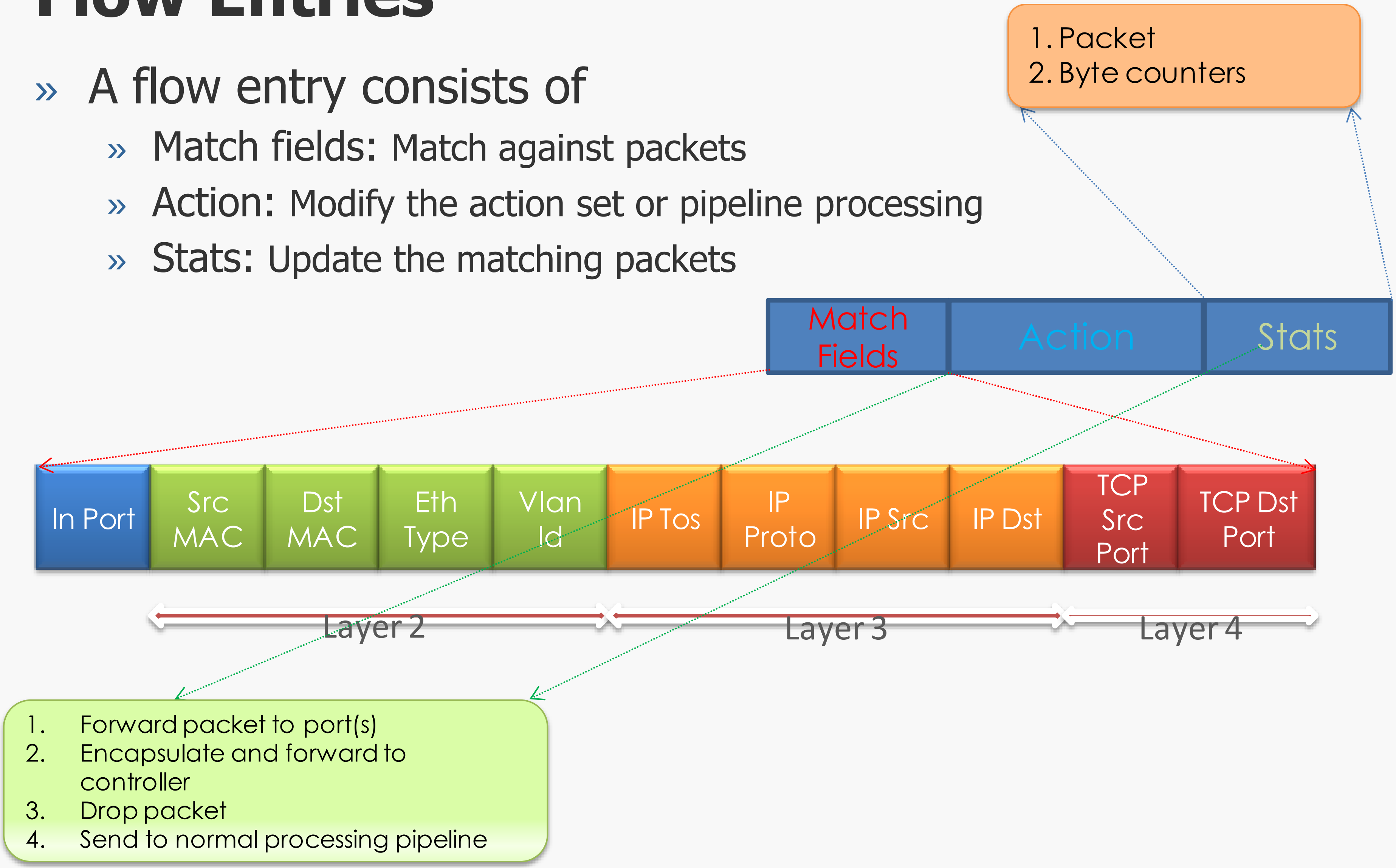
Flow Table

» Flow table in switches, routers, and chipsets

Flow 1.	Rule (exact & wildcard)	Action	Statistics
Flow 2.	Rule (exact & wildcard)	Action	Statistics
Flow 3.	Rule (exact & wildcard)	Action	Statistics
	....		
Flow N.	Rule (exact & wildcard)	Default Action	Statistics

Flow Entries

- A flow entry consists of
  - Match fields: Match against packets
  - Action: Modify the action set or pipeline processing
  - Stats: Update the matching packets



Examples (1/2)

Switching

Switch Port	MAC src	MAC dst	Eth type	VLAN ID	IP Src	IP Dst	IP Prot	TCP sport	TCP dport	Action
*	*	00:1f:..	*	*	*	*	*	*	*	port6

Flow Switching

Switch Port	MAC src	MAC dst	Eth type	VLAN ID	IP Src	IP Dst	IP Prot	TCP sport	TCP dport	Action
port3	00:20..	00:1f..	0800	vlan1	1.2.3.4	5.6.7.8	4	17264	80	port6

Firewall

Switch Port	MAC src	MAC dst	Eth type	VLAN ID	IP Src	IP Dst	IP Prot	TCP sport	TCP dport	Action
*	*	*	*	*	*	*	*	*	22	drop

Examples (2/2)

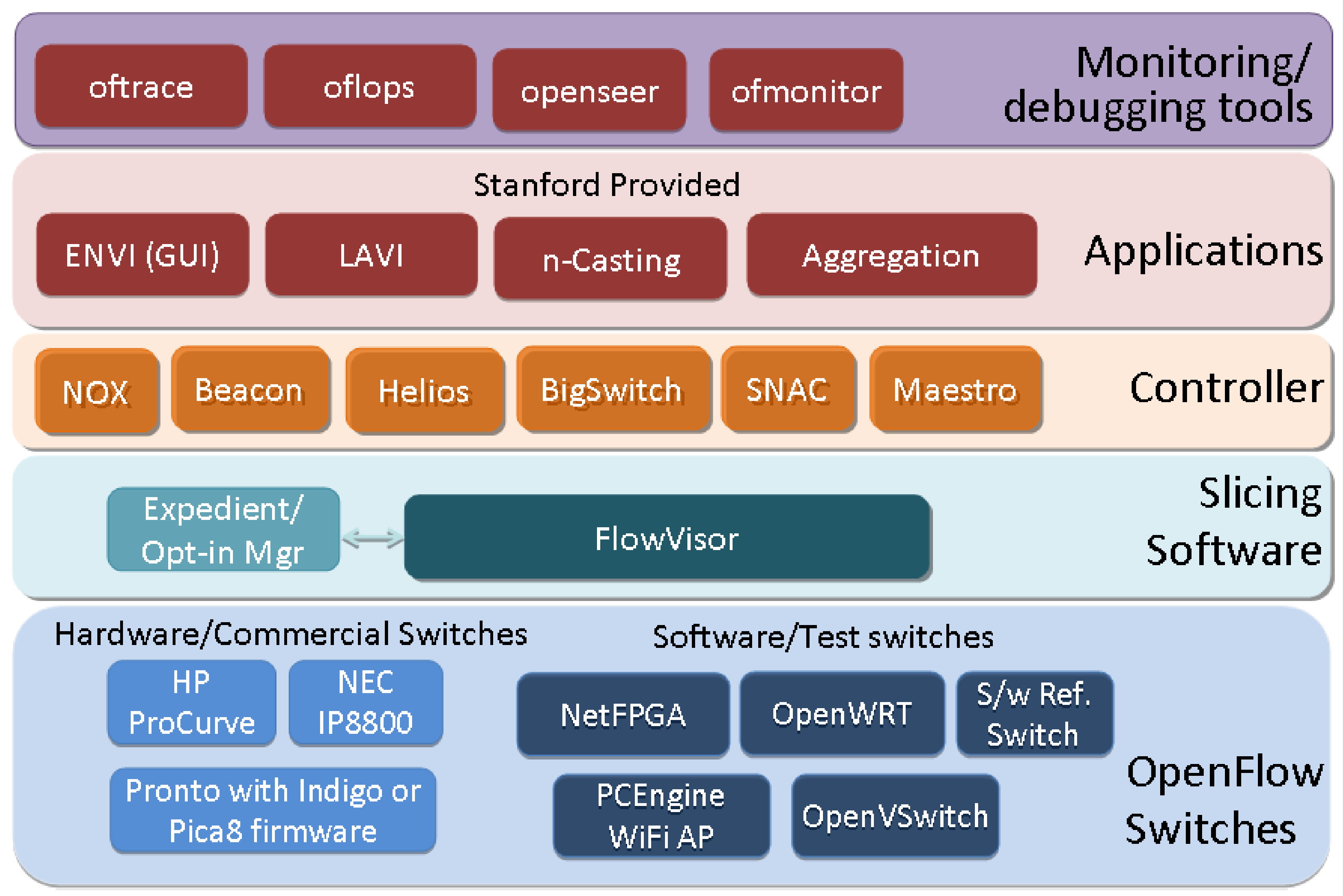
Routing

Switch Port	MAC src	MAC dst	Eth type	VLAN ID	IP Src	IP Dst	IP Prot	TCP sport	TCP dport	Action
*	*	*	*	*	*	5.6.7.8	*	*	*	port6

VLAN Switching

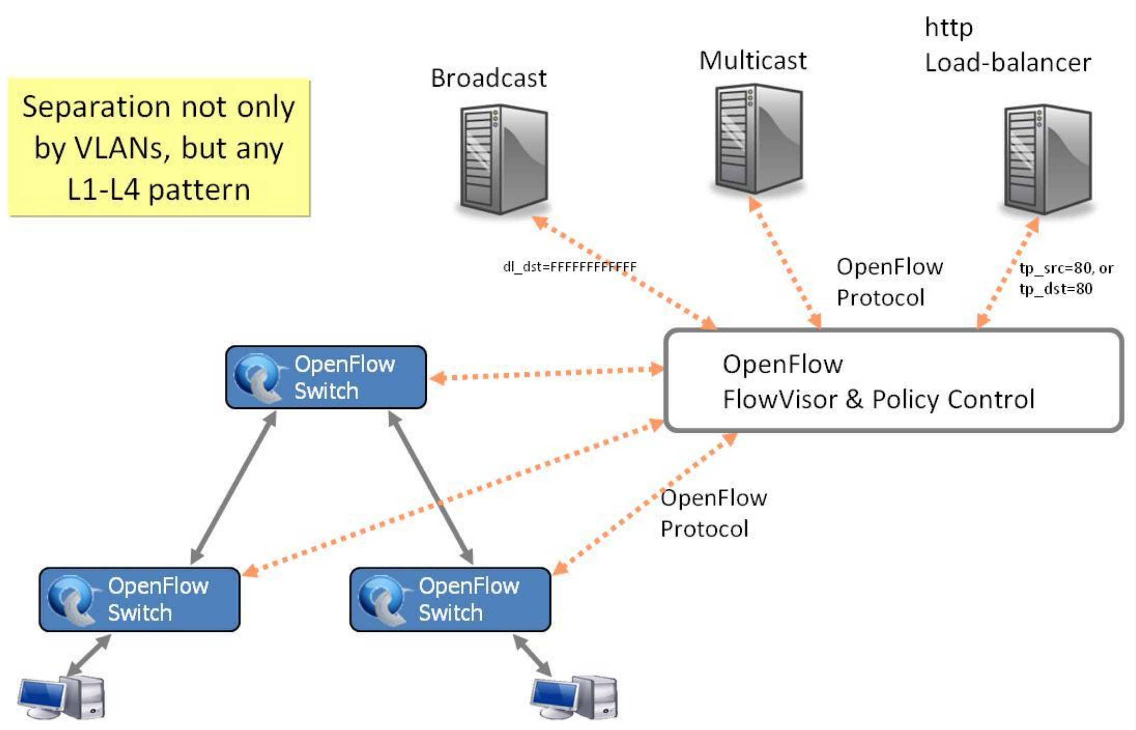
Switch Port	MAC src	MAC dst	Eth type	VLAN ID	IP Src	IP Dst	IP Prot	TCP sport	TCP dport	Action
*	*	00:1f..	*	vlan1	*	*	*	*	*	port6, port7, port9

OpenFlow Building Blocks



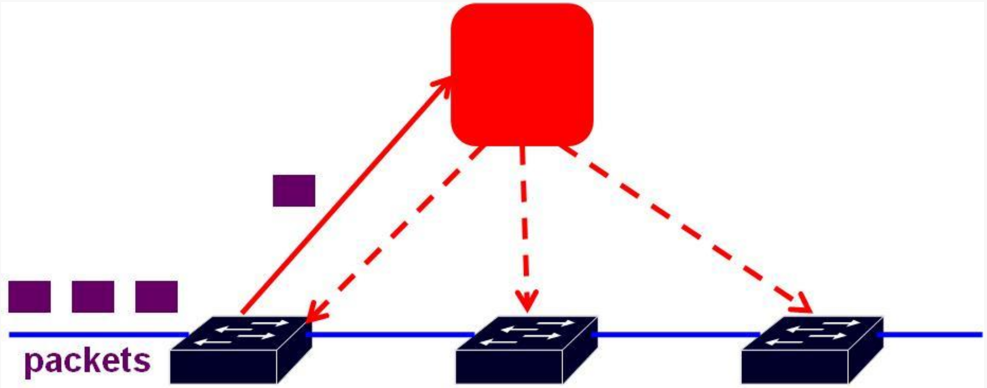
Slicing

- FlowVisor
  - software proxy between the forwarding and control planes of network devices
  - it assigns hardware resources to “slices”
  - topology discovery is per slice
- Separate VLANs for Production and Research Traffic



Reactive operation

- Packets are managed as flows
  - The 1st packet of a flow is sent to the controller
  - The controller programs the actions of datapath for a flow
    - Usually one rule, but may be a list
    - Actions include: Forward to a port or ports, Mirror, Encapsulate and forward to controller, Drop
  - And returns the packet to the datapath
  - Subsequent packets are handled directly by the datapath

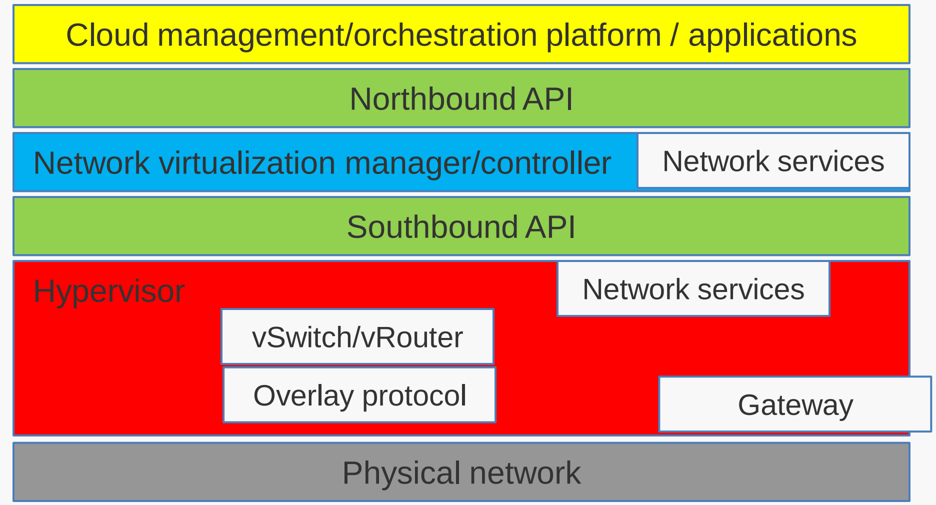


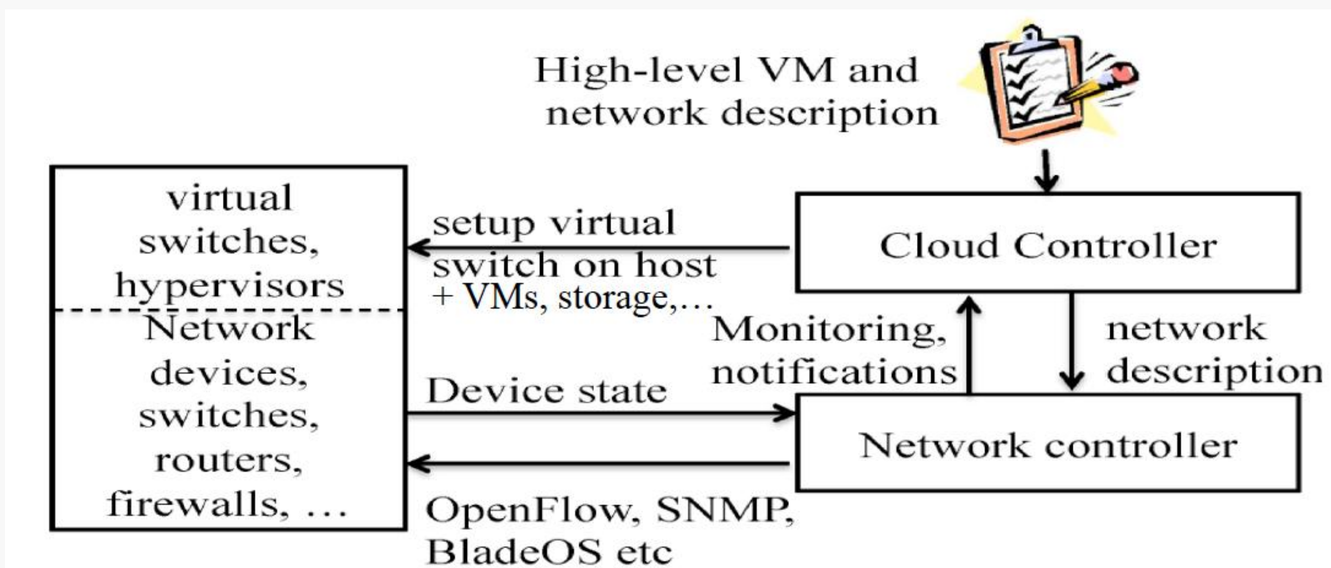
SDN in the Cloud

- Instead of reactive operation…
  - 1st packet sent to controller ⇨ delay
  - end-to-end: many rule entries, scalability problem
  - tenant and VM changes affect all physical switches
- …pro-active operation with overlay networks
  - physical network provides L2/L3 connectivity
  - controller pre-programs devices in advance ⇨ low delay
  - tunnels: tenant state only in endpoints (servers: hypervisor, virtual switch/router), scalable
  - less entries in forwarding tables
    - not for each VM, but only for physical servers
  - tenant and VM changes do not affect physical switches

Cloud Management and SDN

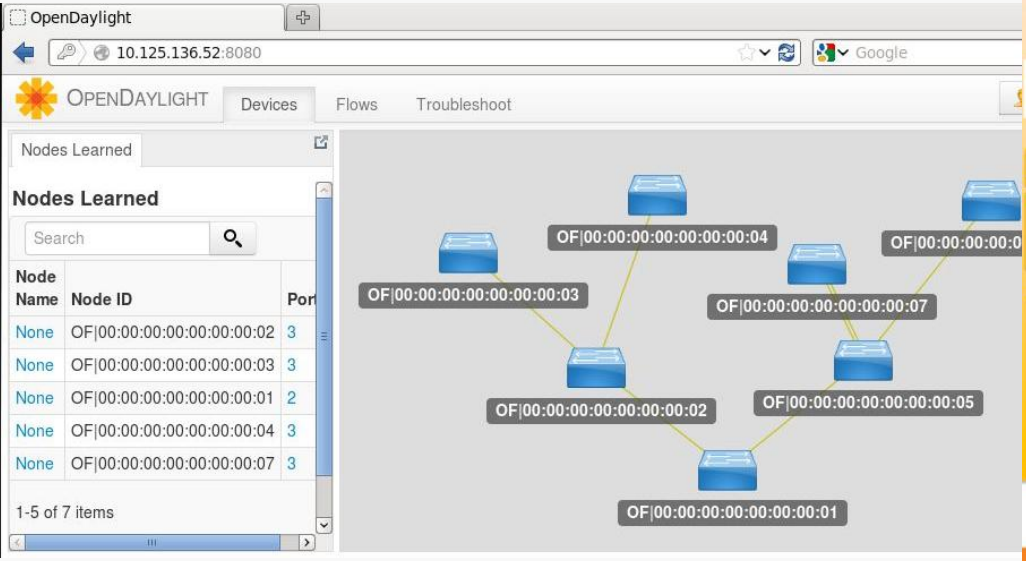
- Orchestration functions by OpenStack
  - higher level abstraction
    - deals with virtual resources
  - not only for network, but for a whole application system
    - VMs, storage, etc. + network
  - CLI or horizon dashboard
  - automation: Heat templates
- SDN
  - lower level network realization of the above

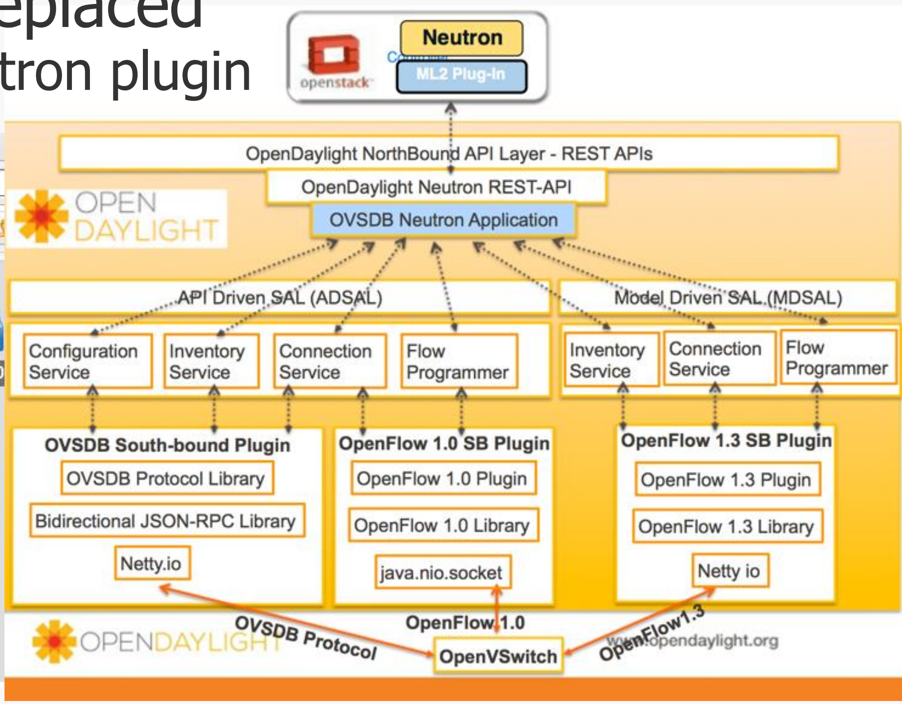




OpenStack

- OVS Neutron plugin
  - OpenFlow for programming virtual switch tables
    - mapping VM MAC address and server hypervisor transport IP address – known by the orchestration
    - proactive
    - northbound interface: Neutron
    - southbound interface: OpenFlow
- SDN controller plugins can be replaced
  - e.g. OpenDaylight OpenStack Neutron plugin





SDN in the Cloud

» Not only for virtual switches/routers, but also for physical network devices

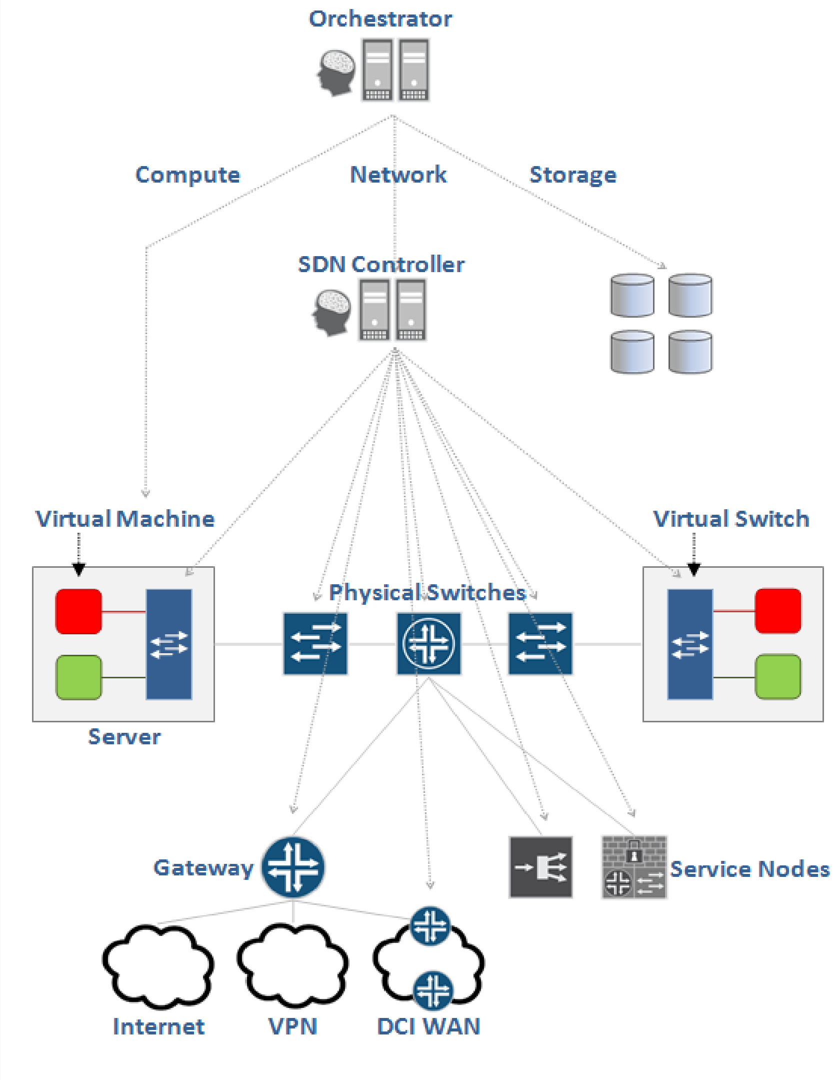


Figure 22: The Role of Orchestration in the Data Center

Source: http://www.opencontrail.org/opencontrail-architecture-documentation/

Data Center Network Requirements

- Minimizing the configuration and stored states of network devices
  - automation, as much as possible
- Effective traffic forwarding, high performance
  - no loops
  - adaptation to traffic changes
  - meet tenant SLA
- Quick and easy VM migration
  - transparent migration
- Fast and effective fault detection/recovery
  - quite frequent because of the large number of elements
  - network must adjusted to the fault recovery

Traditional networking solutions

- Layer 3
  - + hierarchical addressing ⇨ small forwarding tables
  - + OSPF fast fault handling
  - + IP TTL: to prevent loops
  - - high administration burden (to configure sub-networks, DHCP, etc.)
- Layer2
  - + Flat MAC addressing (locality independent)
  - + to prevent loops: STP
  - + less administration burden
  - - broadcast traffic (not very scalable)
  - - STP: unused links in the topology
- VLAN
  - scalalbility limit (max. 4K)
  - disadvantages from static configuration

Networking with SDN

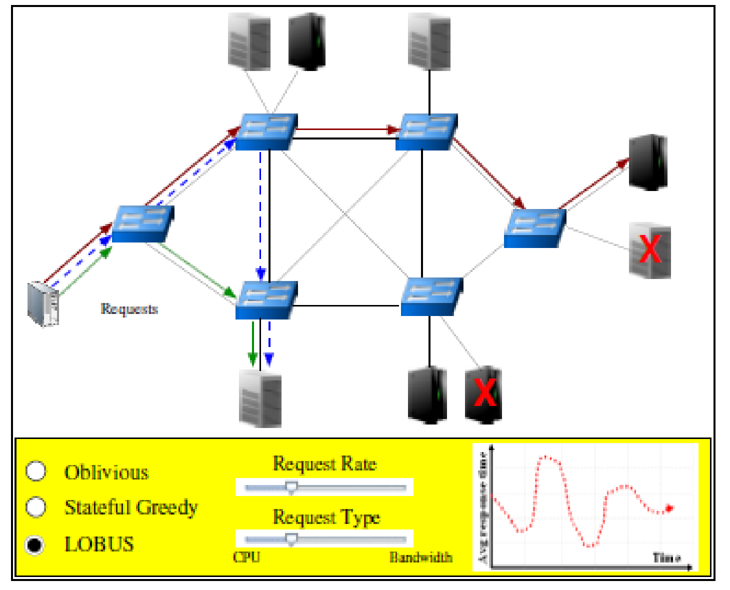
- controller is aware about the whole network
  - device discovery
  - MAC, IP addresses, connections
- realizing the network on a lower level according to orchestration tasks
- quick and dynamic network provisioning
  - flexible: tenant self-service
  - automated network resource allocation and management
  - optimizing traffic, even between data centers
- scalable
- NFV

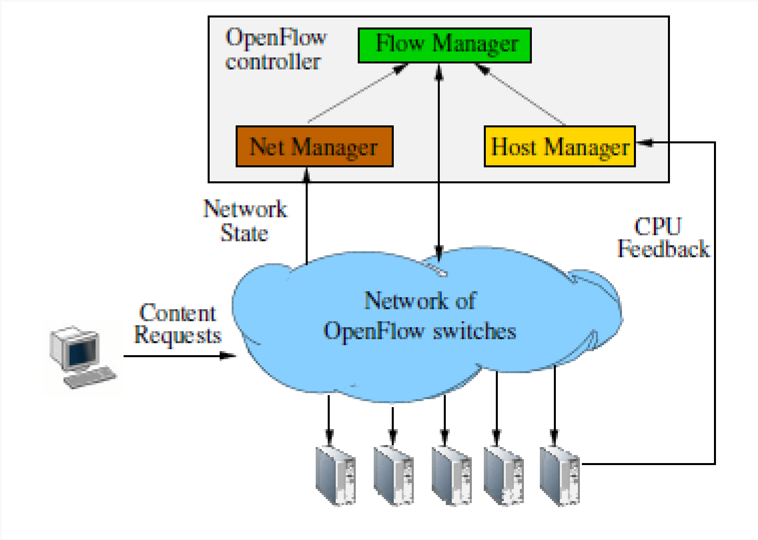
Examples of cloud specific tasks

- Load Balancing – LB
- inter-DC tunnel
- VM migration
- scalable packet forwarding

Load Balancing

- Dynamism
  - timer for OpenFlow rule entries
- Required operations for Load Balancing
  - rewrite public IP to server IP
  - forwarding to server output port
  - the opposite operations in the backward direction
- To do
  - hash based routing
  - TCP flag checking to identify new flows
- Plug-n-Serve: Load-Balancing Web Traffic using OpenFlow
  - Load balancing according to network and server loads in a distributed way

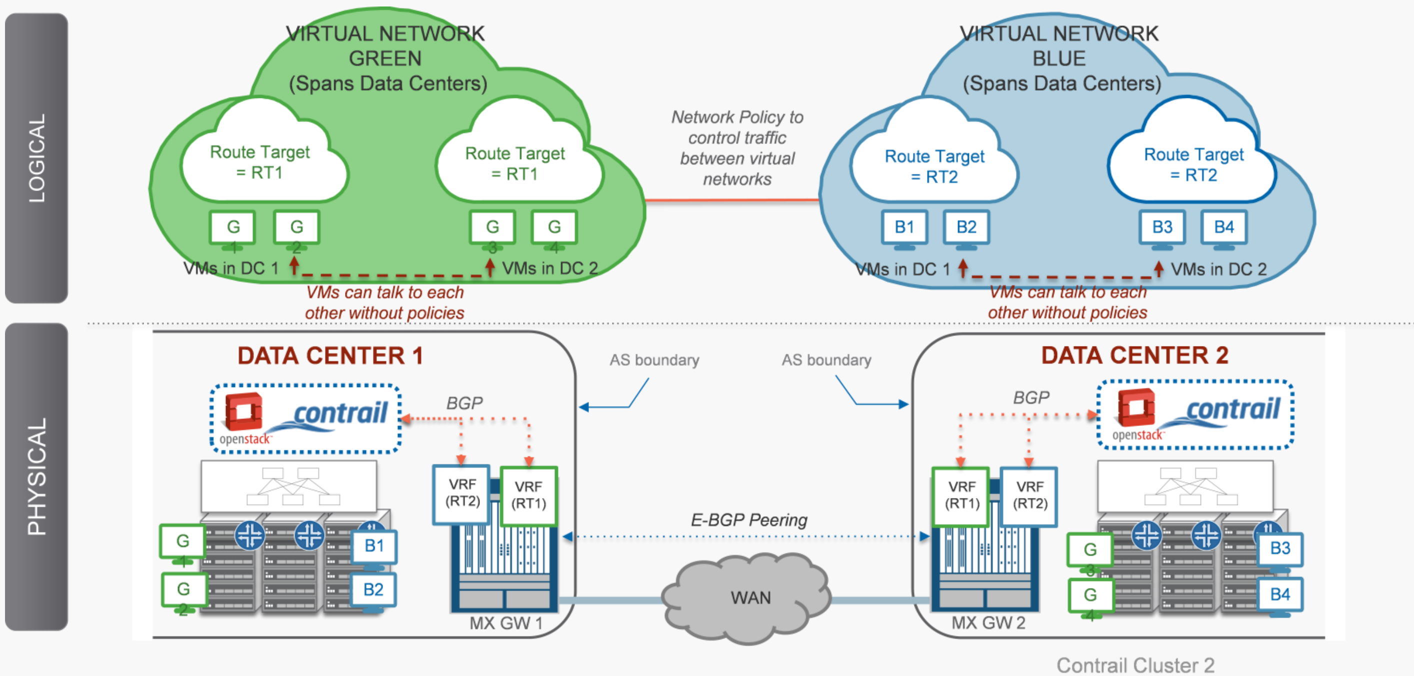




Source: http://conferences.sigcomm.org/sigcomm/2009/demos/sigcomm-pd-2009-final26.pdf

SDN for inter-DC traffic

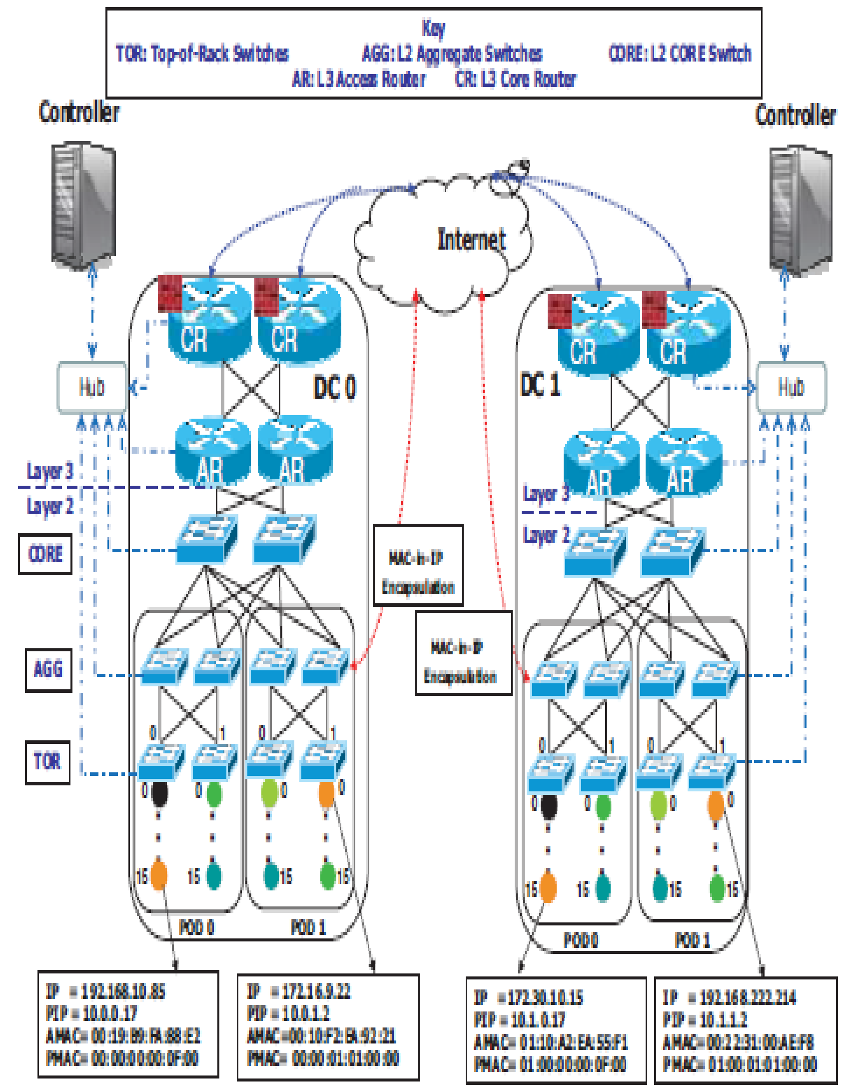
- Traffic
  - cloud bursting
  - geographical aspects in load balancing
- Tunnel provisioning with reactive operation
  - multipath
  - changes in paths = reprogramming packet headers on-the-fly



Source: http://www.opencontrail.org/how-to-setup-opencontrail-gateway-juniper-mx-cisco-asr-and-software-gw/

VM migration

- Reasons
  - maintenance, load balancing
  - VM consolidation (energy savings)
  - disaster recovery: migrating full application stacks
- Difficulties of migration to another subnet
  - hierarchical IP addressing
  - manual reconfiguration is not viable
  - without disrupting live TCP connections
- CrossRoads
  - locality independence: pseudo MAC (PMAC) and IP addresses (PIP)
  - SDN controlles manages the mapping



Source: Mann, V.; Vishnoi, A; Kannan, K.; Kalyanaraman, S., "CrossRoads: Seamless VM mobility across data centers through software defined networking," *Network Operations and Management Symposium (NOMS), 2012 IEEE , vol., no., pp.88,96, 16-20 April 2012*

SDN scalability

- A challenge for the control plane
  - number of VMs, tenant rules, SLAs, flows, etc.
- in multi domain environment: federation of controllers
  - information exchange
  - sharing states
  - easily extensible
- NEC tests from 2014
  - Trema OpenFlow controller
  - Layer 2 networks with VXLAN technology
  - controllers with load balancing
    - a controller manages 410 switches, scales linearly
  - running 16 000 virtual networks
    - 1024 switch, 128 VM on each
  - to provision a virtual network takes constant 4 sec

Deployments and Applications

- Amazon, Google, Facebook, Microsoft Azure
  - individual SDN solutions
- Google inter-datacenter WAN using SDN and OpenFlow
  - centralized traffic engineering
  - lowering network costs
- Data Centers provisioned by NEC
  - lowering network costs
- VMware
  - Nicira (SDN, network virtualization)
    - Network Virtualization Platform (NVP): overlay networking technology ⇨ VMware NSX

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