CSC 458/2209 – Computer Networks

Handout # 16: Software-Defined Networking

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Announcements

- Programming Assignment 2
  - To be completed individually.
  - Due: Friday, Nov. 29th at 5pm

- No tutorials this week

Announcements

- Final Exam
  - Time: Tue. December 10th, 2019; 14:00-16:00
  - Location:
    - A-KE: GB304
    - KI-OM: MS2170
    - OU-ZZ: MS3153

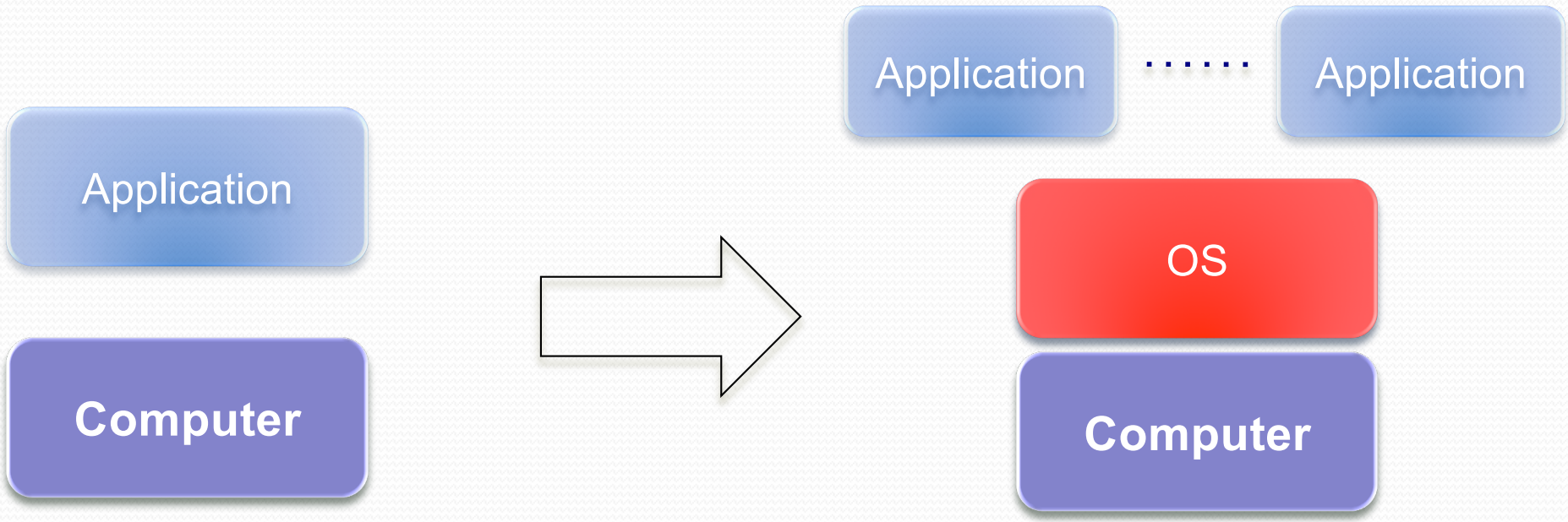
The Story So Far

- Layering
  - Link layer
    - Media, framing, error detection/correction, switches, hubs, …
  - Network layer
    - Addressing (CIDR, subnet), routing and forwarding, DNS, BGP, …
  - Transport layer
    - TCP, UDP, flow control, congestion control, queue management, …
- **Misc**: Queueing Mechanisms, Middleboxes
- **Next**: Software-defined networking

Innovation – Computers vs. Networks

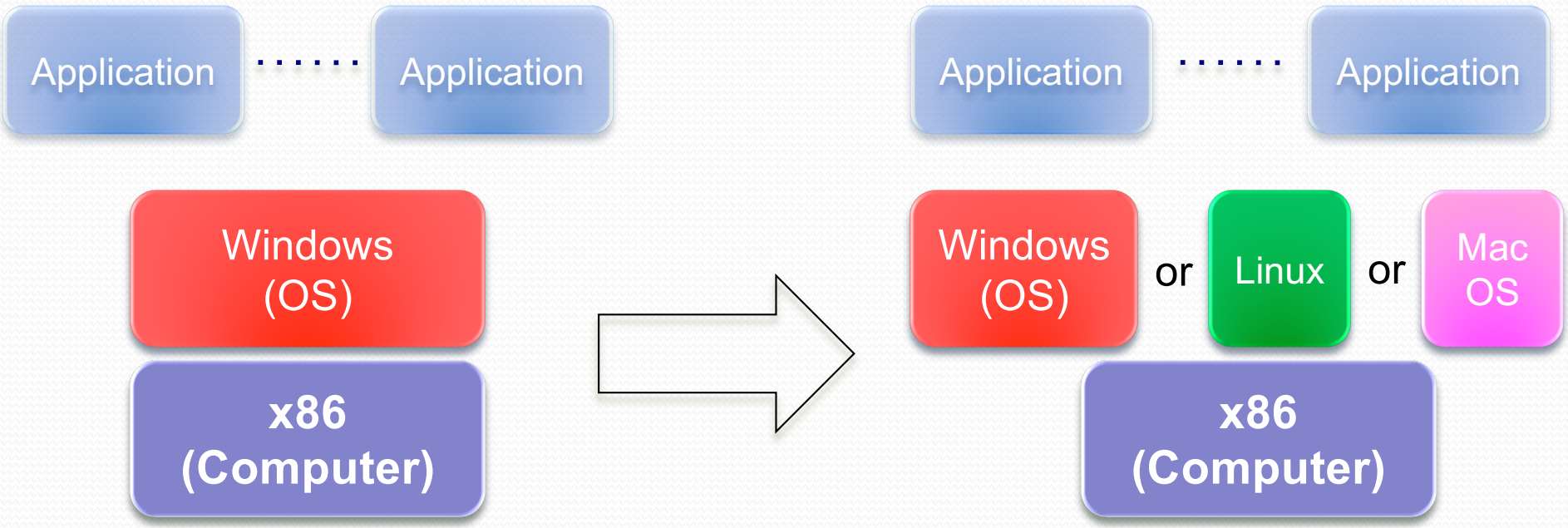
- How difficult is it to create/modify a computer application?
- How difficult is it to create/modify a network feature?
- What is the difference?
- What are the tools available for each?

Innovation in Applications



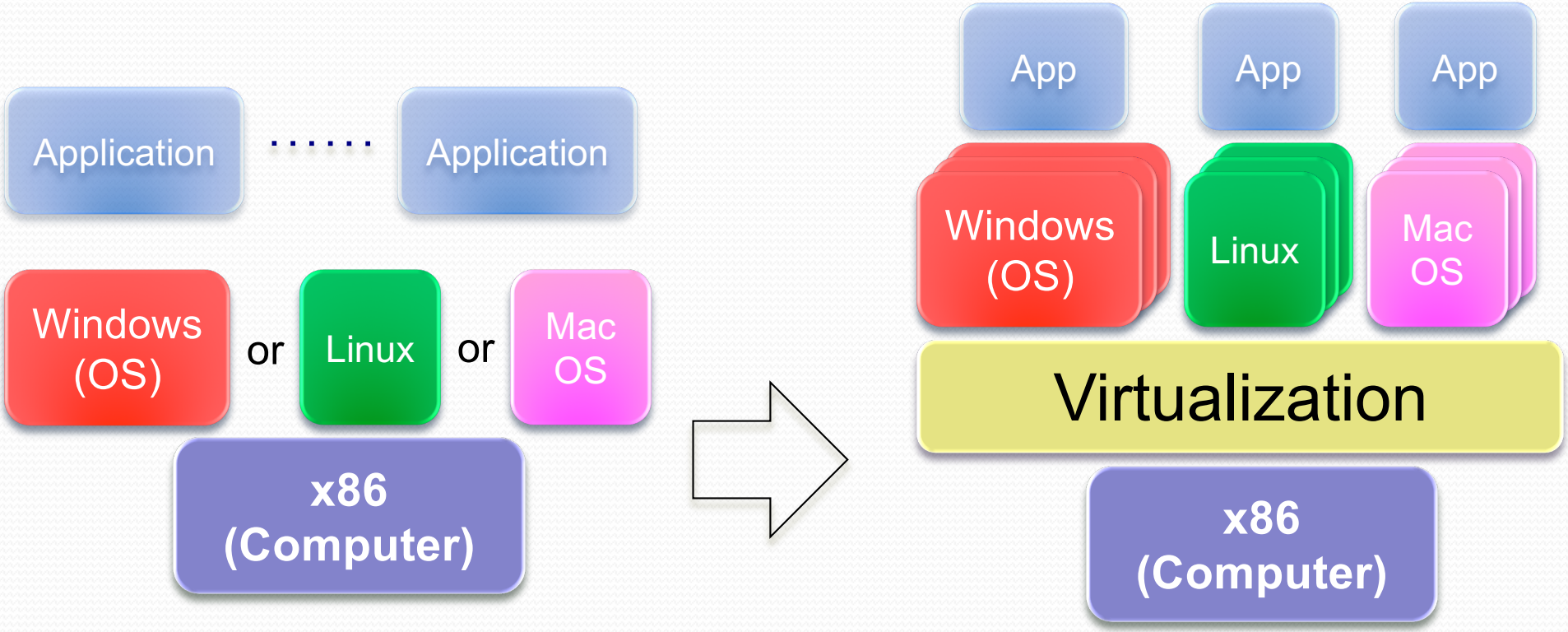
OS abstracts hardware substrate
→ Innovation in applications

Innovation in OS and Applications

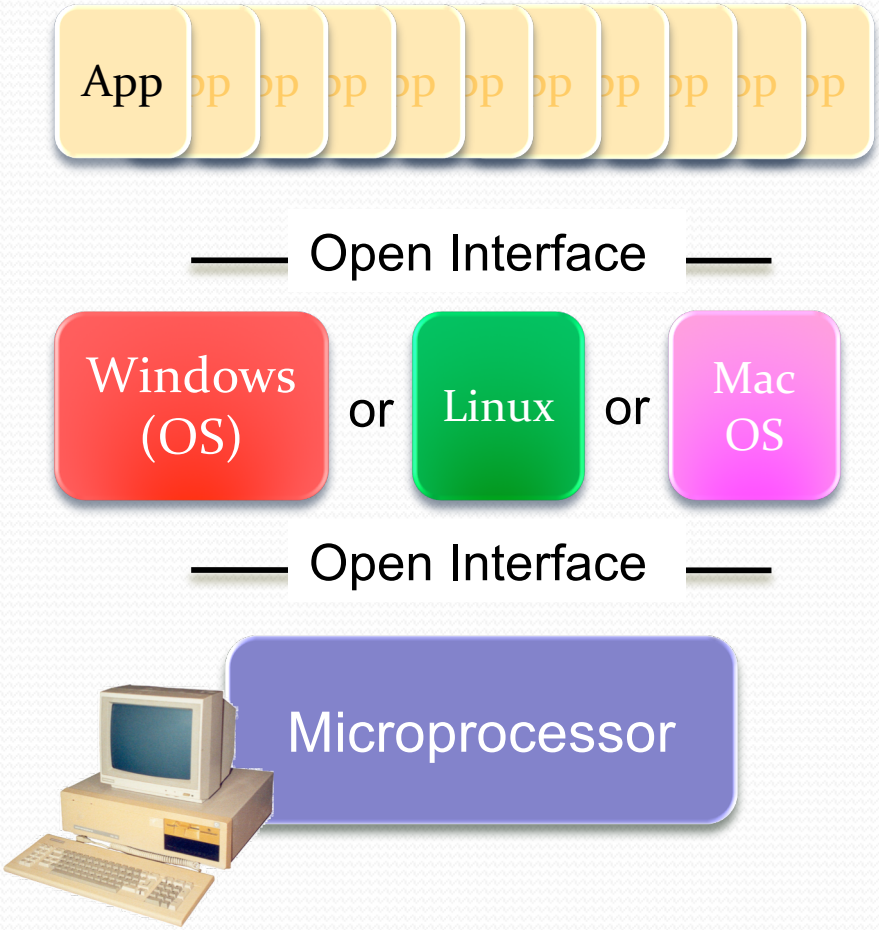


Simple, common, stable, hardware substrate below
+ Programmability
+ Competition
→ Innovation in OS and applications

Innovation in Infrastructure



Simple, common, stable, hardware substrate below
+ Programmability
+ Strong isolation model
+ Competition above
→ Innovation in infrastructure

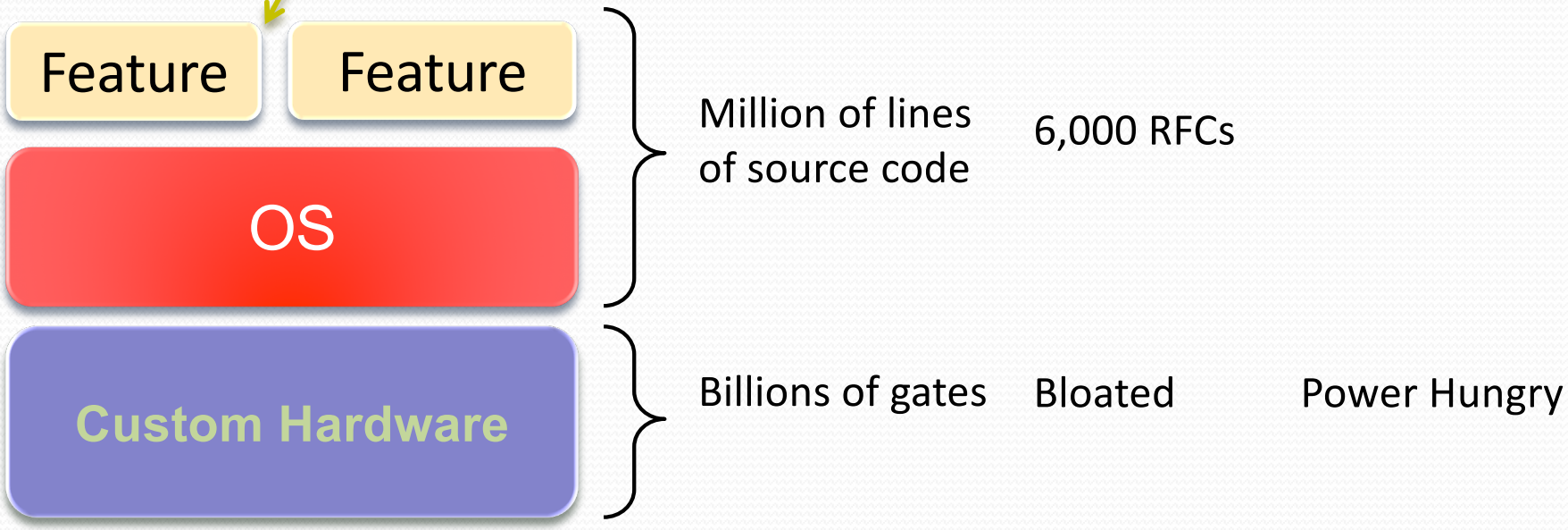


Vertically integrated
Closed, proprietary
Slow innovation
Small industry

Horizontal
Open interfaces
Rapid innovation
Huge industry

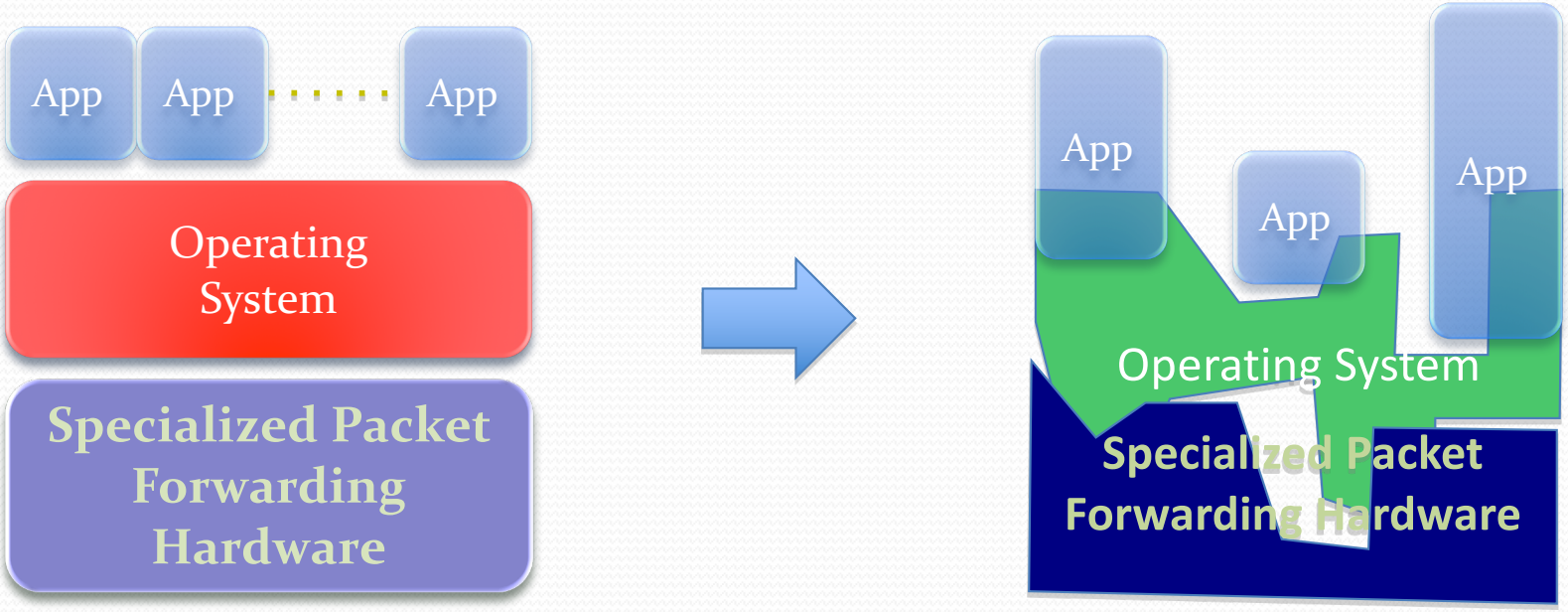
We Have Lost Our Way

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

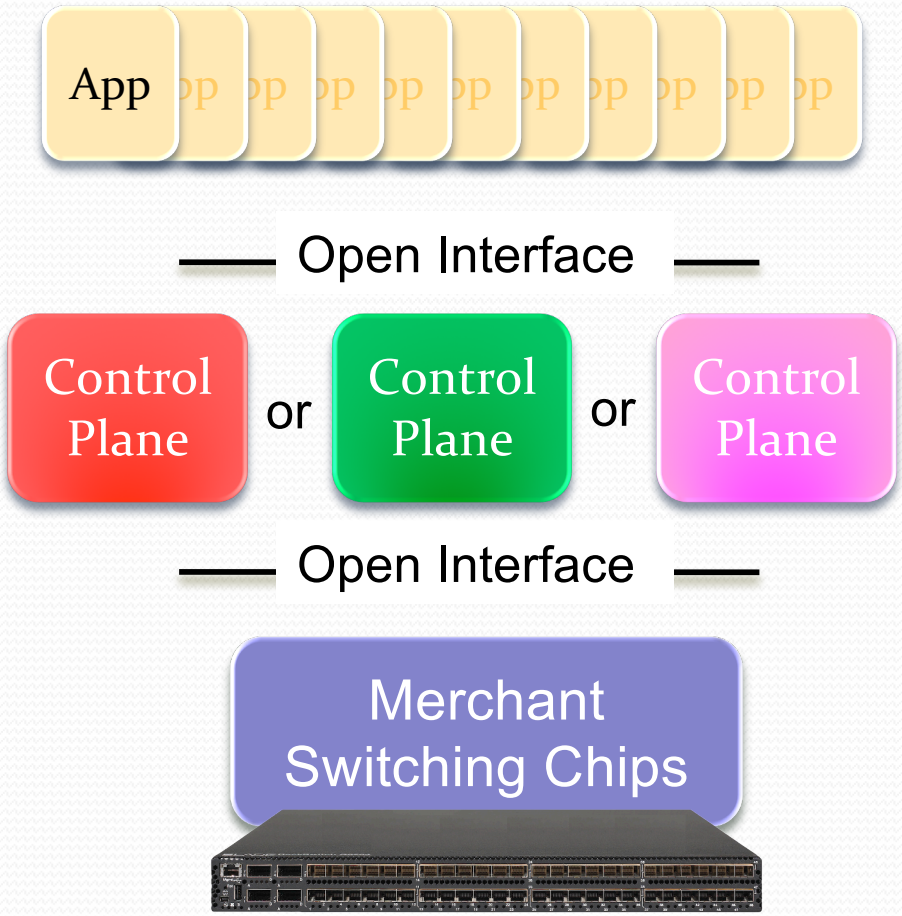


- Vertically integrated, complex, closed, proprietary
- Networking industry with "mainframe" mind-set

Reality is Even Worse



- Lack of competition means glacial innovation
- Closed architecture means blurry, closed interfaces



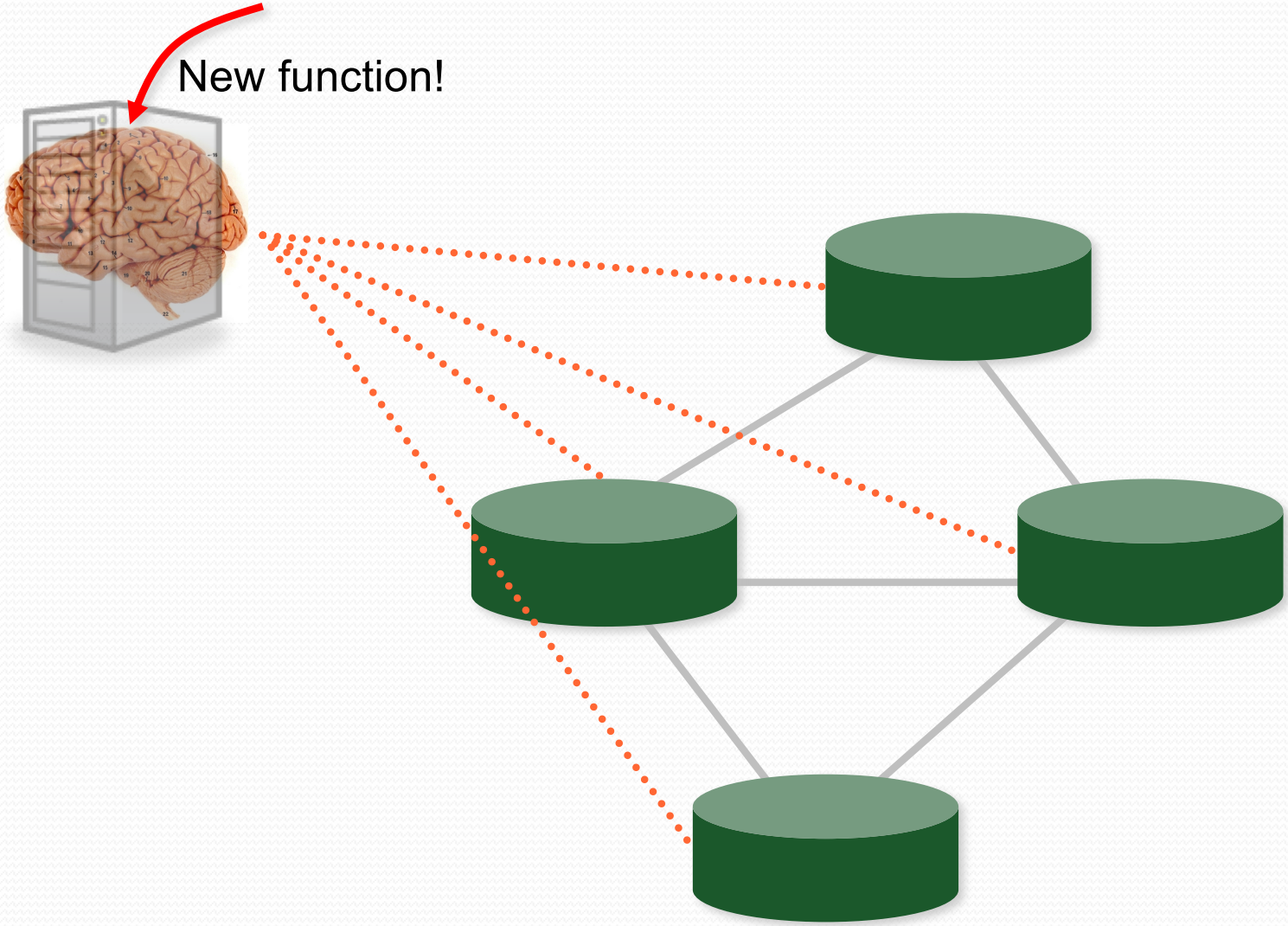
Vertically integrated
Closed, proprietary
Slow innovation

Horizontal
Open interfaces
Rapid innovation

What we need …

1) Separate Intelligence from Datapath

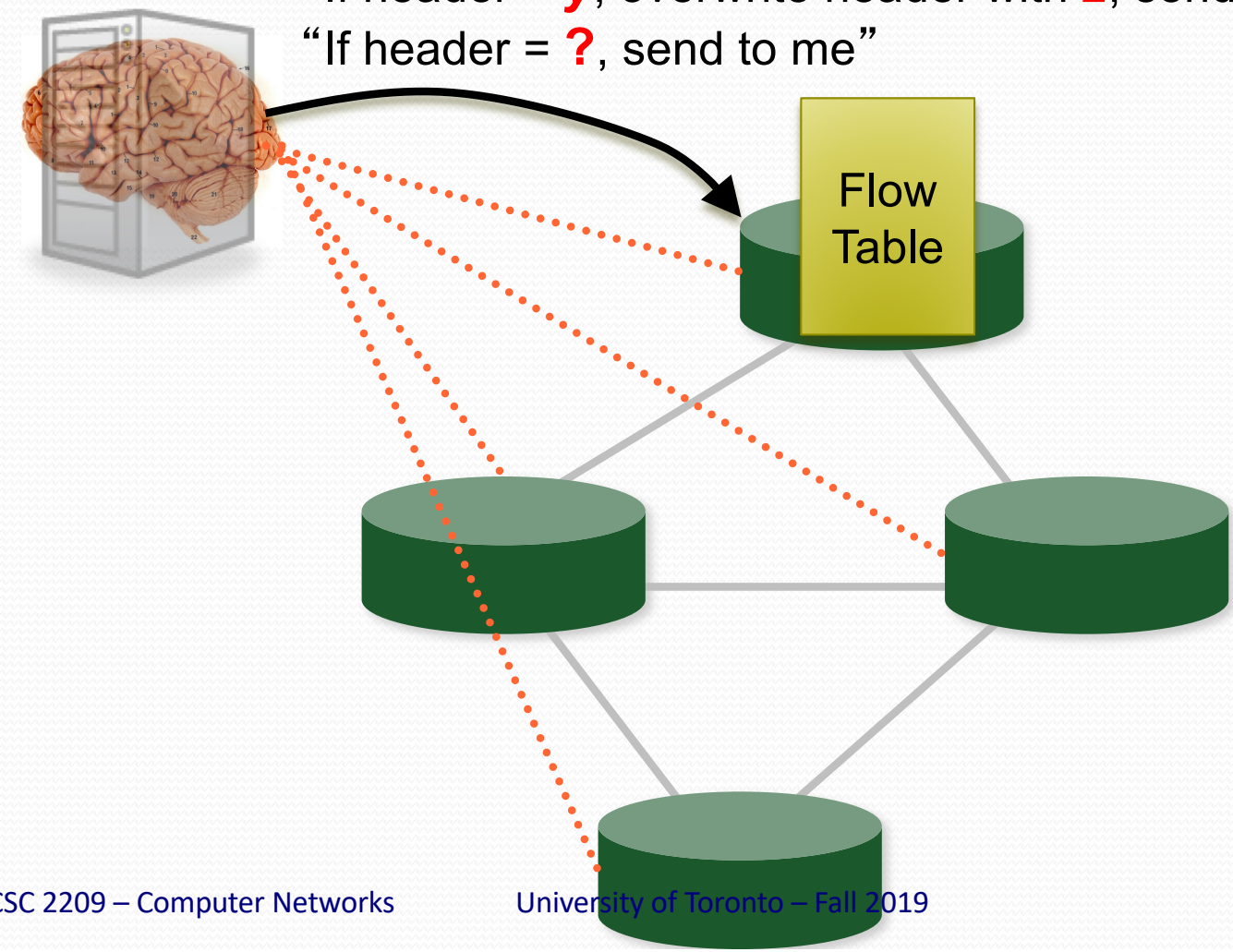
Operators, users, 3rd party developers, researchers, …



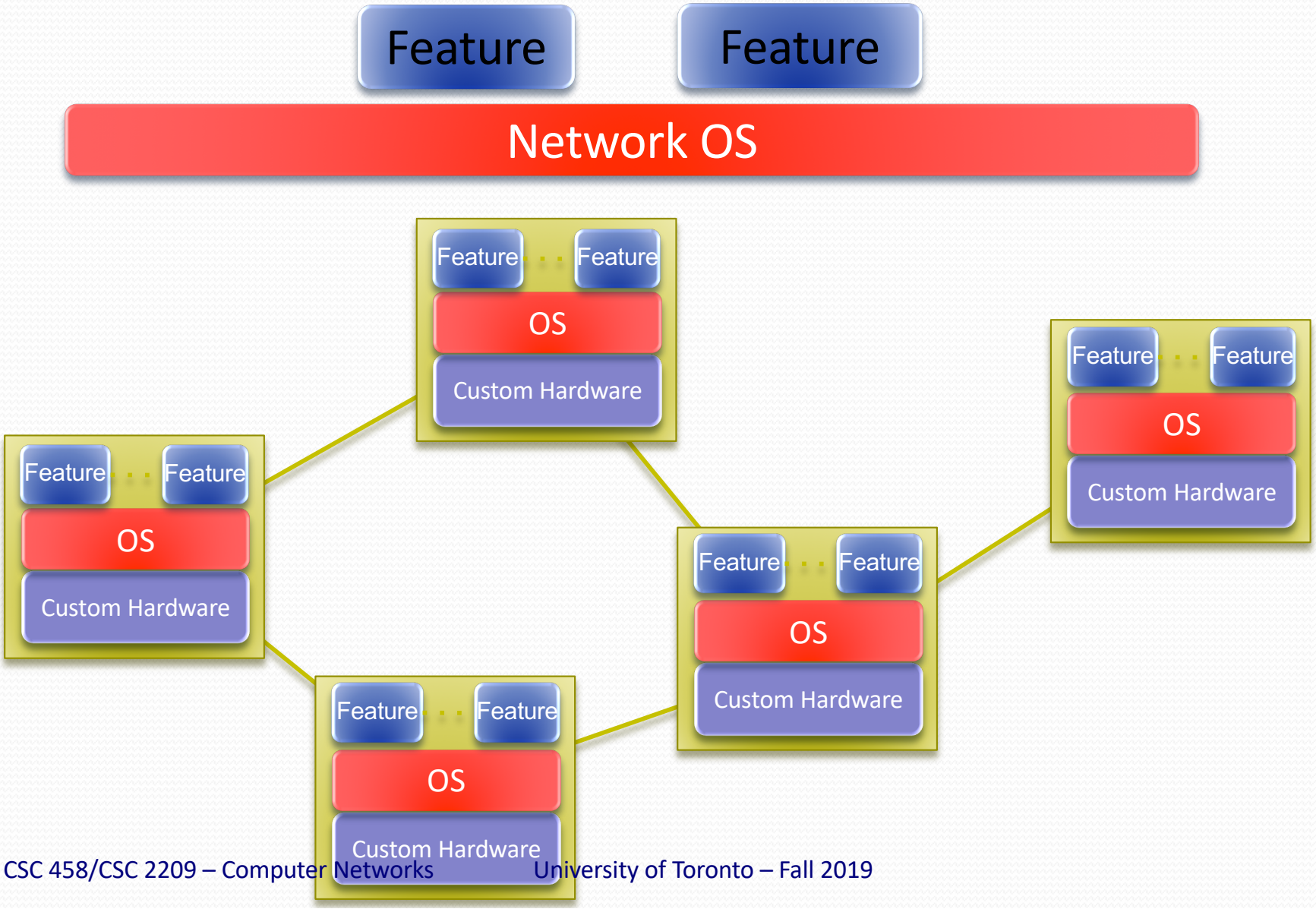
2) Cache Decisions

- In minimal flow-based datapath

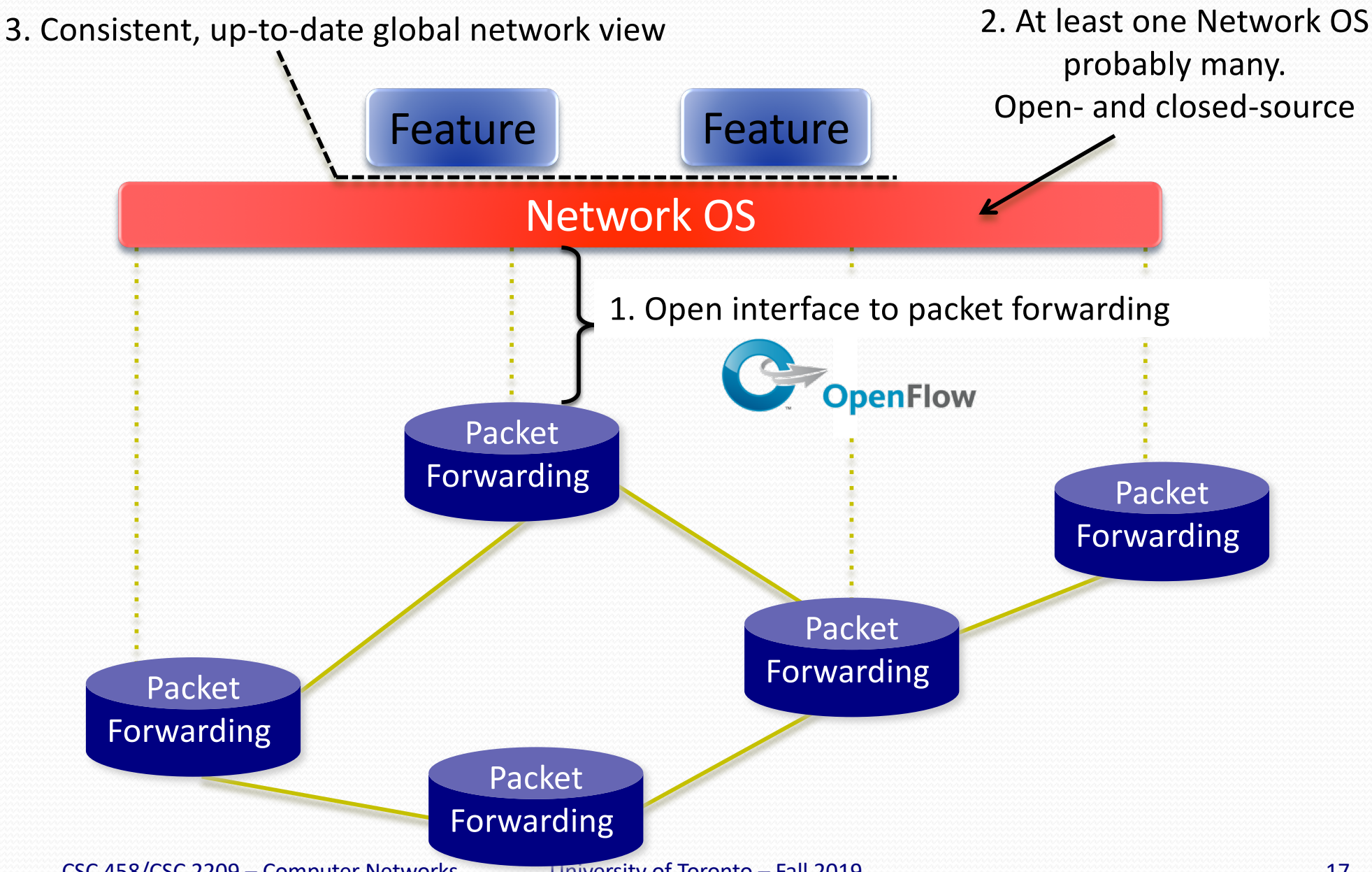
"If header = ***x***, send to port 4"
"If header = ***y***, overwrite header with ***z***, send to ports 5,6"
"If header = **?**, send to me"



How Can We Do This?



Software Defined Network (SDN)



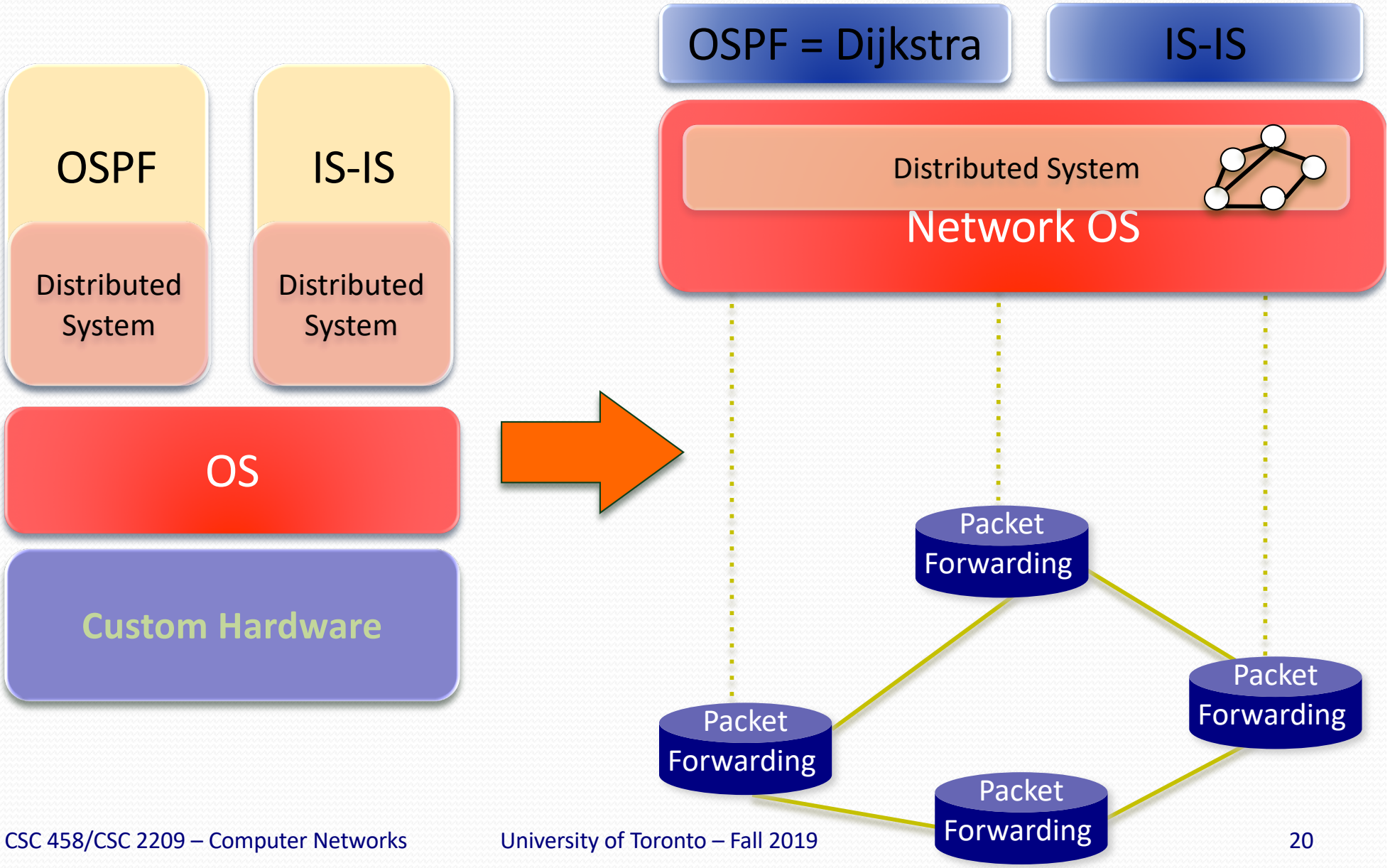
Consequences

- More innovation in network services
  - Owners, operators, 3rd party developers, researchers can improve the network
  - E.g. energy management, data center management, policy routing, access control, denial of service, mobility
- Lower barrier to entry for competition
  - Healthier market place, new players
- Lower cost
  - Infrastructure
  - Management

Example: Routing

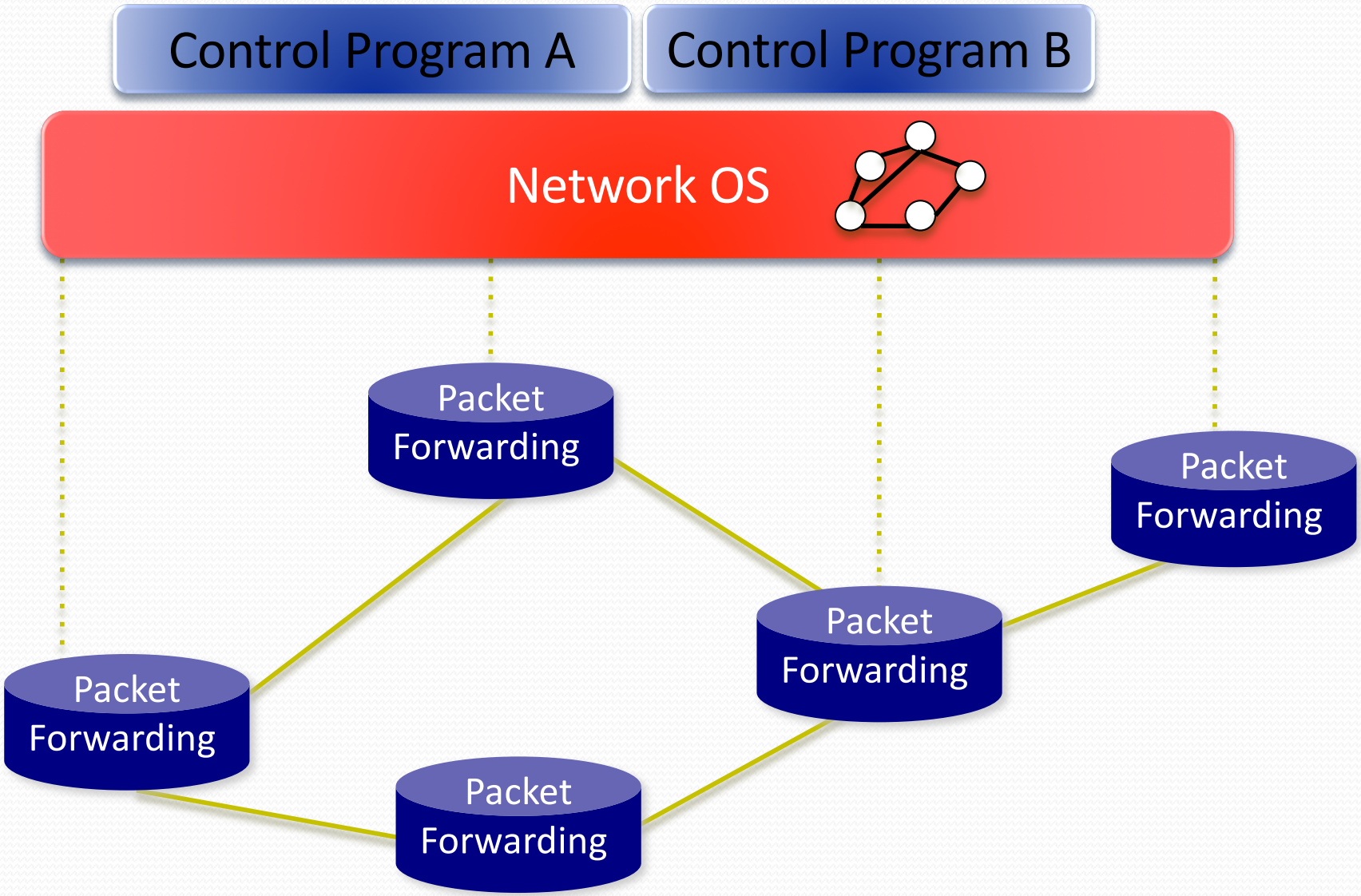
- OSPF
  - RFC 2328: 245 pages
- Distributed System
  - Builds consistent, up-to-date map of the network: 101 pages
- Dijkstra's Algorithm
  - Operates on map: 4 pages

Example: Routing



Back to the story …

Software Defined Network (SDN)



Network OS

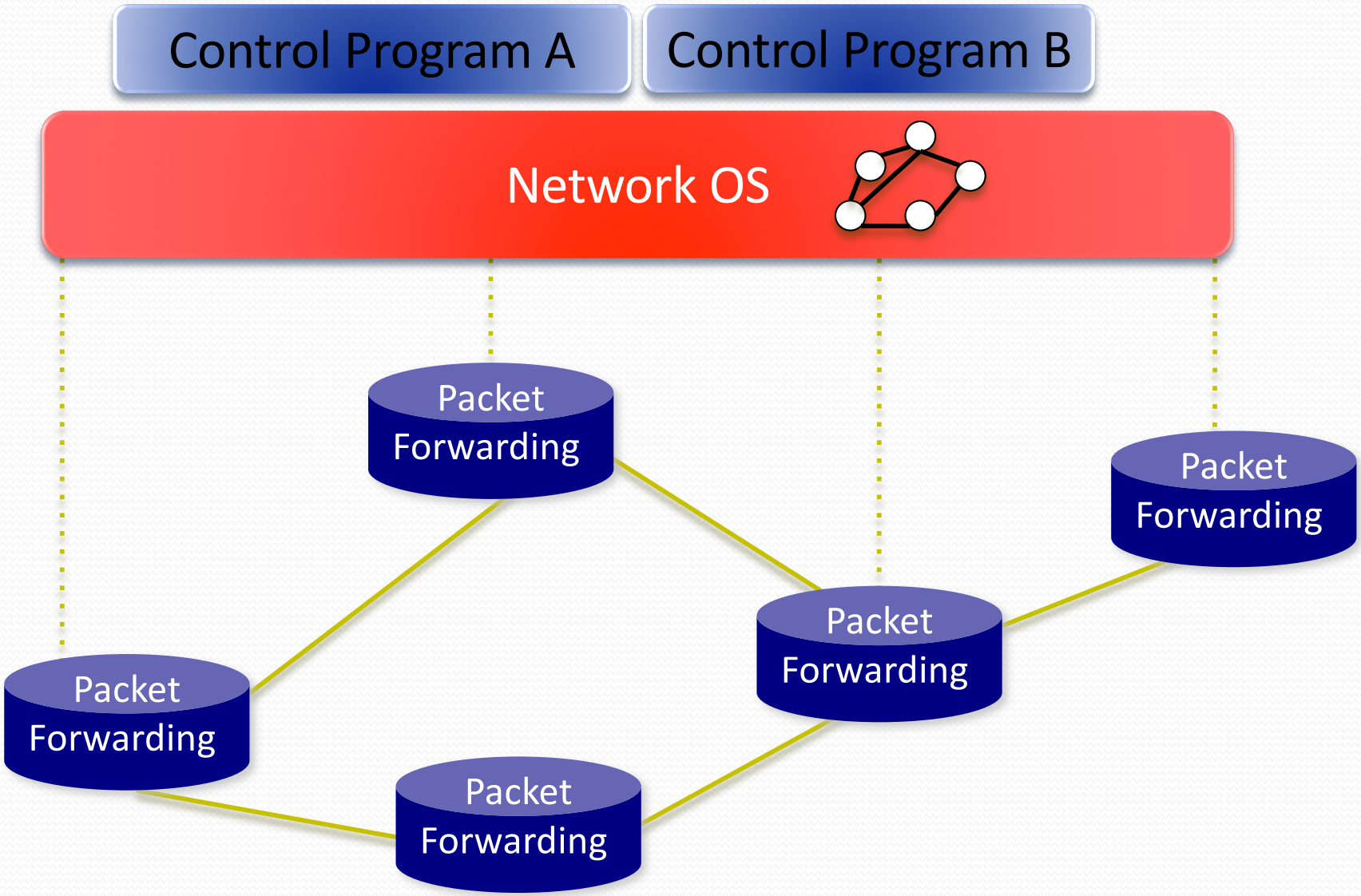
Network OS: distributed system that creates a consistent, up-to-date network view

- Runs on servers (controllers) in the network
- NOX, ONIX, HyperFlow, Kandoo, Floodlight, Trema, Beacon, Maestro, BeeHive, OpenDayLight, … + more

Uses forwarding abstraction to:

- Get state information **from** forwarding elements
- Give control directives **to** forwarding elements

Software Defined Network (SDN)



Control Program

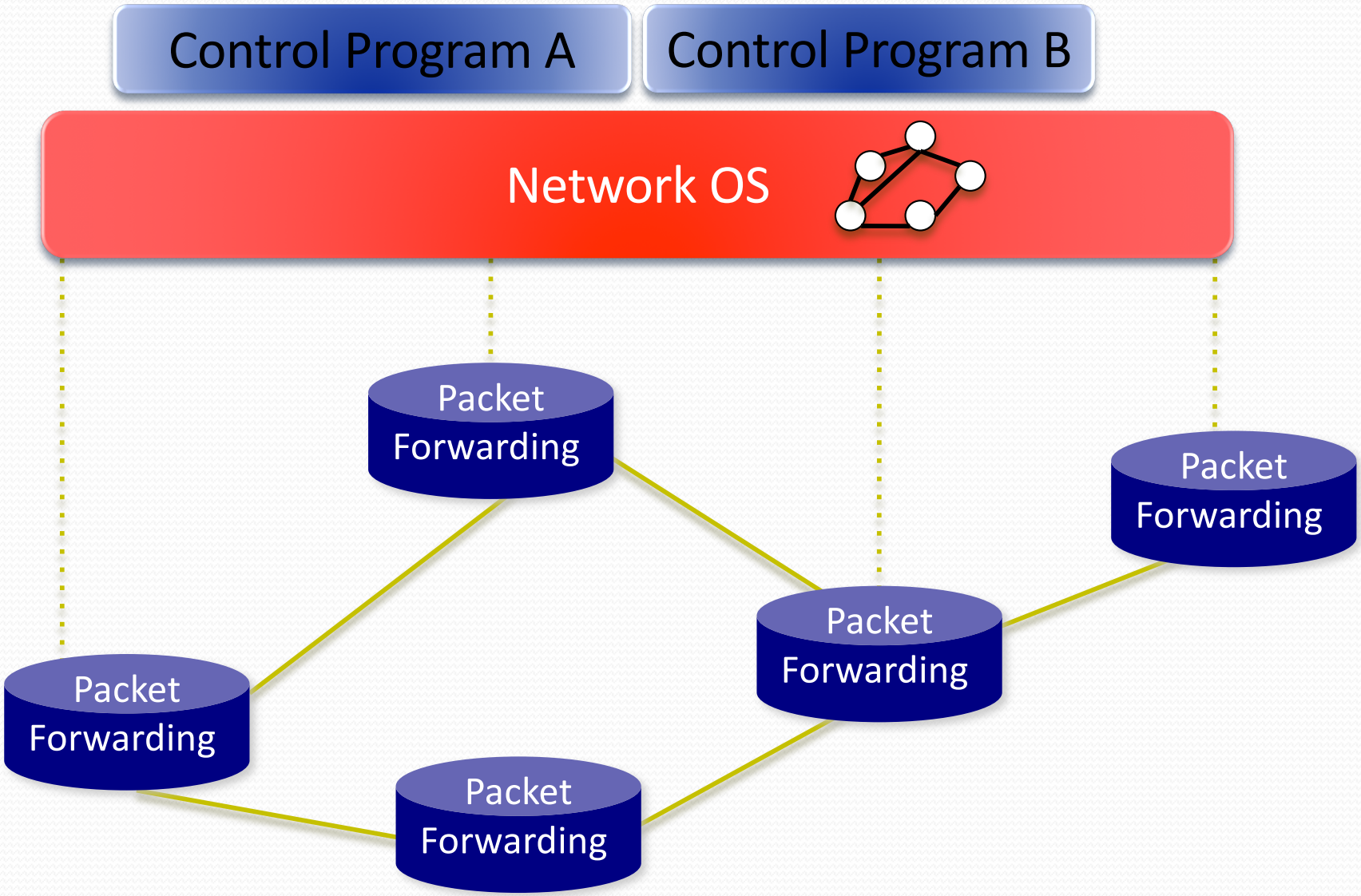
Control program operates on view of network

- **Input**: global network view (graph/database)
- **Output**: configuration of each network device

Control program is not a distributed system

- Abstraction hides details of distributed state

Software Defined Network (SDN)



Forwarding Abstraction

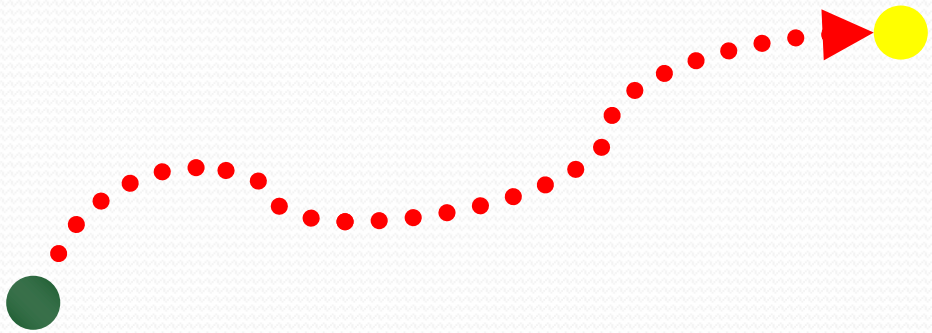
Purpose: Abstract away forwarding hardware

- 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 of such an abstraction

Forwarding Substrate

- Flow-based
- Small number of actions for each flow
  - Plumbing: Forward to port(s)
  - Control: Forward to controller
  - Routing between flow-spaces: Rewrite header
  - Bandwidth isolation: Min/max rate
- External open API to flow-table



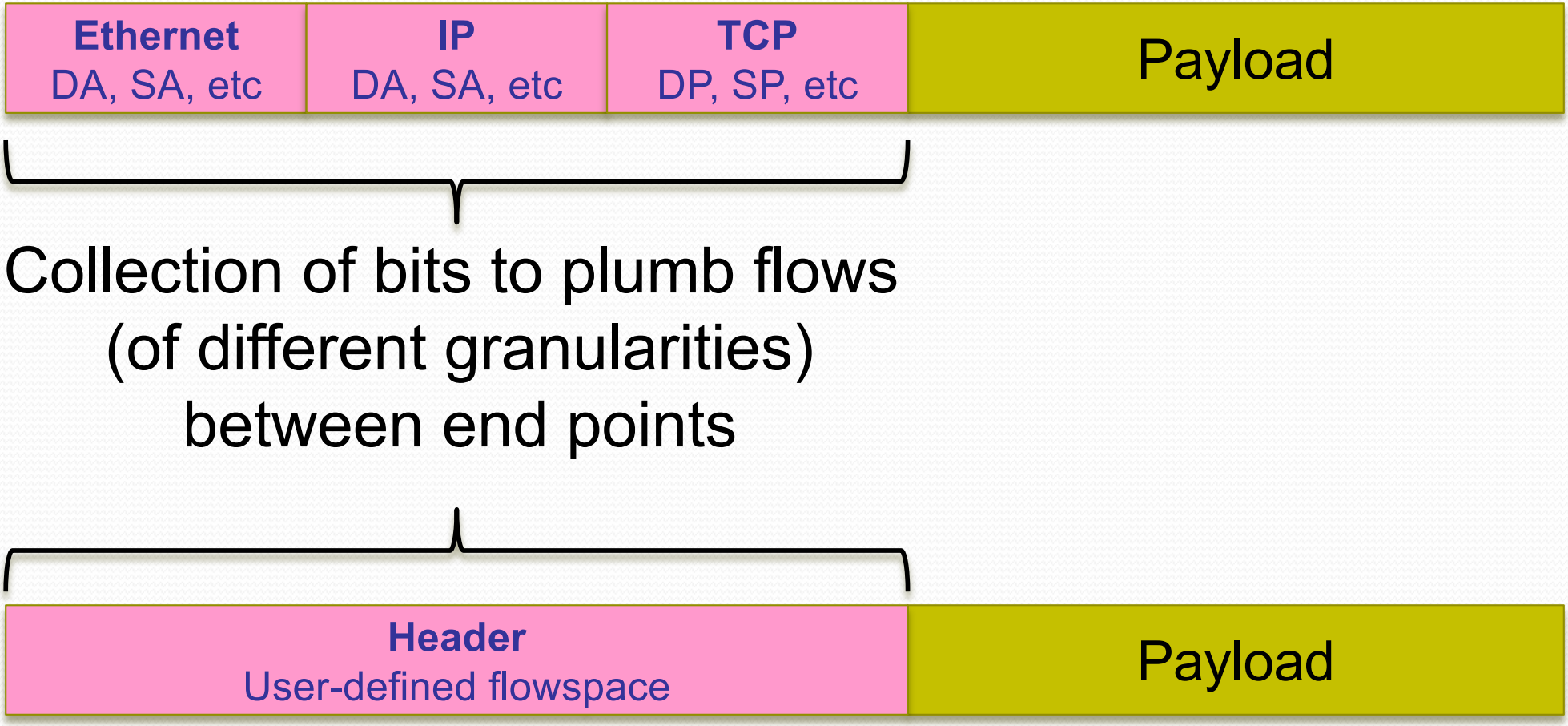
What is a flow?

- Application flow
- All http
- Jim's traffic
- All packets to Canada
- …

Types of action

- Allow/deny flow
- Route & re-route flow
- Isolate flow
- Make flow private
- Remove flow

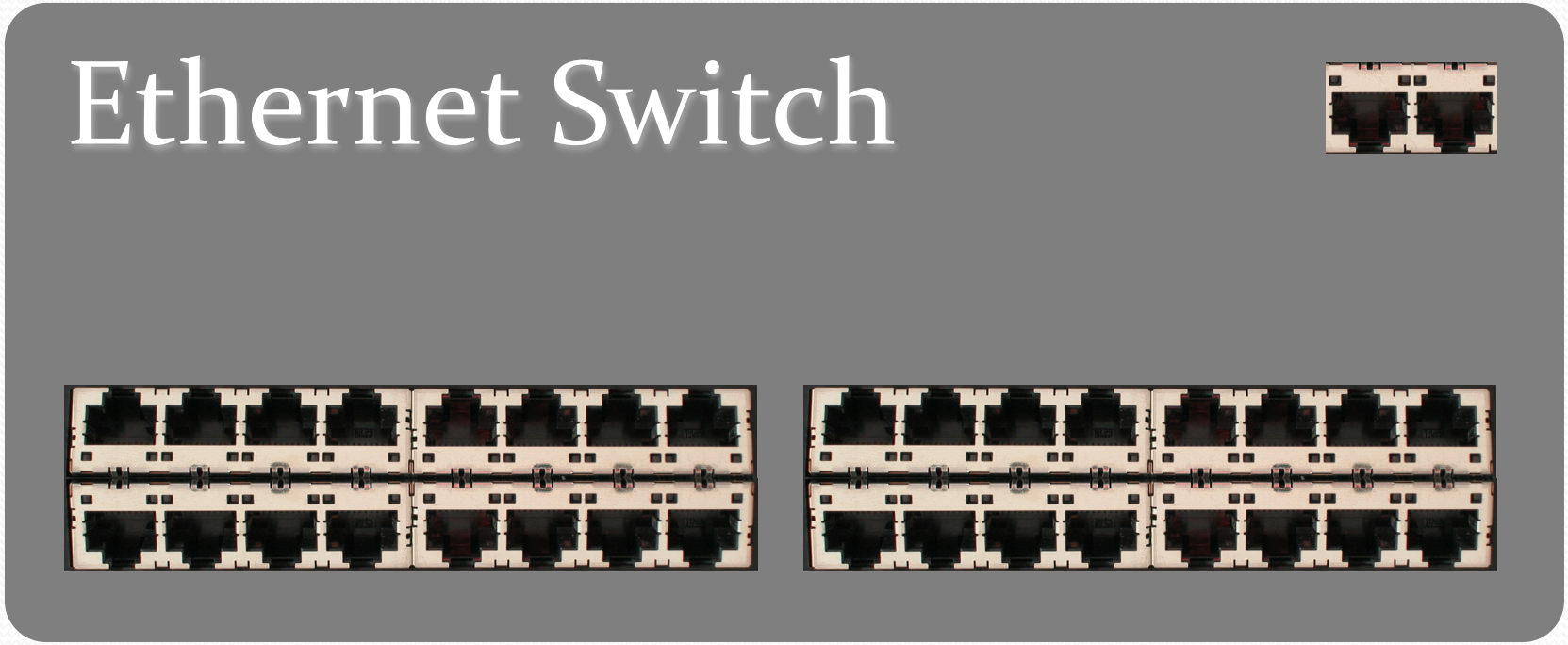
Substrate: "Flowspace"



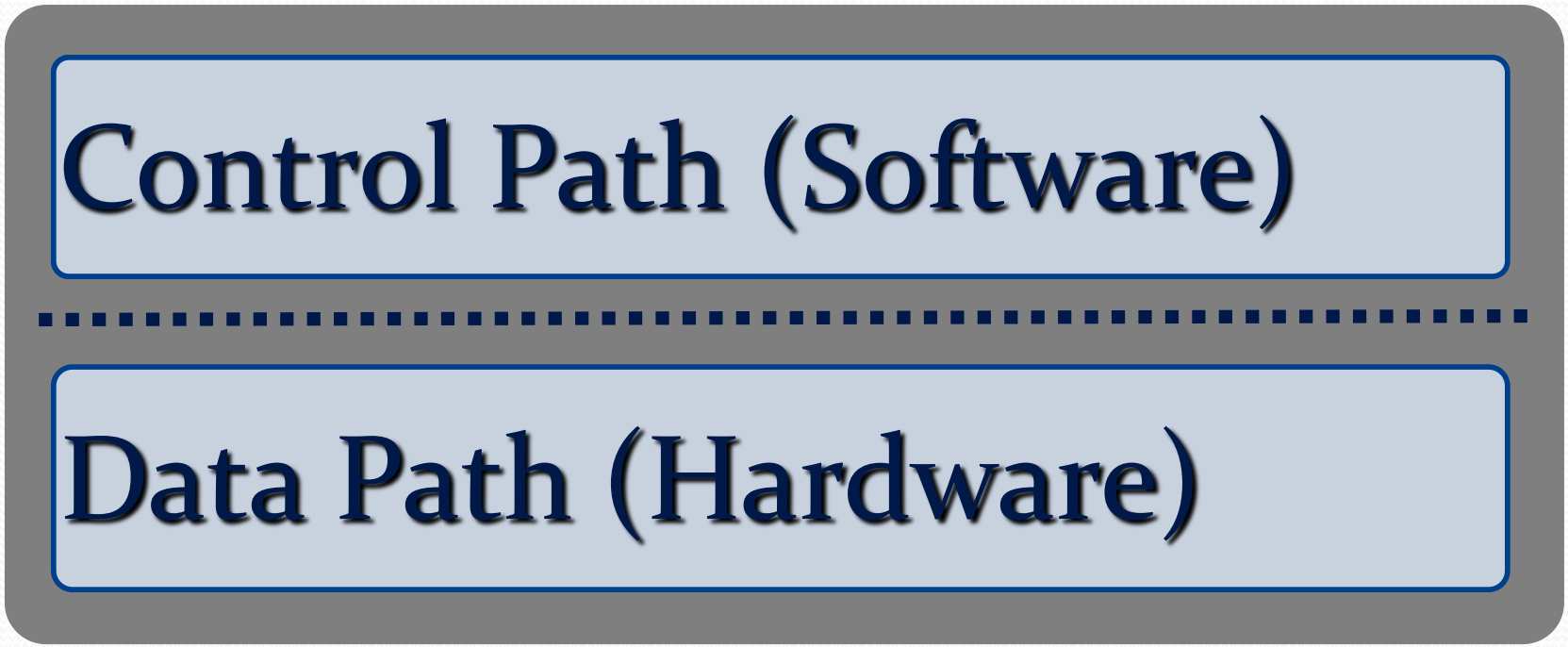
OpenFlow

- OpenFlow
  - Open standard to run experimental protocols in production networks
    - API between the forwarding elements and the network OS
  - Based in Stanford, supported by various companies (Cisco, Juniper, HP, NEC, …)
  - Used by universities to deploy innovative networking technology

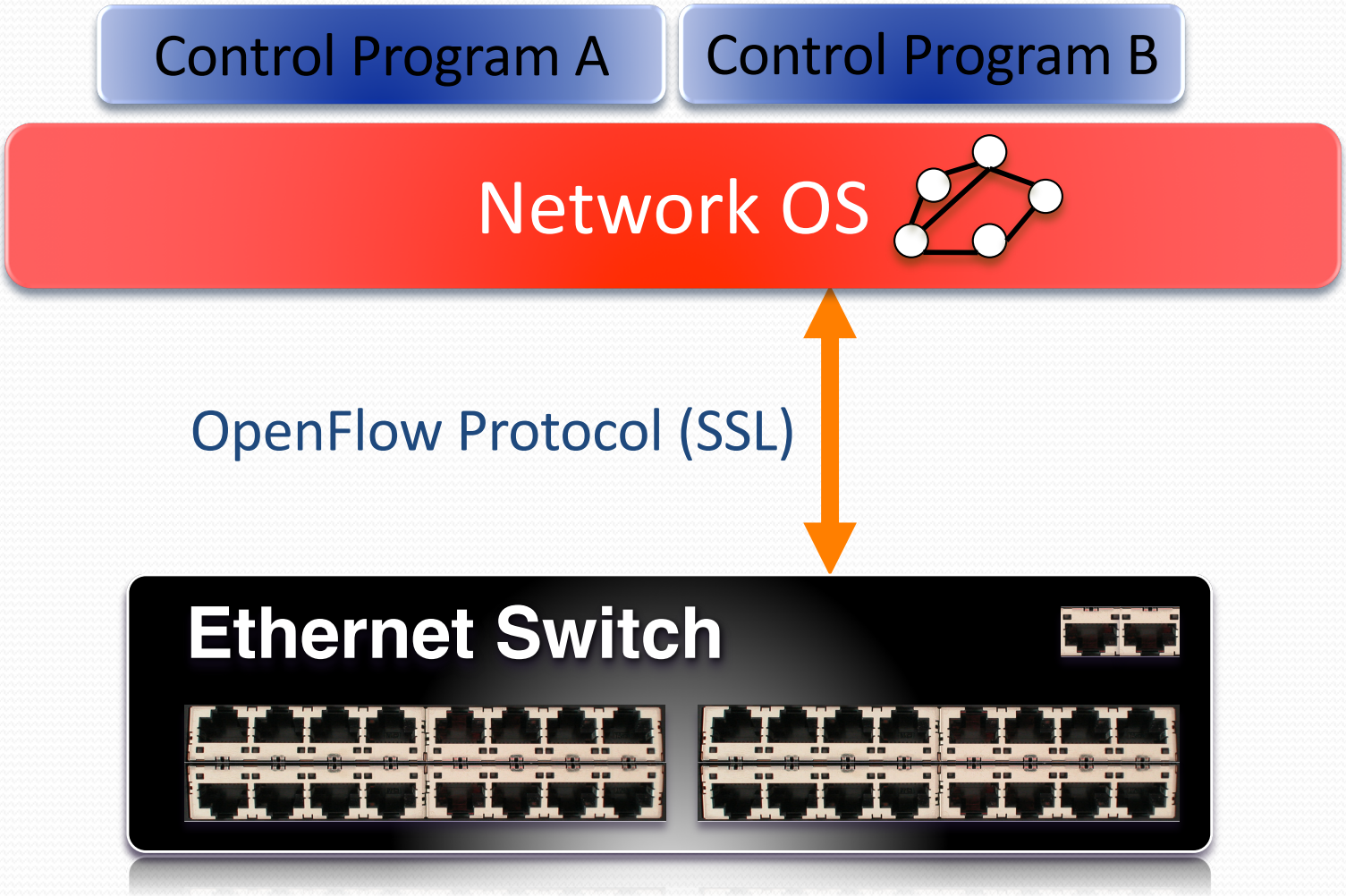
Traditional Switch



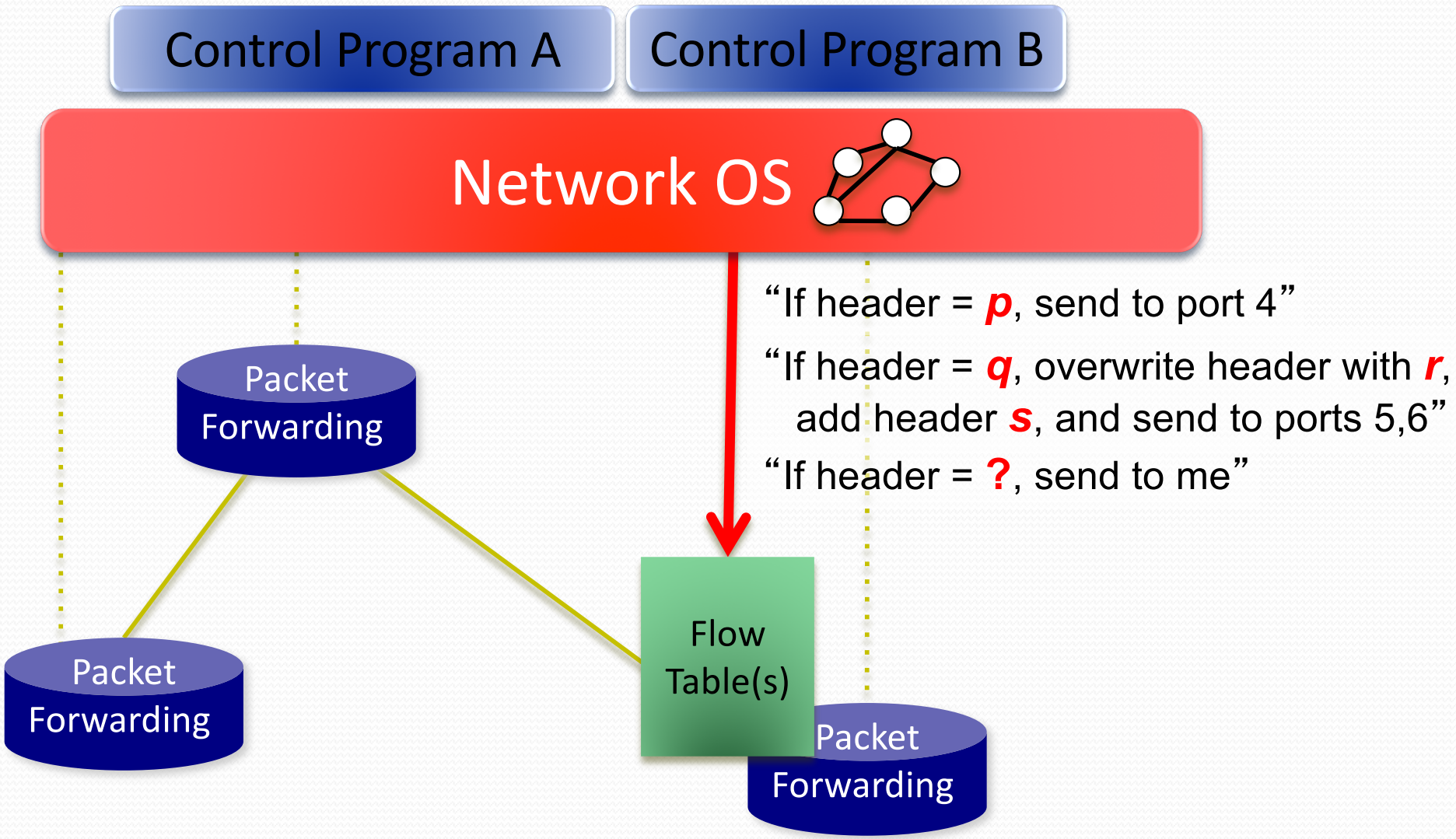
Traditional Switch



OpenFlow Switch



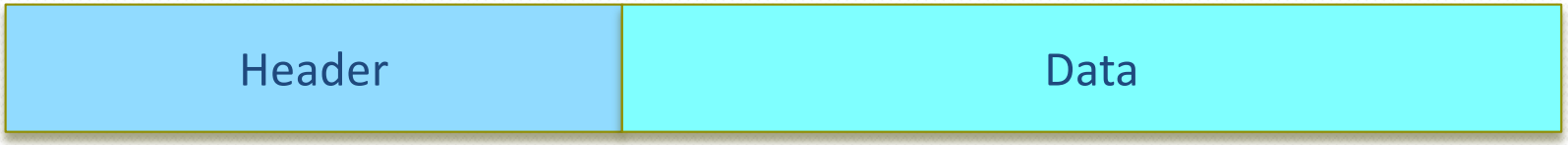
OpenFlow Rules



Plumbing Primitives

<Match, Action>

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

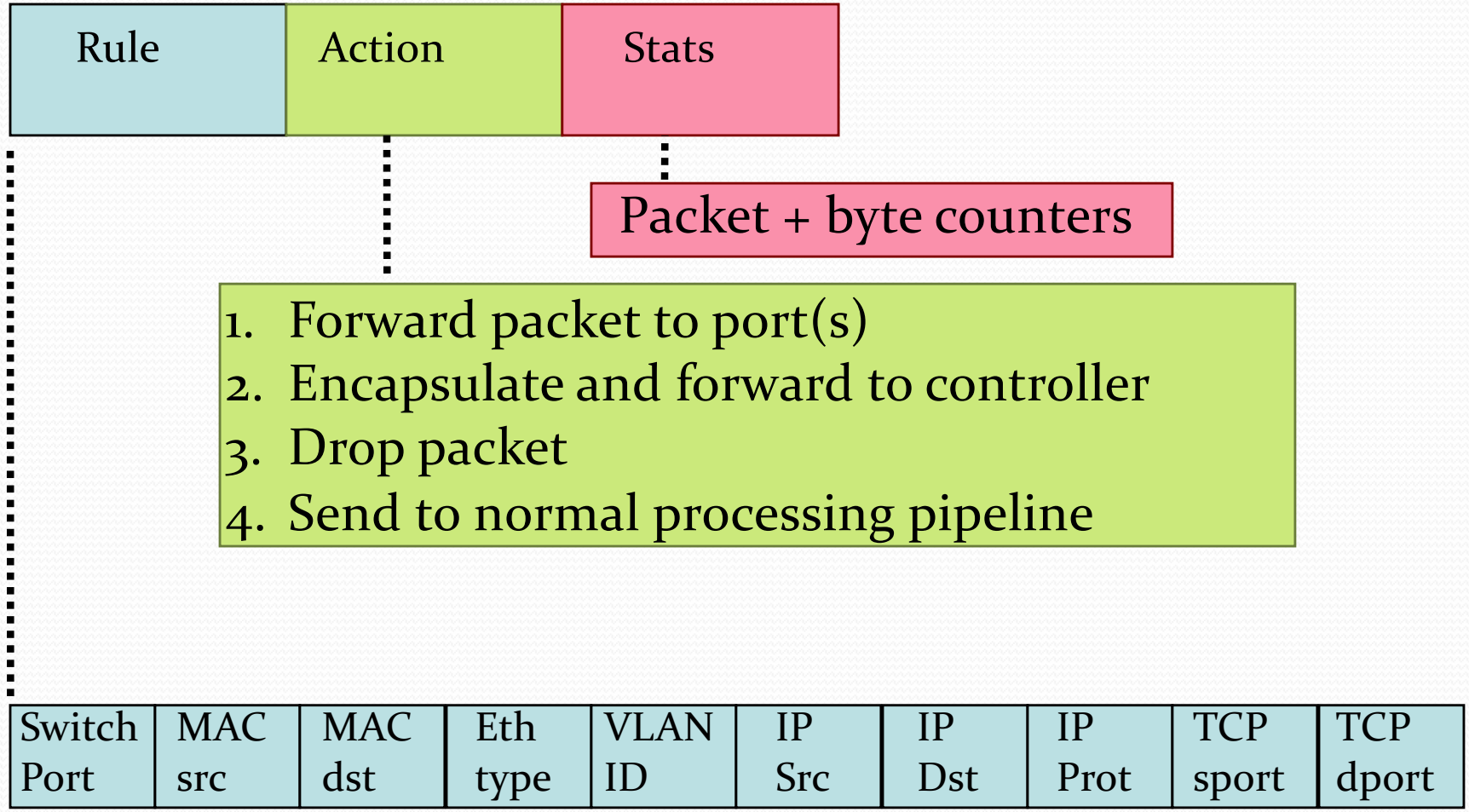
OpenFlow Rules – Cont'd

- Exploit the 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 Table Entry

- OpenFlow Protocol Version 1.0



+ mask what fields to match

Examples

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	00:2e..	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	Forward
*	*	*	*	*	*	*	*	*	22	drop

Examples

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

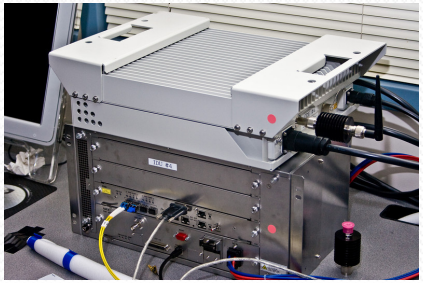
VLAN

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

OpenFlow Hardware

Juniper MX-series

NEC IP8800



WiMax (NEC)

HP Procurve 5400

Cisco Catalyst 6k

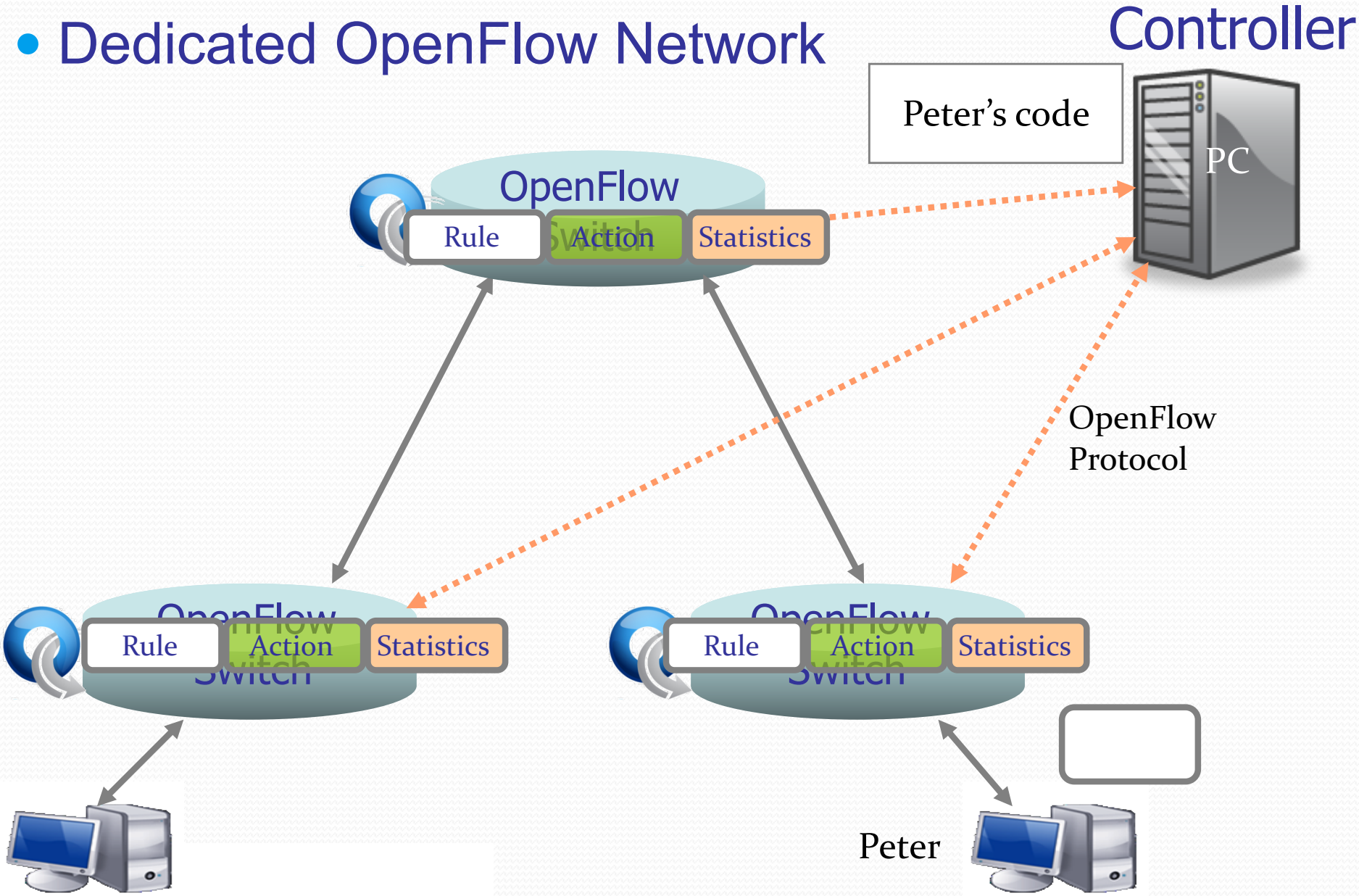
PC Engines

Quanta LB4G

More …

OpenFlow Usage Example

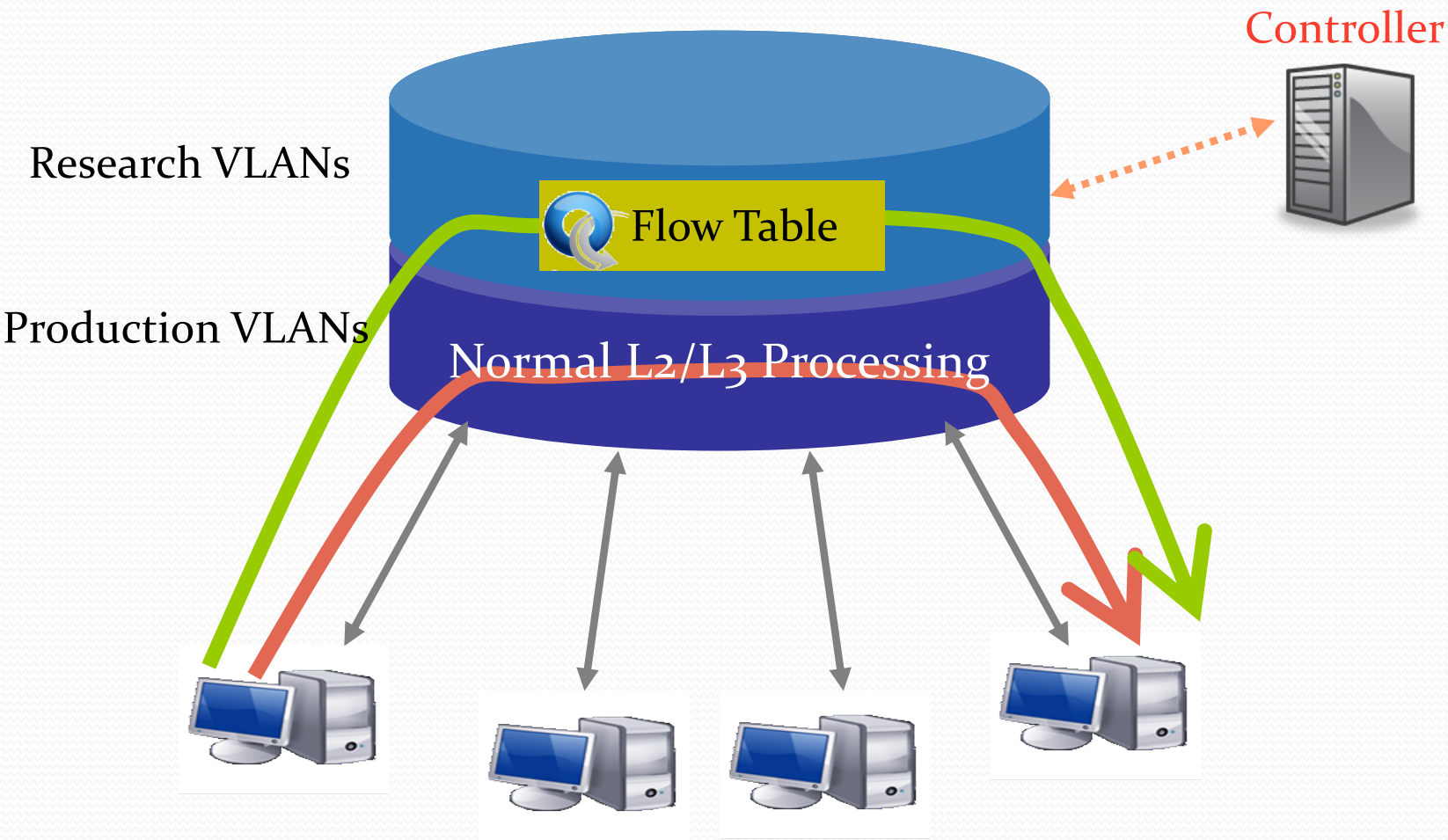
- Dedicated OpenFlow Network



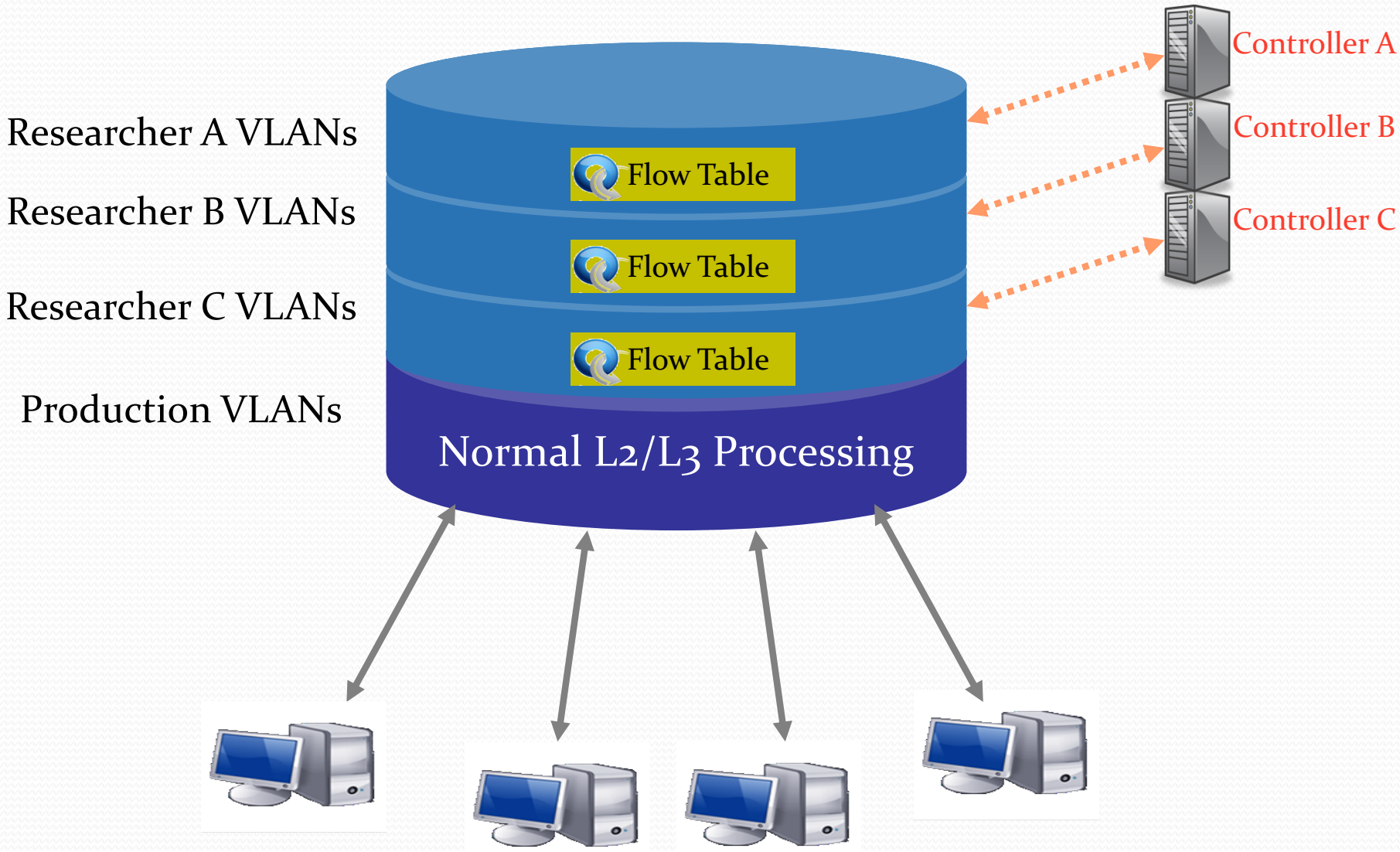
Usage examples

- Peter's code:
  - Static "VLANs"
  - His own new routing protocol: unicast, multicast, multipath, load-balancing
  - Network access control
  - Home network manager
  - Mobility manager
  - Energy manager
  - Packet processor (in controller)
  - IPvPeter
  - Network measurement and visualization
  - …

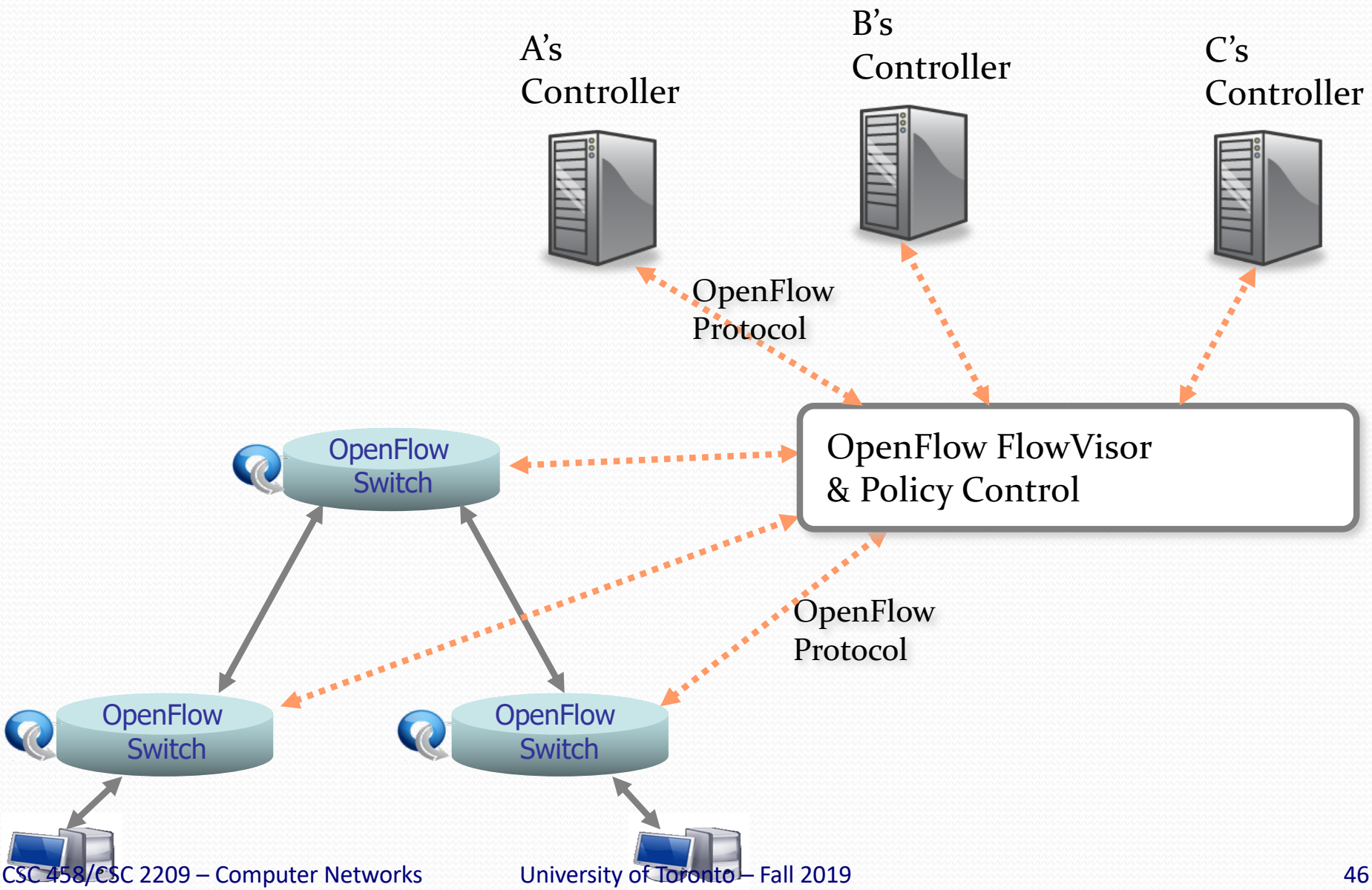
Research/Production VLANS



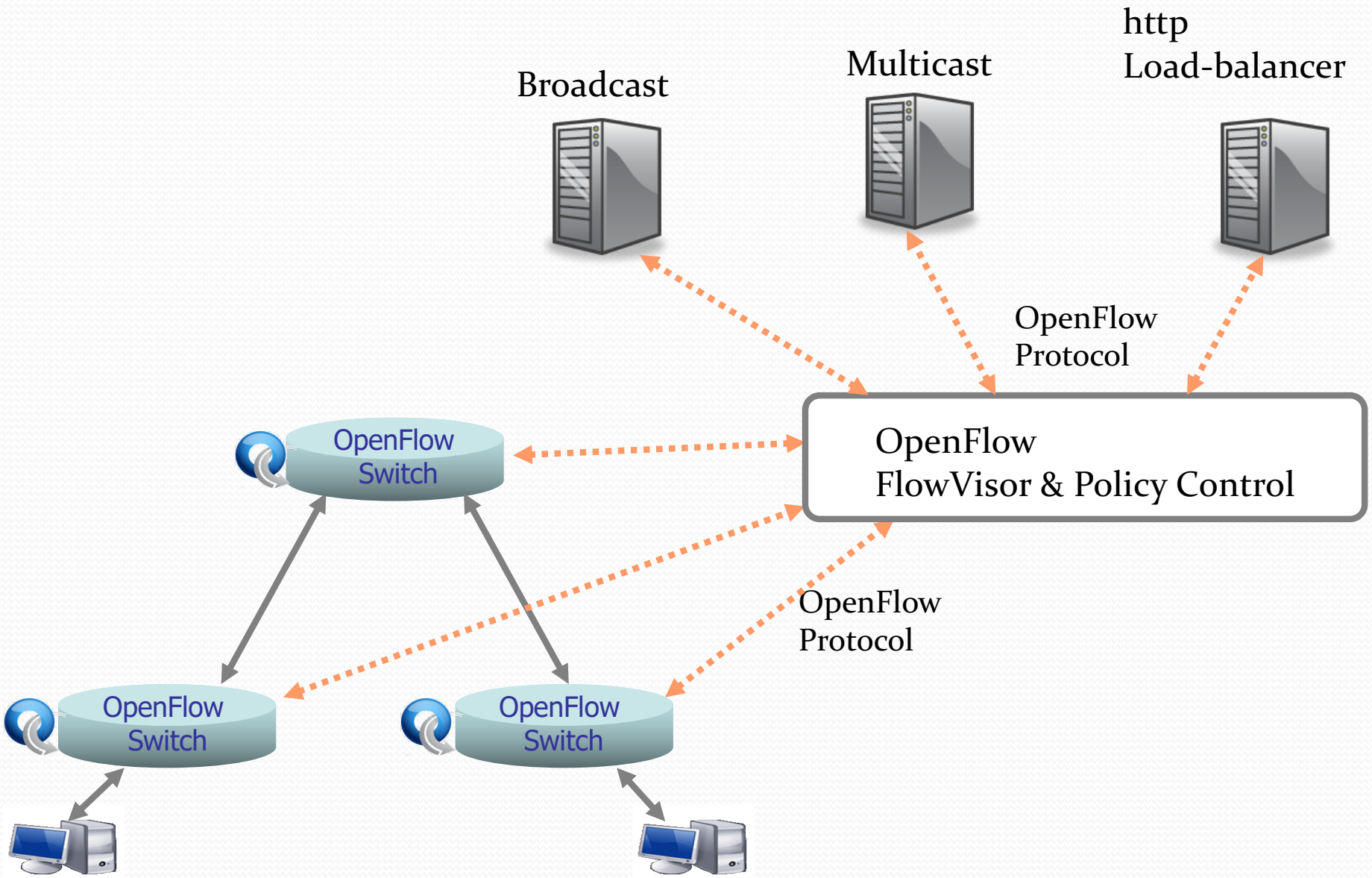
Virtualize OpenFlow Switch



Virtualizing OpenFlow



Virtualizing OpenFlow



Food for Thought

- What are the challenges in switching from traditional networks to OpenFlow networks?

- What are the opportunities?