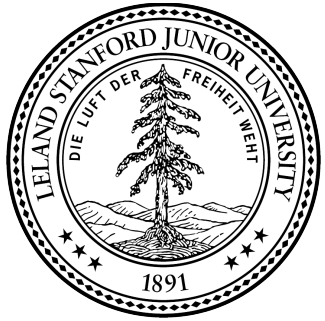


How SDN will shape networking

Nick McKeown
Stanford University

With: **Martín Casado**, Teemu Koponen, Scott Shenker
… and many others

With thanks to: NSF, GPO, Stanford Clean Slate Program,
Cisco, DoCoMo, DT, Ericsson, Google, HP, Huawei, NEC, Xilinx

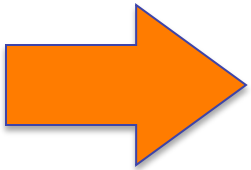
Outline

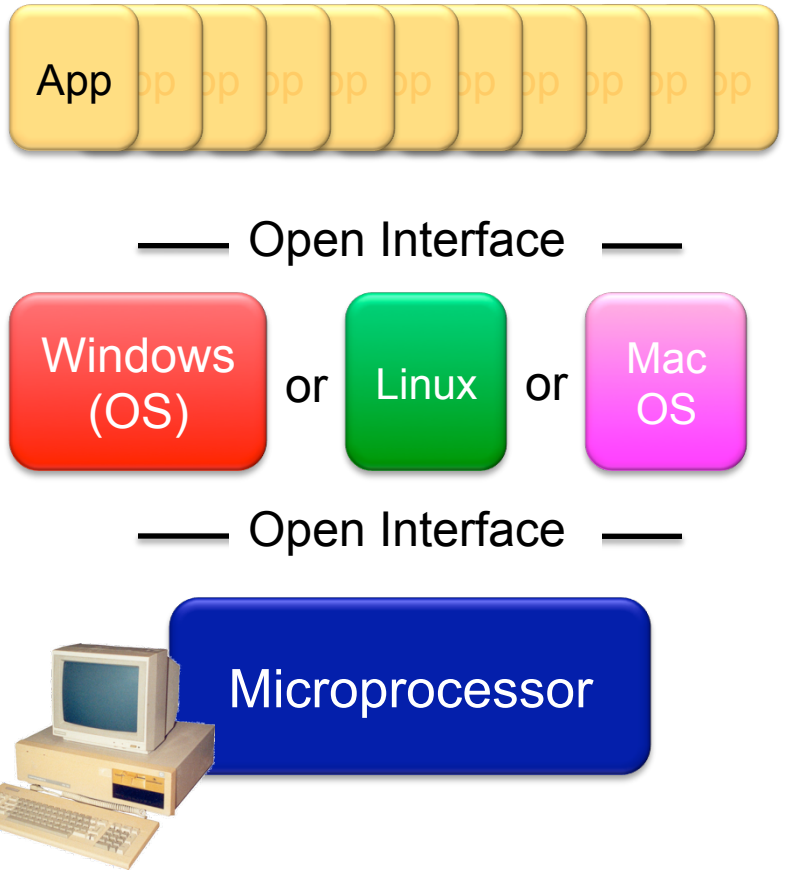
SDN: An industry change

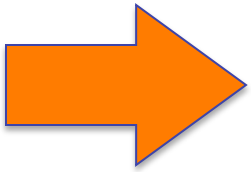
How SDN will shape networking

1. Empower network owners/operators
2. Increase the pace of innovation
3. Diversify the supply chain
4. Build a robust foundation

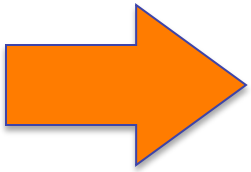
Vertically integrated
Closed, proprietary
Slow innovation
Small industry

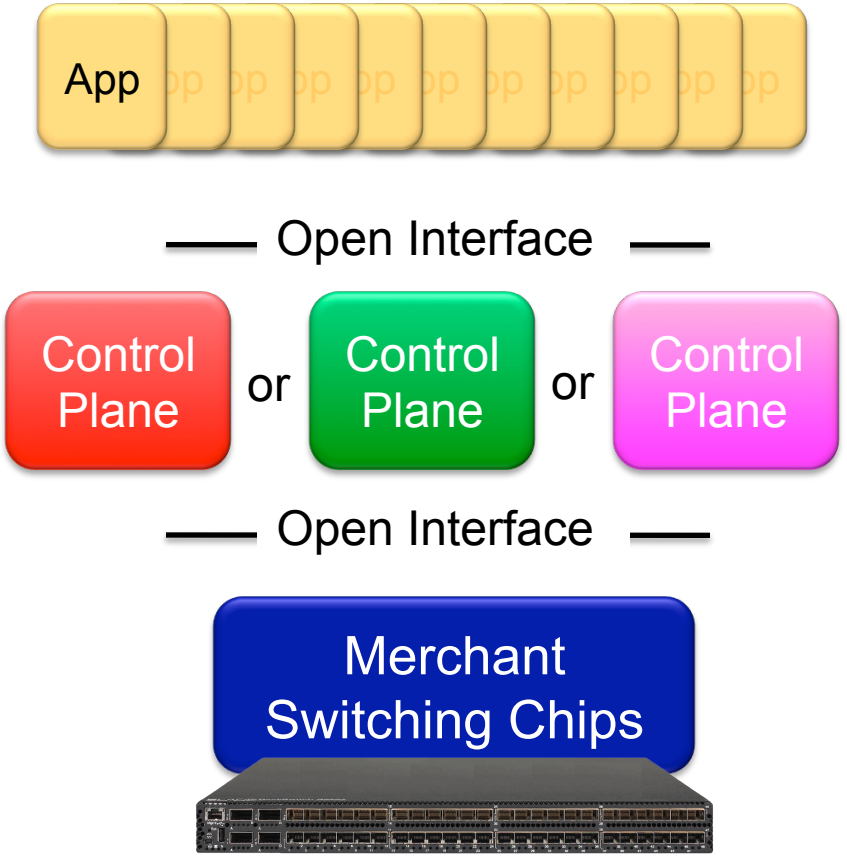




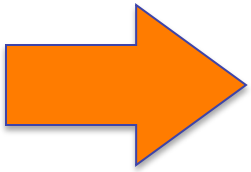


Horizontal
Open interfaces
Rapid innovation
Huge industry



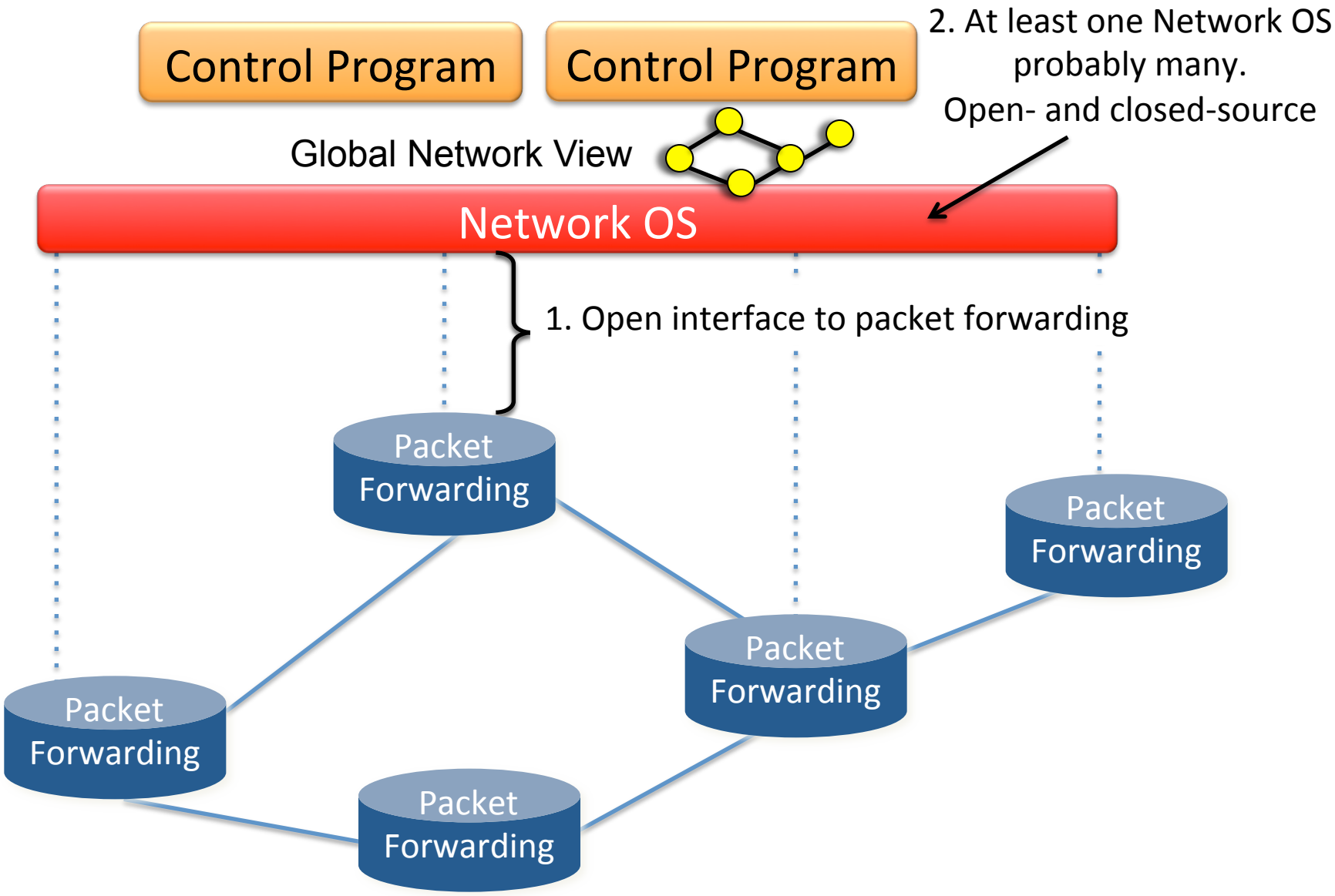


Vertically integrated
Closed, proprietary
Slow innovation



Horizontal
Open interfaces
Rapid innovation

Software Defined Network (SDN)



Simple example

OSPF

- RFC 2328: **245 pages**

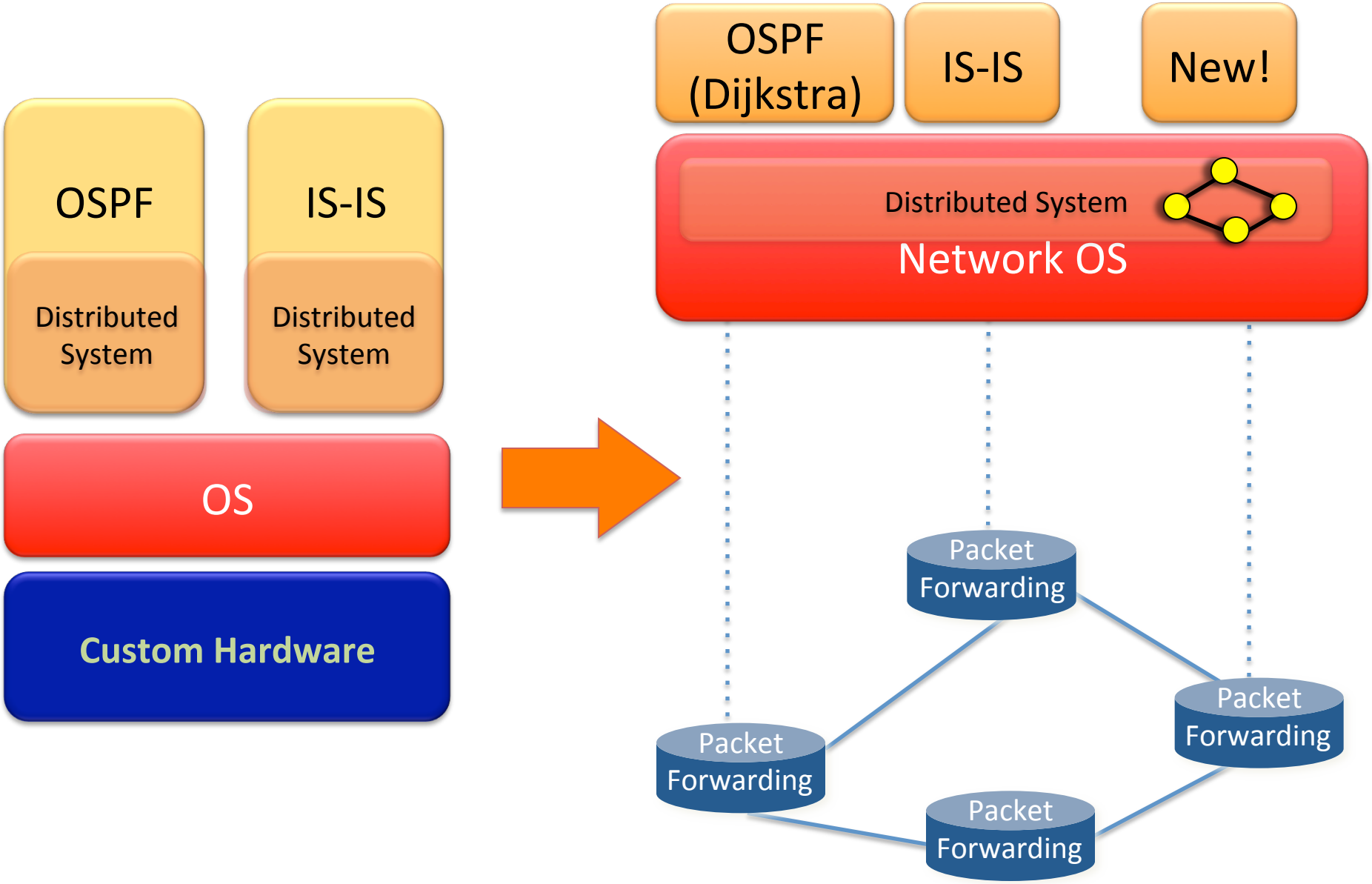
Distributed System

- Builds consistent, up-to-date map of the network: **101 pages**

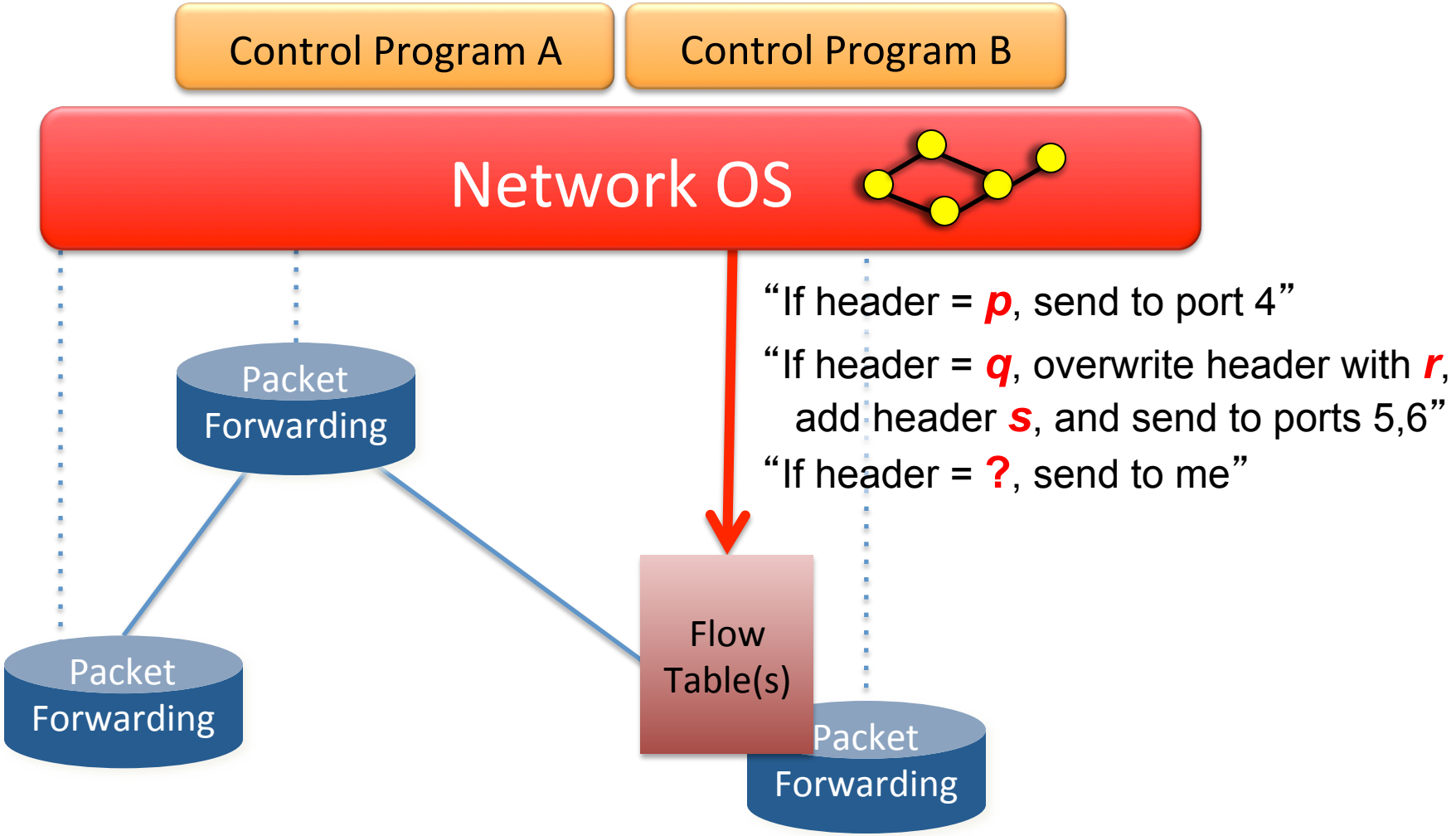
Dijkstra's Algorithm

- Operates on map: **4 pages**

Example


OSPF
Distributed System
IS-IS
Distributed System
OS
Custom Hardware
OSPF (Dijkstra)
IS-IS
New!
Distributed System
Network OS
Packet Forwarding
Packet Forwarding
Packet Forwarding
Packet Forwarding

OpenFlow Forwarding Abstraction



OpenFlow Forwarding Abstraction

<Match, Action>

Match

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 Forwarding Abstraction

Protocol Independent

- Construct Ethernet, IPv4, VLAN, MPLS, …
- Construct new forwarding methods

Backward Compatible

- Run in existing networks

Technology Independent

- Switches, routers, WiFi APs
- Cellular basestations
- WDM/TDM circuits

SDN in development

Domains

- Data centers
- Public clouds
- Enterprise/campus
- Cellular backhaul
- Enterprise WiFi
- WANs
- Home networks

Products

- Switches, routers: About 15 vendors
- Software: 8-10 vendors and startups

New startups. Lots of hiring in networking.

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1. Empower network owners/operators
2. Increase the pace of innovation
3. Diversify the supply chain
4. Build a robust foundation

How SDN will shape networking

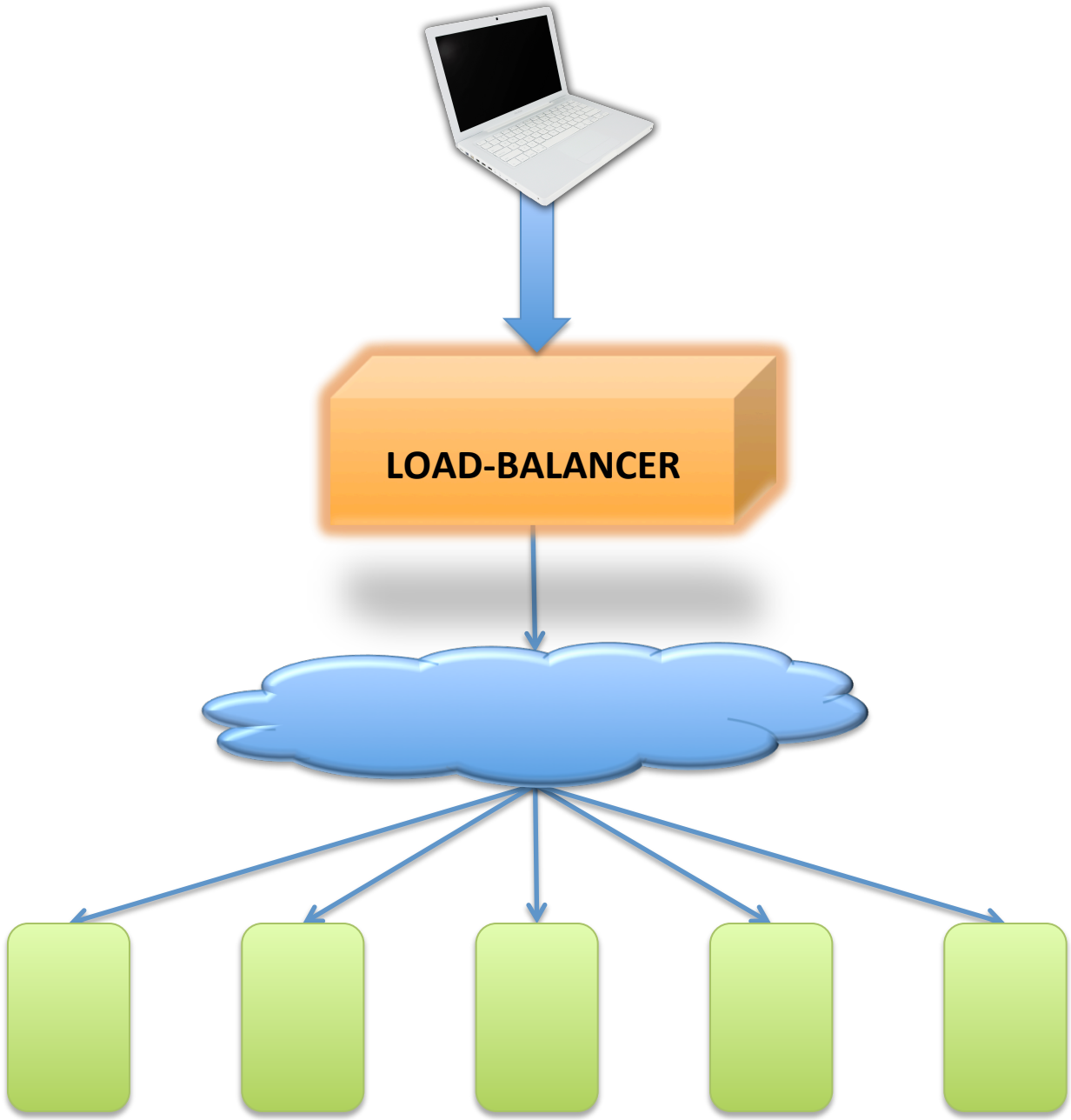
1. Empower network owners and operators
   - Customize networks to local needs — Example 1
   - Eliminate unneeded features
   - Creation of virtual, isolated networks

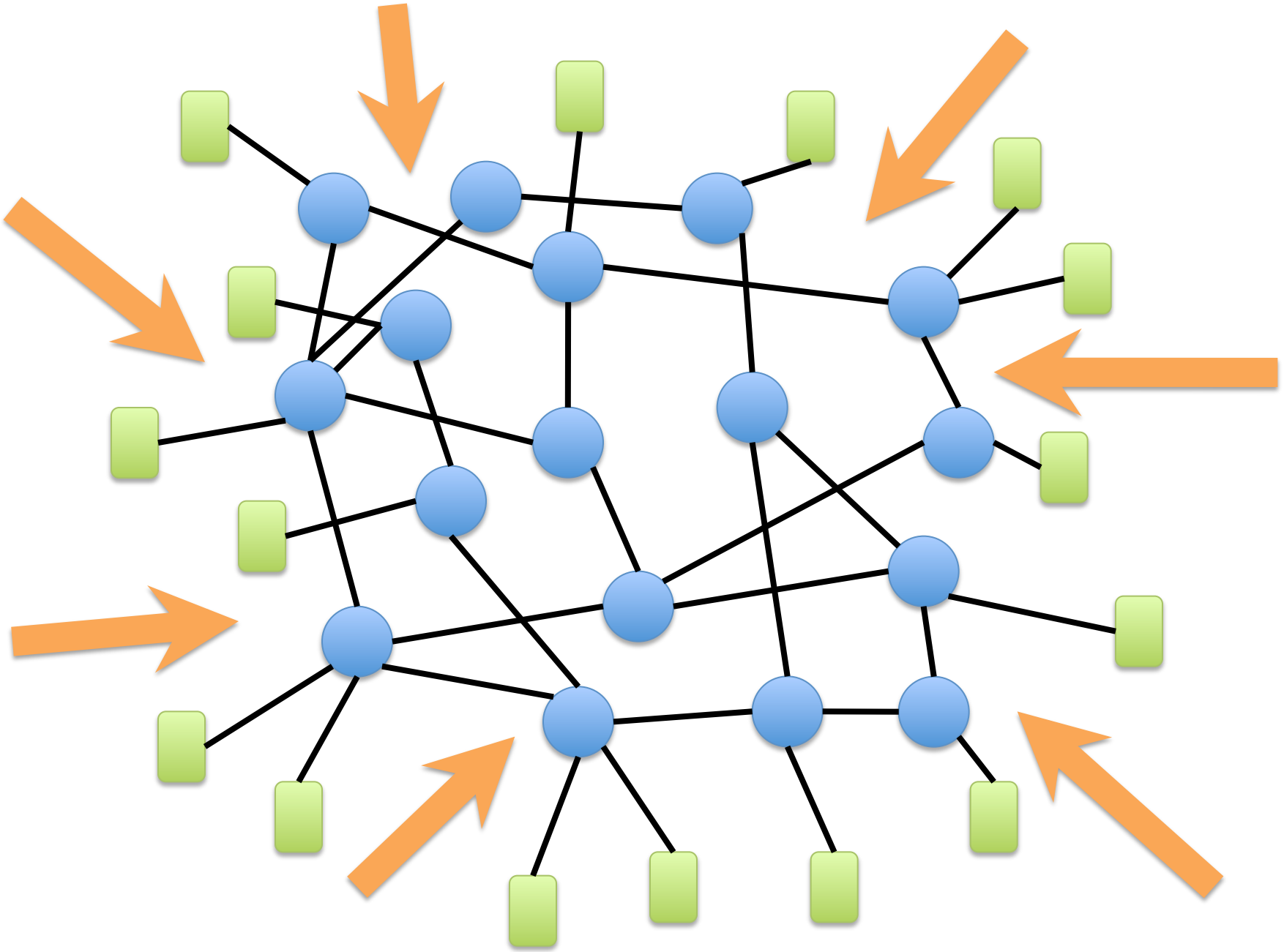
2. Increase the pace of innovation
   - Innovation at software speed
   - Standards (if any) will follow software deployment
   - Technology exchange with partners
   - Technology transfer from universities

Example 1. Customizing the network

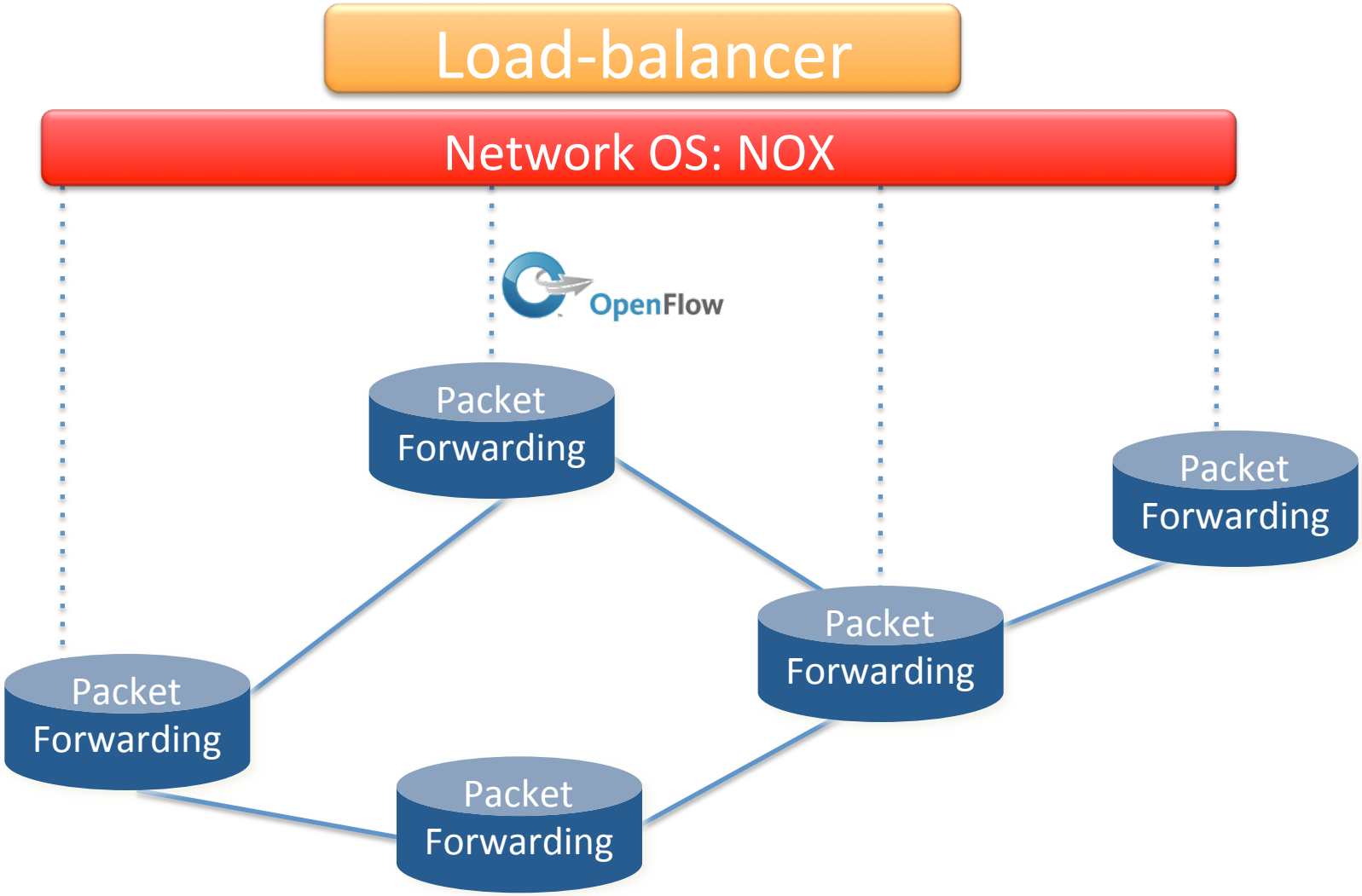
Add distributed load-balancing

Nikhil Handigol, Mario Flajslik, Srini Seetharaman

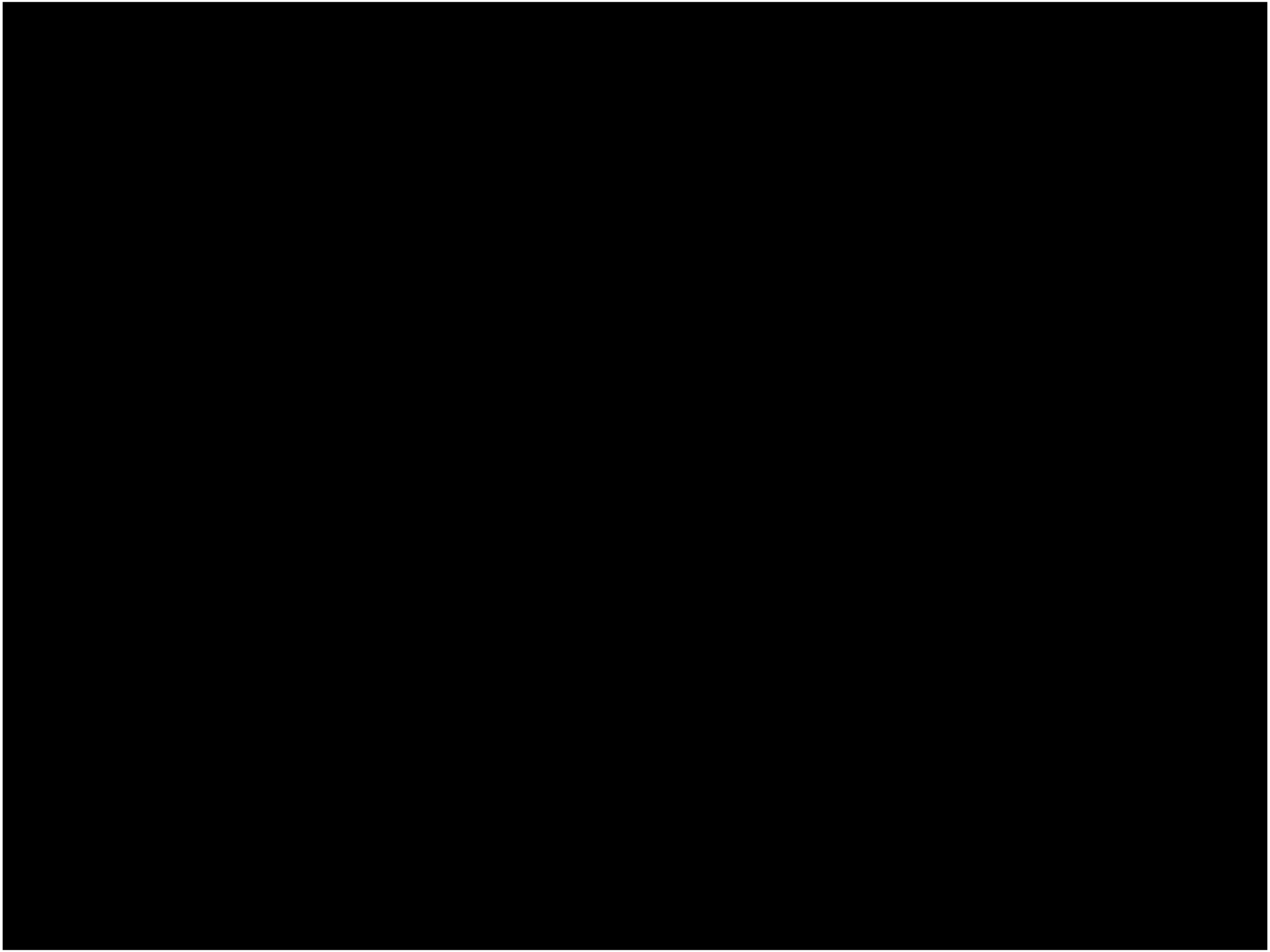

LOAD-BALANCER

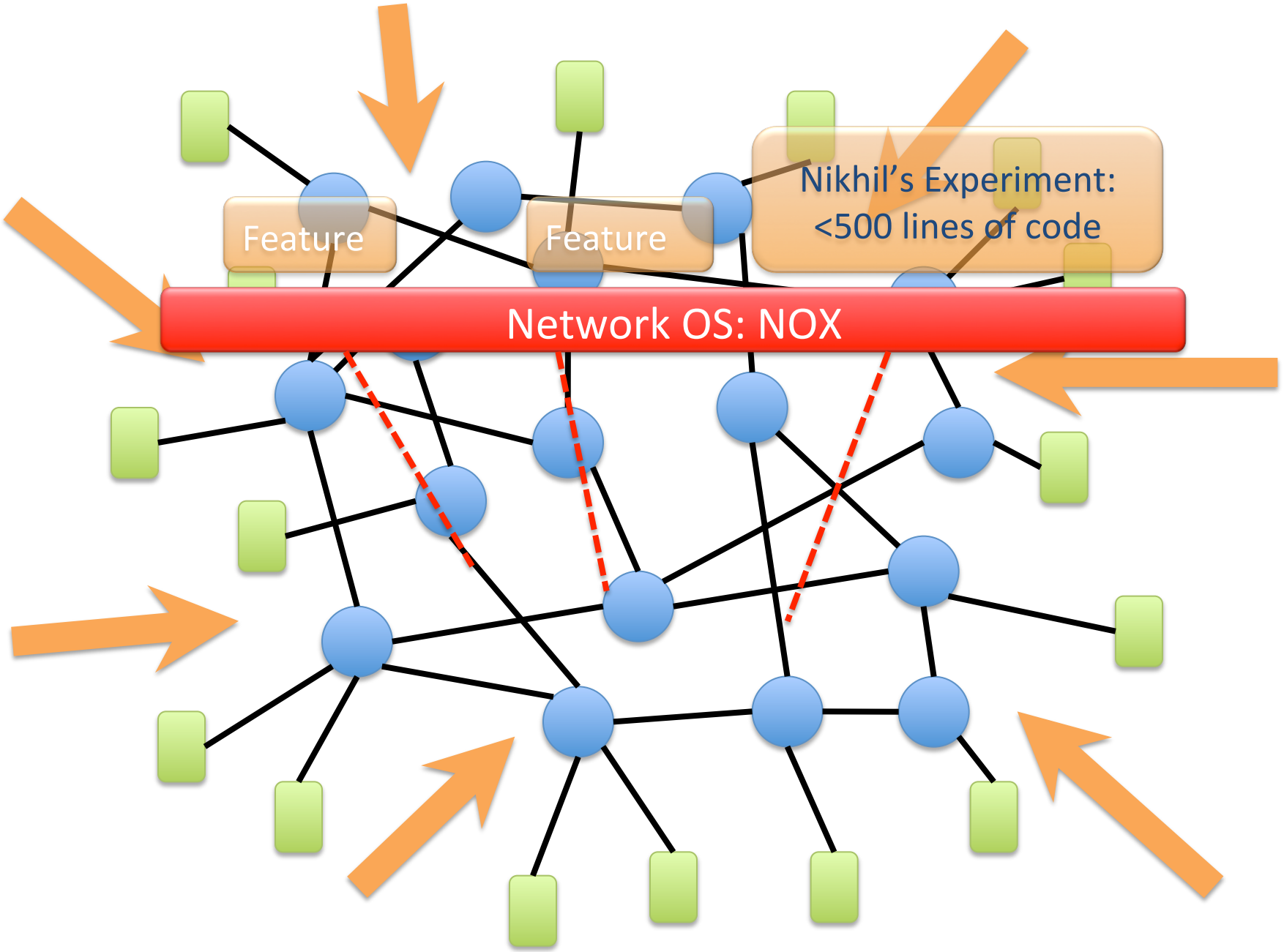


Experimental Setup




NLR




Feature
Feature
Nikhil's Experiment:
<500 lines of code
Network OS: NOX

More videos

openflow.org/videos

How SDN will shape networking

1. Empower network owners and operators
   - Customize networks to local needs
   - Eliminate unneeded features
   - Creation of virtual, isolated networks

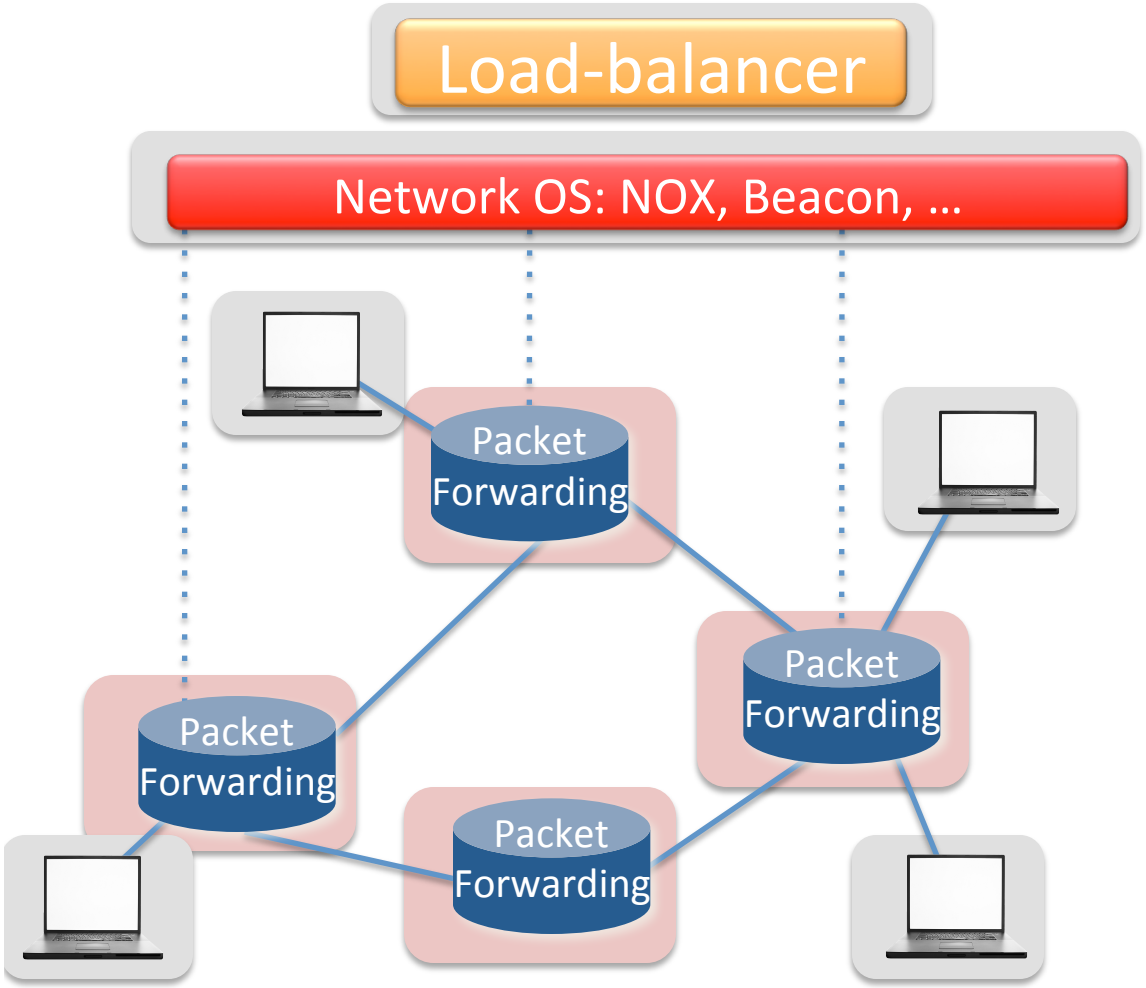
2. Increase the pace of innovation
   - Innovation at software speed — Example 2
   - Standards (if any) will follow software deployment
   - Technology exchange with partners
   - Technology transfer from universities

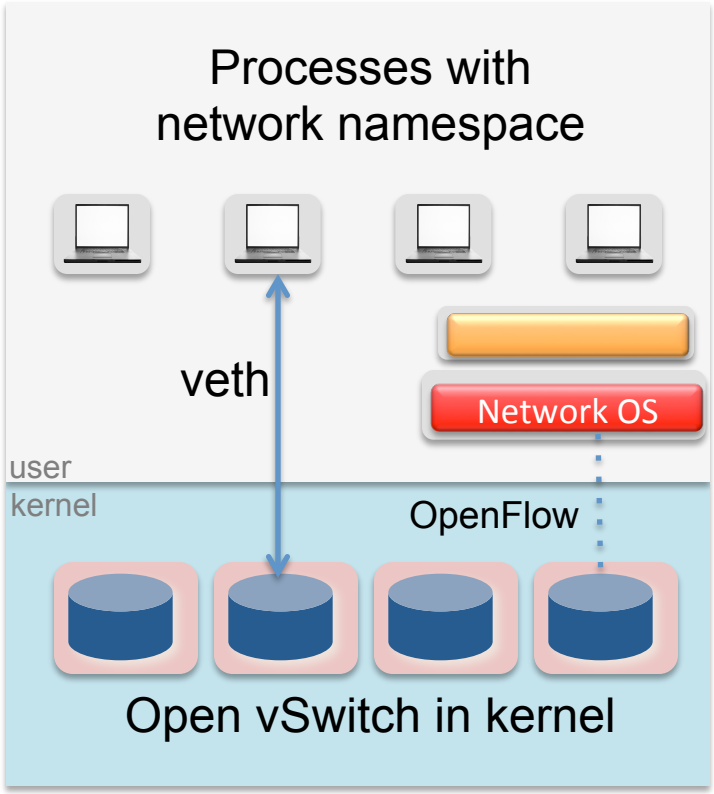
Example 2. Innovation at software speed

Mininet: Rapid prototyping

Brandon Heller, Bob Lantz, Nikhil Handigol, Vimal Jeyakumar

Mininet: Rapid Prototyping





Mininet: Rapid Prototyping

Fast

- Emulate network with 10s of switches on one laptop
- Processes easily mapped to cores and servers
- Emulate network with 1000s of switches in server rack

Rapid transfer

- Deploy unmodified code directly into live network

Code available

- openflow.org/mininet

How SDN will shape networking

3. Diversify the supply chain
   - A variety of software suppliers
   - Vendors, homegrown, outsourced, open-source
   - Common hardware abstraction, with extensions

4. Build a robust foundation
   - Standardized forwarding abstraction
   - Provable network properties at every step

Example 3

Example 3. Provable network properties

Header Space Analysis

Peyman Kazemian

Header Space Analysis: Static checking

In today's networks, simple questions are hard

- Can A talk to B?
- What are all the packet headers from A that can reach B?
- Are there any loops in the network?
- Is VLAN X (or 'slice') isolated totally from VLAN Y?

< Match, Action >

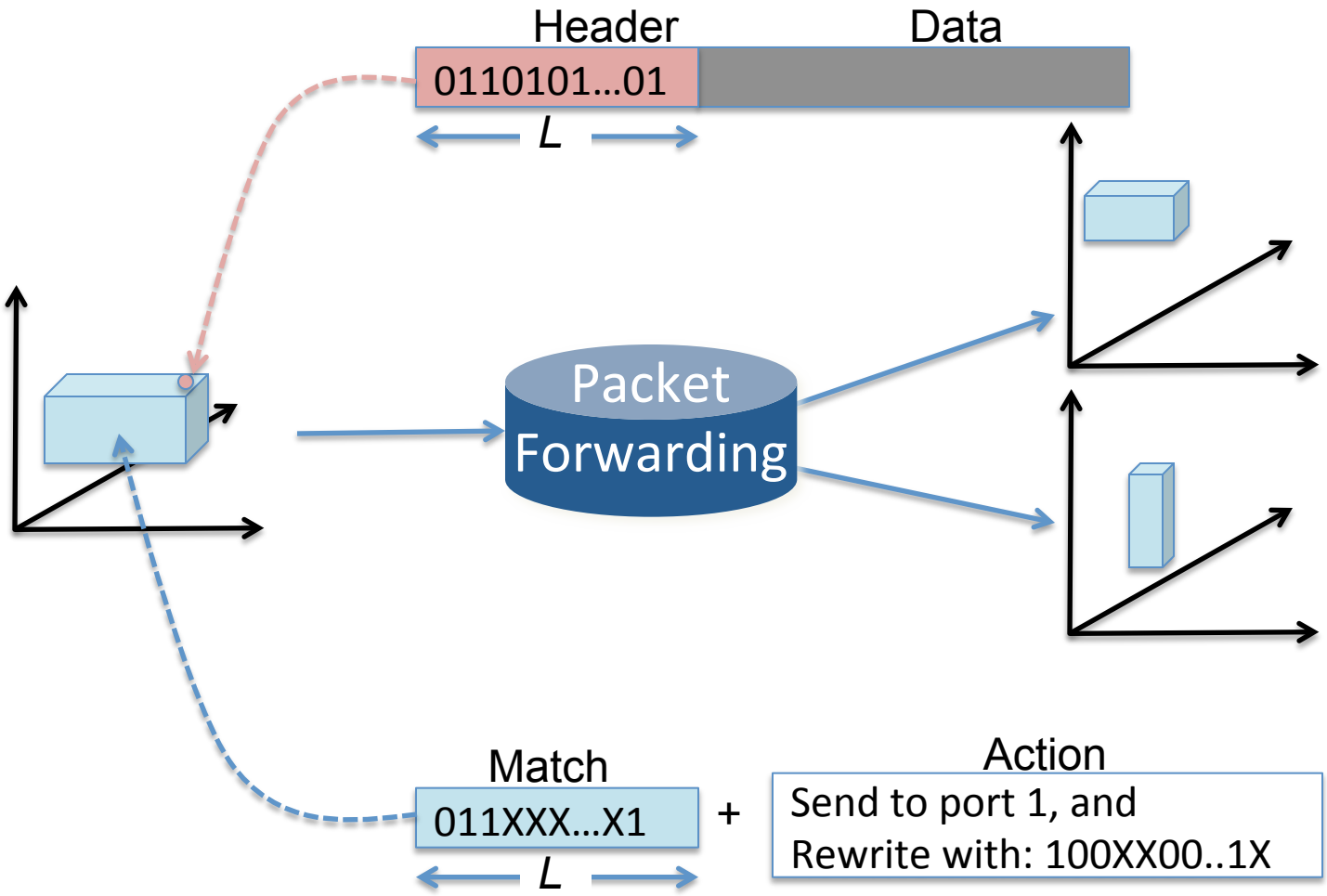
Step 1: Model packet header as a point in $\{0,1\}^L$

Step 2: Model all switches as transforms of $\{0,1\}^L$

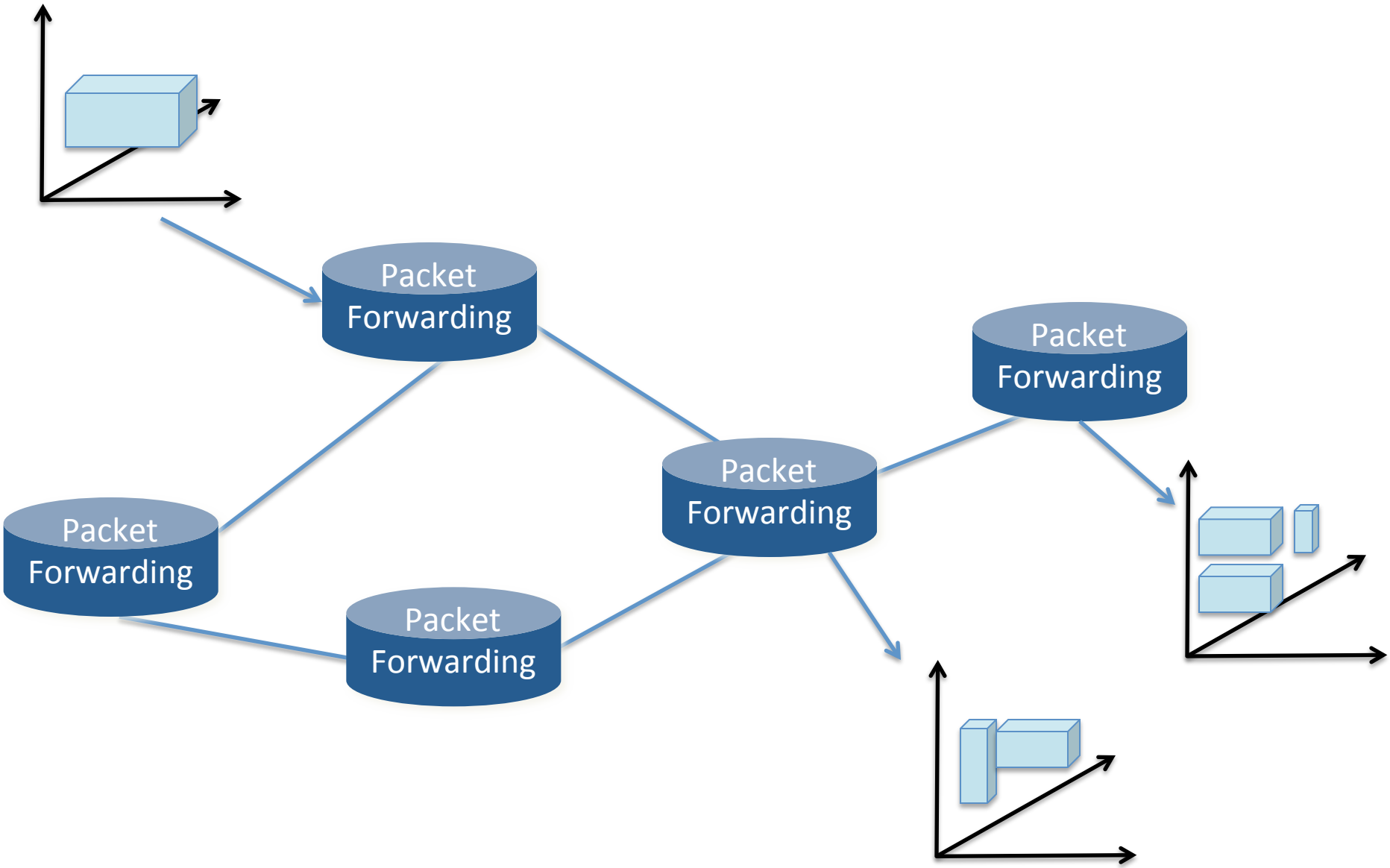
Step 3: Analyze reachability, loops, slice isolation, …

Protocol independent, general, and surprisingly fast

Basic Model


Header
Data
0110101…01
L
Packet
Forwarding
Match
011XXX…X1
L
+
Action
Send to port 1, and
Rewrite with: 100XX00..1X

Network Transfer Function



Properties

Network transfer function: set of Boolean expressions

Only relies on <Match, Action>

- Subsumes Ethernet, IPv4, firewalls, NAT, …

Can prove reachability, isolation and find loops

Used to find faults in real networks

- e.g. Analyzed Stanford backbone in 10mins

Code publicly available

Outline

SDN: An industry change

How SDN will shape networking

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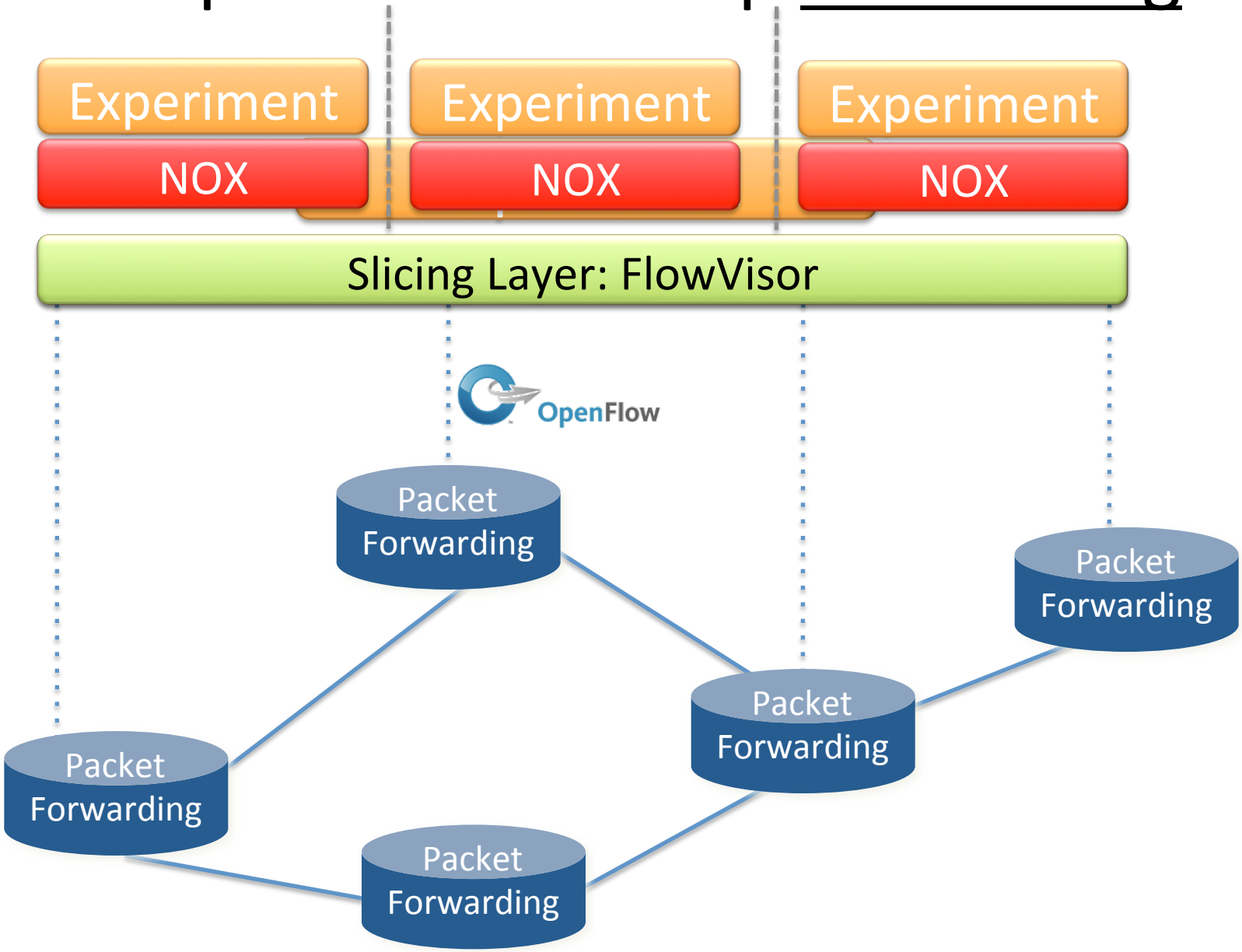
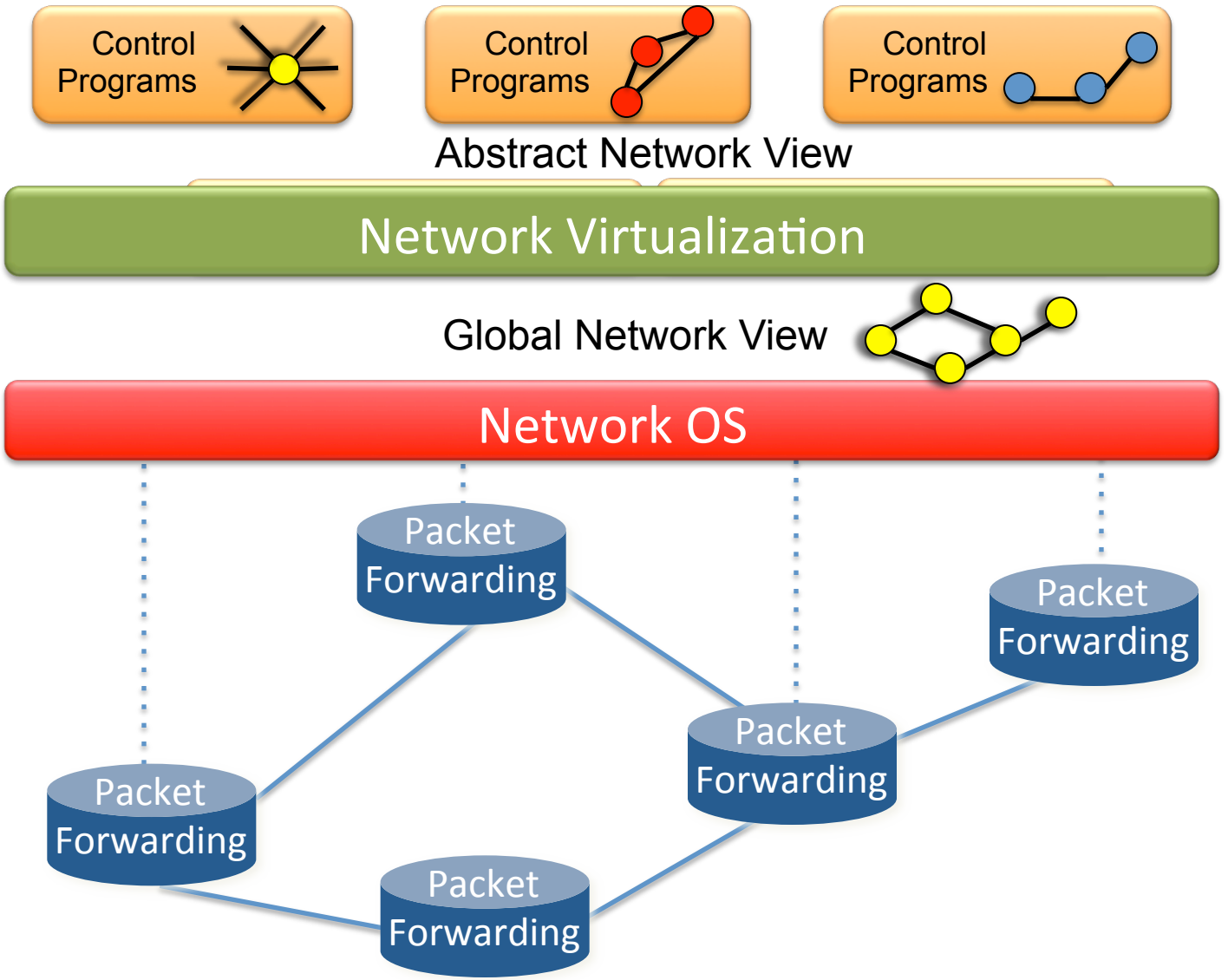
Thank you!

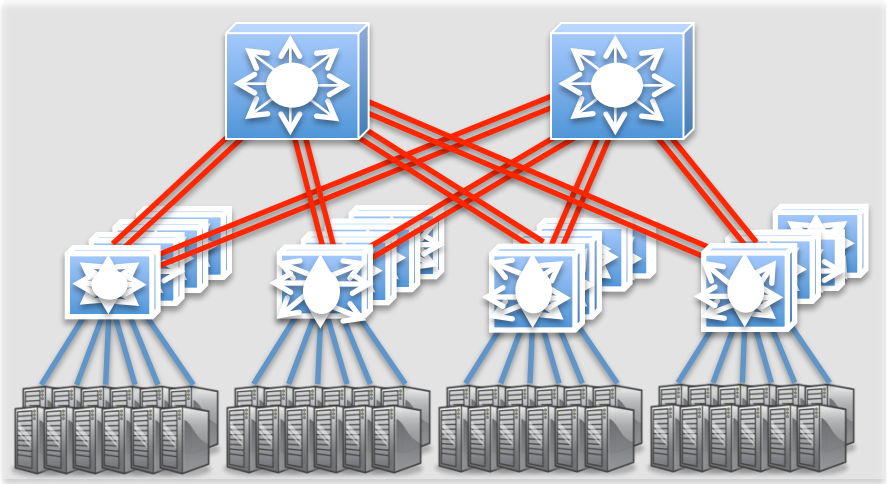
Experimental Setup with Slicing



Software Defined Network (SDN)



Example: New Data Center



Cost

200,000 servers

Fanout of 20 ➔ 10,000 switches

$5k vendor switch = $50M

$1k commodity switch = $10M

Savings in 10 data centers = $400M

Control

More flexible control

Tailor network for services

Quickly improve and innovate

Consequences for research

Ease of trying new ideas

- Existing tools: NOX, Beacon, switches, Mininet
- More rapid technology transfer
- GENI, Ofelia and many more

A stronger foundation to build upon

- Provable properties of forwarding
- New languages and specification tools

Consequences for standards

Standards will define the interfaces

The role of standards will change:

- Network owners will define network behavior
- Features will be adopted without standards

Programming world

- Good software is adopted, not standardized

Summary

Networks becoming

- More programmatic
- Defined by owners and operators, not vendors
- Faster changing, to meet operator needs
- Lower opex, capex and power

Abstractions

- Will shield programmers from complexity
- Make behavior more provable
- Will take us places we can't yet imagine