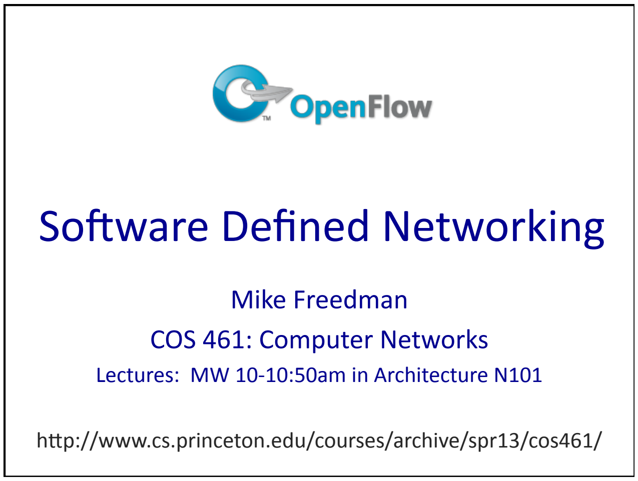


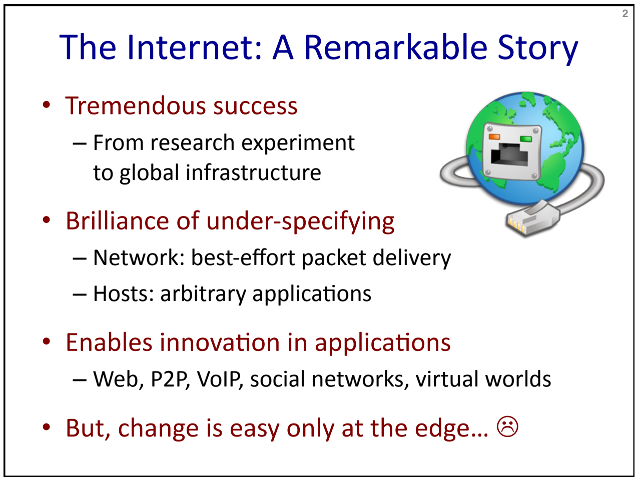
Software Defined Networking

Mike Freedman

COS 461: Computer Networks

Lectures: MW 10-10:50am in Architecture N101

http://www.cs.princeton.edu/courses/archive/spr13/cos461/



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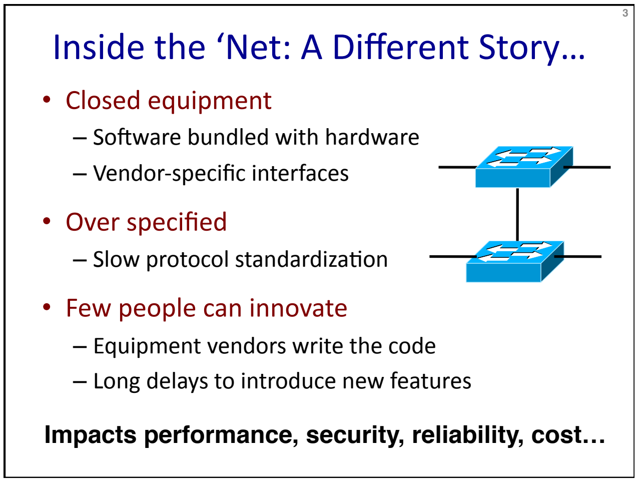
The Internet: A Remarkable Story

- Tremendous success
  - From research experiment to global infrastructure
- Brilliance of under-specifying
  - Network: best-effort packet delivery
  - Hosts: arbitrary applications
- Enables innovation in applications
  - Web, P2P, VoIP, social networks, virtual worlds
- But, change is easy only at the edge… ☹



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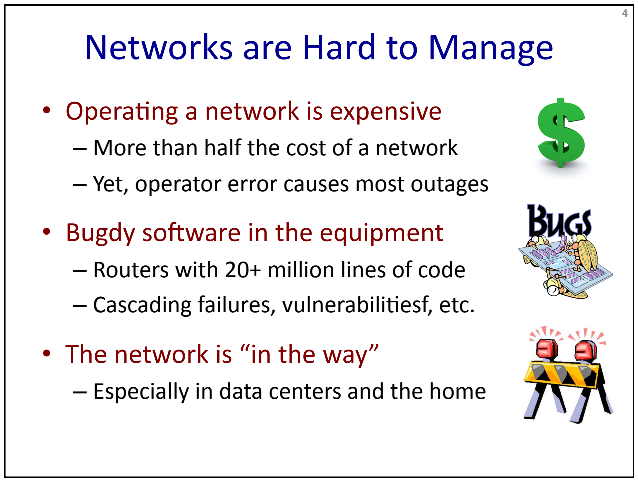
Inside the ‘Net: A Different Story…

- Closed equipment
  - Software bundled with hardware
  - Vendor-specific interfaces
- Over specified
  - Slow protocol standardization
- Few people can innovate
  - Equipment vendors write the code
  - Long delays to introduce new features

Impacts performance, security, reliability, cost…



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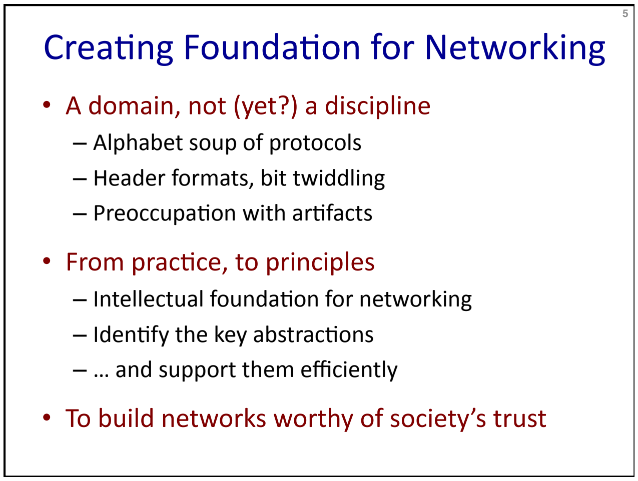
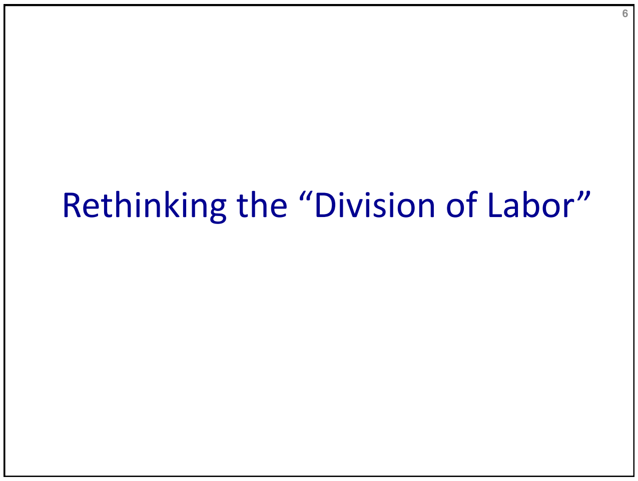
Networks are Hard to Manage

- Operating a network is expensive
  - More than half the cost of a network
  - Yet, operator error causes most outages
- Bugdy software in the equipment
  - Routers with 20+ million lines of code
  - Cascading failures, vulnerabilitiesf, etc.
- The network is “in the way”
  - Especially in data centers and the home

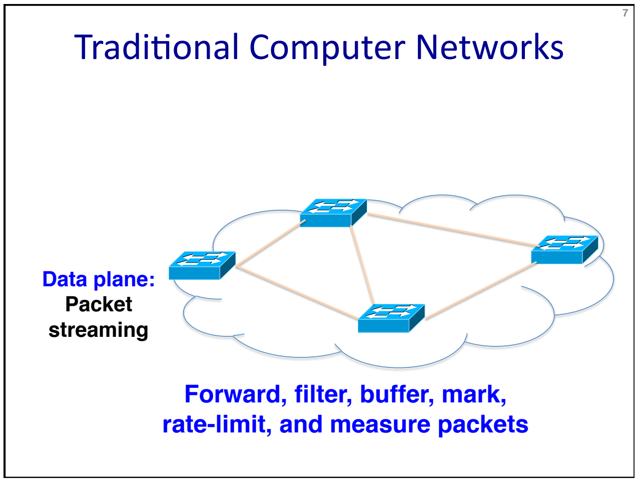


Creating Foundation for Networking

- A domain, not (yet?) a discipline
  - Alphabet soup of protocols
  - Header formats, bit twiddling
  - Preoccupation with artifacts
- From practice, to principles
  - Intellectual foundation for networking
  - Identify the key abstractions
  - … and support them efficiently
- To build networks worthy of society's trust



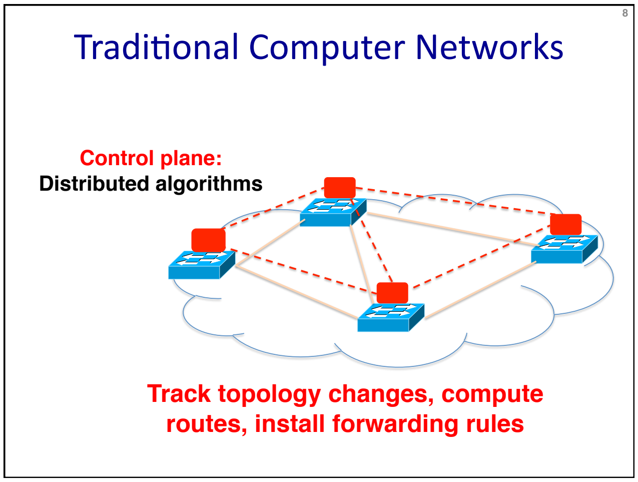
Rethinking the "Division of Labor"



Traditional Computer Networks

Data plane: Packet streaming

Forward, filter, buffer, mark, rate-limit, and measure packets

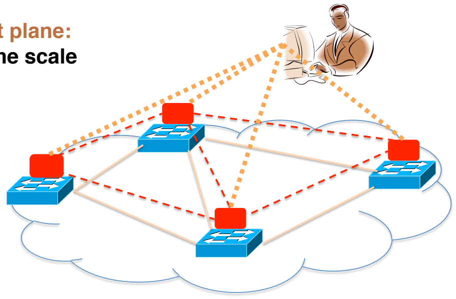


Traditional Computer Networks

Control plane: Distributed algorithms

Track topology changes, compute routes, install forwarding rules

Traditional Computer Networks

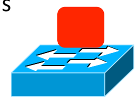


Management plane:
Human time scale

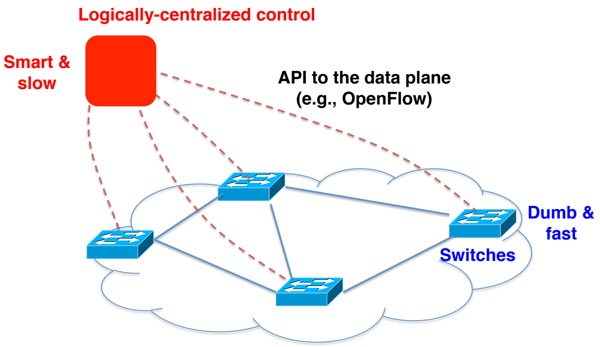
Collect measurements and configure the equipment

Death to the Control Plane!

- Simpler management
  - No need to "invert" control-plane operations
- Faster pace of innovation
  - Less dependence on vendors and standards
- Easier interoperability
  - Compatibility only in "wire" protocols
- Simpler, cheaper equipment
  - Minimal software



Software Defined Networking (SDN)



Logically-centralized control

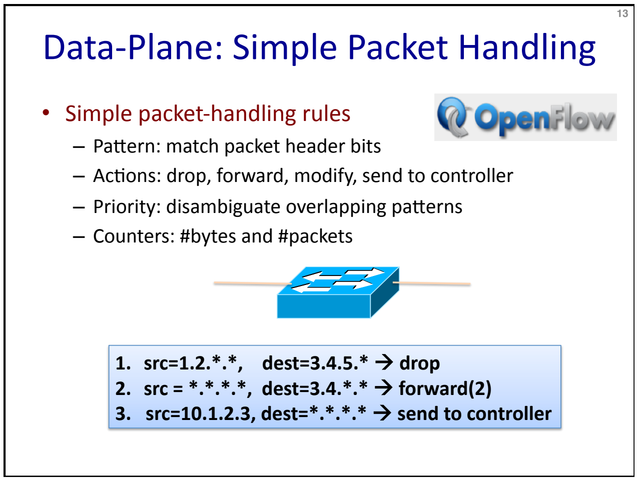
Smart & slow

API to the data plane (e.g., OpenFlow)

Dumb & fast

Switches

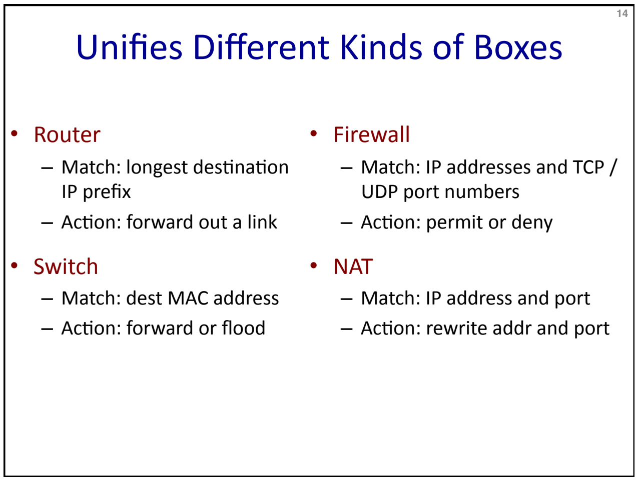
OpenFlow Networks



Data-Plane: Simple Packet Handling

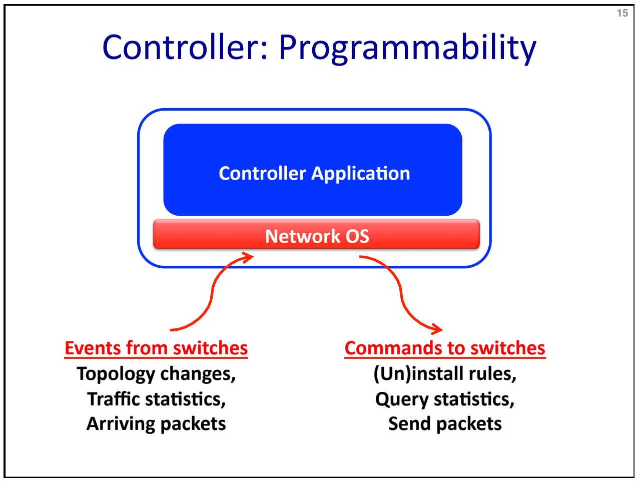
- Simple packet-handling rules
  - Pattern: match packet header bits
  - Actions: drop, forward, modify, send to controller
  - Priority: disambiguate overlapping patterns
  - Counters: #bytes and #packets

1. src=1.2.*.*, dest=3.4.5.* → drop
2. src = *.*.*.*, dest=3.4.*.* → forward(2)
3. src=10.1.2.3, dest=*.*.*.* → send to controller



Unifies Different Kinds of Boxes

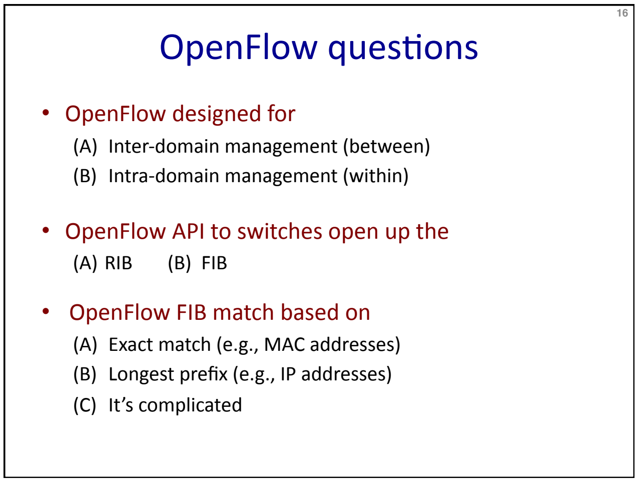
- Router
  - Match: longest destination IP prefix
  - Action: forward out a link
- Switch
  - Match: dest MAC address
  - Action: forward or flood
- Firewall
  - Match: IP addresses and TCP / UDP port numbers
  - Action: permit or deny
- NAT
  - Match: IP address and port
  - Action: rewrite addr and port



Controller: Programmability

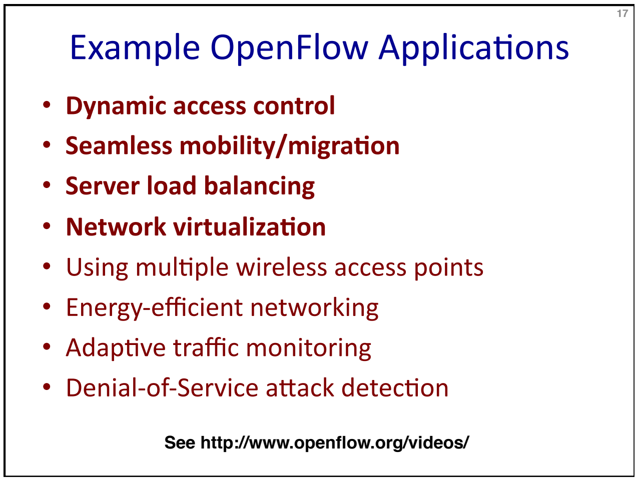
Events from switches
Topology changes,
Traffic statistics,
Arriving packets

Commands to switches
(Un)install rules,
Query statistics,
Send packets



OpenFlow questions

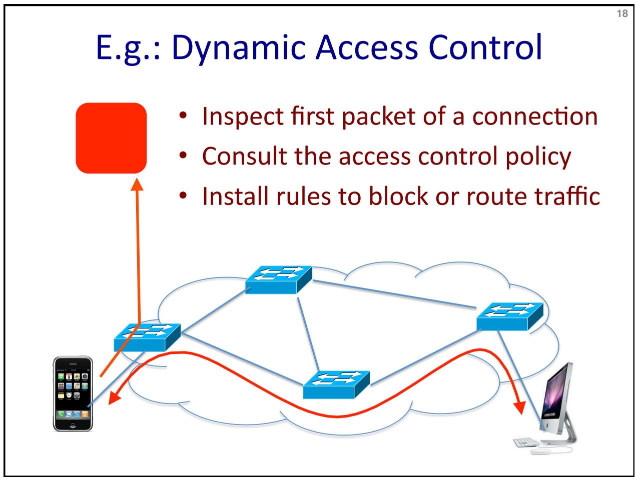
- OpenFlow designed for
  - (A) Inter-domain management (between)
  - (B) Intra-domain management (within)
- OpenFlow API to switches open up the
  - (A) RIB (B) FIB
- OpenFlow FIB match based on
  - (A) Exact match (e.g., MAC addresses)
  - (B) Longest prefix (e.g., IP addresses)
  - (C) It's complicated



Example OpenFlow Applications

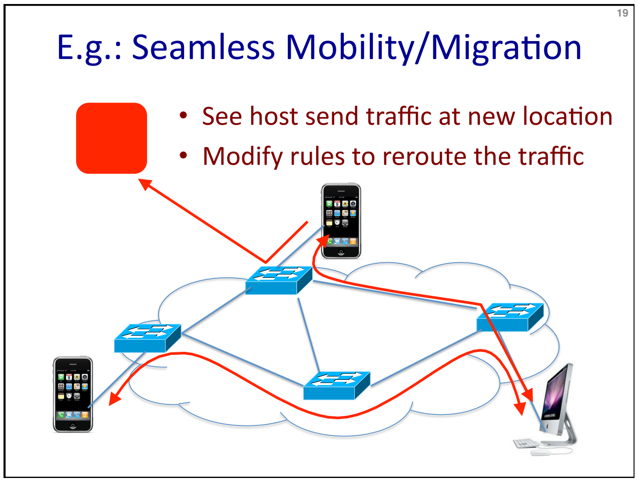
- **Dynamic access control**
- **Seamless mobility/migration**
- **Server load balancing**
- **Network virtualization**
- Using multiple wireless access points
- Energy-efficient networking
- Adaptive traffic monitoring
- Denial-of-Service attack detection

See http://www.openflow.org/videos/



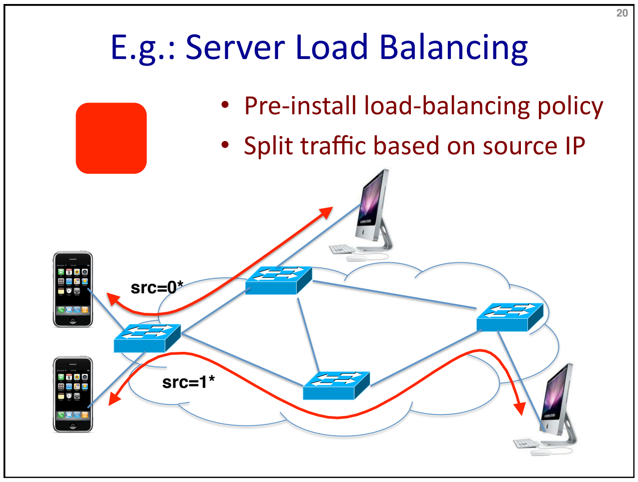
E.g.: Dynamic Access Control

- Inspect first packet of a connection
- Consult the access control policy
- Install rules to block or route traffic



E.g.: Seamless Mobility/Migration

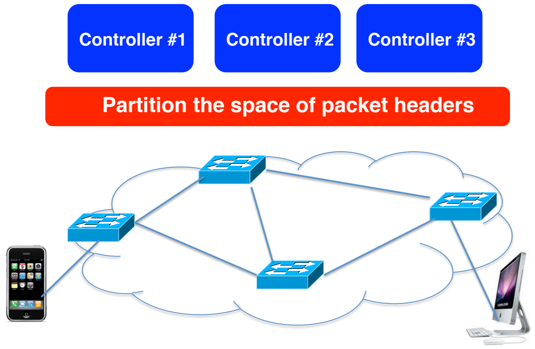
- See host send traffic at new location
- Modify rules to reroute the traffic



E.g.: Server Load Balancing

- Pre-install load-balancing policy
- Split traffic based on source IP

E.g.: Network Virtualization



Controller and the FIB

- Forwarding rules should be added

  (A) Proactively

  (B) Reactively (e.g., with controller getting first packet)

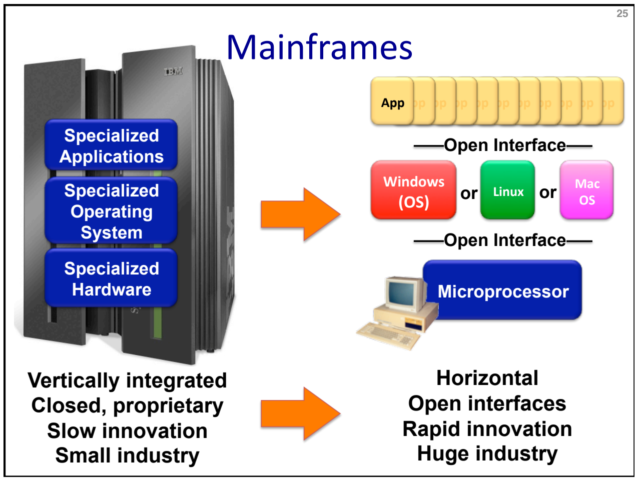
  (C) Depends on application

OpenFlow in the Wild

- Open Networking Foundation
  - Google, Facebook, Microsoft, Yahoo, Verizon, Deutsche Telekom, and many other companies
- Commercial OpenFlow switches
  - Intel, HP, NEC, Quanta, Dell, IBM, Juniper, …
- Network operating systems
  - NOX, Beacon, Floodlight, Nettle, ONIX, POX, Frenetic
- Network deployments
  - Eight campuses, and two research backbone networks
  - Commercial deployments (e.g., Google backbone)

A Helpful Analogy

From Nick McKeown's talk "Making SDN Work" at the Open Networking Summit, April 2012



Mainframes

Specialized Applications

Specialized Operating System

Specialized Hardware

App

Open Interface

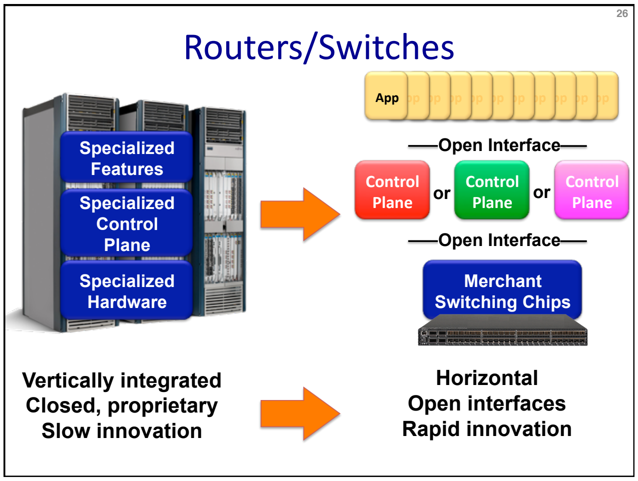
Windows (OS) or Linux or Mac OS

Open Interface

Microprocessor

Vertically integrated
Closed, proprietary
Slow innovation
Small industry

Horizontal
Open interfaces
Rapid innovation
Huge industry



Routers/Switches

Specialized Features

Specialized Control Plane

Specialized Hardware

App

Open Interface

Control Plane or Control Plane or Control Plane

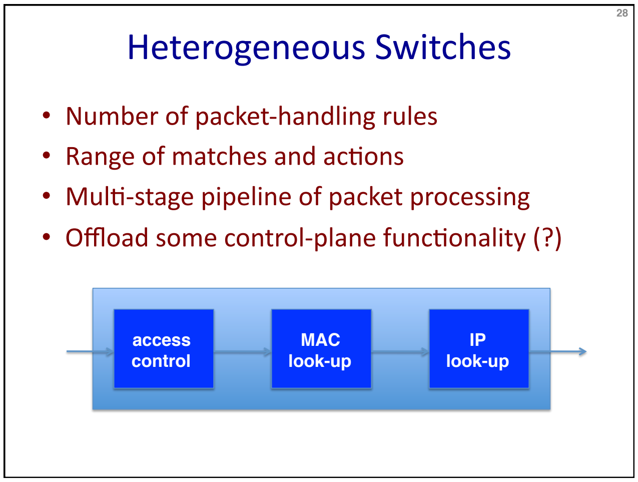
Open Interface

Merchant Switching Chips

Vertically integrated
Closed, proprietary
Slow innovation

Horizontal
Open interfaces
Rapid innovation

Challenges



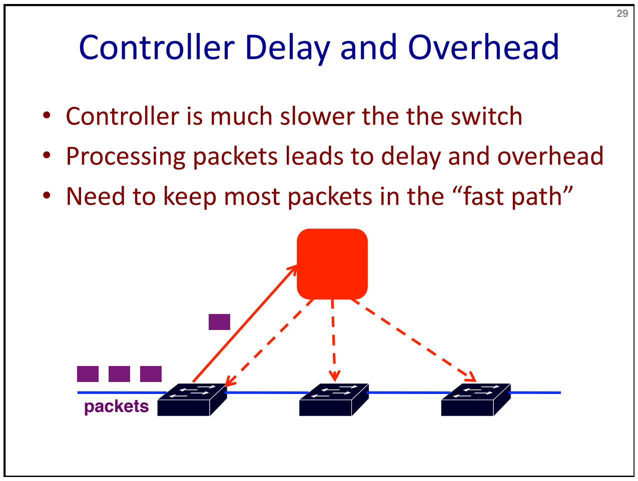
Heterogeneous Switches

- Number of packet-handling rules
- Range of matches and actions
- Multi-stage pipeline of packet processing
- Offload some control-plane functionality (?)

access control

MAC look-up

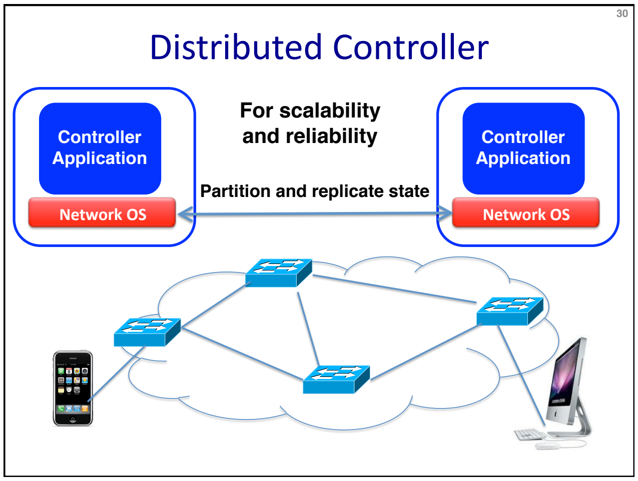
IP look-up



Controller Delay and Overhead

- Controller is much slower the the switch
- Processing packets leads to delay and overhead
- Need to keep most packets in the “fast path”

packets



Distributed Controller

Controller Application

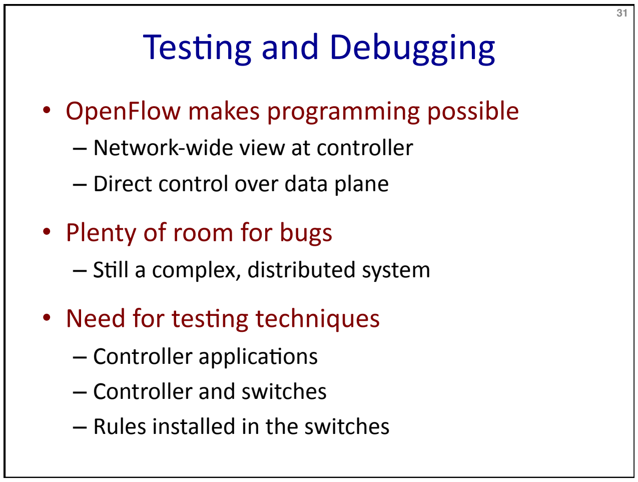
Network OS

For scalability and reliability

Partition and replicate state

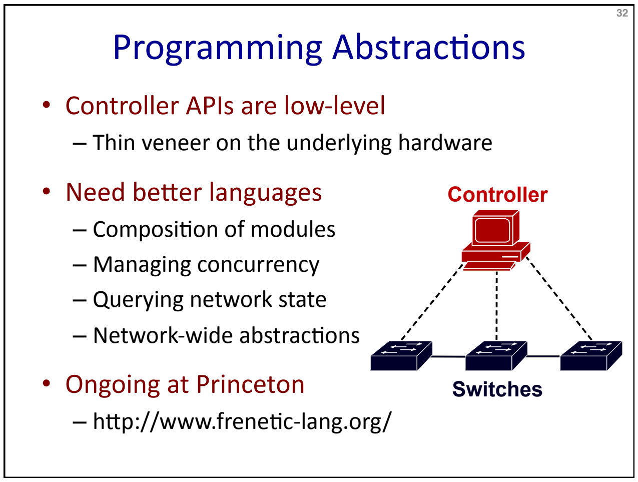
Controller Application

Network OS



Testing and Debugging

- OpenFlow makes programming possible
  - Network-wide view at controller
  - Direct control over data plane
- Plenty of room for bugs
  - Still a complex, distributed system
- Need for testing techniques
  - Controller applications
  - Controller and switches
  - Rules installed in the switches

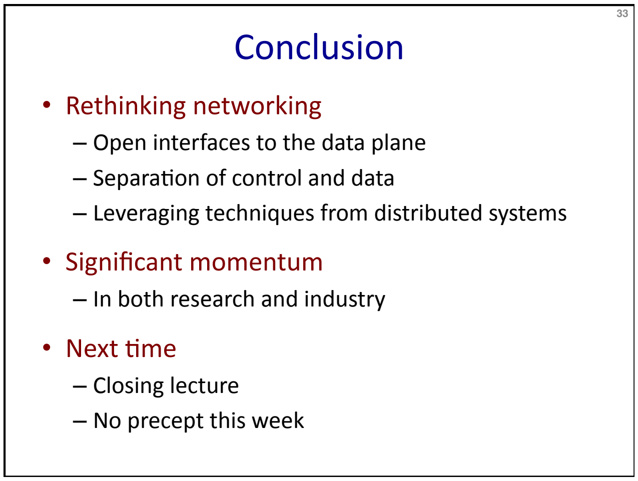


Programming Abstractions

- Controller APIs are low-level
  - Thin veneer on the underlying hardware
- Need better languages
  - Composition of modules
  - Managing concurrency
  - Querying network state
  - Network-wide abstractions
- Ongoing at Princeton
  - http://www.frenetic-lang.org/

Controller

Switches



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Conclusion

- Rethinking networking
  - Open interfaces to the data plane
  - Separation of control and data
  - Leveraging techniques from distributed systems
- Significant momentum
  - In both research and industry
- Next time
  - Closing lecture
  - No precept this week