

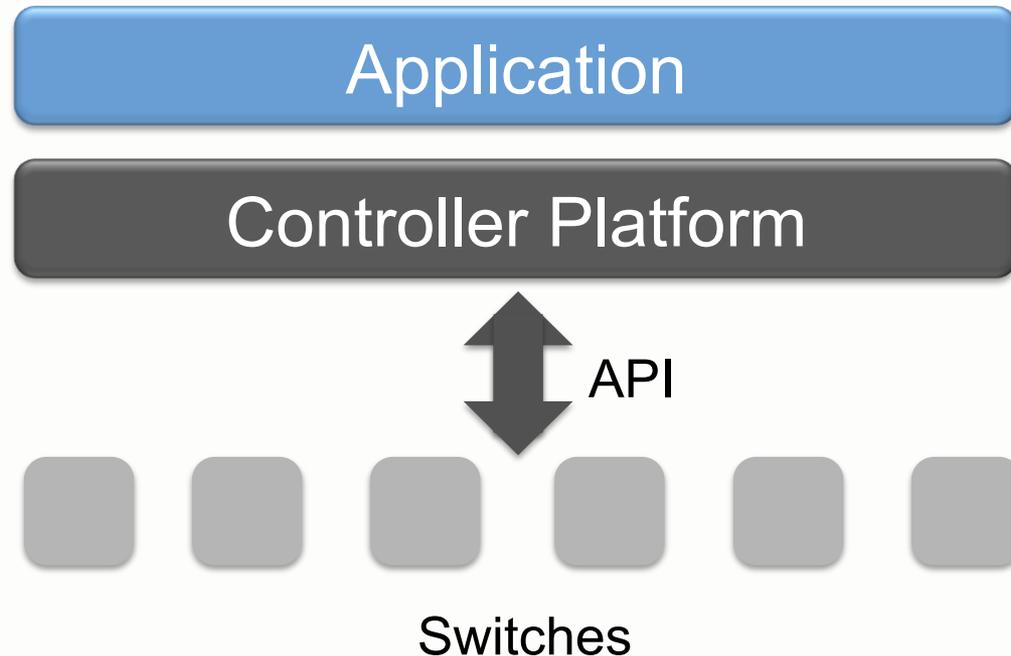
Future of SDN

Jennifer Rexford

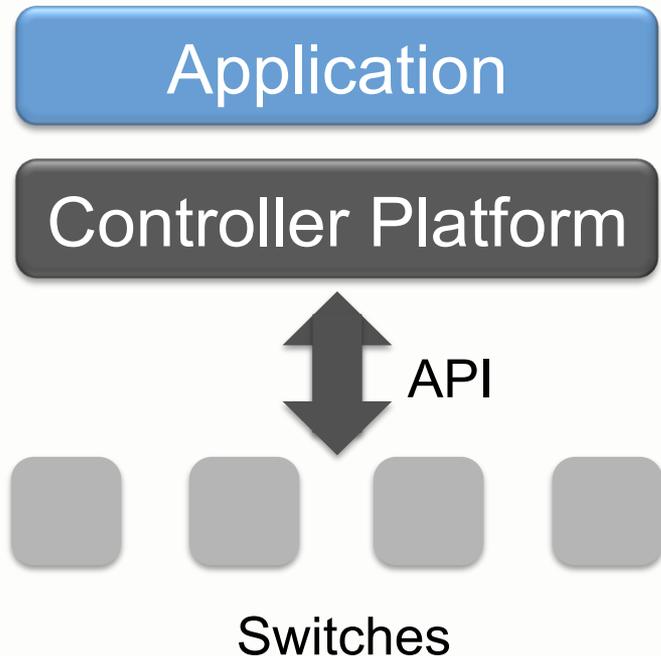
Princeton University

www.cs.princeton.edu/~jrex

Simple SDN Architecture

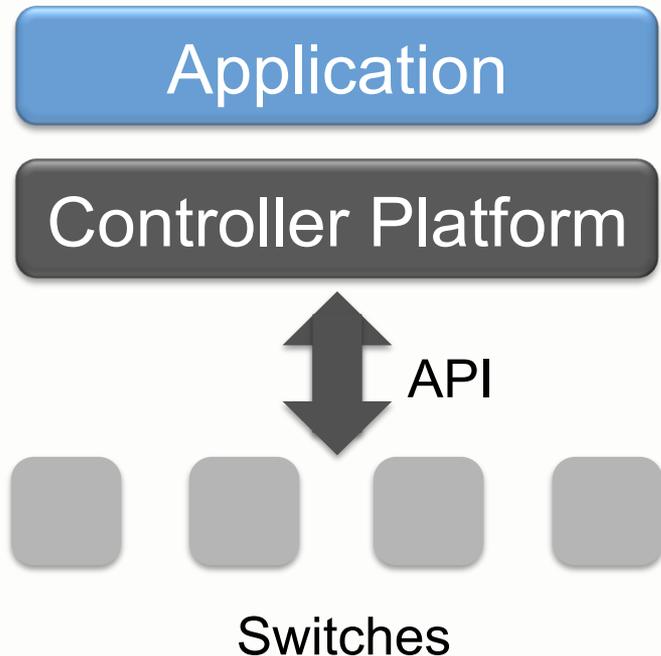


SDN Success: Applications



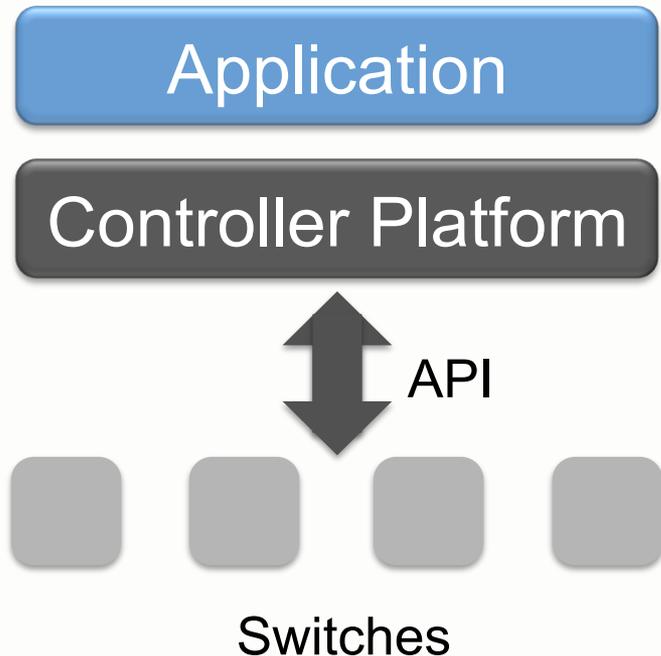
- Network virtualization
- Traffic engineering
- Dynamic access control
- VM migration, user mobility
- Server load balancing
- Energy-efficient network
- Blocking DoS attacks
- <Your app here!>

SDN Success: Controllers



- NOX
- Beacon
- Floodlight
- ONIX
- POX
- Ryu
- Open Daylight
- Trema
- Mul
- Maestro
- Nettle
- Frenetic
- Pyretic
- Maple
- ONOS
- ...

SDN Success: OpenFlow Switches

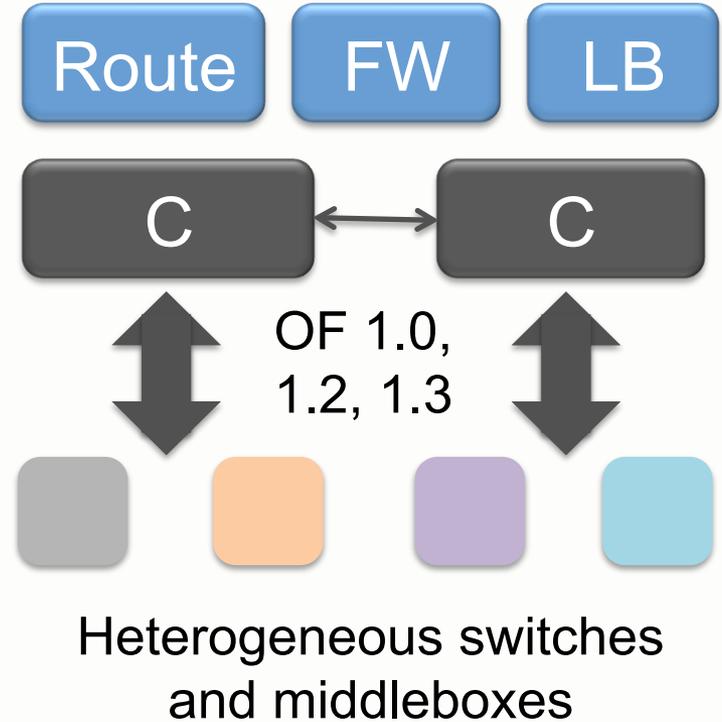
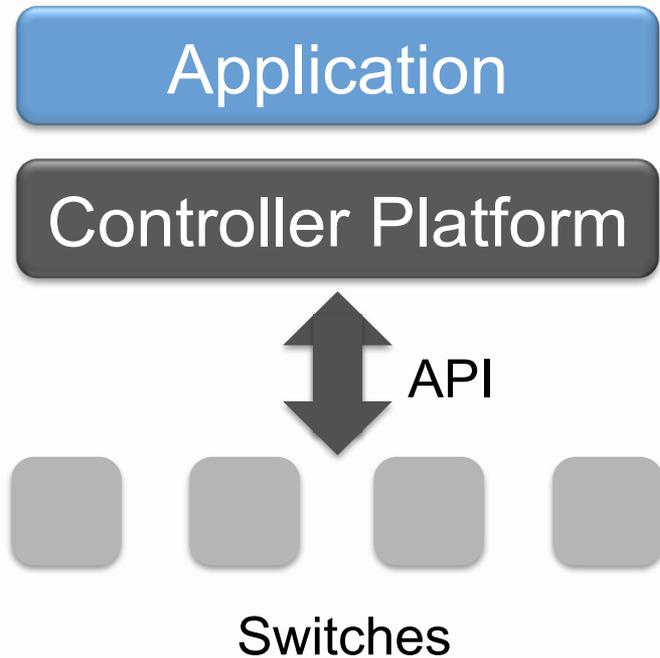


- Arista
- Brocade
- Cisco
- Dell
- Extreme Networks
- HP
- Huawei
- IBM
- Juniper
- NEC
- NetGear
- Open vSwitch
- Pica8
- Pronto

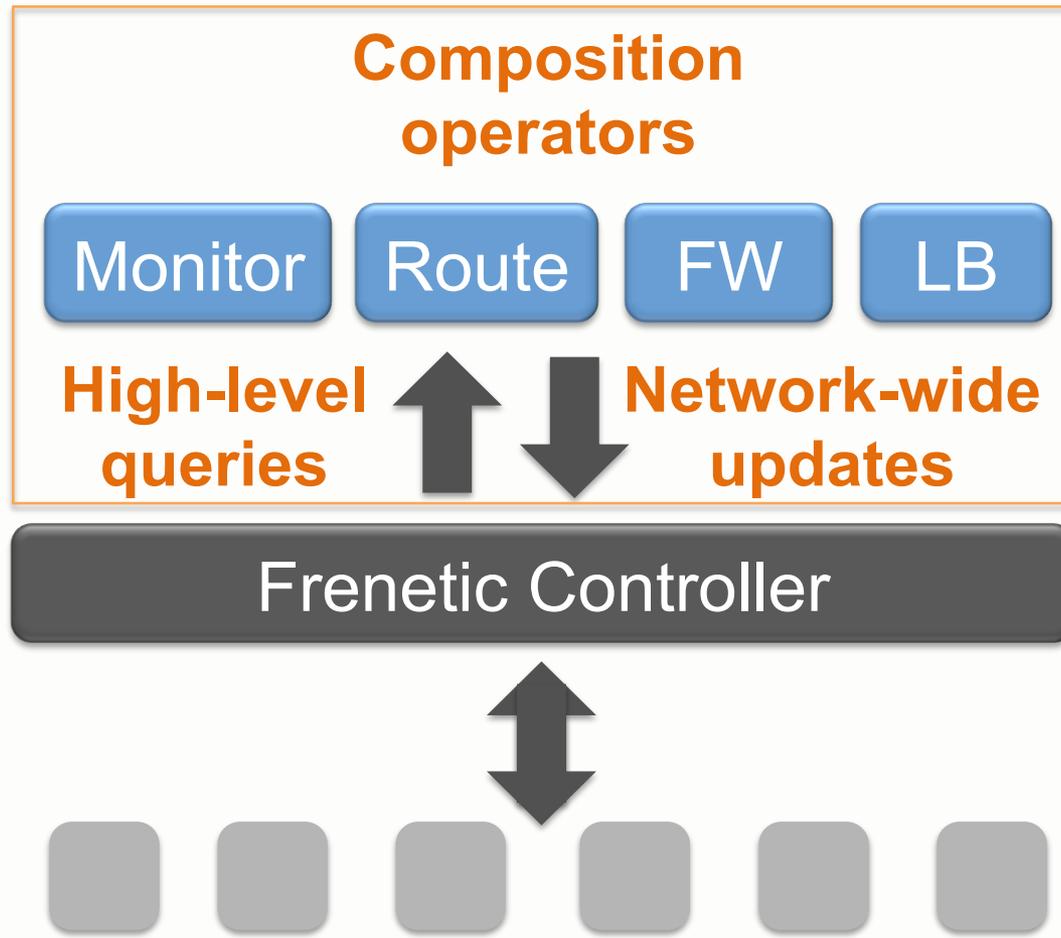
Future of SDN

- Better SDN software stack
- More diverse network settings
- Overcoming deployment hurdles

SDN Software Reality



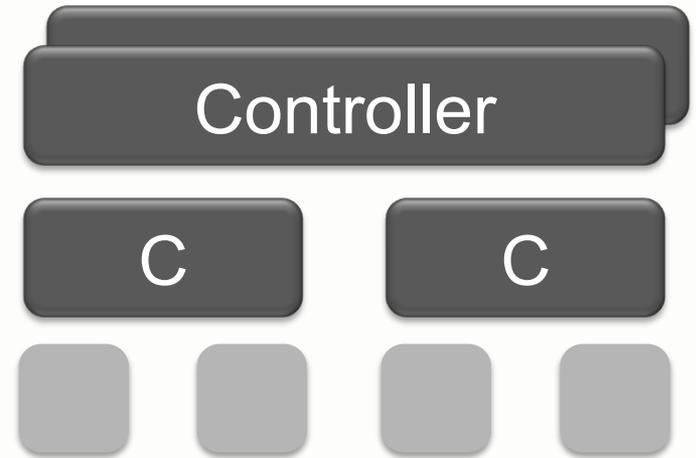
Programming Abstractions



- More abstractions
- Traffic monitoring
 - Quality-of-service
 - Security policy
 - Traffic optimization

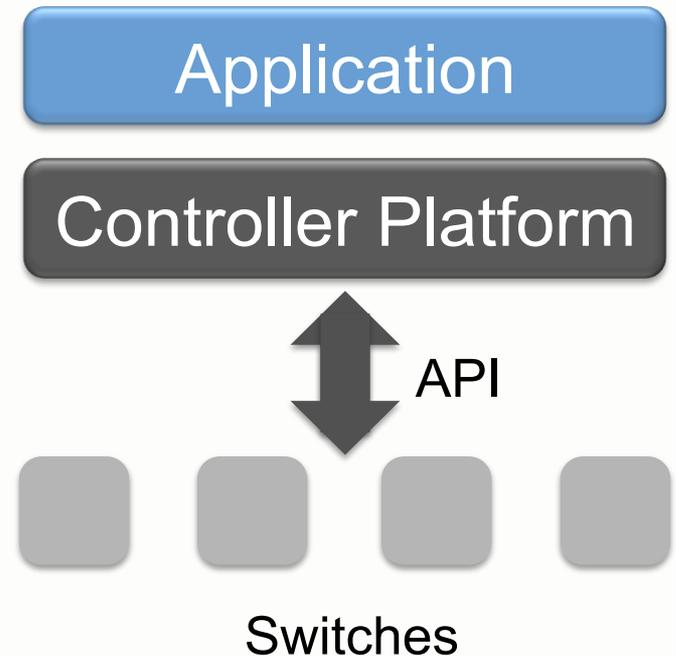
Distributed Controllers

- Reasons to distribute
 - Scalability
 - Reliability
 - Performance
- Challenges
 - Efficient state management
 - Fast failure recovery
 - Simple abstractions
- Leverage/extend distributed systems ideas



Software Reliability

- Software reliability
 - Testing, verification, and debugging
- At every layer
 - Application, controller, switch rules, switches
- Leverage simple APIs
 - Boolean predicates, small set of actions & events



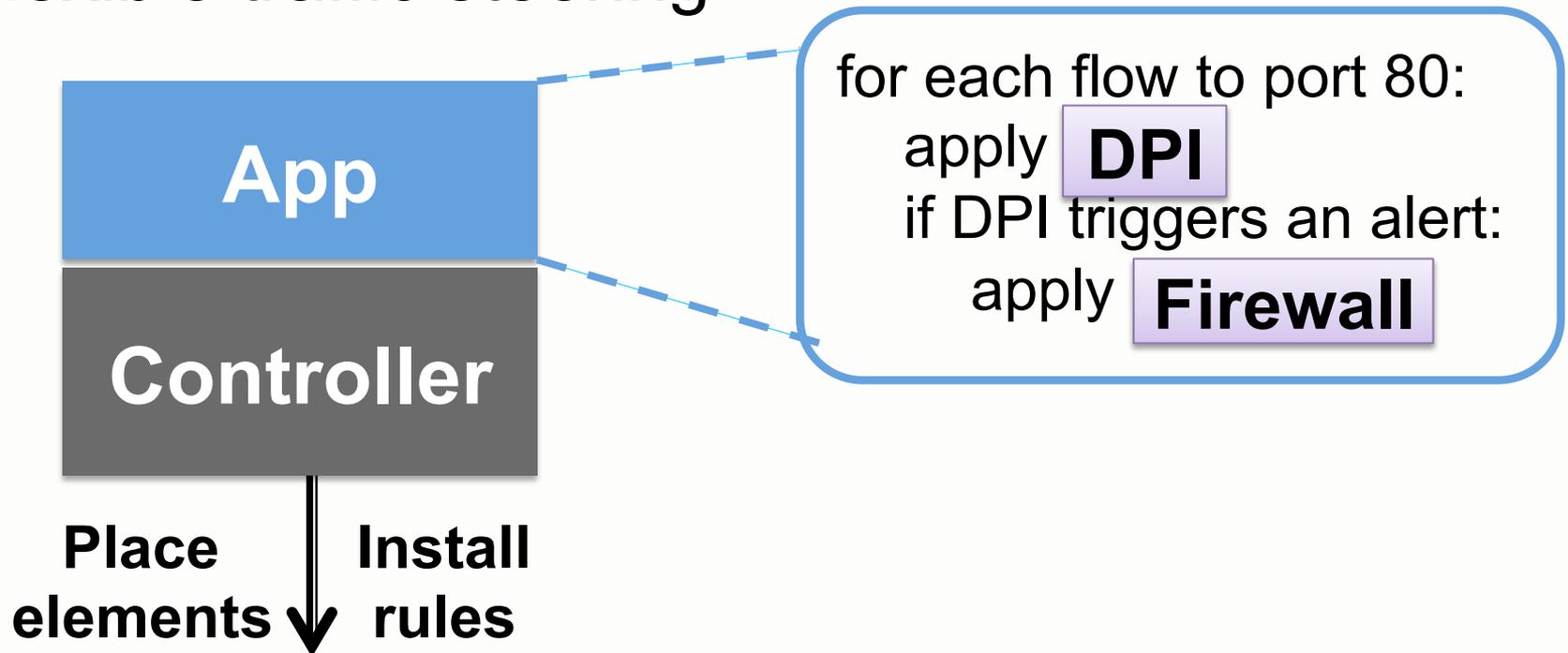
Heterogeneous Devices

Version	# Fields	Headers
OF 1.0	12	Ethernet, IPv4, TCP/UDP
OF 1.1	15	+ MPLS, inter-table meta-data
OF 1.2	36	+ ARP, ICMP, IPv6, etc.
OF 1.3	40	+ miscellaneous tweaks

- **Better intermediate representation**
 - Protocol-independent (packet parser)
 - Target-independent (switch compiler)
 - Reconfigurable in the field

Network Function Virtualization

- Middleboxes running on virtual machines
- VM replicated and placed as needed
- Flexible traffic steering

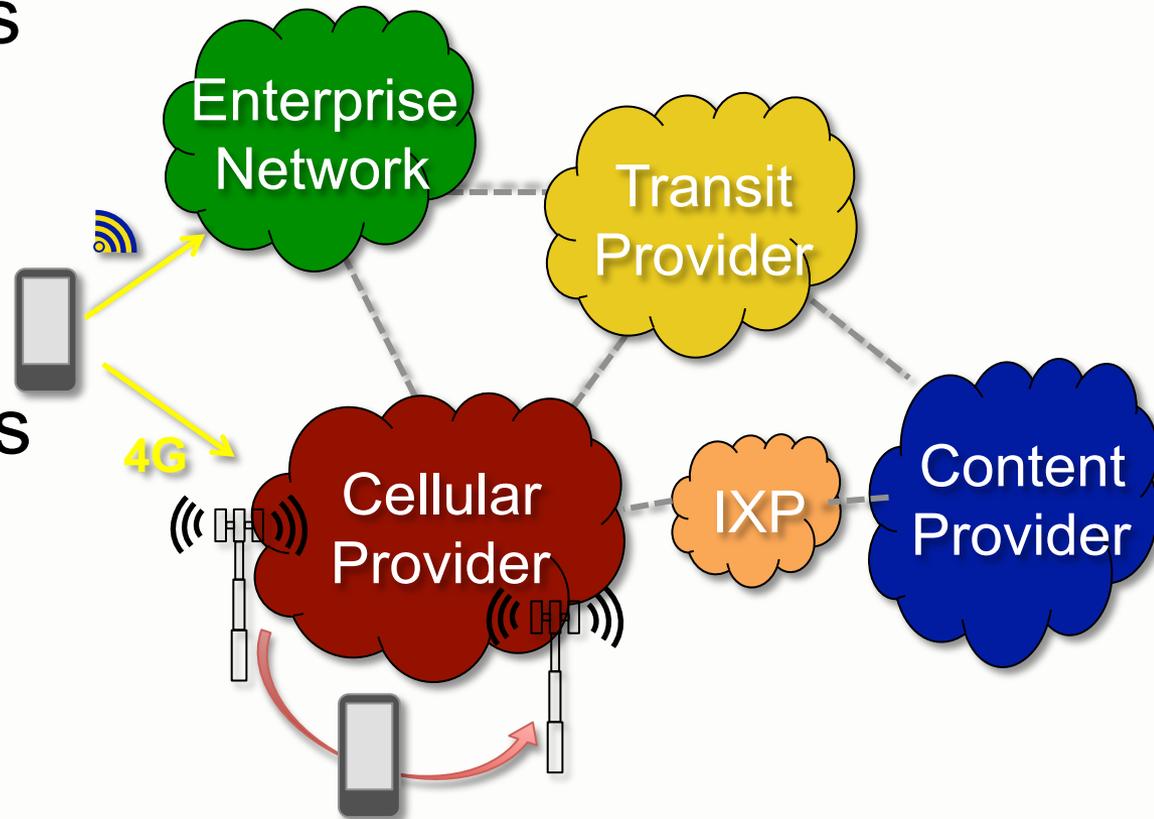


Initial Deployment Successes

- Cloud services
 - Multi-tenant data centers (Nicira)
 - Private inter-datacenter backbones (Google)
- Natural starting point
 - Killer applications (virtualization, TE)
 - Large, greenfield deployments
 - Homogeneous SDN switches
- Can SDN penetrate other kinds of networks?

SDN in Different Kinds of Networks

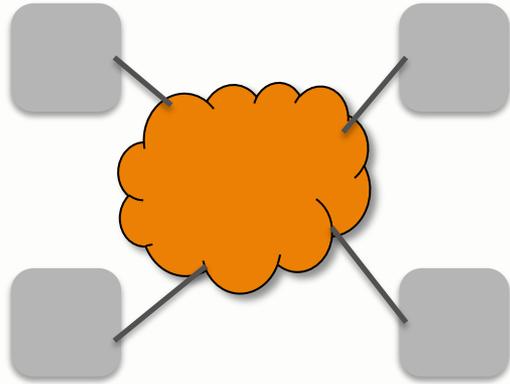
- Different networks
 - Enterprise
 - Transit backbone
 - Cellular core
- Between networks
 - Exchange points
 - Interdomain SDN
- Underlying media
 - Wireless
 - Optical transport



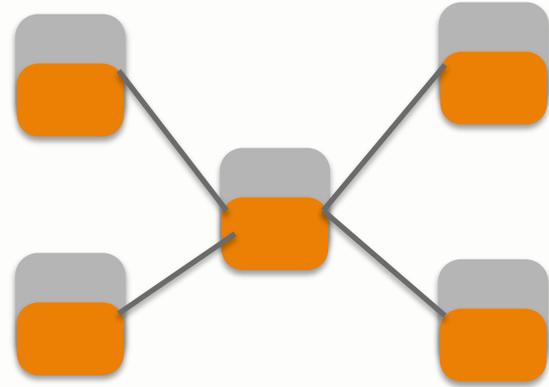
Deploying SDN More Widely

- New killer apps in these networks (?)
 - Dynamic access control
 - Connecting branch offices across domains
 - Cross-layer resource management
 - Cheaper switches, mobility/migration, NFV, ...
- Systems challenges
 - Scalability: many routable end-points
 - Heterogeneity: diverse network equipment
 - Interoperability: LTE protocols, BGP, ...

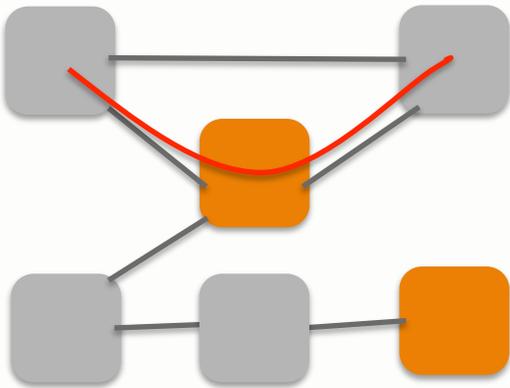
Incremental Deployment



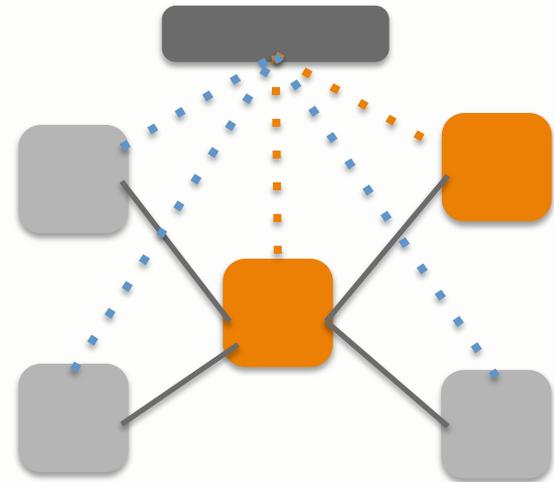
Overlay



Ships-in-the-night



Panopticon



Multiple control APIs

Education and Training

- New generation of networking professionals
 - Network-aware software developers
 - Software-aware network operators
- Software ecosystem
 - SDN platforms, tools, and apps
 - APIs for network operators
- Professional development
 - Courses, books, tutorials, certification, ...
 - E.g., Nick Feamster's popular Coursera MOOC



Conclusions

- SDN is happening
 - OpenFlow switches, controllers, and apps
 - Initial deployments in cloud settings
- SDN can go further
 - Richer software stack
 - Wider deployment scenarios
 - Overcoming deployment hurdles
- The future looks exciting!