Cloud and Datacenter Networking

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Software Defined Networking

Lesson outline

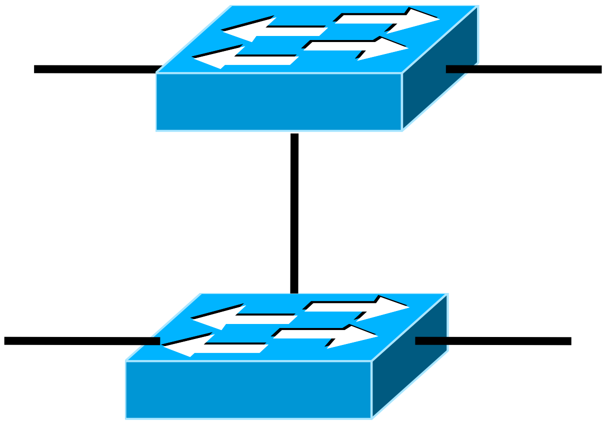
- Software Defined Networks (SDN)
- Credits for the material:
  - Jennifer Rexford
  - Nick McKeown
  - Scott Shenker

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… ☹

Inside the network: a different story…

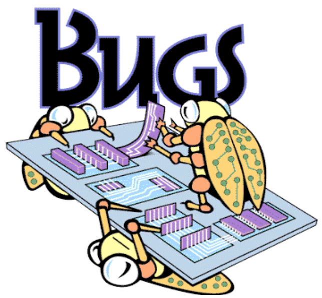
- Closed equipment
  - Software bundled with hardware
  - Vendor-specific interfaces
- Over specified
  - Slow protocol standardization
- Few people can innovate
  - Equipment vendors write the code
  - Long delays to introduce new features



Impacts performance, security, reliability, cost…

Networks are Hard to Manage

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

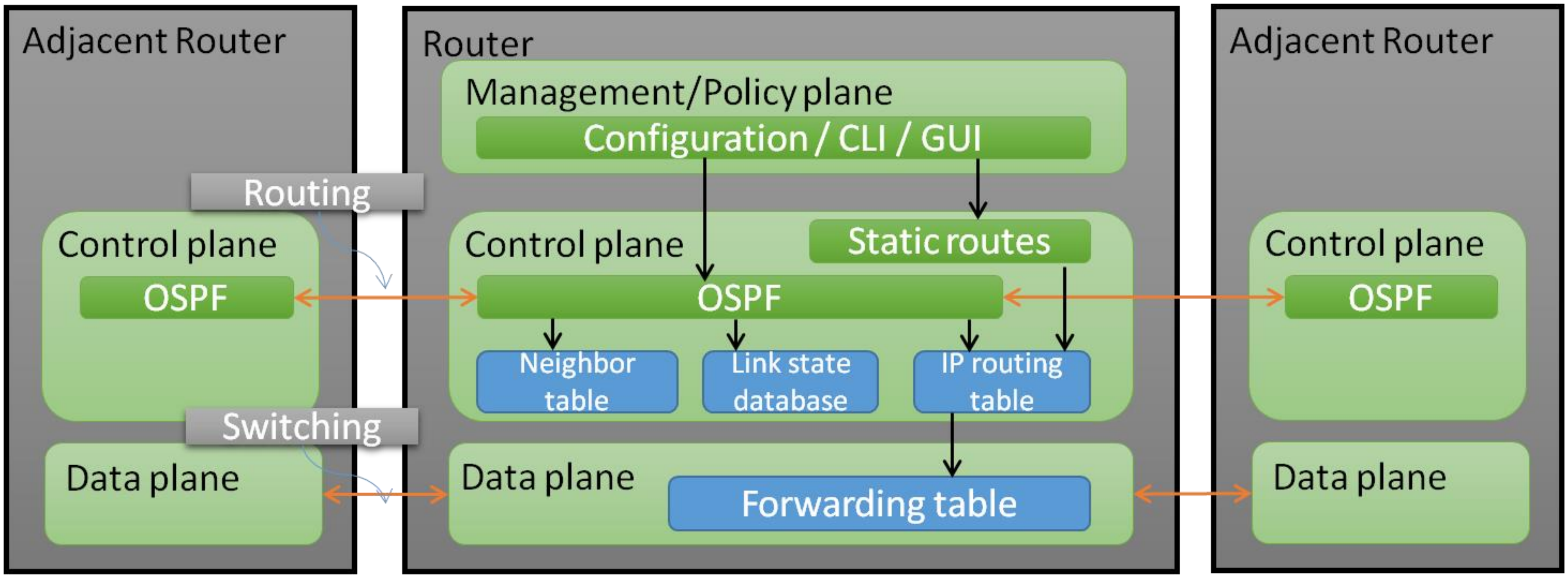


Traditional networking

- Each networking device operates at three different planes
- **Data Plane**: responsible of processing and forwarding of packets
  - Based on state in routers and endpoints
  - E.g., IP, TCP, Ethernet, etc.
  - Fast timescales (per-packet)
- **Control Plane**: decision – responsible of establishing the state in routers
  - Determines how and where packets are forwarded
  - Routing, traffic engineering, firewall state, …
  - Slow time-scales (per control event)
- **Management plane:** configuration – responsible of general device behavior
  - Determines how the control plane should be configured
  - Slow time-scales (manual configuration by network administrators)

Traditional networking: a router's view

- In an IP router, the control plane role is played by dynamic routing protocols and the associated state
  - E.g. OSPF and the Link State Database



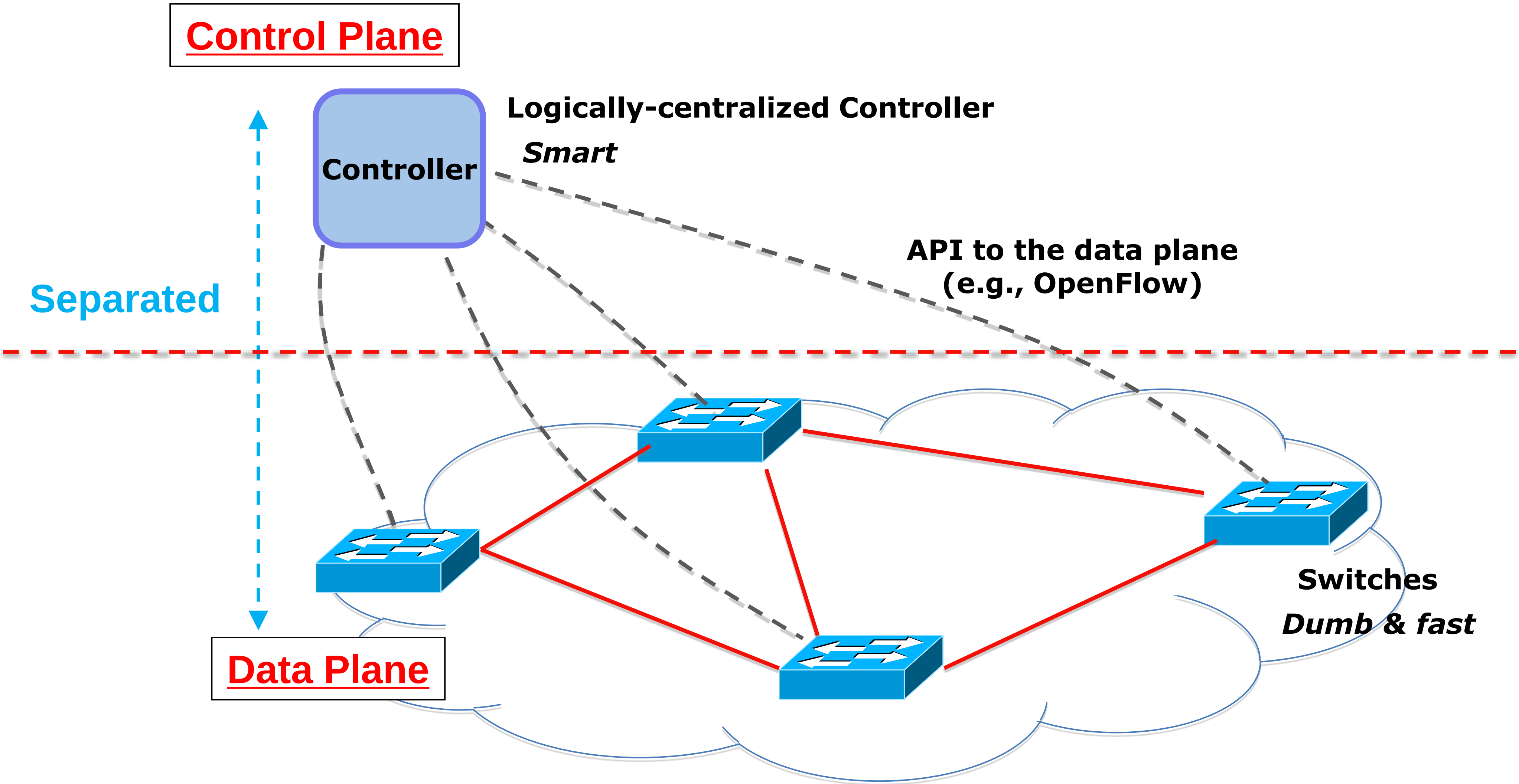
Tradional planes and time scales

	Data	Control	Management
Time scales	Packets	Events	Humans
Task	Forwarding/ buffering/ filtering/ scheduling	Routing, circuit set-up	Analysis, configuration
Location	Hardware • Specialized hardware • Processes at line rate • Every packet • Very fast	Router software • Uses CPU • Can only process a small number of packets • Very slow	Human or perl scripts

SDN Concept

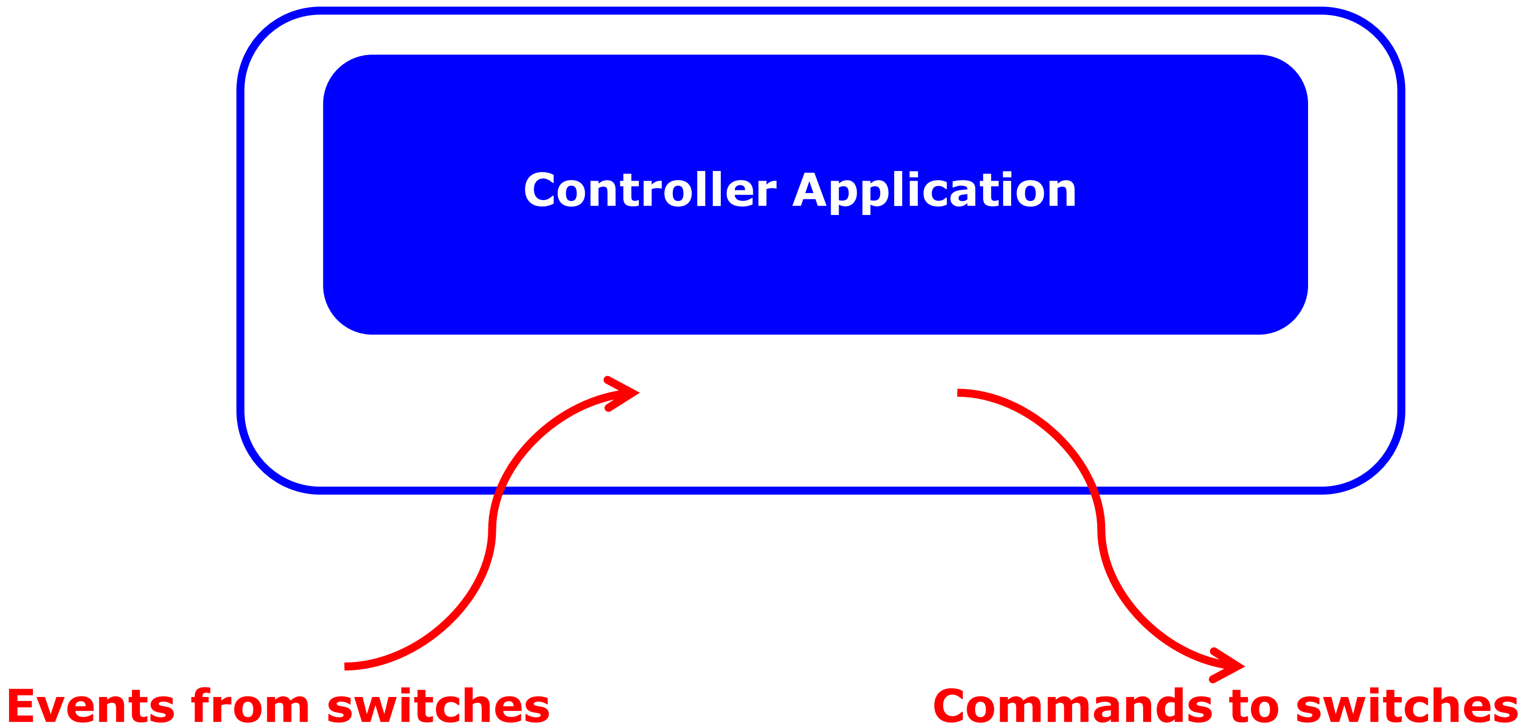
- Separate control plane and data plane entities
  - Network intelligence and state are **logically centralized**
  - The underlying network infrastructure is **abstracted** from the applications
- Remotely control network devices from a central entity
- Execute or run control plane software on general purpose hardware
  - Decouple from specific networking hardware
  - Use commodity servers
- An architecture to control
  - not just a networking device …
  - but an entire network
- Expected advantages:
  - Ability to innovate through software
    - Overcome the “Internet ossification problem”
  - Cost reductions through increased competition, hardware commoditization and open-source software

Software Defined Networking (SDN)



- A logically centralized "Controller" uses an open protocol (e.g. OpenFlow) to:
  - Get state information **from** forwarding elements (i.e. switches)
  - Give controls and directives **to** forwarding elements

SDN: controller programmability



SDN allows to unify different kinds of boxes

- Router
  - Match: longest destination IP prefix
  - Action: decrement TTL, re-compute header checksum, forward out a link
- Switch
  - Match: destination 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 address and port

All the above boxes may be replaced by "generic" SDN switches whose behaviour is programmed in the controller

By decoupling the network function from the physical infrastructure, the SDN approach is also useful to second another emerging trend in the telecommunications industry: *Network Function Virtualization* (NFV)

A Short History of SDN

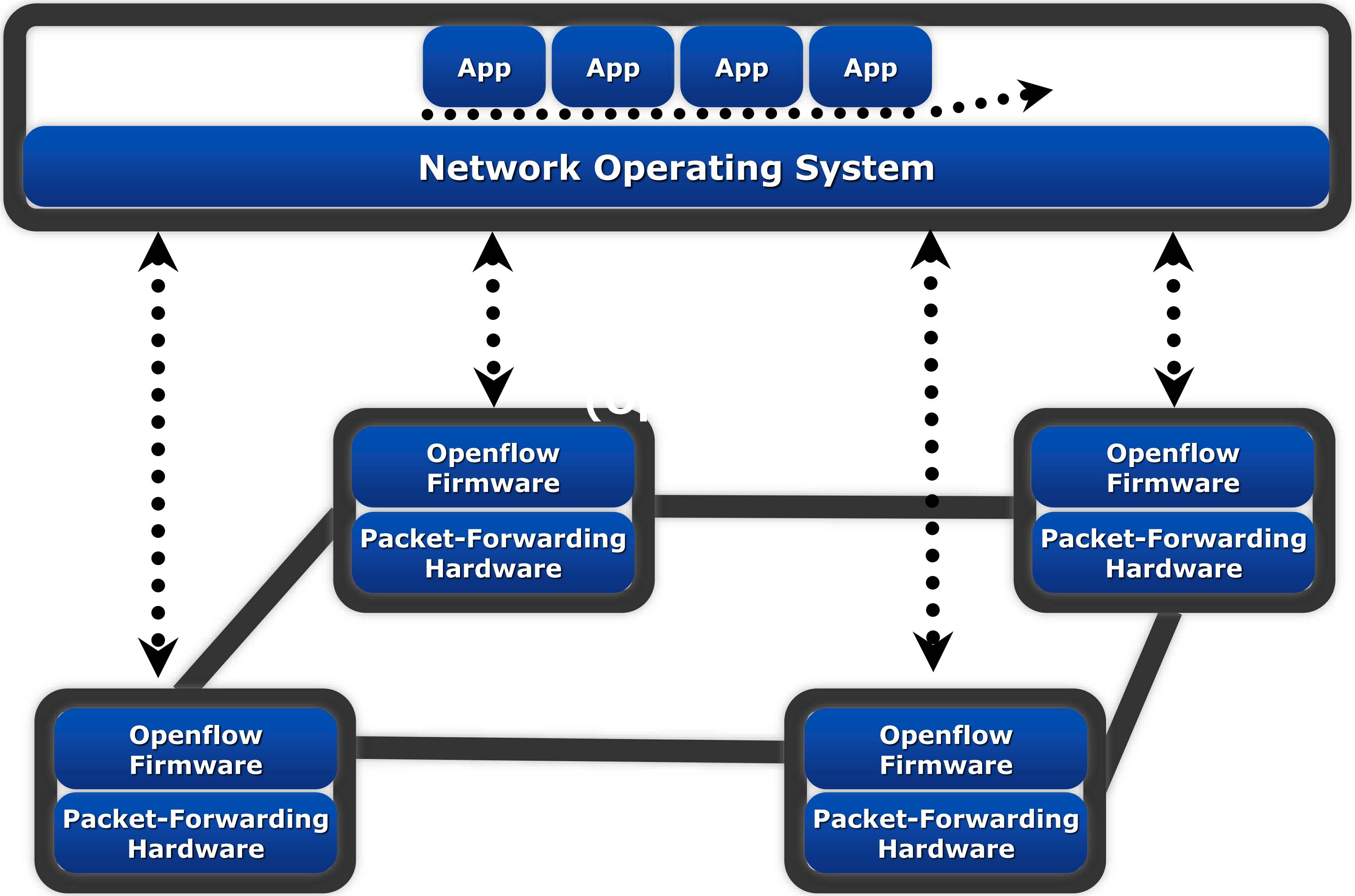
- ~2004: Research on new management paradigms
  - RCP, 4D [Princeton, CMU,....]
- 2006: Martin Casado, a PhD student at Stanford and team propose a clean-slate security architecture (SANE) which defines a centralized control of security (instead of at the edge as normally done)
- 2008: the idea of *Software Defined Network* is originated from OpenFlow project (*ACM SIGCOMM 2008*)
- 2009: Stanford publishes OpenFlow V1.0.0 specs
- June 2009: Martin Casado co-founds Nicira
- 2011: Open Networking Foundation (~69 members)
  - **Board**: Google, Yahoo, Verizon, DT, Msoft, F'book, NTT
  - **Members**: Cisco, Juniper, HP, Dell, Broadcom, IBM,.....
- 2012: OpenFlow in production use
- July 2012: VMware buys Nicira for **$1.26B**

SDN: latest developments

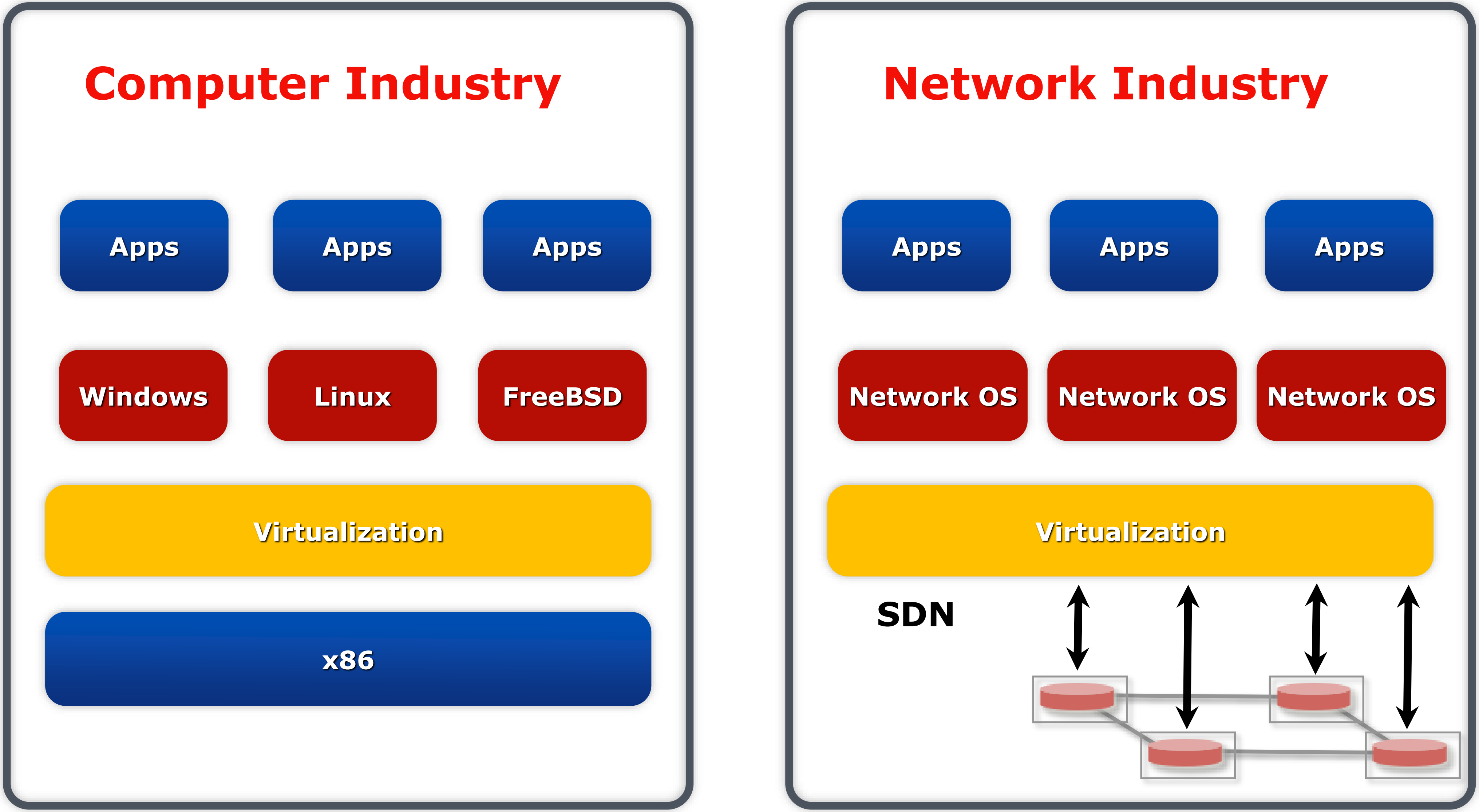
- 2012: Google employs SDN principles and OpenFlow to build:
  - Jupiter: a data center interconnect capable of supporting more than 100,000 servers
  - B4: a WAN interconnecting its data centers to replicate data in real-time and better manage inter-DC traffic
- 2014: Some network equipment vendors start promoting their own SDN solutions, non Openflow compliant
  - Cisco announced the OpFlex protocol
- 2014: The Open Networking Lab (ON.Lab) non-profit organization is founded by SDN inventors and leaders from Stanford University and UC Berkeley to foster open source communities for developing tools and platforms to realize the full potential of SDN, NFV and cloud technologies
- 2016: Emerging SDN-based WAN solutions (SD-WAN)
- 2017: Google announces that they will start partnering with leading mobile network operators, by building an SDN-based platform for operators to run their network services

An OS for networks thanks to SDN

- The whole network as one big machine
- The key is to have a standardized control interface that speaks directly to hardware

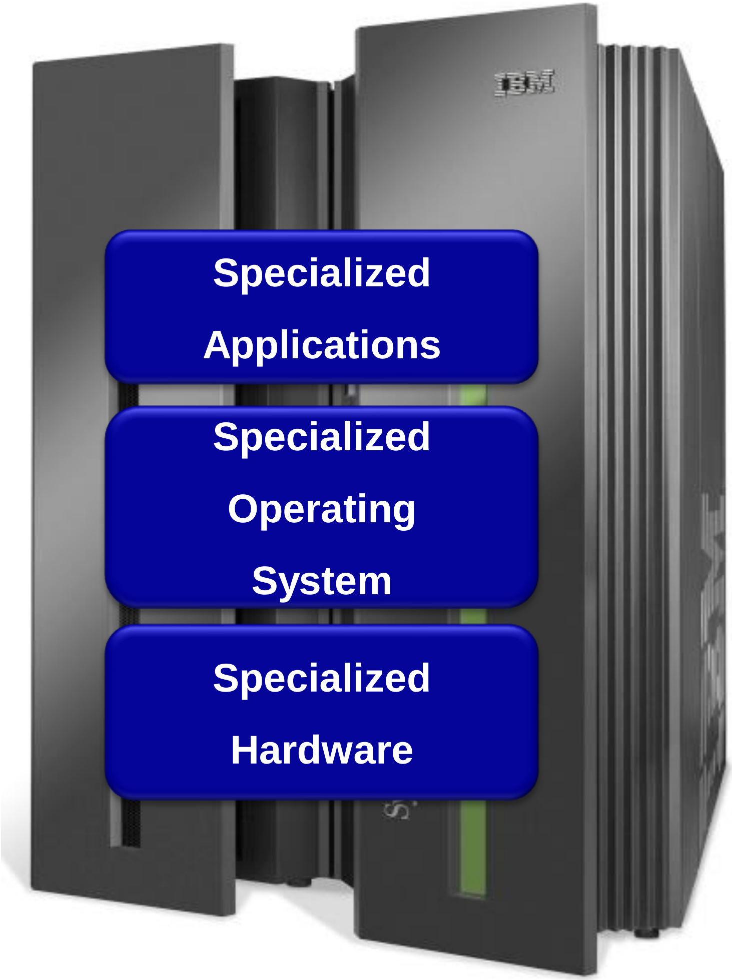


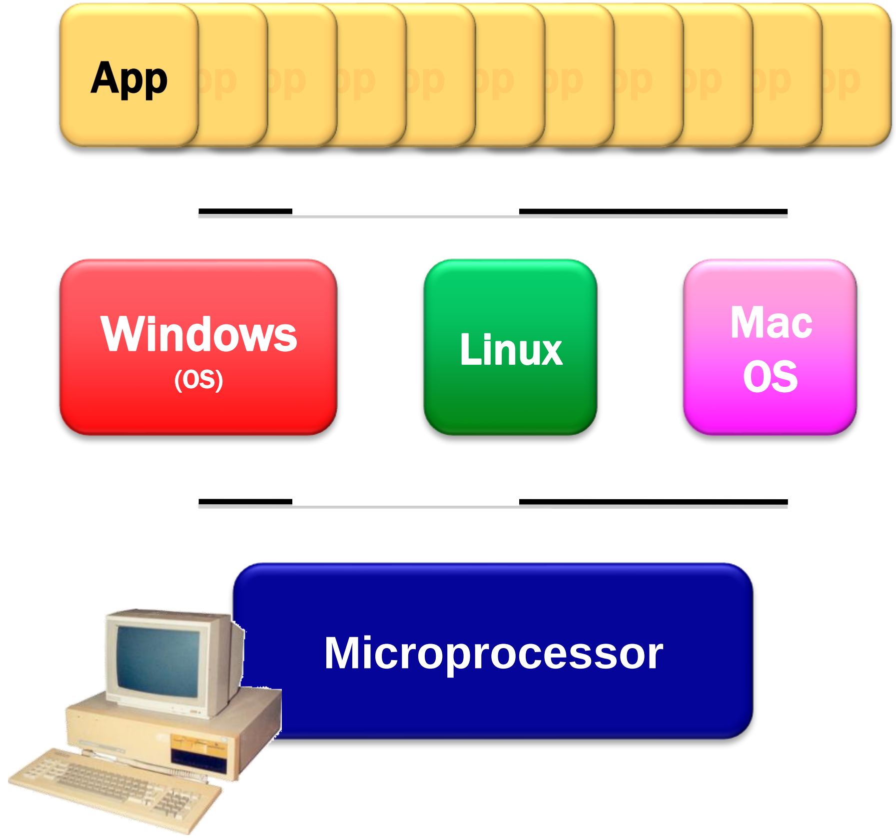
The "Software-Defined Networking" (r)evolution



Computers evolution: from mainframes to microprocessors

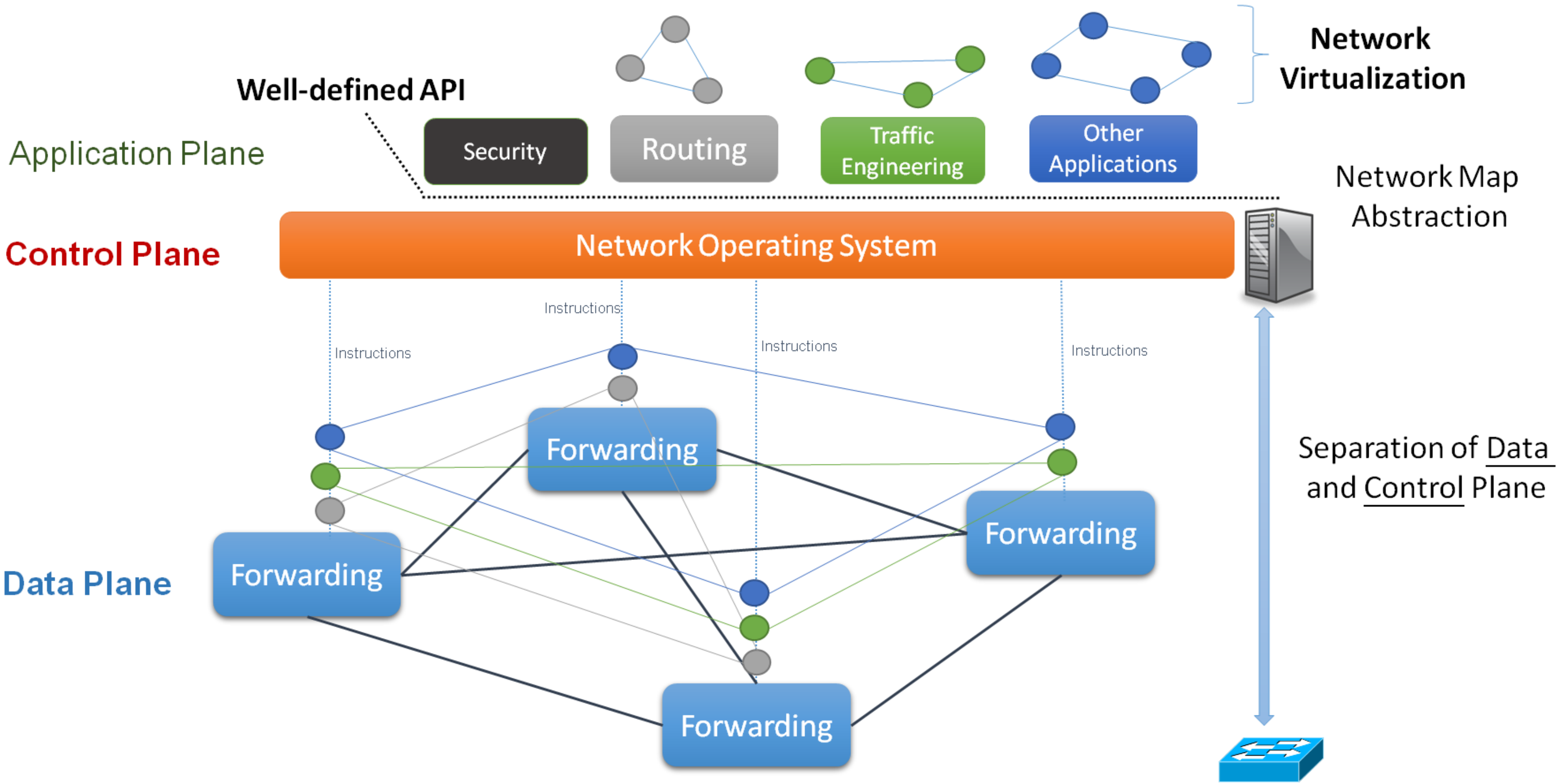
From Nick McKeown's talk "Making SDN Work" at the Open Networking Summit, April 2012





Vertically integrated	Horizontal
Closed, proprietary	Open interfaces
Slow innovation	Rapid innovation
Small industry	Huge industry

SDN: the role of the Network Operating System



Two examples uses

- Scale-out router:
  - Abstract view is single router
  - Physical network is collection of interconnected switches
  - Allows routers to “scale out, not up”
  - Use standard routing protocols on top

- Multi-tenant networks:
  - Each tenant has control over their “private” network
  - Network virtualization layer compiles all of these individual control requests into a single physical configuration

- **Hard to do without SDN, easy** *(in principle)* **with SDN**

Does SDN work?

Is it scalable?	**Yes**
Is it less responsive?	**No**
Does it create a single point of failure?	**No**
Is it inherently less secure?	**No**
Is it incrementally deployable?	**Yes**

SDN: clean separation of concerns

- **Control program: specify behavior on abstract model**
  - Driven by **Operator Requirements**
- **Network Virtualization: map abstract model to global view**
  - Driven by **Specification Abstraction**
- **NOS: map global view to physical switches**
  - API: driven by **Distributed State Abstraction**
  - Switch/fabric interface: driven by **Forwarding Abstraction**

Where SDN is and will be deployed

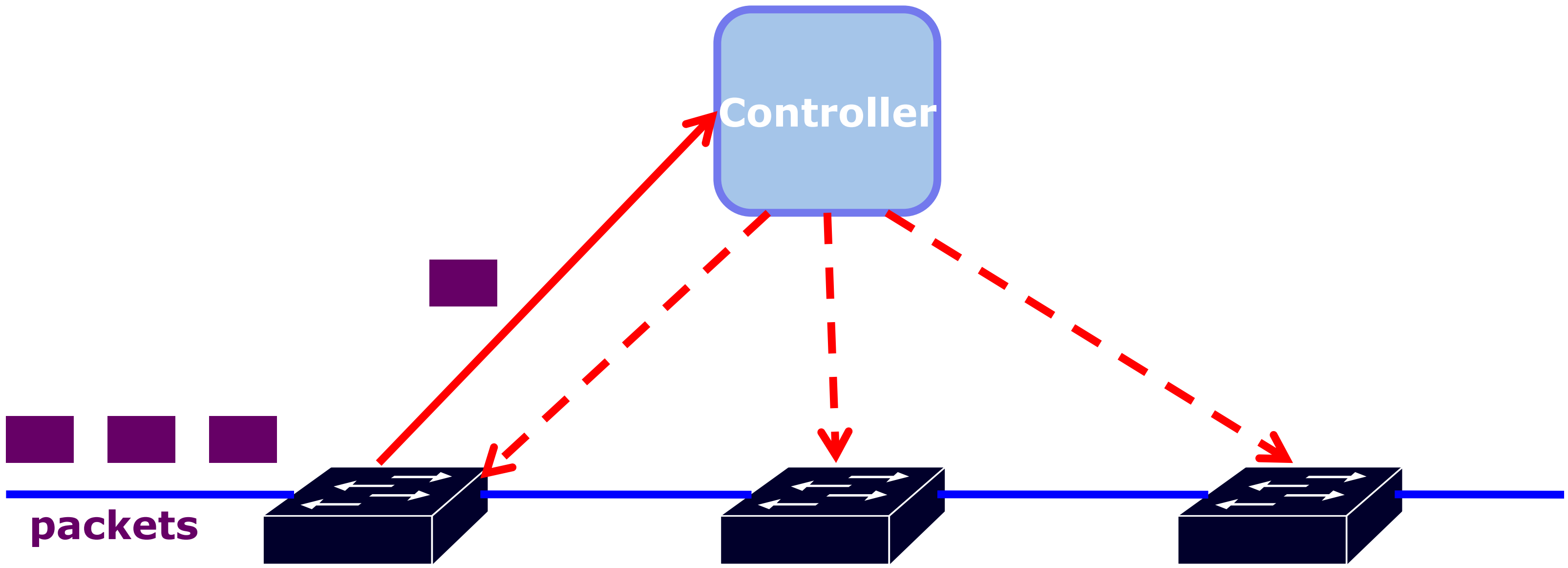
- Multi-tenant "virtualized" data centers
  - Public and private clouds
- WANs
  - Google WAN
  - Eventually, public WANs
- Enterprise networks
  - Greater control, fewer middleboxes

Where SDN is and will be deployed (2)

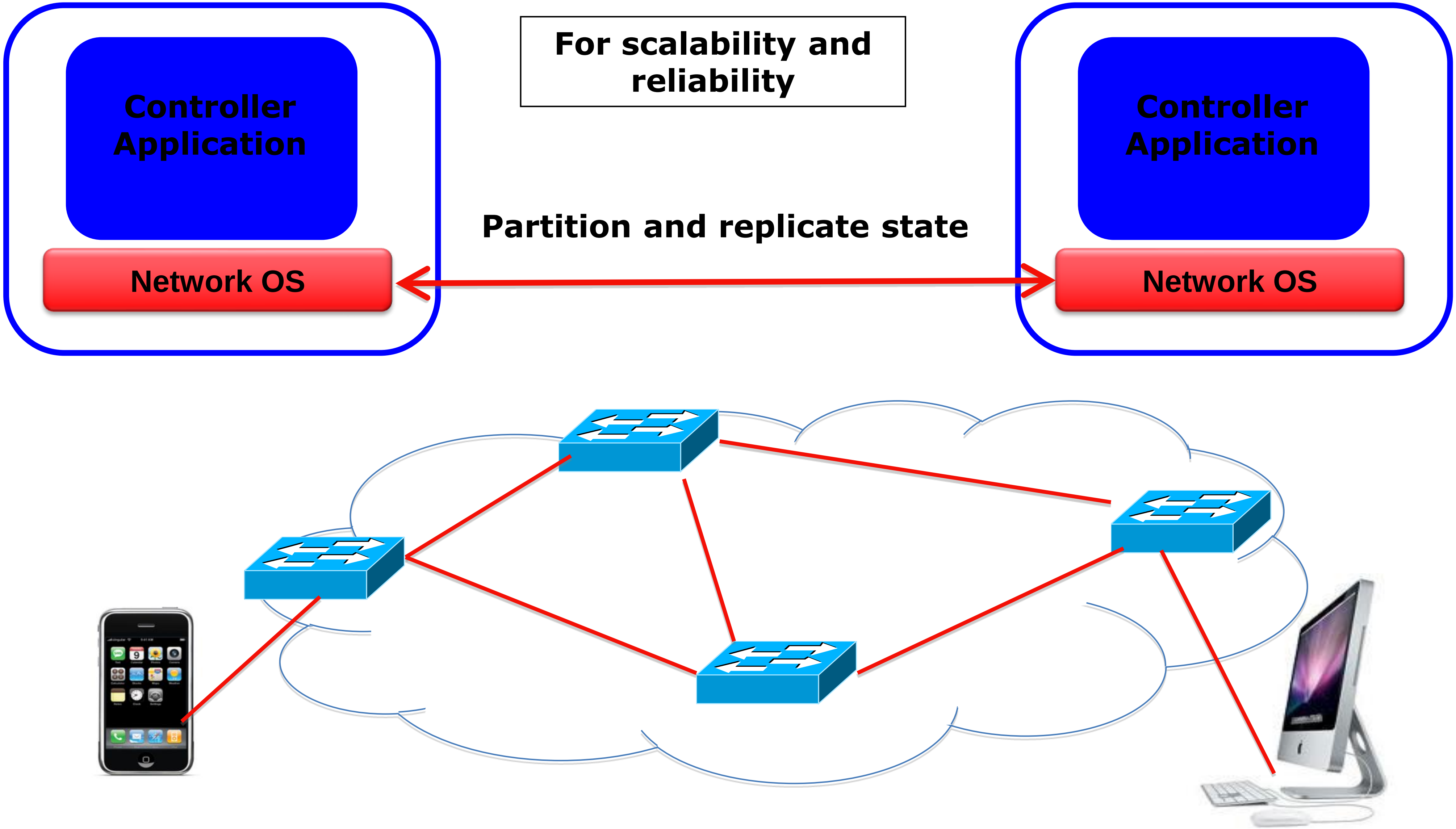
- Home networks
  - Outsourced management
- Cellular Networks
  - Separation of service from physical infrastructure
- Research and Education Networks
  - National backbones
  - College campus networks

Challenge: 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”



SDNs with distributed controllers

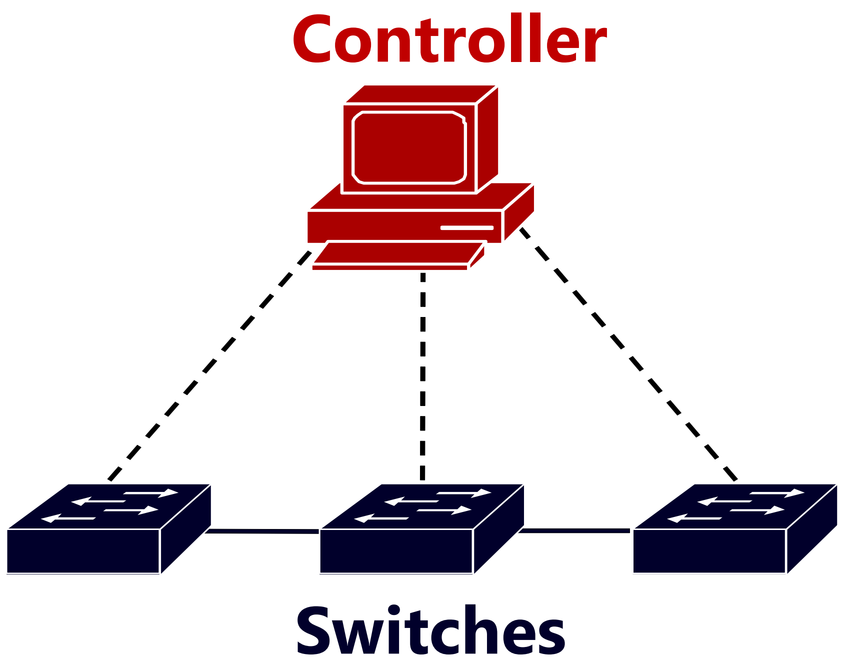


Challenge: testing and debugging

- 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

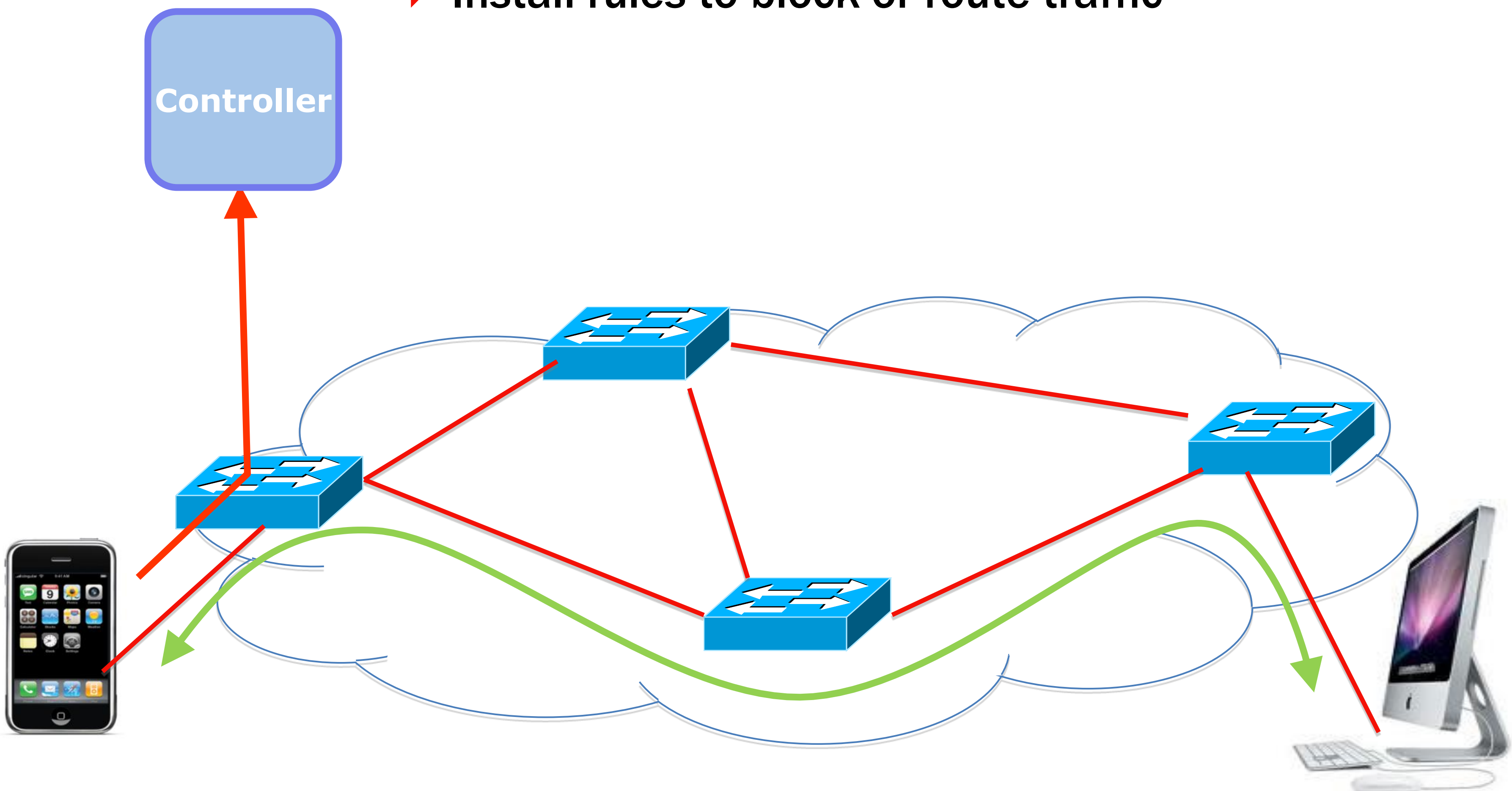
Challenge: programming abstractions

- Controller APIs are low-level
  - Thin layer on top of the underlying hardware
- Need better languages
  - Composition of modules
  - Managing concurrency
  - Querying network state
  - Network-wide abstractions



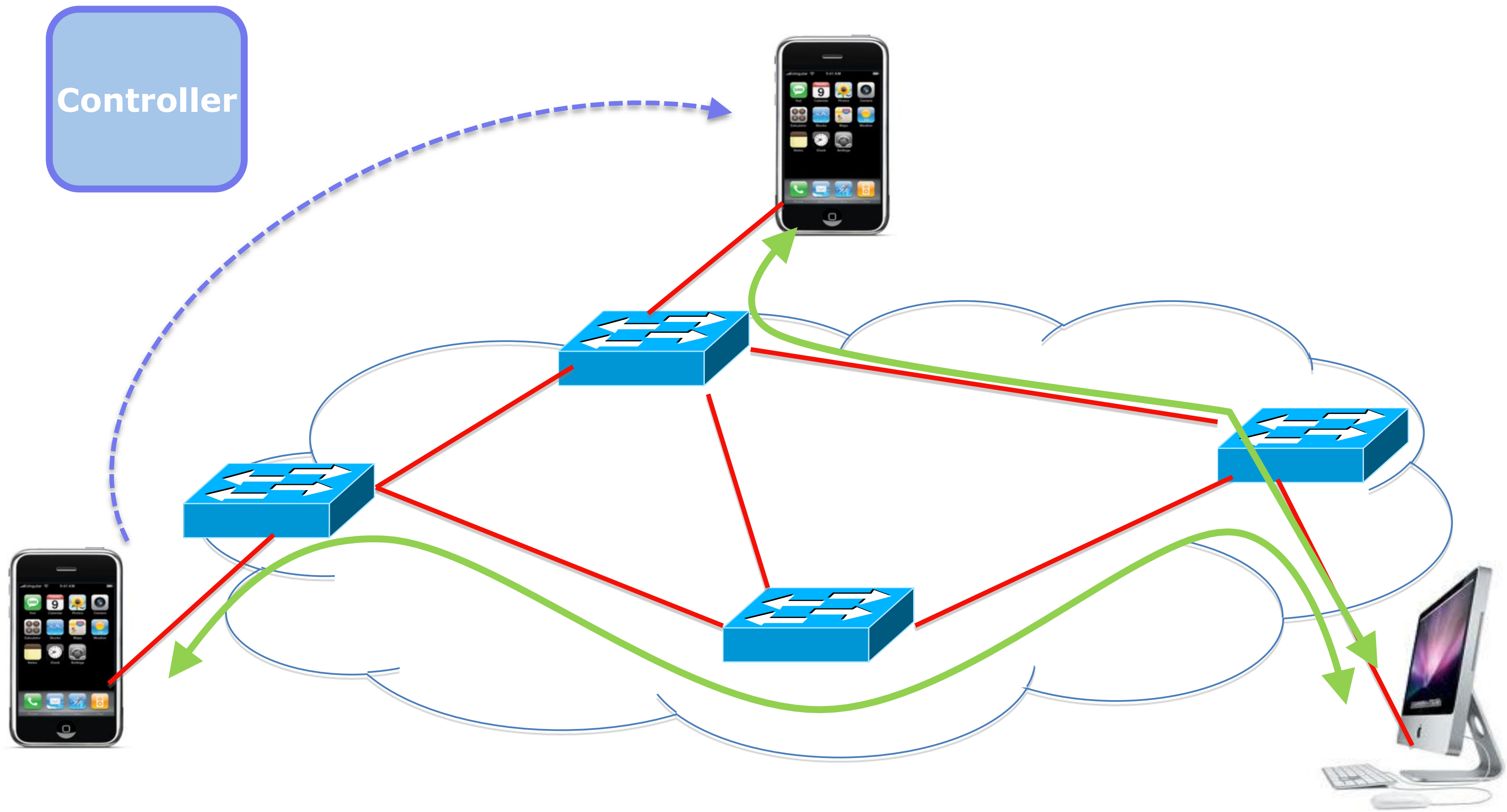
SDN use case: Dynamic Access Control

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



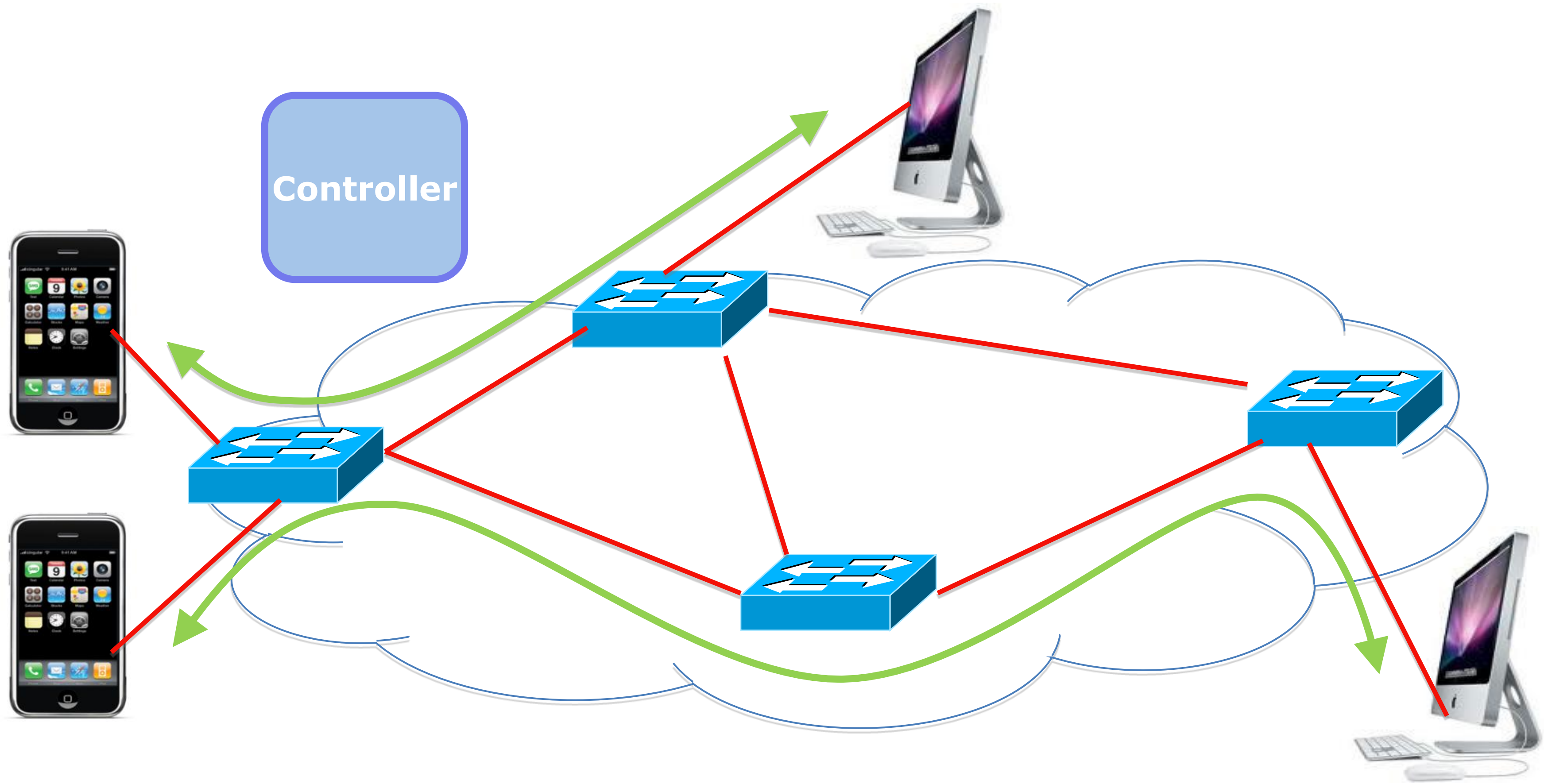
SDN use case: Seamless Mobility/Migration

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

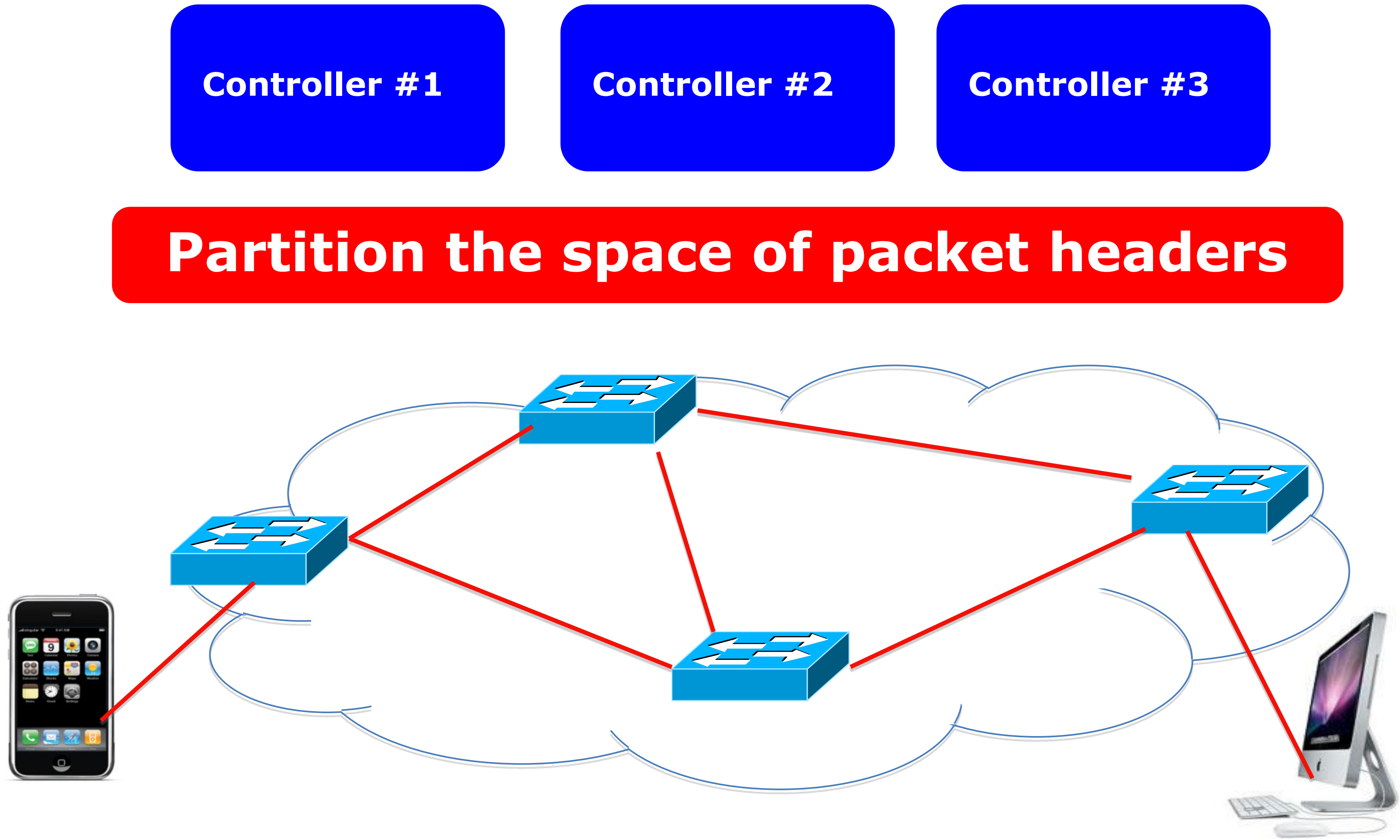


SDN use case: Server Load Balancing

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

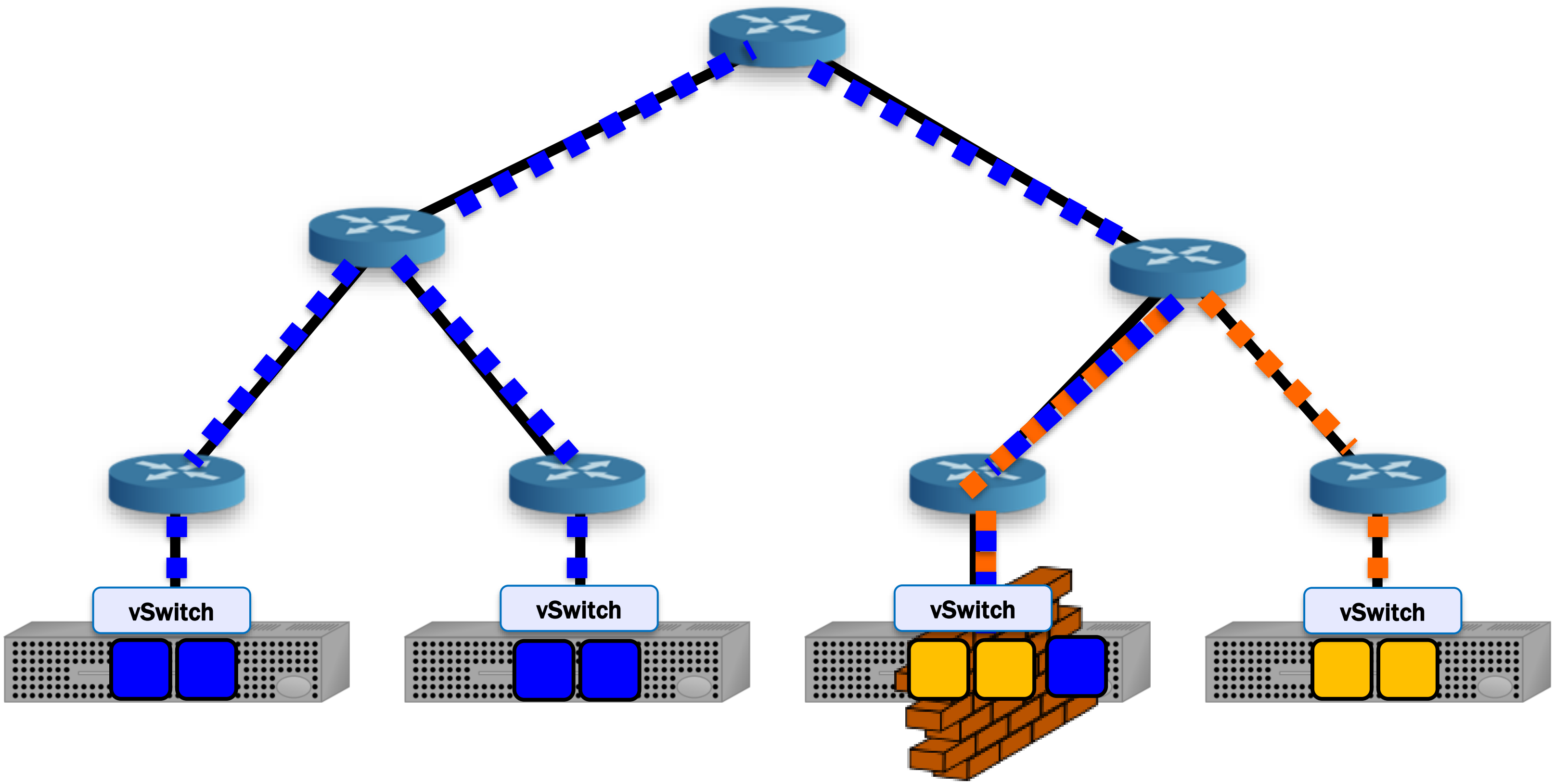


SDN use case: Network Virtualization



SDN use case: multi-tenant datacenter

- In a multi-tenant datacenter, the cloud provider has to implement and manage mechanisms to isolate traffic of different tenants both in the network and in the hypervisors
- With SDN connectivity between VMs is controlled by network automation and programming
- SDN extends its action in the hypervisor through software v-switches



SDN in Real World – Google's Story

- The industries were skeptical whether SDN was possible
- Google had big problems:
  - **High financial cost** managing their datacenters: Hardware and software upgrade, over provisioning (fault tolerant), manage large backup traffic, time to manage individual switch, and a lot of men power to manage the infrastructure
  - **Delay** caused by rebuilding connections after link failure
    - Slow to rebuild the routing tables after link failure
    - Difficult to predict what the new network may perform
- Google went ahead and implemented SDN
  - Built their hardware and wrote their own software for their internal datacenters
  - Surprised the industries when Google announced SDN was possible in production
- How did they do it?
  - "*B4: Experience with a Globally-Deployed Software Defined WAN*", ACM SIGCOMM 2013

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