Topic Preview Sessions

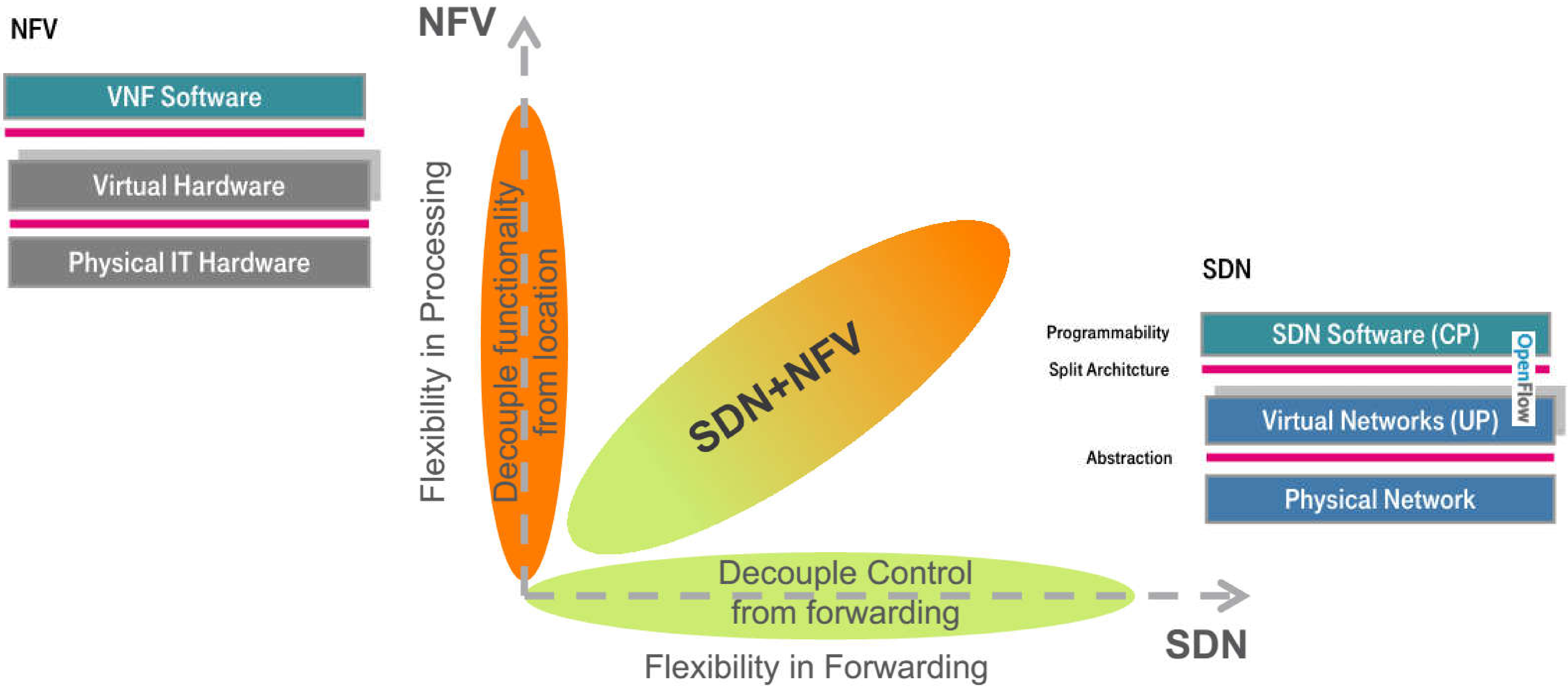
SDN/NFV: Software Defined Networking & Network Function Virtualization

Christian Esteve Rothenberg *(University of Campinas)*

Rodrigo Fonseca *(Brown University)*

Monday, August 22, 2016

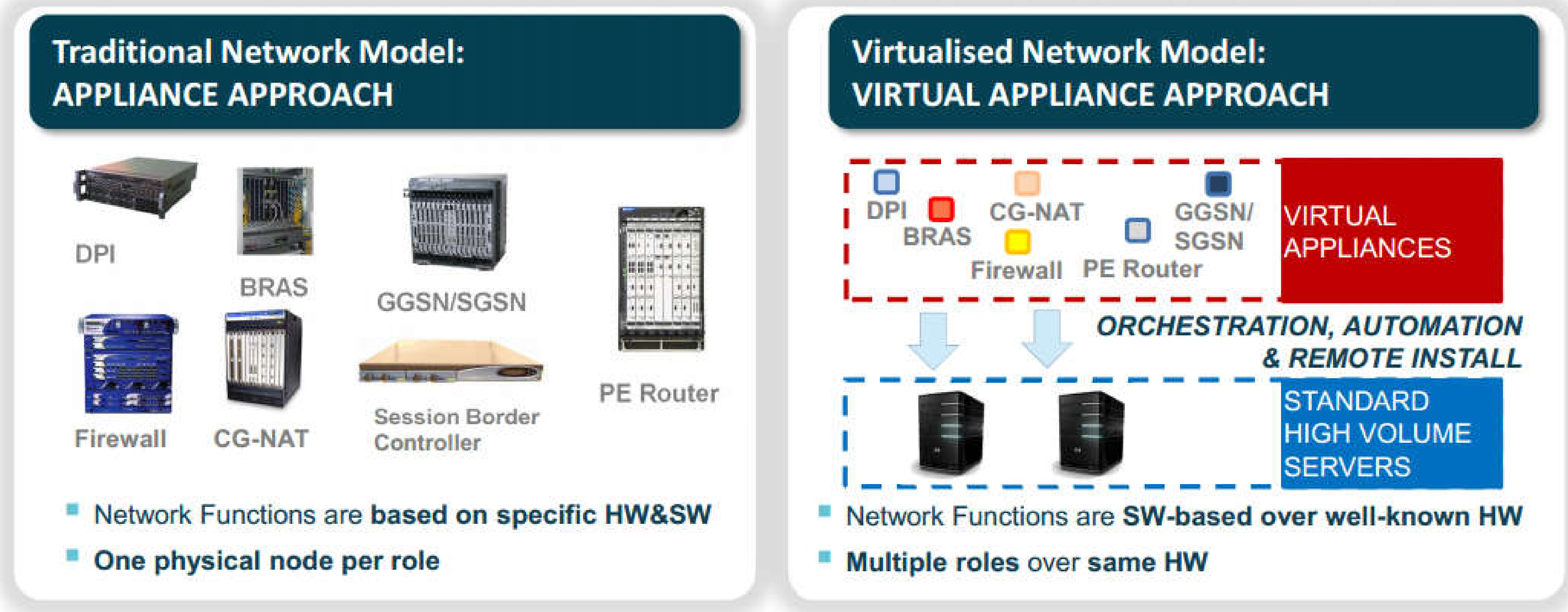
SDN & NFV :: Network Programmabilty /Flexibility



Sources: Ahmad Rostami, Ericsson Research (Kista): http://www.itc26.org/fileadmin/ITC26_files/ITC26-Tutorial-Rostami.pdf and Uwe Michel, T-Systems

The NFV Concept

A means to make the network more flexible and simple by minimising dependence on HW



Source: Adapted from D. Lopez Telefonica I+D, NFV

Why NFV/SDN?

1. **Virtualization:** Use network resource without worrying about where it is physically located, how much it is, how it is organized, etc.
2. **Orchestration:** Manage thousands of devices
3. **Programmability:** Should be able to change behavior on the fly.
4. **Dynamic Scaling:** Should be able to change size, quantity, as a F(load)
5. **Automation:** Let machines / software do humans' work
6. **Visibility:** Monitor resources, connectivity
7. **Performance:** Optimize network device utilization
8. **Multi-tenancy:** Slice the network for different customers (as-a-Service)
9. **Service Integration:** Let network management play nice with OSS/BSS
10. **Openness:** Full choice of modular plug-ins

Note: These are exactly the same reasons why we need/want SDN/NFV.

Obs: Differences on the (complementary) SDN and NFV approaches on how.

(SDN :: decoupling of control plane, NFV : decoupling of SW function from HW)

Source: Adapted from Raj Jain

NFV vs. SDN

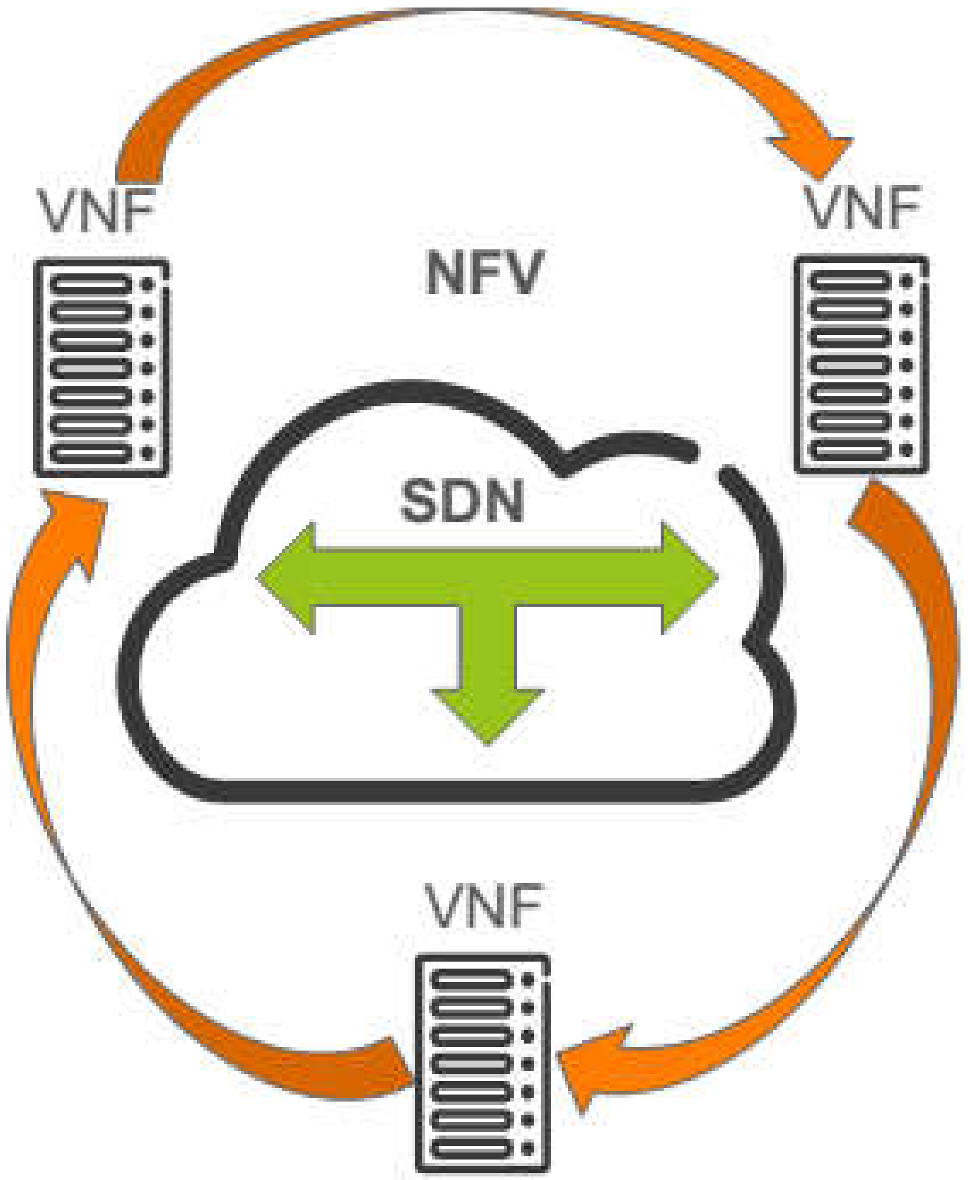
SDN ››› flexible forwarding & steering of traffic in a physical or virtual network environment

[Network Re-Architecture]

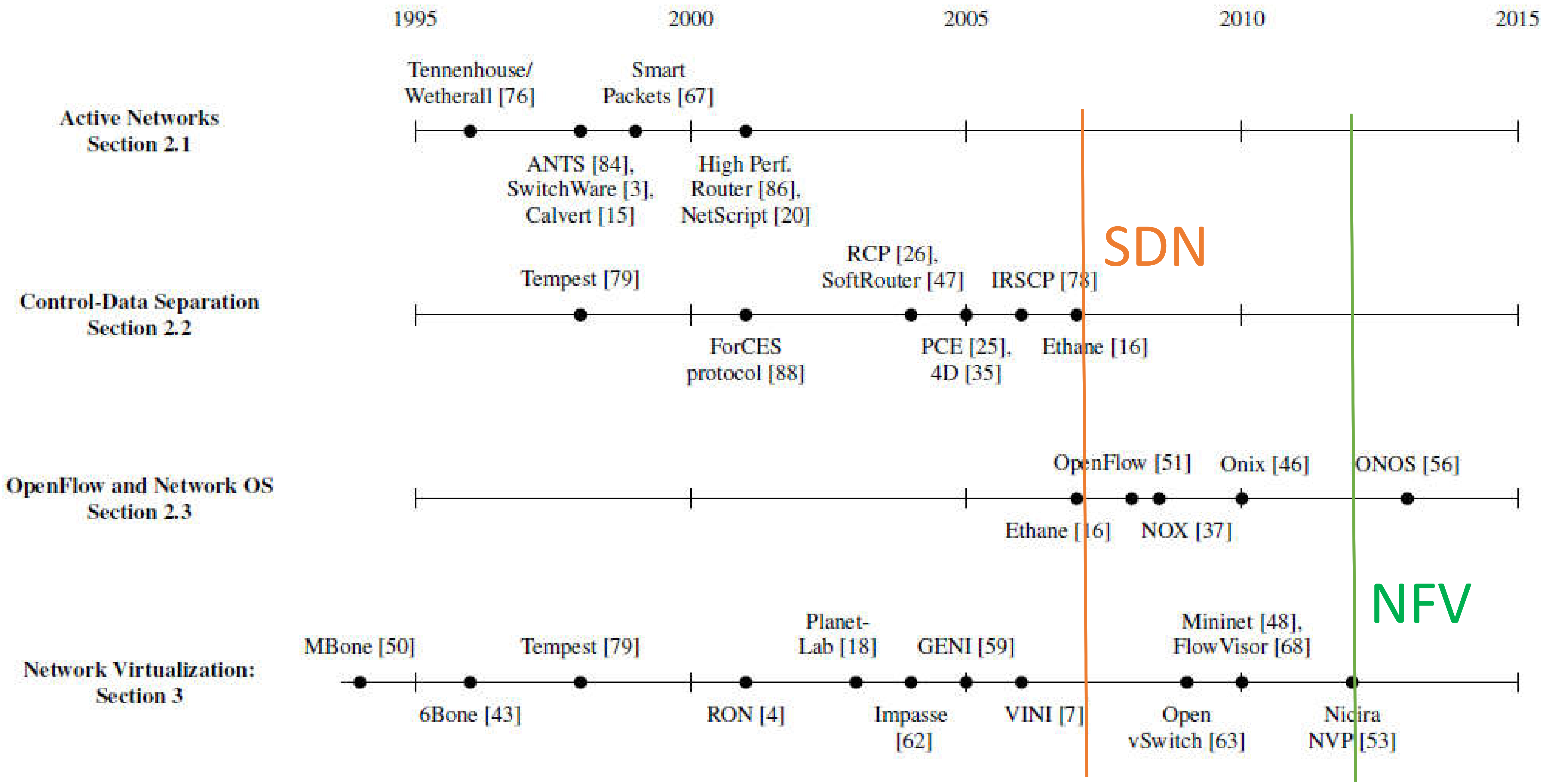
NFV ››› flexible placement of virtualized network functions across the network & cloud

[Appliance Re-Architecture] (initially)

››› SDN & NFV are complementary tools for achieving full **network programmability**

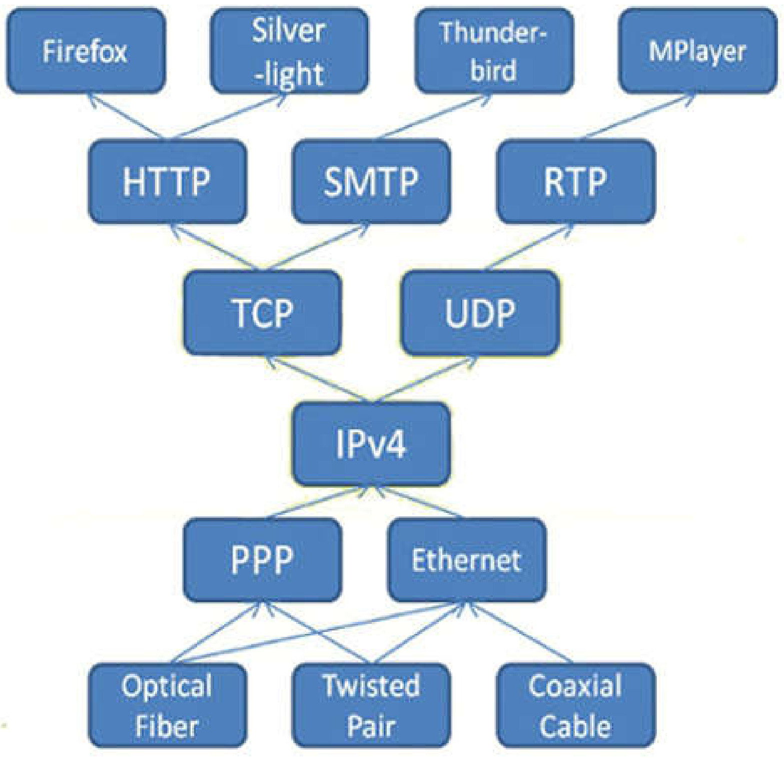


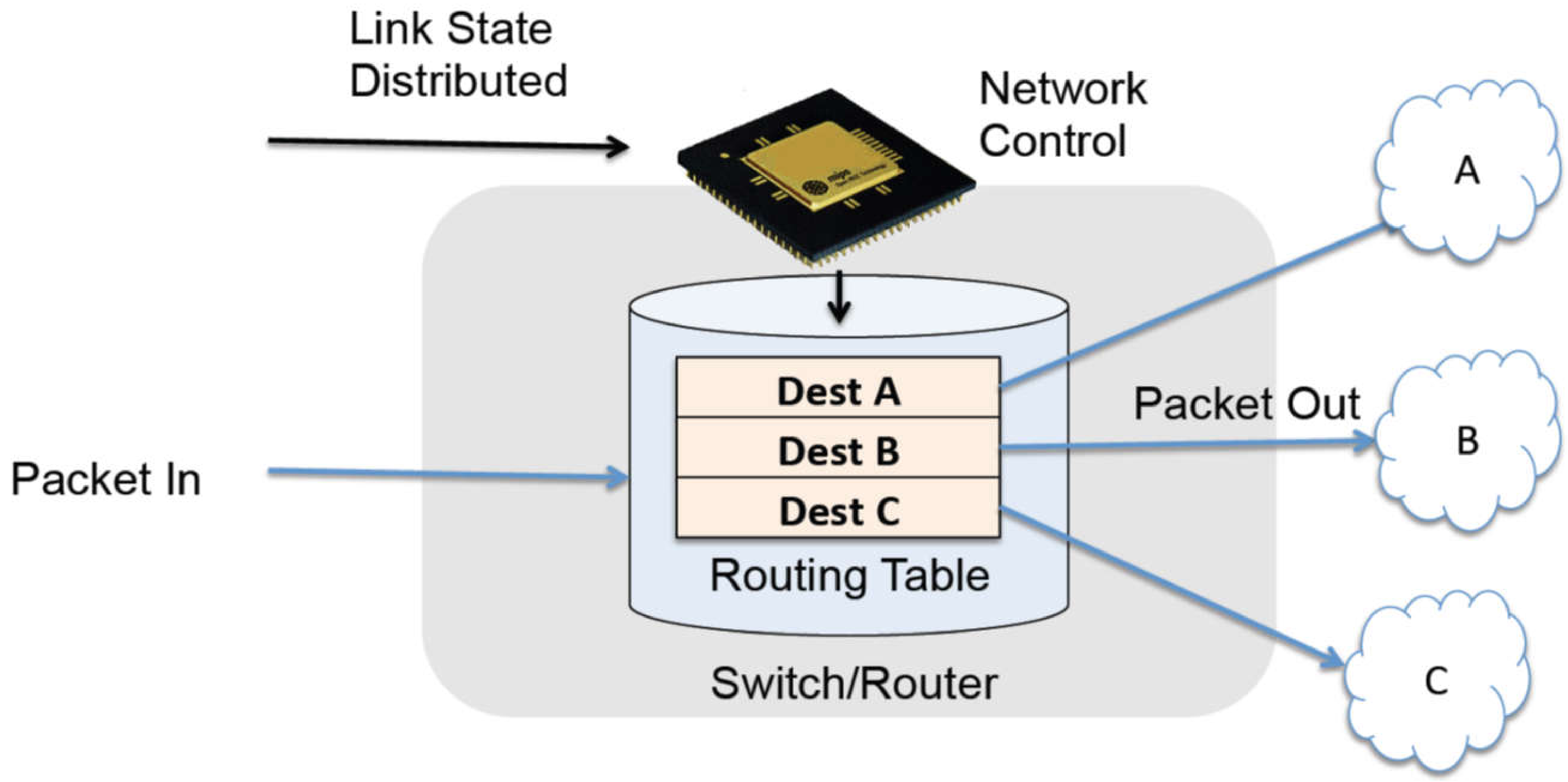
Intellectual History of Programmable Networks



Source: N. Feamster, J. Rexford, E. Zegura. The Road to SDN: An Intellectual History of Programmable Networks.
http://gtnoise.net/papers/drafts/sdn-cacm-2013-aug22.pdf

Networking as Learned in School (text books)

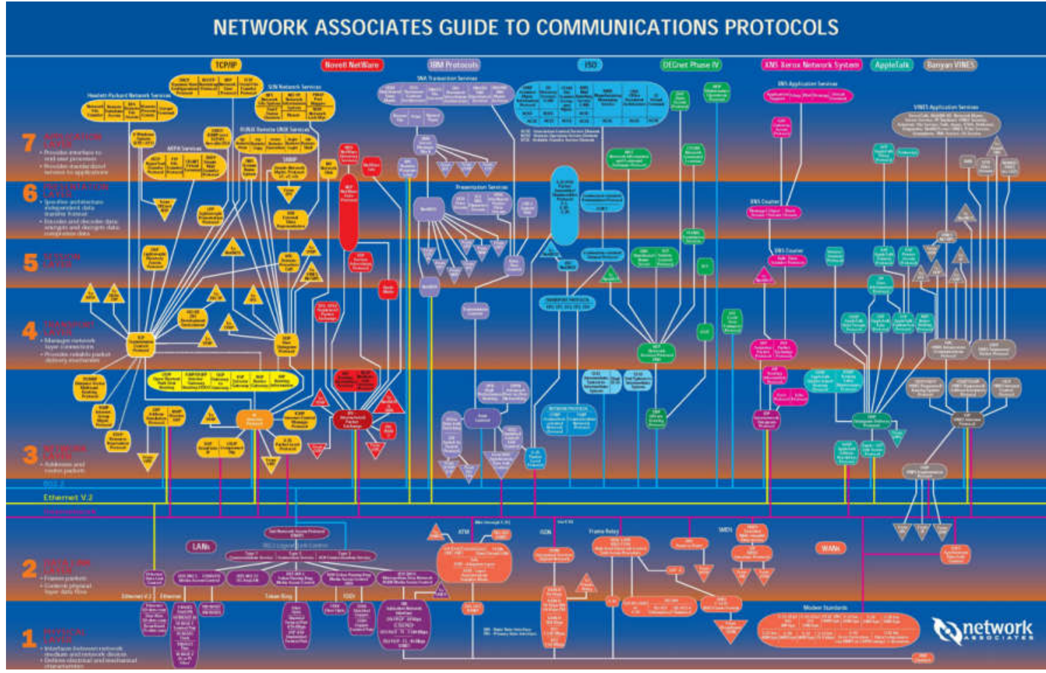


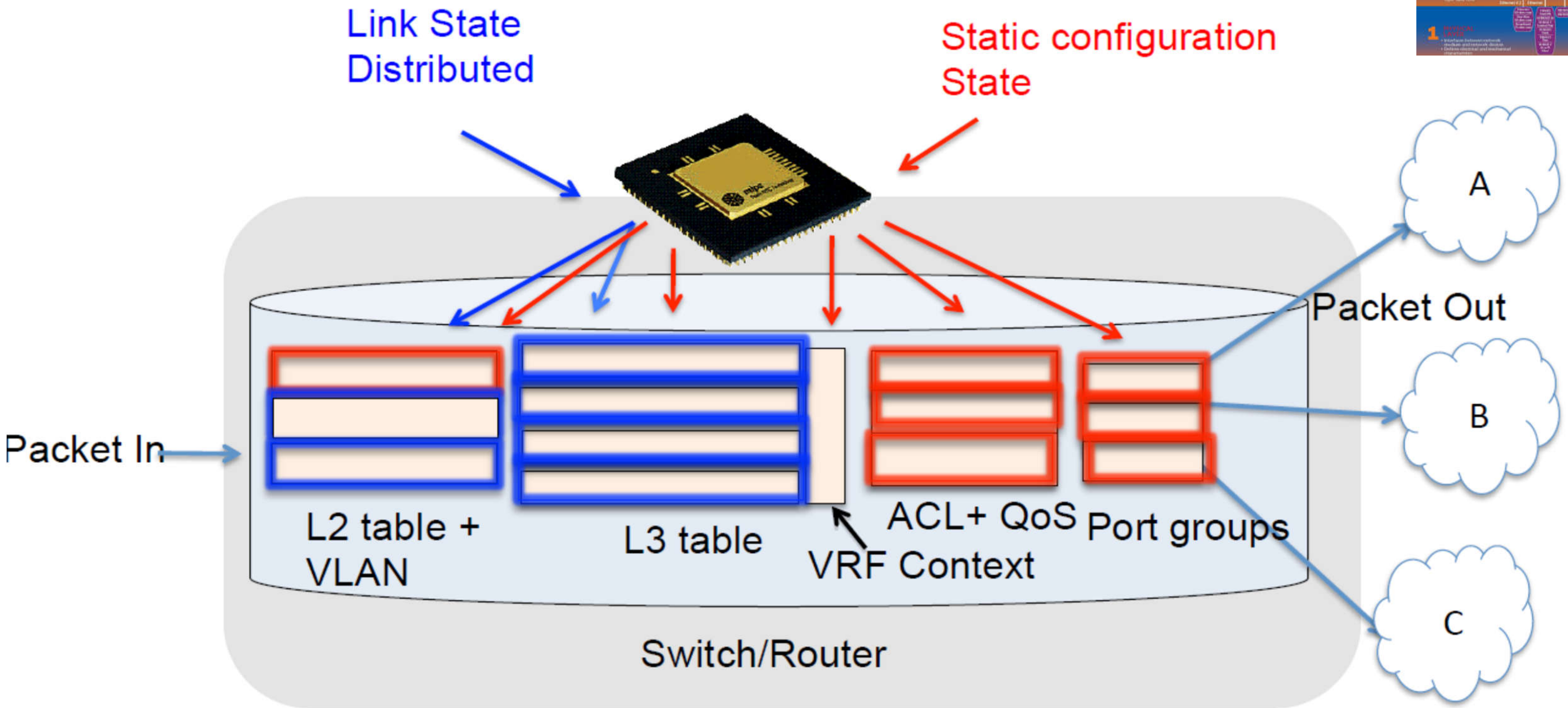


Source: Martin Casado CS244 Spring 2013, Lecture 6, SDN

Networking in Practice

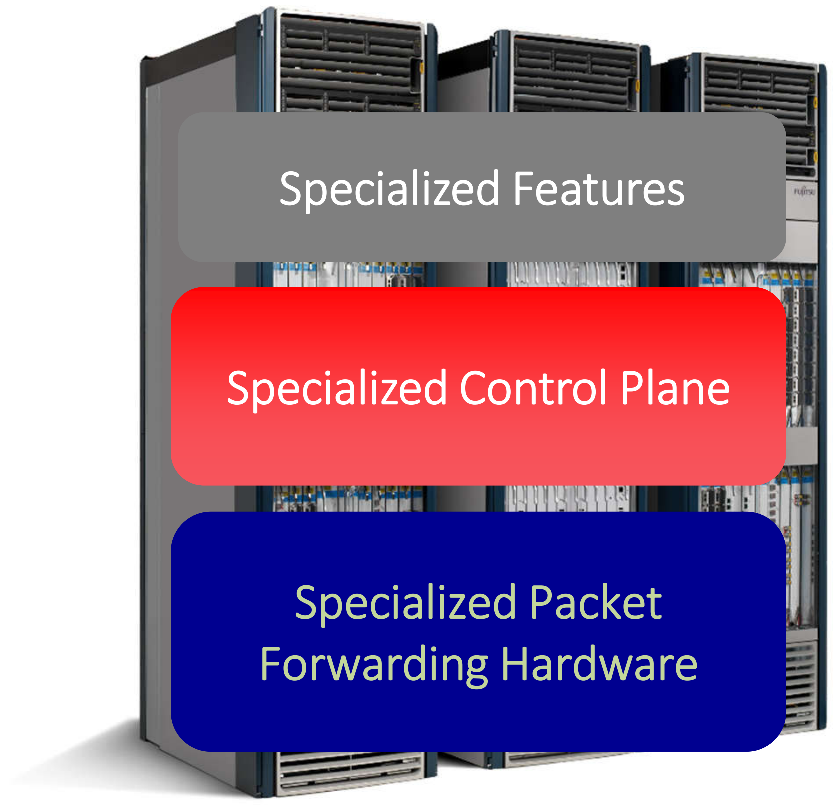
"in theory, theory and practice are the same; in practice they are not..."





Source: Martin Casado CS244 Spring 2013, Lecture 6, SDN

Problem with Internet Infrastructure



Hundreds of protocols
6,500 RFCs

Tens of Millions of lines of code
Closed, proprietary, outdated

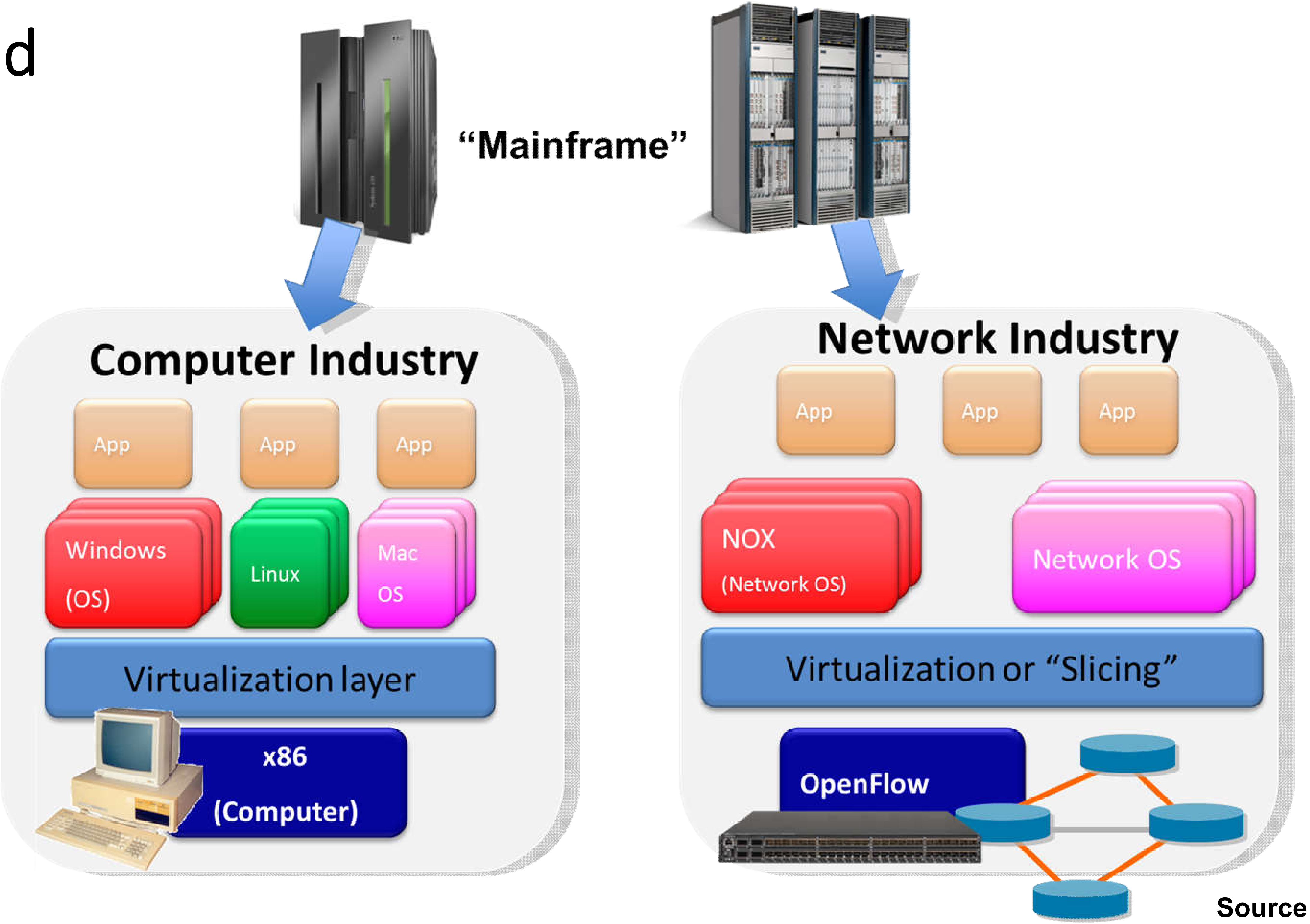
Billions of gates
Power hungry and bloated

Vertically integrated, complex, closed, proprietary

Not good for network owners and users

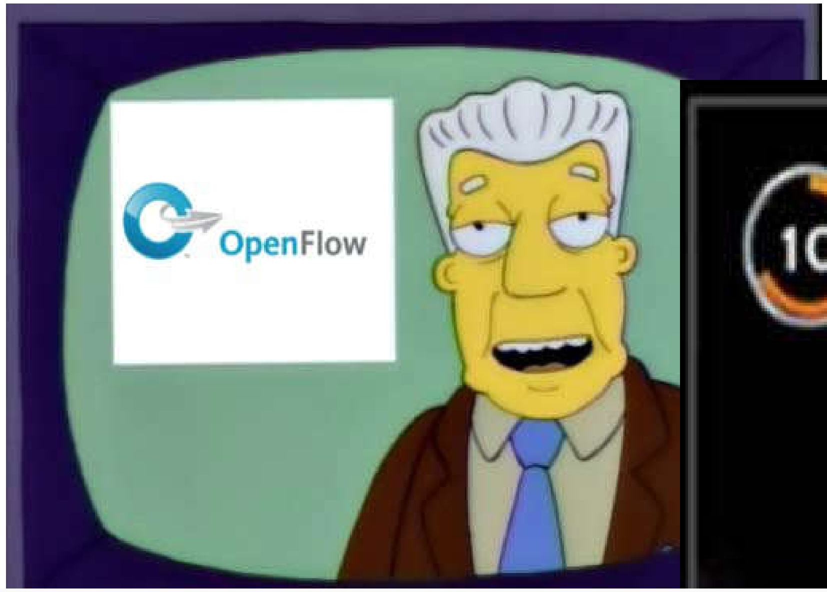
Source: ON.LAB

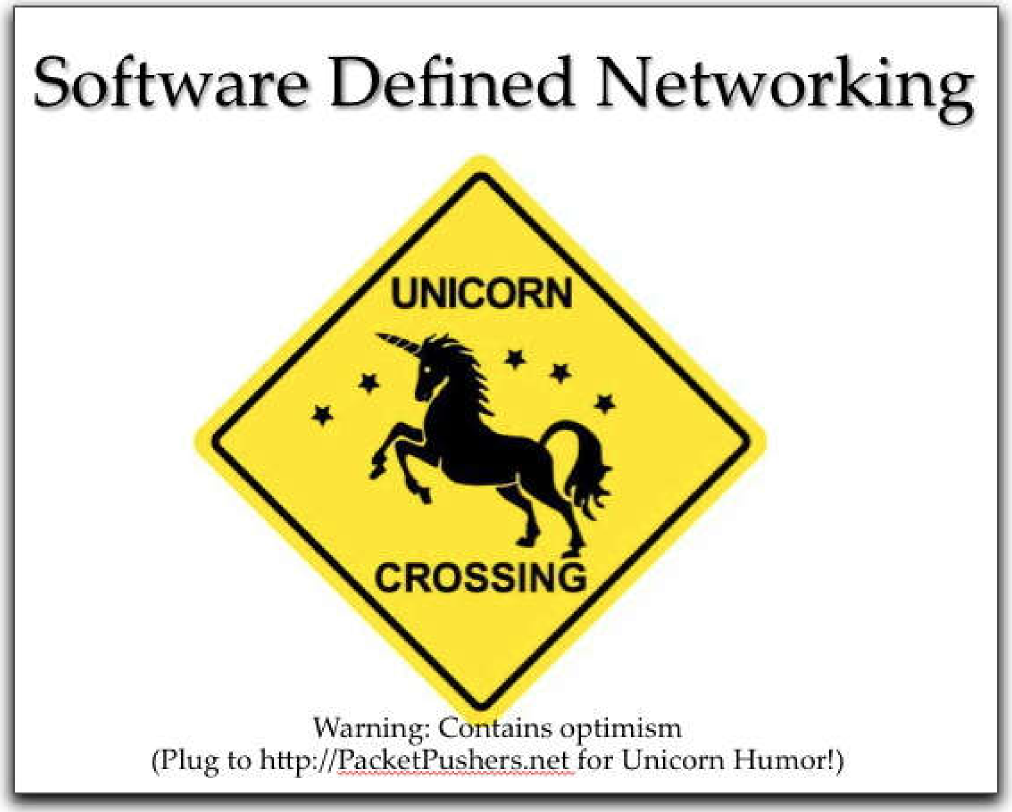
Trend



Source: ON.LAB

SDN to the rescue!





So, What is SDN?

"OpenFlow is SDN, but SDN is not OpenFlow"

(Does not say much about SDN) Networking community

"Don't let humans do machines' work"

(probably right…) Networking Professional

"Let's call SDN whatever we can ship today"

(aka SDN washing) Vendor X

"SDN is the magic buzzword that will bring us VC funding"

(hmmm… N/A, N/C) Startup Y

"SDN is the magic that will get my paper/grant accepted"

(maybe but not at SIGCOMM?) Researcher Z

What is SDN?

In the SDN architecture, the control and data planes are decoupled, network intelligence and state are logically centralized, and the underlying network infrastructure is abstracted from the applications.

Open Networking Foundation white paper

Software Defined Networking (SDN) refactors the relationship between network devices and the software that controls them. Open interfaces to network switches enable more flexible and predictable network control, and they make it easier to extend network function.

HotSDN CFP

SDN definitions

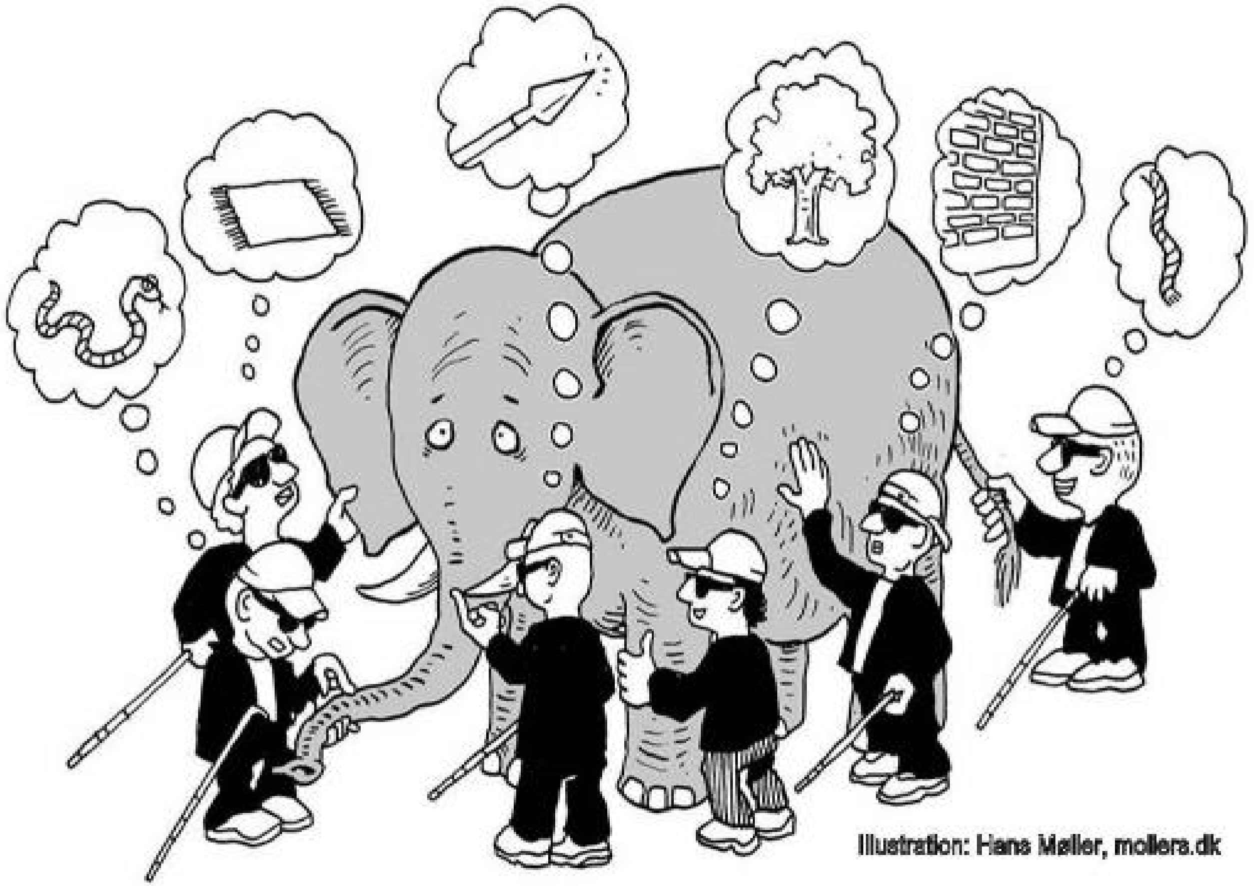
- With the original (OpenFlow) definition, SDN represented a network architecture where the forwarding state is solely managed by a control plane and is decoupled from the data plane.
- The industry, however, has moved on from the *original academic purist view* of SDN to referring *to anything disruptive or fundamentally new* as part of SDN.

At least two definitions for SDN:

1.academic
(purist view : strict decoupling of the data and control plane)

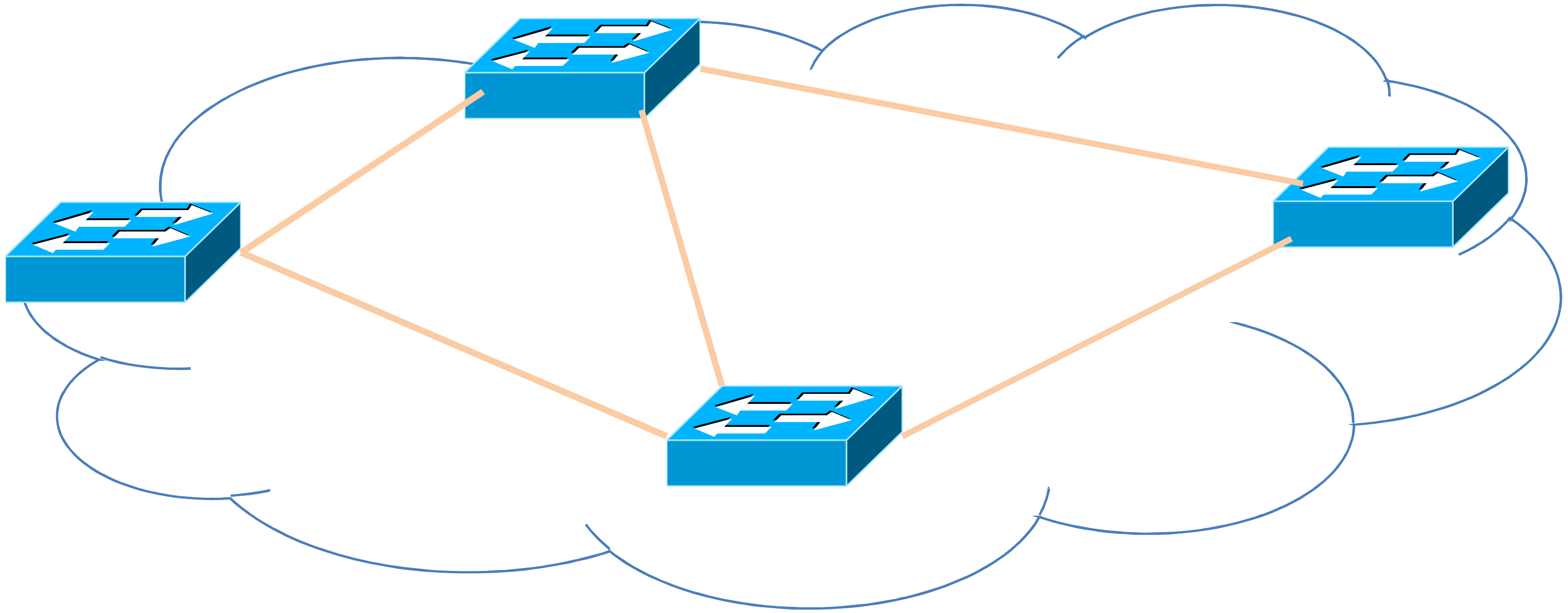
2.industry
(many-fold business-driven views)

SDN :: Evolving Definition



Rethinking the "Division of Labor"
Traditional Computer Networks

Data plane:
Packet streaming

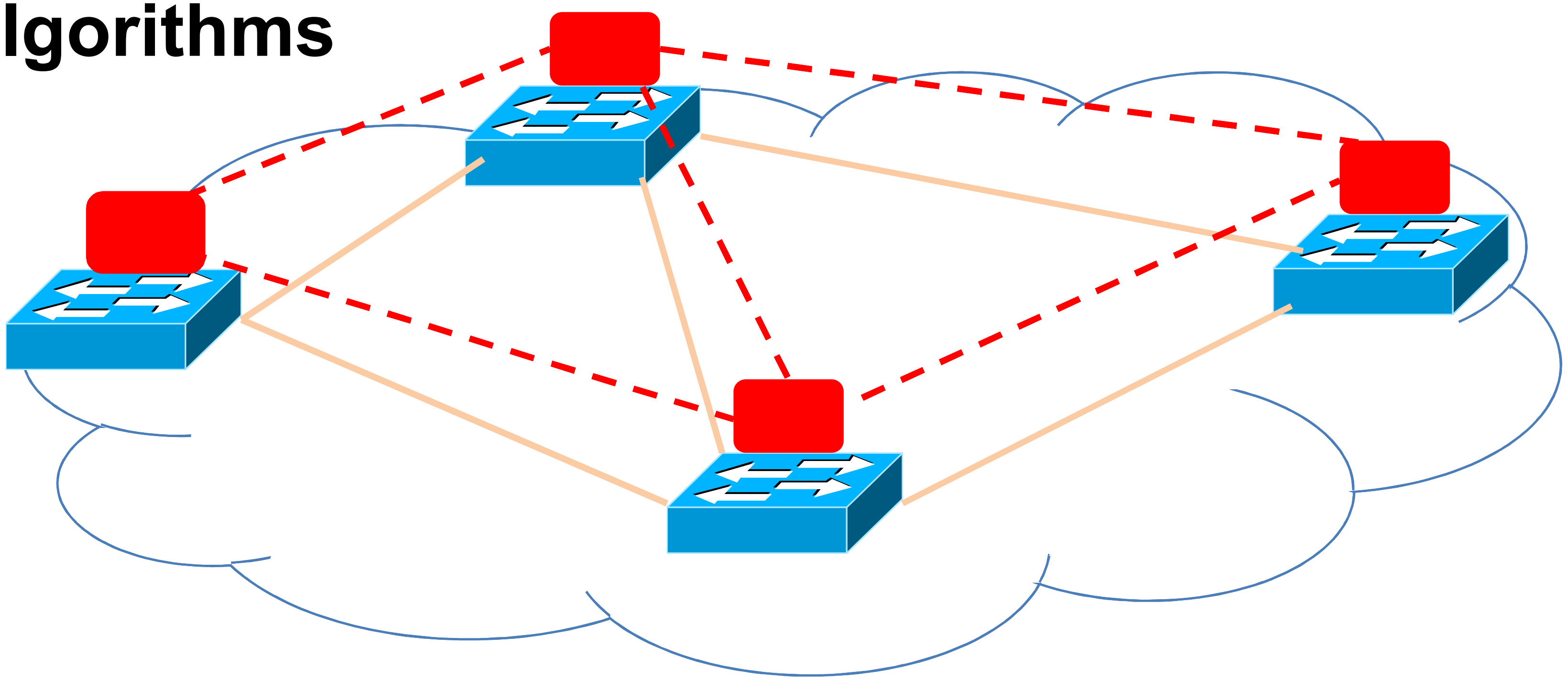


Forward, filter, buffer, mark, rate-limit, and measure packets

Source: Adapted from J. Rexford

Rethinking the "Division of Labor"
Traditional Computer Networks

Control plane:
Distributed algorithms



Track topology changes, compute routes, install forwarding rules

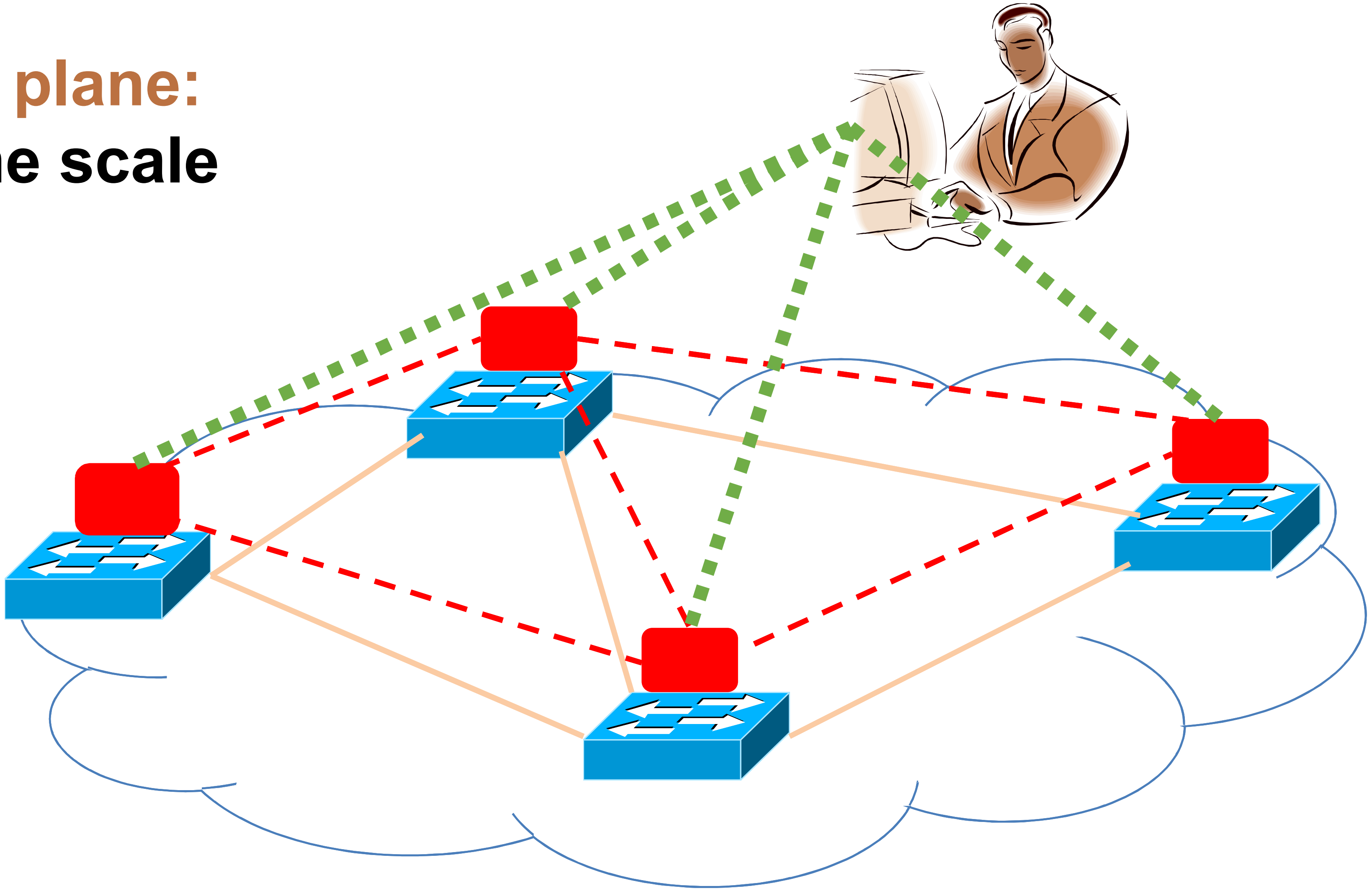
Source: Adapted from J. Rexford

Rethinking the “Division of Labor”

Traditional Computer Networks

Management plane:

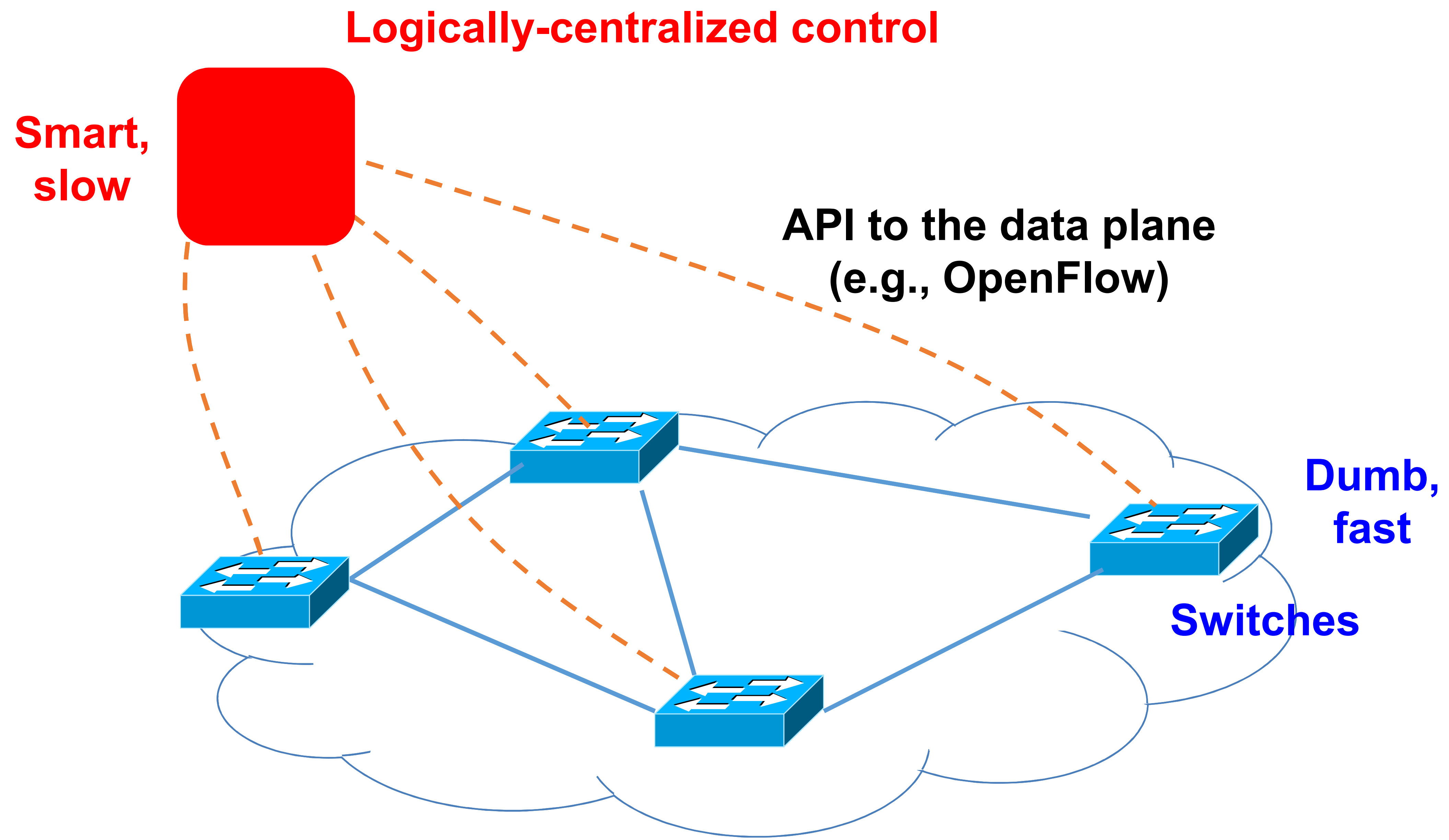
Human time scale



Collect measurements and configure the equipment

Source: Adapted from J. Rexford

Software Defined Networking (SDN)

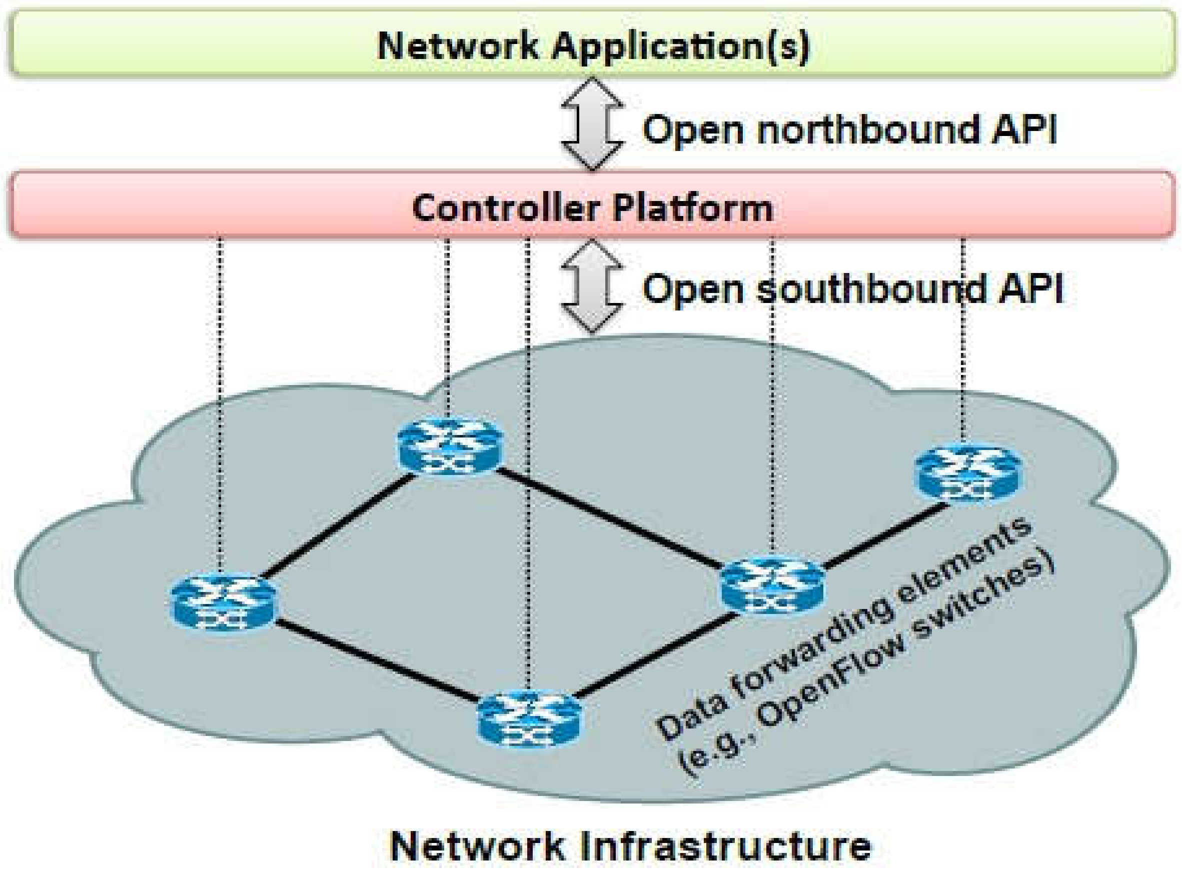


Source: Adapted from J. Rexford

SDN: Definitions, Concepts, and Terminology

SDN refers to software-defined networking architectures where:

- Data- and control planes decoupled from one another.
- Data plane at forwarding devices managed and controlled (remotely) by a “controller”.
- Well-defined programming interface between control- and data planes.
- Applications running on controller manage and control underlying (abstract) data plane

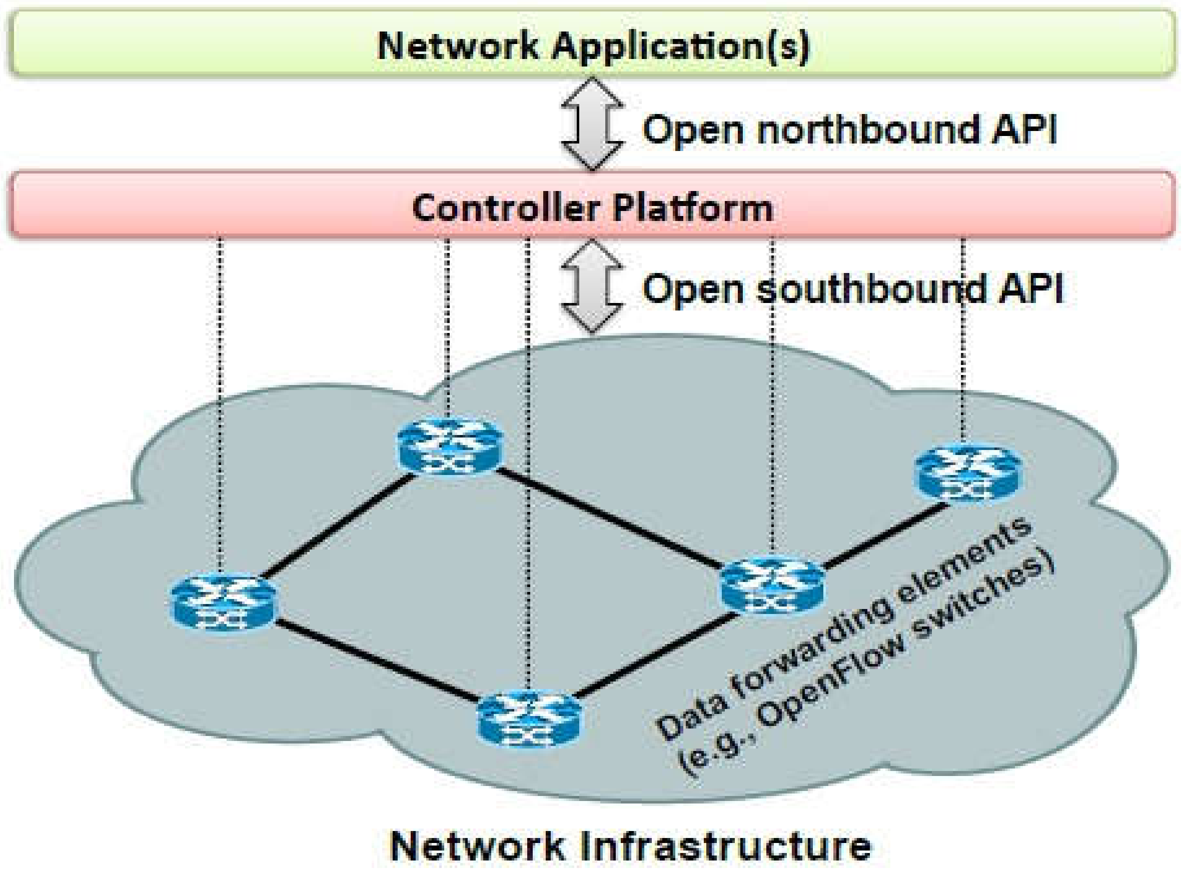


Source:
“Software-Defined Networking: A Comprehensive Survey”,
Kreutz et al., In Proceedings of the IEEE, Vol. 103, Issue 1, Jan. 2015..

SDN: Definitions, Concepts, and Terminology

- **Control plane:** controls the data plane; logically centralized in the "controller" (a.k.a., network operating system).

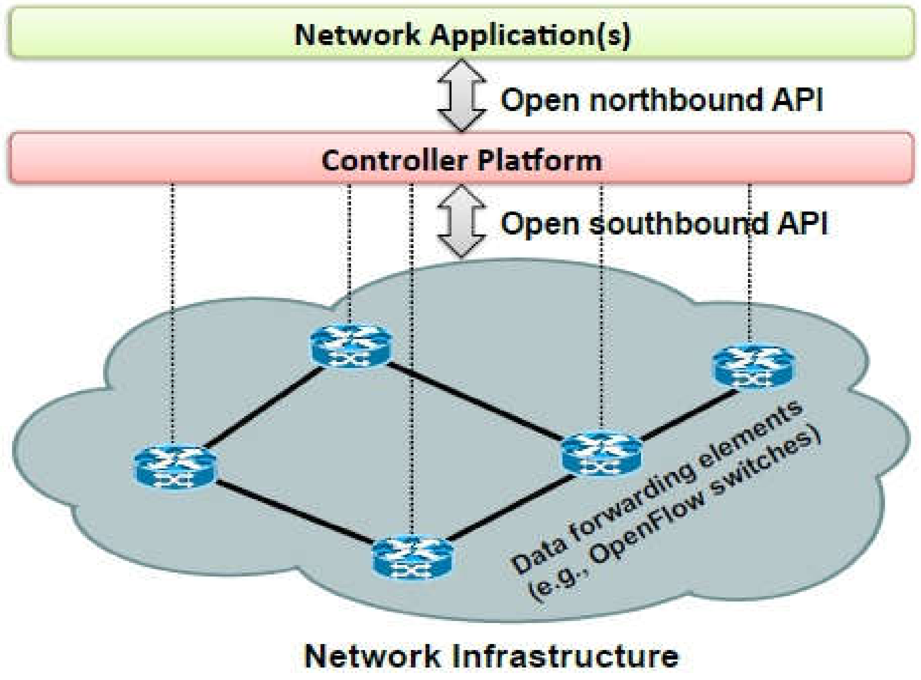
- **Southbound interface:**
  (instruction set to program the data plane
  +
  (protocol btw control- and data planes).
  E.g., OpenFlow, POF, Forces, Netconf



Source:
"Software-Defined Networking: A Comprehensive Survey",
Kreutz et al., In Proceedings of the IEEE, Vol. 103, Issue 1, Jan. 2015..

SDN: Definitions, Concepts, and Terminology

- **Data plane:** network infrastructure consisting of interconnected forwarding devices (a.k.a., forwarding plane).
- **Forwarding devices:** data plane hardware- or software devices responsible for data forwarding.
- **Flow:** sequence of packets between source-destination pair; flow packets receive identical service at forwarding devices.
- **Flow rules:** instruction set that act on incoming packets (e.g., drop, forward to controller, etc)
- **Flow table:** resides on switches and contains rules to handle flow packets.



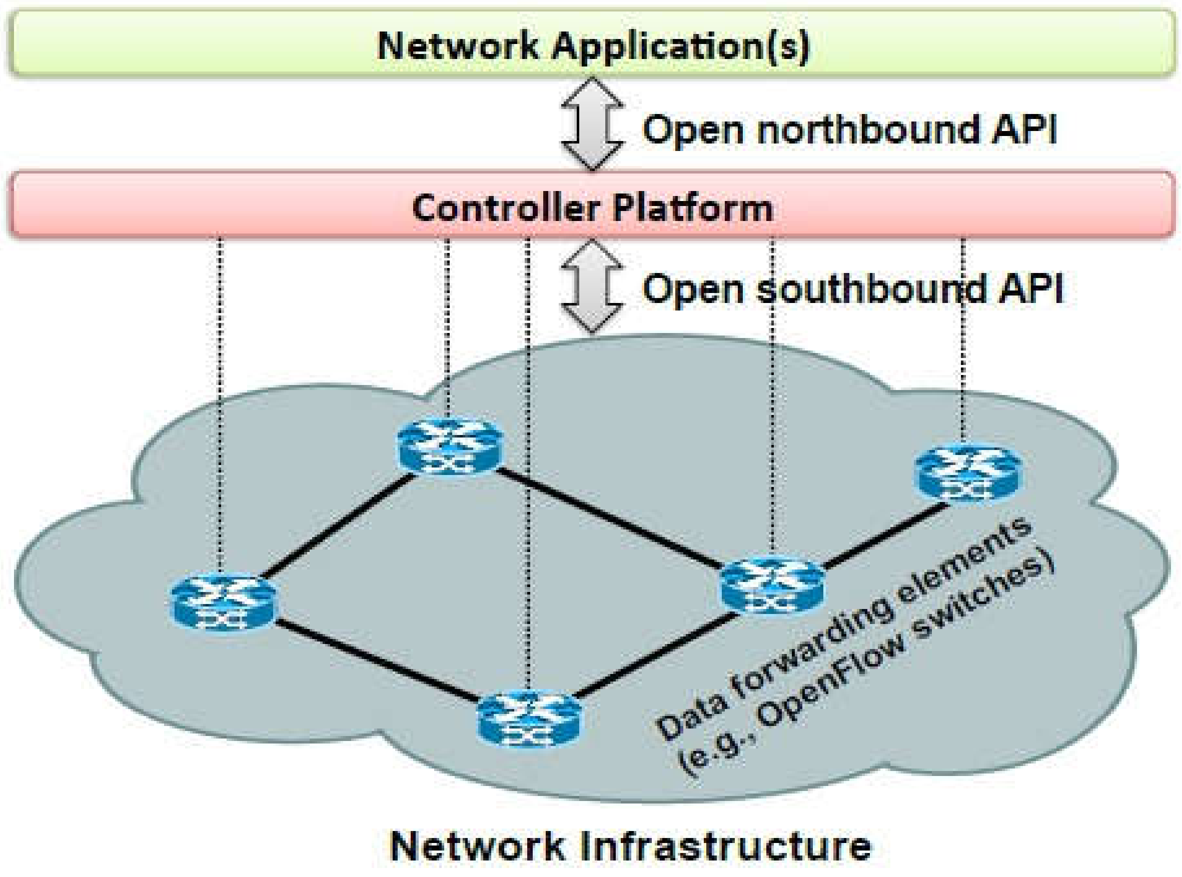
	Switch port	MAC src	MAC dst	Eth type	VLAN ID	IP Src	IP Prot	TCP sport	TCP dport	Action
Switching	*	*	00:1f :..	*	*	*	*	*	*	Port6
Flow switching	Port3	00:20 ..	00:1f ..	0800	Vlan1	1.2.3.4	5.6.7.8	4	17264	Port6
Firewall	*	*	*	*	*	*	*	*	22	Drop
Routing	*	*	*	*	*	*	5.6.7.8	*	*	Port6
VLAN switching	*	*	00:1f ..	*	Vlan1	*	*	*	*	Port6,port7, port8

Source:
"Software-Defined Networking: A Comprehensive Survey",
Kreutz et al., In Proceedings of the IEEE, Vol. 103, Issue 1, Jan. 2015..

SDN: Definitions, Concepts, and Terminology

- **Northbound interface:** API offered by control plane to develop network control- and management applications.

- **Application Layer / Business Applications (Management plane):** functions, e.g., routing, traffic engineering, that use Controller functions / APIs to manage and control network infrastructure.



Source:
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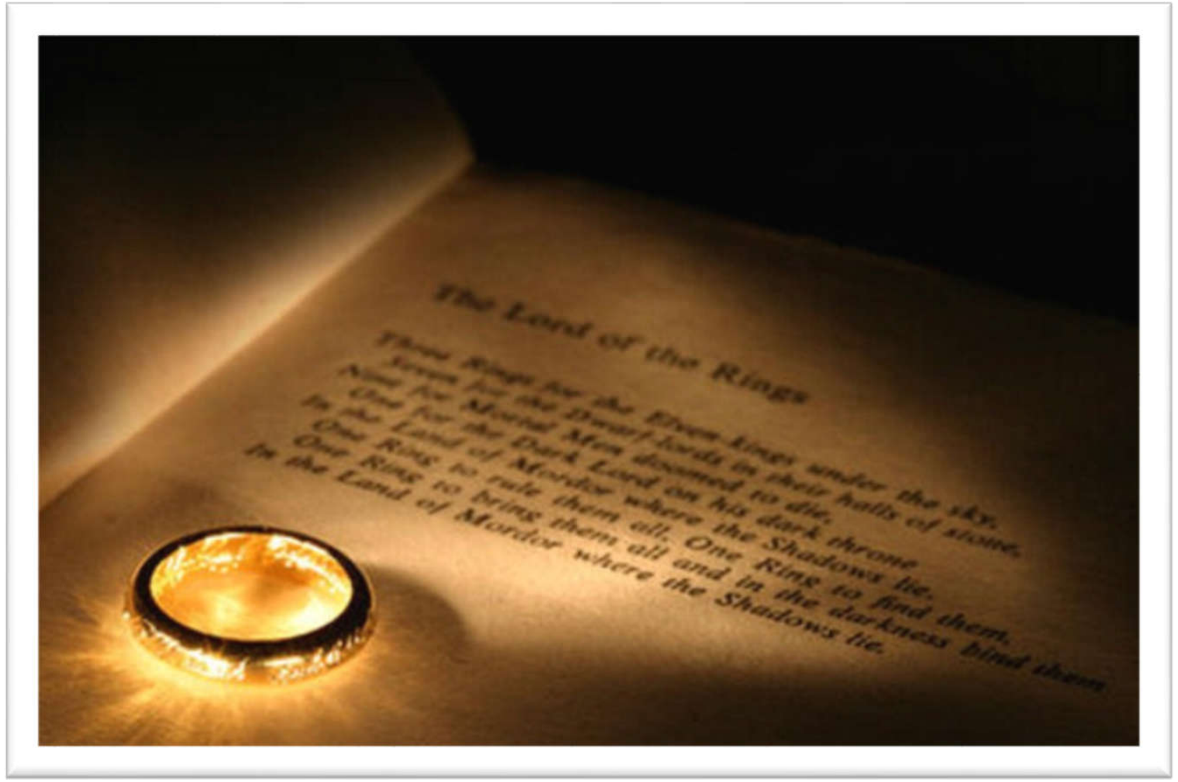
Kreutz et al., In Proceedings of the IEEE, Vol. 103, Issue 1, Jan. 2015..

One SDN controller to rule them all, with
a discovery app to find them,
One SDN controller to tell them all, on
which switchport to bind them.
In the Data Center, where the packets fly.

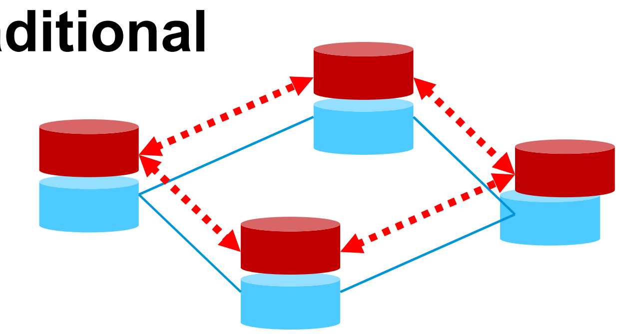


One SDN to rule them all

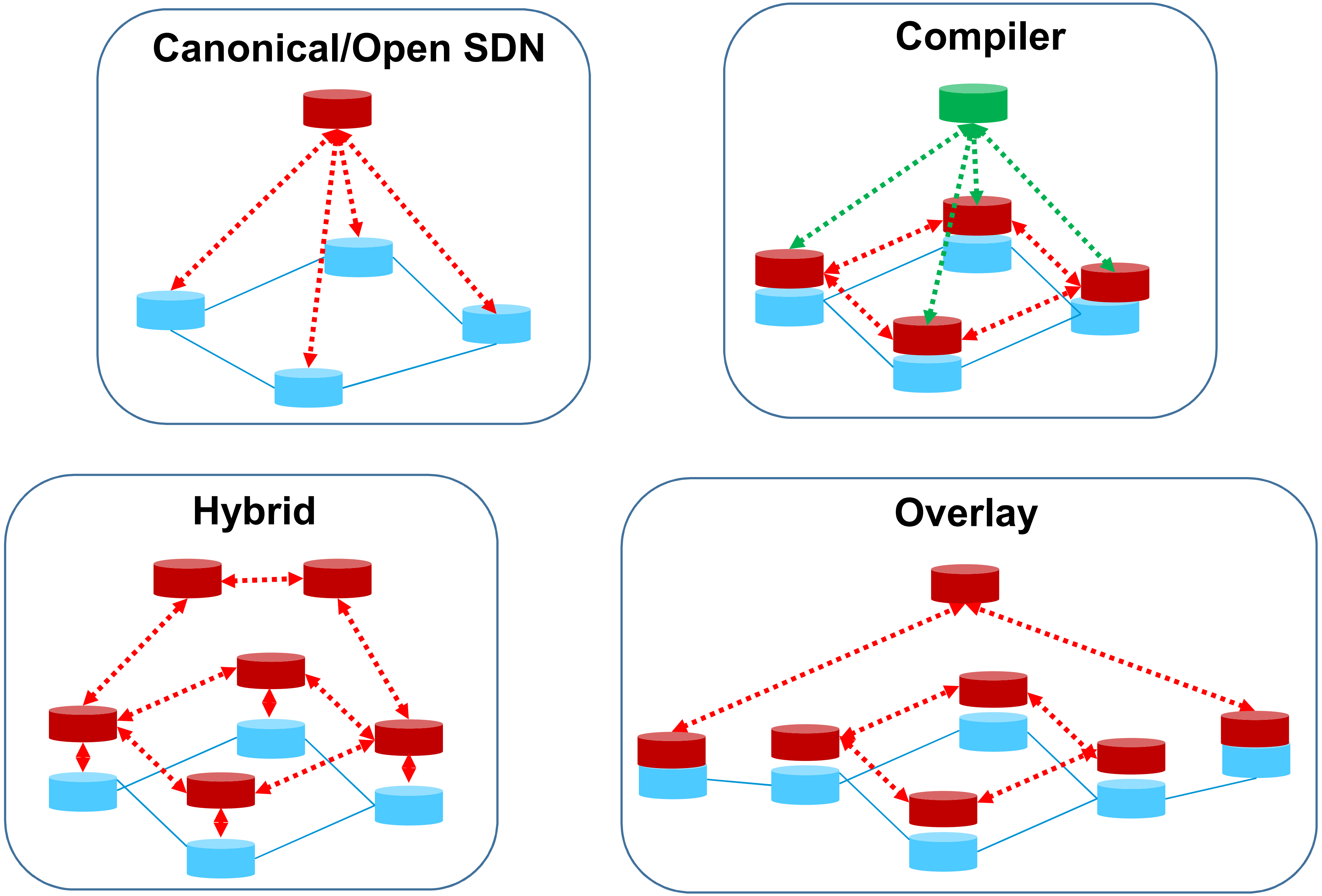
Actually not, different reasonable models and approaches to SDN are being pursued

Source Poem: http://dovernetworks.com/?p=83
Further reading: http://theborgqueen.wordpress.com/2014/03/31/the-legend-of-sdn-one-controller-to-rule-them-all/

Different SDN Models



Control-plane component(s) Data-plane component(s)



SDN asks (at least) three major questions

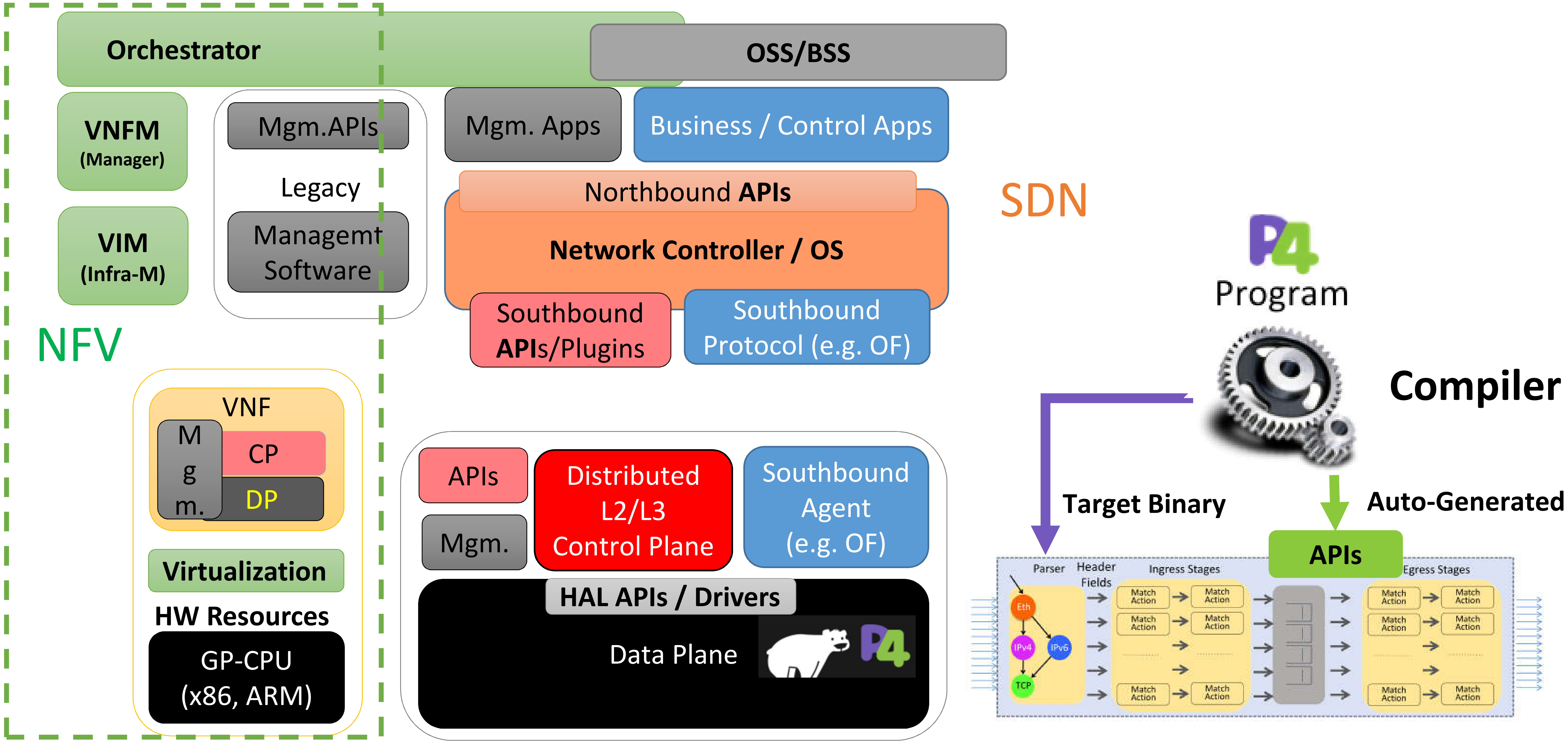
Where the control plane resides
“Distributed vs Centralized” ?

How does the Control Plane talk
to the Data Plane ?

How are Control and
Data Planes programmed ?

Source: Adapted from T. Nadeu, slides-85-sdnrg-5.pptx

Different SDN Models to Program / Refactor the Stack



PAPER PREVIEWS

Tuesday, August 23, 2016

11:00am - 12:40pm Session 1 - SDN & NFV I

Session Chair: Nate Foster *(Cornell University)*

ClickNP: Highly Flexible and High Performance Network Processing with Reconfigurable Hardware

Bojie Li *(USTC / Microsoft Research)*, Kun Tan *(Microsoft Research)*, Layong *(Larry)* Luo *(Microsoft)*, Yanqing Peng *(SJTU / Microsoft Research)*, Renqian Luo *(USTC / Microsoft Research)*, Ningyi Xu *(Microsoft Research)*, Yongqiang Xiong *(Microsoft Research)*, Peng Cheng *(Microsoft Research)*, Enhong Chen *(USTC)*

Packet Transactions: High-Level Programming for Line-Rate Switches

Anirudh Sivaraman *(MIT CSAIL)*, Alvin Cheung *(University of Washington, Seattle)*, Mihai Budiu *(VMWare Research)*, Changhoon Kim *(Barefoot Networks)*, Mohammad Alizadeh *(MIT CSAIL)*, Hari Balakrishnan *(MIT CSAIL)*, George Varghese *(Microsoft Research)*, Nick McKeown *(Stanford University)*, Steve Licking *(Barefoot Networks)*

SNAP: Stateful Network-Wide Abstractions for Packet Processing

Mina Tahmasbi Arashloo *(Princeton University)*, Yaron Koral *(Princeton University)*, Michael Greenberg *(Pomona College)*, Jennifer Rexford *(Princeton University)*, David Walker *(Princeton University)*

Programmable Packet Scheduling at Line Rate

Anirudh Sivaraman *(MIT CSAIL)*, Suvinay Subramanian *(MIT CSAIL)*, Mohammad Alizadeh *(MIT CSAIL)*, Sharad Chole *(Cisco Systems)*, Shang-Tse Chuang *(Cisco Systems)*, Anurag Agrawal *(Barefoot Networks)*, Hari Balakrishnan *(MIT CSAIL)*, Tom Edsall *(Cisco Systems)*, Sachin Katti *(Stanford University)*, Nick McKeown *(Stanford University)*

Tuesday, August 23, 2016 | 11:00am - 12:40pm Session 1 - SDN & NFV I

ClickNP: Highly Flexible and High Performance Network Processing with Reconfigurable Hardware

Bojie Li[§†] Kun Tan[†] Layong (Larry) Luo[‡] Yanqing Peng[•†] Renqian Luo[§†]
Ningyi Xu[†] Yongqiang Xiong[†] Peng Cheng[†] Enhong Chen[§]
[†]Microsoft Research [§]USTC [‡]Microsoft [•]SJTU

#programmability

#performance

#openness

Contributions

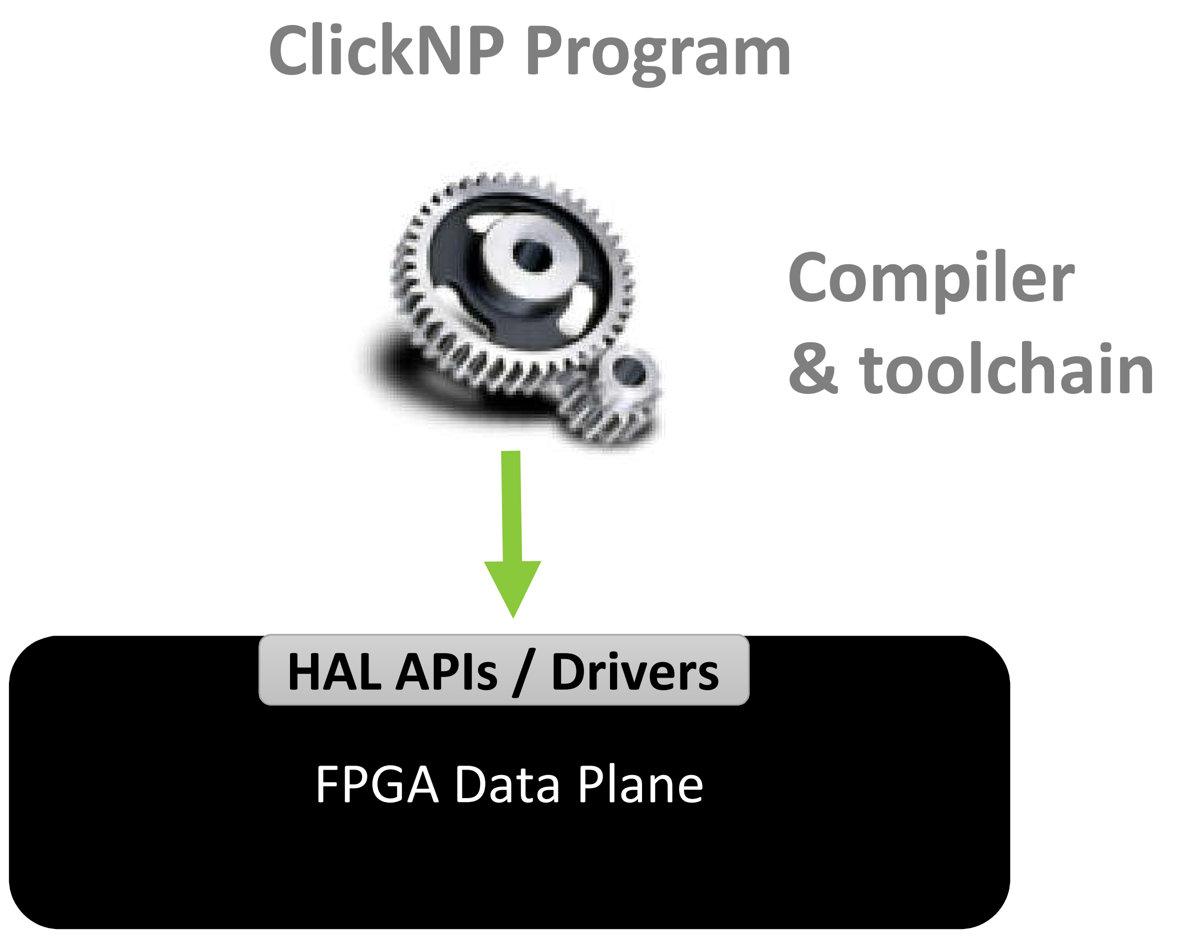
- Accelerating NFs with programmable HW (FPGA)
- ClickNP: C-like DSL & toolchain
- 40 Gbps line rate
- Five demonstration NFs: (1) traffic capture and generator, (2) a firewall, (3) IPSec gateway, (4) Layer-4 load balancer, (5) pFabric scheduler

Topic Challenges

- High-performance programamble DP implementation
- Programmer-friendly high-level DSL for networking

How are Control & Data Planes programmed ?

Scope



Tuesday, August 23, 2016 | 11:00am - 12:40pm Session 1 - SDN & NFV I

Packet Transactions: High-Level Programming for Line-Rate Switches

Anirudh Sivaraman[¶], Alvin Cheung[‡], Mihai Budiu[§*], Changhoon Kim[†], Mohammad Alizadeh[¶], Hari Balakrishnan[¶], George Varghese[++], Nick McKeown[+], Steve Licking[†]
[¶]MIT CSAIL, [‡]University of Washington, [§]VMWare Research, [†]Barefoot Networks, [++]Microsoft Research, [+]Stanford University

#programmability

#performance

#openness

Scope

Contributions

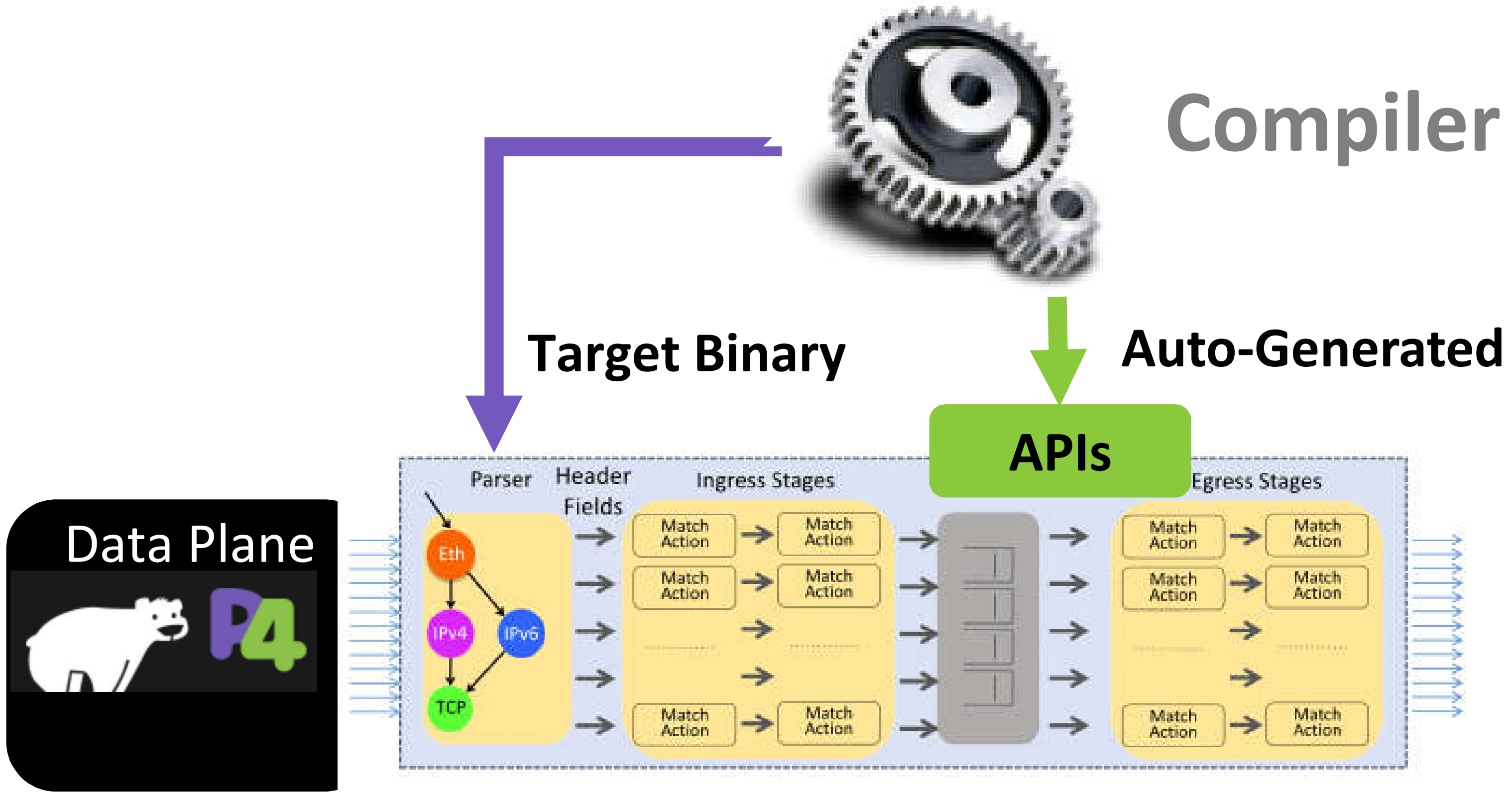
- Program data-plane algorithms in a high-level language and compile them
- Domino, a C-like imperative language + compiler
- Banzai machine model for DP

Topic Challenges

- High-performance programamble DP implementation
- DP algorithms create and modify algorithmic state
- SW algorithms on programmable line-rate HW

How are Control & Data Planes programmed ?

Domino program



Statefull processing units, called *atoms*

Tuesday, August 23, 2016 | 11:00am - 12:40pm Session 1 - SDN & NFV I

Programmable Packet Scheduling at Line Rate

Anirudh Sivaraman*, Suvinay Subramanian*, Mohammad Alizadeh*, Sharad Chole‡, Shang-Tse Chuang‡, Anurag Agrawal†, Hari Balakrishnan*, Tom Edsall‡, Sachin Katti+, Nick McKeown+
*MIT CSAIL, †Barefoot Networks, ‡Cisco Systems, +Stanford University

#programmability

#performance

#openness

Contributions

- Programmable scheduler using a single abstraction: the push-in first-out queue (PIFO)
- HW design for a 64-port 10 Gbit/s switch
- Verilog code available at http://web:mit:edu/pifo/

Topic Challenges

- High-performance programamble DP implementation
- Scheduling algorithms—potentially algorithms that are unknown today—to be programmed into a switch without requiring hardware redesign
- How will programmable scheduling be used in practice?

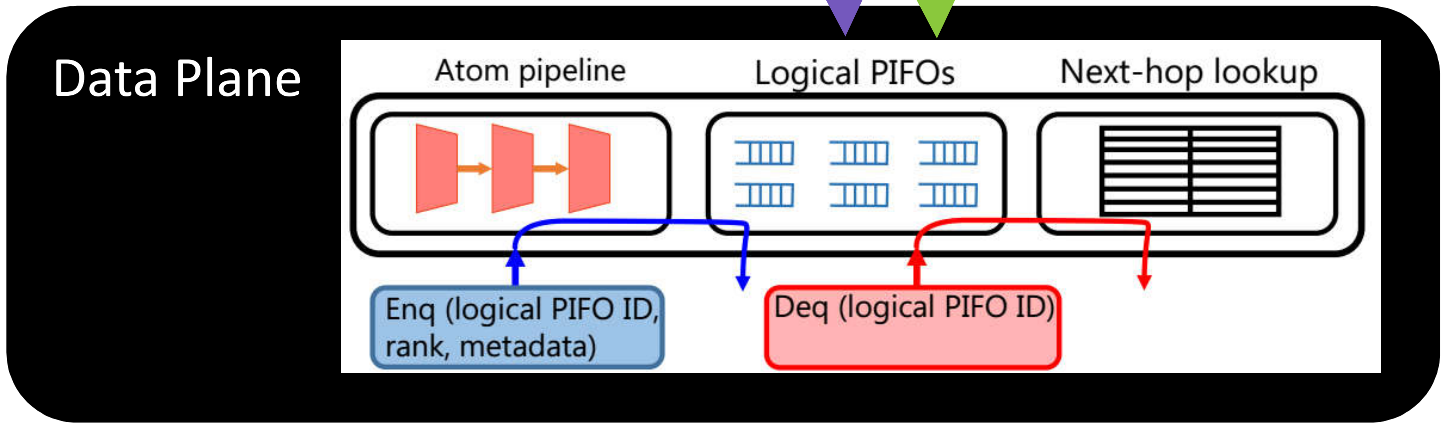
How are Control & Data Planes programmed ?

Domino program

Compiler

Target Binary

Auto-Generated APIs



Statefull processing units, called *atoms*

SNAP: Stateful Network-Wide Abstractions for Packet Processing

Mina Tahmasbi Arashloo[1], Yaron Koral[1], Michael Greenberg[2], Jennifer Rexford[1], and David Walker[1]

[1]Princeton University , [2]Pomona College

#programmability

#visibility

#automation

#virtualization

Contributions

- Programming language with persistent global arrays, transactions, one-big-switch illusion
- Compiler that decides where to place state, how to route traffic (through MILP)
- 20 Example applications

Topic Challenges

- Managing distributed state
- Consistency of state
- Efficient use of routes, switch resources

Where does the control plane reside?

How are Control & Data Planes programmed ?

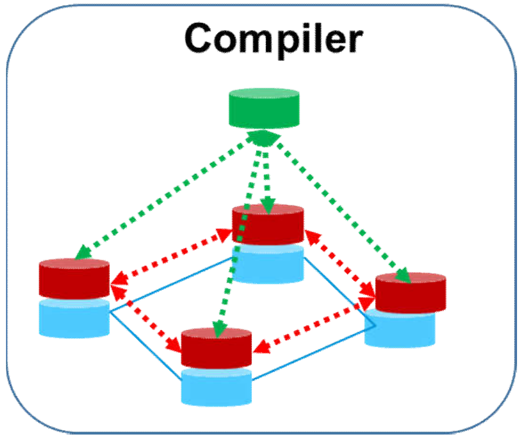
Scope

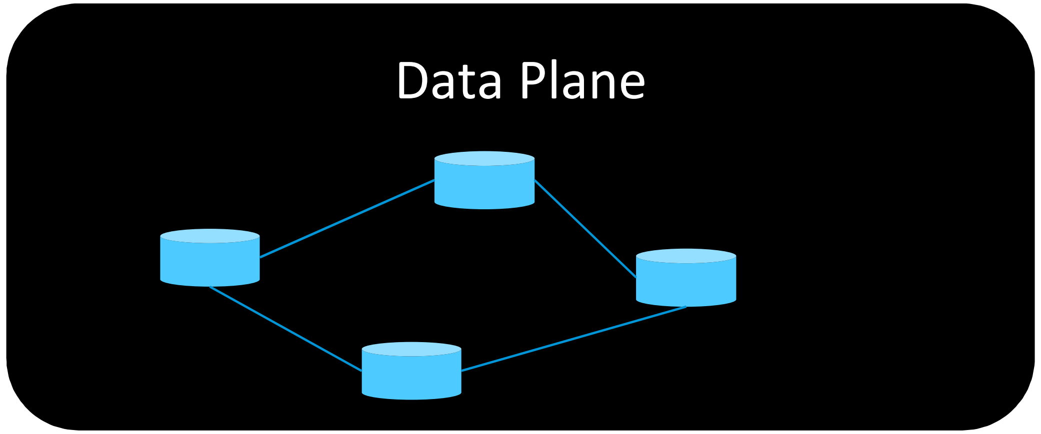
SNAP program

Stateful
Distributed state
One Big Switch abstraction

Compiler

Distributing state
Routing





Thursday, August 25, 2016

3:45pm - 5:00pm Session 11 - SDN & NFV II

Session Chair: Aditya Akella *(University of Wisconsin Madison)*

OpenBox: A Software-Defined Framework for Developing, Deploying, and Managing Network Functions
Anat Bremler-Barr *(The Interdisciplinary Center, Herzliya)*, Yotam Harchol *(The Hebrew University of Jerusalem)*, David Hay *(The Hebrew University of Jerusalem)*

PISCES: A Programmable, Protocol-Independent Software Switch
Muhammad Shahbaz *(Princeton University)*, Sean Choi *(Stanford University)*, Ben Pfaff *(VMware)*, Changhoon Kim *(Barefoot Networks)*, Nick Feamster *(Princeton University)*, Nick McKeown *(Stanford University)*, Jennifer Rexford *(Princeton University)*

Dataplane Specialization for High-performance OpenFlow Software Switching
László Molnár *(Ericsson Research, Hungary)*, Gergely Pongrácz *(Ericsson Research, Hungary)*, Gábor Enyedi *(Ericsson Research, Hungary)*, Zoltán Kis *(Ericsson Research, Hungary)*, Levente Csikor *(Budapest University of Technology and Economics)*, Ferenc Juhász *(Budapest University of Technology and Economics)*, Attila Kőrösi *(Budapest University of Technology and Economics)*, Gábor Rétvári *(Budapest University of Technology and Economics)*

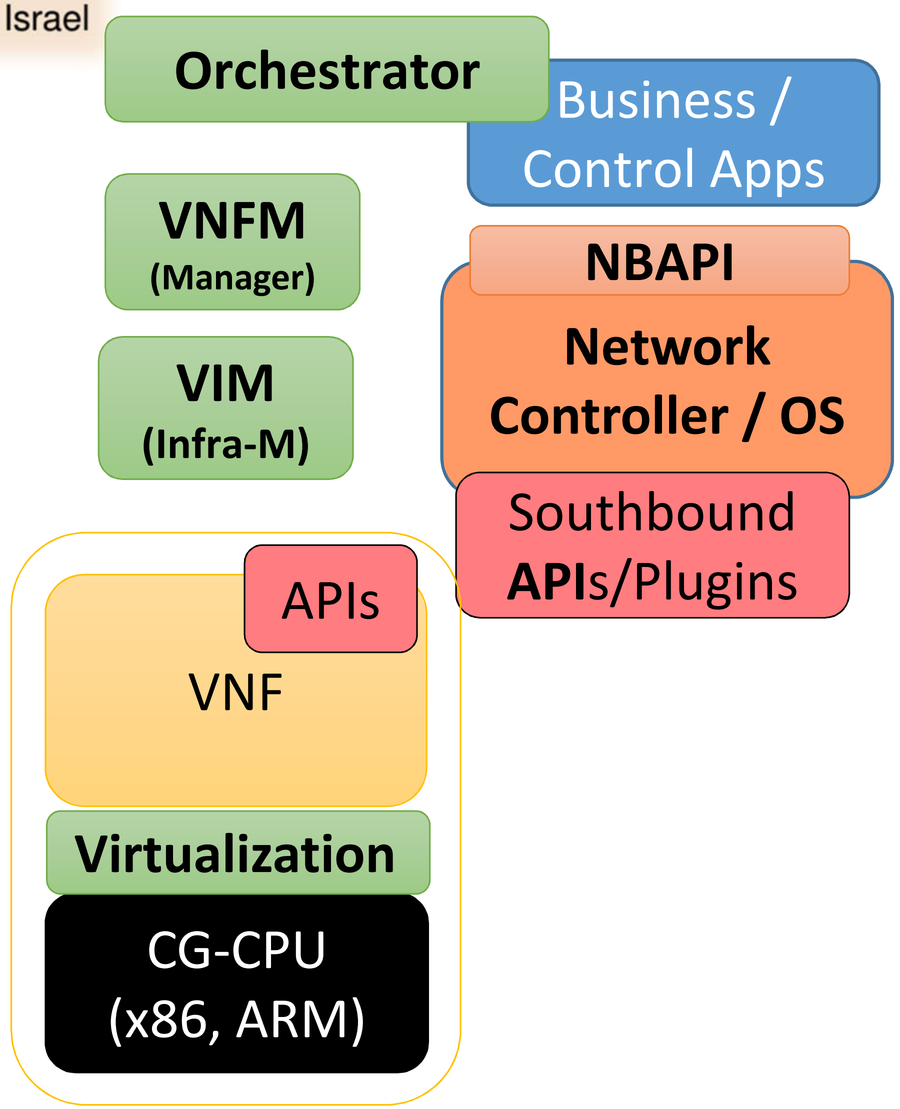
OpenBox: A Software-Defined Framework for Developing, Deploying, and Managing Network Functions

Anat Bremler-Barr * bremler@idc.ac.il
Yotam Harchol † yotamhc@cs.huji.ac.il
David Hay† dhay@cs.huji.ac.il

* School of Computer Science, The Interdisciplinary Center, Herzliya, Israel
† School of Computer Science and Engineering, The Hebrew University, Jerusalem, Israel

#virtualization
#orchestration
#performance
#service_integration
#automation
#openness

Scope

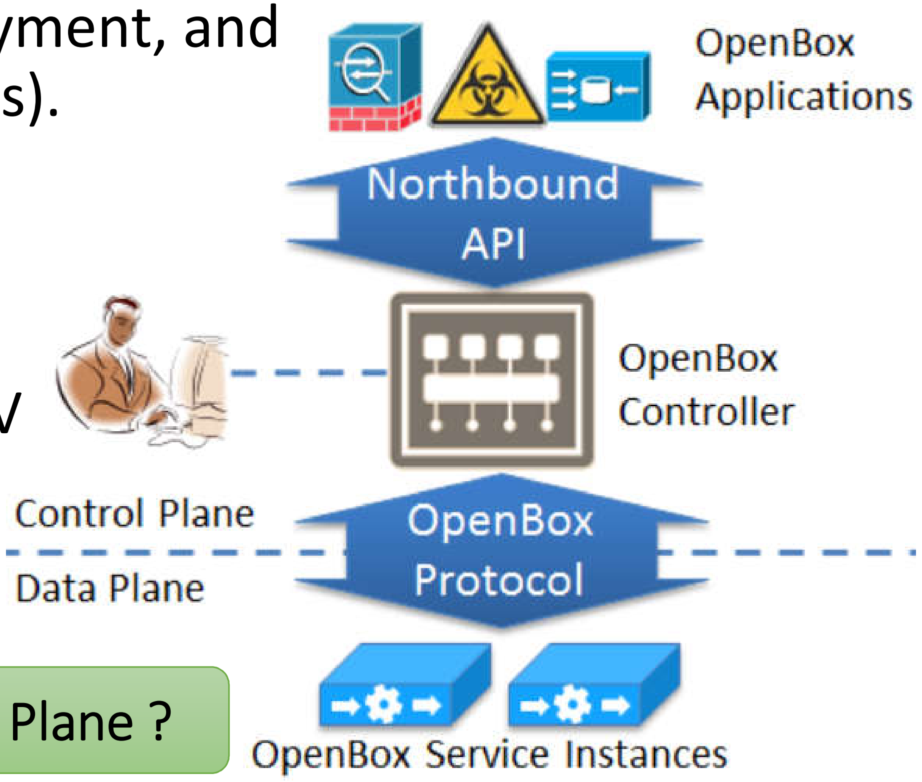


Contributions

- Framework
  for network-wide development, deployment, and management of network functions (NFs).
- OpenBox Protocol & Controller

Topic Challenges

- Flexibility/programmability of SDN/NFV
- Management & DP Performance of Service Function Chains



How does the Control Plane talk to the Data Plane ?

How are Control & Data Planes programmed ?

Thursday, August 25, 2016 | 3:45pm - 5:00pm Session 11 - SDN & NFV II

PISCES: A Programmable, Protocol-Independent Software Switch

Muhammad Shahbaz*, Sean Choi°, Ben Pfaff†, Changhoon Kim‡, Nick Feamster*, Nick McKeown°, Jennifer Rexford*

*Princeton University °Stanford University †VMware, Inc ‡Barefoot Networks, Inc

http://pisces.cs.princeton.edu

#programmable

#performance

#openness

Contributions

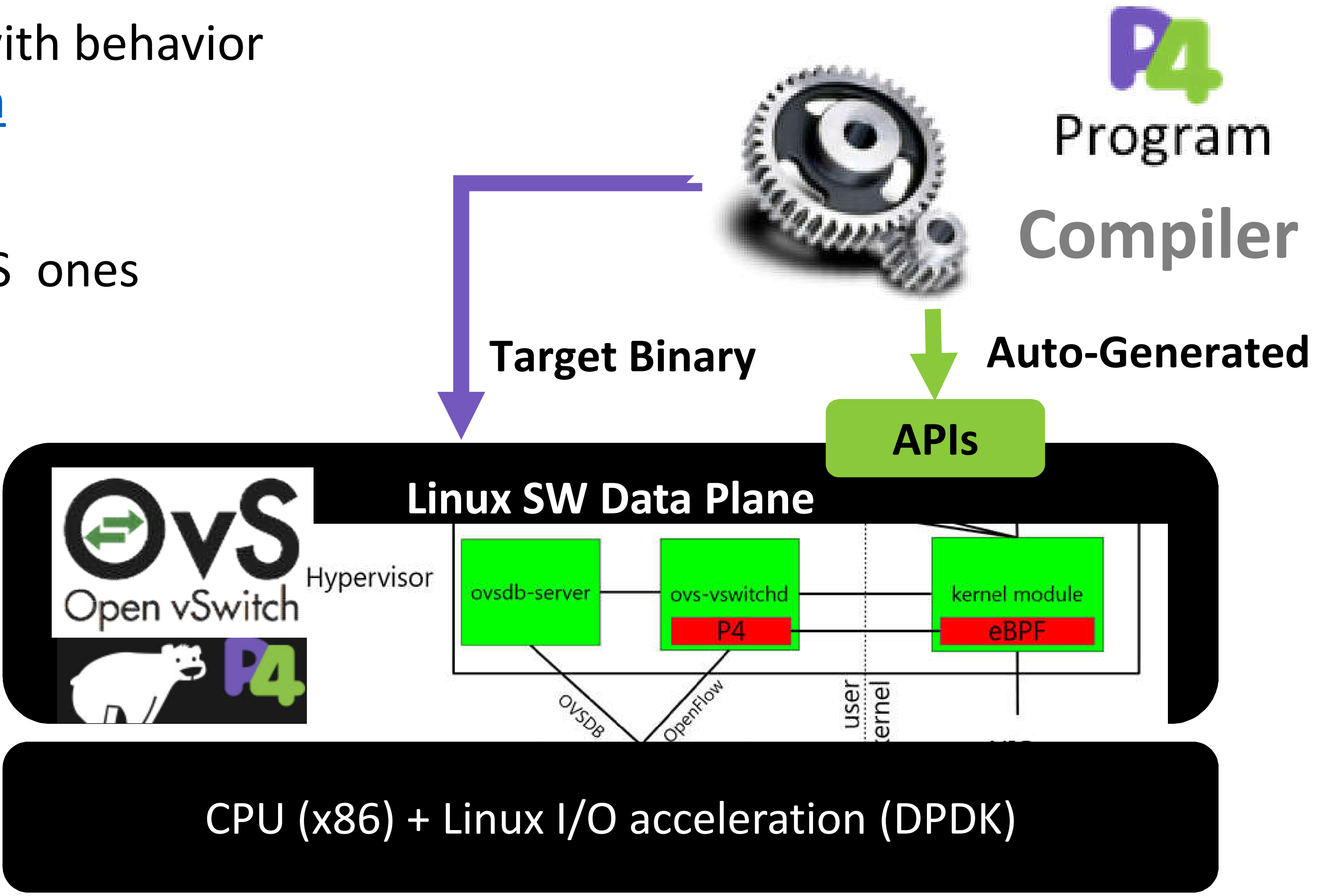
- Software switch derived from Open vSwitch (OVS) with behavior customized using P4: https://github.com/P4-vSwitch
- Compiler to optimize forwarding performance
- Programs are about 40x shorter than equivalent OVS ones

Topic Challenges

- High-performance SW-based DP implementation
- Flexible hypervisor switches ("hard-wired" today)

How are Control & Data Planes programmed ?

Scope



Thursday, August 25, 2016 3:45pm - 5:00pm Session 11 - SDN & NFV II

Dataplane Specialization for High-performance OpenFlow Software Switching

László Molnár*, Gergely Pongrácz*, Gábor Enyedi*, Zoltán Lajos Kis*, Levente Csikor†, Ferenc Juhász*,†, Attila Kőrösi‡, Gábor Rétvári†,‡
*TrafficLab, Ericsson Research
†Department of Telecommunications and Media Informatics, BME
‡MTA-BME Information Systems Research Group

#programmable

#performance

#openness

Contributions

- ESWITCH switch architecture using on-the-fly template-based to compile OpenFlow pipeline into efficient machine code
- A case against flow caching and general purpose switch fast paths

→ dataplane specialized with respect to the workload

- 100+ Gbps on a single Intel blade and 100Ks flow entries, while supporting fast updates

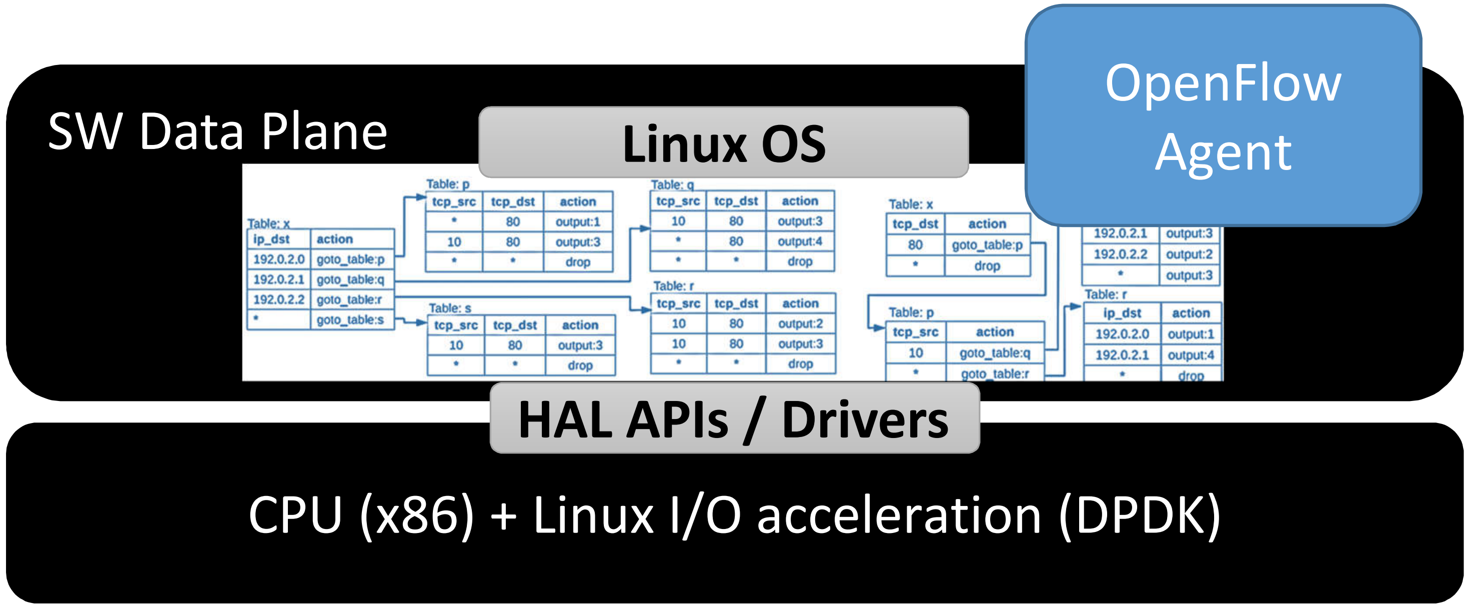
Topic Challenges

- High-performance SW-based OpenFlow/DP implementation

How are Control & Data Planes programmed ?

Scope

SBI Protocol (OpenFlow)



Tuesday, August 23, 2016

4:15pm - 5:30pm Session 3 - Monitoring and Diagnostics

Session Chair: Jeff Mogul *(Google)*

One Sketch to Rule Them All: Rethinking Network Flow Monitoring with UnivMon

Zaoxing Liu *(Johns Hopkins University)*, Antonis Manousis *(Carnegie Mellon University)*, Gregory Vorsanger *(Johns Hopkins University)*, Vyas Sekar *(Carnegie Mellon University)*, Vladimir Braverman *(Johns Hopkins University)*

Trumpet: Timely and Precise Triggers in Data Centers

Masoud Moshref *(University of Southern California)*, Minlan Yu *(University of Southern California)*, Ramesh Govindan *(University of Southern California)*, Amin Vahdat *(Google)*

The Good, the Bad, and the Differences: Better Network Diagnostics with Differential Provenance

Ang Chen *(University of Pennsylvania)*, Yang Wu *(University of Pennsylvania)*, Andreas Haeberlen *(University of Pennsylvania)*, Wenchao Zhou *(Georgetown University)*, Boon Thau Loo *(University of Pennsylvania)*

One Sketch to Rule Them All: Rethinking Network Flow Monitoring with UnivMon

#programmability

#visbility

Zaoxing Liu[†], Antonis Manousis[*], Gregory Vorsanger[†], Vyas Sekar[*], Vladimir Braverman[†]
[†] Johns Hopkins University [*] Carnegie Mellon University

Contributions

- Universal Streaming implementation using P4
  - Heavy hitters on successive sampled substreams
- One-big-switch abstraction for monitoring sketches
- Comparable accuracy to custom sketches

Scope

Monitoring with limited resources

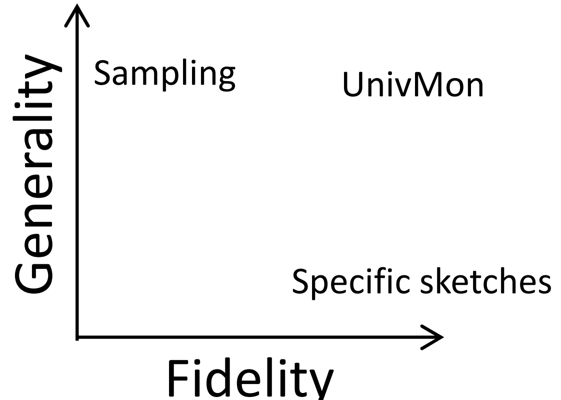
Sketches/Streaming algorithms:

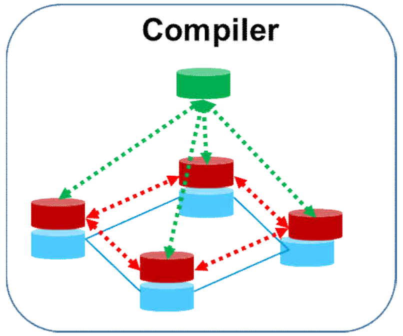
Single or constant passes over data, sublinear space, approximate given statistical measure (mean,median, moments,..)

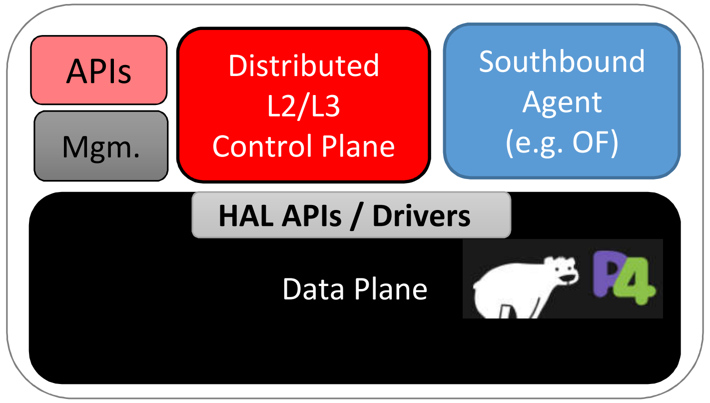
Seminal paper AMS paper (ref [9])

Topic Challenges

- Several algorithm and sketches exist for specific problems
  - Data structures and algorithms specific to desired metric
- Solution that is both general and accurate is an open problem







Tuesday, August 23, 2016 — 4:15pm - 5:30pm Session 3 - Monitoring and Diagnostics

The Good, the Bad, and the Differences: Better Network Diagnostics with Differential Provenance

Ang Chen, University of Pennsylvania
Yang Wu, University of Pennsylvania
Andreas Haeberlen, University of Pennsylvania
Wenchao Zhou, Georgetown University
Boon Thau Loo, University of Pennsylvania

#programmability

#visbility

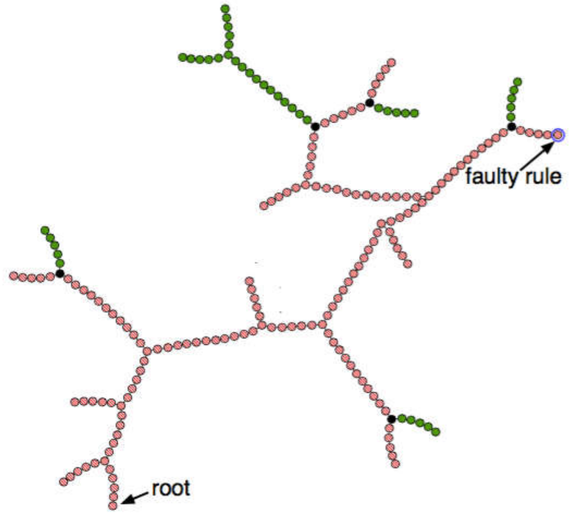
#performance

Contributions

- Finding root causes by differential provenance
  - Given a reference (good) provenance tree, and a bad one, find the events you have to change in the bad one to make it good

Topic Challenges

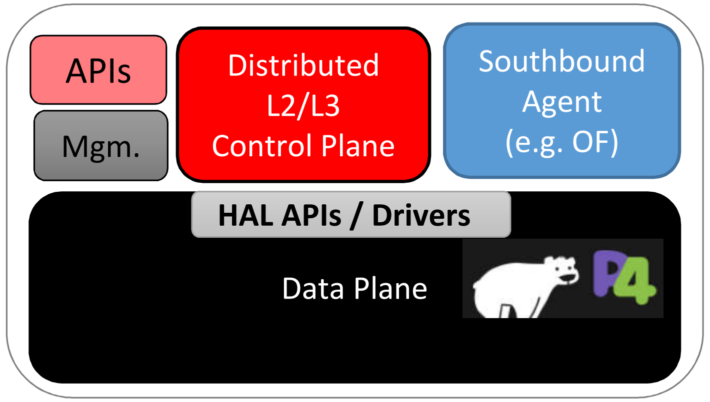
- Provenance produces *sufficient*, but extensive information to diagnose root causes



Scope

Diagnostics of networked systems based on provenance

SDNs one use case in which programmability helps with recording of provenance and replay of events



Trumpet: Timely and Precise Triggers in Data Centers

Masoud Moshref (USC) Minlan Yu (USC) Ramesh Govindan (USC)
Amin Vahdat (Google, inc.)

#programmability

#visbility

Scope

- Control loop for monitoring and acting on the network
  - Programmability enables software control loop (not human timescale)
- Datacenter *active* monitoring
  - Faults detection, network planning, traffic engineering, performance diagnosis
- Goals:

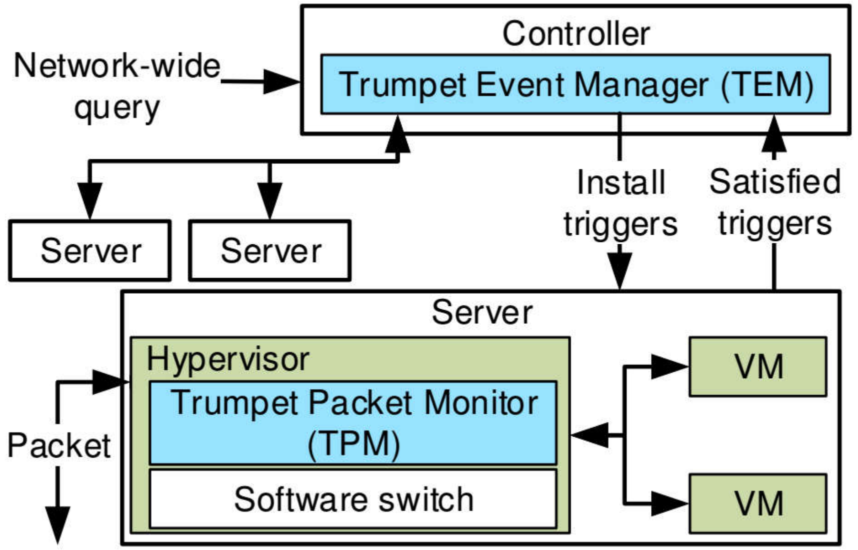
Network-wide predicates over every packet with µs reaction time

Contributions

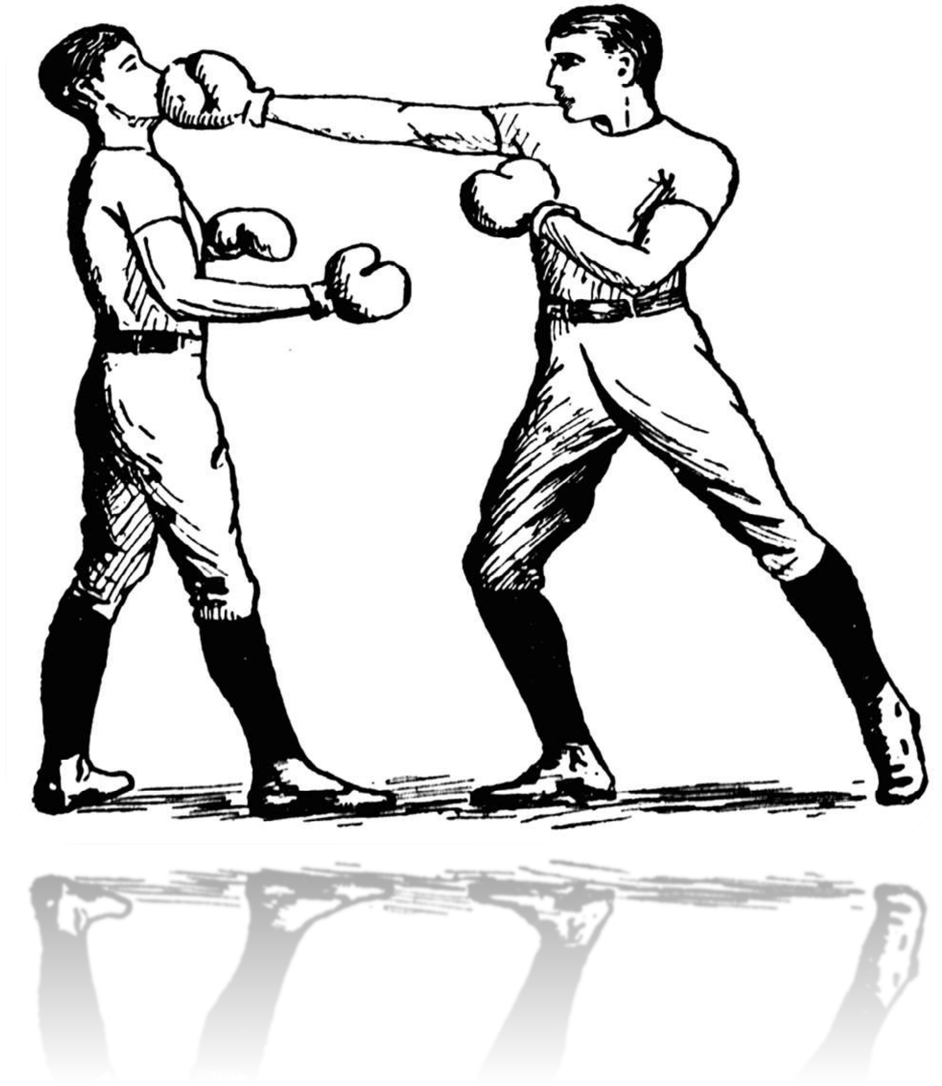
- Language for specifying network-wide predicates
- Leverage end-host CPU resources to achieve the goals
  - Many useful optimizations for processing

Topic Challenges

- Scale
  - Volume of traffic
  - # of events
  - # of endpoint
  - 70ns/packet (64b @ 10G)



SDN/NFV: The Frontier of Networking



Existing

- CLIs
- Closed Source
- Vendor Lead
- Classic Network Appliances

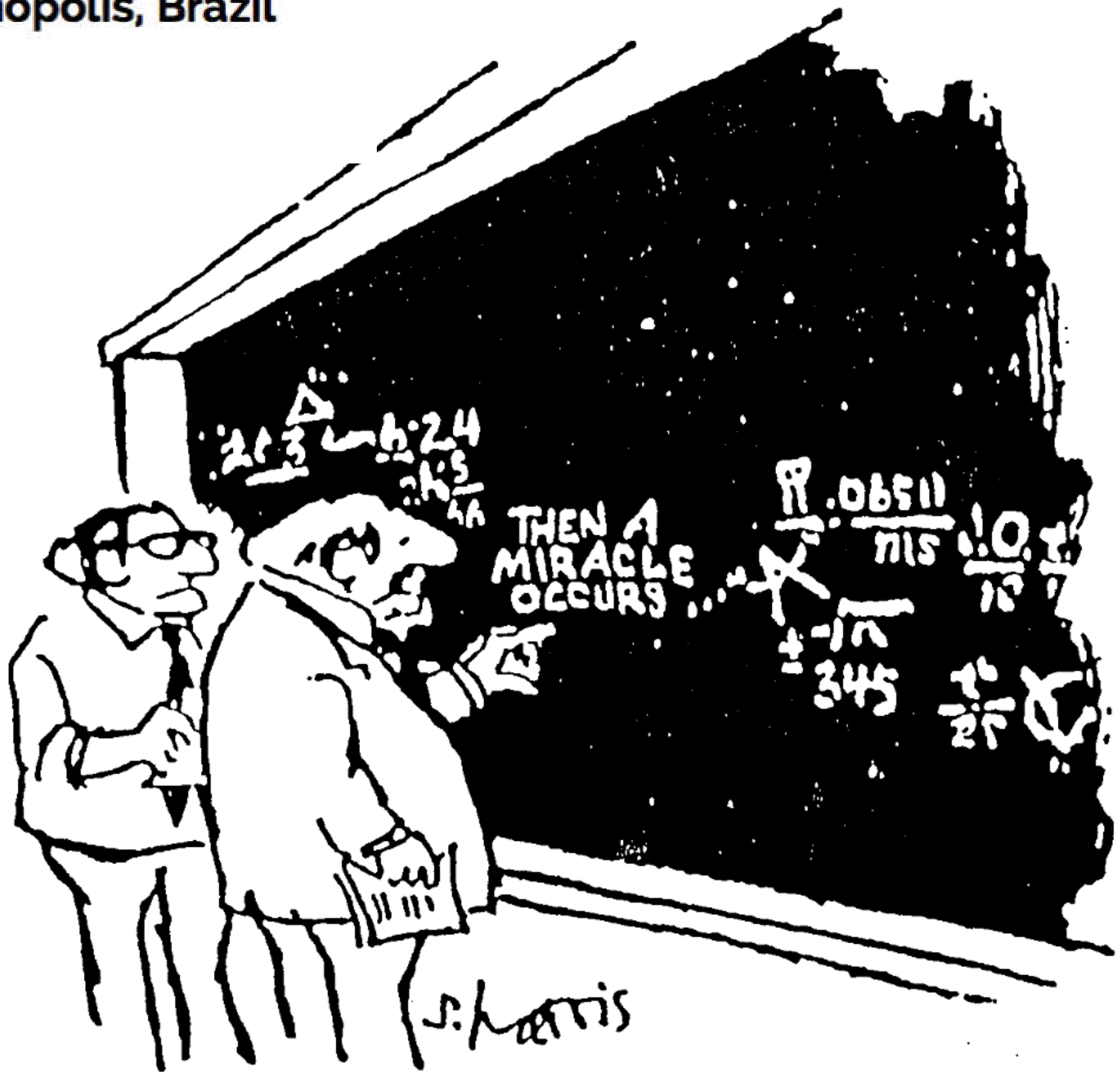
New

- APIs
- Open Source
- Customer Lead
- Network Function Virtualization (NFV)

Adapted from: Kyle Mestery, Next Generation Network Developer Skills s16comm Florianópolis, Brazil

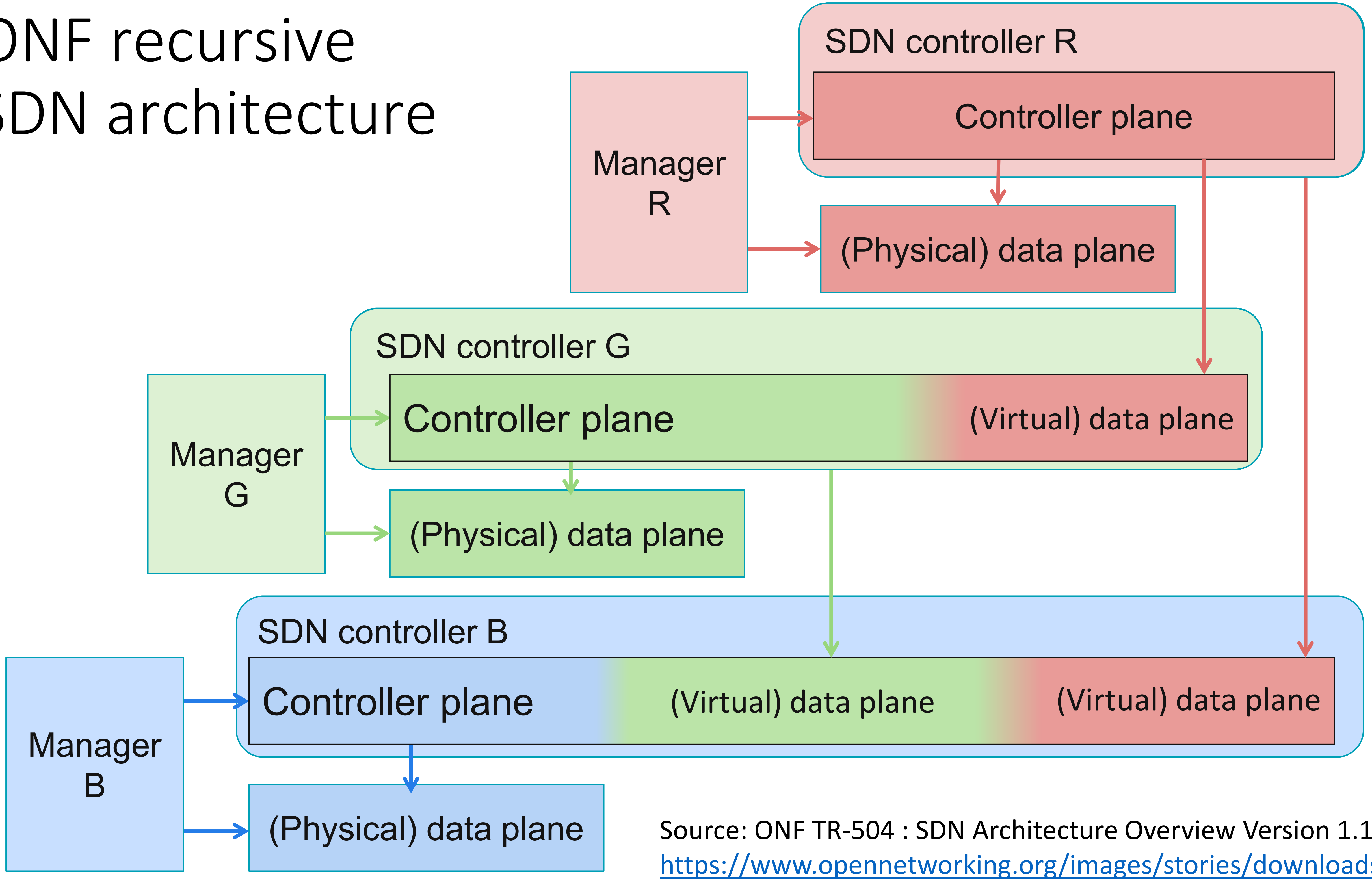
Topic Preview Sessions

Thank you!
Questions?



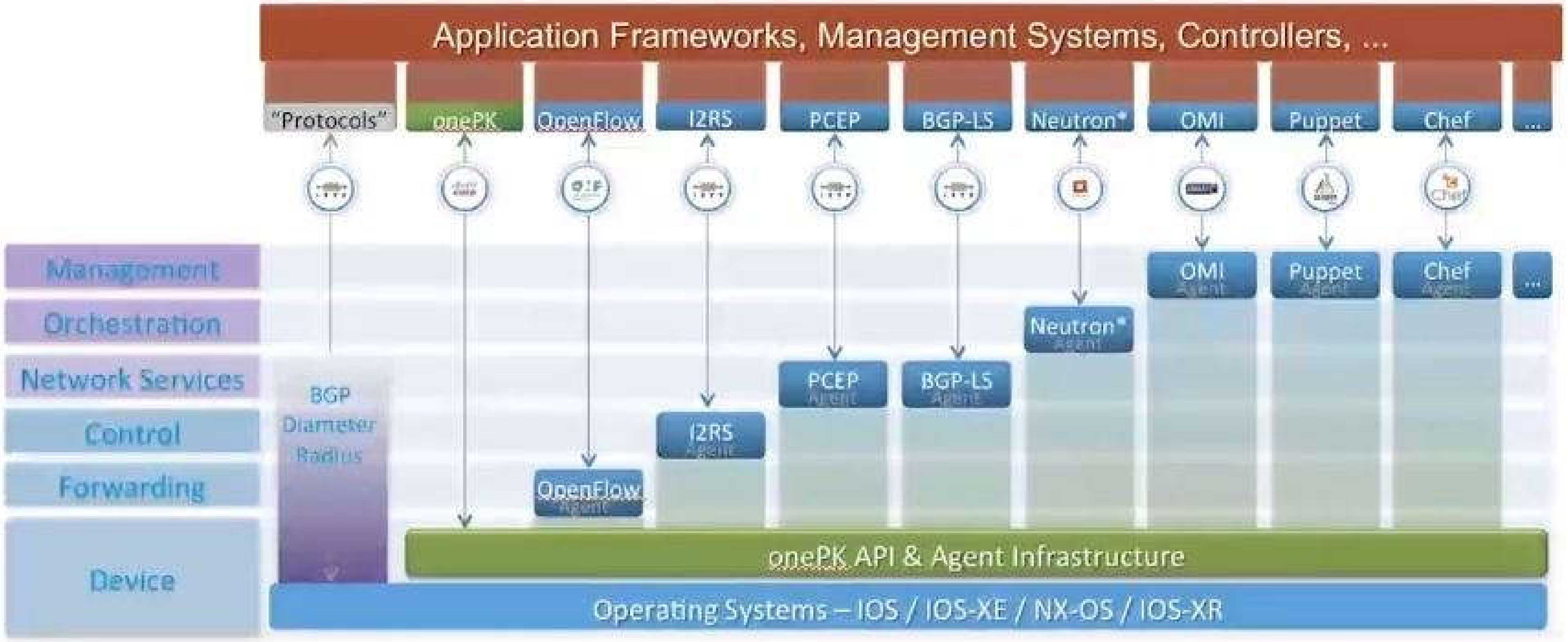
BACKUP

ONF recursive SDN architecture



Source: ONF TR-504 : SDN Architecture Overview Version 1.1, https://www.opennetworking.org/images/stories/downloads/sdn-resources/technical-reports/TR_SDN-ARCH-Overview-1.1-11112014.02.pdf

Network Programmability Layers



Source: Introducing Network Programmability Fundamentals
Part#: CTOD-SDN-1.0-017141 https://learningnetworkstore.cisco.com/skillsoft/introducing-network-programmability-fundamentals-ctod-sdn-1-0-017141

SDN asks (at least) three major questions

Where the control plane resides
"Distributed vs Centralized" ?

1

- **What state belongs in distributed protocols?**
- **What state must stay local to switches?**
- **What state should be centralized?**

- What are the effects of each on:

- state synchronization overhead
- total control plane overhead
- system stability and resiliency
- efficiency in resource use
- control loop tightness

Source: E. Crabbe, slides-85-sdnrg-7.pdf

SDN asks (at least) three major questions

How does the Control Plane talk to the Data Plane ?

2

- **Prop. IPC**
- **OpenFlow (with or w/extensions)**
- **Open Source south-bound protocols**
- **Via SDN controller broker and south-bound plug-ins**
- **Other standardized protocols**

- What are the effects of each on:
  - Interoperability, Evolvability, Performance
  - Vendor Lock-in

SDN asks (at least) three major questions

How are Control and
Data Planes programmed ?

3

- **Levels of Abstraction**
- **Open APIs**
- **Standardized Protocols**

•What are the effects of each on:

- Data plane flexibility
- Integration with legacy
- Interoperability (CP / DP)
- Vendor lock-in

Source: E. Crabbe, slides-85-sdnrg-7.pdf

NFV Concepts

- **Network Function (NF):** Functional building block with a well defined interfaces and well defined functional behavior
- **Virtualized Network Function (VNF):** Software implementation of NF that can be deployed in a virtualized infrastructure
- **VNF Set:** Connectivity between VNFs is not specified, e.g., residential gateways
- **VNF Forwarding Graph:** Service chain when network connectivity order is important, e.g., firewall, NAT, load balancer
- **NFV Infrastructure (NFVI):** Hardware and software required to deploy, mange and execute VNFs including computation, networking, and storage.
- **NFV Orchestrator:** Automates the deployment, operation, management, coordination of VNFs and NFVI.

Source: Adapted from Raj Jain

NFV Concepts

- **NFVI Point of Presence (PoP):** Location of NFVI
- **NFVI-PoP Network:** Internal network
- **Transport Network:** Network connecting a PoP to other PoPs or external networks
- **VNF Manager:** VNF lifecycle management e.g., instantiation, update, scaling, query, monitoring, fault diagnosis, healing, termination
- **Virtualized Infrastructure Manager:** Management of computing, storage, network, software resources
- **Network Service:** A composition of network functions and defined by its functional and behavioral specification
- **NFV Service:** A network services using NFs with at least one VNF.

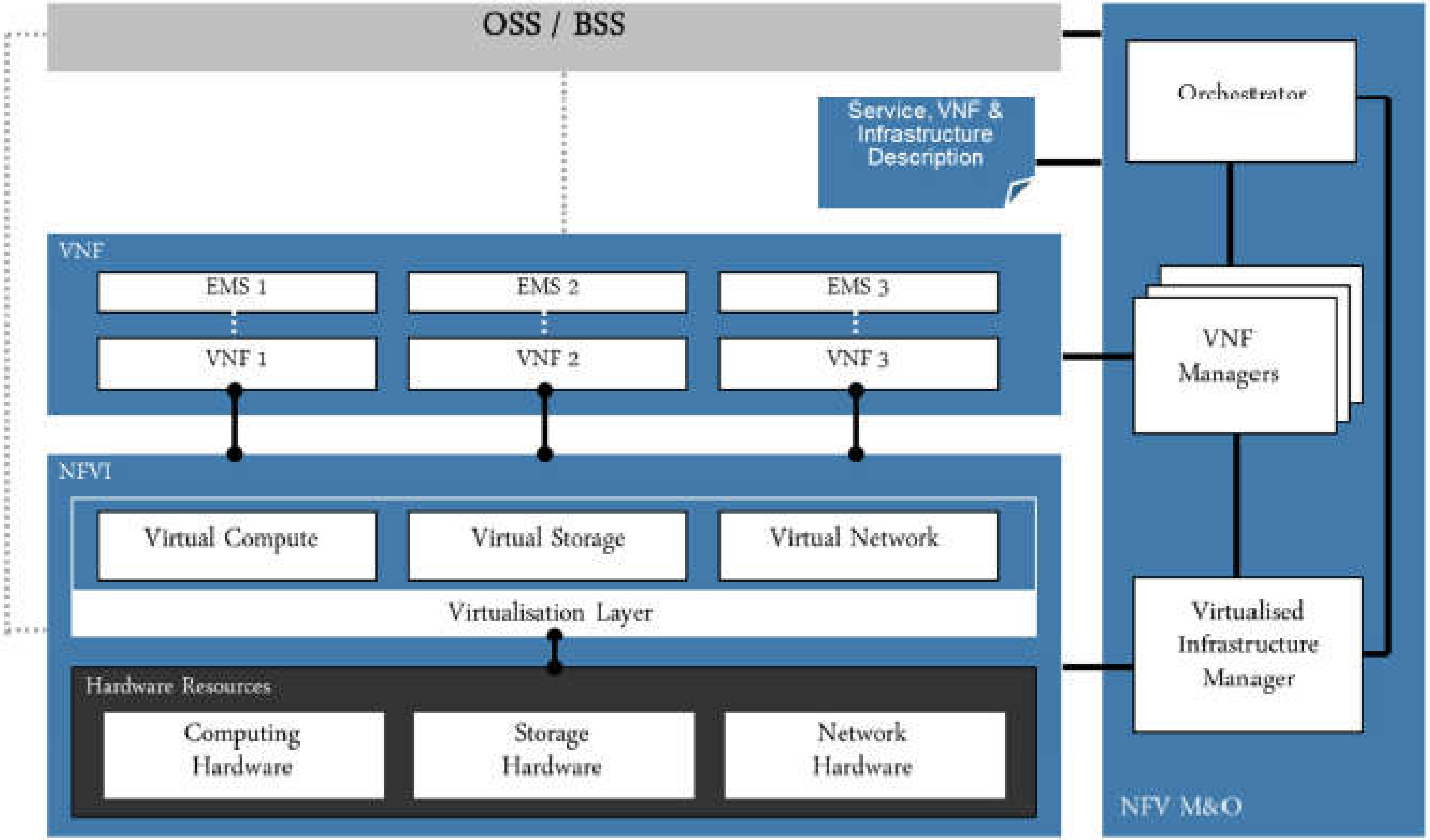
Source: Adapted from Raj Jain

NFV Concepts

- **User Service:** Services offered to end users/customers/subscribers.
- **Deployment Behavior:** NFVI resources that a VNF requires, e.g., Number of VMs, memory, disk, images, bandwidth, latency
- **Operational Behavior:** VNF instance topology and lifecycle operations, e.g., start, stop, pause, migration, …
- **VNF Descriptor:** Deployment behavior + Operational behavior

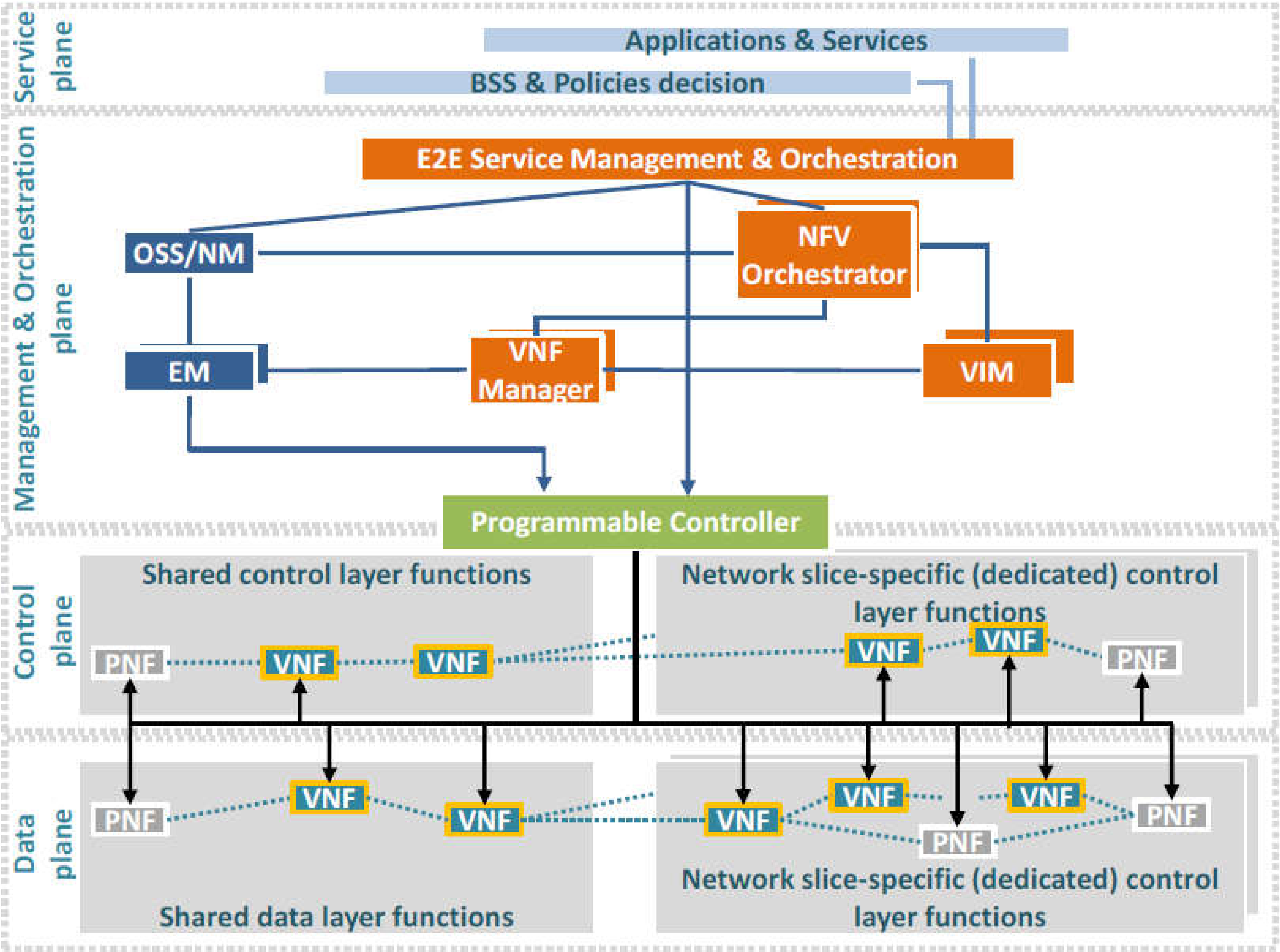
Source: Adapted from Raj Jain

Architectural Framework [ETSI NFV]



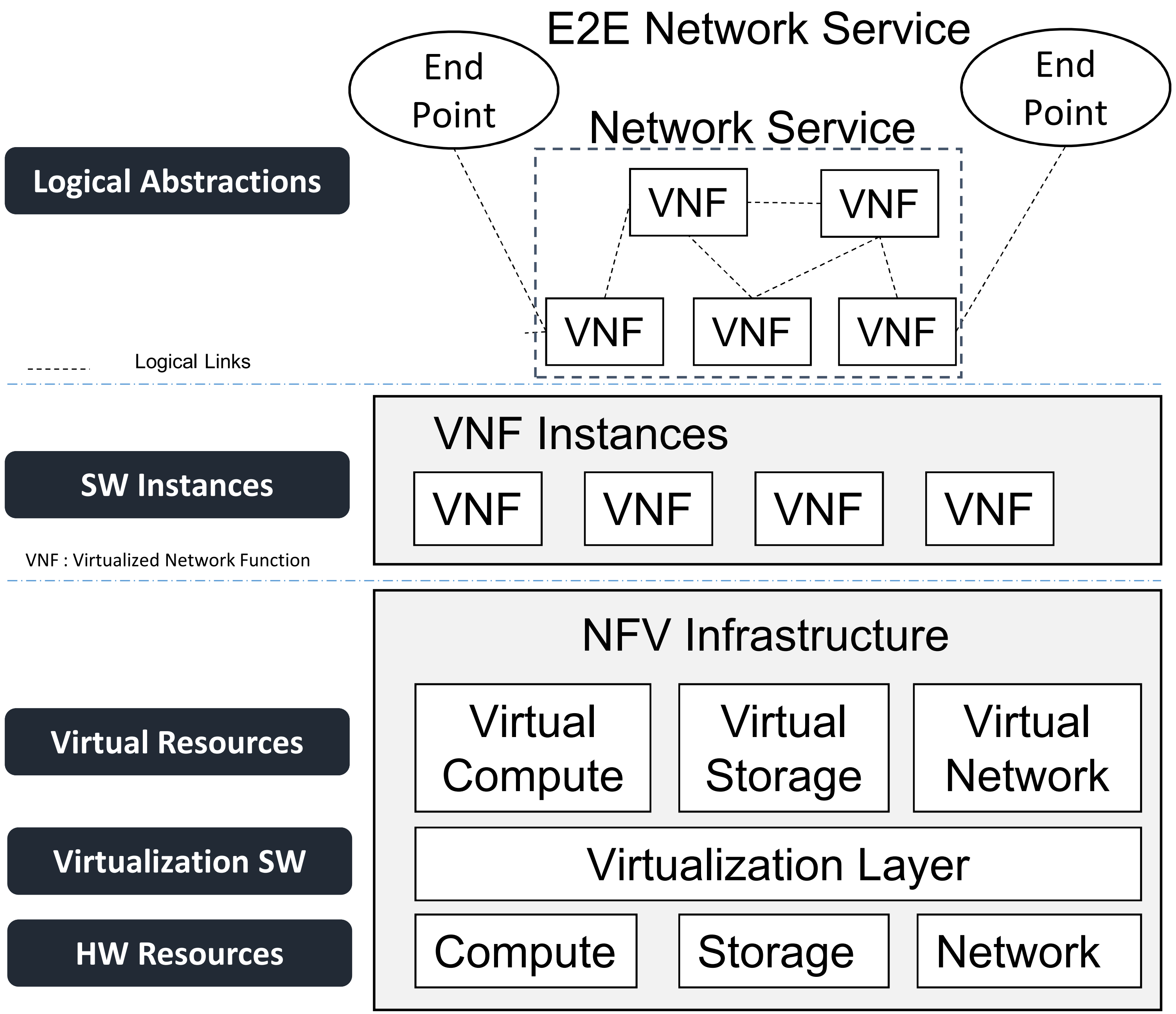
Souce: ETSI NFV White Paper 2

NFV



Source: View on 5G Architecture - 5G PPP Architecture Working Group (2016)

NFV Layers



Source: Adapted from D. Lopez Telefonica I+D, NFV

Alternative options to virtualize NFV apps