Project 3 and Software-Defined Networking (SDN)

EE122 Fall 2011

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Materials with thanks to Jennifer Rexford, Ion Stoica, Vern Paxson
and other colleagues at Princeton and UC Berkeley

Introducing Project 3

- Scott: Background on Software-Defined Networking (40 minutes)
- Yahel: Project Overview (10 minutes)
- Murphy: Software Architecture (10 minutes)
- TD and Kyriakos: Demo and Details (15 minutes)

Preliminaries

- Wanted to let you program a real device
  - Marvell donated 250 of these “plug computers”, which we are sharing with NUST (Pakistan)
- Be gentle with us, we’ll be gentle with you…
  - You break it early, we’ll fix it early
- If you are interested in doing something neat with your box, send me a proposal and we’ll let you continue to play with the box after end of semester.
- **Do not lose your device – we need it back**

My Portion of Presentation

- SDN is a new approach to networking
  - Not about “architecture”: IP, TCP, etc.
  - But about design of network control (routing, TE,…)

- Full Disclosure: SDN invented by Nicira Networks
  - Based on earlier work at Stanford, UCB, Princeton, CMU

- But this is ***not*** a sales pitch for Nicira
  - Nicira sells products that happen to use SDN internally
  - It does not sell SDN, nor market itself as an SDN company

Status of SDN

- Open Networking Foundation is standards body
  - SDN endorsed by 49 companies
  - Almost everyone who matters…..
- A few products on market, many more coming
  - Some large companies using SDN internally
- **SDN has won the war of words, the real battle over customer adoption is just beginning….**

How is Project 3 Related to SDN?

- Project 3 uses SDN technology
  - But SDN will be invisible to you (as it should be!)
- You will write program to control single switch
  - **Easy** (in principle)!
- **Similar program could control entire network**
  - Impossible without SDN…and whole goal of SDN
- I will provide motivation and context for SDN
  - Absolutely no design details

Rules of Engagement

- Because short on time, I will not ask questions
- If you don’t understand what I’m saying, **stop me**.
- To pursue points more deeply, do so after class
  - Goal here is not depth, but general intuition about SDN

Two Key Definitions

- **Data Plane**: processing and delivery of packets
  - Based on state in routers and endpoints
  - E.g., IP, TCP, Ethernet, etc.
  - Fast timescales (per-packet)

- **Control Plane**: establishing the state in routers
  - Determines how and where packets are forwarded
  - Routing, traffic engineering, firewall state, …
  - Slow time-scales (per control event)

The Future of Networking,

and the Past of Protocols

Scott Shenker

*with **Martín Casado**, Teemu Koponen, Nick McKeown*

(and many others….)

Key to Internet Success: Layers

Applications

…built on…

Reliable (or unreliable) transport

…built on…

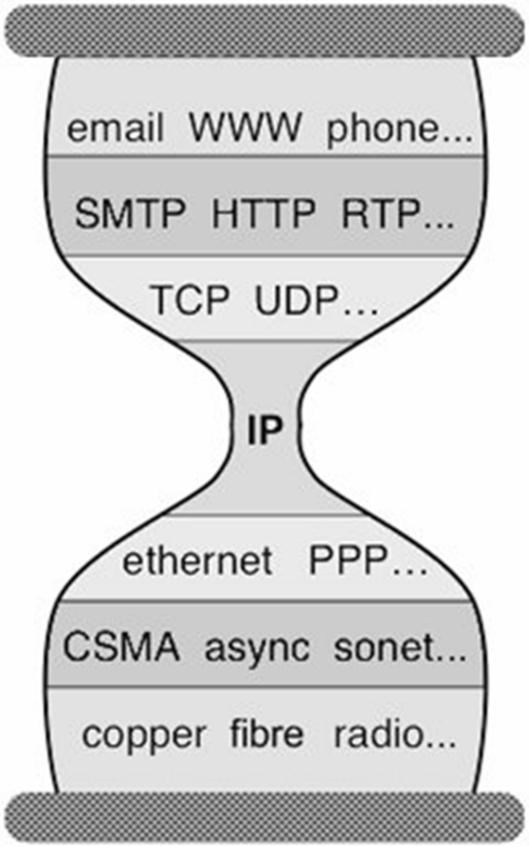
Best-effort global packet delivery

…built on…

Best-effort local packet delivery

…built on…

Physical transfer of bits



Why Is Layering So Important?

- Decomposed delivery into fundamental components
- Independent but compatible **innovation** at each layer
- A practical success of unprecedented proportions…
- **…but an academic failure**

Built an Artifact, Not a Discipline

- Other fields in “systems”: OS, DB, DS, etc.
  - Teach basic principles
  - Are easily managed
  - Continue to evolve

- Networking:
  - Teach big bag of protocols
  - Notoriously difficult to manage
  - Evolves very slowly

Why Does Networking Lag Behind?

- Networks used to be simple: Ethernet, IP, TCP….

- New **control** requirements led to great complexity
  - Isolation ➔ VLANs, ACLs
  - Traffic engineering ➔ MPLS, ECMP, Weights
  - Packet processing middleboxes ➔ Firewalls, NATs,
  - Payload analysis ➔ Deep packet inspection (DPI)
  - …..

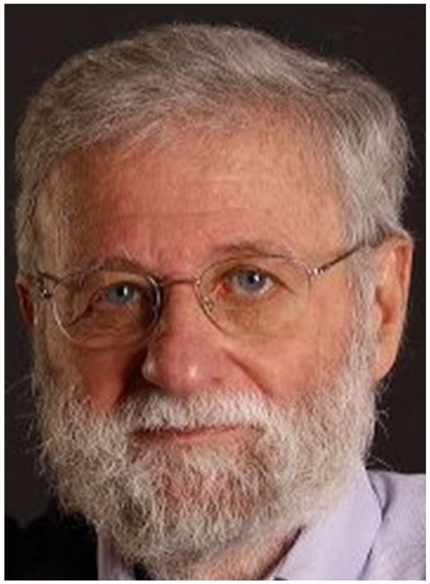
- Mechanisms designed and deployed independently
  - Complicated "control plane" design, primitive functionality
  - Stark contrast to the elegantly modular "data plane"

Infrastructure Still Works!

- **Only** because of “our” ability to master complexity
- This ability to master complexity is both a blessing…
  - **…and a curse!**

A Simple Story About Complexity

- ~1985: Don Norman visits Xerox PARC
  - Talks about user interfaces and stick shifts



What Was His Point?

- The ability to ***master complexity*** is not the same as the ability to ***extract simplicity***

- When first getting systems to work….
  - Focus on mastering complexity

- When making system easy to use and understand
  - Focus on extracting simplicity

- **You will never succeed in extracting simplicity**
  - If don't recognize it is different from mastering complexity

What Is *My* Point?

- Networking still focused on mastering complexity
  - Little emphasis on extracting simplicity from control plane
  - No recognition that there's a difference….

- Extracting simplicity builds intellectual foundations
  - **Necessary for creating a discipline….**
  - **That's why networking lags behind**

A Better Example: Programming

- Machine languages: no abstractions
  - Mastering complexity was crucial
- Higher-level languages: OS and other abstractions
  - File system, virtual memory, abstract data types, ...
- Modern languages: even more abstractions
  - Object orientation, garbage collection,…

Abstractions key to extracting simplicity

“The Power of Abstraction”

“Modularity based on abstraction is the way things get done”

–

Barbara Liskov

Abstractions → Interfaces → Modularity

What abstractions do we have in networking?

Layers are Great Abstractions

- Layers only deal with the **data plane**
- We have no powerful ***control plane*** abstractions!
- How do we find those control plane abstractions?
- Two steps: ***define*** problem, and then ***decompose*** it.

The Network Control Problem

- Compute the configuration of each physical device
  - E.g., Forwarding tables, ACLs,…
- Operate without communication guarantees
- Operate within given network-level protocol

Only people who love complexity would find this a reasonable request

Programming Analogy

- What if programmers had to:
  - Specify where each bit was stored
  - Explicitly deal with all internal communication errors
  - Within a programming language with limited expressability

- Programmers would redefine problem:
  - Define a higher level abstraction for memory
  - Build on reliable communication abstractions
  - Use a more general language

- **Abstractions** divide problem into tractable pieces
  - And make programmer's task easier

From Requirements to Abstractions

1. Operate without communication guarantees

   Need an abstraction for **distributed state**

2. Compute the configuration of each physical device

   Need an abstraction that **simplifies configuration**

3. Operate within given network-level protocol

   Need an abstraction for general **forwarding model**

Once these abstractions are in place, control mechanism has a much easier job!

My Entire Talk in One Sentence

- SDN is defined *precisely* by these three abstractions
  - Distribution, forwarding, configuration

- SDN not just a random good idea…
  - Fundamental validity and general applicability

- SDN may help us *finally* create a discipline
  - Abstractions enable reasoning about system behavior
  - Provides environment where formalism can take hold….

- OK, but what are these abstractions?

1. Distributed State Abstraction

- Shield control mechanisms from state distribution
  - While allowing access to this state

- Natural abstraction: ***global network view***
  - Annotated network graph provided through an API

- Implemented with “Network Operating System”

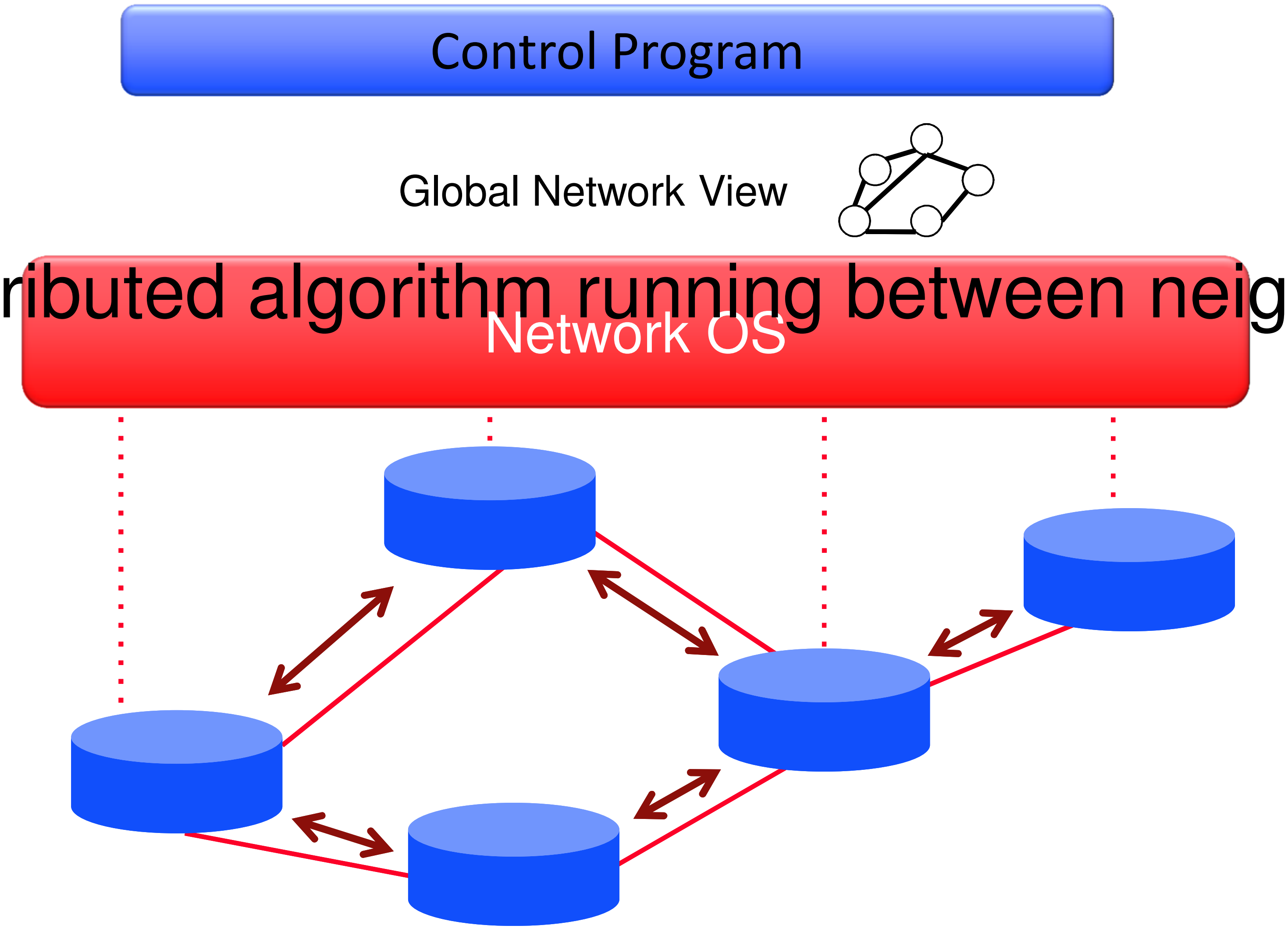
- Control mechanism is now program using API
  - No longer a distributed protocol, now just a graph algorithm
  - E.g. Use Dijkstra rather than Bellman-Ford

Network of Switches and/or Routers

Software Defined Network (SDN)

Traditional Control Mechanisms

e.g. routing, access control



Distributed algorithm running between neighbors

Major Change in Paradigm

- No longer designing distributed control protocols
  - Design one distributed system (NOS)
  - Use for all control functions

- Now just defining a centralized control ***function***

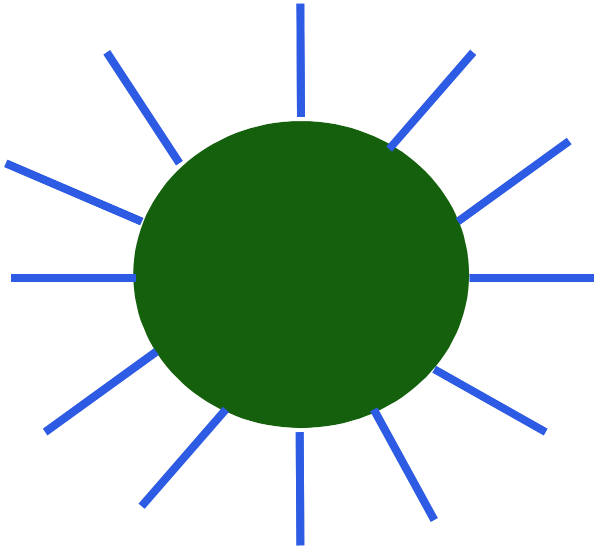
Configuration = Function(view)

- If you understand this, raise your hand.

2. Specification Abstraction

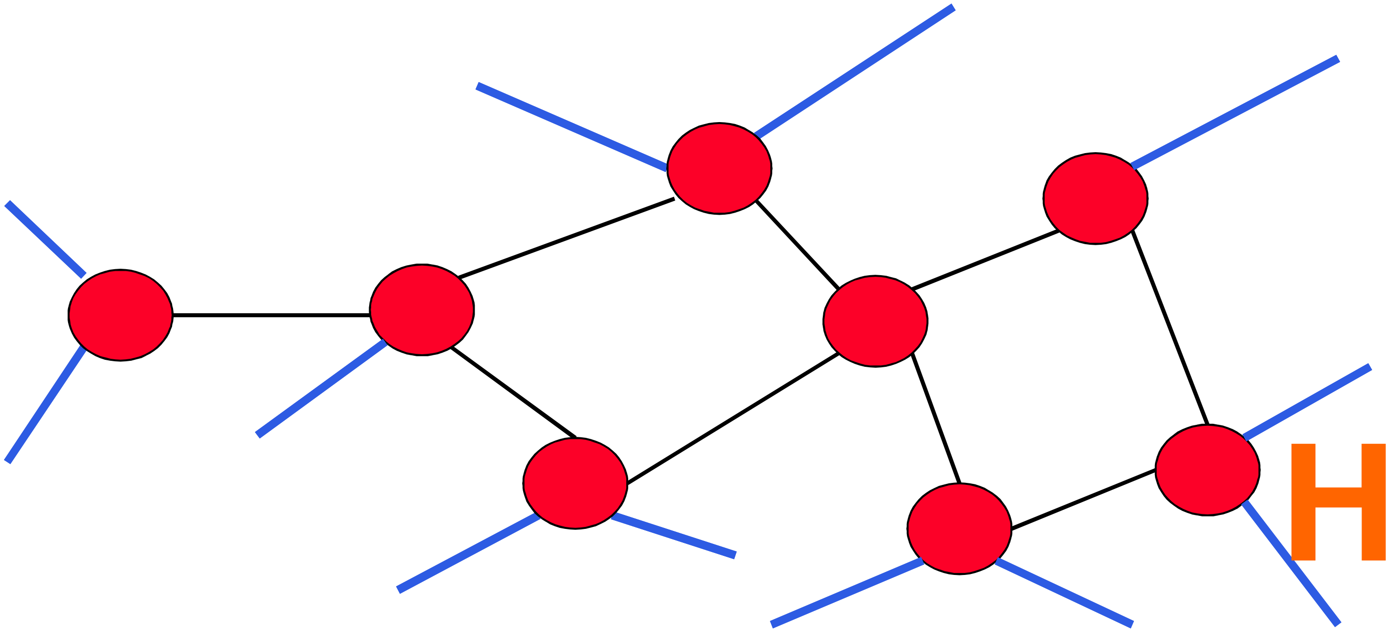
- Control program should express desired behavior
- It should not be responsible for implementing that behavior on physical network infrastructure
- Natural abstraction: **simplified model** of network
  - Simple model with only enough detail to specify goals
- Requires a new shared control layer:
  - **Map abstract configuration to physical configuration**
- This is "network virtualization"

Simple Example: Access Control



What

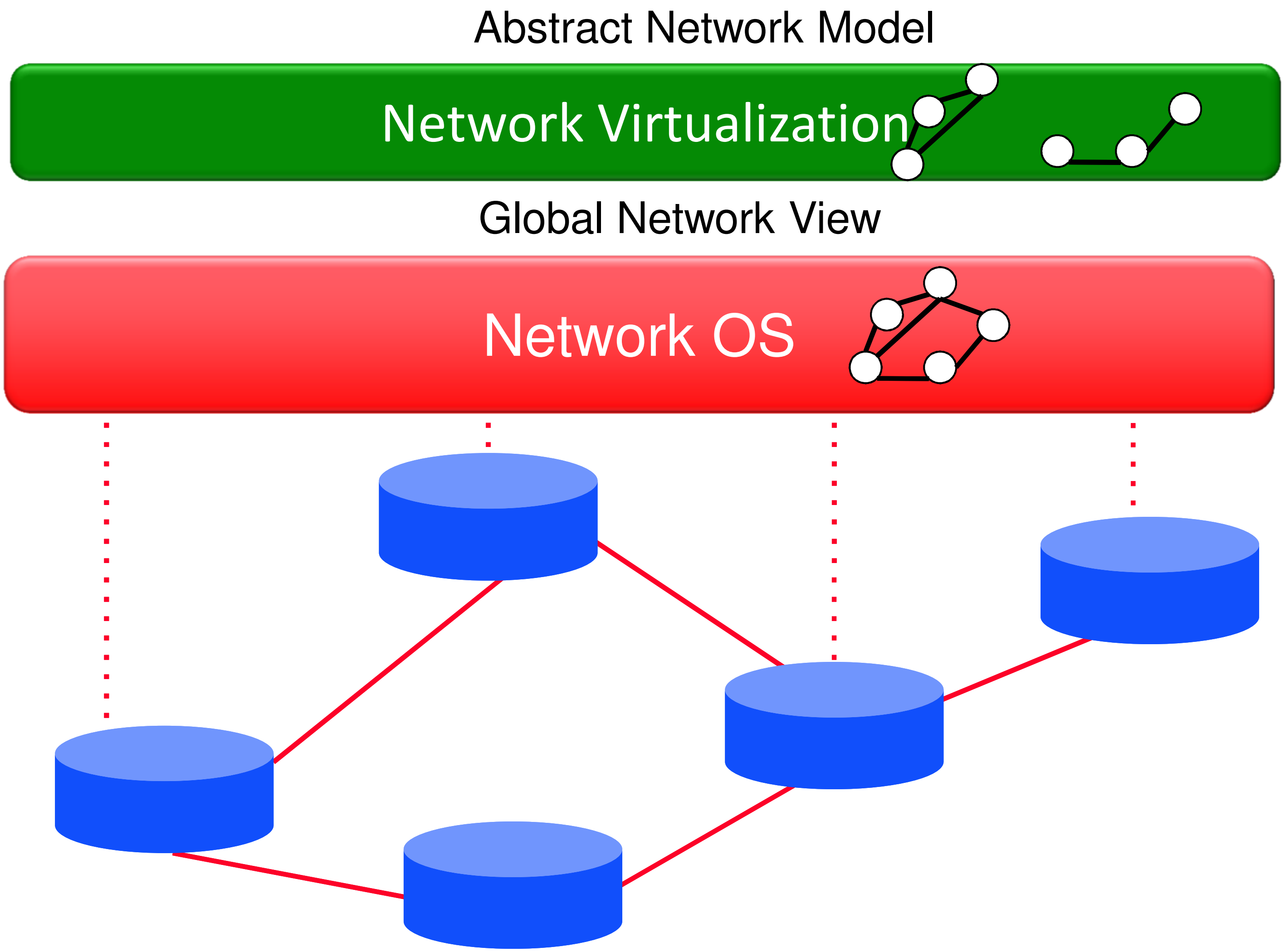
Abstract
Network
Model



Global
Network
View

How

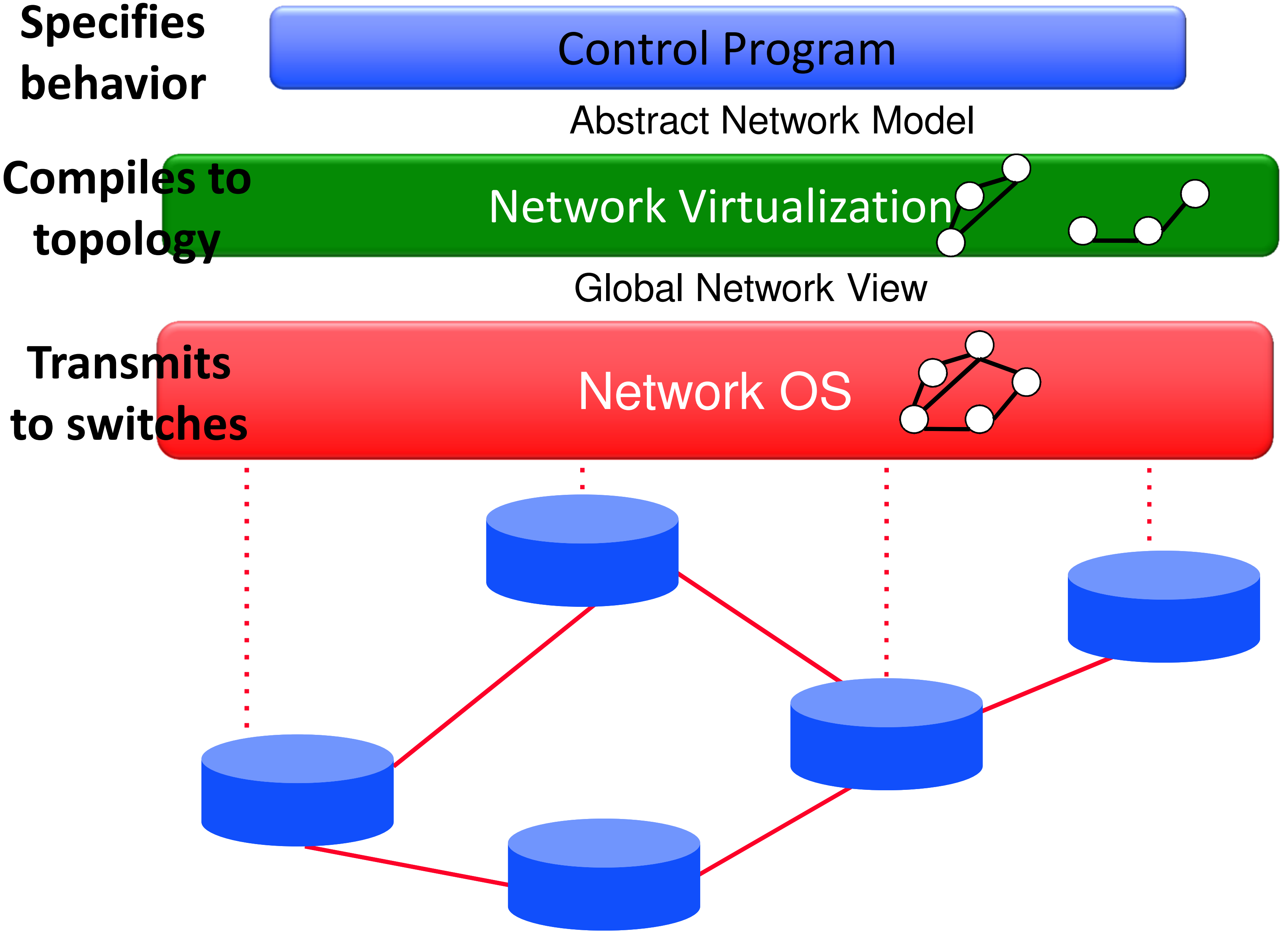
Software Defined Network: Take 2



What Does This Picture Mean?

- Write a simple program to configure a simple model
  - Configuration merely a way to specify what you want
- Examples
  - ACLs: who can talk to who
  - Isolation: who can hear my broadcasts
  - Routing: only specify routing to the degree you care
    - Some flows over satellite, others over landline
  - TE: specify in terms of quality of service, not routes
- Virtualization layer "compiles" these requirements
  - Produces suitable configuration of actual network devices
- NOS then transmits these settings to physical boxes

Software Defined Network: Take 2



Specifies behavior

Control Program

Abstract Network Model

Compiles to topology

Network Virtualization

Global Network View

Transmits to switches

Network OS

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**

3. Forwarding Abstraction

- Switches have two “brains”
  - Management CPU (smart but slow)
  - Forwarding ASIC (fast but dumb)

- Need a forwarding abstraction for both
  - CPU abstraction can be almost anything

- ASIC abstraction is much more subtle: **OpenFlow**

- OpenFlow:
  - Control switch by inserting <header;action> entries
  - Essentially gives NOS remote access to forwarding table
  - Instantiated in OpenvSwitch

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 prgm: specify behavior on abstract model**
  - Driven by **Operator Requirements**

- **Net Virt’n: 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**

We Have Achieved Modularity!

- Modularity enables independent innovation
  - Gives rise to a thriving ecosystem

- Innovation is the true value proposition of SDN
  - SDN doesn’t allow you to do the impossible
  - It just allows you to do the possible much more easily

- ***This is why SDN is the future of networking…***