The Future of Networking,

and the Past of Protocols

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(and many others….)

Software-Defined Networking

- SDN clearly has advantages over status quo
- But is SDN the “right” solution?
- My talk: Not **what** SDN is, but **why** SDN is

Key to Internet Success: Layers

Applications

…built on…

Reliable (or unreliable) transport

…built on…

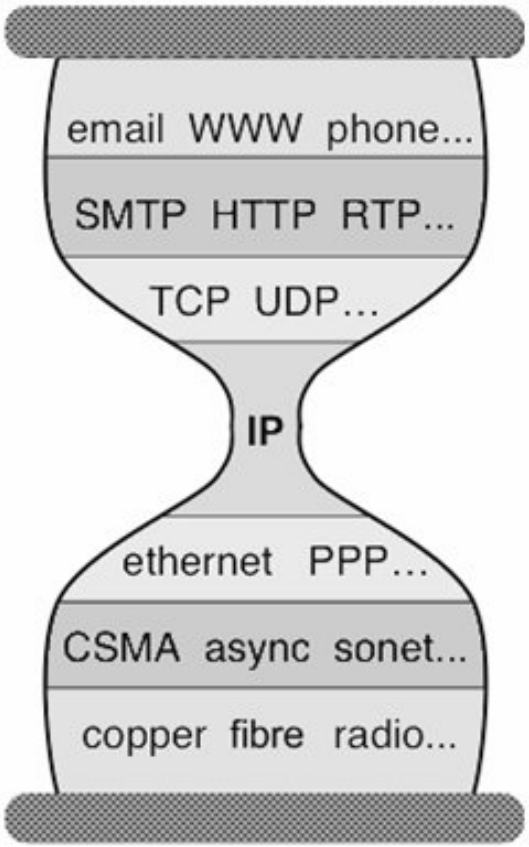
Best-effort global packet delivery

…built on…

Best-effort local packet delivery

…built on…

Physical transfer of bits



The Importance of Layering

- Decomposed delivery into fundamental components
- Independent but compatible innovation at each layer
- An amazing success…
- …but an academic failure

Built an Artifact, Not a Discipline

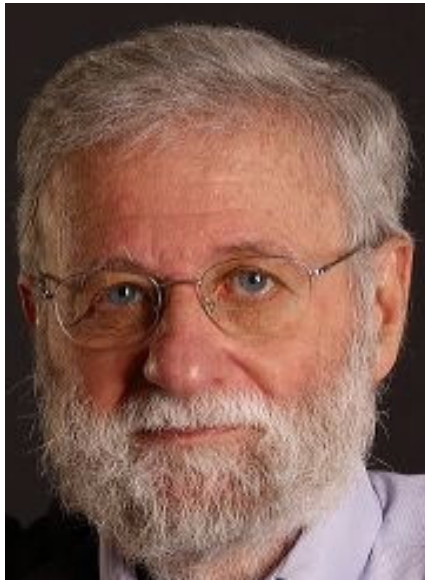
- Other fields in “systems”: OS, DB, etc.
  - Teach basic principles
  - Are easily managed
  - Continue to evolve
- Networking:
  - Teach big bag of protocols
  - Notoriously difficult to manage
  - Evolves very slowly

Why Does Networking Lag Behind?

- Networks used to be simple
- New **control** requirements led to great complexity
- Fortunately, the infrastructure still works...
  - **Only** because of your great 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 has never made the distinction…
- And therefore has never made the transition
  - Still focused on mastering complexity
  - Little emphasis on extracting simplicity from control plane
- Extracting simplicity builds intellectual foundations
  - **Necessary for creating a discipline….**

An Example Transition: 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 abstractions?
- Define our 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
  - Make task of control program 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**

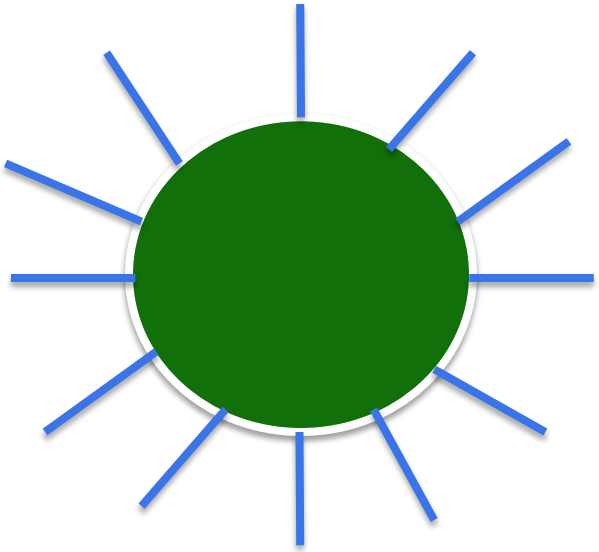
1. Distributed State Abstraction

- Shield mechanisms from vagaries of distributed state
  - While allowing access to this state
- Natural abstraction: ***global network view***
  - Annotated network graph provided through an API
- 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

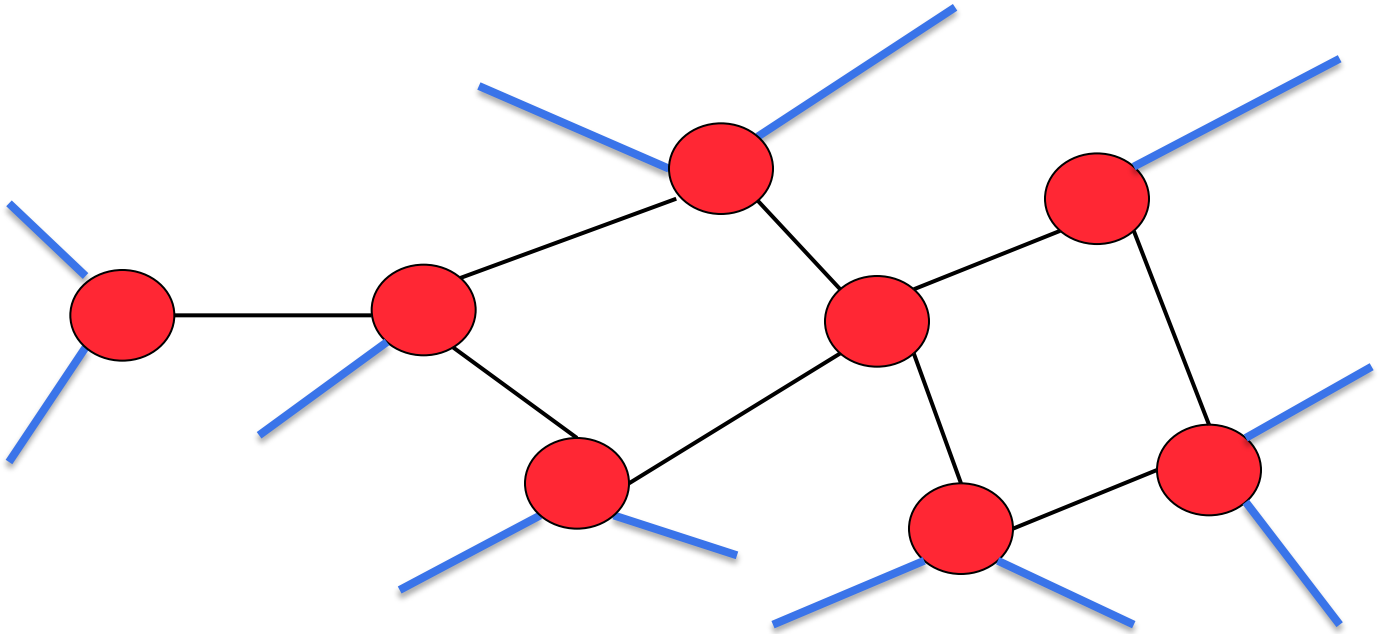
2. Specification Abstraction

- 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 only enough detail to specify goals
- This is “network virtualization”

Simple Example: Access Control



Abstract
Network
Model



Global
Network
View

3. Forwarding Abstraction

- Control plane needs **flexible** forwarding model
- Abstraction *should not* constrain control program
  - Should support whatever forwarding behaviors needed
- It *should* hide details of underlying hardware
  - Crucial for evolving beyond vendor-specific solutions

My Entire Talk in One Sentence

- SDN is defined *precisely* by these three abstractions
  - Distribution, forwarding, configuration
- SDN not just a random good idea…
- ...can be “derived” from decomposing network control
- Fundamental validity and general applicability

Realizing These Abstractions

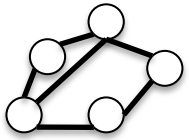
- Core challenge:
  - make distributed control problem a logically centralized one
- This involves designing a common distribution layer
  - Gathers information from network elements (topology)
  - Disseminates control commands to network elements
- This is done by a “Network Operating System”

Network Control Functions

e.g. routing, access control

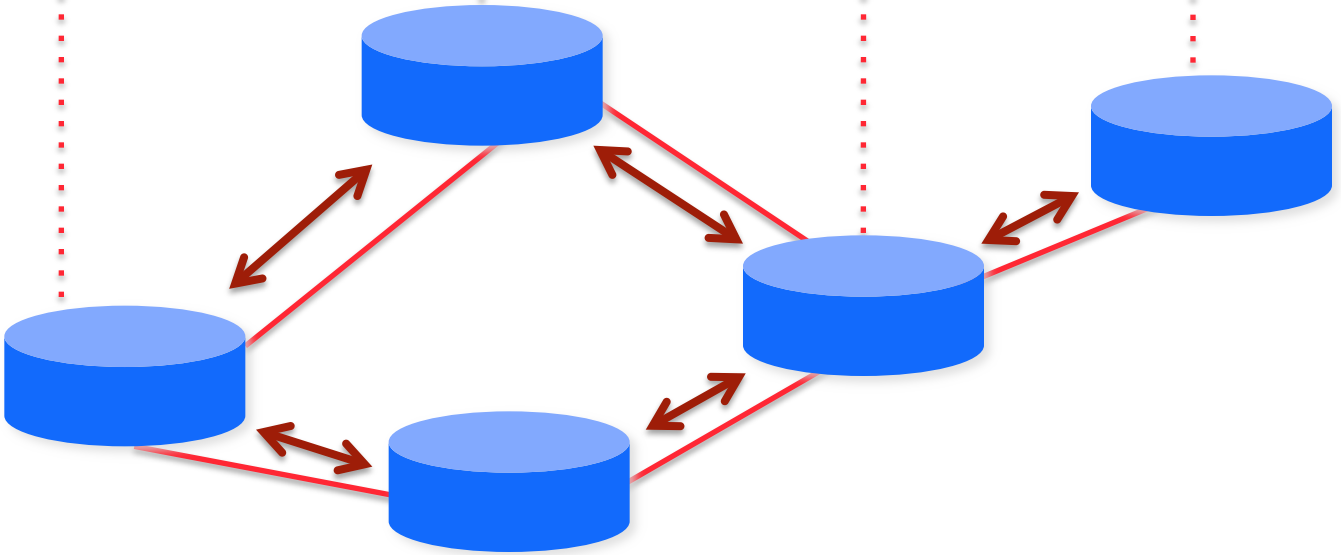
Control Program

Global Network View



Network OS

Distributed algorithm running between neighbors



Major Change in Paradigm

- No longer designing distributed control protocols
- Now just defining a centralized control function

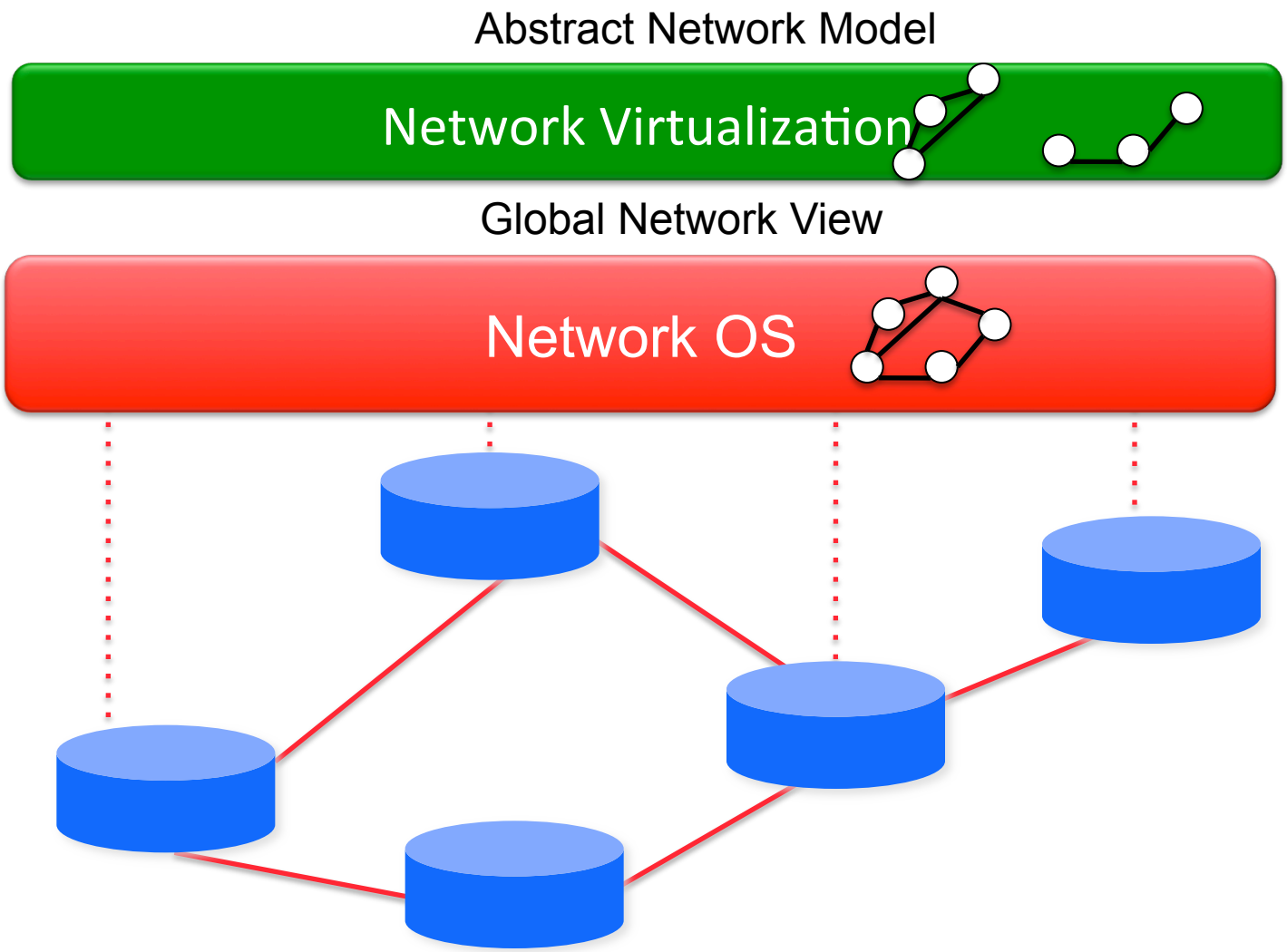
  Configuration = Function(view)

- This spells the end for distributed protocols
  - Easier to write, reason about, maintain, ….
- Beginning of the “software era” of networking
  - Rate of change, nature of standards, different culture, etc.

2. Specification Abstraction

- Abstraction is a simplified model of network
- Control program merely configures abstract model
  - Abstract configuration = Function(abstract model)
- Requires a new shared control layer:
  - **Map abstract configuration to physical configuration**

Software Defined Network



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**
- All this assumes **switches** are unit of abstraction
  - **Why not fast, cheap fabrics?** (in datacenters)

Keep in Mind

- As we debate the finer points of OpenFlow
  - OF is a detail in the overall SDN architecture
- OpenFlow is crucial for the industry
  - But a minor piece architecturally
- Don’t let the tail wag the dog…

Dog: 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**

Final Words

- Future of networking lies in finding right abstractions
  - The era of “a new protocol per problem” is over
- Takes years to internalize and evaluate abstractions
  - **Even longer to adjust to software-oriented culture**
- We are in the early stages of an intellectual voyage
  - We should keep our minds open while charting our course

Thank You…..