Advanced Networking and Cybersecurity

IBI Darmajaya

2022-2023

6.888
Advanced Topics in Networking

Introduction to Data Center Networking

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Spring 2016

- Includes material from lectures by Nick McKeown (Stanford), Jennifer Rexford (Princeton), and George Porter (UCSD)

The Internet: An Exciting Time

One of the most influential inventions

- A research experiment that escaped from the lab
- … to be the global communications infrastructure

Ever wider reach

- Today: 2 billion users, 15 billion devices
- Tomorrow: more users, content, sensors, “things”, 40 billion devices by 2020

Constant innovation

- Web, P2P, video, online shopping, social networks, cloud, …

Transforming Everything

The ways we do business

– E-commerce, advertising, cloud computing, ...

The way we have relationships

– E-mail, IM, Facebook friends, virtual worlds

The way we think about law and govern

– Interstate commerce, national boundaries?

– Censorship and wiretapping

The way we fight

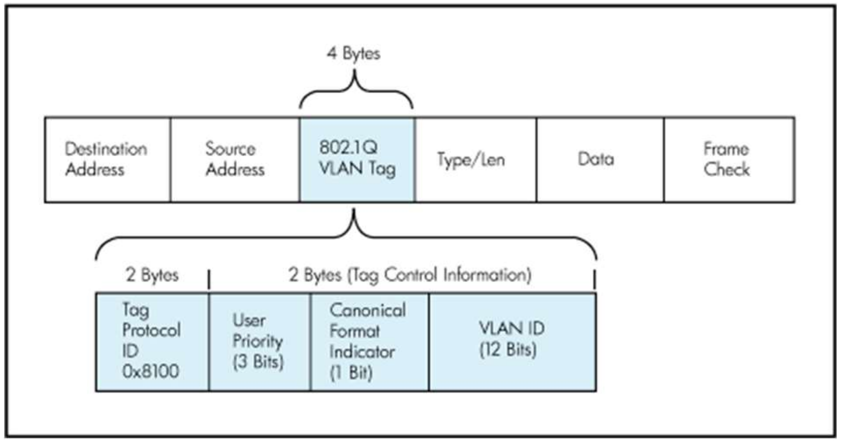
– Cyber-attacks, including nation-state attacks

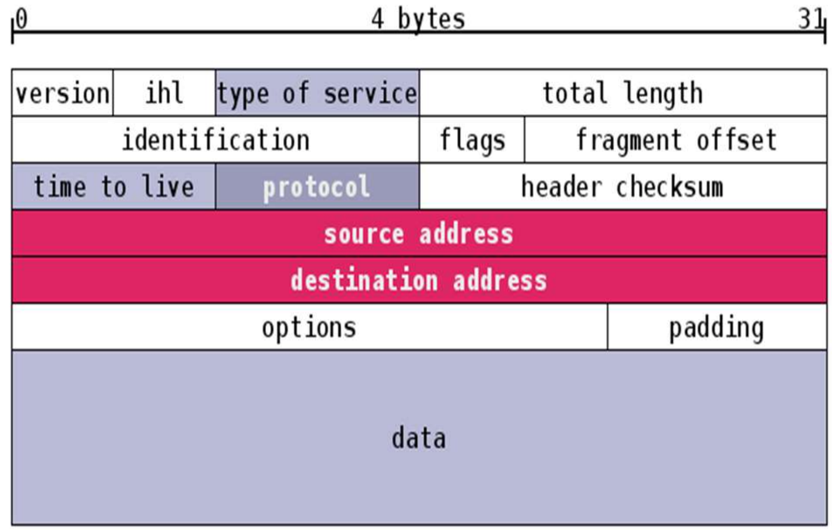
But what *is* networking?

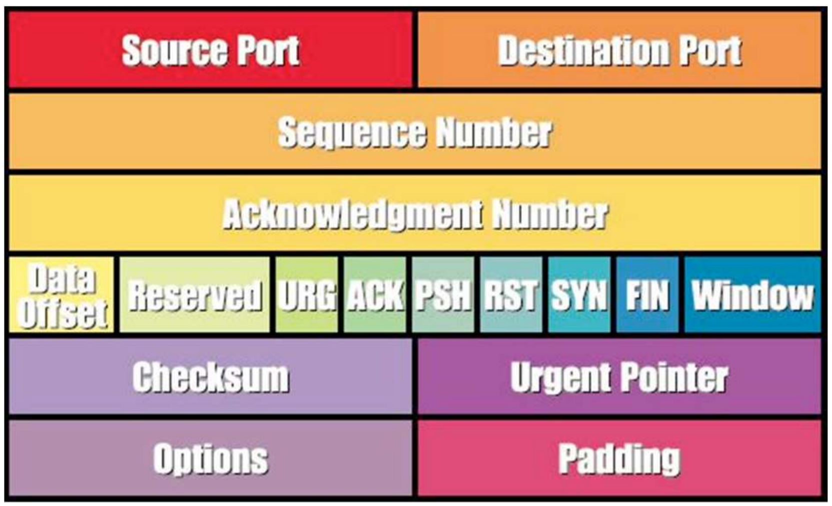
A Plethora of Protocol Acronyms?

SNMP WAP SIP PPP IPX MAC
LLDP FTP UDP
OSPF RTP ICMP IMAP IGMP HIP
PIM RED BGP HTTP ARP ECN
RIP IP MPLS TCP RTCP
SMTP RTSP BFD CIDR
NNTP SACK TLS NAT STUN
DNS SSH DHCP
POP VLAN LISP VTP TFTP LDP

A Heap of Header Formats?



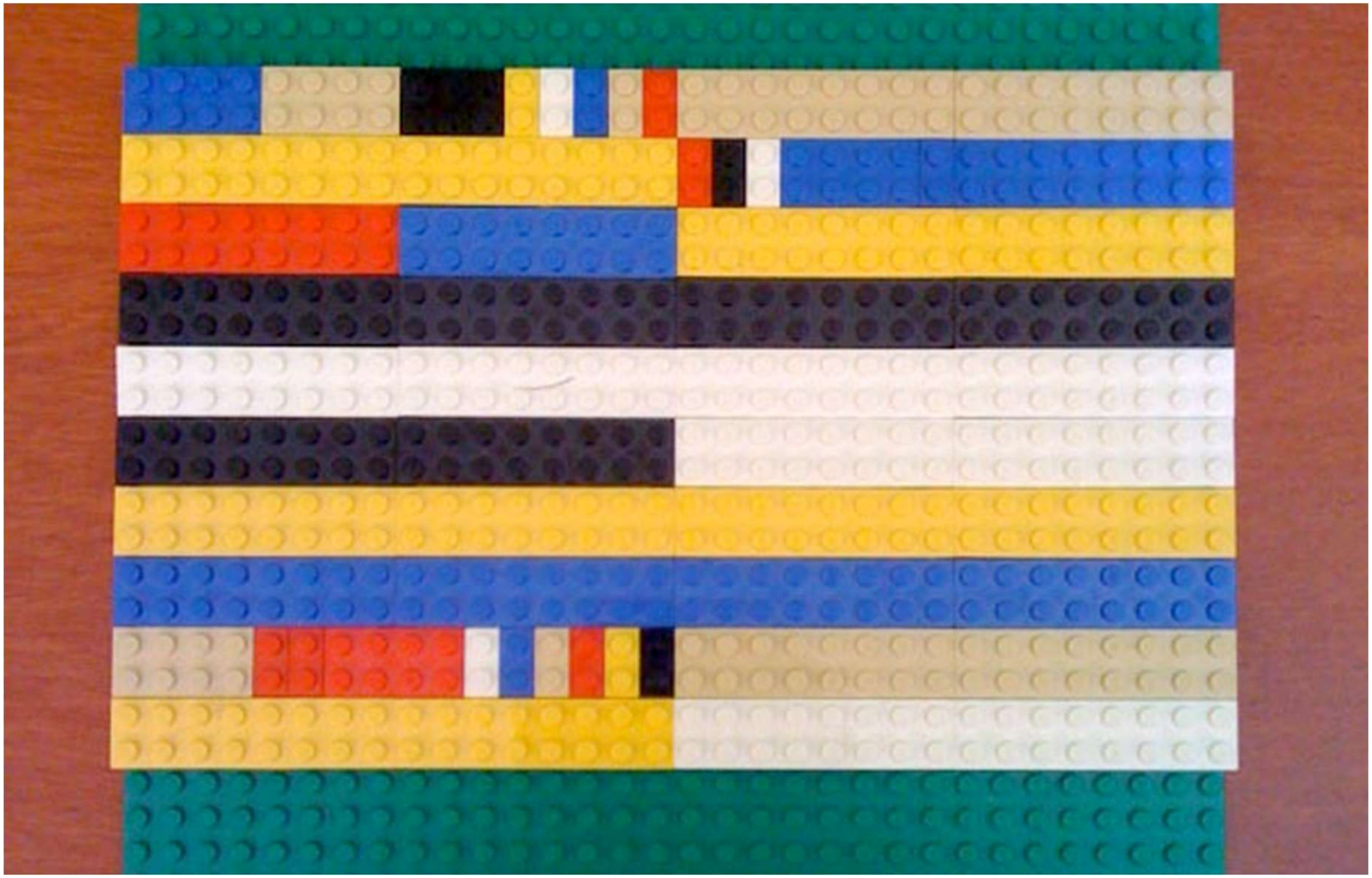




HTTP Response Header

Name	Value
HTTP Status Code: HTTP/1.1 200 OK	
Date:	Thu, 27 Mar 2008 13:37:17 GMT
Server:	Apache/2.0.55 (Ubuntu) PHP/5.1.2
Last-Modified:	Fri, 21 Mar 2008 13:57:30 GMT
ETag:	"358a4e4-56000-ddf5c680"
Accept-Ranges:	bytes
Content-Length:	352256
Connection:	close
Content-Type:	application/x-msdos-program

TCP/IP Header Formats in Lego



A Big Bunch of Boxes?

Router

Label Switched Router

Load balancer

Switch

Scrubber

Repeater

Gateway

Intrusion Detection System

Bridge

Route Reflector

Deep Packet Inspection

DHCP server

Packet shaper

Firewall

NAT

Hub

Packet sniffer

WAN accelerator

DNS server

Base station

Proxy

An Application Domain?

A place to apply theory?

Algorithms and data structures

Control theory

Queuing theory

Optimization theory

Game theory and mechanism design

Formal methods

Cryptography

Programming languages

Graph theory

A place to build systems?

Distributed systems

Operating systems

Computer architecture

Software engineering

…

So, Why is Networking Cool?

Relevant

- Can impact the real world
- Can measure/build things

Interdisciplinary

- Well-motivated problems + rigorous solution techniques

Widely-read papers

- Many of the most cited papers in CS are in networking
- Congestion control, distributed hash tables, resource reservation, self-similar traffic, multimedia protocols

So, Why is Networking Cool?

Young, relatively immature field

- Tremendous intellectual progress is still needed
- *You* can help decide what networking really is

Defining the problem is a big part of the challenge

- Recognizing a need, formulating well-defined problem
- … is at least as important as solving the problem.

Lots of platforms for building your ideas

- Testbeds: Emulab, PlanetLab, Orbit, GENI
- Programmability: Click, Mininet, NetFPGA, Switch chips

This course

... is about the latest in networking research

Main goal:

Prepare for high quality research in this field

We'll focus mostly on…

Data Center Networking

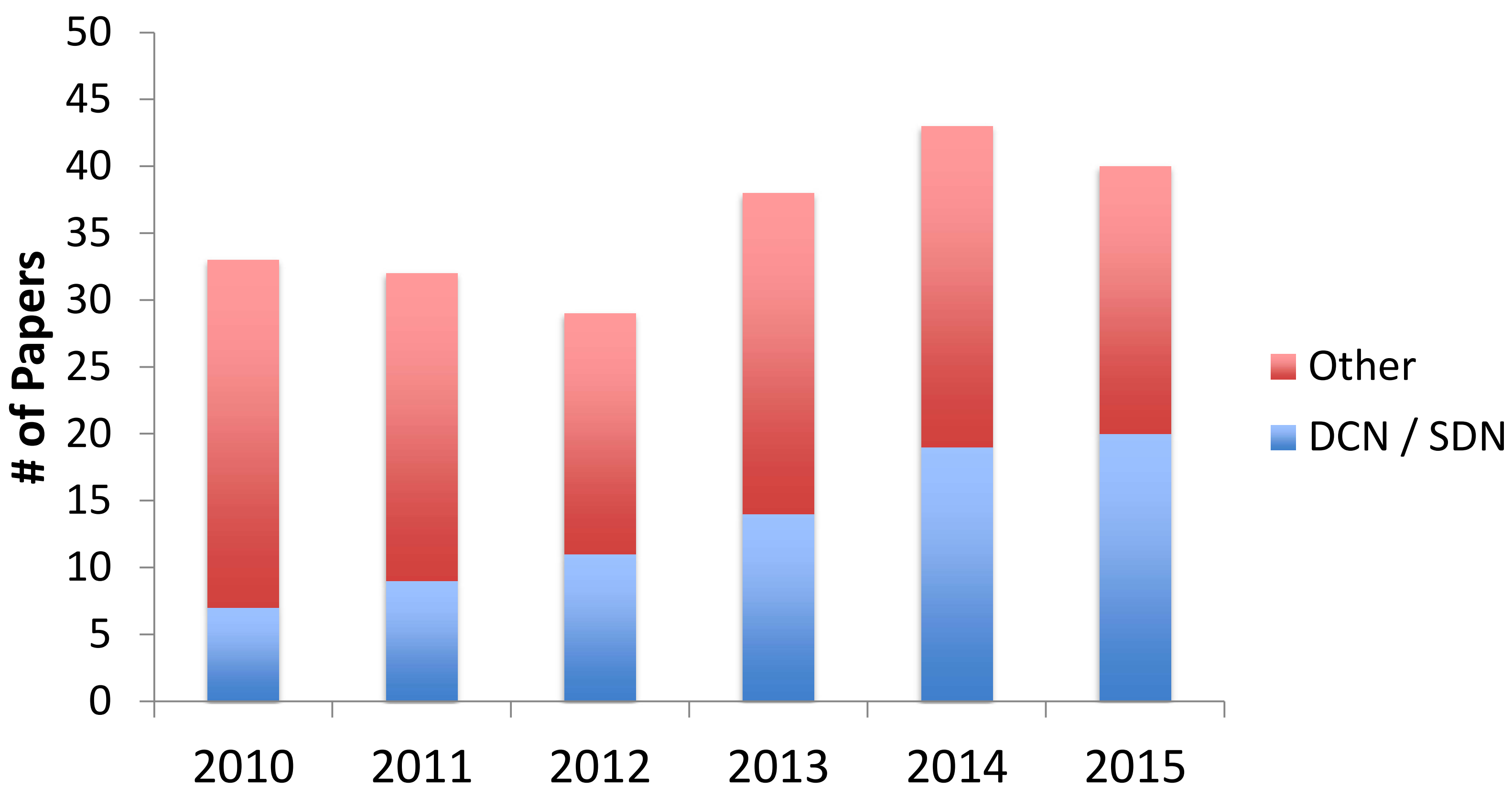
Software Defined Networking

Two "hot" areas of research

Significant interest in both academia & industry

Lots of opportunities for impact

DCN/SDN Papers at SIGCOMM



Readings & Presentations

Each group of two students will present *one* paper on Last Lecture (offline class)

- Read paper and relevant references
- 15 minute talk

Data Center Networking

What are Data Centers?

Large facilities with 10s of thousands of networked servers

- Compute, storage, and networking working in concert
- "Warehouse-Scale Computers"

Types of Data Centers

Specialized data centers built for one big app

- Social networking: Facebook
- Web Search: Google, Bing

"Cloud" data centers

- Amazon EC2, Windows Azure
- Google App Engine

Cloud Computing

On-demand

– Use resources when you need it; pay-as-you-go

Elastic

– Scale up & down based on demand

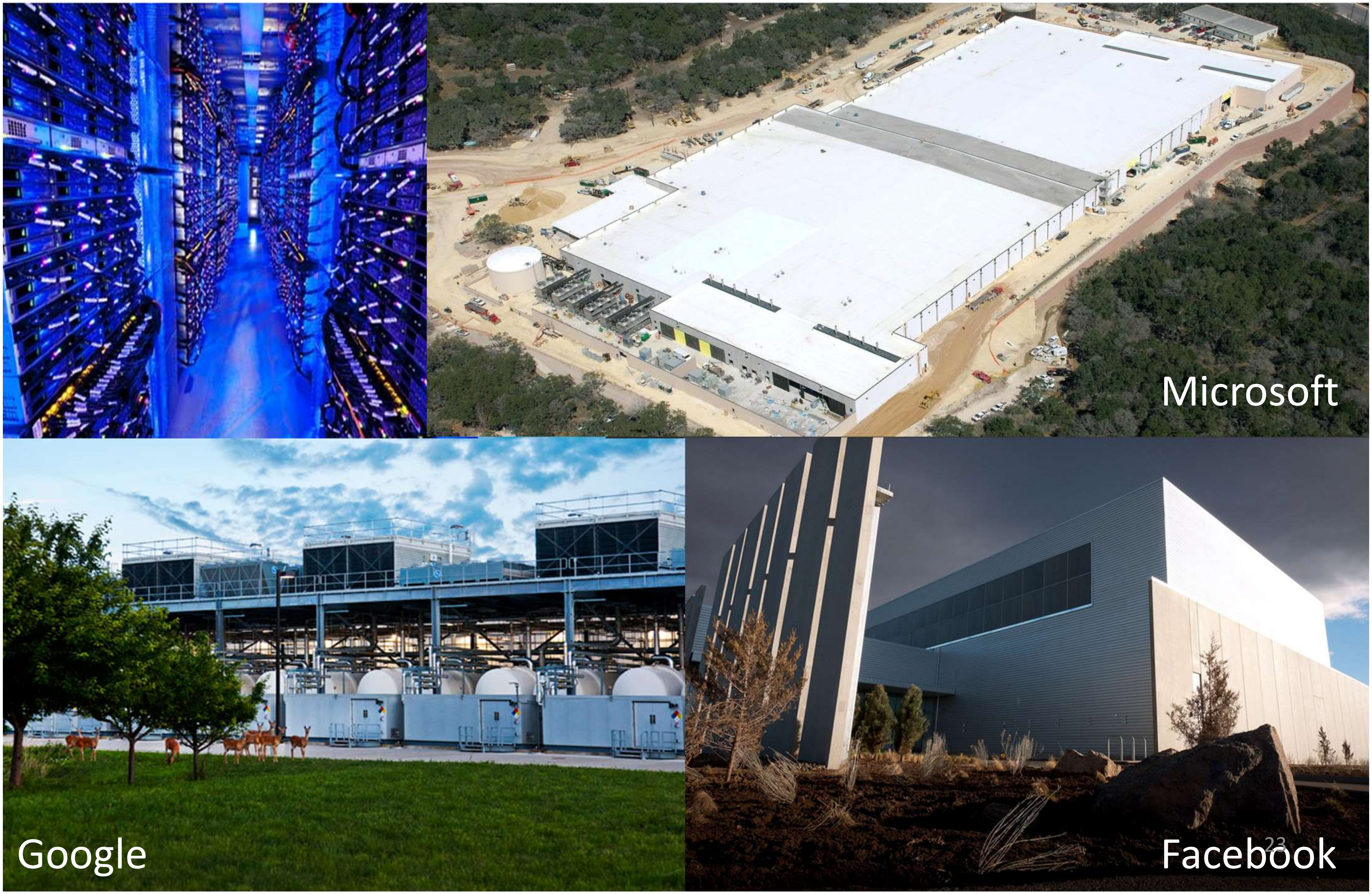
Multi-tenancy

– Multiple independent users share infrastructure
– Security and resource isolation
– SLAs on performance & reliability (sometimes)

Dynamic Management

– Resiliency: isolate failure of servers and storage
– Workload movement: move work to other locations

Data Centers with 100,000+ Servers




Microsoft

These things are *really* big

10-100K servers

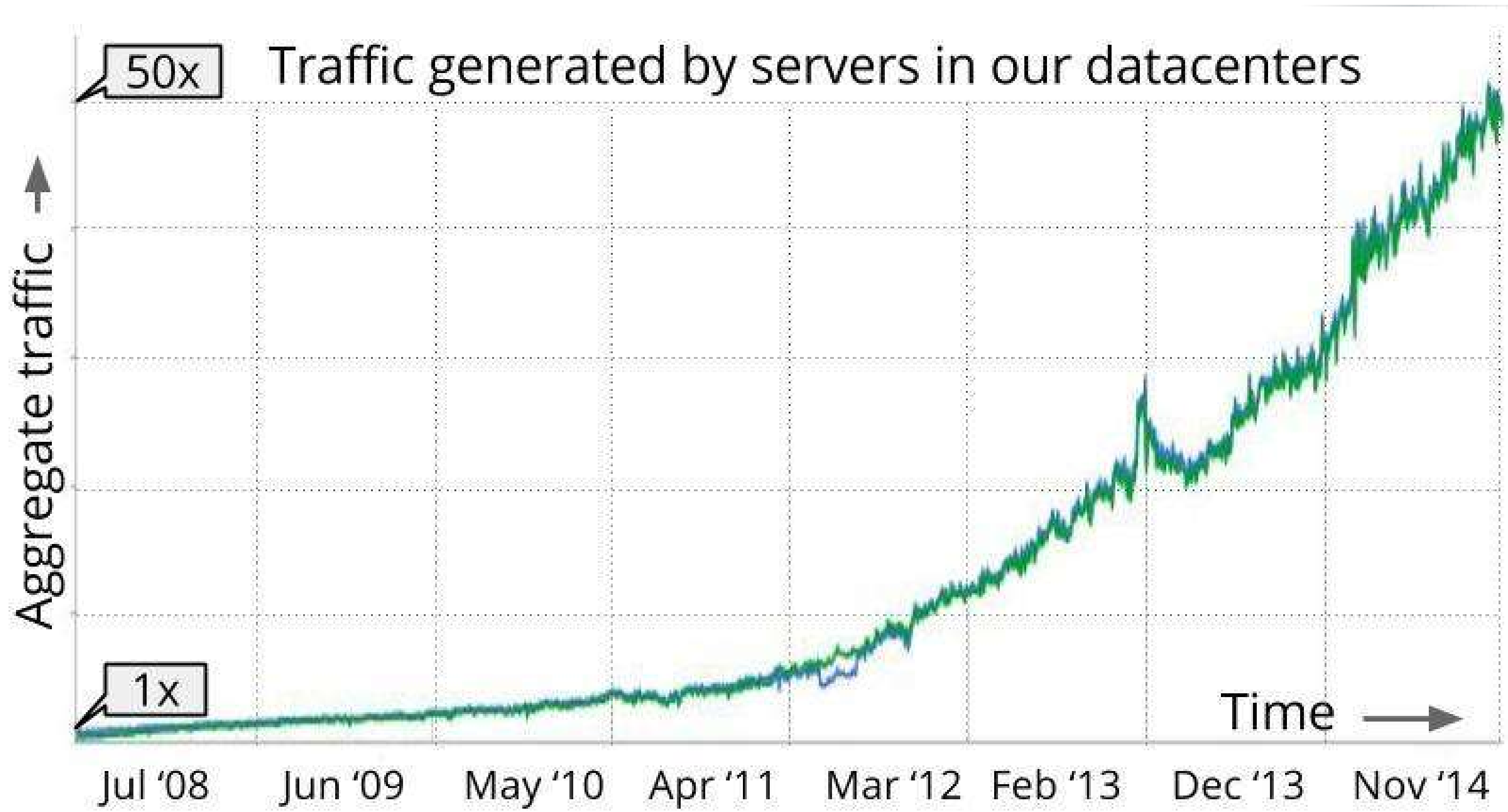
100s of Petabytes of storage

100s of Terabits/s of Bw
(more than core of Internet)

10-100MW of power
(1-2 % of global energy consumption)

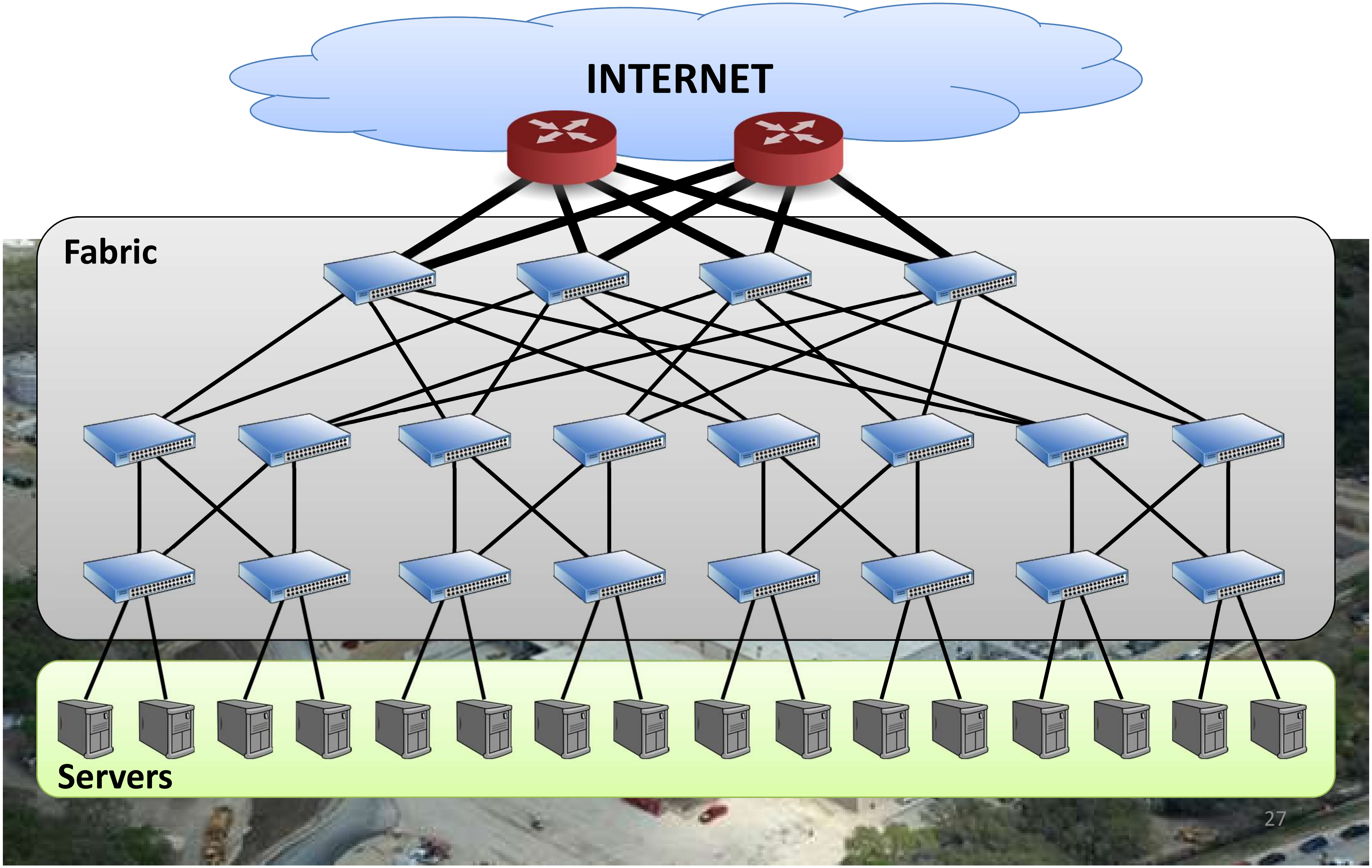
100s of millions of dollars

Datacenter Traffic Growth



✧ Source: "Jupiter Rising: A Decade of Clos Topologies and Centralized Control in Google's Datacenter Network", SIGCOMM 2015.

What's Different about DCNs?



What’s Different about DCNs?

Single administrative domain

No need to be compatible with outside world

Tiny round trip times (microseconds)

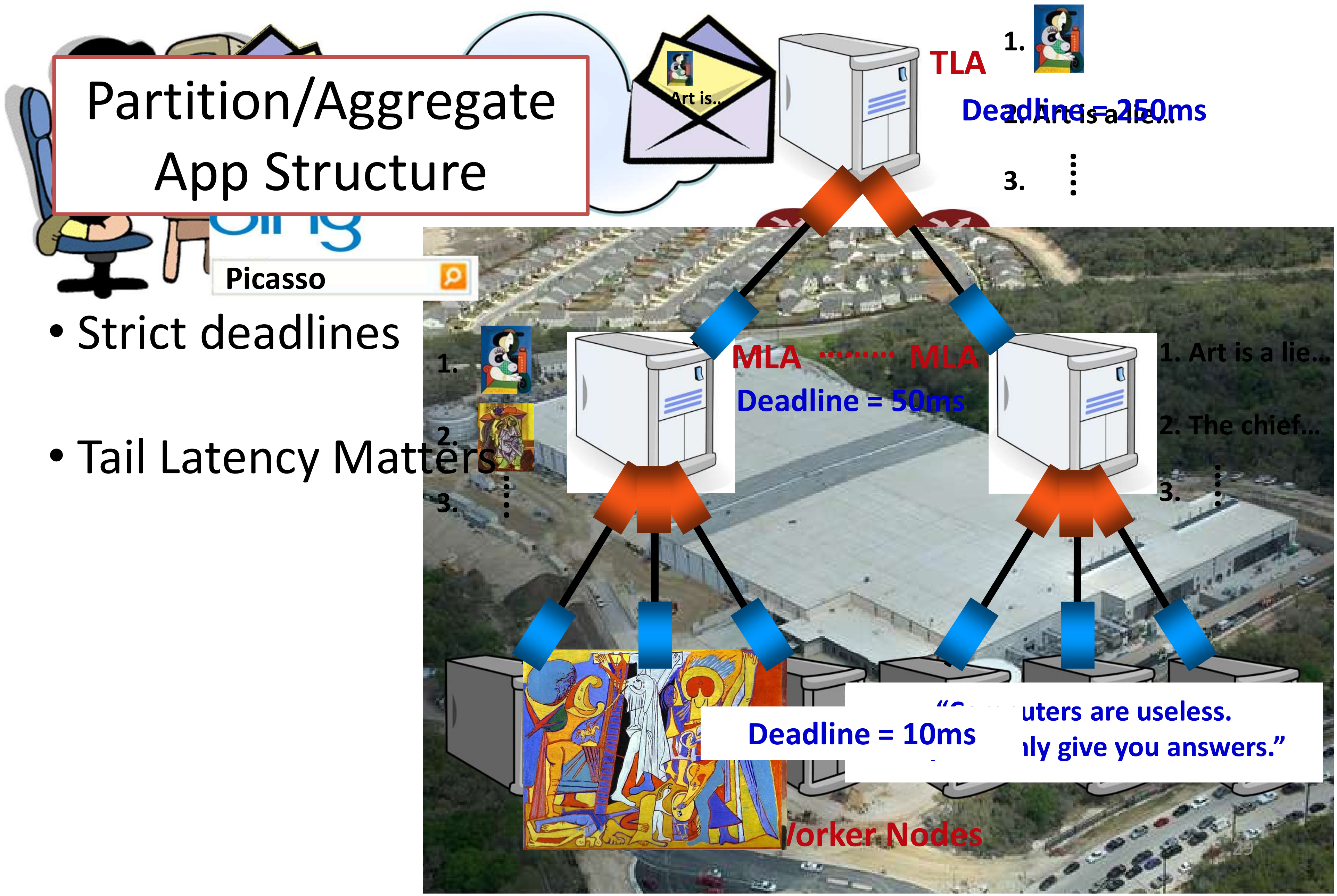
Latency/tail latency critical

Massive multipath topologies

Shallow buffers

Backplane for large-scale parallel computation

Example: Web Search



- Strict deadlines
- Tail Latency Matters

Data Center Challenges

Massive bisection bandwidth

- Topologies
- Load balancing
- Optics

Ultra-Low latency (<10 microseconds)

- Rate-control or packet scheduling?
- Centralized or distributed?

Managing resources across network & servers

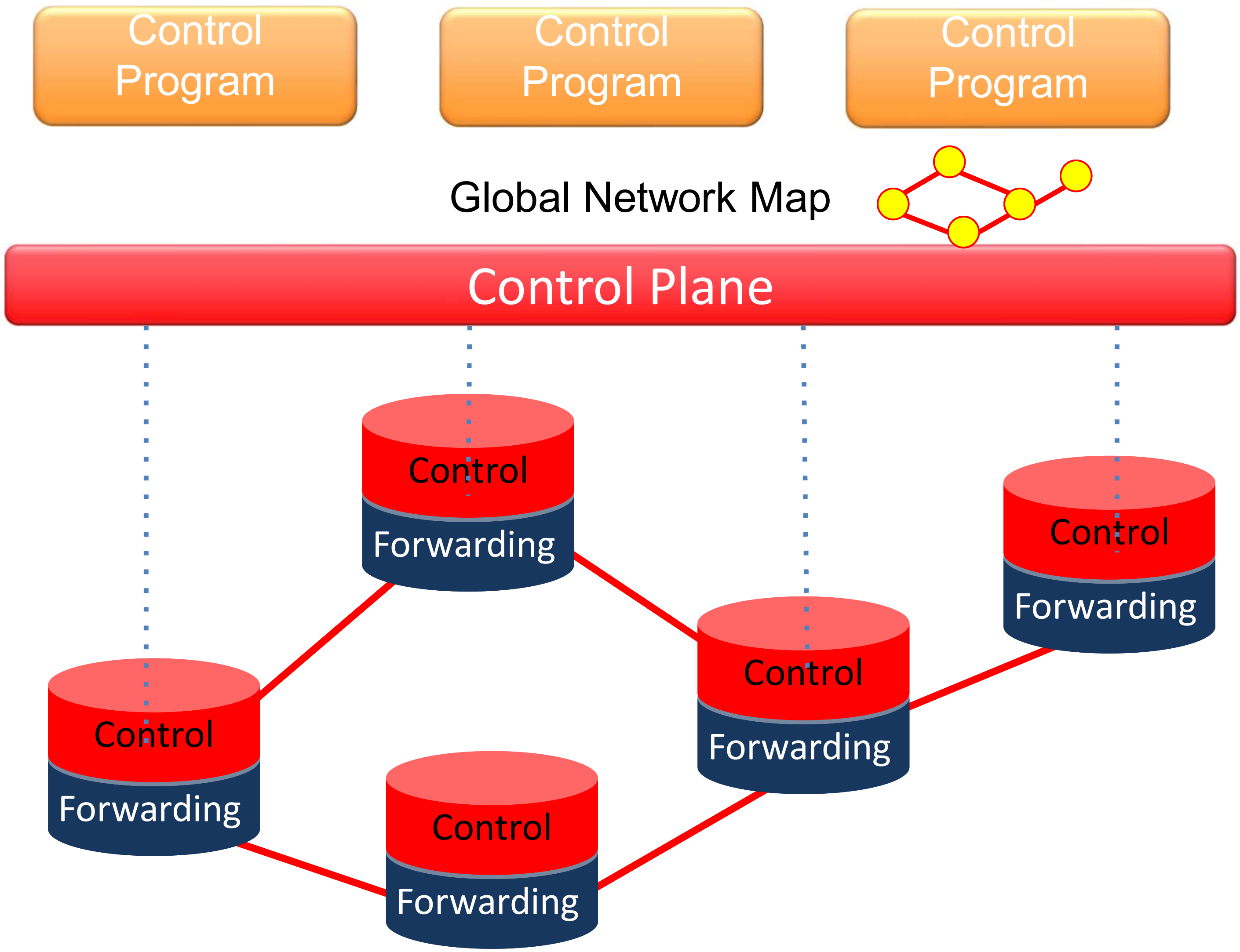
- Multi-tenant performance isolation
- App-aware network scheduling (e.g. for big data)

Next-generation hardware

- RDMA, Rack-Scale Computing

Software Defined Networking

Software Defined Network (SDN)



Software Defined Network

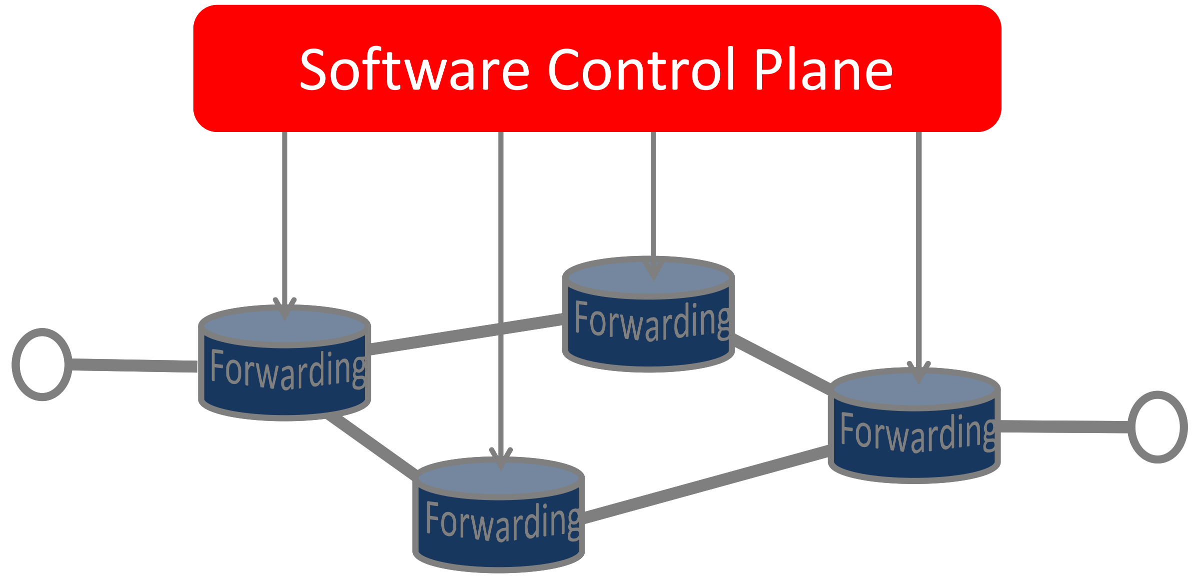
A network in which the control plane is physically separate from the forwarding plane.

and

A single control plane controls several forwarding devices.

(That’s it)

SDN



Intended consequences...

1. Put network owners and operators in control.
2. Networks that are more reliable and more secure.
3. Networks that cost less: simpler, streamlined hardware.
4. Networks that cost less to operate (fewer features).

An example

Routing

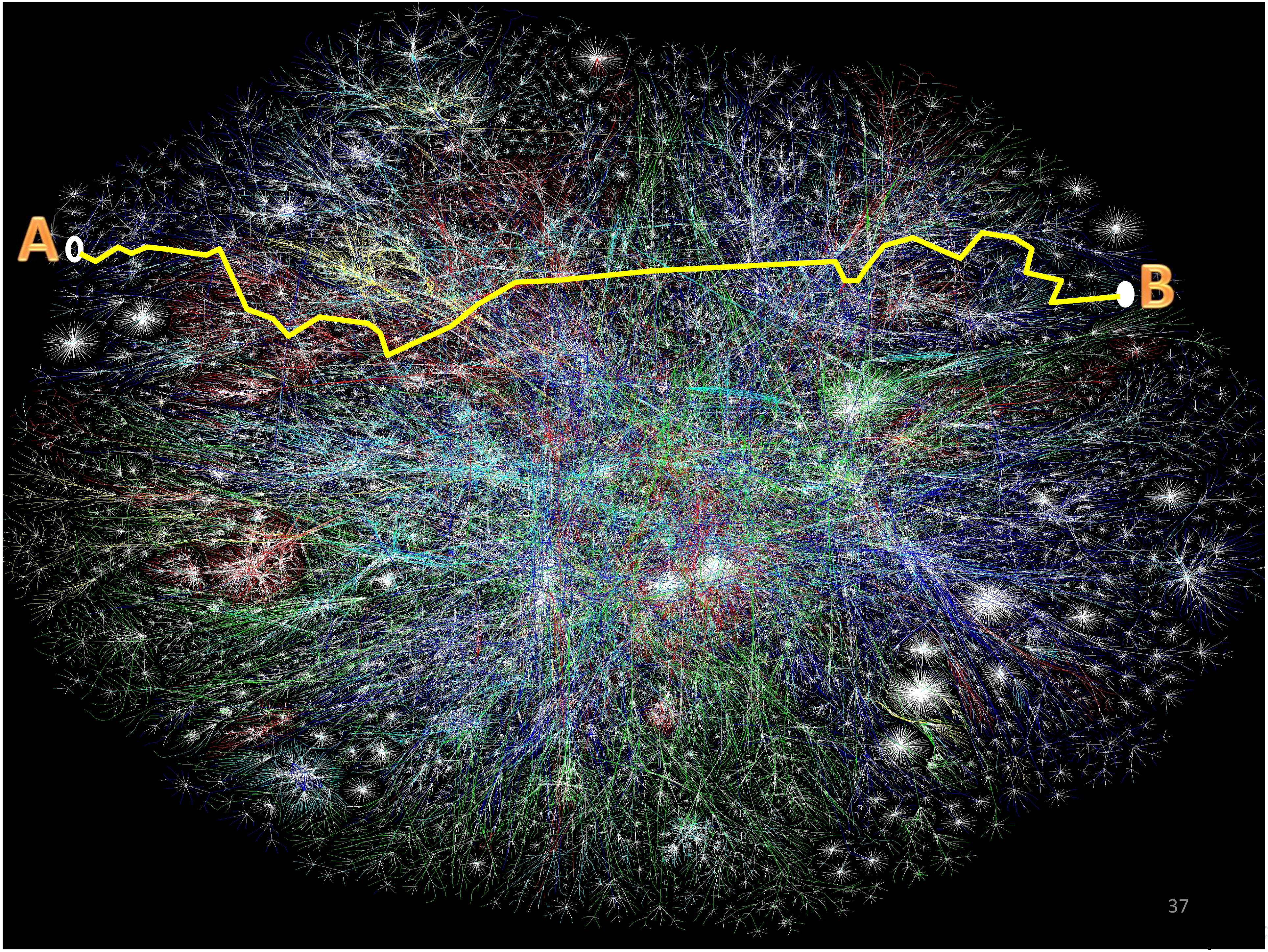
Edsger Dikjstra
1930-2002

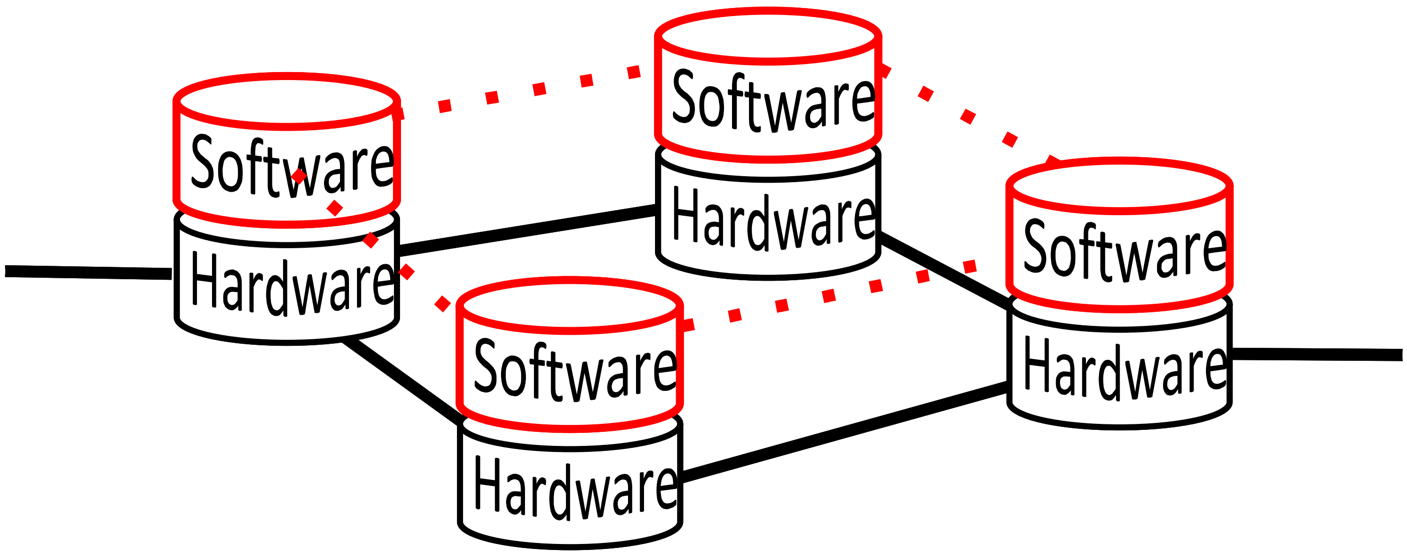
function Dijkstra(Graph, source):

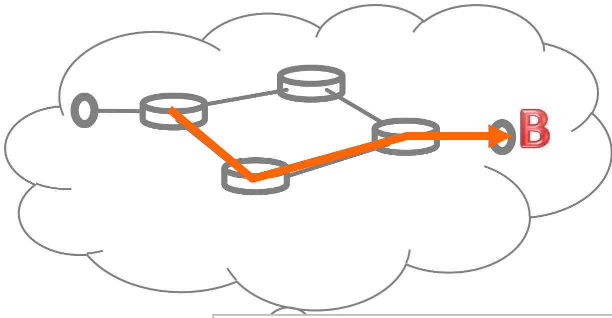
```
    for each vertex v in Graph:
        dist[v]  := infinity ;
        previous[v]  := undefined;
dist[source]  := 0 ;
Q := the set of all nodes in Graph ;
while Q is not empty:                          // The main loop
    u := vertex in Q with smallest distance in dist[] ;
    remove u from Q ;
    if dist[u] = infinity:
        break ;

    for each neighbor v of u:
        alt := dist[u] + dist_between(u, v) ;
        if alt < dist[v]:
            dist[v]  := alt ;
            previous[v]  := u ;
            decrease-key v in Q;
return dist[], previous[];
end function
```

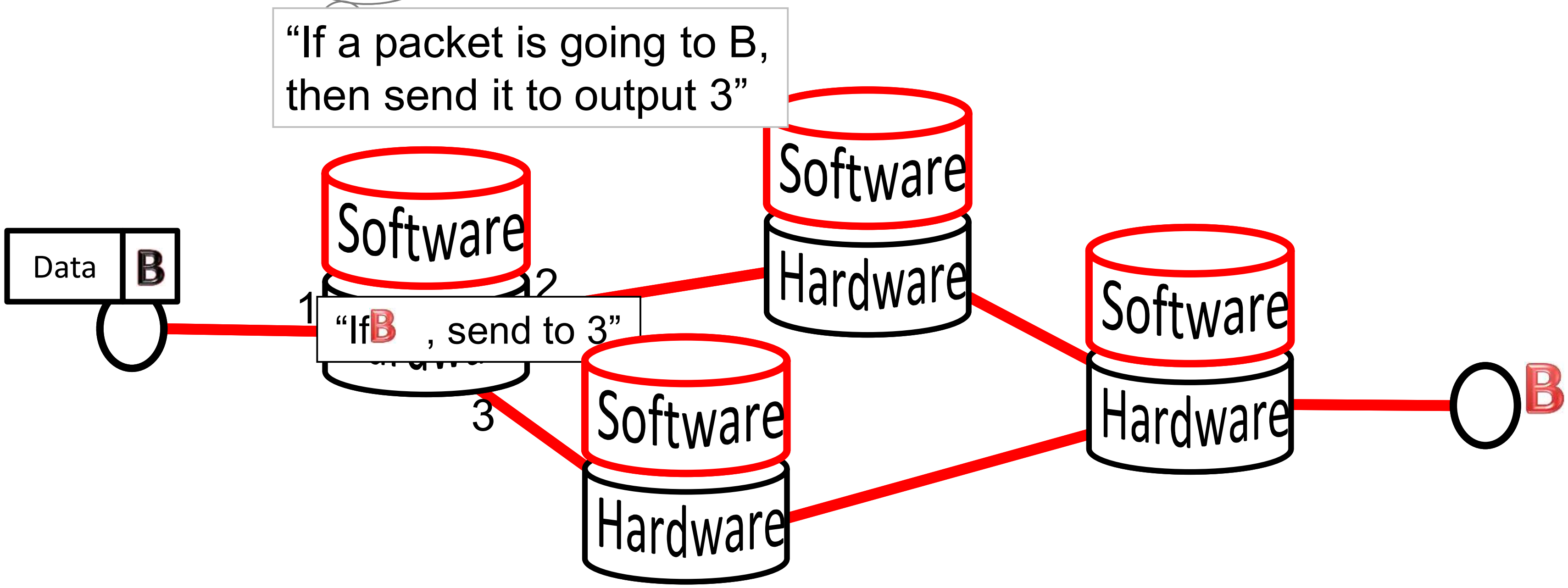
Photo: Hamilton Richards


A
B


Software
Hardware
Software
Hardware
Software
Hardware
Software
Hardware



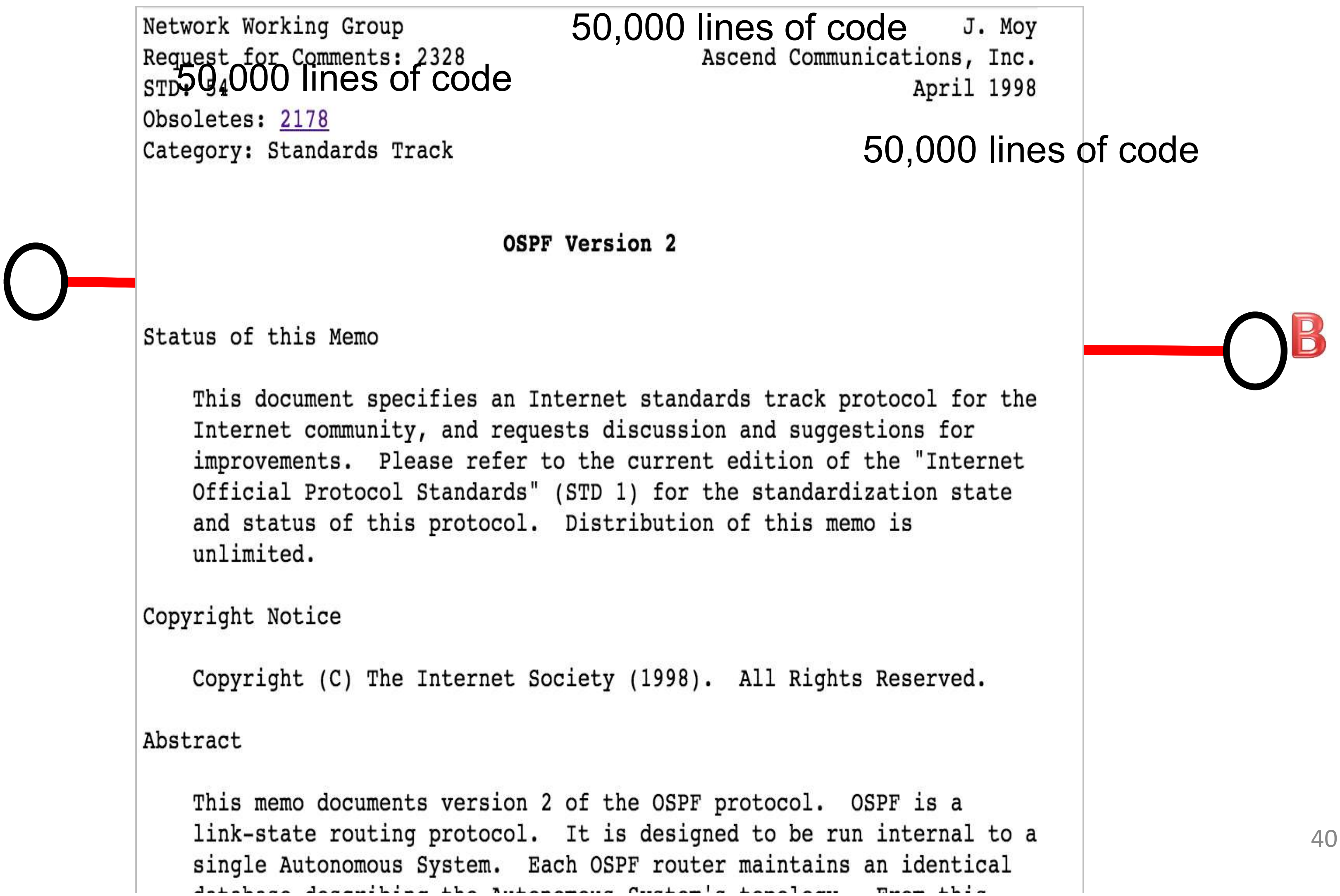
1. Figure out which routers and links are present.
2. Run Dijkstra's algorithm to find shortest paths.



95%

1. Figure out which routers and links are present.
2. Run Dijkstra's algorithm to find shortest paths.

5%



Network Working Group J. Moy
Request for Comments: 2328 Ascend Communications, Inc.
STD: 54 April 1998
Obsoletes: 2178
Category: Standards Track

OSPF Version 2

Status of this Memo

This document specifies an Internet standards track protocol for the Internet community, and requests discussion and suggestions for improvements. Please refer to the current edition of the "Internet Official Protocol Standards" (STD 1) for the standardization state and status of this protocol. Distribution of this memo is unlimited.

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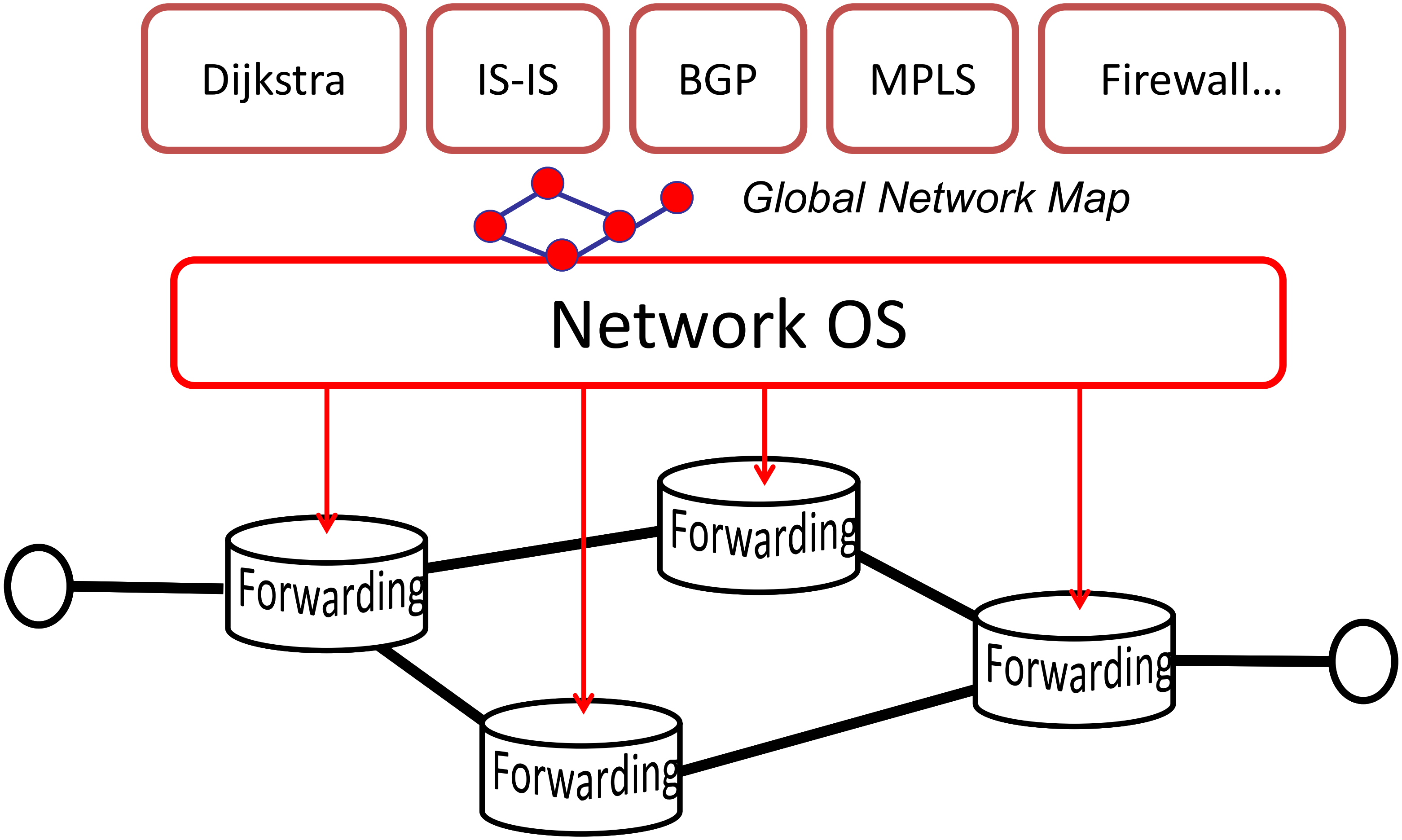
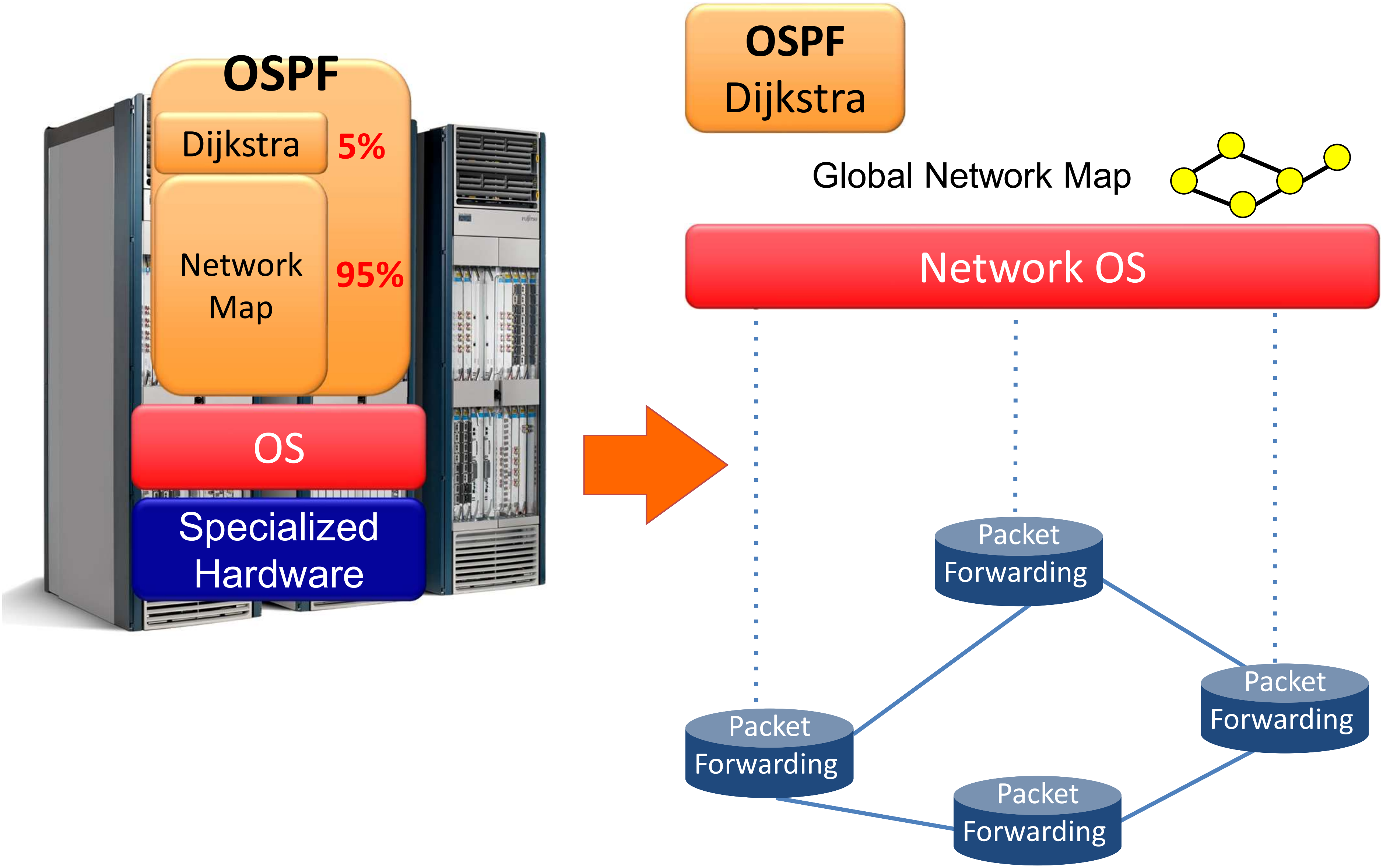
Abstract

This memo documents version 2 of the OSPF protocol. OSPF is a link-state routing protocol. It is designed to be run internal to a single Autonomous System. Each OSPF router maintains an identical

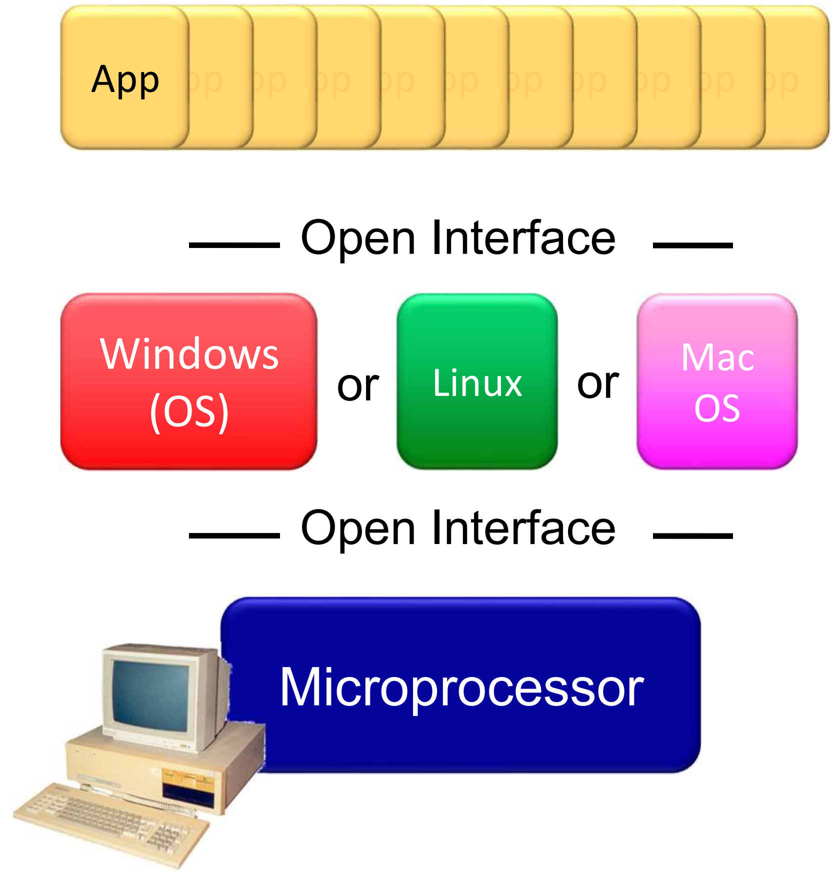

Dijkstra
IS-IS
BGP
MPLS
Firewall…
Global Network Map
Network OS
Forwarding
Forwarding
Forwarding
Forwarding


OSPF
Dijkstra
5%
Network Map
95%
OS
Specialized Hardware
OSPF
Dijkstra
Global Network Map
Network OS
Packet Forwarding
Packet Forwarding
Packet Forwarding
Packet Forwarding

Hundreds of protocols
6,500 RFCs

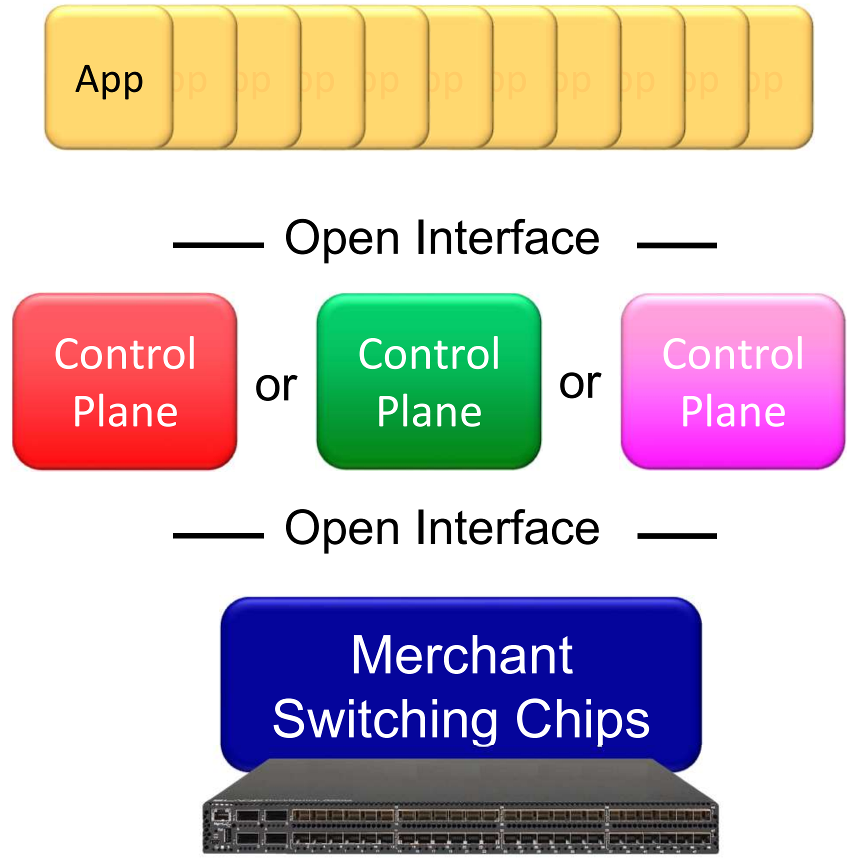
Tens of millions of lines of code.
Closed, proprietary, outdated.

Billions of gates.
Power hungry and bloated.



Vertically integrated
Closed, proprietary
Slow innovation
Small industry

Horizontal
Open interfaces
Rapid innovation
Huge industry



Vertically integrated
Closed, proprietary
Slow innovation

Horizontal
Open interfaces
Rapid innovation

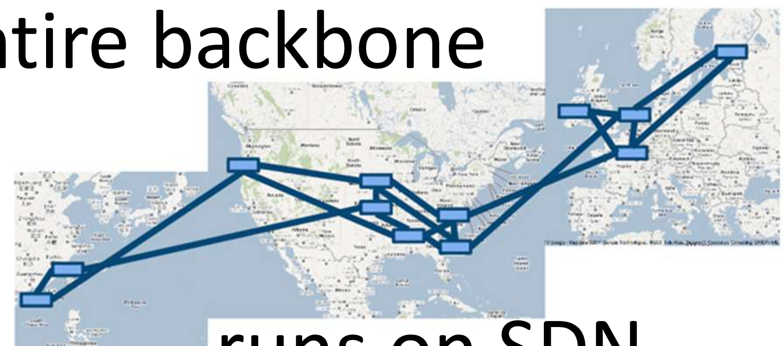
A Major Trend in Networking

OPEN NETWORKING FOUNDATION

Deutsche Telekom · facebook · Goldman Sachs · Google · Microsoft · NTT Communications · verizon · YAHOO!

Google

Entire backbone



runs on SDN

nicira

Bought for **$1.2 billion**
(mostly cash)

An Opportunity to Rethink

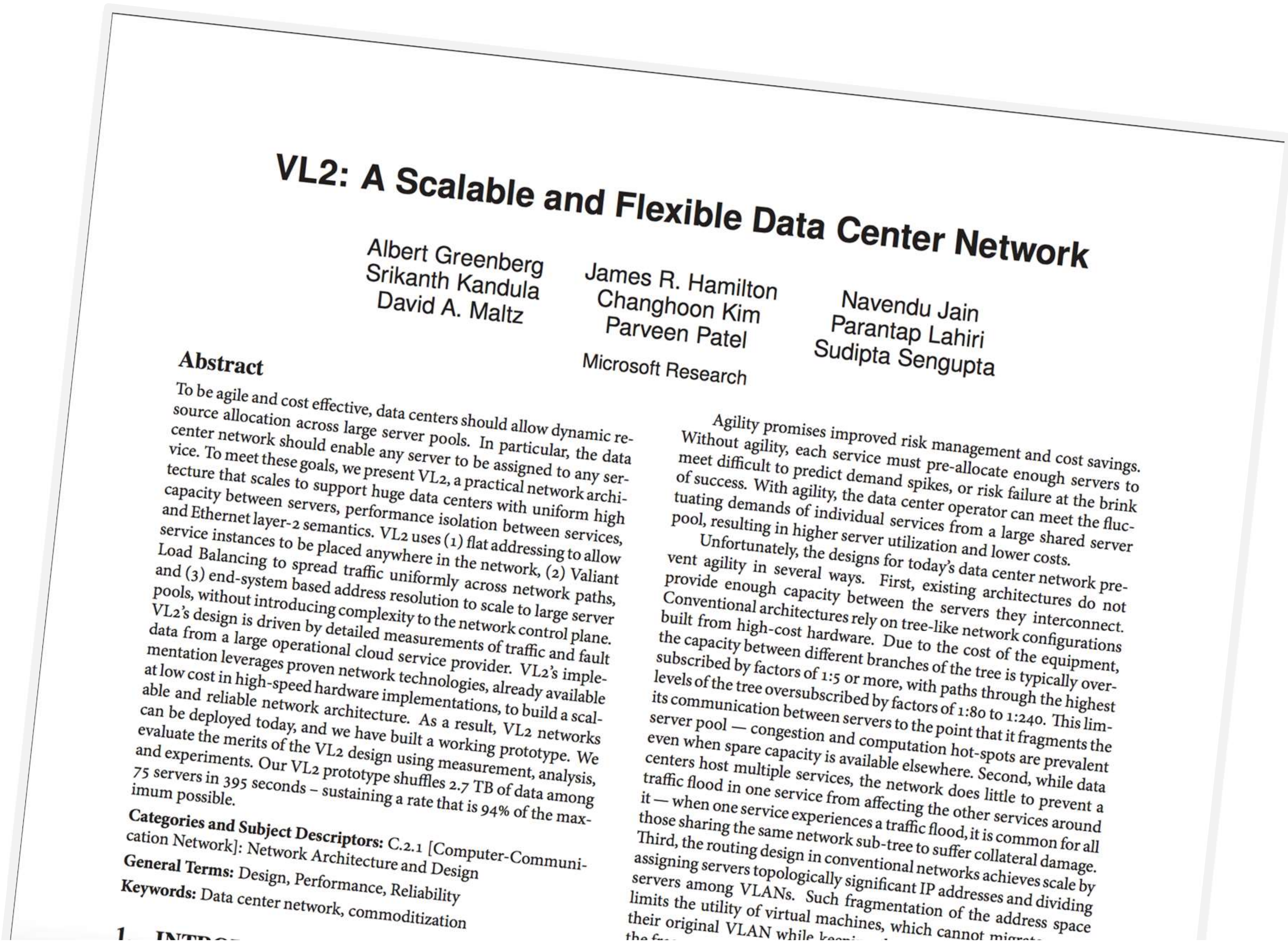
How should future networks be

- Designed
- Managed
- Programmed

What are the right abstractions

- Simple
- Powerful
- Reusable

For next time…



VL2: A Scalable and Flexible Data Center Network

Albert Greenberg, Srikanth Kandula, David A. Maltz, James R. Hamilton, Changhoon Kim, Parveen Patel, Navendu Jain, Parantap Lahiri, Sudipta Sengupta

Microsoft Research

Abstract

To be agile and cost effective, data centers should allow dynamic resource allocation across large server pools. In particular, the data center network should enable any server to be assigned to any service. To meet these goals, we present VL2, a practical network architecture that scales to support huge data centers with uniform high capacity between servers, performance isolation between services, and Ethernet layer-2 semantics. VL2 uses (1) flat addressing to allow service instances to be placed anywhere in the network, (2) Valiant Load Balancing to spread traffic uniformly across network paths, and (3) end-system based address resolution to scale to large server pools, without introducing complexity to the network control plane. VL2's design is driven by detailed measurements of traffic and fault data from a large operational cloud service provider. VL2's implementation leverages proven network technologies, already available at low cost in high-speed hardware implementations, to build a scalable and reliable network architecture. As a result, VL2 networks can be deployed today, and we have built a working prototype. We evaluate the merits of the VL2 design using measurement, analysis, and experiments. Our VL2 prototype shuffles 2.7 TB of data among 75 servers in 395 seconds – sustaining a rate that is 94% of the maximum possible.

Categories and Subject Descriptors: C.2.1 [Computer-Communication Network]: Network Architecture and Design

General Terms: Design, Performance, Reliability

Keywords: Data center network, commoditization

Agility promises improved risk management and cost savings. Without agility, each service must pre-allocate enough servers to meet difficult to predict demand spikes, or risk failure at the brink of success. With agility, the data center operator can meet the fluctuating demands of individual services from a large shared server pool, resulting in higher server utilization and lower costs.

Unfortunately, the designs for today's data center network prevent agility in several ways. First, existing architectures do not provide enough capacity between the servers they interconnect. Conventional architectures rely on tree-like network configurations built from high-cost hardware. Due to the cost of the equipment, the capacity between different branches of the tree is typically oversubscribed by factors of 1:5 or more, with paths through the highest levels of the tree oversubscribed by factors of 1:80 to 1:240. This limits communication between servers to the point that it fragments the server pool — congestion and computation hot-spots are prevalent even when spare capacity is available elsewhere. Second, while data centers host multiple services, the network does little to prevent a traffic flood in one service from affecting the other services around it — when one service experiences a traffic flood, it is common for all those sharing the same network sub-tree to suffer collateral damage. Third, the routing design in conventional networks achieves scale by assigning servers topologically significant IP addresses and dividing servers among VLANs. Such fragmentation of the address space limits the utility of virtual machines, which cannot migrate out of their original VLAN while keeping …