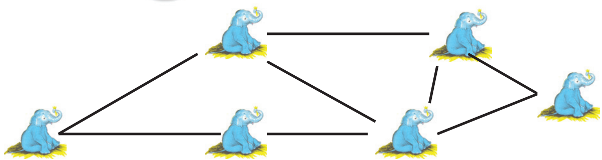
Networking Issues For Big Data



Raj Jain
Washington University in Saint Louis
Saint Louis, MO 63130
Jain@cse.wustl.edu

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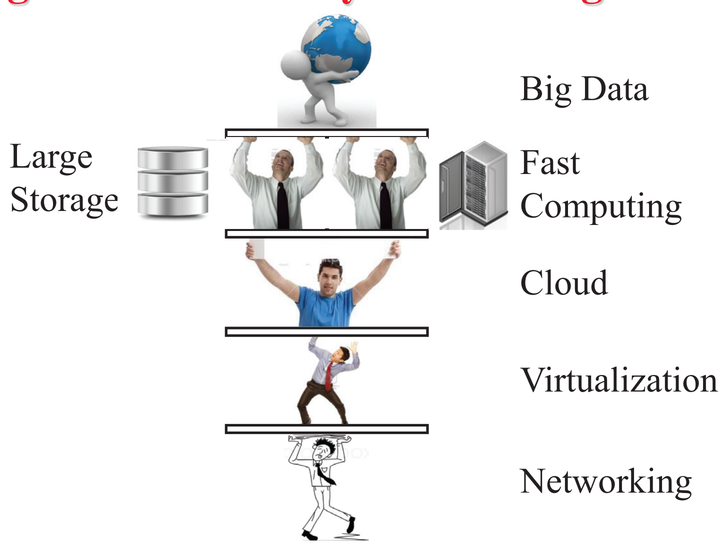
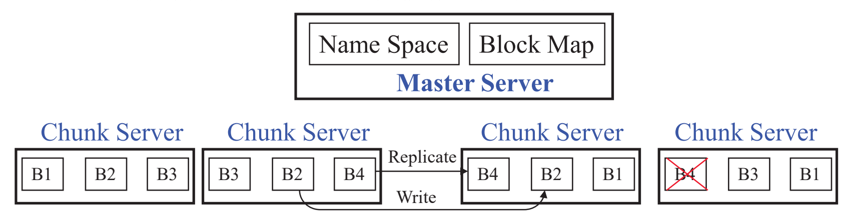
1. Why, What, and How of Big Data:
   It's all because of advances in networking
2. Recent Developments in Networking and their role in Big Data (Virtualization, SDN, NFV)
3. Networking needs Big Data

Big Data Enabled by Networking



Google File System

- Commodity computers serve as "Chunk Servers" and store multiple copies of data blocks
- A master server keeps a map of all chunks of files and location of those chunks.
- All writes are propagated by the writing chunk server to other chunk servers that have copies.
- Master server controls all read-write accesses



Ref: S. Ghemawat, et al., "The Google File System", OSP 2003, http://research.google.com/archive/gfs.html

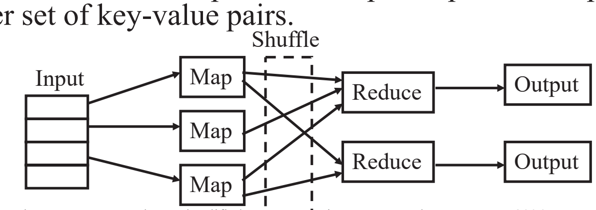
BigTable

- Distributed storage system built on Google File System
- Data stored in rows and columns
- Optimized for sparse, persistent, multidimensional sorted map.
- Uses commodity servers
- Not distributed outside of Google but accessible via Google App Engine

Ref: F. Chang, et al., "Bigtable: A Distributed Storage System for Structured Data," 2006, http://research.google.com/archive/bigtable.html

MapReduce

- Software framework to process massive amounts of unstructured data in parallel
- **Goals**:
  - Distributed: over a large number of inexpensive processors
  - Scalable: expand or contract as needed
  - Fault tolerant: Continue in spite of some failures
- **Map**: Takes a set of data and converts it into another set of key-value pairs..
- **Reduce**: Takes the output from Map as input and outputs a smaller set of key-value pairs.



Ref: J. Dean and S. Ghemawat, "MapReduce: Simplified Data Processing on Large Clusters," OSDI 2004, http://research.google.com/archive/mapreduce-osdi04.pdf

MapReduce Example

- 100 files with daily temperature in two cities. Each file has 10,000 entries.
- For example, one file may have (Toronto 20), (New York 30), ..
- Our goal is to compute the maximum temperature in the two cities.
- Assign the task to 100 Map processors each works on one file. Each processor outputs a list of key-value pairs, e.g., (Toronto 30), New York (65), …
- Now we have 100 lists each with two elements. We give this list to two reducers – one for Toronto and another for New York.
- The reducer produce the final answer: (Toronto 55), (New York 65)

Ref: IBM. "What is MapReduce?," http://www-01.ibm.com/software/data/infosphere/hadoop/mapreduce/

MapReduce Optimization

- **Scheduling**:
  - Task is broken into pieces that can be computed in parallel
  - Map tasks are scheduled before the reduce tasks.
  - If there are more map tasks than processors, map tasks continue until all of them are complete.
  - A new strategy is used to assign Reduce jobs so that it can be done in parallel
  - The results are combined.
- **Synchronization**: The map jobs should be comparables so that they finish together. Similarly reduce jobs should be comparable.
- **Code/Data Collocation**: The data for map jobs should be at the processors that are going to map.
- **Fault/Error Handling**: If a processor fails, its task needs to be assigned to another processor.

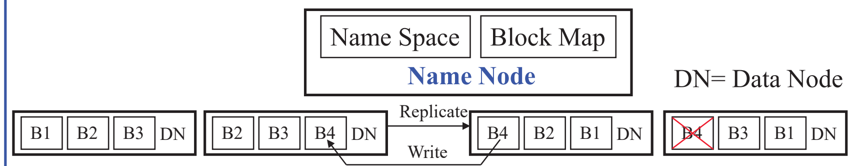
Story of Hadoop

- Doug Cutting at Yahoo and Mike Caferella were working on creating a project called “Nutch” for large web index.
- They saw Google papers on MapReduce and Google File System and used it
- Hadoop was the name of a yellow plus elephant toy that Doug’s son had.
- In 2008 Amr left Yahoo to found Cloudera. In 2009 Doug joined Cloudera.

Ref: Michael Minelli, "Big Data, Big Analytics: Emerging Business Intelligence and Analytic Trends for Today's Businesses," Wiley, 2013, ISBN:'111814760X

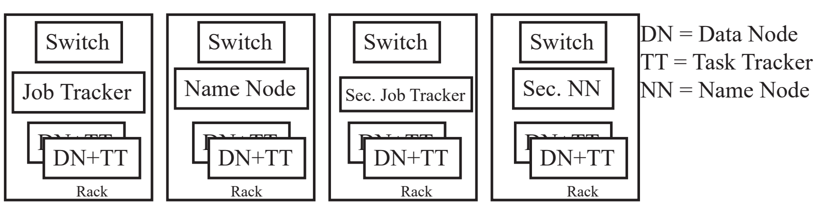
Hadoop

- An open source implementation of MapReduce
- Named by Doug Cutting at Yahoo after his son’s yellow plus elephant
- Hadoop File System (**HDFS**) requires data to be broken into blocks. Each block is stored on 2 or more data nodes on different racks.
- **Name node**: Manages the file system name space ⇒ keeps track of blocks on various **Data Nodes**.



Hadoop (Cont)

- **Job Tracker**: Assigns MapReduce jobs to task tracker nodes that are close to the data (same rack)
- **Task Tracker**: Keep the work as close to the data as possible.



Hadoop (Cont)

- Data nodes get the data if necessary, do the map function, and write the results to disks.
- Job tracker than assigns the reduce jobs to data nodes that have the map output or close to it.
- All data has a check attached to it to verify its integrity.

Networking Requirements for Big Data

1. **Code/Data Collocation**: The data for map jobs should be at the processors that are going to map.
2. **Elastic bandwidth**: to match the variability of volume
3. **Fault/Error Handling**: If a processor fails, its task needs to be assigned to another processor.
4. **Security**: Access control (authorized users only), privacy (encryption), threat detection, all in real-time in a highly scalable manner
5. **Synchronization**: The map jobs should be comparables so that they finish together. Similarly reduce jobs should be comparable.

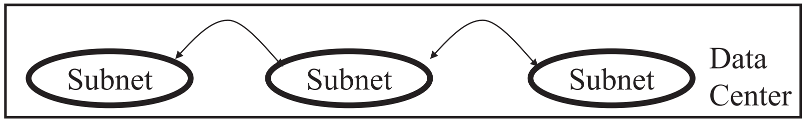
Recent Developments in Networking

1. High-Speed: 100 Gbps Ethernet
   ⇒ 400 Gbps ⇒ 1000 Gbps
   ⇒ Cheap storage access. Easy to move big data.
2. Virtualization
3. Software Defined Networking
4. Network Function Virtualization

Virtualization (Cont)

- Recent networking technologies and standards allow:
  1. Virtualizing Computation
  2. Virtualizing Storage
  3. Virtualizing Rack Storage Connectivity
  4. Virtualizing Data Center Storage
  5. Virtualizing Metro and Global Storage

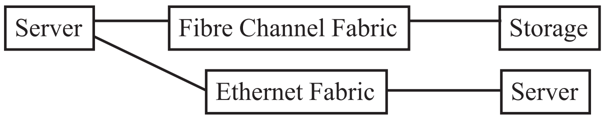
1. Virtualizing Computation



- Initially data centers consisted of multiple IP subnets
  - Each subnet = One Ethernet Network
  - Ethernet addresses are globally unique and do not change
  - IP addresses are locators and change every time you move
  - If a VM moves inside a subnet ⇒ No change to IP address ⇒ Fast
  - If a VM moves from one subnet to another ⇒ Its IP address changes ⇒ All connections break ⇒ Slow ⇒ Limited VM mobility
- IEEE 802.1ad-2005 Ethernet Provider Bridging (PB), IEEE 802.1ah-2008 Provider Backbone Bridging (PBB) allow Ethernets to span long distances ⇒ Global VM mobility

2. Virtualizing Storage

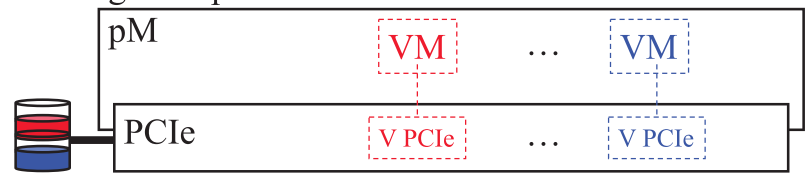
- Initially data centers used Storage Area Networks (Fibre Channel) for server-to-storage communications and Ethernet for server-to-server communication



- IEEE added 4 new standards to make Ethernet offer low loss, low latency service like Fibre Channel:
  - Priority-based Flow Control (IEEE 802.1Qbb-2011)
  - Enhanced Transmission Selection (IEEE 802.1Qaz-2011)
  - Congestion Control (IEEE 802.1Qau-2010)
  - Data Center Bridging Exchange (IEEE 802.1Qaz-2011)
- Result: Unified networking ⇒ Significant CapEx/OpEx saving

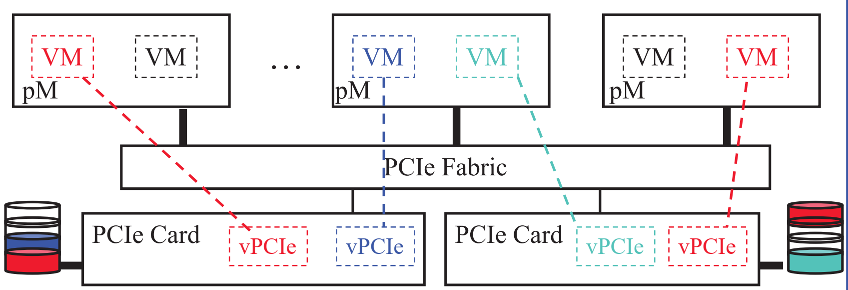
3. Virtualizing Rack Storage Connectivity

- MapReduce jobs are assigned to the nodes that have the data
- Job tracker assigns jobs to task trackers in the rack where the data is.
- High-speed Ethernet can get the data in the same rack.
- Peripheral Connect Interface (PCI) Special Interest Group (SIG)'s Single Root I/O virtualization (**SR-IOV**) allows a storage to be virtualized and shared among multiple VMs.



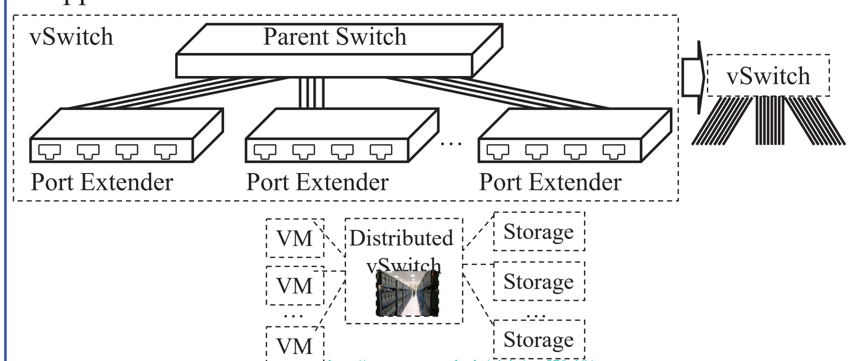
Multi-Root IOV

- PCI-SIG Multi-Root I/O Virtualization (**MR-IOV**) standard allows one or more PCIe cards to serve multiple servers and VMs in the same rack
- Fewer adapters ⇒ Less cooling. No adapters ⇒ Thinner servers



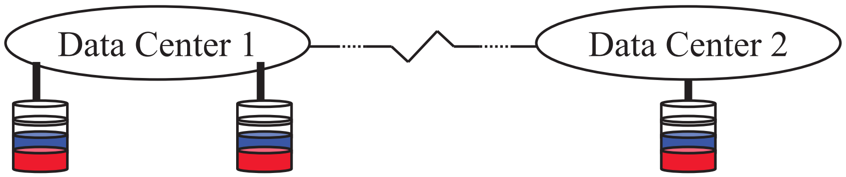
4. Virtualizing Data Center Storage

- IEEE 802.1BR-2012 Virtual Bridgeport Extension (VBE) allows multiple switches to combine in to a very large switch
- Storage and computers located anywhere in the data center appear as if connected to the same switch



5. Virtualizing Metro Storage

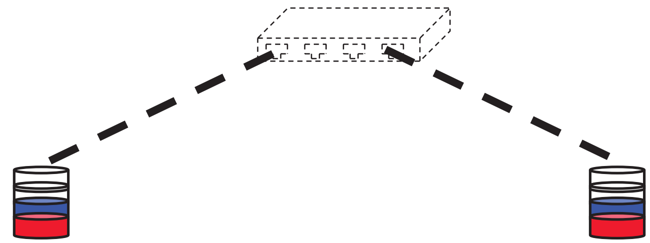
- Data center Interconnection standards:
  - Virtual Extensible LAN (VXLAN),
  - Network Virtualization using GRE (NVGRE), and
  - Transparent Interconnection of Lots of Link (TRILL)
  - ⇒ data centers located far away to appear to be on the same Ethernet



Ref: http://tools.ietf.org/html/draft-mahalingam-dutt-dcops-vxlan-04, http://tools.ietf.org/html/draft-sridharan-virtualization-nvgre-03, RFC 5556

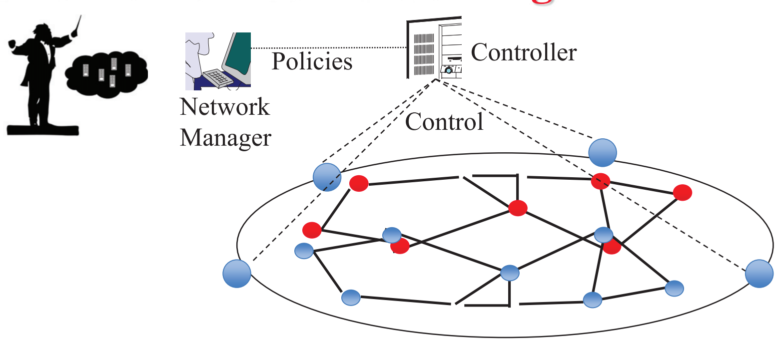
Virtualizing the Global Storage

- Energy Science Network (ESNet) uses virtual switch to connect members located all over the world
- Virtualization ⇒ Fluid networks ⇒ The world is flat ⇒ You draw your network ⇒ Every thing is virtually local



Ref: I. Monga, "Software Defined Networking for Big-data Science," http://www.es.net/assets/pubs_presos/Monga-WAN-Switch-SC12SRS.pdf

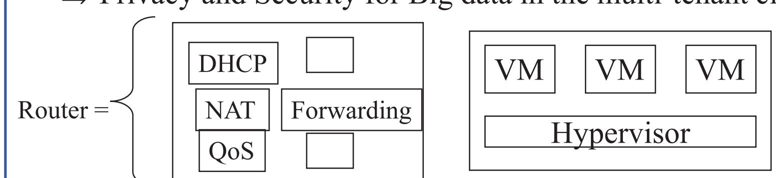
Software Defined Networking



- Centralized Programmable Control Plane
- Allows automated orchestration (provisioning) of a large number of virtual resources (machines, networks, storage)
- Large Hadoop topologies can be created on demand

Network Function Virtualization (NFV)

- Fast standard hardware ⇒ Software based Devices
  Virtual networking modules (DHCP, Firewall, DNS, …) running on standard processors
- Modules can be combined to create any combination of function for data privacy, access control, …
- Virtual Machine implementation ⇒ Quick provisioning
- Standard Application Programming Interfaces (APIs)
  ⇒ Networking App Market
  ⇒ Privacy and Security for Big data in the multi-tenant clouds



Big Data for Networking

- Today's data center:
  - Tens of tenants
  - Hundreds of switches and routers
  - Thousands of servers
  - Hundreds of administrators
- Tomorrow:
  - 1k of clients
  - 10k of pSwitches ⇒ 100k of vSwitches
  - 1M of VMs
  - Tens of Administrators
- Need to monitor traffic patterns and rearrange virtual networks connecting millions of VMs in real-time ⇒ Managing clouds is a real-time big data problem.
- Internet of things ⇒ Big Data generation and analytics

Summary

1. I/O virtualization allows all storage in the rack to appear local to any VM in that rack ⇒ Solves the co-location problem of MapReduce
2. Network virtualization allows storage anywhere in the data center or even other data centers to appear local
3. Software defined networking allows orchestration of a large number of resources ⇒ Dynamic creation of Hadoop clusters
4. Network function virtualization will allow these clusters to have special functions and security in multi-tenant clouds.

Acronyms

ADCOM	Advanced Computing and Communications
API	Application programming interface,
CapEx	Capital Expenditure
DARPA	Defense Advanced Project Research Agency
DHCP	Dynamic Host Control Protocol
DN	Data Node
DNS	Domain Name System
DoD	Department of Defense
DOE	Department of Energy
ESNet	Energy Science Network
GDP	Gross Domestic Production
GRE	Generic Routing Encapsulation
HDFS	Hadoop Distributed File System
IEEE	Institution of Electrical and Electronic Engineers
IOV	I/O Virtualization
IP	Internet Protocol

Acronyms (Cont)

LAN	Local Area Network
MR-IOV	Multi-root I/O Vertualization
NAT	Network Address Translation
NFV	Network Function Virtualization
NN	Name Node
NSA	National Security Agency
OpEx	Operational Expences
PB	Provider Bridging
PBB	Provider Backbone Bridging
PCI-SIG	PCI Special Interest Group
PCI	Peripheral Computer Interface
PCIe	PCI Express
pM	Physical Machine
pSwitches	Physical Switch
QoS	Quality of Service
RFC	Request for Comments

Acronyms (Cont)

- SDN .Software Defined Networking
- SR-IOV Single Root I/O Vertualization
- TRILL Transparent Interconnection of Lots of Link
- TT Task Tracker
- USGS United States Geological Survey
- VBE Virtual Bridgeport Extension
- VM Virtual Machine
- vSwitch Virtual Switch
- WAN Wide-Area Network

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Raj Jain
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CSE473S: Introduction to Computer Networks (Fall 2011),
https://www.youtube.com/playlist?list=PLjGG94etKypJWOSPMh8Azcgy5e_10TiDw

Wireless and Mobile Networking (Spring 2016),
https://www.youtube.com/playlist?list=PLjGG94etKypKeb0nzyN9tSs_HCd5c4wXF

CSE571S: Network Security (Fall 2011),
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