CS 5413: High Performance Systems and Networking

Hakim Weatherspoon

Assistant Professor, Dept of Computer Science

CS 5413: High Performance Systems and Networking

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Goals for Today

- Background
- Why take this course?
- How does this class operate?
- Class details

Who am I?

- Prof. Hakim Weatherspoon
  - (Hakim means Doctor, wise, or prof. in Arabic)
  - Background in Education
    - Undergraduate University of Washington
      - Played Varsity Football
        - » Some teammates collectively make $100's of millions
        - » I teach!!!
    - Graduate University of California, Berkeley
      - Some class mates collectively make $100's of millions
      - I teach!!!
  - Background in Operating Systems
    - Peer-to-Peer Storage
      - Antiquity project - Secure wide-area distributed system
      - OceanStore project – Store your data for 1000 years
    - Network overlays
      - Bamboo and Tapestry – Find your data around globe
    - Tiny OS
      - Early adopter in 1999, but ultimately chose P2P direction

Context

- The promise of the Cloud
  - A computer utility; a commodity
  - Catalyst for technology economy
  - Revolutionizing for health care, financial systems, scientific research, and society

Context

- The promise of the Cloud
  - *ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction.* NIST Cloud Definition

Context

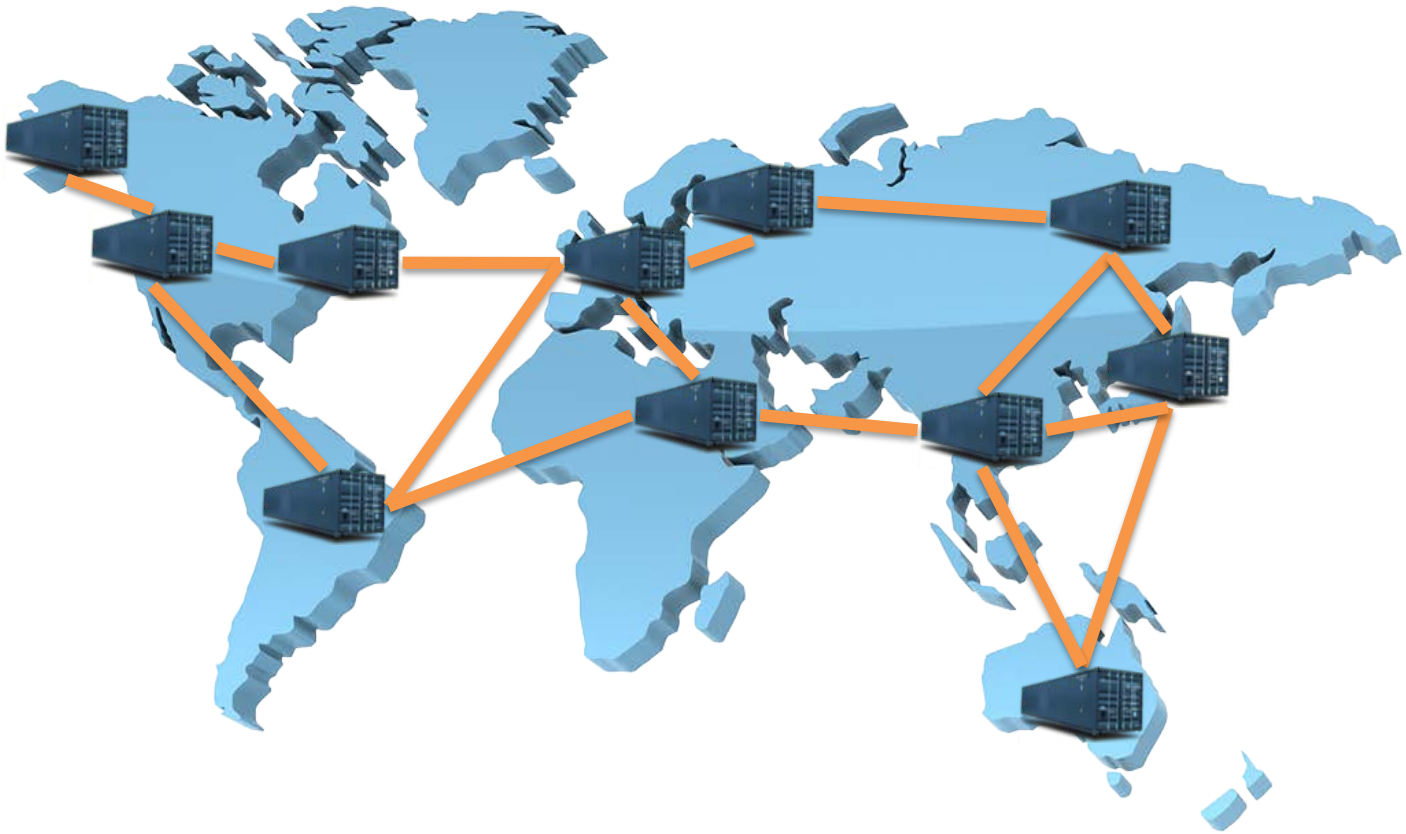
- The promise of the Cloud
  - *ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction.* NIST Cloud Definition

Context

- The promise of the Cloud
  - *ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction.* NIST Cloud Definition
- Requires fundamentals in distributed systems
  - Networking
  - Computation
  - Storage

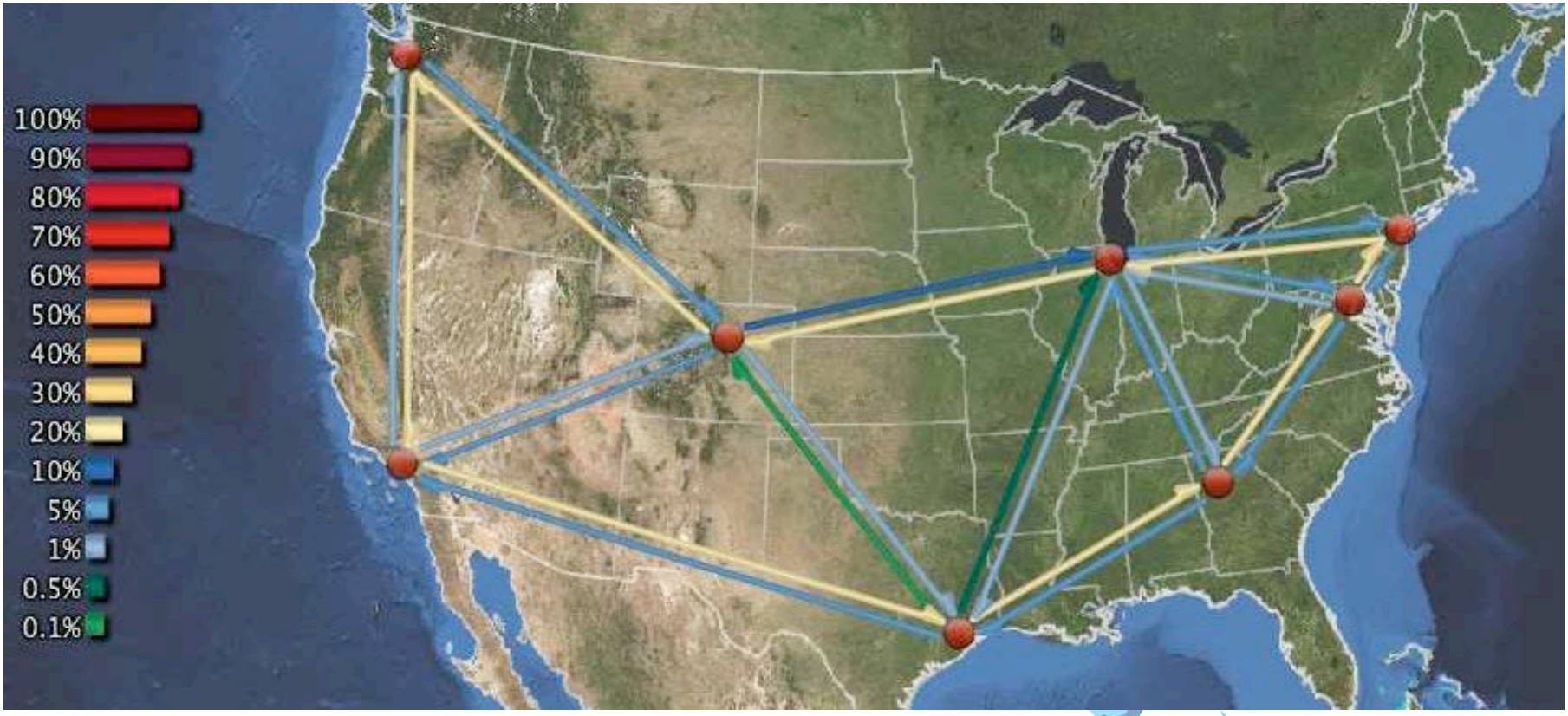
High Performance Networks

- How to optimize a global network of data centers?



High Performance Networks

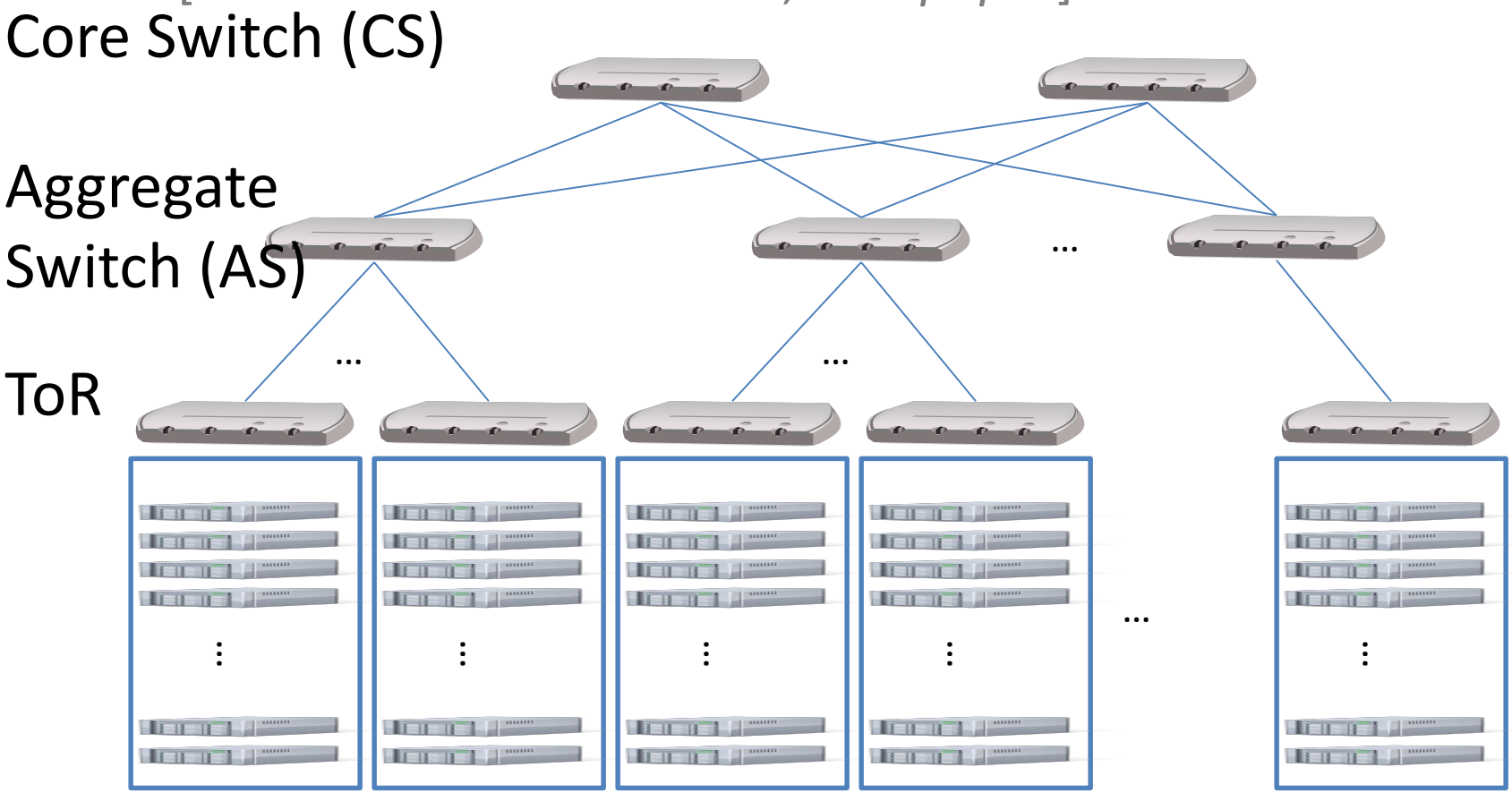
- How to optimize a global network of data centers?
  - E.g. Need to optimize movement of data between DCs
  - [NSDI 2013, NSDI 2008, FAST 2009, IMC 2010, DSN 2010]



High Performance Networks

- How to optimize a global network of data centers?
  - E.g. Investigate novel data center designs

    [ToN 2013 and ANCS 2012; *best paper*]



High Performance Networks

- How to optimize a global network of data centers?

- Rack-scale computers
  - Rack is now the new computing block
  - New hardware trends allows to create a rack containing ~100s-1000 SoC

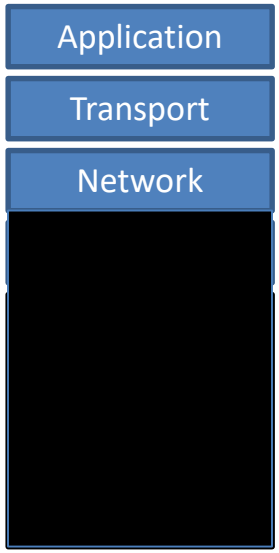
HP Moonshot

Boston Viridis

AMD SeaMicro

High Performance Networks

SW Programming the L1/L2 of the Network



- Dataplane programming (e.g. P4)
  via P4FPGA [SOSR'16, http://p4fpga.org]
- Physical Layer programming
  via SoNIC [NSDI'13,'14, IMC'14, SIGCOMM 2016]

High Performance Networks

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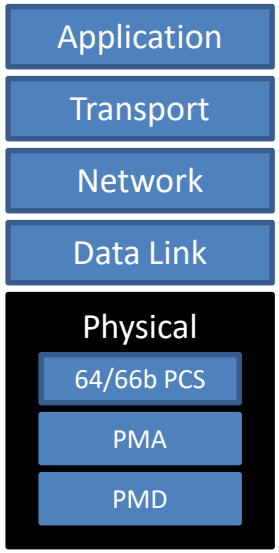

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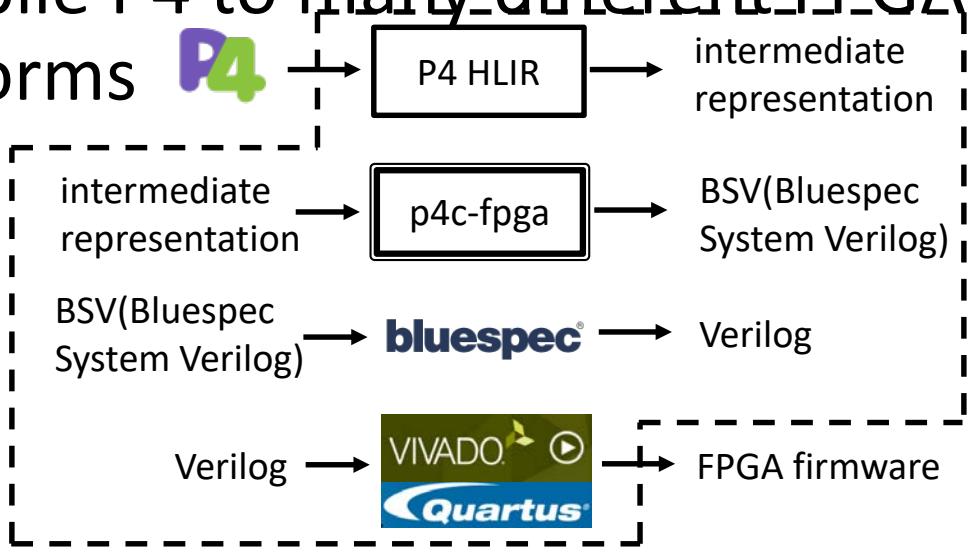
High Performance Networks

SW Programming the L1/L2 of the Network

- P4: Programming Protocol-Independent Packet Processors

  [SOSR'16]
- Use P4 to describe many different network applications
- Compile P4 to many different FPGA platforms



High Performance Networks

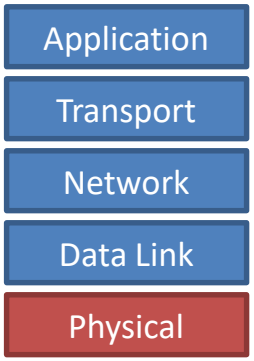
SW Programming the L1/L2 of the Network

- E.g. Move Consensus into the network
  - Consensus as a Service (CAANS)
  - Consensus protocols are the foundation for fault-tolerant systems
- Key: Low latency and high throughput

High Performance Networks

SW Programming the L1/L2 of the Network

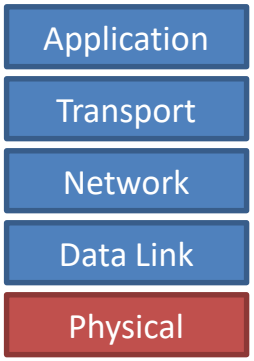
- Datacenter Time Protocol [SIGCOMM 2016]
- Synchronization protocol in the PHY
  - Each physically link is already synchronized!
  - No protocol stack overhead
  - No network overhead
  - Scalable: peer-to-peer and decentralized



High Performance Networks

SW Programming the L1/L2 of the Network

- Datacenter Time Protocol [SIGCOMM 2016]
- Synchronization protocol in the PHY
  - Bounded and precise synchronization
  - Bounded by 4 oscillator ticks (25ns) peer-to-peer
  - Bounded by 150ns for an entire datacenter
    - No clock differs by more than 150ns
  - Free – No network traffic: Use the PHY!



High Performance Networks

Network Latency Control via Rack-scale computing

- Assuming synchronized time, schedule every packet
- Every node is allocated a full time slot to a single destination
- No two nodes will be able to communicate with the same destination at the same time

	1	2	3	4
Node 1	2	3	4	5
Node 2	3	4	5	1
Node 3	4	5	1	2
Node 4	5	1	2	3
Node 5	1	2	3	4

High Performance Networks

Network Latency Control via Rack-scale computing

Benefits

- No network contention
- Full bisection bandwidth
  - Direct connect topology
  - Route through one random intermediate node
- Bounded latency
- Low power

	1	2	3	4
Node 1	2	3	4	5
Node 2	3	4	5	1
Node 3	4	5	1	2
Node 4	5	1	2	3
Node 5	1	2	3	4

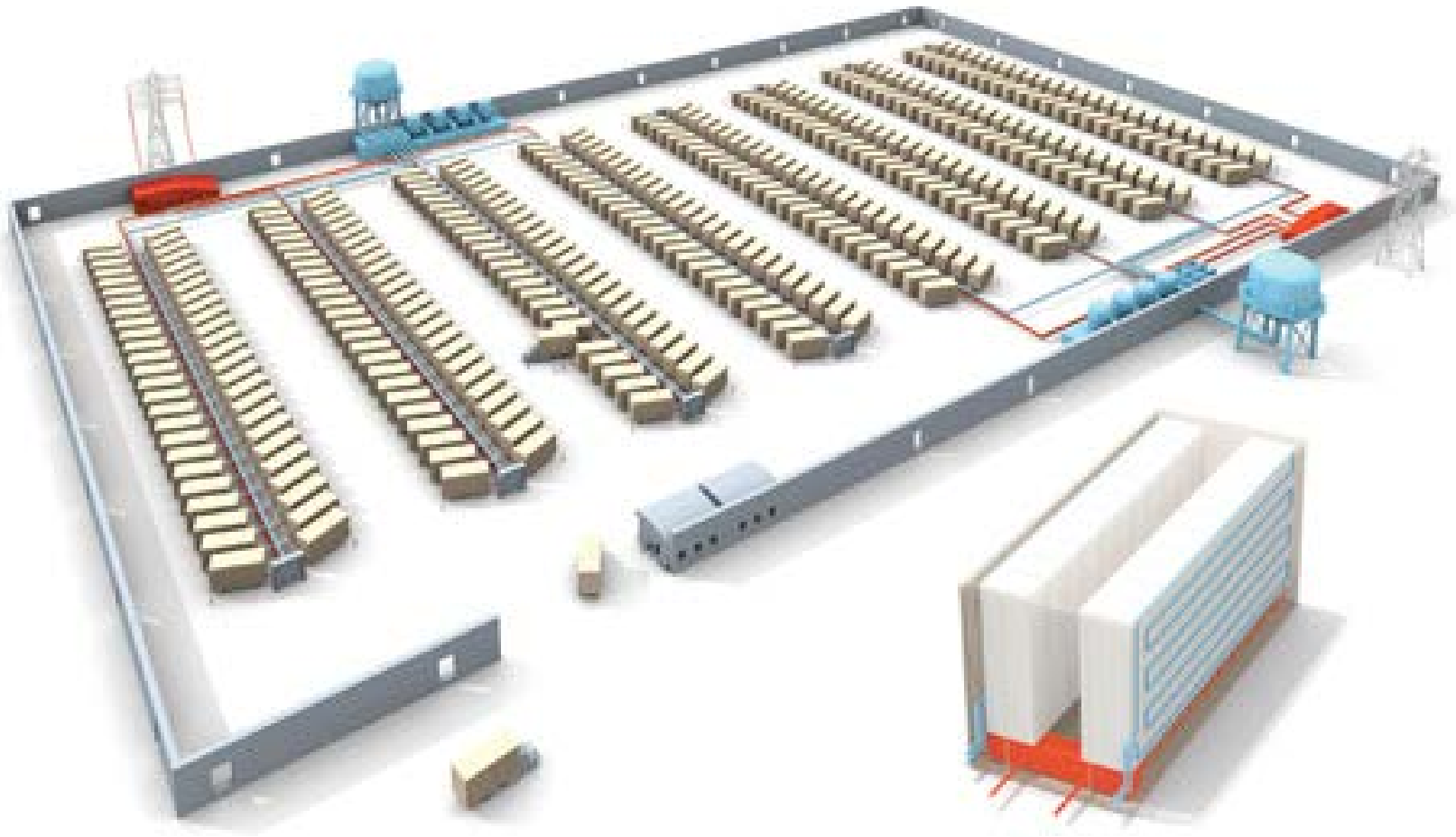
High Performance Storage

- Large organizations ~~considering~~ using the cloud
  - New York Times
  - Netflix
  - Nintendo
  - Cornell
  - Library of Congress

- The more data you have, the harder it is to move
  - Switching providers entails paying for bandwidth *twice*
  - Inhibits opportunistic migration

High Performance Storage

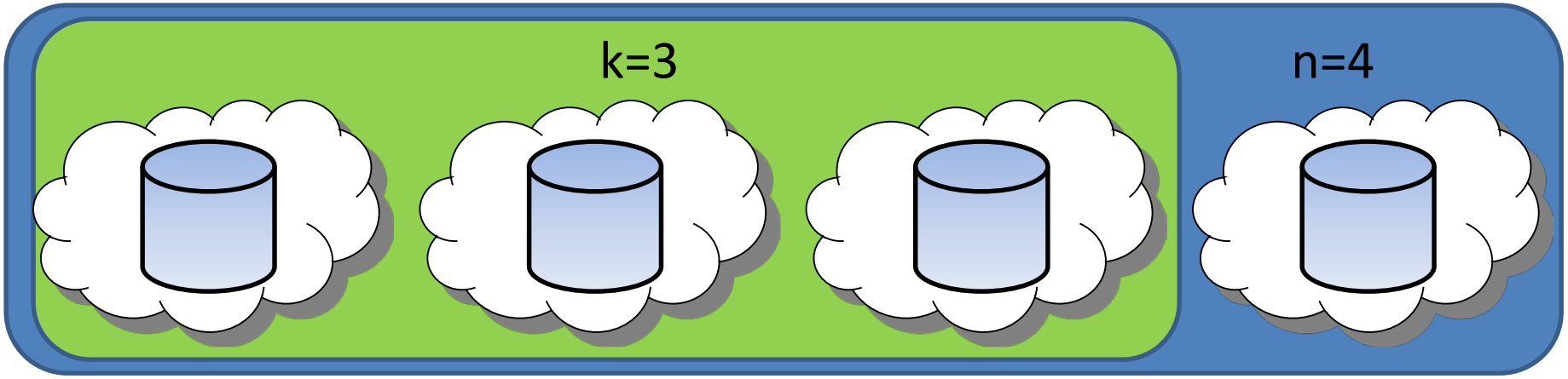
- How hard is it to move a PetaByte?



Titan tech boom, randy katz, 2008

High Performance Storage

- All my valuable data/computation is in the cloud
  Am I locked in to one provider forever?
  - The more data you have, the harder it is to move
- RACS: Redundant Array of Cloud Storage
  - Collaboration with the Internet Archive and IBM
  - [SOCC 2010]; See Also [EuroSys 2007, FAST 2009, FAST 2013]



RACS(3,4)

High Performance Storage

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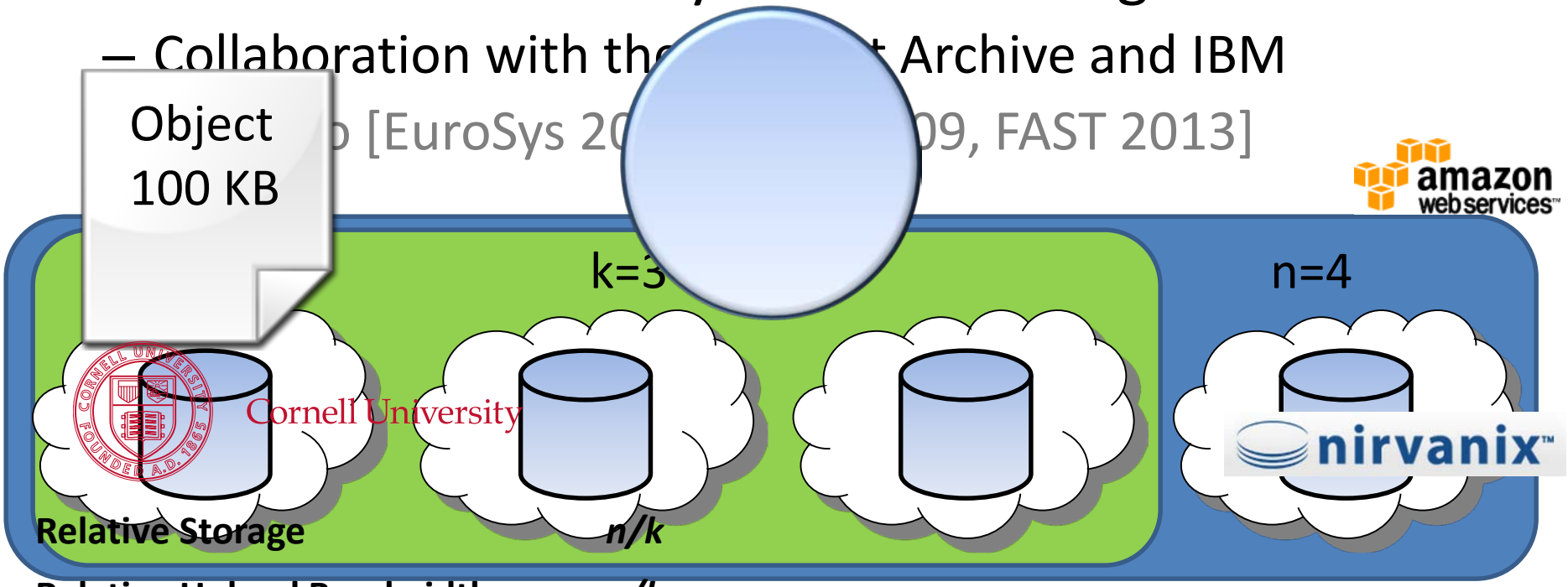
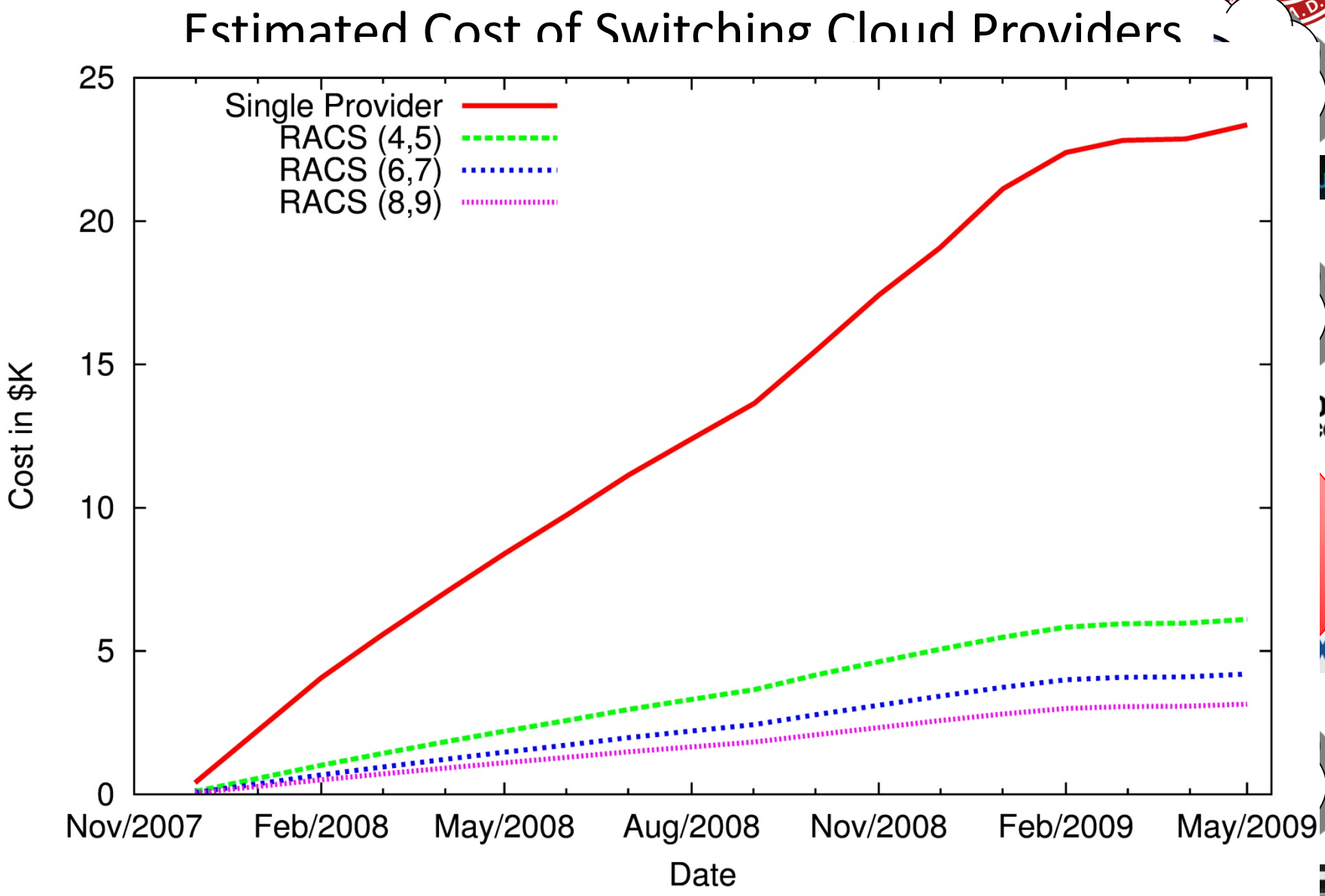
  - The more data you have, the harder it is to move
- RACS: Redundant Array of Cloud Storage
  - Collaboration with the [illegible] Archive and IBM
    [illegible] [EuroSys 20[illegible]09, FAST 2013]



Relative Storage	***n/k***
Relative Upload Bandwidth	***n/k***
Relative Download Bandwidth	***1***

RACS(3,4)

High Performance Storage



High Performance Storage

- RACS: How do I optimize storage globally
  - Collaboration with Internet Archive / IBM
- Gecko: How do I optimize storage locally
  - Collaboration with Google and Microsoft

Cornell University

RACS(3,4)

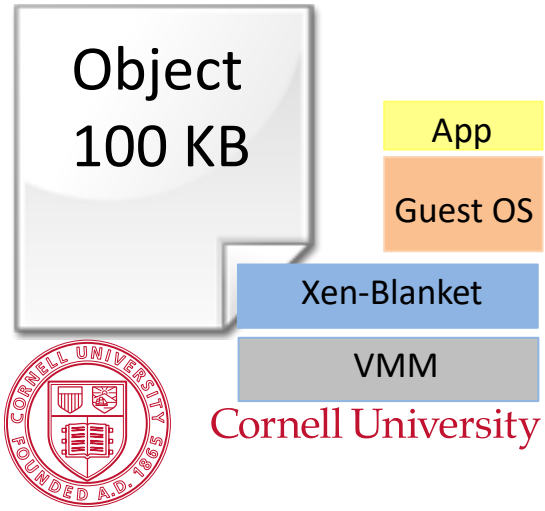
Relative Storage	***n/k***
Relative Upload Bandwidth	***n/k***
Relative Download Bandwidth	***1***

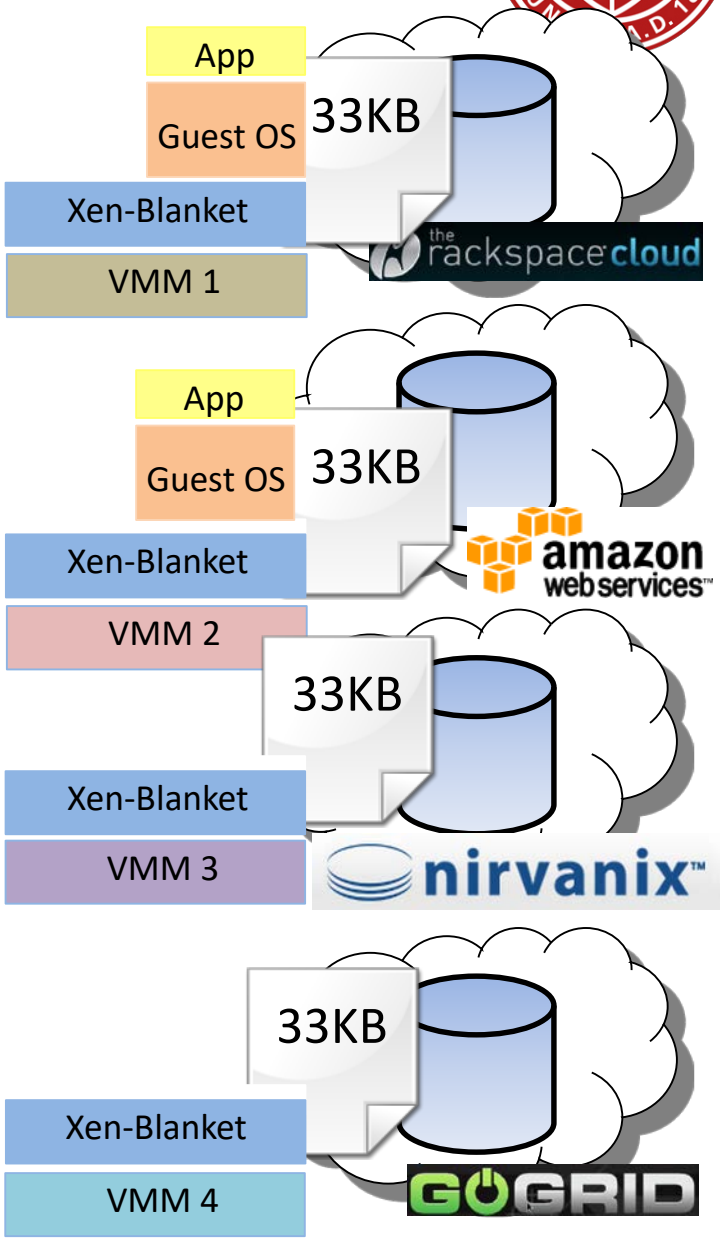
High Performance Computation

- Can I compute in the cloud if some of my data is in a vault at home or on another provider
- Xen-Blanket and VirtualWire
  - Collaboration with IBM
  - [HotCloud 2012, EuroSys 2012]

High Performance Computation

- Can create your own *Cloud-within-a-Cloud*



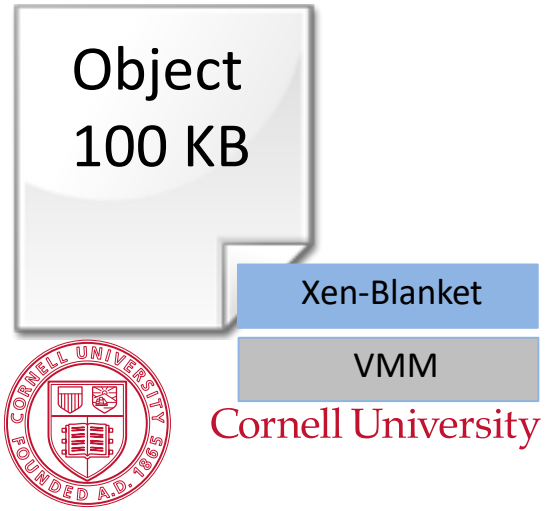


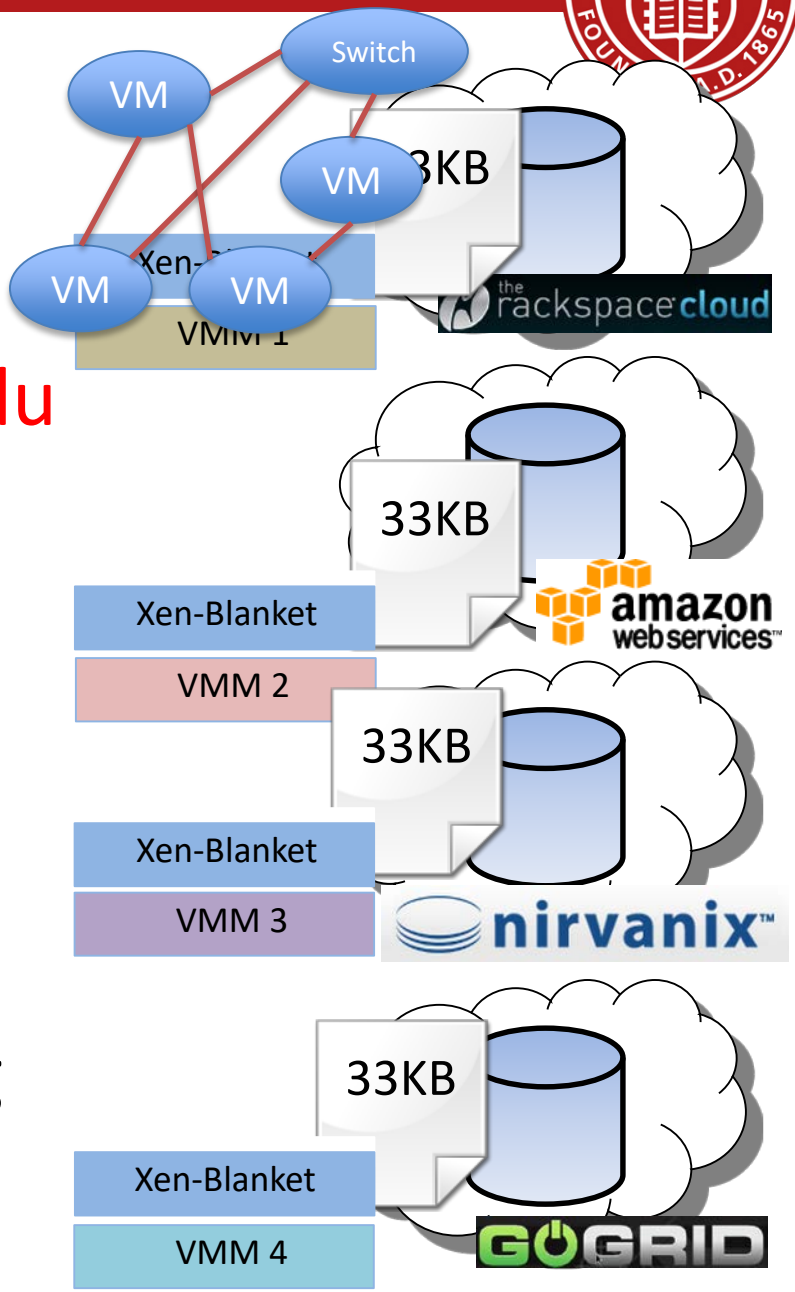
- Migrate computation among different cloud providers

High Performance Computation

- Can create your own *Cloud-within-a-Cloud*

Demo: http://supercloud.cs.cornell.edu





- Migrate computation among different cloud providers

My Contributions

- Cloud Networking
  - SoNIC/DTP in SIGCOMM 2016, NSDI 2014/2013, and IMC 2014
  - Wireless DC in ANCS 2012 (best paper) and NetSlice in ANCS 2012
  - Bifocals in IMC 2010 and DSN 2010
  - Maelstrom in ToN 2011 and NSDI 2008
  - Chaired Tudor Marian (2010), Ki Suh Lee (2016), Han Wang (2017) PhD
- Cloud Computation & Vendor Lock-in
  - Supercloud in SoCC 2016, OSR 2015 / IEEE Internet Computing-2013
  - Xen-Blanket in EuroSys-2012 and HotCloud-2011
  - Overdriver in VEE-2011
  - Chaired Dan William (2012) and Zhiming Shen (~2017) PhD
- Cloud Storage
  - Isotope/Gecko in FAST 2015, 2013 / HotStorage 2012
  - RACS in SOCC-2010
  - SMFS in FAST 2009
  - Antiquity in EuroSys 2007 / NSDI 2006
  - Chaired Lakshmi Ganesh (2011) and Ji Yong Shin PhD 2016

Goals for Today

- Be brief!
- Background on course and Professor
- Why take this course?
- How does this class operate?
- Class details

Why take this course

- Learn about systems abstractions, principles, and artifacts that have lead to the high performance systems and networks we see in the cloud,
- Understand attributes of systems research that is likely to have impact,
- Become comfortable navigating the state of the art in systems and networking,
- Gain experience in thinking critically and analytically about systems research, and
- **Acquire the background needed to work on cloud and data center problems currently under study at Cornell and elsewhere.**

Who is the course "for"?

- MEng students
  - Students who have mastered 4410/4411
  - PhD students as well
  - Serious undergraduates

- MEng Project
  - Projects in this course can be used to satisfy MEng project requirements

Goals for Today

- Be brief!
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How this class operates

- Instructor: Hakim Weatherspoon
  - hweather@cs.cornell.edu
  - Office Location: 427 Gates Hall

- TA: Vishal Shrivastav
  - vishal@cs.cornell.edu

- Lectures:
  - CS 5413: M,W,F: 1:25–2:15 PM, 110 Hollister Hall
  - Three slots reserved a week,

  ******but lecture will be twice a week on average******

Course Help

- Course staff, office hours, etc:
  - http://www.cs.cornell.edu/courses/cs5413/2017sp

- MEng projects
  - http://www.cs.cornell.edu/courses/cs5413/2017sp/projects.htm

CS 5413: Overview

- **This is a *hands-on* course**
  - **Objective: Have fun!**
  - **Build systems and networks**
- Prerequisite:
  - Mastery of CS 4410 and 4411 material
    - Fundamentals of OS design
    - How parts of the OS are structured
    - What algorithms are commonly used
    - What are the mechanisms and policies used
    - Programming in C/C++
- Class Structure
  - Lecture/Readings/Reading questions
  - In-class labs/Take-home Homeworks
  - Course Project/BOOM
  - Prelim

CS 5413: Topics

- Overview
  - Cloud computing, and Internet vs Data Center Networks
- High Performance Networking Basics
  - Textbook networking vs Data Center Networks
  - Network protocol stack: TCP/IP protocol stack
- High Performance Data Center Systems & Networks
  - Basic Switching Technologies: 50Gb/s routers &NetFPGA
  - Data Center Topologies, Software Router Designs,
  - Alternative switching technologies, Data Center Transport
  - Software defined networking, virtual networks
  - Rack-scale networks and computers
  - Disaggregated Datacenters
  - Middleboxes, advanced topics
  - Data Center traffic and analysis

CS 5413: Paper Readings

- Required reading is always *one* paper and/or book reading
  - Book reading provides basic background knowledge
  - Papers pulled from, best journals and conferences
    - TOCS, SOSP, OSDI, …
- Read papers before each class and bring notes
  - takes ~1 hr, write notes and questions
- Answer a paper related question and turn in *at least* ***two hours*** before beginning of class
  - Turn on online via Course Management System (CMS)
  - ***No late reviews will be accepted***

CS 5413: Paper Reading Questions

- A question(s) related to the reading will be posted at usually a week before class.
- Each student is *required* to write a response to question
- Turn question response in online before class via CMS
  - Be succinct
    - Usually can answer question in two or three sentences or at most one paragraph

CS 5413: Lecture Format

- 40 minute presentation
- All students are required to read ahead of time and participate!
- Counts in final grading.

- May have student (group) presentations

CS 5413: In-class Labs/Homeworks

- In-class Labs
  - Work in groups
  - ~once per week
  - Need a laptop
  - Designed to finish during class
- Take-home Homeworks
  - work in groups
  - 1-3 weeks per lab/homework
  - Topics
    - Building a network proxy (singled, then multi-threaded)
    - Building a chatserver
    - Implement a programmable dataplane device or softward-defined network (sdn) switch/controller
- Facilities
  - Laptops and local Fractus cloud

CS 5413: Project/BOOM

- One major project per group
  - Groups include ***three*** people
- Group formation – early February
- Initial selection of project topic – due mid-February
- Survey of area (related works)–late begin of February

- Midterm draft paper – late of March
- Peer reviews—due a week later

- Final demo/presentation–due begin of May
- Final project report – due a week later

Extra – BOOM

- http://boom.cornell.edu/students-and-faculty/project-guidelines/
- BOOM Submission – due March 31st
- BOOM Presentation – April 19th

CS 5413: Project Infrastructure

- SoNIC: Software Network Interface Cards
- NetFPGA/P4FPGA

- Fractus: our very own (mini) cloud
- Amazon's Cloud Infrastructure EC2/S3
- Emulab
- PlanetLab
- Cornell's Center for Advanced Computing (CAC)
- …

Academic Integrity

- Submitted work should be your own

- Acceptable collaboration:
  - Clarify problem, C syntax doubts, debugging strategy
  - You may use any idea from any other person or group in the class or out, provided you ***clearly state what you have borrowed and from whom***.
  - If you do not provide a citation (i.e. you turn other people's work in as your own) that is *cheating*.

- Dishonesty has no place in any community
  - May NOT be in possession of someone else's homework/project
  - May NOT copy code from another group
  - May NOT copy, collaborate or share homework/assignments
  - University Academic Integrity rules are the general guidelines

- Penalty can be as severe as an 'F' in CS 5413

Stress, Health and Wellness

- Need to pace yourself to manage stress
  - Need regular sleep, eating, and exercising

- Do ***not*** come to class sick (with the flu)!
  - Email me ***ahead*** of time that you are not feeling well
  - People not usually sick more than once in a semester

Before Next time

- Read *one* paper below and write review
  - *The Cost of a Cloud: Research Problems in Data Center Networks*, A. Greenberg, J. Hamilton, D. A. Maltz, P. Patel. ACM SIGCOMM computer communication review, Volume 39, Issue 1 (January 2009), pages 68--73. http://dl.acm.org/citation.cfm?id=1496103 (can only access link within Cornell network). http://131.107.65.14/en-us/um/people/dmaltz/papers/DC-Costs-CCR-editorial.pdf (can access outside Cornell network)

- Check website for updated schedule