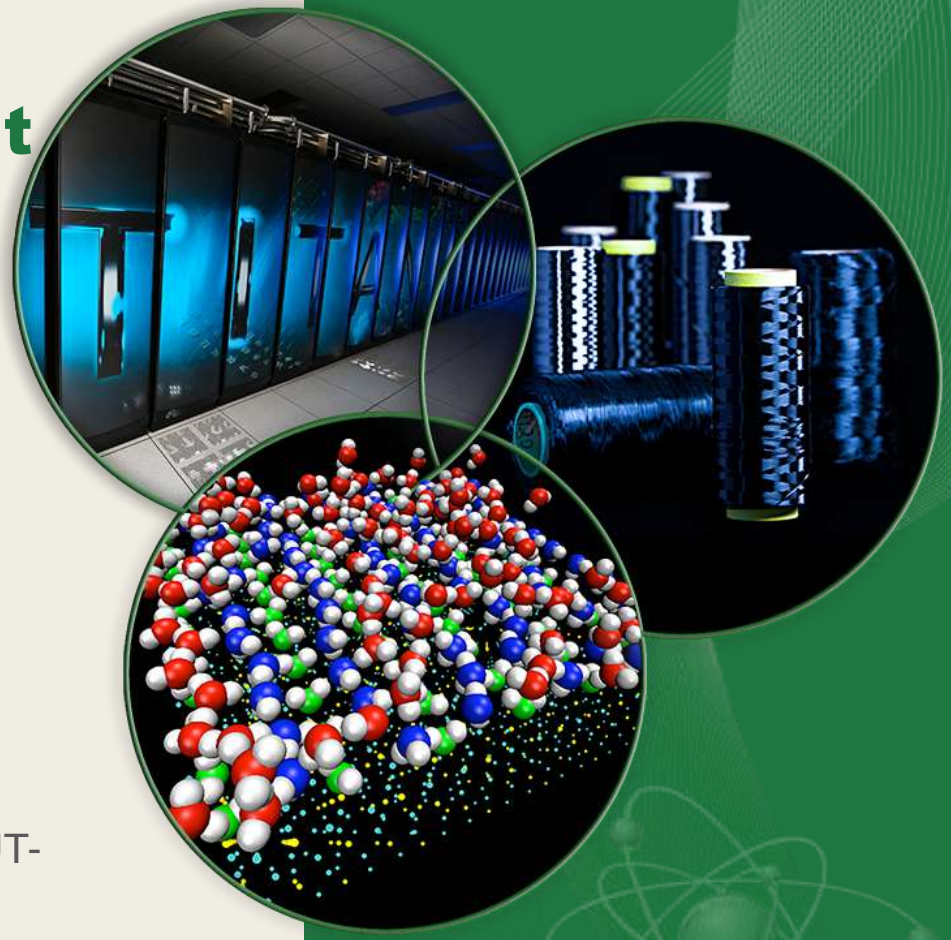
Bridging the Gap Between Computer Science and Facility Engineering for Data Center Management



HPC User Forum

September 7, 2016

Jim Serafin, PE, PMP

Computational Complex Facilities Manager, UT-Battelle, LLC

ORNL is managed by UT-Battelle
for the US Department of Energy

OAK RIDGE National Laboratory

THE UNIVERSITY OF TENNESSEE KNOXVILLE

DATA Center Technology

Data Center Technology and Management

Minor Degree Program, UTK CoE

Dr. Mark E Dean, PhD

Fisher Distinguished Professor
UT Knoxville College of Engineering,
EECS Dept.

OAK RIDGE National Laboratory

THE UNIVERSITY OF TENNESSEE KNOXVILLE

Data Center Technology and Management Minor Degree Program

The College of Engineering offers a minor in datacenter technology and management to establish broad awareness of datacenter requirements, design and management technologies and methodologies, including reliability, security, network systems, storage systems, industrial design, systems management, application environments/ management, operations, logistics and energy efficiencies.

The program is not expected to deliver deep knowledge in a specific area, but to give a student sufficient basic insight on datacenter operational characteristics and requirements.

Proposed Minor in "Datacenter Technology and Management".

Objectives: Establish broad awareness of datacenter requirements, design and management technologies and methodologies, including reliability, security, network systems, storage systems, industrial design, systems management, application environments/management, operations, logistics and energy efficiencies. The program is not expected to deliver deep knowledge in a specific area, but give a student sufficient basic insight on datacenter operational characteristics and requirements.

Disciplines appropriate to entry into this program include: CS, CpE, EE, IE, and ME.

The NSA will process clearances for anyone in the program who applies for the NSA's internship program. There will also be opportunities for students to complete the program and intern at commercial companies interested in this skill set.

Requirements:
Total number of courses required = 7
Total number of course hours required = 22
Total number of intern semesters (strongly recommended) = 2
Note: internships should occur at the end of a student's sophomore year and at the end of a student's junior year--primarily during the summer semester. Internships will be hosted at ORNL, NSA datacenters and commercial datacenters (where appropriate).

Core Courses Required – 9 Hours:

IE 483 – Introduction to Reliability Engineering

3 Credit Hours: Probabilistic failure models and parameter estimation (maximum likelihood, Bayes techniques). Model identification and comparison, accelerated life tests, failure prediction, system reliability, preventive maintenance, and warranties. (Same as Chemical and Biomolecular Engineering 483; Nuclear Engineering 483; Mechanical Engineering 483.)
Registration Restriction(s): Minimum student level – Junior.
Registration Permission: Consent of instructor.

IE 484 – Introduction to Maintainability Engineering

3 Credit Hours: Principles of maintenance and reliability engineering and maintenance management. Topics include information extraction from machinery measurements, rotating machinery diagnostics, nondestructive testing, life prediction, failure models, lubrication oil analysis, established [illegible] maintenance program, and computerized maintenance [illegible]

Data Center Technology and Management Minor Degree Program

Disciplines appropriate for entry into this program include:

Computer Science, Computer Engineering, Electrical Engineering, Industrial Engineering, and Mechanical Engineering.

Requirements:

Total number of courses required = 6
(+1 for non-EECS students, COSC 130 or equivalent)

T**otal number of course hours required** = 18
(+4 for non-EECS students, COSC 130 or equivalent)

Total number of intern semesters (strongly recommended) = 2

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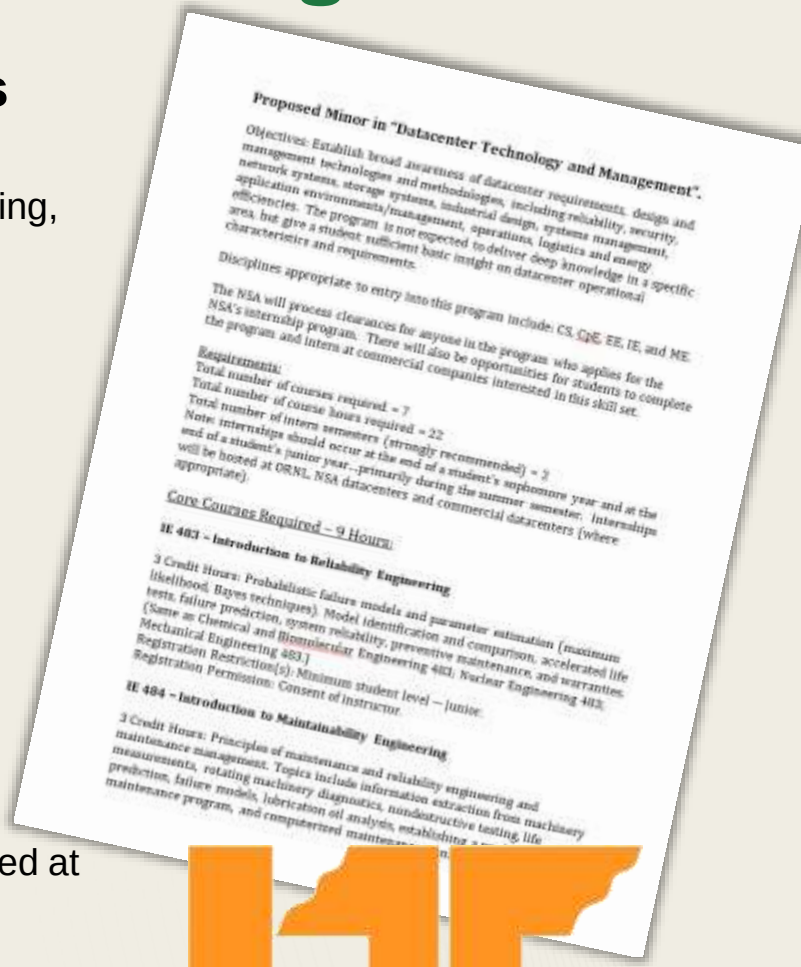
Additional minor specific classes include:

- IE 483 - Introduction to Reliability Engineering
- IE 484 - Introduction to Maintainability Engineering



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OAK RIDGE National Laboratory

ECE463 – Description and Goals

Class Description

This is a senior-level course focused on developing multi-disciplinary insights into datacenter technology. The primary objective of this coarse is to deliver broad awareness of datacenter requirements, design and management technologies and methodologies. This includes: reliability, security, network systems, storage systems, industrial design, systems management, operating environments, application environments/management, operations, logistics and energy efficiencies. The program is not expected to deliver deep knowledge in a specific area, but give a student sufficient basic insight on datacenter operational characteristics and requirements. Engineering disciplines which can take this course include EE, CpE, CS, ME and IE.

Rationale

The complexity and diversity of the computing services and computing environments has made datacenter design, operation and management challenging. This course fills a critical gap in knowledge around datacenter technology and best practices in the datacenter infrastructure to deliver information services.

Learning outcomes

Students will be presented with a broad overview of datacenter technology and the interactions and interdependencies of datacenter components (facilities, cooling, power, management, computers, networks, OSes, applications, security, safety, etc.). Students will gain knowledge in datacenter infrastructure, operations and management best practices.

Class Structure

Sections of class will be delivered by experts and practitioners in datacenter deployment and management from ORNL. Classes are meant to be interactive and foster lots of questions and discussion from students.

Text Book: Data Center Handbook, by Hwaiyu Geng, Wiley Publishing 2015

ECE463 – Class Assignments and Grading

Class Assignments

50% of Grade

- Pre-reads, internet research, and other class prep activities
- Reports, Essays and/or Papers
- In-class exercises
- Take-home Tests

Photo Courtesy of DollarPhotoclub.com

Graduate Class Project

50% of Grade

Example Projects

- Design a Datacenter from a RFP (request for proposal)
- Requirements document provided on first day of class. But may change during the semester to meet customer needs.
- Design and model a fire suppression system
- Development of a software environment proposal to support application management, system allocation, security, application development, system monitoring, real-time performance analysis, upgrade processing and other software system tools.
- Design Proposal document (Maximum of 10 pages of single spaced 12pt text + supporting drawings)
- Develop a proof-of-concept visualization tool
- Final Exam

Courtesy of ORNL

Class Attendance

(worth 0.7 points out of 4.0)

- Students are expected to attend 90% of classes
- Sign-in sheet provided at each class
- Any exceptions must be reviewed, approved and documented by the faculty member responsible for the class. All exceptions must be approved prior to the occurrence of the class missed.

Photo Courtesy of DollarPhotoclub.com

OAK RIDGE National Laboratory

Thom Mason
Laboratory Director

Computing and Computational Sciences

Energy and Environmental Sciences

Global Security

Neutron Sciences

Nuclear Science and Engineering

Physical Sciences

Science and Technology Partnerships

U.S. ITER Project

Business Services

Environment, Safety, and Health

Facilities and Operations

Human Resources


Jeff Smith
Deputy Director
For Operations
OAK RIDGE
National Laboratory
Thom Mason
Laboratory Director
Thomas Zacharia
Deputy Director
of Science
Facilities &
Operations
Jimmy Stone
Software Applications
TBD
Extreme Scale
Systems Center
Neena Imam
Program Director
Computational
Facilities
Jim Serafin
Complex Manager
Computing
and Facilities
Jim Rogers
Director
Mechanical
David Grant
Engineer
Complex
Darren Norris
HPC Operations
Stephen
McNally
Lessons Learned in
Selecting a Large-Scale
Data Center Design
Electrical/
Instrumentation
Rick Griffin
Engineer
Network
Operations
Brett Ellis
Group Leader
(acting)
Exascale Computing
Project
Kathlyn Boudwin
Project Director
Line Item/GPP/
IGPP Projects
Bart Hammontree
SCADA Support
Saeed Ghezawi
BP HPC
Keith Gray
Manager

ECE463 – Introduction to Data Center Tech. (Course Syllabus/Material Covered)

- **Introduction to Course (1)**
  - ✓ What to expect from this course
  - ✓ What is a Data Center
- **Data Center Strategy (2)**
  - ✓ Datacenter Strategy overview
  - ✓ Models (Cost and Operations)
- **Cooling (2)**
  - ✓ Fundamentals
  - ✓ Technologies
  - ✓ Design
  - ✓ Operations
  - ✓ Future Direction
- **Efficiency metrics for data centers (1)**
- **Infrastructure/Space (2)**
  - ✓ Infrastructure/Space
  - ✓ Security and integration
  - ✓ Managing the space
- **Project Management (1)**
  - ✓ General Topics – What is a Project and what is project management
  - ✓ Project Life Cycle
  - ✓ Organizational Influences
  - ✓ Planning Process
- **Software Applications (1)**
- **Energy Efficiency for Mechanical and electrical systems (2)**
  - ✓ Measures of efficiency
  - ✓ Technologies (Inherent Efficiencies)
  - ✓ Heat Recovery/Reuse
  - ✓ Air Flow Management
  - ✓ Case Studies/ White Papers
- **Power (4)**
  - ✓ Power Systems
  - ✓ Metering, SCADA, EEM systems
  - ✓ Load Factors, capacity, …
  - ✓ Efficiency and sustainability
  - ✓ Reliability, Safety, Standards,
- **Data Center Network (2)**
- **Industrial Controls (2)**
  - ✓ SCADA Overview, Brands/Types of SCADA
  - ✓ System Hardware (Metering, Networking, Communications, Security Considerations)
- **Commissioning a Data Center (1)**
- **Management of a Data Center During Construction (1)**
- **Data Center Facility Operations (1)**
- **Computing Configuration Management DCIM (2)**

Computing and Facilities: Who knows both?

ORNL's HPC partners have expressed an interest in workplace development to address a lack of skilled managers understanding both computing and facilities to tackle unique challenges of large data center environments.

Rationale for this class

- The environment within which we design and operate data center facilities has become more complex.
  - Federal mandates to consolidate data centers causing many to go away in the next 10 years.
  - Federal sustainability goals.
  - 10MW is no longer unheard of for a single computer, current Exascale estimates are closer to 30MW.

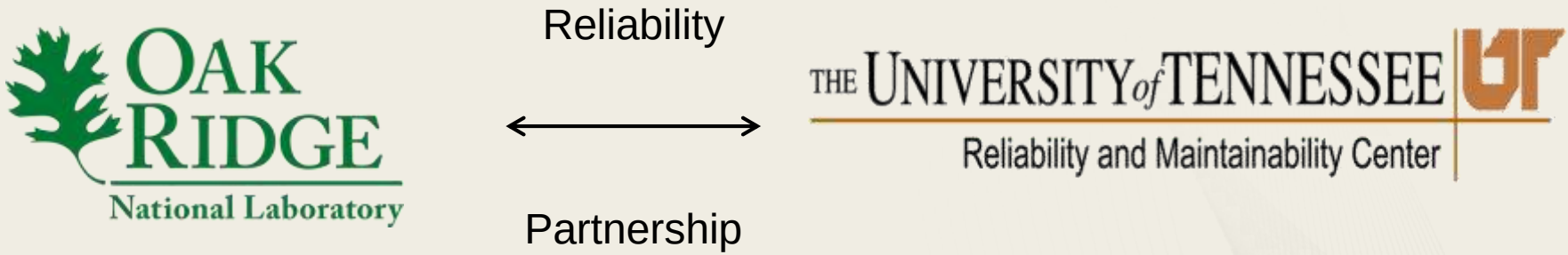
- "Outside the box" thinking.
- Scalability of our data center infrastructure.

Develop Internship Pipeline

- How many of you landed in this industry by accident?
- This class will help ORNL and it's partners migrate to a structured plan to attract people into this field.
- Internships strongly encouraged.
- Example lesson: What is Total Cost of Ownership?
  - How do I contribute to the bottom line?
    programmers, system administrators, computer engineers
  - Tradeoffs between investing in computing performance versus redundancy?

Reliability & Maintainability
Improvement Initiative

- ORNL's Computational Facilities Complex has partnered with the Reliability and Maintainability Center of the University of Tennessee to evaluate and improve the operations and maintenance processes of the High Performing Computing Program.



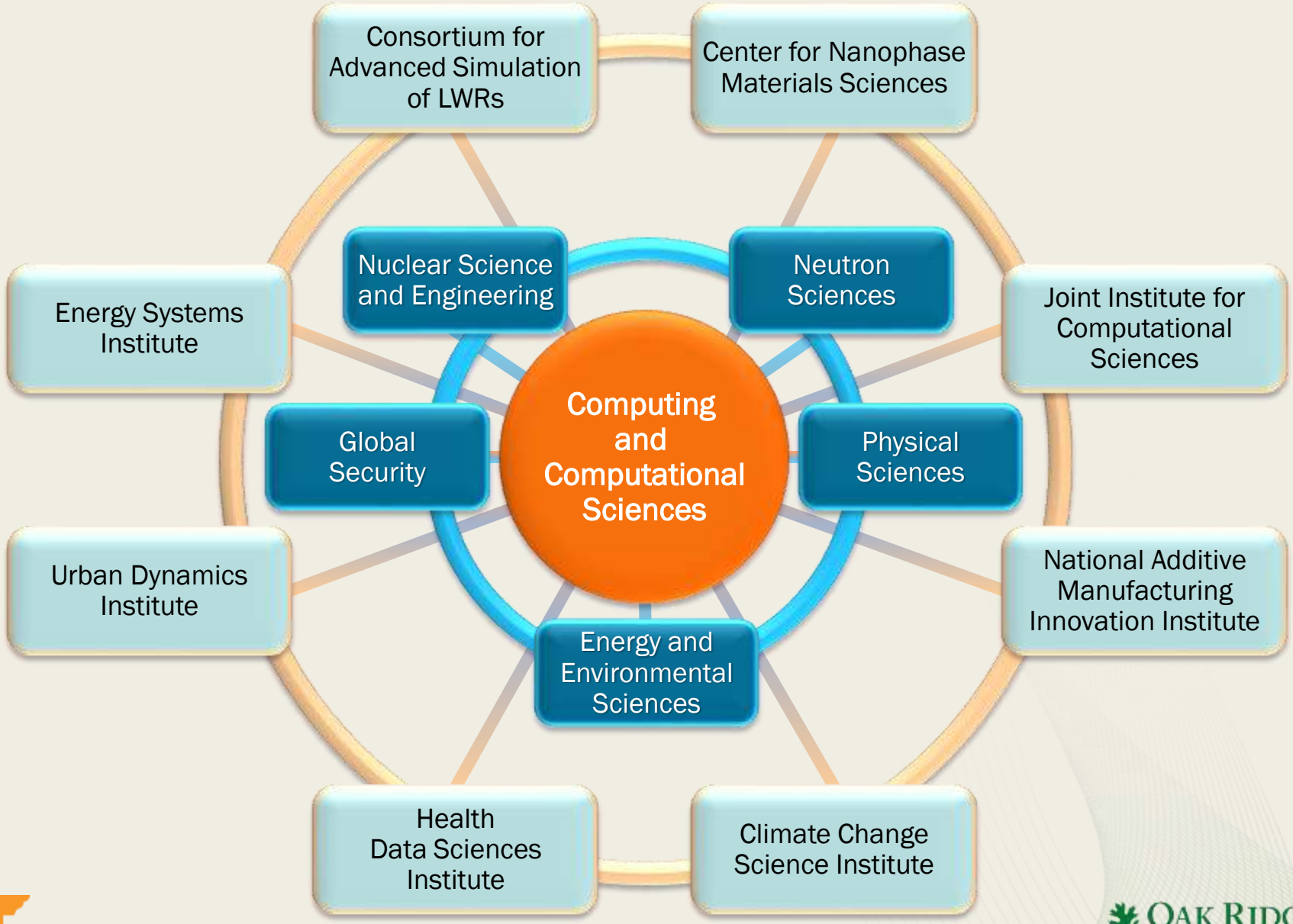
Reliability & Maintainability
CFC Project Goals Roadmap

- Establish reliability and maintainability program to ensure continued availability level as capacity increases.
- Ensure computerized maintenance management system (CMMS) provides appropriate functionality to meet complex needs.
- Maximize power & cooling availability with a Tier 1/Tier 2 power and cooling distribution system.
- Obtain the right people with the right level of training.
- PM Optimization and Predictive Technologies.

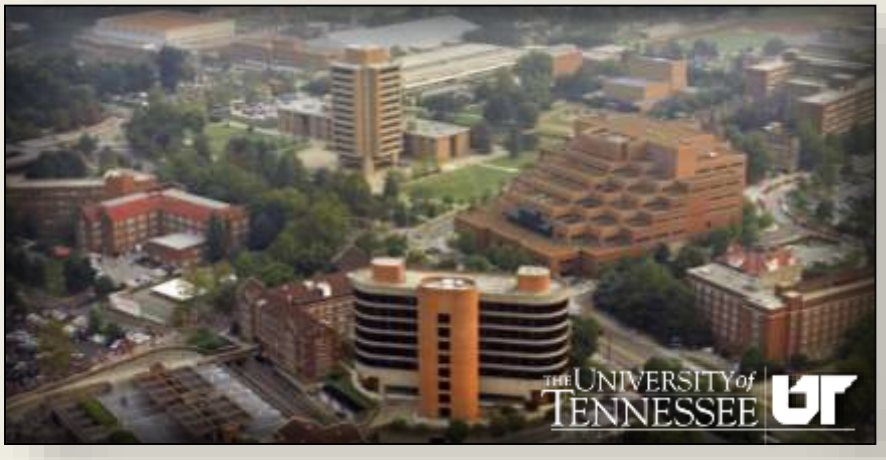
ORNL is DOE's largest science and energy laboratory

- $1.5B budget
- Forefront scientific computing facilities
- $750M modernization investment
- Nation's largest materials research portfolio
- 3,200 research guests annually
- World's most intense neutron source
- 4,300 employees
- Nation's most diverse energy portfolio
- World-class research reactor
- Managing billion-dollar US ITER project

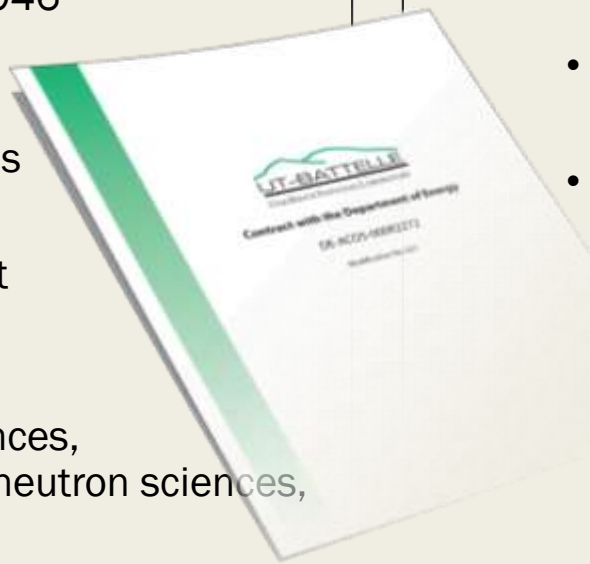
What makes ORNL computing unique?



ORNL is managed by UT-Battelle, LLC



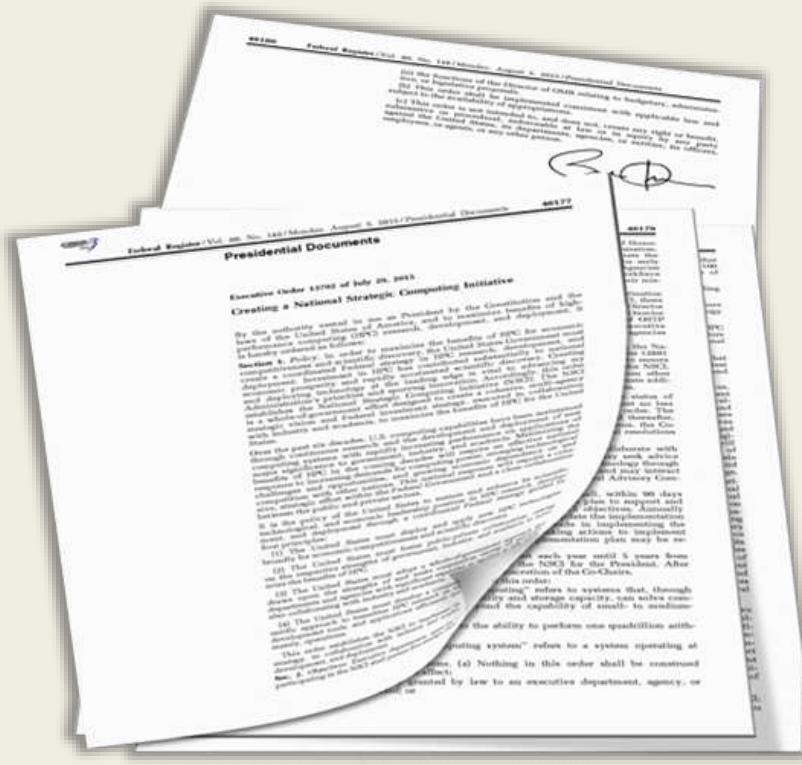
- An ORNL partner since 1946
- State-funded Science Alliance started in 1982, to build programs with ORNL
- Shared research and joint appointments
- Joint institutes: Advanced materials, biological sciences, computational sciences, neutron sciences, nuclear physics



- A 70-year relationship with DOE
- Develops and deploys technology worldwide
- Manages or co-manages 6 national labs: ORNL (with UT), Brookhaven (with SUNY-Stony Brook), Idaho, Lawrence Livermore (with UC and Bechtel), NREL (with MRI), Pacific Northwest

Executive order: National Strategic Computing Initiative (NSCI)

- There are three lead agencies for the NSCI:
  - the Department of Energy (DOE),
  - the Department of Defense (DOD),
  - the National Science Foundation (NSF).
- The DOE Office of Science and DOE National Nuclear Security Administration: will execute a joint program focused on advanced simulation through a capable exascale computing program emphasizing sustained performance on relevant applications and analytic computing to support their missions.
- DOD will focus on data analytic computing to support its mission. The assignment of these responsibilities reflects the historical roles that each of the lead agencies have played in pushing the frontiers of HPC, and will keep the Nation on the forefront of this strategically important field.

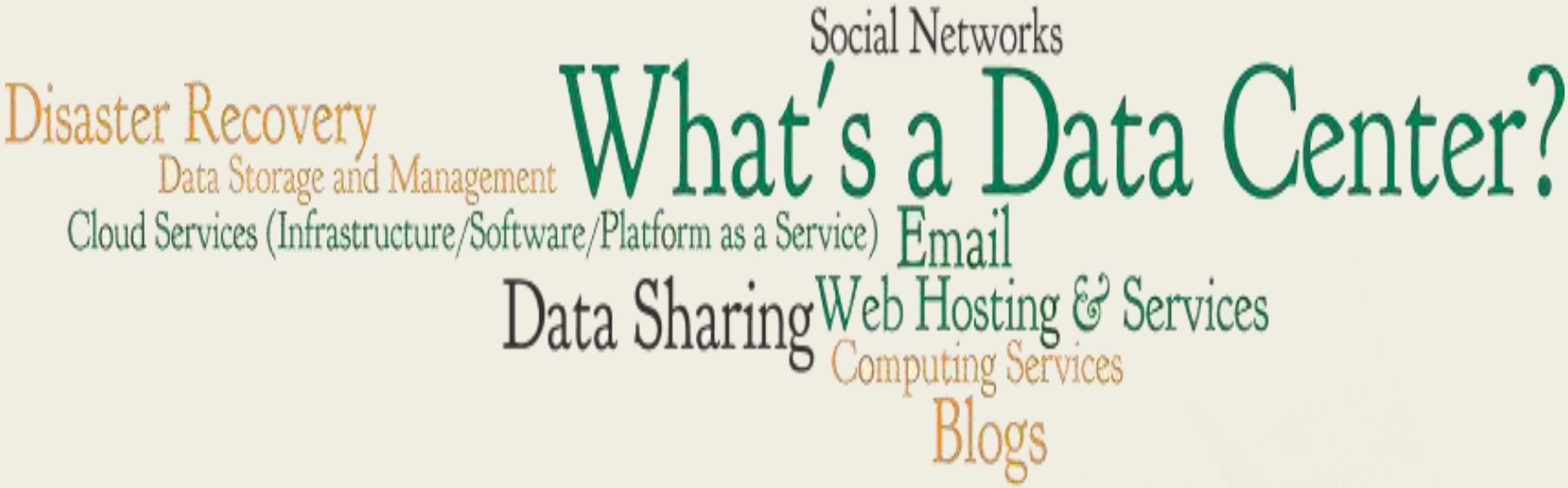


DATA Center Technology

What is a Data Center?

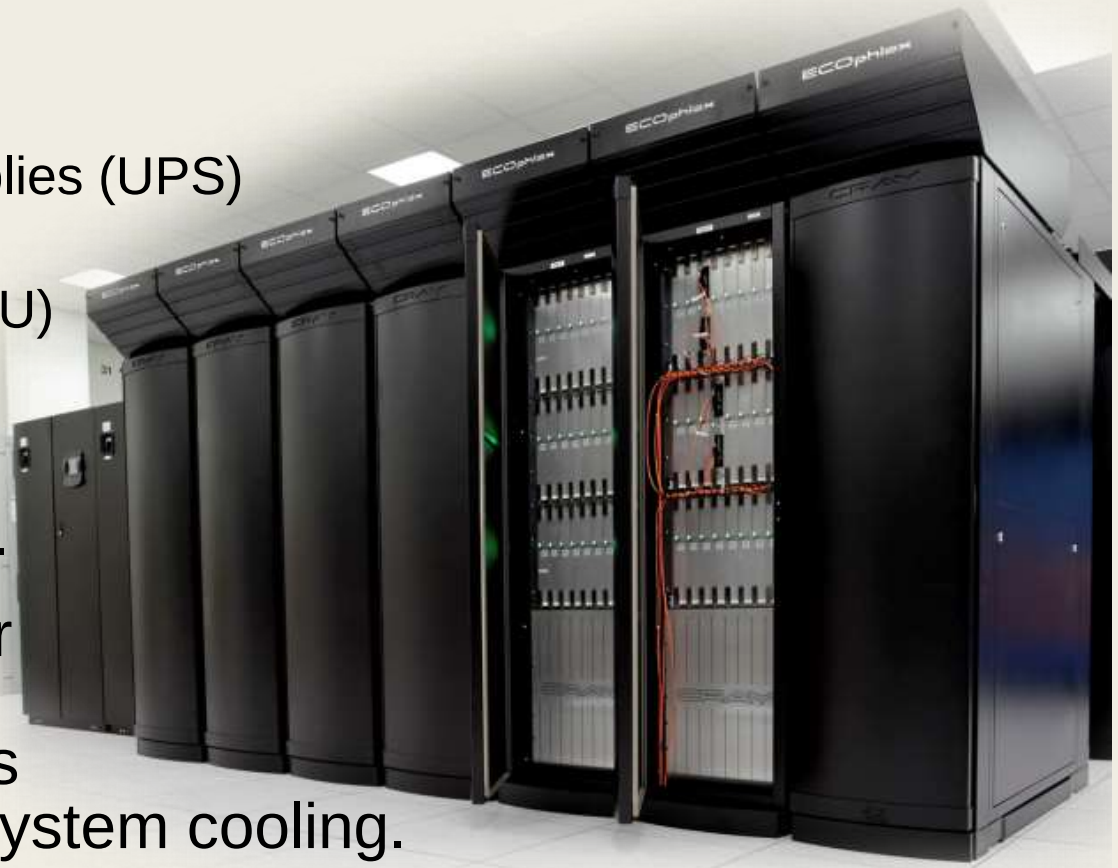
What is a data center

Data centers provide a range of information and computing technology services



Data Center Characteristics

- Data centers are *designed* to house information systems and supporting components such as:
  - Servers
  - Routers
  - Storage
  - Uninterruptable power supplies (UPS)
  - Cooling Units
  - Power Distribution Unit (PDU)
- Data centers have unique and typically large power requirements.
- They are often raised floor designs to accommodate the large amount of cables required and to facilitate system cooling.



Data center Benefits

Economies of Scale

Primarily beneficial to companies requiring large computing, storage and/or network facilities.

- Purchasing savings based on large purchases
- Dedicated IT staff
- Shared resources

Security

Physical

- Limited access to servers, networks and storage systems
- Surveillance

Virtual

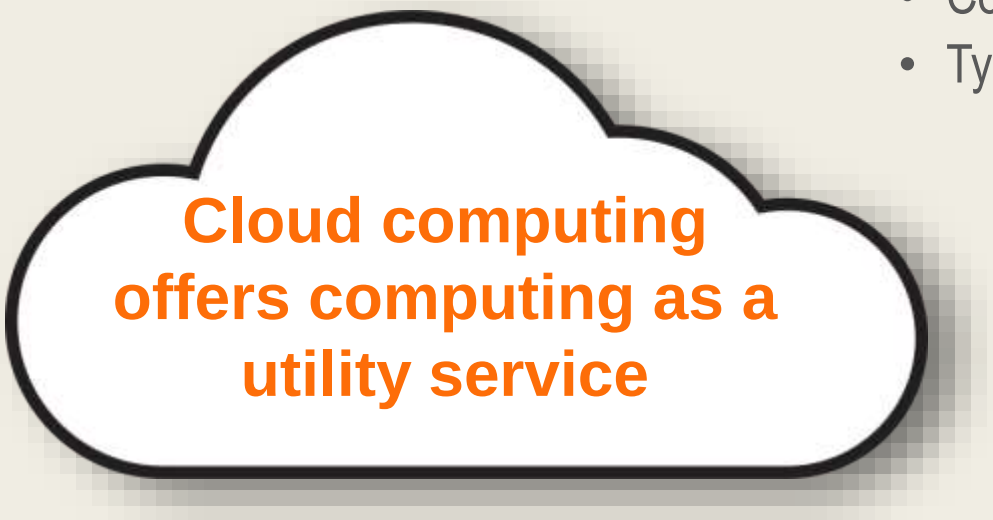
- Firewalls
- Anti-virus
- Password Protection
- Custom Environments & Applications

Note: Cloud Services (a subset of the Data Center industry) is becoming the most economical and efficient approach for acquiring computing, storage and application capability.

Data Center vs. Cloud

Data Centers

- Require specialized equipment and knowledge
- Owner maintains complete control over hardware and software
- Highly customized
- Component of a cloud



Cloud Computing

- Self service, Pay per use
- Platform independent
- Requires no specialized knowledge in computing
- Often represents outsourcing as a Risk Transference Strategy
- Composed of many data centers
- Types of service offered
  - Infrastructure as a service (IaaS) ex. Servers, Networking, Storage, etc.
  - Platform as a service (PaaS) ex. Windows, Red Hat, etc.
  - Application or Software as a service (SaaS) ex. Email, Oracle, MSWord etc.

DATA Center Technology

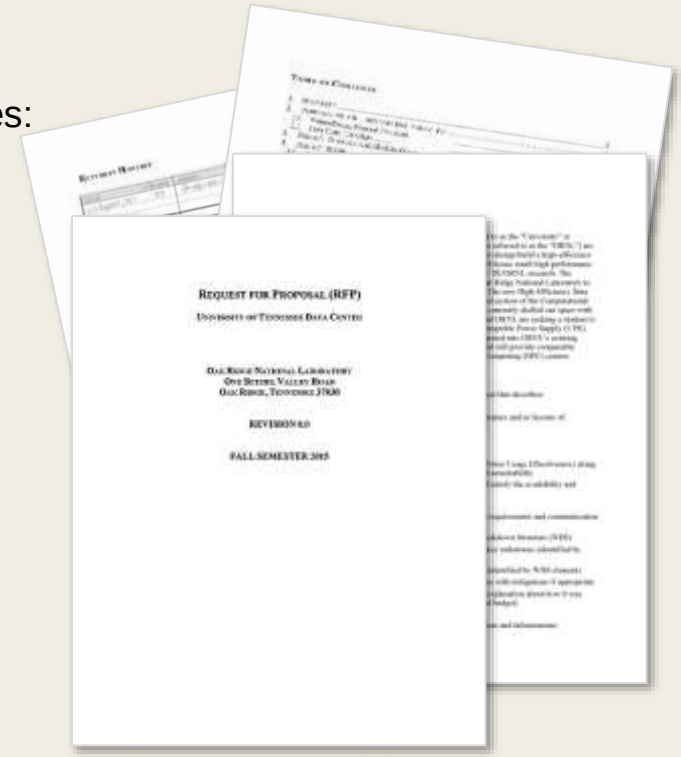
Class Project: Data Center Design

Project: Summary

The University of Tennessee Knoxville (hereinafter referred to as the "University" or “UTK”) and the Oak Ridge National Laboratory (hereinafter referred to as the "ORNL”) are seeking proposals from experienced and qualified students to design/build a high-efficiency state of the art data center for the UTK. This data center will house small high performance computers, business systems, and servers that will support UTK/ORNL research. The University is building a Remote Data Center (DC) at the Oak Ridge National Laboratory to meet the changing demands of the high density computing. The new High-Efficiency Data Center will be located on the second floor of a new expanded section of the Computational Science Building (CSB). This room and the floor below are currently shelled out space with the two floors above being finished office spaces. UTK and ORNL are seeking a student to design/build a data center with cooling, rack space, Un-interruptible Power Supply (UPS), Power distribution units (PDUs), generator, etc. that is integrated into ORNL’s existing electrical and Information Technology (IT) infrastructure and will provide comparable availability for the IT equipment as the High Performance Computing (HPC) centers.

Proposal Guidelines and Deliverables

Written Design Proposal Document



- At a minimum, the student is to provide a written proposal that describes:
  - Data center design strategy
  - Design narrative description and supporting schematics and/or layouts of:
    - Electrical distribution system
    - Cooling systems
    - Networking design
  - Measures proposed to obtain the required PUE (Power Usage Effectiveness) along with steps to be taken to maximize efficiency and sustainability
  - Electrical and mechanical configurations that will satisfy the availability and concurrent maintenance requirements.
  - Project Plan inputs:
    - Short description of customer requirements and communication strategy
    - Scope organized by Work Breakdown Structure (WBS)
    - Proposed schedule including key milestones (identified by WBS element)
    - Proposed budgetary estimate (identified by WBS element)
    - Identify risks to project success with mitigations if appropriate
    - Identify contingency with an explanation about how it was determined (both schedule and budget)
  - Future growth strategy
  - Integration into existing ORNL computer operations and infrastructure

Proposal Guidelines and Deliverables

Floor Plans / Drawings

- Also provide floor plans and other drawings that shows the following:
  - The layout of the data center showing IT equipment footprint, ramps to access raised floor areas if proposed, passageways in room, floor loading requirements, fire protection features, security barriers, floor trains, cabinets.
  - Location of electrical distribution equipment (e.g. generator, UPS, PDUs Remote Distribution Units (RDUs), etc.).
  - Routing of electrical circuits.
  - Routing of network circuits.
  - Location of the cooling equipment.
  - Routing of chilled water piping.
  - Network infrastructure to include network cable routing and type of cable to connect this new DC to existing network infrastructure.
  - Single line electrical drawings showing normal power source and generator backed up UPS source and the distribution from these systems for IT and cooling equipment (basic level single line, minimum of breaker/wire/device).
  - Piping and instrumentation drawings showing chilled water sources and piping required for cooling the new DC.

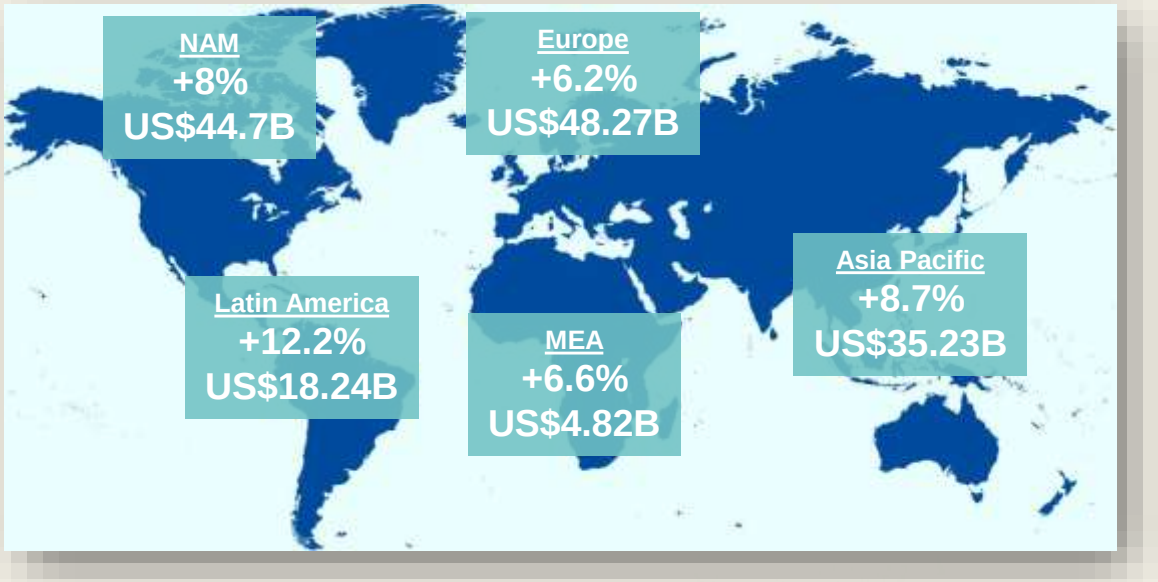
DATA Center Technology

Business Trends and Impact

Worldwide Datacenter Market Investment Growth

Global Investment (2013):

- Expenditures –
- construction, infrastructure, IT
- $151.3 Billion US
- 8% increase from 2012



Major Growth Drivers:

- Growing number of devices connected to the internet or 'The Internet of Things'.
- Social Media, Entertainment, and instant data any time, anywhere and on any device.
- Businesses relying on the internet to enable customers to shop, research, and perform tasks.
- New data center models and the rise of service and cloud providers - Amazon, Baidu, Alibaba, and Google.

Source: DCD Intelligence, 2013 Census Report: Global Data Center Investment 2013

The Nexus of Forces

The Nexus of Forces
Source: Gartner 2013

- Social media, Mobile devices, Information (big data) and Cloud Technologies are reshaping the way businesses and individuals rely on datacenters for on-demand information and computing services.

Keeping up with the Digital Explosion

- **On Demand Business:**
  Anytime, anywhere, any device, and any data
  - Mobility
  - Social media
  - Cloud services
  - Big data

- **Convergence of users, business, technology, and facilities**
- **Shift from functional to integrated enterprise platforms**

- **Digital Universe will contain 44 Zetabytes of data by 2020 (EMC Digital Universe Study - 2014)…doubling every two years. Zetabyte = 1 trillion Gigabytes**

Business Trends For The Data Center

- **Increased Reliance of Business on The Data Center**
- **Decreased Enterprise Data Center Spending Due To:**
  - Virtualization
  - Energy Efficiencies
  - Outsources Services
    - Multi-Tenant Data Centers
    - Hyperscale Data Center Services

Increased Reliance of Business on The Data Center

In The Past, the Data Center Was:

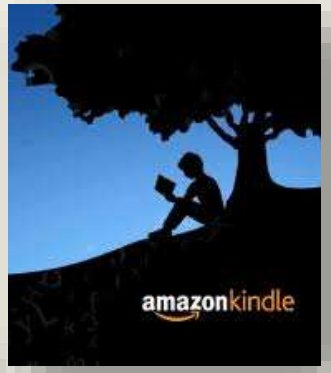
- Mechanism to Drive Business
- Supported Business
- Rarely Interactive with Consumer
- Businesses Established Practices and Created IT Around The Data Center
- Strict Control of All IT Aspects and Requests
- Risk Adverse – Protect the Business Assets

Increased Reliance of Business on The Data Center

- **Today's Modern Data Center**
  - Central Hub of the Organization--REGARDLESS of Sizes and Verticals
  - Globally Connected and Relied Upon
  - Complete Mobile Access to Data
  - True Device-Agnostic Connectivity
  - New Types of End-Points (Zero-Client Technology)
    - Users Access Their Data on 3-4 Devices
    - Consistent Look and Feel Across All Platforms
    - Best Possible User Experience – Regardless of What Device

Reliance of Business on The Data Center - Examples

- **Amazon's Kindle and Digital Media Publishing**
  - $5B in Kindle E-Reader Sales*
  - $4.5B in Amazon Web Services (Cloud)
  - 77M+ Users
- **Netflix Mail Order and Streaming Video Content**
  - Begins Producing Own Content
  - 44 Million Paid Subscribers Worldwide (33 Million in US)
  - $1.18B in Revenue
- **Video Gaming Industry On-line Multi-Player Games**
  - $67B in Revenues
- **Dropbox – Fast Data Replication and Synchronization**
  - 200 Million Subscribers Worldwide (~ 30% paid)*
  - $110 Million in Revenue* (Mostly Advertisements)
- **Apples iTunes Music and More**
  - Eliminates Traditional Music Purchasing Model
  - $37.5B in Revenue
- **Pandora Internet Radio**
  - Design Your Own Content
  - 54.9M Users



*-Morgan Stanley Estimate

Decreased Enterprise Data Center Spending

- **Outsources Services**
  - Multi-Tenant Data Centers
    - Space and Services
    - Looking at Cloud Services
    - $6.5 Billion in Revenue

EQUINIX

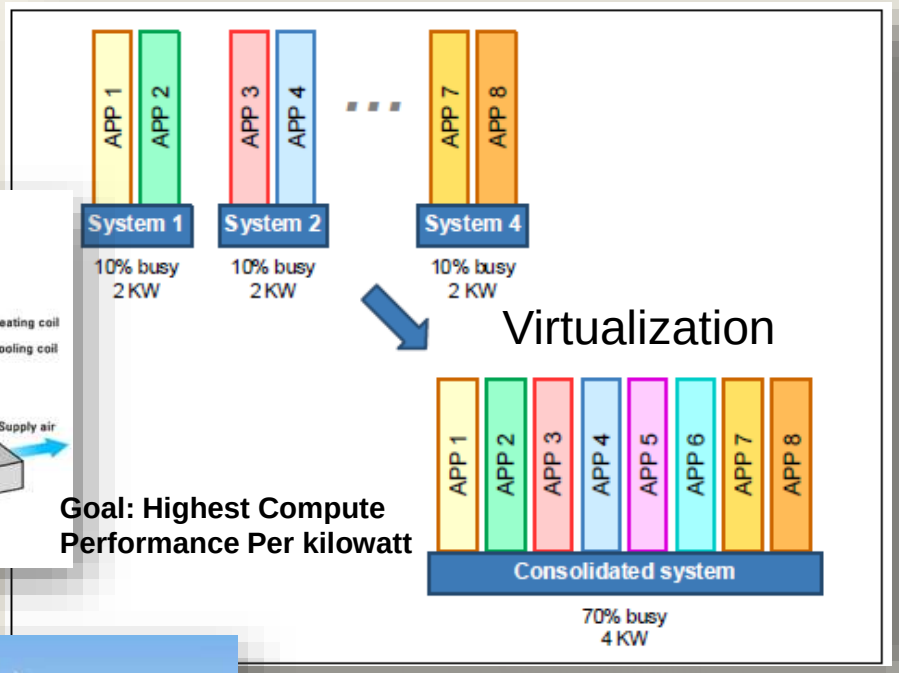
DuPont Fabros Technology

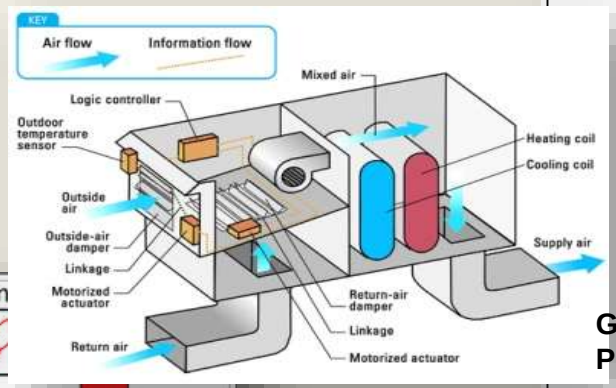
Decreased Enterprise Data Center Spending

- **Outsources Services**
  - Hyperscale Data Center Services
    - Cloud Services
    - $288 Billion Worldwide Revenue

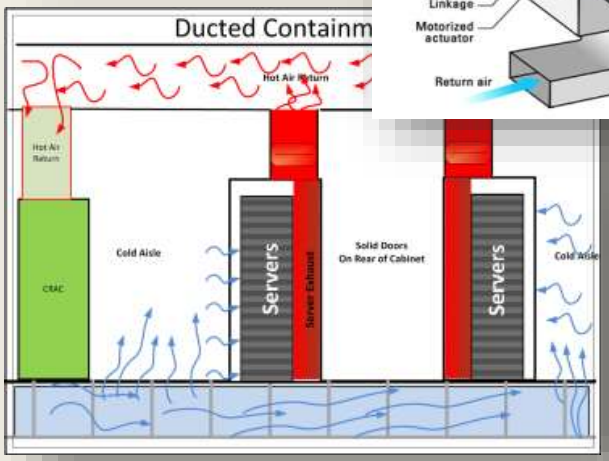
Decreased Enterprise Data Center Spending

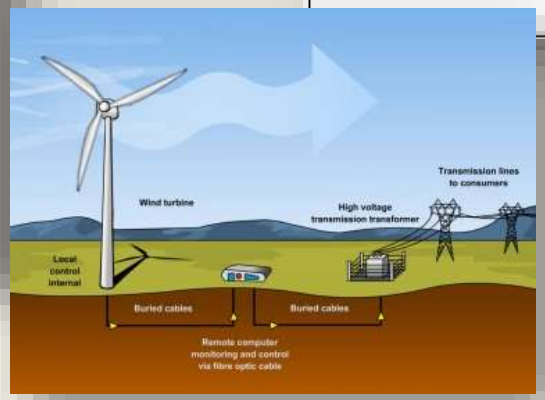
- Virtualization
- Energy Efficiencies



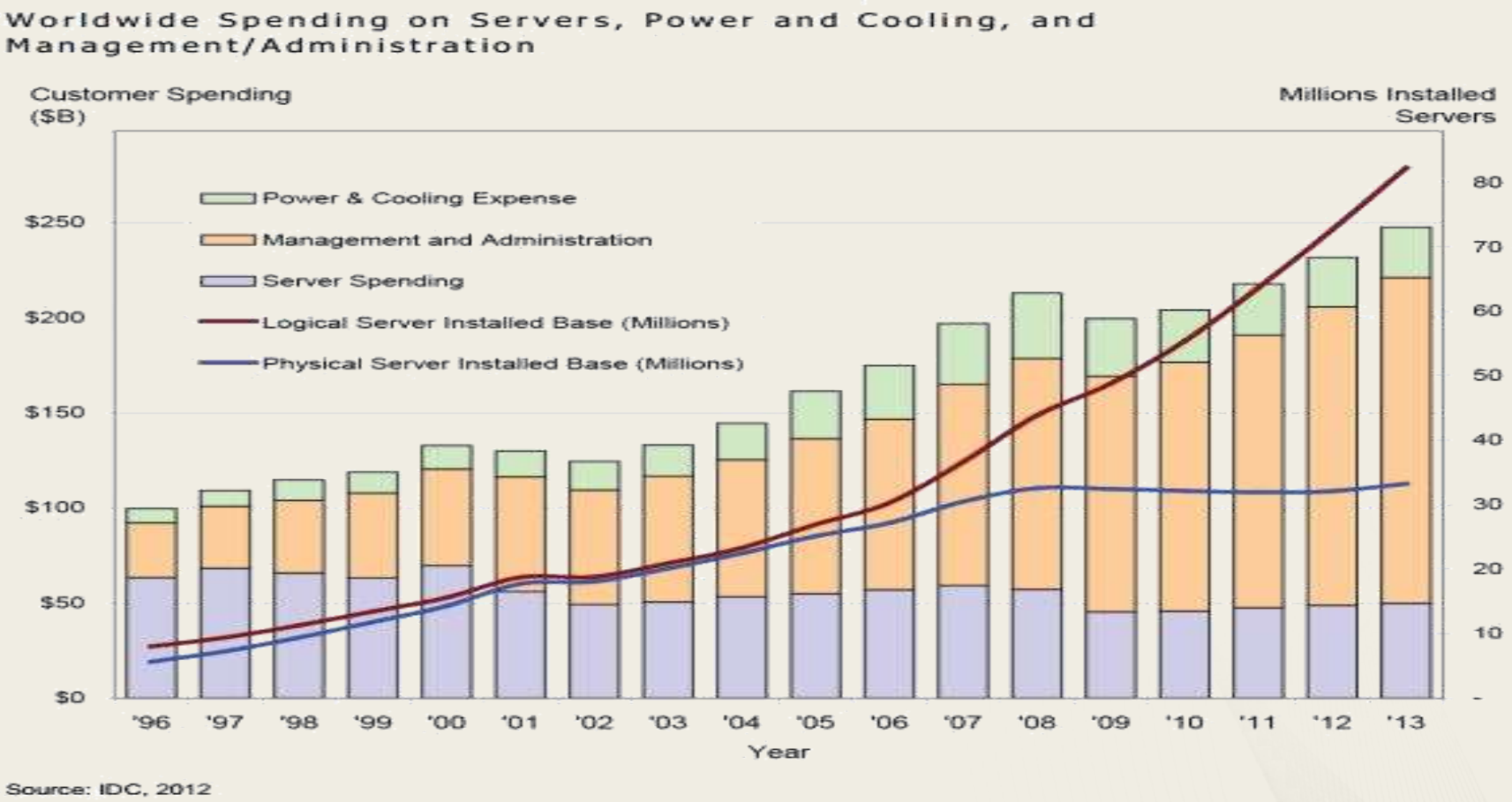


Goal: Highest Compute Performance Per kilowatt





Delaying the Next Data Center Build Out



Source: IDC, 2012

Top Data Center Concerns (an Operators Prospective)

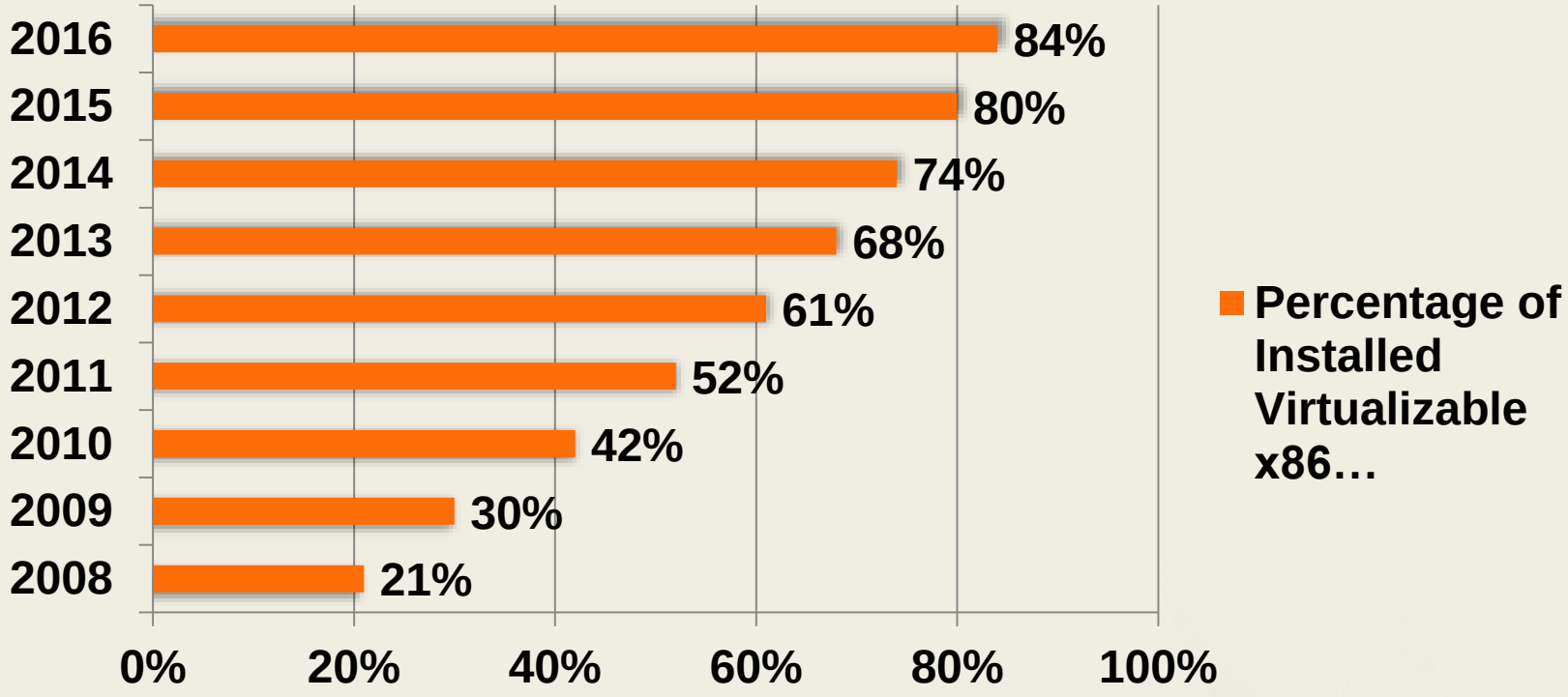
Top 6 Concerns (Forsythe Technology Survey)

- Adequate Monitoring and Management
- Availability (uptime)
- Energy Efficiency
- Cooling
- Power Density
- Space Constraints/Growth

What about:

- Security
- Utilization & Allocation Efficiencies
- Storage Capacity, Recovery, Archiving
- Administrative and Management Cost

Virtualization Adoption Trend



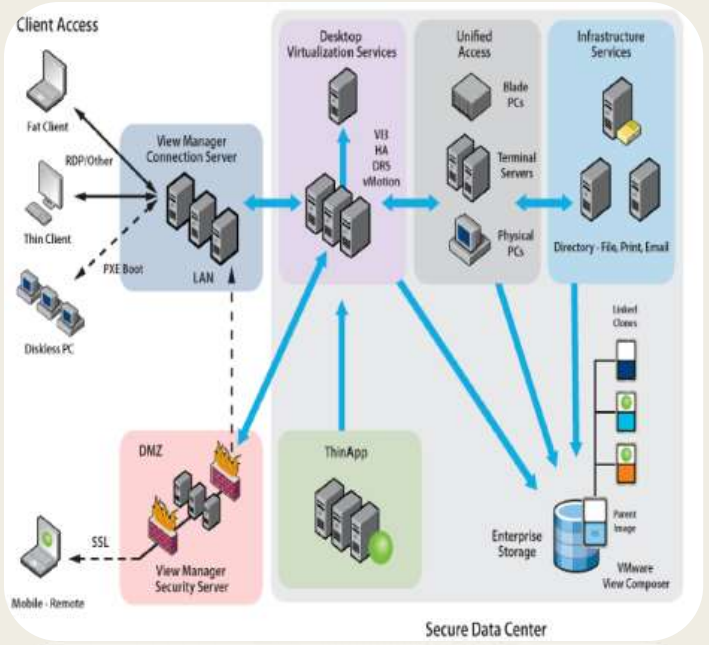
Source: Gartner Forecasts 2013

Technology Trends

- **Adoption of 'Web-Scale' IT designs and processes by the Enterprise**
  - Industrially Designed Infrastructure
  - Web Oriented Architecture
  - API Based Management
  - Velocity Focused Processes
  - Collaboratively Aligned Organization – Silos to Service Teams
  - Risk Embracing Culture
  - Open Source

Technology Trends

- **Industrial Designed Infrastructure**
  - Agile, Standardization, Scalable, & Rapid Deploy
  - Energy Efficient
  - Extensive Monitoring (Measure, Monitor, Manage)
  - Lean Principles
  - Vanity Free Designs
    - Use Holistic Design Principles
  - Automated Processes
  - Focus on Workflows NOT Workloads
  - Focus on NOT where the work is located but WHAT the work is doing



Technology Trends

- **Technology innovation is bringing new and exciting things to respond to the needs of today's business**
  - Convergence of Servers, Storage, and Networking is growing
  - Software Defined Everything (SDx)
  - Fabrics
  - Extremely Low Energy (ELE) Servers
  - Original Design Manufacturer (ODM) or DIY Servers (aka Skinless)
  - Silicon Photonics

DATA Center Technology

Data Center Facilities Examples

Data Center Example: Yahoo Chicken Coop

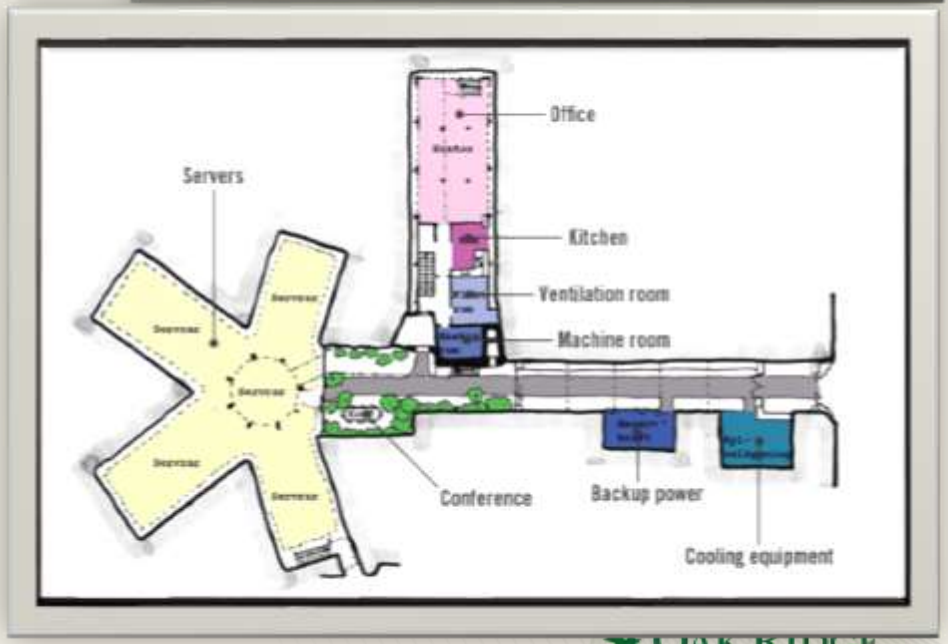
- The 155,000-square-foot data center in Lockport, NY
- Accommodates 50,000 servers
- Cooled almost 100 percent by outside air using 40 percent less energy than typical data centers.
- The building is important because it will effect the efficiency of the data center
- There are many ways to have an efficient building
  - Yahoo Chicken Coop
  - Designed to take advantage of “free cooling”
  - PUE 1.1

Data Center Example: Barcelona Supercomputing Center (BSC)

- The Barcelona Supercomputing Center
  - 19th century Torre Girona chapel in Barcelona, Spain.
- **MareNostrum Supercomputer**
  - “Divine Data Cruncher”
  - Once the most powerful supercomputer in Europe
  - 63.8 TFLOPS PowerPC-based supercomputer
  - ranked 465th in the world in June 2012
- Also hosts a newer 103.2 TFLOPS supercomputer
  - Xeon E5649 processors
- PUE 1.3

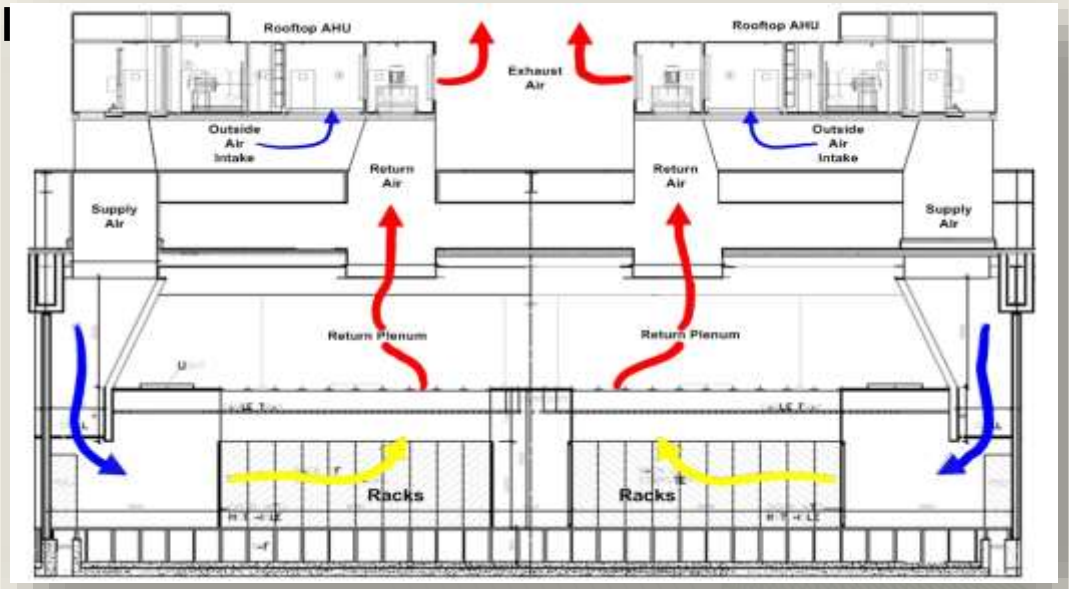
Data Center Example: Stockholm Data Center

- Headquarters of Bahnhof
  - a Swedish Internet Service Provider
- Named **“Pionen White Mountains”**
- Stockholm, Sweden converted nuclear bunker
- A hundred feet under the city of Stockholm
- Designed to take advantage of “free cooling”
  - PUE 1.1



Data Center Example: Microsoft

- **Microsoft Dublin data center**
  - Designed to take advantage of Ireland's low ambient temperatures for "free cooling" using airside economizers
  - Uses shipping container to create modularization to facilitate future expansi
  - PUE 1.25



Data Center Example: Sun

- A decommissioned coal mine in Chubu region on Japan's Honshu island.
- Contains 30 Blackbox self-contained data centers
  - containing a total of 10,000 servers (cores) - scalable to 30,000 cores
- **Blackbox concept** –
  - 250 servers mounted in seven racks inside a standard 20-foot shipping container.
- A subterranean data center easy to secure against unauthorized entry and terrorist attacks.
- The project was initially estimated to cost $405 million and was to start operations in April 2010.