Sierra

https://hpc.llnl.gov/hardware/platforms/sierra

CS 644: Introduction to Big Data

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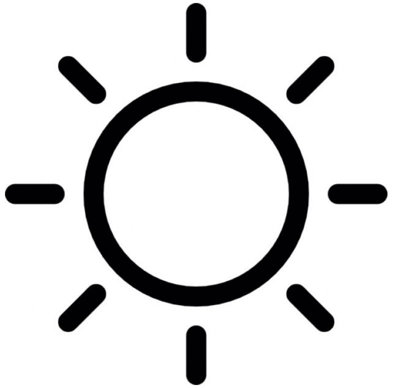
New Jersey Institute of Technology

Outline

- Introduction
  - Motivation
  - Where are the big data sets from?
  - Key enablers
- Objectives and Challenges
- Computing Technologies
  - High-performance Computing
  - Grid Computing
  - Cloud Computing
  - Mobile Computing
- Ongoing Research
  - High-performance Networking
  - Data-intensive Computing



Motivation

- Solving the *big problems*

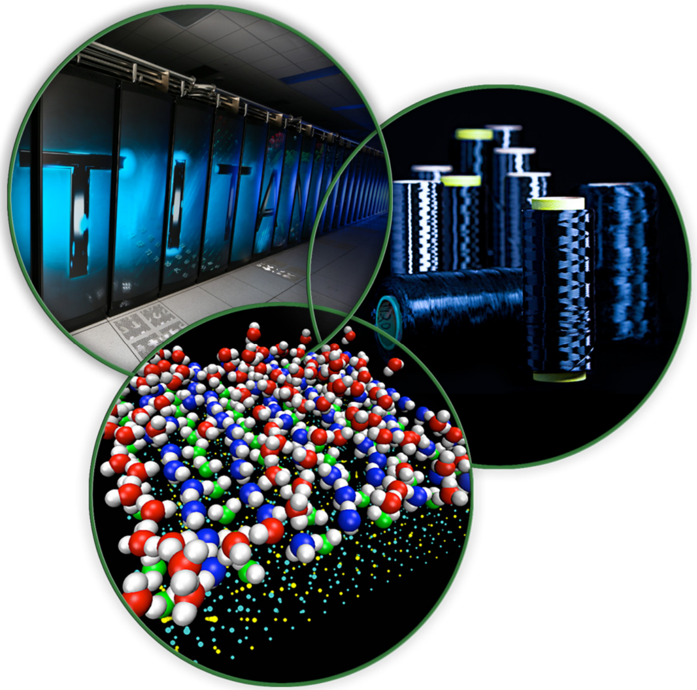
Then what are
the big problems?

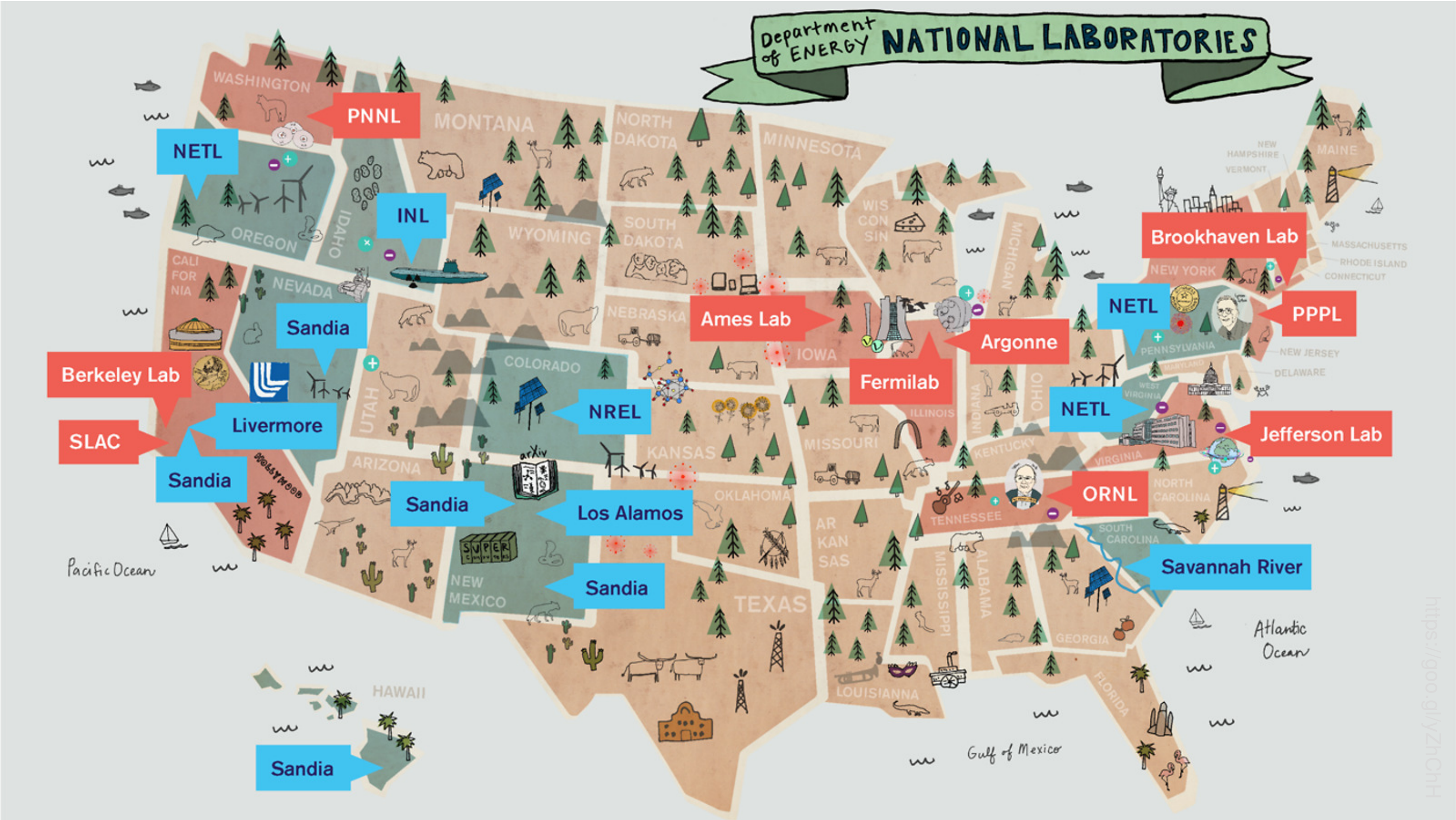
What is big data?

- “Big” data is similar to small data, but only bigger?
- Having data bigger consequently requires different approaches
  - Techniques, tools, and architectures,
  - With an aim to solve new problems,
  - And old problems in a better way

Where are the big data sets from?

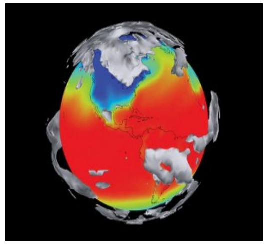
- Large-scale scientific applications

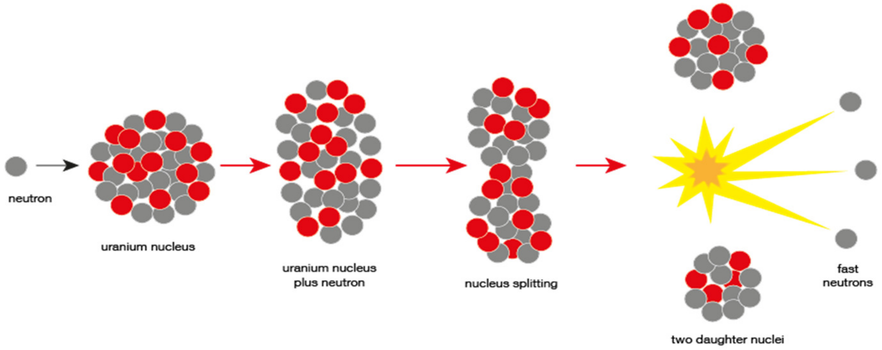




Where are the big data sets from?

- Large-scale scientific applications
  - Simulation
    - Astrophysics, climate modeling, combustion research, etc.
  - Experimental
    - Spallation neutron source, large hadron collider, microarray, genome sequencing, protein folding, etc.
  - Observational
    - Large-scale sensor networks, astronomical imaging/radio devices (Dark Energy Camera, Five-hundred-meter Aperture Spherical Telescope – FAST, etc.)





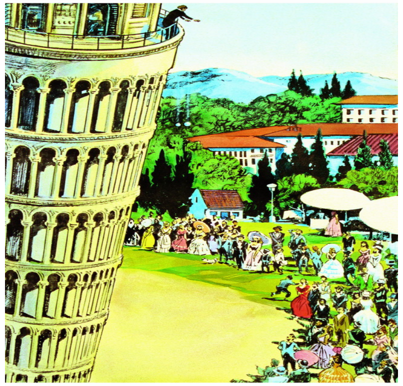
Science is changing…

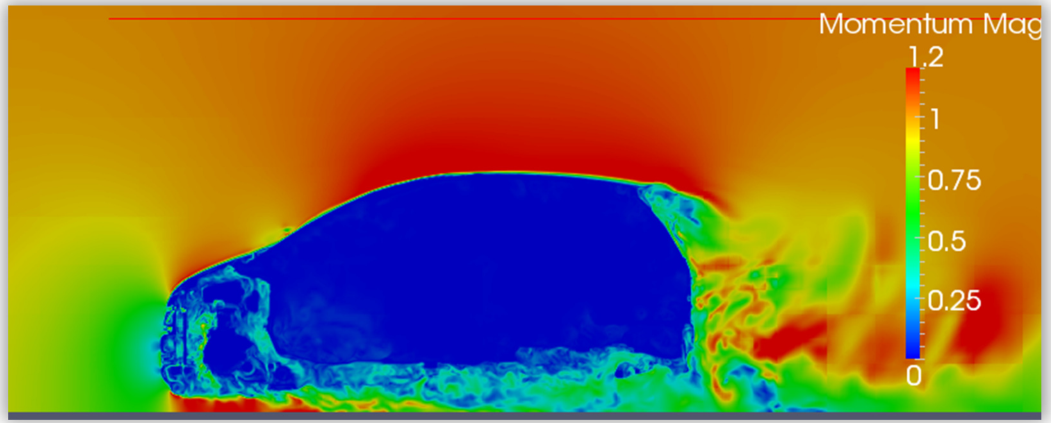
- Thousand years ago, science was empirically describing natural phenomena

- Last few hundred years, theoretical branch using models, generalizations

- Last few decades, a computational branch simulating complex phenomena

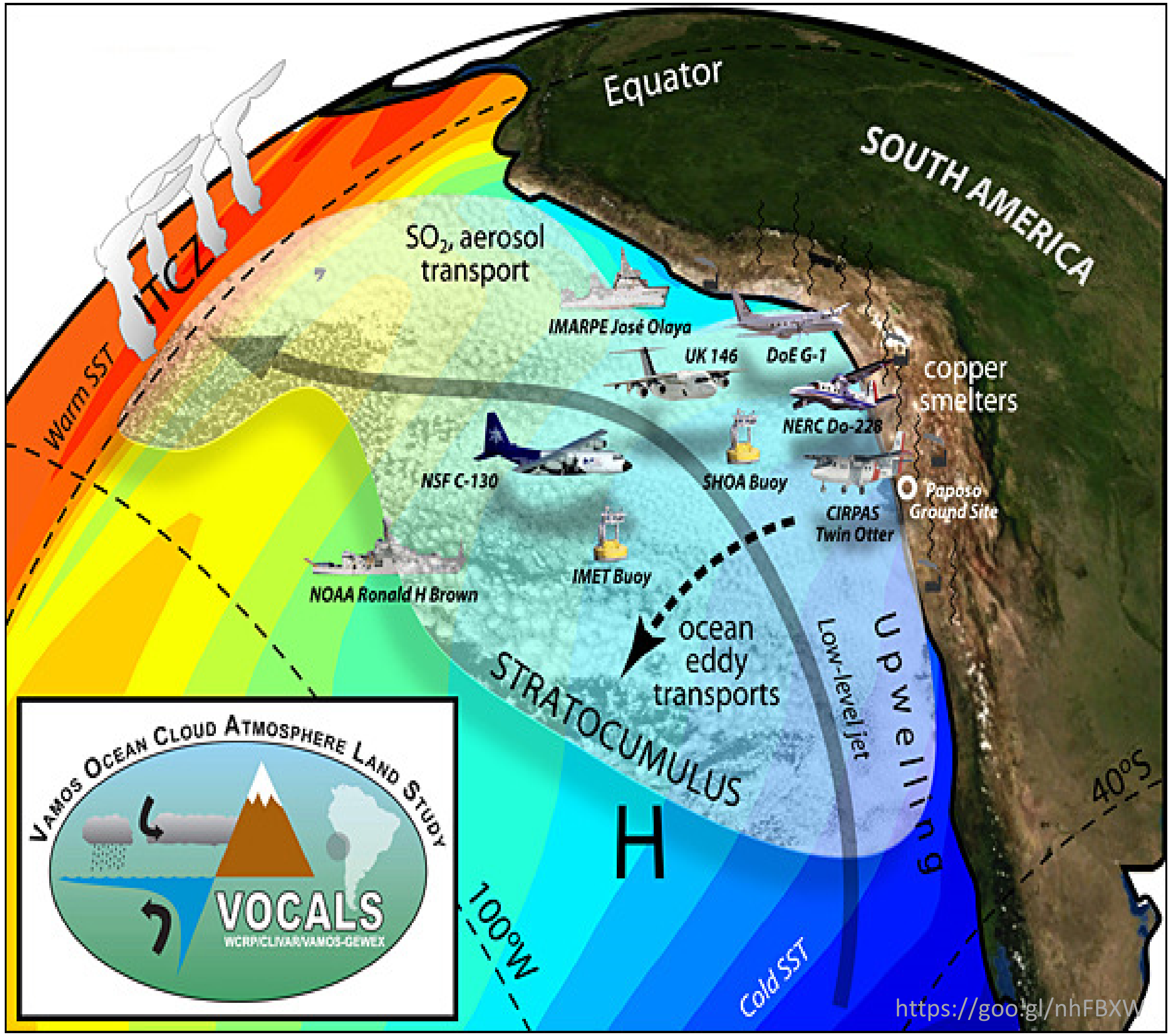
- Today, data-intensive science, synthesizing theory, experiment and computation with statistics, i.e., new way of thinking required





Science is becoming data-driven

- Convergence of physical and life sciences through Big Data (statistics and computing) and a scientific revolution in how discovery takes place, which is a rare and unique opportunity



Albert Einstein
Old Grove Rd.
Nassau Point
Peconic, Long Island

August 2nd, 1939

F.D. Roosevelt,
President of the United States,
White House
Washington, D.C.

Sir:

Some recent work by E.Fermi and L. Szilard, which has been communicated to me in manuscript, leads me to expect that the element uranium may be turned into a new and important source of energy in the immediate future. Certain aspects of the situation which has arisen seem to call for watchfulness and, if necessary, quick action on the part of the Administration. I believe therefore that it is my duty to bring to your attention the following facts and recommendations:

In the course of the last four months it has been made probable - through the work of Joliot in France as well as Fermi and Szilard in America - that it may become possible to set up a nuclear chain reaction in a large mass of uranium,by which vast amounts of power and large quantities of new radium-like elements would be generated. Now it appears almost certain that this could be achieved in the immediate future.

This new phenomenon would also lead to the construction of bombs, and it is conceivable - though much less certain - that extremely powerful bombs of a new type may thus be constructed. A single bomb of this type, carried by boat and exploded in a port, might very well destroy the whole port together with some of the surrounding territory. However, such bombs might very well prove to be too heavy for transportation by air.

The United States has only very poor ores of uranium in moderate quantities. There is some good ore in Canada and the former Czechoslovakia, while the most important source of uranium is Belgian Congo.

In view of this situation you may think it desirable to have some permanent contact maintained between the Administration and the group of physicists working on chain reactions in America. One possible way of achieving this might be for you to entrust with this task a person who has your confidence and who could perhaps serve in an inofficial capacity. His task might comprise the following:

a) to approach Government Departments, keep them informed of the further development, and put forward recommendations for Government action, giving particular attention to the problem of securing a supply of uranium ore for the United States;

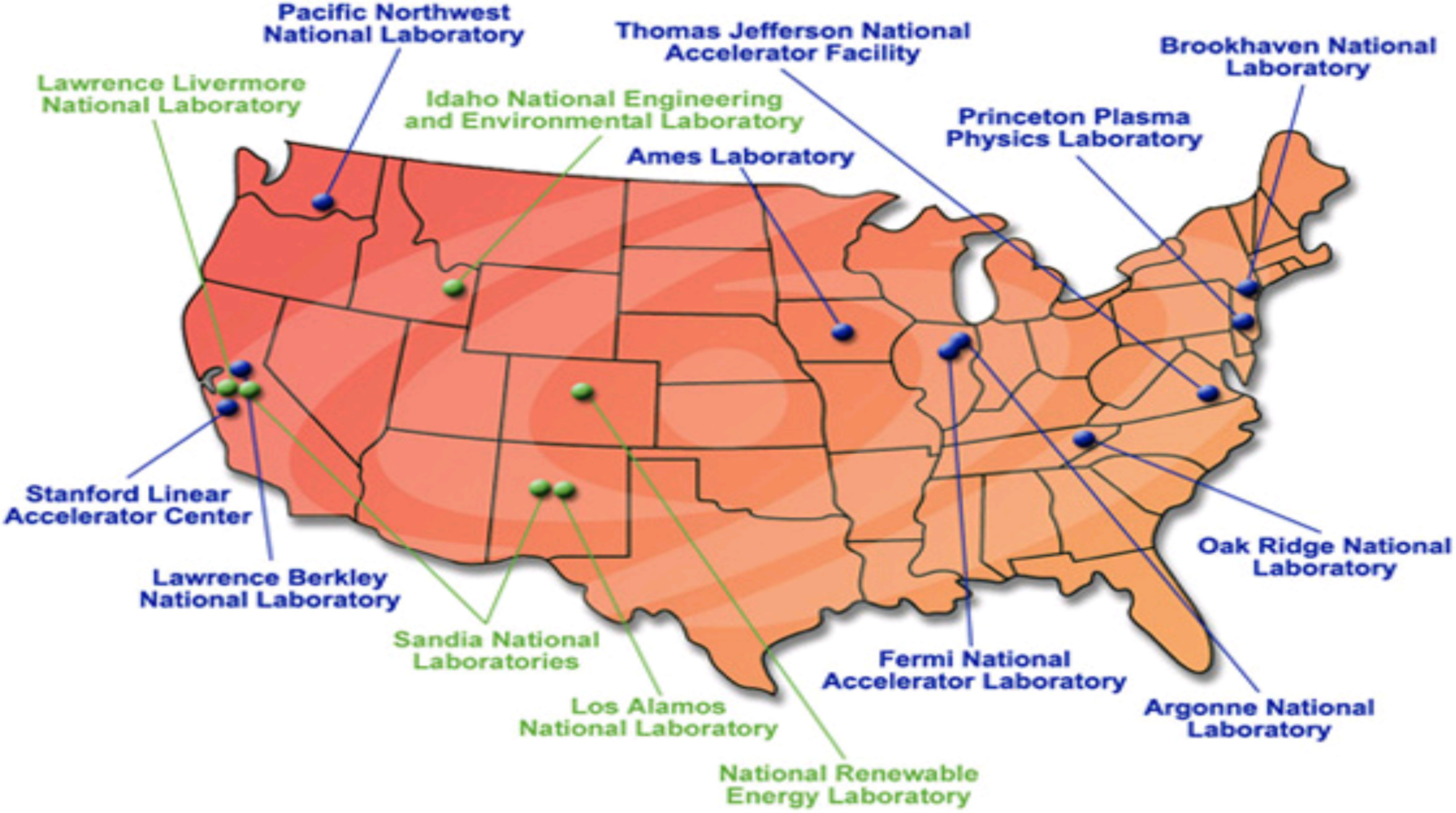
b) to speed up the experimental work,which is at present being carried on within the limits of the budgets of University laboratories, by providing funds, if such funds be required, through his contacts with private persons who are willing to make contributions for this cause, and perhaps also by obtaining the co-operation of industrial laboratories which have the necessary equipment.

I understand that Germany has actually stopped the sale of uranium from the Czechoslovakian mines which she has taken over. That she should have taken such early action might perhaps be understood on the ground that the son of the German Under-Secretary of State, von Weizsäcker, is attached to the Kaiser-Wilhelm-Institut in Berlin where some of the American work on uranium is now being repeated.

Yours very truly,

A. Einstein

(Albert Einstein)


Pacific Northwest National Laboratory
Thomas Jefferson National Accelerator Facility
Brookhaven National Laboratory
Lawrence Livermore National Laboratory
Idaho National Engineering and Environmental Laboratory
Princeton Plasma Physics Laboratory
Ames Laboratory
Stanford Linear Accelerator Center
Oak Ridge National Laboratory
Lawrence Berkley National Laboratory
Sandia National Laboratories
Fermi National Accelerator Laboratory
Argonne National Laboratory
Los Alamos National Laboratory
National Renewable Energy Laboratory


IBM
summit

solving the BIG PROBLEMS

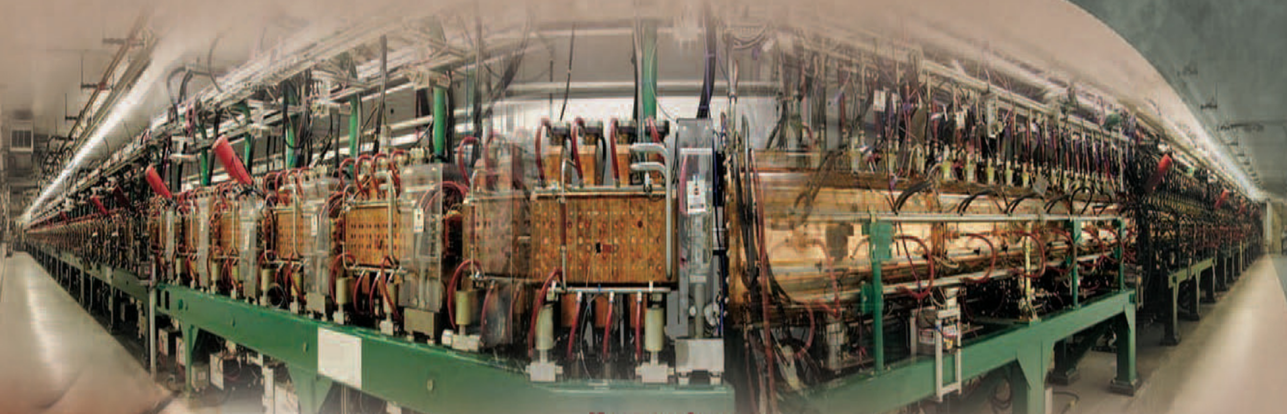
OAK RIDGE NATIONAL LABORATORY

MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Six Scientific Themes

Born of necessity. Inspired by our quest to know. We have always been called upon to address America's greatest scientific challenges.

"Men love to wonder, and that is the seed of science."
. . . Ralph Waldo Emerson



Biological Systems
Developing New Options

Whether converting biomass to fuel or understanding the impacts of climate change, biological research at ORNL is helping develop new options for energy, environmental protection, and human health. **mannre@ornl.gov**

Neutron Science
Leading the World

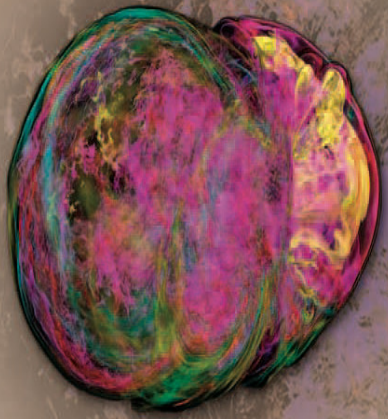
The Spallation Neutron Source and the High Flux Isotope Reactor together make Oak Ridge the world's foremost center for neutron science.
andersonian@ornl.gov

Advanced Materials
Strengthening American Industry

With DOE's first Nanoscience Center, the world's most powerful electron microscope, and the High Temperature Materials Laboratory, Oak Ridge plays a critical role in American industrial competitiveness.
buchananmv@ornl.gov

National Security
Guarding the Gates

From biochemical sensors to stopping the proliferation of nuclear weapons, technologies that make America safer are among the laboratory's top research priorities.
akersfhjr@ornl.gov



High Performance Computing
Tackling the Big Problems

With unmatched computational capacity for open scientific research, Oak Ridge is on a path by 2009 to reach a petaflop, or 1 quadrillion mathematical calculations per second, making it possible to model the most complex scientific problems.
zachariat@ornl.gov

Energy
Providing Energy Alternatives

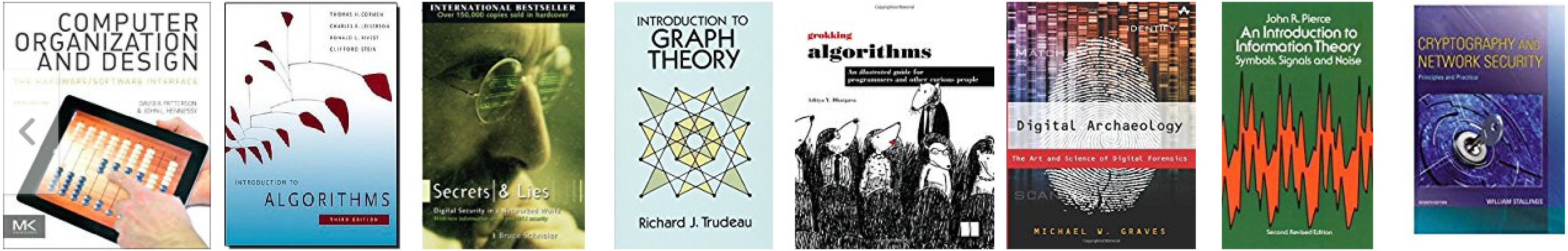
Increased production, improved transmission, reduced consumption: Oak Ridge is addressing our energy challenges on all fronts, from safer nuclear power to more energy-efficient cars and homes.
christensend@ornl.gov

Where are the big data sets from?

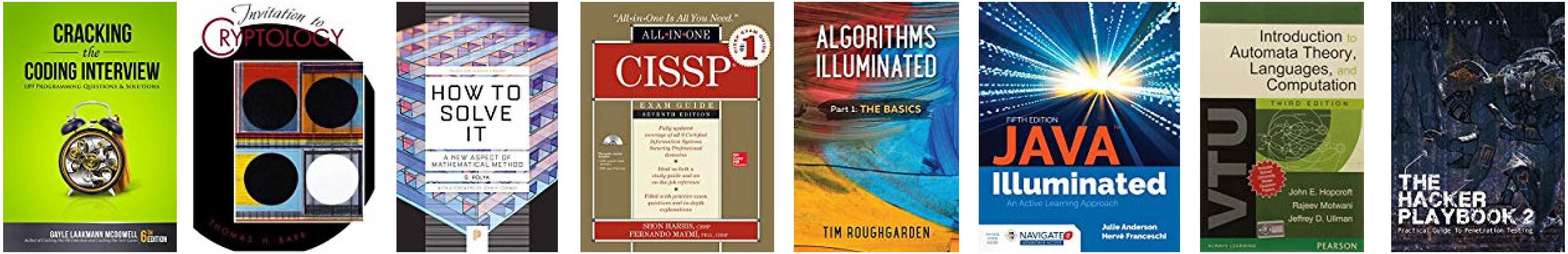
- Business
    - Financial transactions: walmart headquarter, stock traders, etc.

- Social media
    - Weblogs, twitter feeds, click streams, WeChat, etc.

Recommendations for you in Books

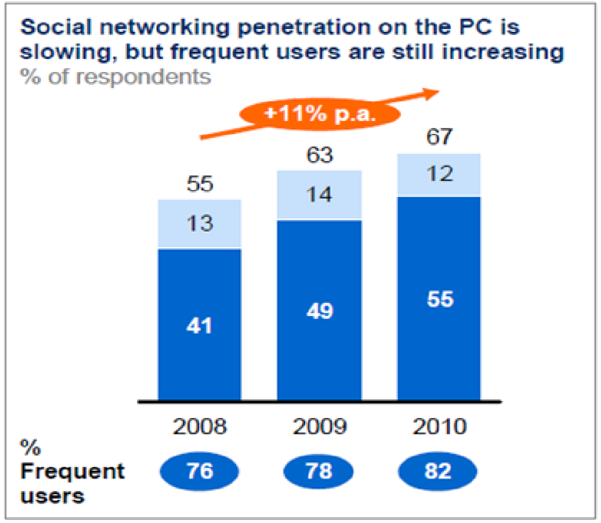


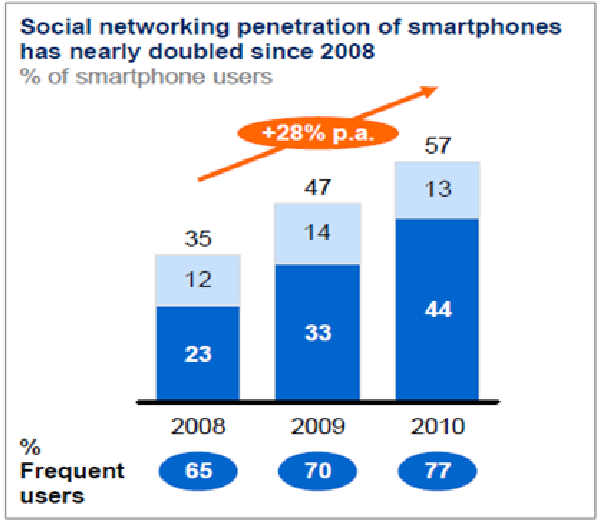
Recommendations for you in Books

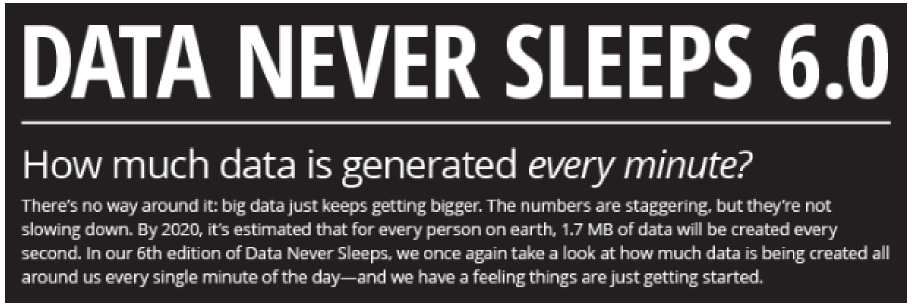


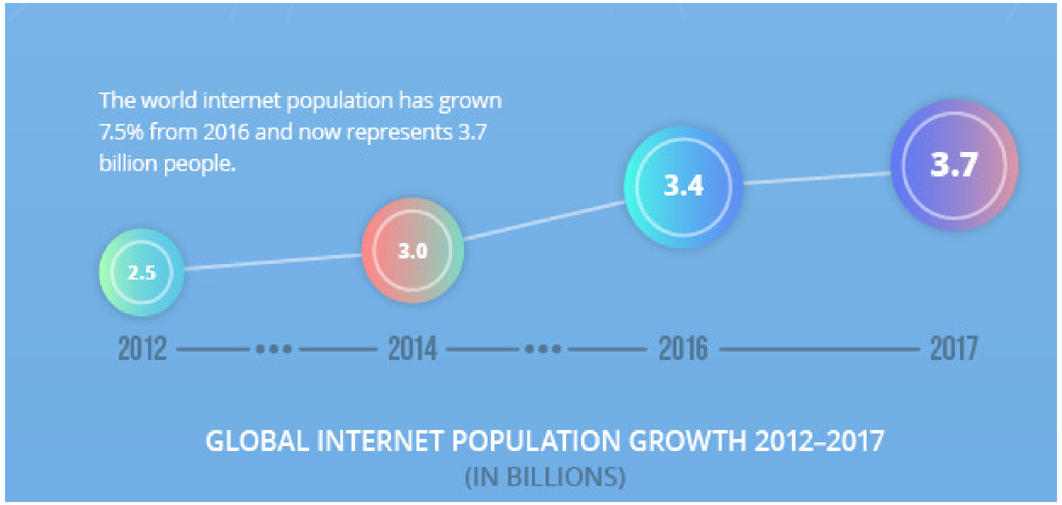
Example - Recommendation

Social networks and mobile devices









Example - Social Media Monitoring

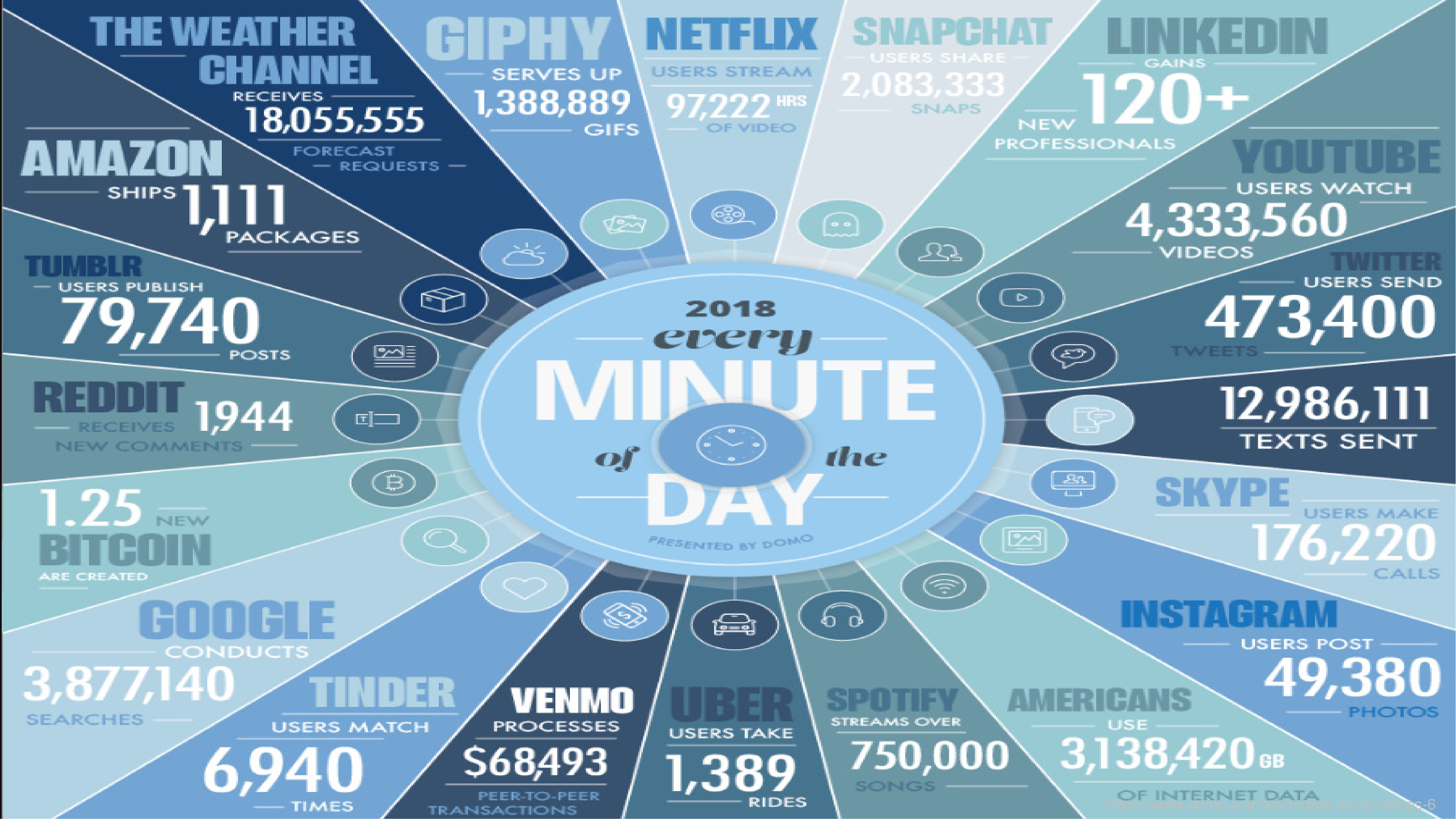
Image Source: the courtesy of Dr. Ching-Yung Lin at Columbia University

Live Tweets, Sentiment, Keywords

Dynamic Graphs

Zooming / Panning

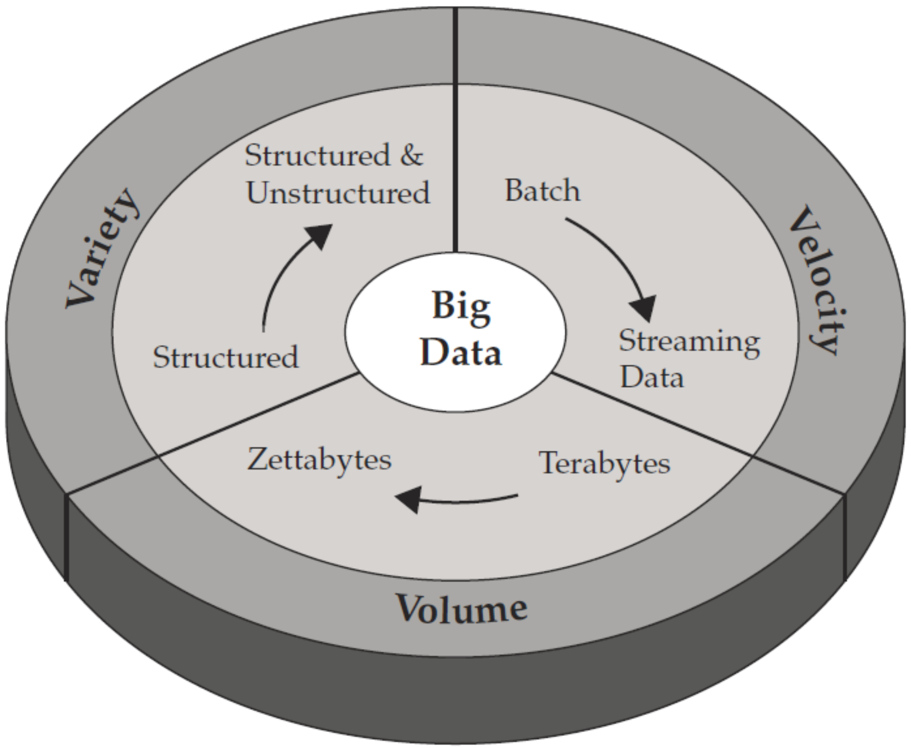
Real-Time Translation, Locations, Top Retweets



2018 every MINUTE of the DAY
PRESENTED BY DOMO
THE WEATHER CHANNEL RECEIVES 18,055,555 FORECAST REQUESTS
GIPHY SERVES UP 1,388,889 GIFS
NETFLIX USERS STREAM 97,222 HRS OF VIDEO
SNAPCHAT USERS SHARE 2,083,333 SNAPS
LINKEDIN GAINS 120+ NEW PROFESSIONALS
YOUTUBE USERS WATCH 4,333,560 VIDEOS
TWITTER USERS SEND 473,400 TWEETS
12,986,111 TEXTS SENT
SKYPE USERS MAKE 176,220 CALLS
INSTAGRAM USERS POST 49,380 PHOTOS
AMERICANS USE 3,138,420 GB OF INTERNET DATA
SPOTIFY STREAMS OVER 750,000 SONGS
UBER USERS TAKE 1,389 RIDES
VENMO PROCESSES $68,493 PEER-TO-PEER TRANSACTIONS
TINDER USERS MATCH 6,940 TIMES
GOOGLE CONDUCTS 3,877,140 SEARCHES
1.25 NEW BITCOIN ARE CREATED
REDDIT RECEIVES 1,944 NEW COMMENTS
TUMBLR USERS PUBLISH 79,740 POSTS
AMAZON SHIPS 1,111 PACKAGES
https://www.domo.com/learn/data-never-sleeps-6

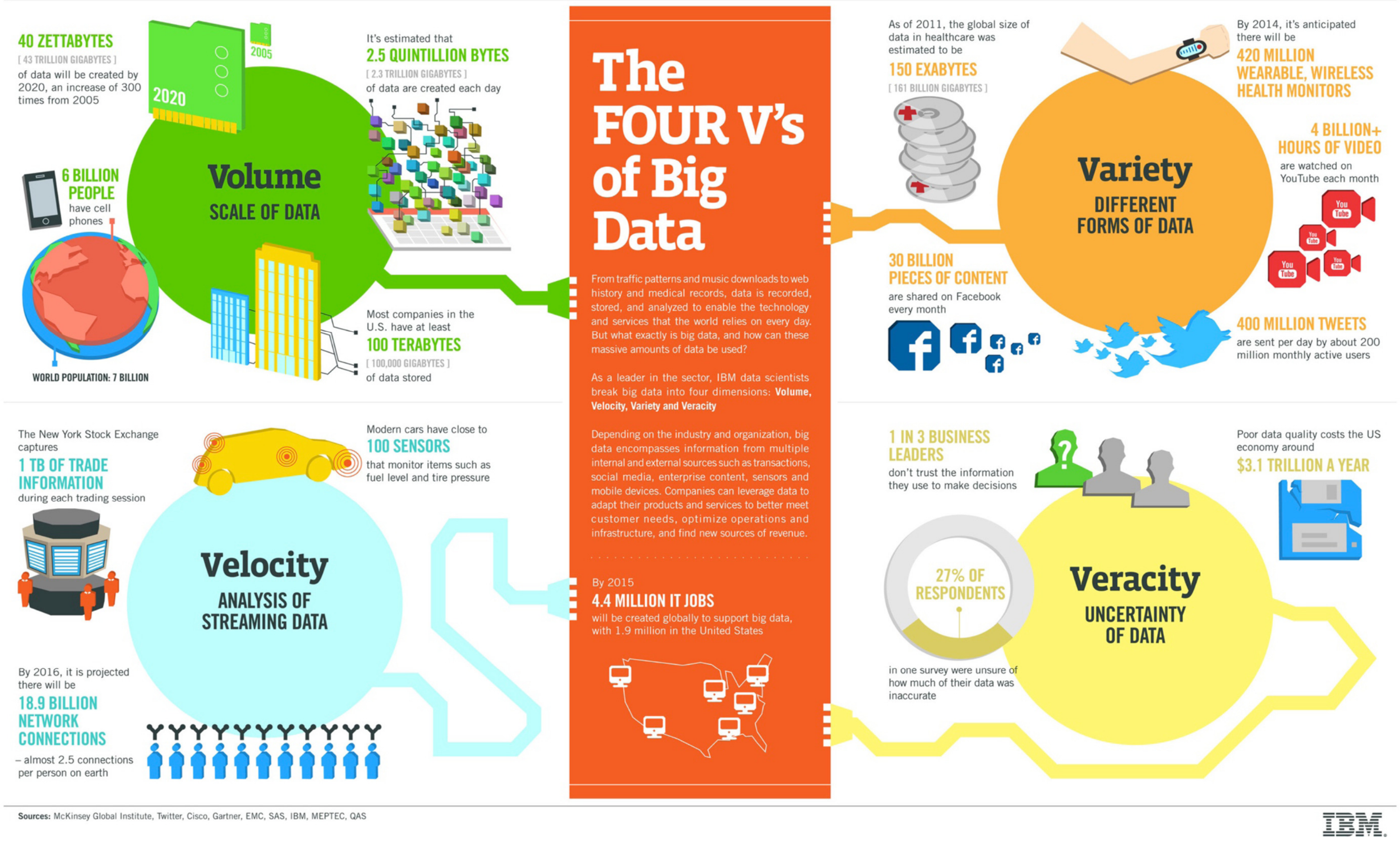
Characterization of big data

- Types, quality, relationships, and processing of data



Characterization of big data

- Four V's



Typical operations on data sets

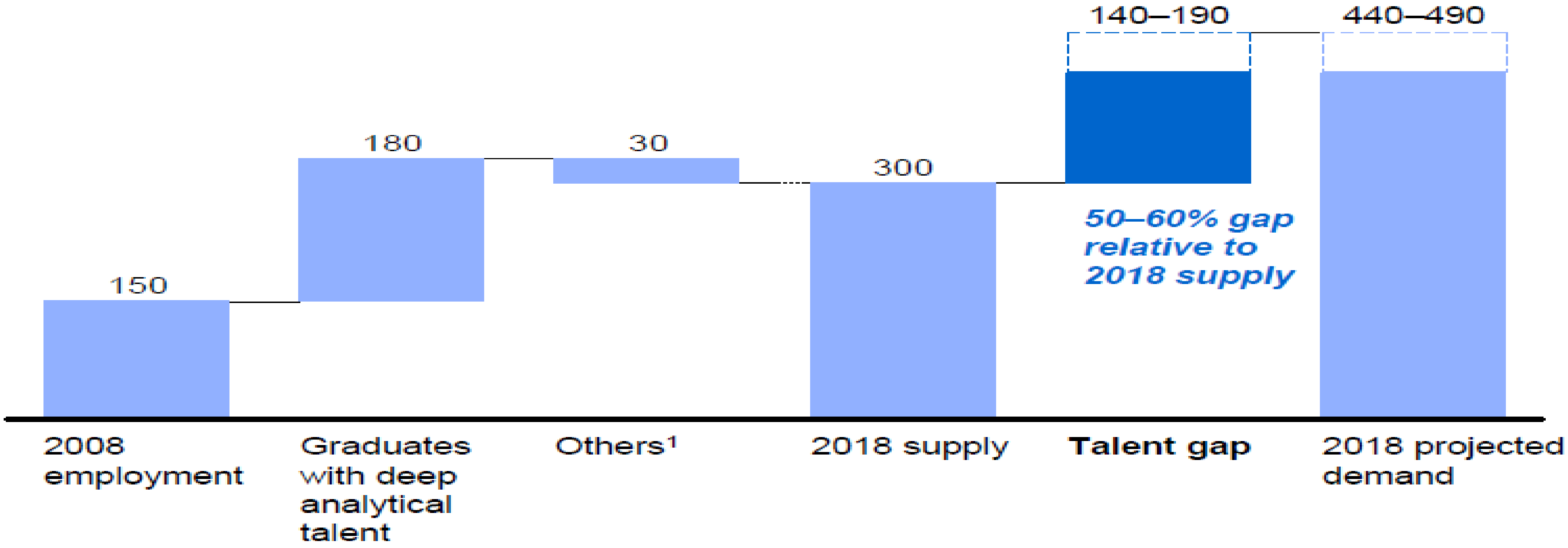
- Smart sampling of data
  - Reducing the original data while not losing the statistical properties of data
- Finding similar items
  - Efficient multi-dimensional indexing
- Incremental updating of the models
  - (v.s. building models from scratch)
  - Crucial for streaming data
- Distributed linear algebra
  - Dealing with large sparse matrices
- Supervised learning
  - Classification, regression, etc.
- Non-supervised learning
  - Clustering, different types of decompositions, etc.

Predicted lack of talent for big data

Demand for deep analytical talent in the United States could be 50 to 60 percent greater than its projected supply by 2018

Supply and demand of deep analytical talent by 2018

Thousand people

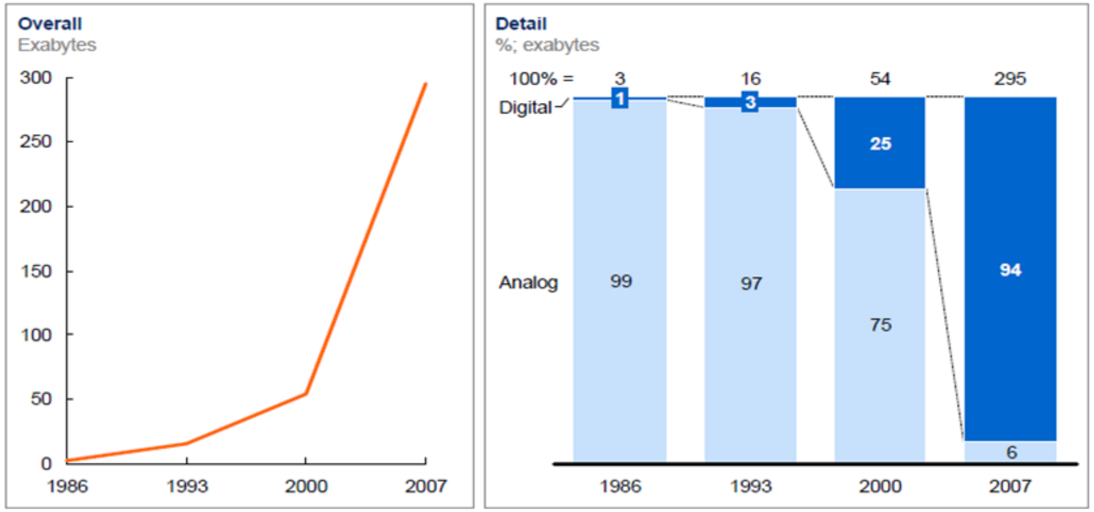


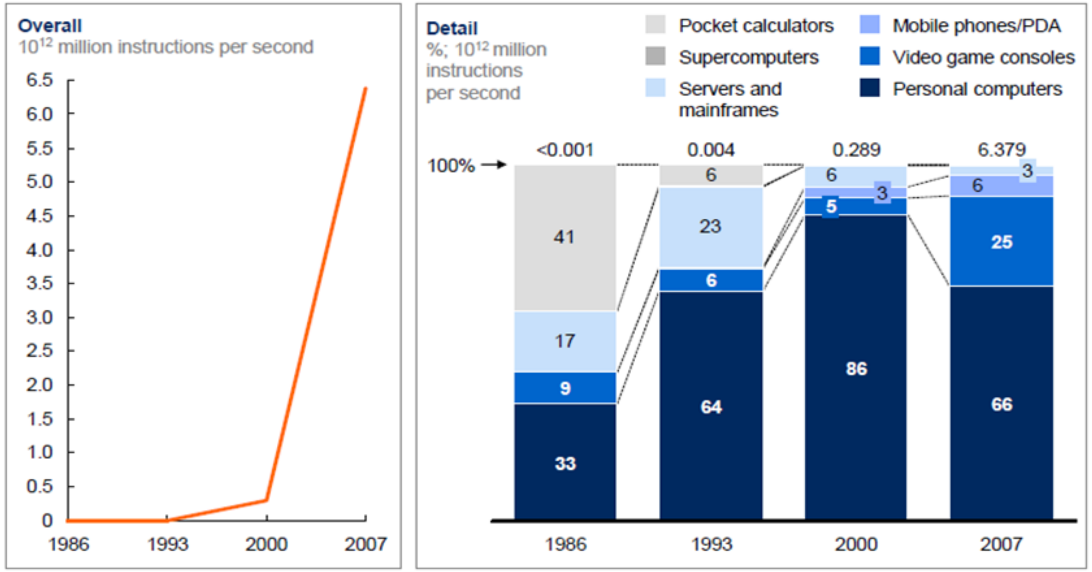
1 Other supply drivers include attrition (-), immigration (+), and reemploying previously unemployed deep analytical talent (+).

SOURCE: US Bureau of Labor Statistics; US Census; Dun & Bradstreet; company interviews; McKinsey Global Institute analysis

Key enablers

- Increase of storage capabilities
- Increase of computing power
- Increase of network capacities
- Availability of data sets

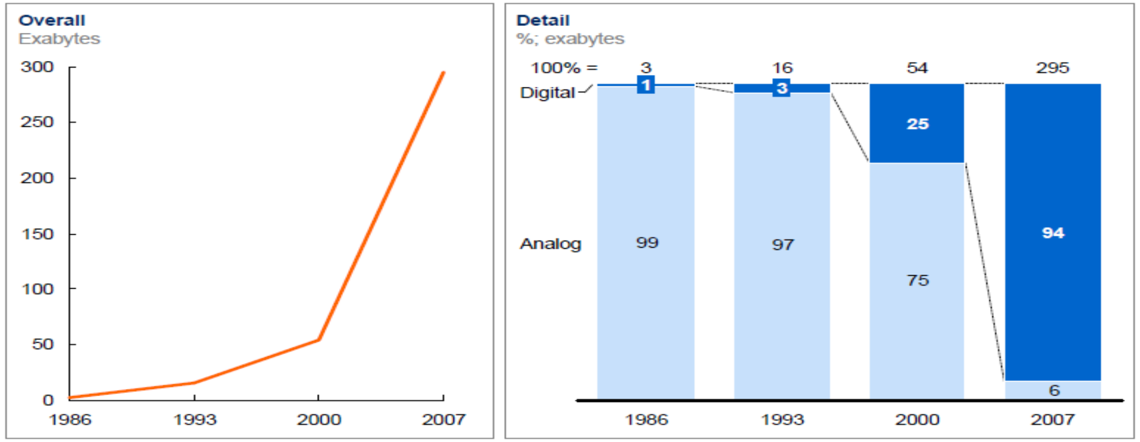




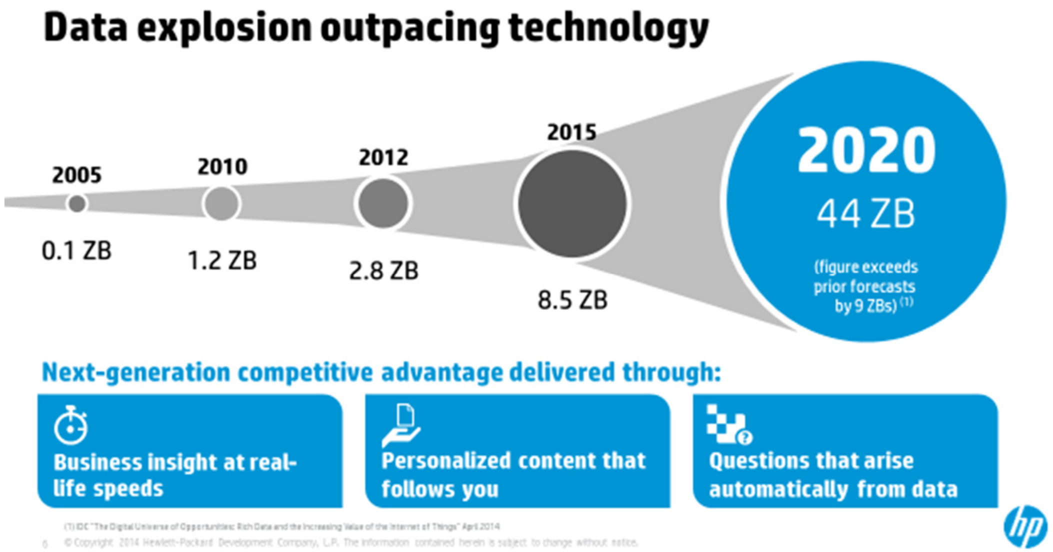
Increase of storage capabilities

Data storage has grown significantly, shifting markedly from analog to digital after 2000

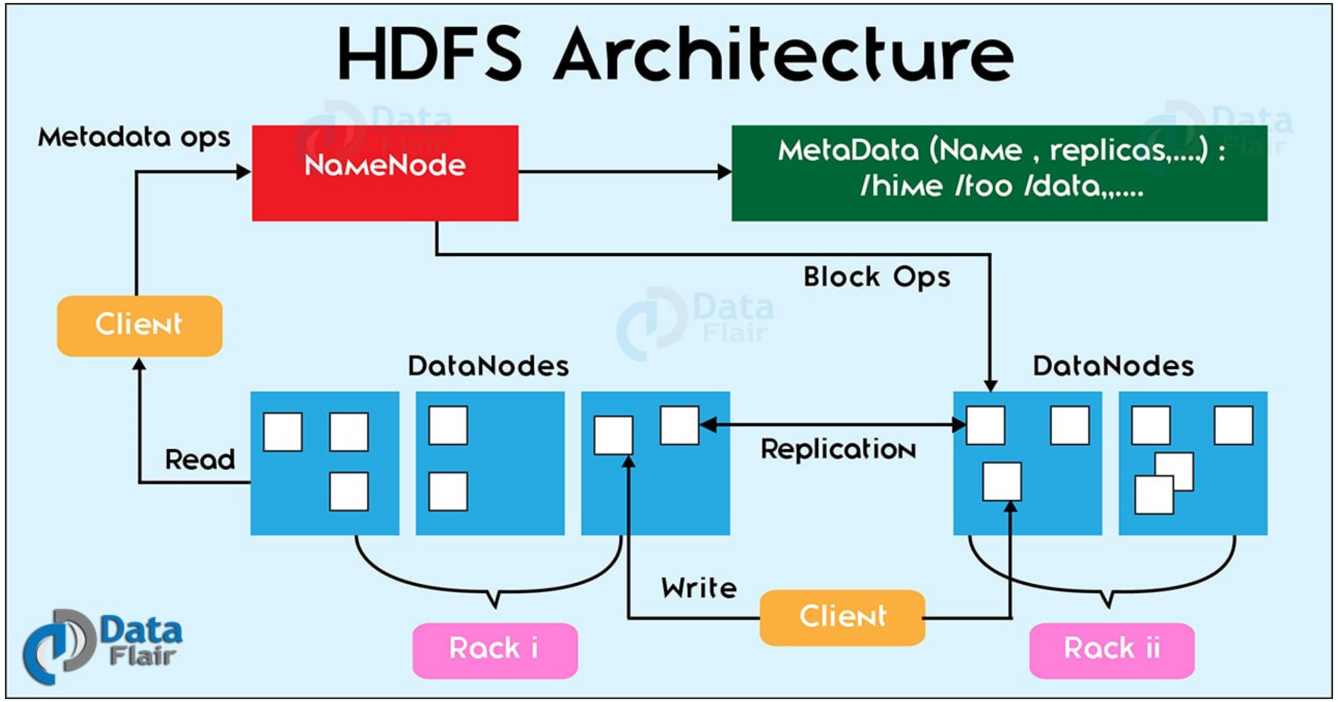
Global installed, optimally compressed, storage

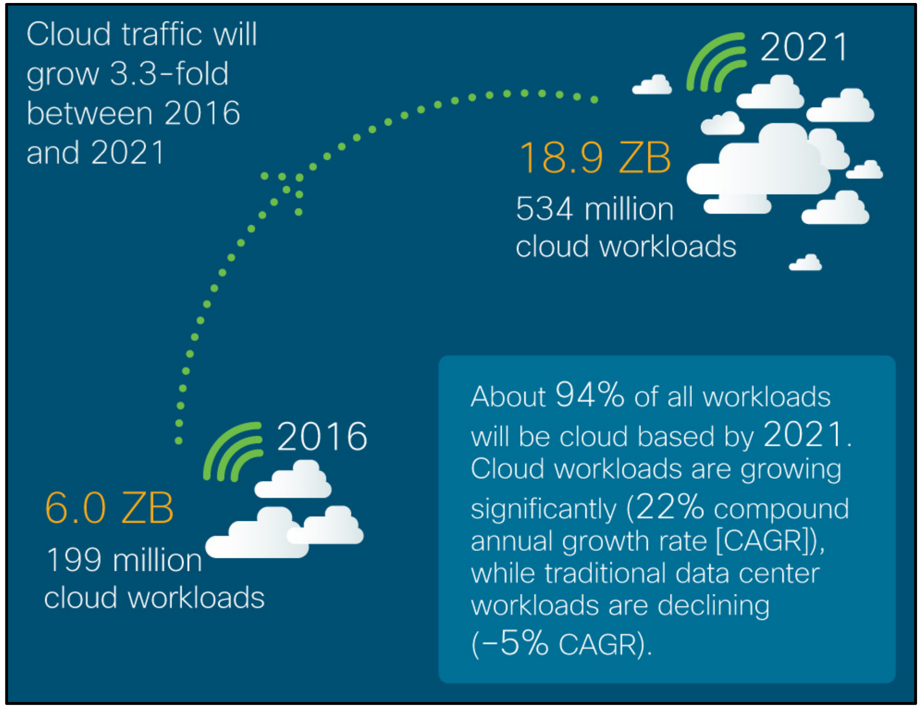


NOTE: Numbers may not sum due to rounding.
SOURCE: Hilbert and López, "The world's technological capacity to store, communicate, and compute information," *Science*, 2011

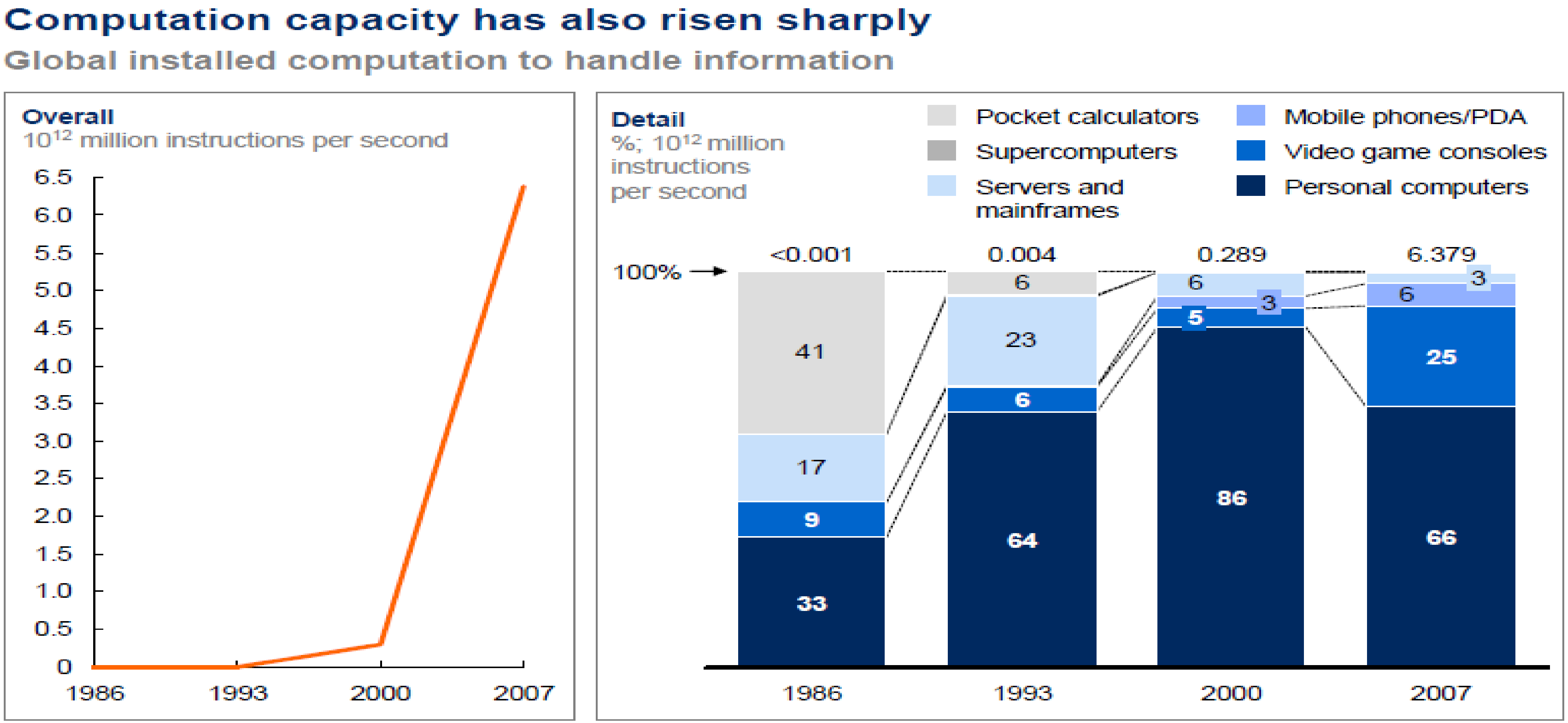


Increase of storage capabilities





Increase of computing power

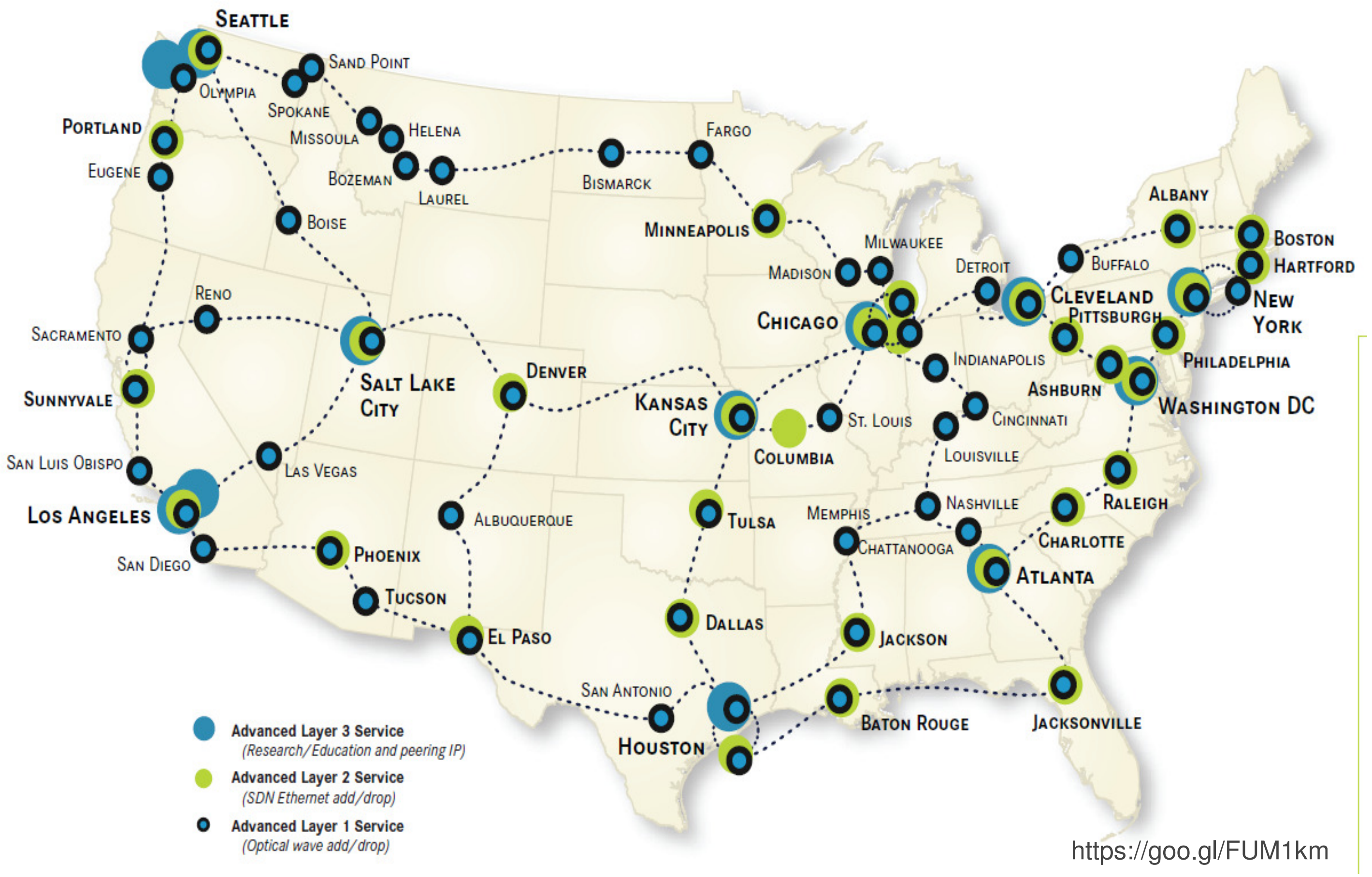


NOTE: Numbers may not sum due to rounding.
SOURCE: Hilbert and López, "The world's technological capacity to store, communicate, and compute information," *Science*, 2011

More platforms, techniques, and tools

Increase of network capacities

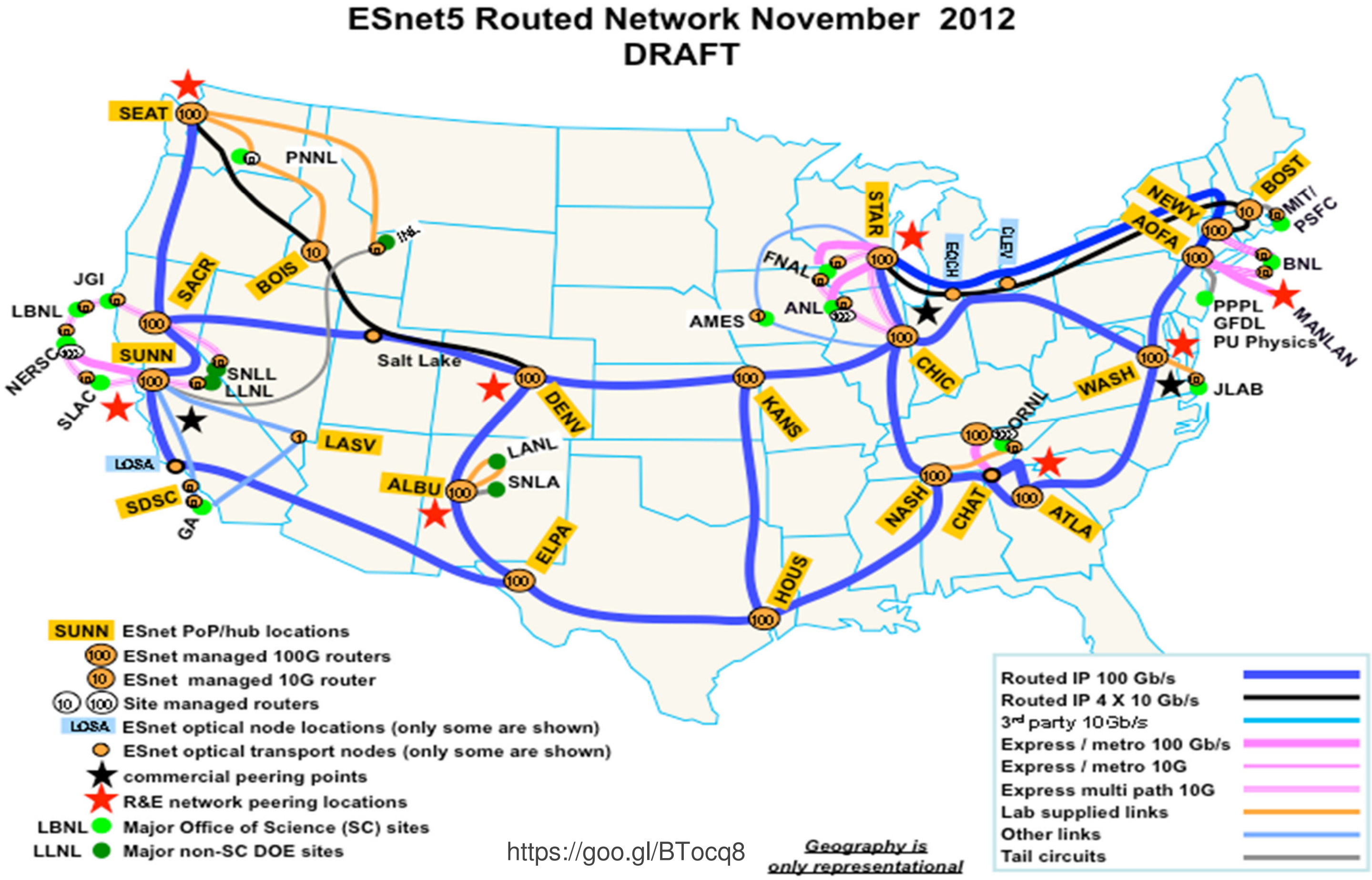
- HPNs: High-performance Networks
- e.g., Internet2



https://goo.gl/FUM1km

Increase of network capacities

- HPNs: High-performance Networks
- e.g., ESnet



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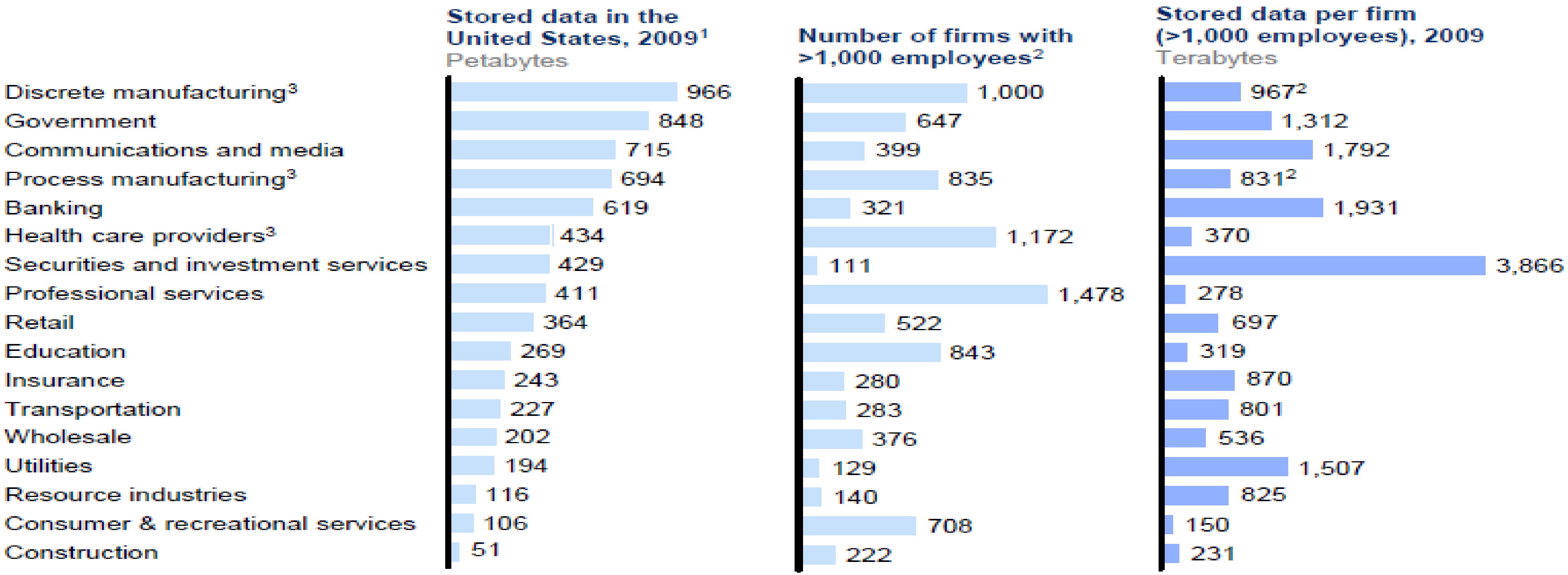
Availability of data sets

Companies in all sectors have at least 100 terabytes of stored data in the United States; many have more than 1 petabyte

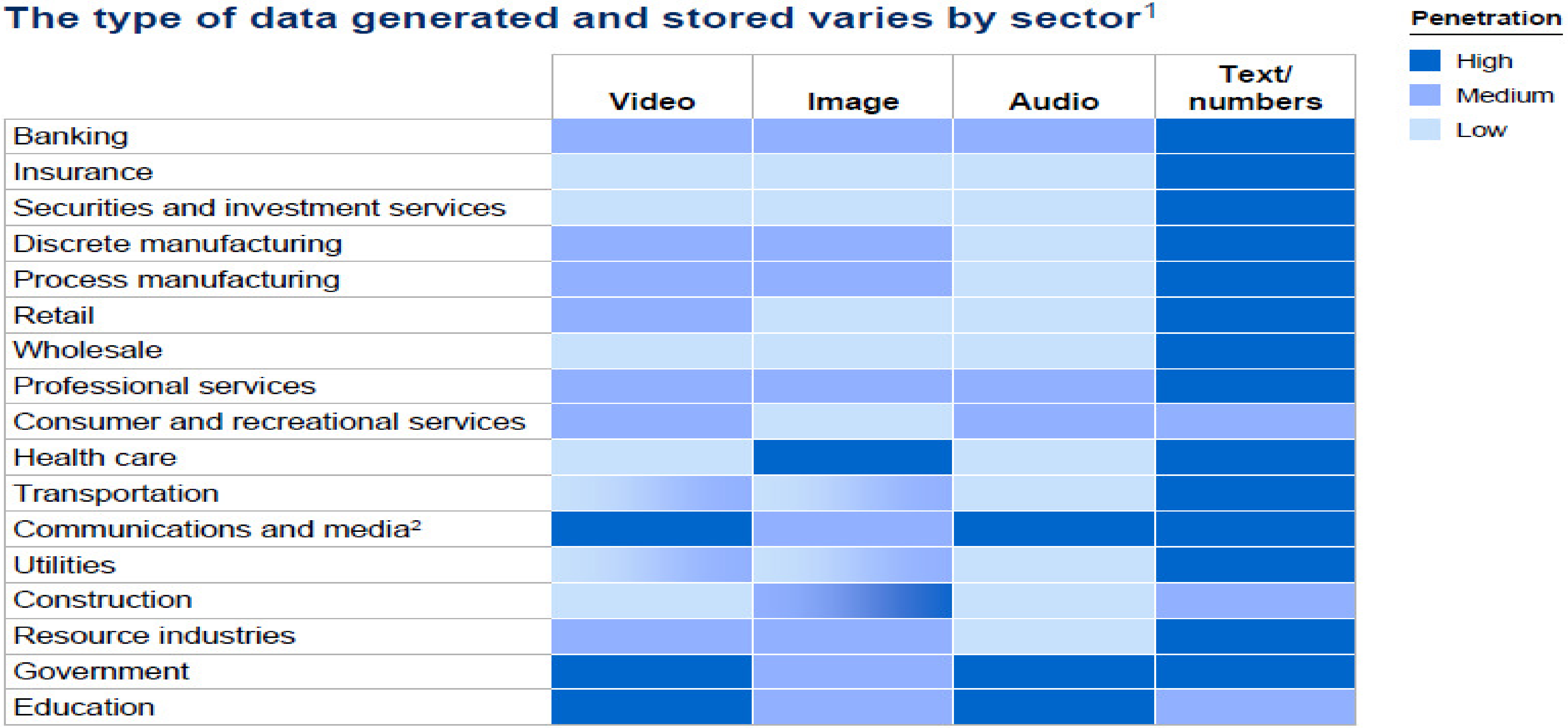


1 Storage data by sector derived from IDC.
2 Firm data split into sectors, when needed, using employment
3 The particularly large number of firms in manufacturing and health care provider sectors make the available storage per company much smaller.

SOURCE: IDC; US Bureau of Labor Statistics; McKinsey Global Institute analysis

Types of available data sets

The type of data generated and stored varies by sector[1]



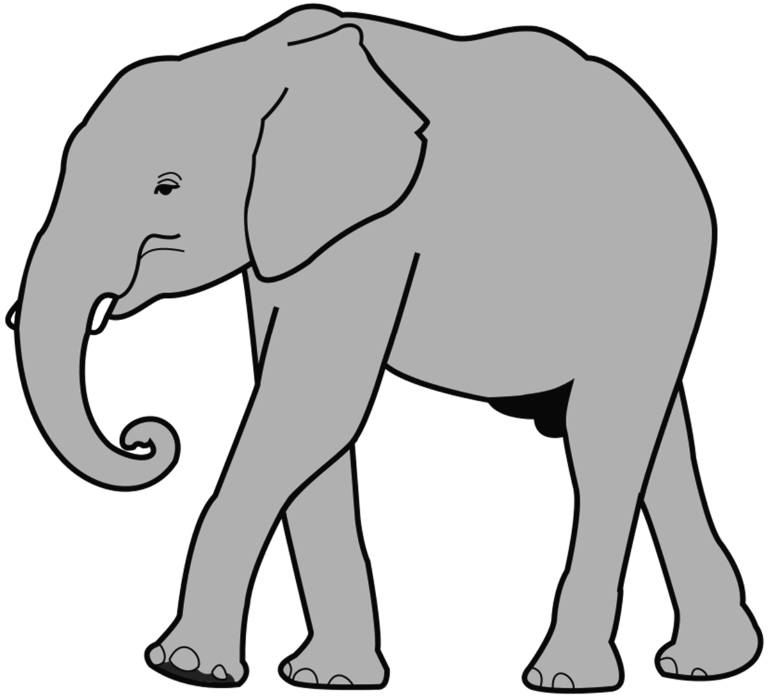
1 We compiled this heat map using units of data (in files or minutes of video) rather than bytes.
2 Video and audio are high in some subsectors.
SOURCE: McKinsey Global Institute analysis

Big-data Applications

- From T(erabyte) to P(etabyte), to E(xabyte), to Z(ettabyte), to Y(ottabyte), and beyond…
- Sciences: Simulation, Experimental, Observational
- Business: Financial Transactions
- Social Media: Weblogs, Twitter feeds, etc.

No matter which type of data is considered, we need a high-performance end-to-end computing solution to support data generation, storage, transfer, processing, and analysis!

V.S.



Objective

- A high-performance end-to-end computing solution to support
  - Data generation
  - Data storage
  - Data transfer
  - Data processing
  - Data analysis
  - Data visualization
  - …

Big-data Workflows

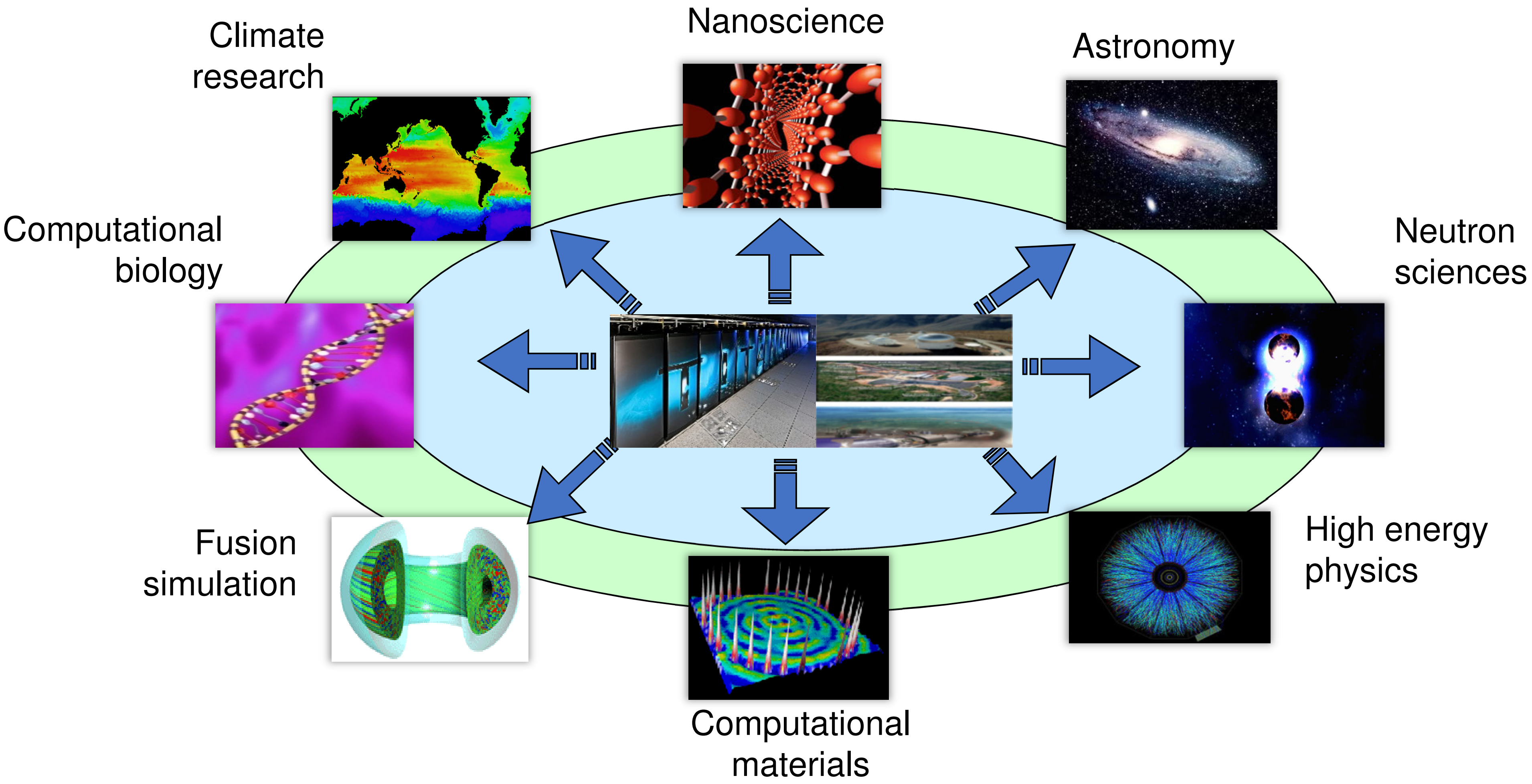
- Require massively distributed resources
  - **Hardware**: computing facilities, storage systems, special rendering engines, display devices (tiled display, powerwall, etc.), network infrastructures, etc.
  - **Software**: Domain-specific data analytics/processing tools, programs, etc.
  - **Data**: Real-time, archival
- Feature different complexities
  - **Simple case**: linear pipeline (a special case of DAG)
  - **Complex case**: DAG-structured graph
- Different application types have different performance requirements
  - **Interactive**: minimize total end-to-end delay for fast response
  - **Streaming**: maximize frame rate to achieve smooth data flow

Computing Paradigms: an Overview

- **Client-Server Model**: client-server computing refers broadly to any distributed application that distinguishes between service providers (servers) and service requesters (clients)
- **High-performance Computing (Supercomputing, Cluster Computing)**
  - Powerful computers: supercomputer, PC cluster
  - Used mainly by large organizations for critical applications, typically bulk data processing such as scientific computing, enterprise resource planning, and financial transaction processing
  - Programming models: MPI, OpenMP, CUDA, MapReduce/Hadoop, Spark
- **Grid Computing**: a form of distributed computing and parallel computing, whereby a “super and virtual computer” is composed of a cluster of networked, loosely coupled computers acting in concert to perform very large tasks
- **Cloud (Utility) Computing**: the packaging of computing resources, such as computation and storage, as a metered service similar to a traditional public utility, such as electricity
- **Service-Oriented Computing**: cloud computing provides services related to computing while, in a reciprocal manner, service-oriented computing consists of the computing techniques that operate on software-as-a-service
- **Peer-to-peer (P2P) Computing**: distributed architecture without the need for central coordination, with participants being at the same time both suppliers and consumers of resources (in contrast to the traditional client–server model)
- **Mobile Computing**: computing on the go!

High-performance Computing
(Supercomputing, Cluster Computing)

Supercomputing for scientific applications



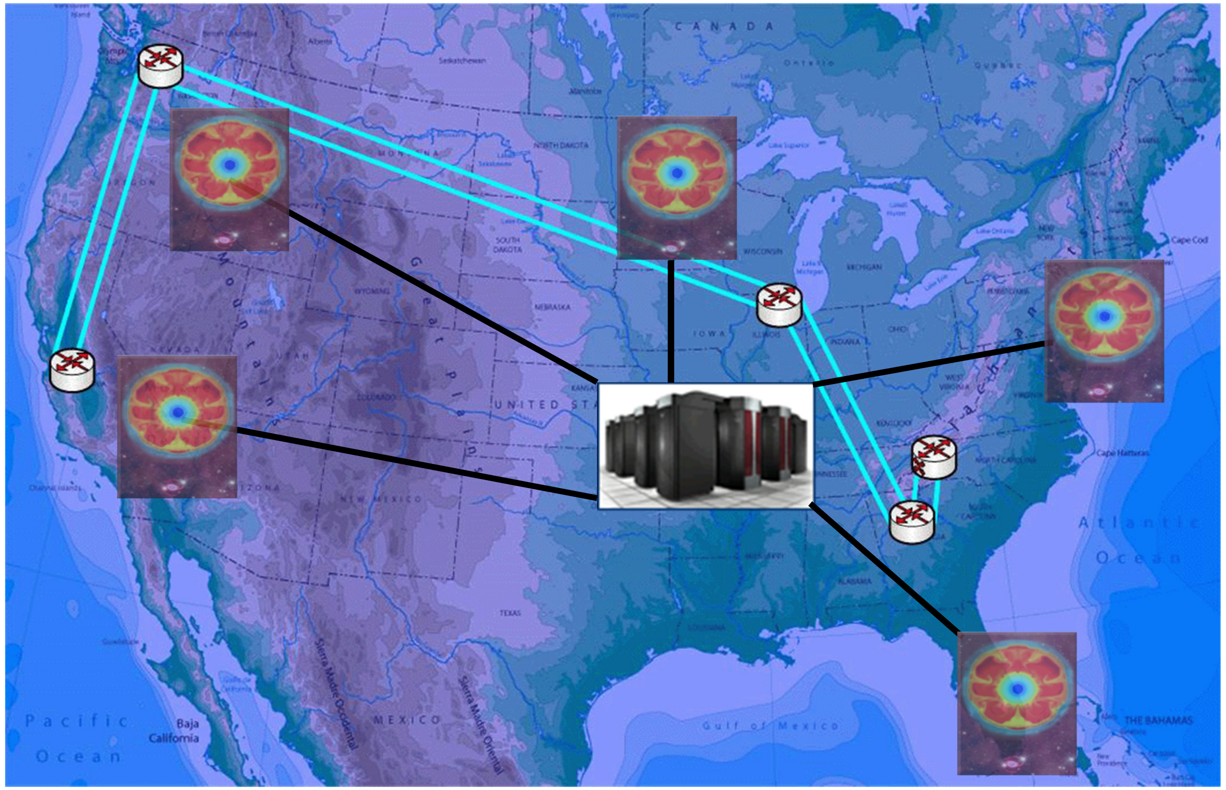
Why do we care about computing power? Computer Security: Exhaustive Key Search

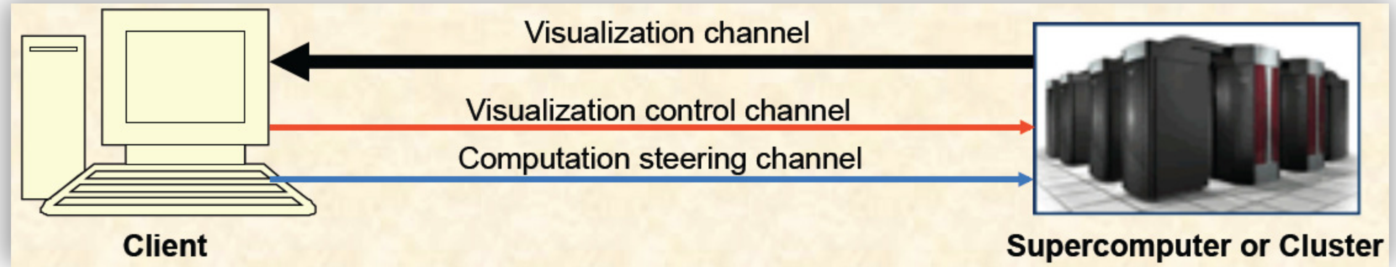
- Two types of security
  - Computational security
  - Unconditional security
- Attack on computational security
  - Always possible to simply try every key
  - Most basic attack, proportional to key size
  - Assume either know / recognize plaintext

Key Size (bits)	Number of Alternative Keys	Time required at 1 decryption/µs	Time required at 10^6 decryptions/µs
32	$2^{32} = 4.3 \times 10^{9}$		
56	$2^{56} = 7.2 \times 10^{16}$		
128	$2^{128} = 3.4 \times 10^{38}$		
168	$2^{168} = 3.7 \times 10^{50}$		
26 letters (permutation)	$26! = 4 \times 10^{26}$		

Science is becoming data-driven
TSI: Terascale Supernova Initiative

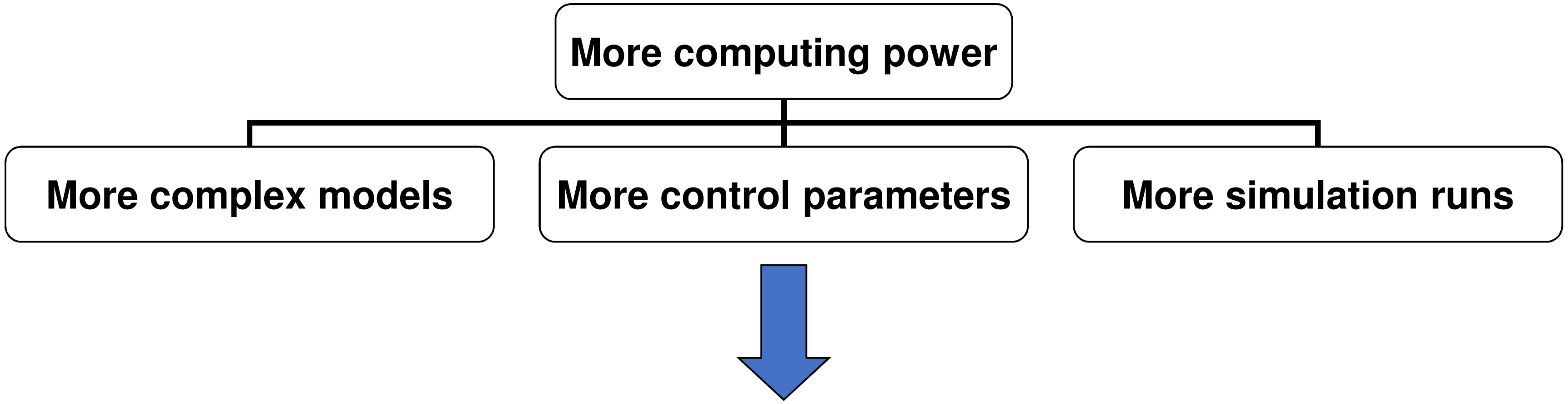
- Collaborative project
  - Supernova explosion
- TSI simulation
  - 1 terabyte a day with a small portion of parameters
  - From TSI to PSI to ESI
- Transfer to remote sites
  - Interactive distributed visualization
  - Collaborative data analysis
  - Computation monitoring
  - Computation steering





Computing power continues to increase over time
DOE NLCF, Cray XK, IBM BlueGene, SGI Altix

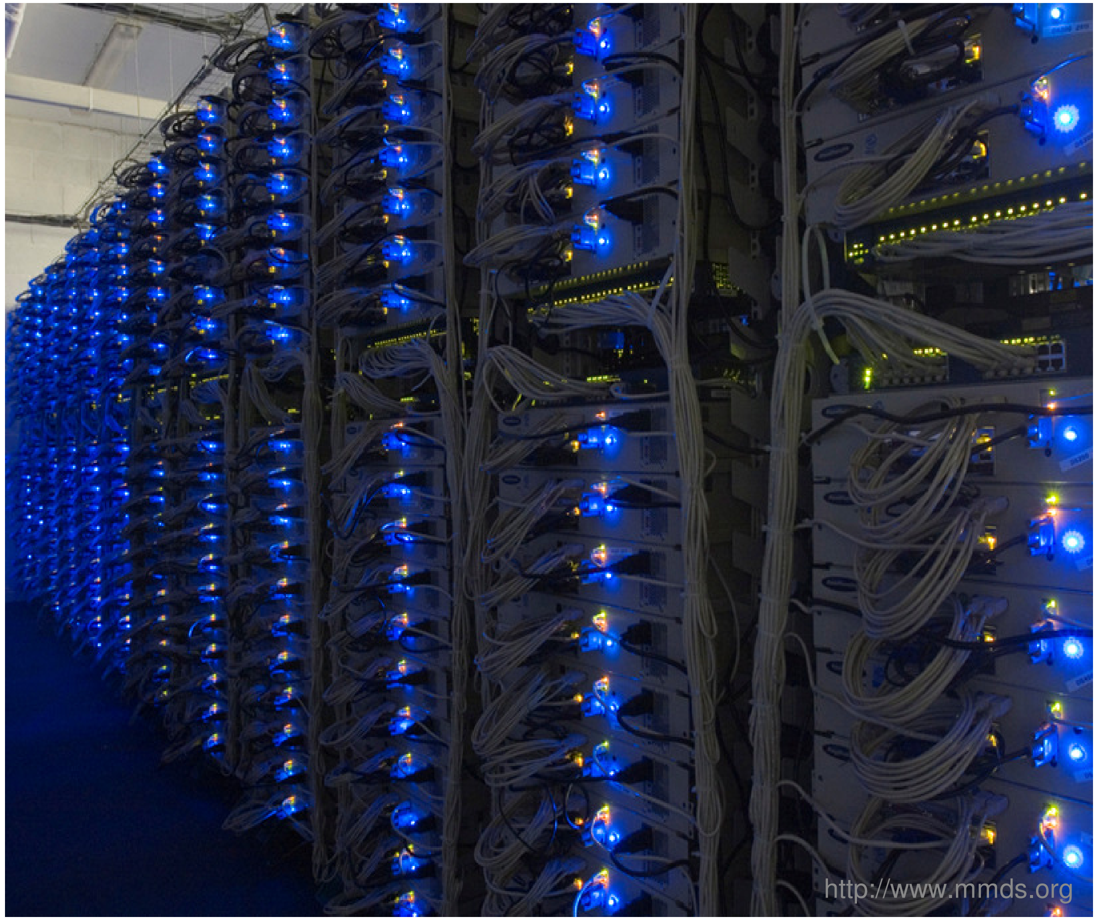
- Two next-generation supercomputers:
  - ORNL's **Summit**
  - LLNL's **Sierra**
    - Use NVIDIA® Tesla® GPU accelerators and NVIDIA NVLink™ high-speed interconnect technology on next-generation IBM POWER servers
    - Each will be significantly faster than today's fastest supercomputer, achieving between 100 to 300 petaflops of peak performance



Colossal amounts of scientific datasets!

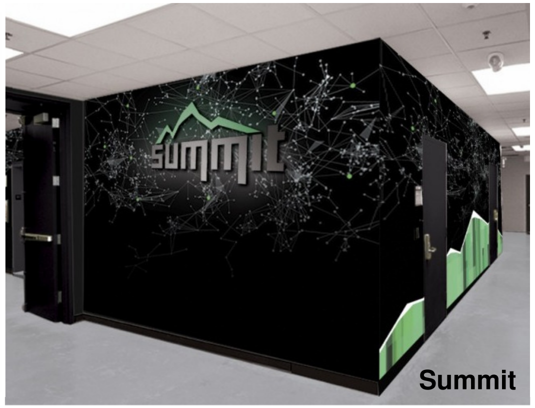
Increase of computing power

Computer Cluster



Increase of computing power

- World-class facilities



US once again boasts the world's fastest supercomputer

The US Department of Energy on Friday unveiled Summit, which can perform 200 quadrillion calculations per second.

By Stephanie Condon for Between the Lines | June 8, 2018 -- 18:10 GMT (11:10 PDT) | Topic: Artificial Intelligence

China Launches Exascale Supercomputer Prototype

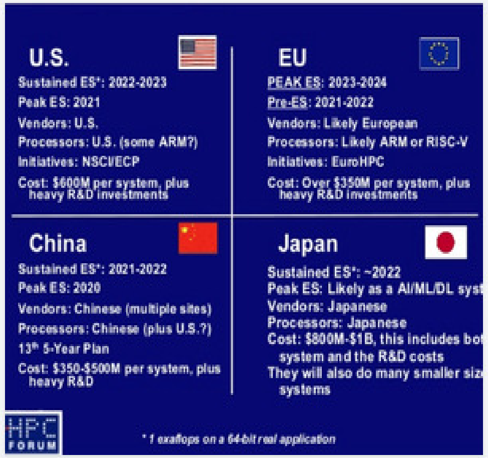
Aug 07, 2018 Email Print Text Size A A Share

Hyperion Provides Update to Exascale Efforts in US, China, Japan, and Europe

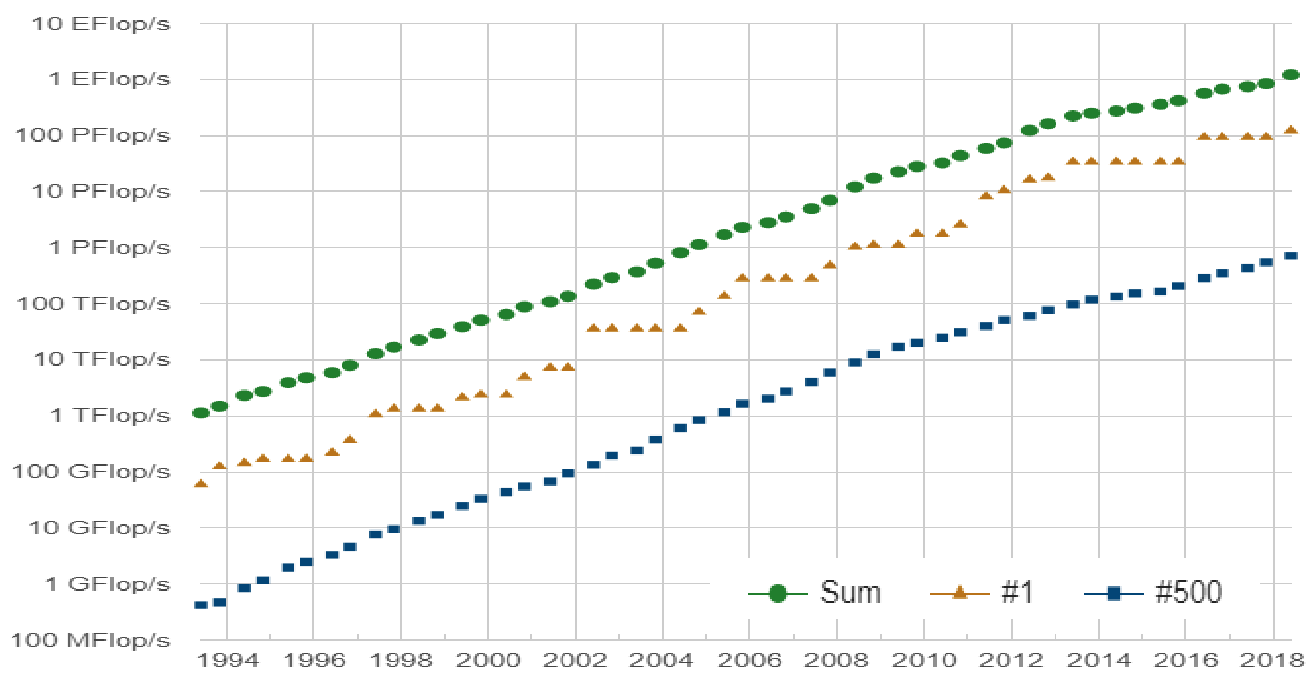
Michael Feldman | September 6, 2018 21:10 CEST

According to the latest analysis from Hyperion Research, the various global efforts to reach exascale supercomputing are making good headway. But in some cases, the decision to develop domestically-produced processors for these systems and the inclusion of new application use cases appears to be stretching out the timelines.

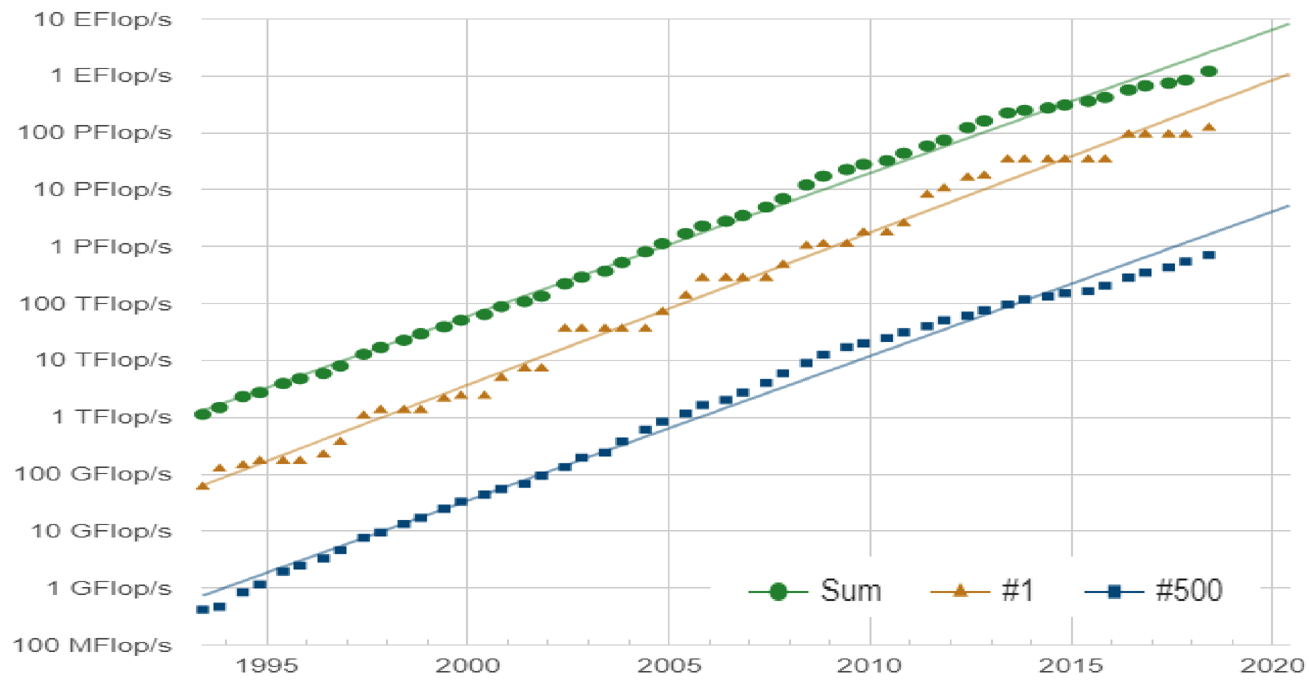
Read more



Performance Development



Projected Performance Development

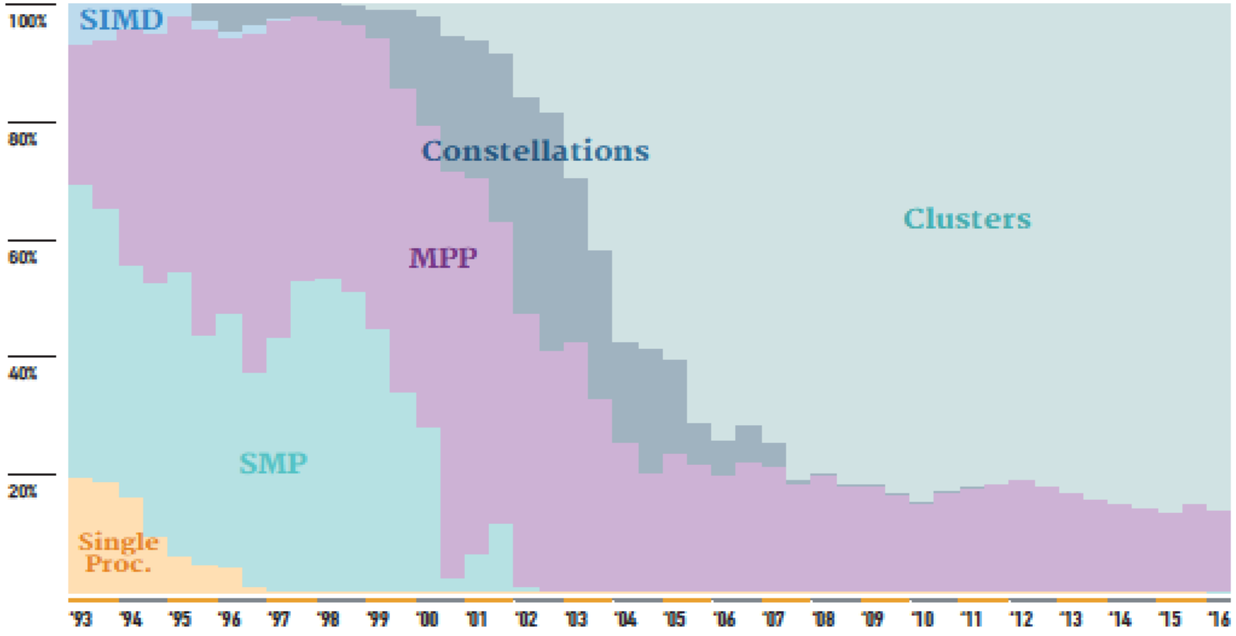


https://www.top500.org/

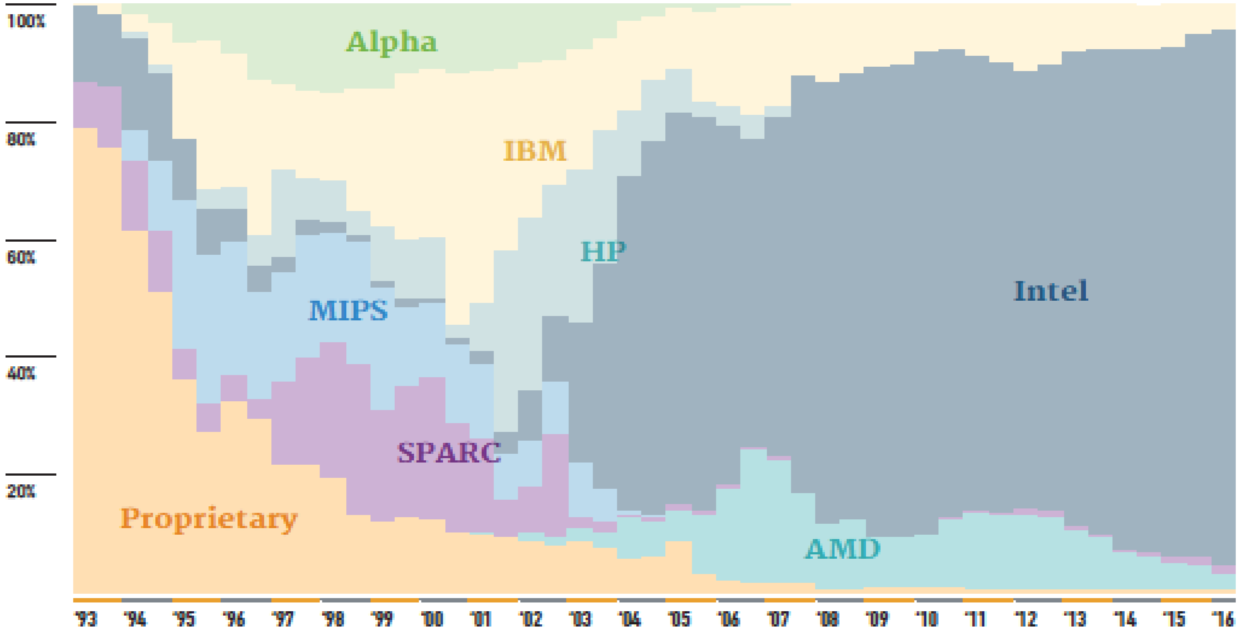
TOP 500 The List.

Rank	System	Cores	Rmax (TFlop/s)	Rpeak (TFlop/s)	Power (kW)
1	**Summit** - IBM Power System AC922, IBM POWER9 22C 3.07GHz, NVIDIA Volta GV100, Dual-rail Mellanox EDR Infiniband , IBM DOE/SC/Oak Ridge National Laboratory United States	2,282,544	122,300.0	187,659.3	8,806
2	**Sunway TaihuLight** - Sunway MPP, Sunway SW26010 260C 1.45GHz, Sunway , NRCPC National Supercomputing Center in Wuxi China	10,649,600	93,014.6	125,435.9	15,371
3	**Sierra** - IBM Power System S922LC, IBM POWER9 22C 3.1GHz, NVIDIA Volta GV100, Dual-rail Mellanox EDR Infiniband , IBM DOE/NNSA/LLNL United States	1,572,480	71,610.0	119,193.6	
4	**Tianhe-2A** - TH-IVB-FEP Cluster, Intel Xeon E5-2692v2 12C 2.2GHz, TH Express-2, Matrix-2000 , NUDT National Super Computer Center in Guangzhou China	4,981,760	61,444.5	100,678.7	18,482
5	**AI Bridging Cloud Infrastructure (ABCI)** - PRIMERGY CX2550 M4, Xeon Gold 6148 20C 2.4GHz, NVIDIA Tesla V100 SXM2, Infiniband EDR , Fujitsu National Institute of Advanced Industrial Science and Technology (AIST) Japan	391,680	19,880.0	32,576.6	1,649
6	**Piz Daint** - Cray XC50, Xeon E5-2690v3 12C 2.6GHz, Aries interconnect , NVIDIA Tesla P100 , Cray Inc. Swiss National Supercomputing Centre (CSCS) Switzerland	361,760	19,590.0	25,326.3	2,272
7	**Titan** - Cray XK7, Opteron 6274 16C 2.200GHz, Cray Gemini interconnect, NVIDIA K20x , Cray Inc. DOE/SC/Oak Ridge National Laboratory United States	560,640	17,590.0	27,112.5	8,209
8	**Sequoia** - BlueGene/Q, Power BQC 16C 1.60 GHz, Custom , IBM DOE/NNSA/LLNL United States	1,572,864	17,173.2	20,132.7	7,890

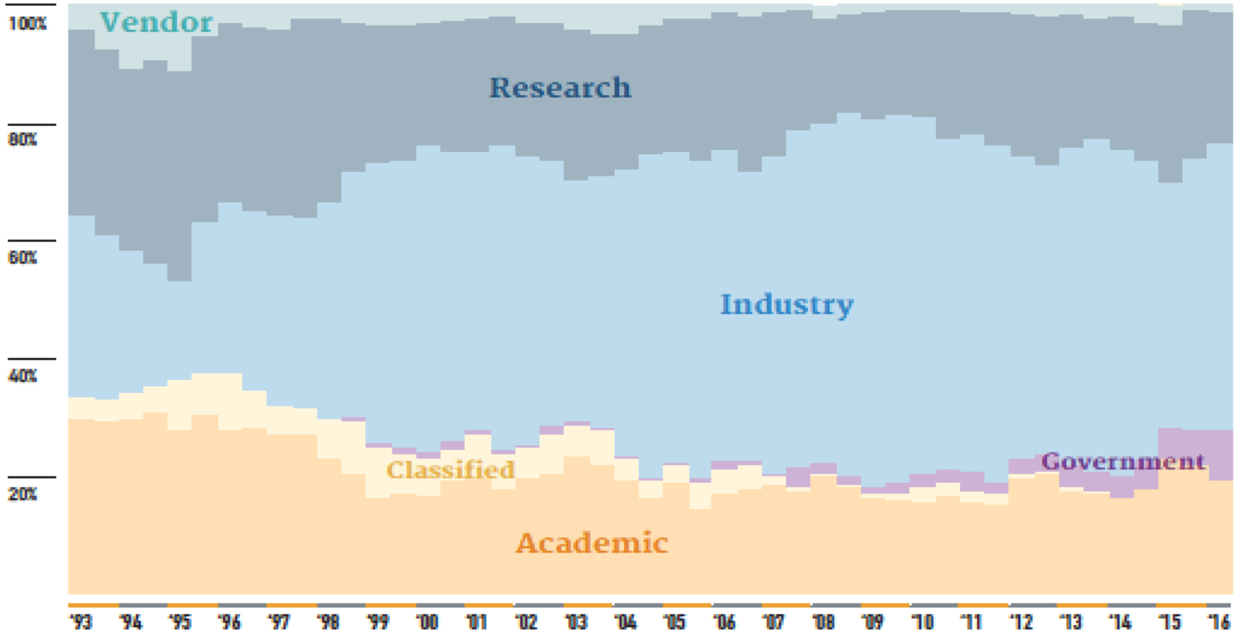
ARCHITECTURES



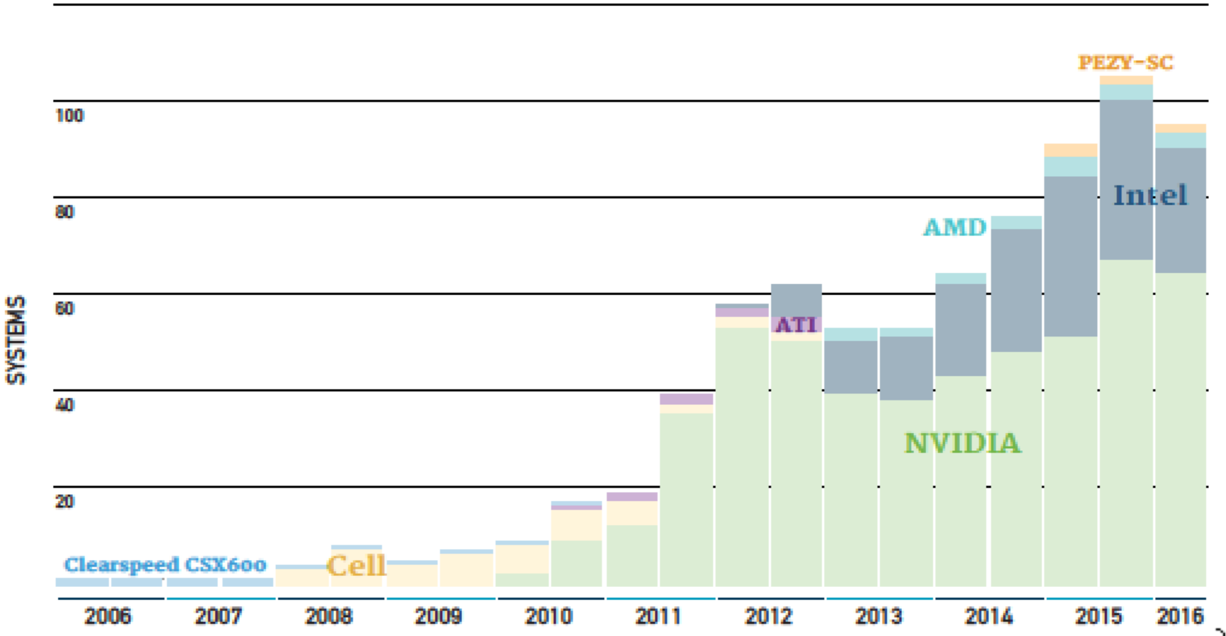
CHIP TECHNOLOGY



INSTALLATION TYPE



ACCELERATORS/CO-PROCESSORS

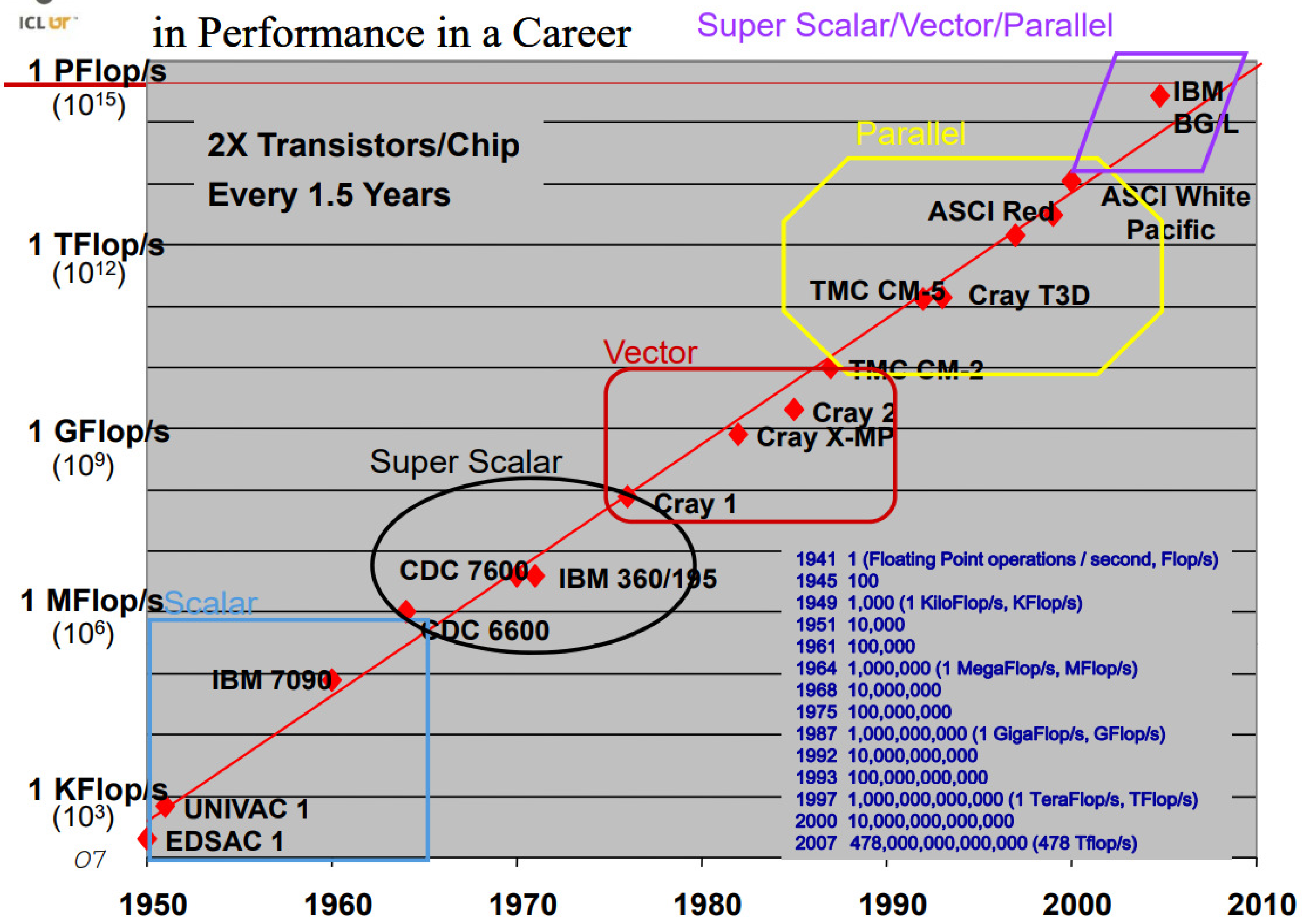


ASCR Computing Upgrades At a Glance

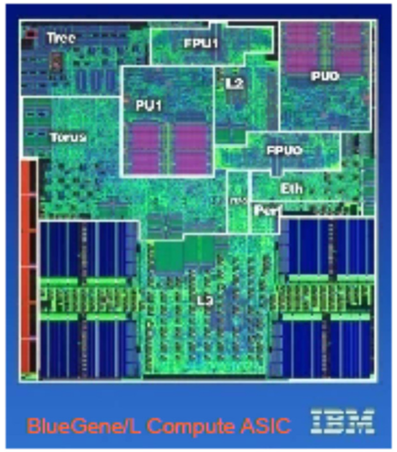
System attributes	NERSC Now	OLCF Now	ALCF Now		NERSC Upgrade	OLCF Upgrade	ALCF Upgrades
Name Planned Installation	**Edison**	**TITAN**	**MIRA**	**Theta 2016**	**Cori 2016**	**Summit 2017-2018**	**Aurora 2018-2019**
System peak (PF)	2.6	27	10	>8.5	> 30	200	180
Peak Power (MW)	2	9	4.8	1.7	< 3.7	13.3	13
Total system memory	357 TB	710TB	768TB	>480 TB DDR4 + High Bandwidth Memory (HBM)	~1 PB DDR4 + High Bandwidth Memory (HBM)+1.5PB persistent memory	> 2.4 PB DDR4 + HBM + 3.7 PB persistent memory	> 7 PB High Bandwidth On-Package Memory Local Memory and Persistent Memory
Node performance (TF)	0.460	1.452	0.204	> 3	> 3	> 40	> 17 times Mira
Node processors	Intel Ivy Bridge	AMD Opteron Nvidia Kepler	64-bit PowerPC A2	Intel Knights Landing Xeon Phi many core CPUs	Intel Knights Landing many core CPUs Intel Haswell CPU in data partition	Multiple IBM Power9 CPUs & multiple Nvidia Voltas GPUS	Knights Hill Xeon Phi many core CPUs
System size (nodes)	5,600 nodes	18,688 nodes	49,152	>2,500 nodes	9,300 nodes 1,900 nodes in data partition	~4,600 nodes	>50,000 nodes
System Interconnect	Aries	Gemini	5D Torus	Aries	Aries	Dual Rail EDR-IB	2nd Generation Intel Omni-Path Architecture
File System	7.6 PB 168 GB/s, Lustre®	32 PB 1 TB/s, Lustre®	26 PB 300 GB/s GPFS™	10PB, 210 GB/s Lustre initial	28 PB 744 GB/s Lustre®	120 PB 1 TB/s GPFS™	150 PB 1 TB/s Lustre®

https://science.energy.gov/ascr/facilities/

A Growth-Factor of a Billion in Performance in a Career



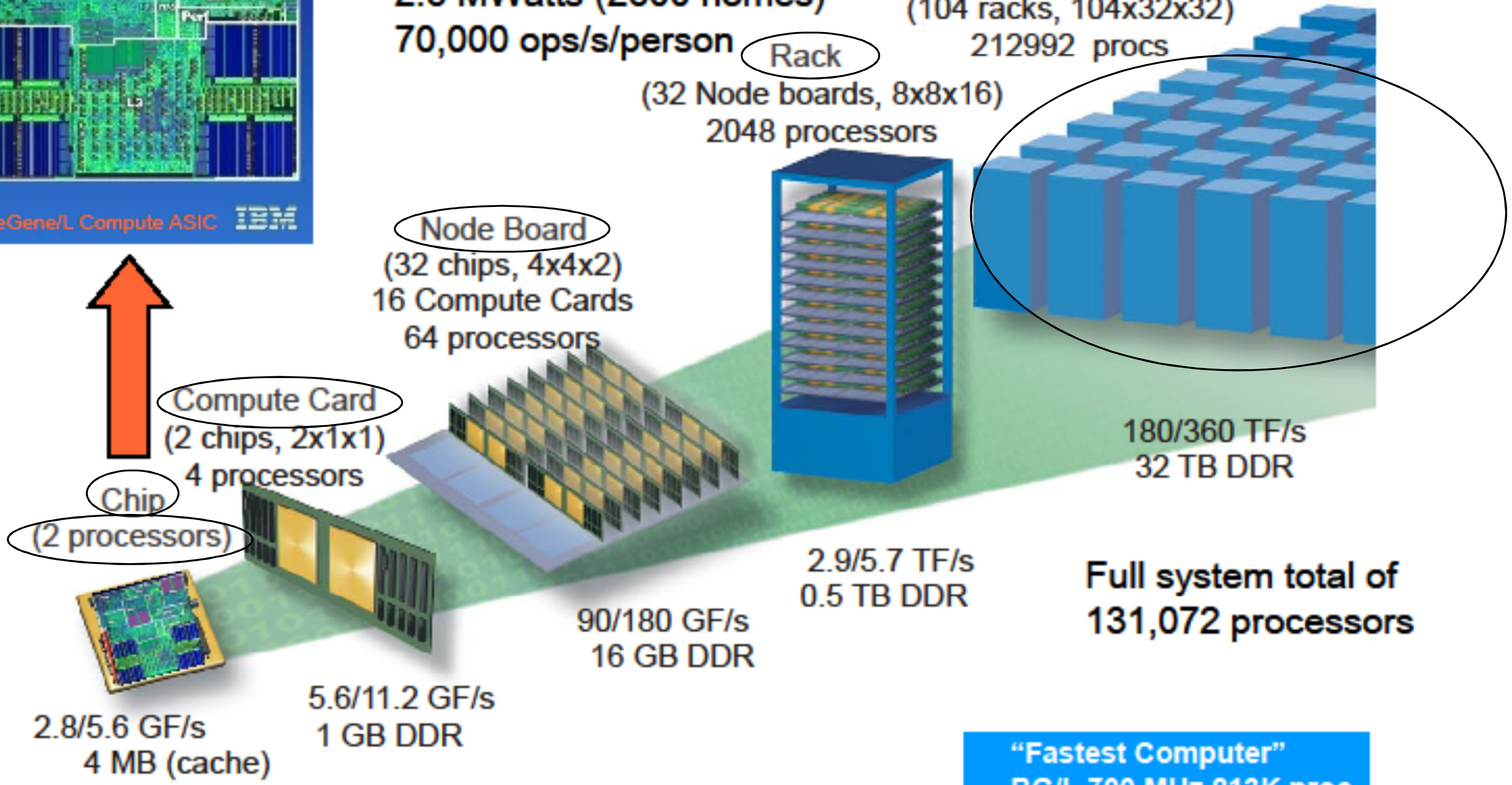
Source: J. Dongarra's top 500 talk



IBM BlueGene/L #1 212,992 Cores

Total of 26 systems all in the Top176

2.6 MWatts (2600 homes)
70,000 ops/s/person



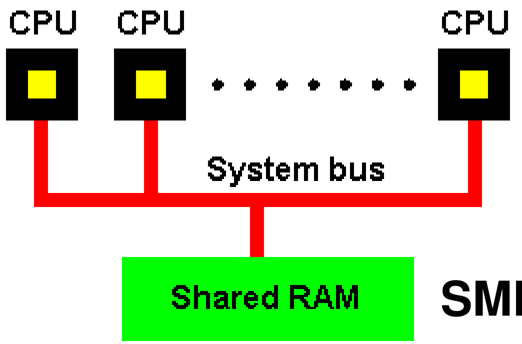
Full system total of 131,072 processors

The compute node ASICs include all networking and processor functionality. Each compute ASIC includes two 32-bit superscalar PowerPC 440 embedded cores (note that L1 cache coherence is not maintained between these cores). (20.7K sec about 5.7hours; n=2.5M)

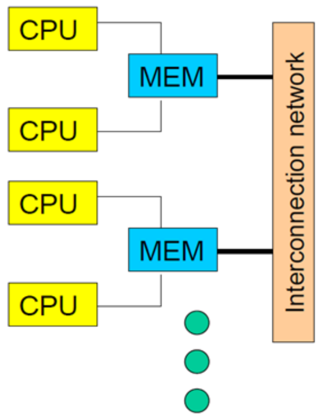
"Fastest Computer"
BG/L 700 MHz 213K proc
104 racks
Peak: 596 Tflop/s
Linpack: 498 Tflop/s
84% of peak

HPC Architecture

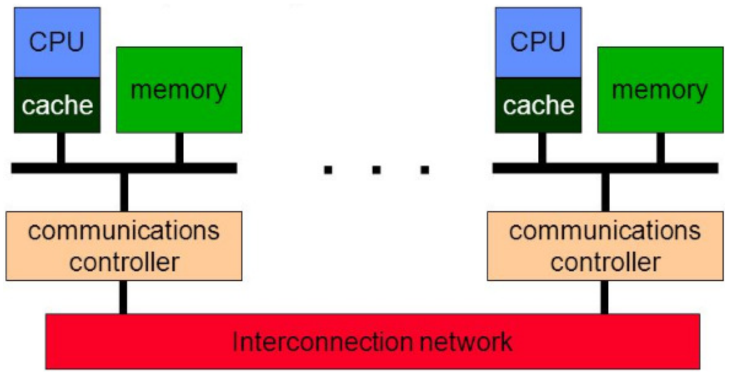
- SMP – symmetric multiprocessing (up to 64 CPUs)
  - All processors access common memory on the same rights
  - Used in desktops
- NUMA – nonuniform memory access
  - Global address space (as in SMP)
  - Faster access to local memory
  - Slower to remote
- Distributed memory multicomputers
  - Communication via messages
- Vector computers
  - Multiple functional units performing the same operation on vector registers (very long ones)
    - e.g., vector addition, dot product
  - Almost disappeared
- Distributed memory multiprocessors
  - MPP: Massively Parallel Processing
    - Tightly integrated
- Constellations
  - Clusters of supercomputers



SMP



NUMA

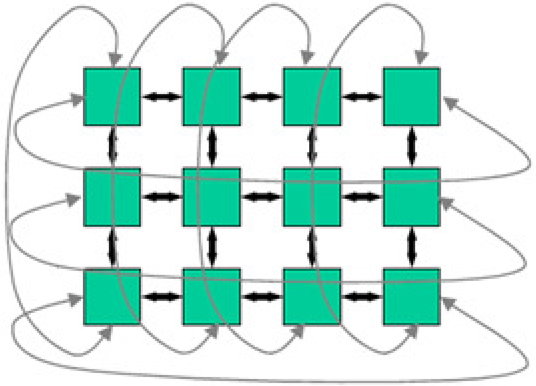


Distributed memory multicomputers

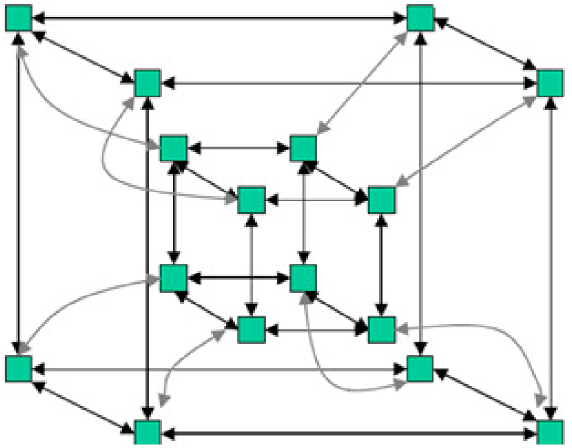
Network Topologies

- Goal
  - Limited number of connections per node
  - Small width
  - Scalability

- Topologies
  - Mesh
  - Ring
  - Torus
  - Hypercube



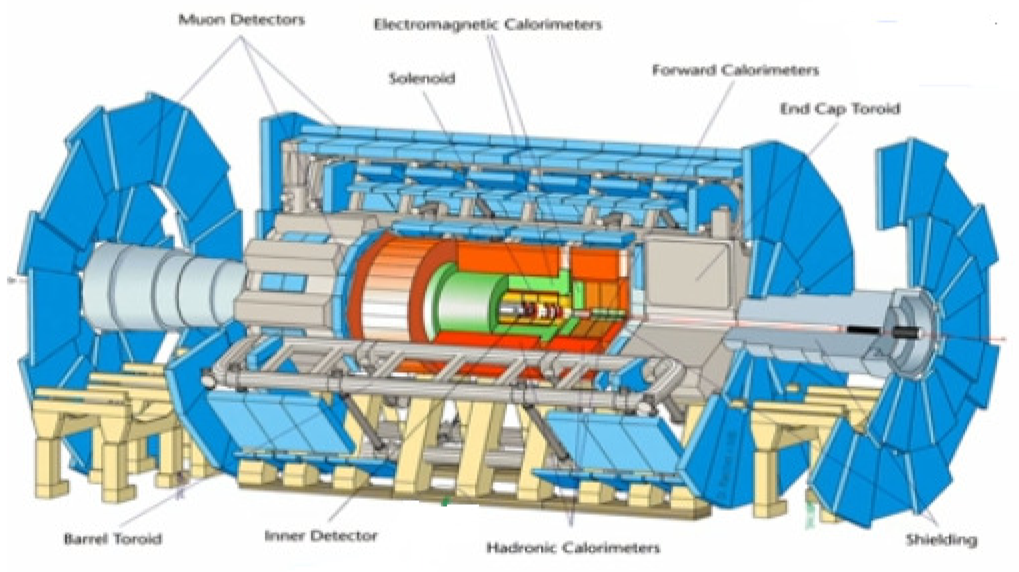
Torus



4D hypercube

Parallel Application Example -- HEP

- Detector simulation
  - Simulate 10,000 events with Geant4
  - One event – (e.g.,) 1 minute
    - One week of computations!
- Trivial parallelization – give parts of all events to different CPUs
- Event analysis
  - Plot a quick histogram of 10,000 events
  - One event – (e.g.,) 0.1s
    - 20 minutes – this is not a quick histogram!



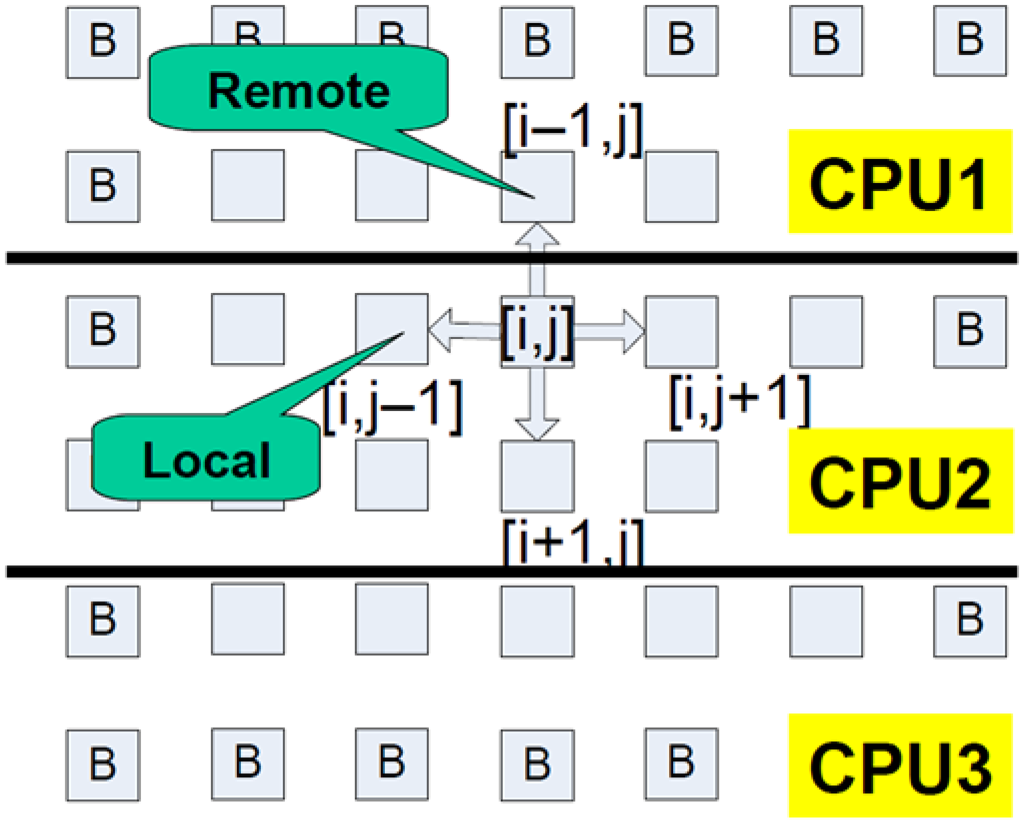
Trivial parallelization – each CPU analyzes a part of all the events.
At the end histograms are added. But making it interactive and transparent is a challenge.

Nontrivial Example – SOR

- SOR – Successive Overrelaxation
  - Solution to Laplace equation
- Boundary rows have to be transferred between CPUs

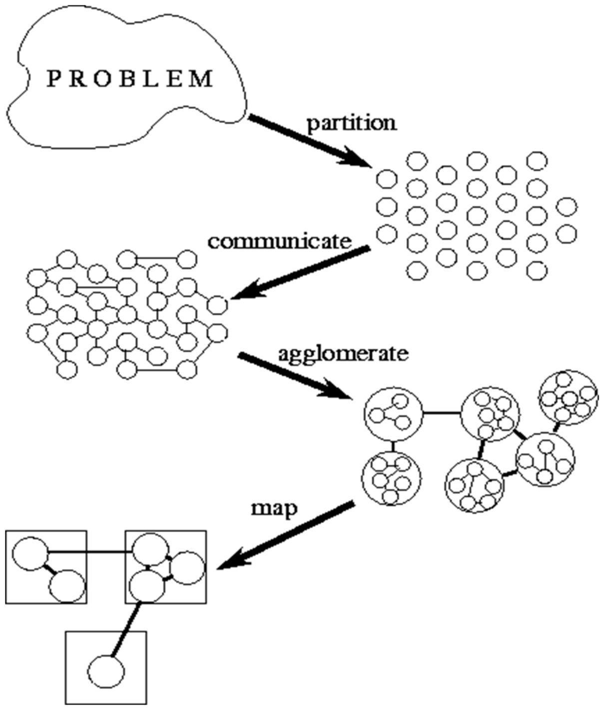
$$
\begin{aligned}
&A_{new}[i,j] \\
&= \frac{\alpha}{4}(A[i-1,j]+A[i+1,j]+ \\
&\qquad A[i,j-1]+A[i,j+1]) \\
&+(1-\alpha)A[i,j]
\end{aligned}
$$

- Nontrivial but easy



Designing a Parallel Application

- **Partitioning**: decompose data and computations into small tasks
- **Communication**: analyze communication required to coordinate tasks
- **Agglomeration – reduce communication**: increase granularity, improve locality
- **Mapping – map processors to tasks**
  - Concurrent tasks on different CPUs
  - Frequently communicating tasks on the same CPU



- **Minimize communication overhead**: data locality is important
- **Load balancing**: make sure processors are never idle
  - Dynamic load balancing: divide work at runtime
- **Take system architecture into account!**
  - Fast local and slow remote memory for NUMA machines
  - Hardware for broadcasting, reduction
  - Faster access to neighboring nodes

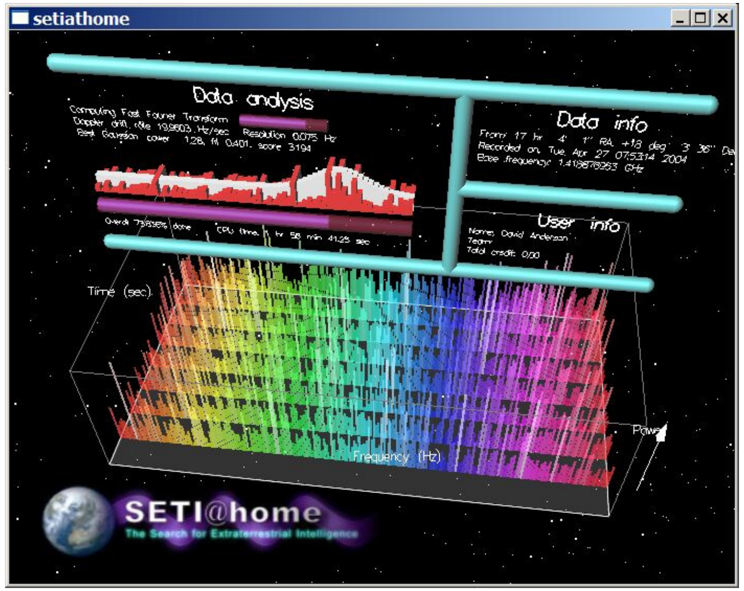
Performance Metrics

- **Execution time**
  - Time when the last processor finishes its work
- **Speedup**
  - (time on 1CPU) / (time on P CPUs)
- **Efficiency**
  - Speedup / P

Seti@home-like Computing

- Idle computers can be used
  - Applications running as a screen saver
- Only computational-intensive application
  - No communication while computing
- Very successful
  - People are willing to share their computing power
- LHC@home
  - Testing stability of the beam (60 particles 100k loops)

http://lhcathome.web.cern.ch/



Grid Computing

Grid Computing

- Who needs grid computing?
  - Particular software capabilities: modeling, simulation, etc.
  - High hardware/computing demands: processing, storage, etc.
  - Large network bandwidth: circuit provisioning to support large data transfer
- Problems, which are hard (or impossible) to solve at a single site, can be solved with the right kind of parallelization and distribution of the tasks involved
- There are two primary types of grids
  - Computational grids:
    - Open Science Grid (OSG)
    - Worldwide LHC Computing Grid (WLCG)
  - Data grids:
    - Earth System Grid (ESG)

Requirements

- Computational grids
  - Manage a variety of computing resources
  - Select computing resources capable of running a user's job
  - Predict loads on grid resources
  - Decide about resource availability
  - Dynamic resource configuration and provisioning
- Data grids
  - Provide data virtualization service
  - Support flexible data access, filtering, and transfer mechanisms
  - Provide security and privacy mechanisms
- Grid computing environments are constructed upon three foundations
  - Coordinated resources
  - Open standard protocols and frameworks
  - Non-trivial QoS

Cloud Computing

Cloud Computing

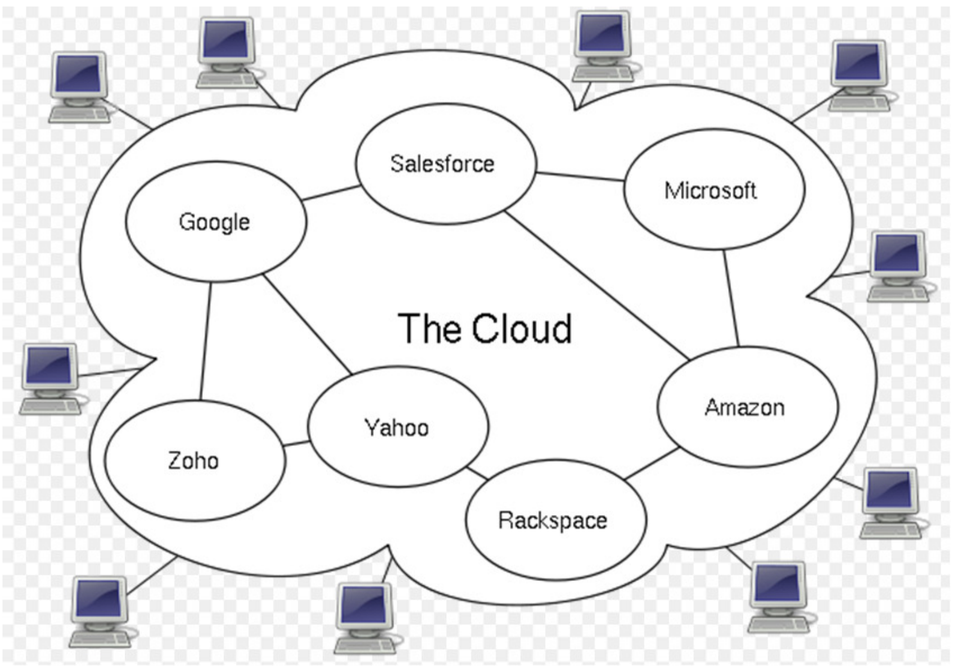
- What is cloud computing?
  - The phrase originated from the cloud symbol used to symbolize the Internet
  - A model for enabling convenient, on-demand network access to a shared pool of configurable computing resources
    - e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction
  - Provide computation, software, data access, and storage services
    - Do not require end-user knowledge of the physical location and configuration of the system that delivers the services
- Cloud architecture
  - Involve multiple cloud components communicating with each other over **application programming interfaces**, usually **web services** and **3-tier architecture**
    - Front end: seen by the user, such as a web browser
    - Back end: the cloud itself comprising computers, servers, data storage devices, etc.

Five Layers in Cloud Computing

- **Client**: a cloud client consists of computer hardware and/or computer software that relies on cloud computing for application delivery, or that is specifically designed for delivery of cloud services
- **Application**: cloud application services or "Software as a Service (SaaS)" deliver software as a service over the Internet, eliminating the need to install and run the application on the customer's own computers and simplifying maintenance and support
- **Platform**: cloud platform services or "Platform as a Service (PaaS)" deliver a computing platform and/or solution stack as a service, often consuming cloud infrastructure and sustaining cloud applications
- **Infrastructure**: cloud infrastructure services, also known as "Infrastructure as a Service (IaaS)", delivers computer infrastructure – typically a platform virtualization environment – as a service
- **Server**: the servers layer consists of computer hardware and/or computer software products that are specifically designed for the delivery of cloud services, including multi-core processors, cloud-specific operating systems and combined offerings

Real-life Cloud Computing Environment

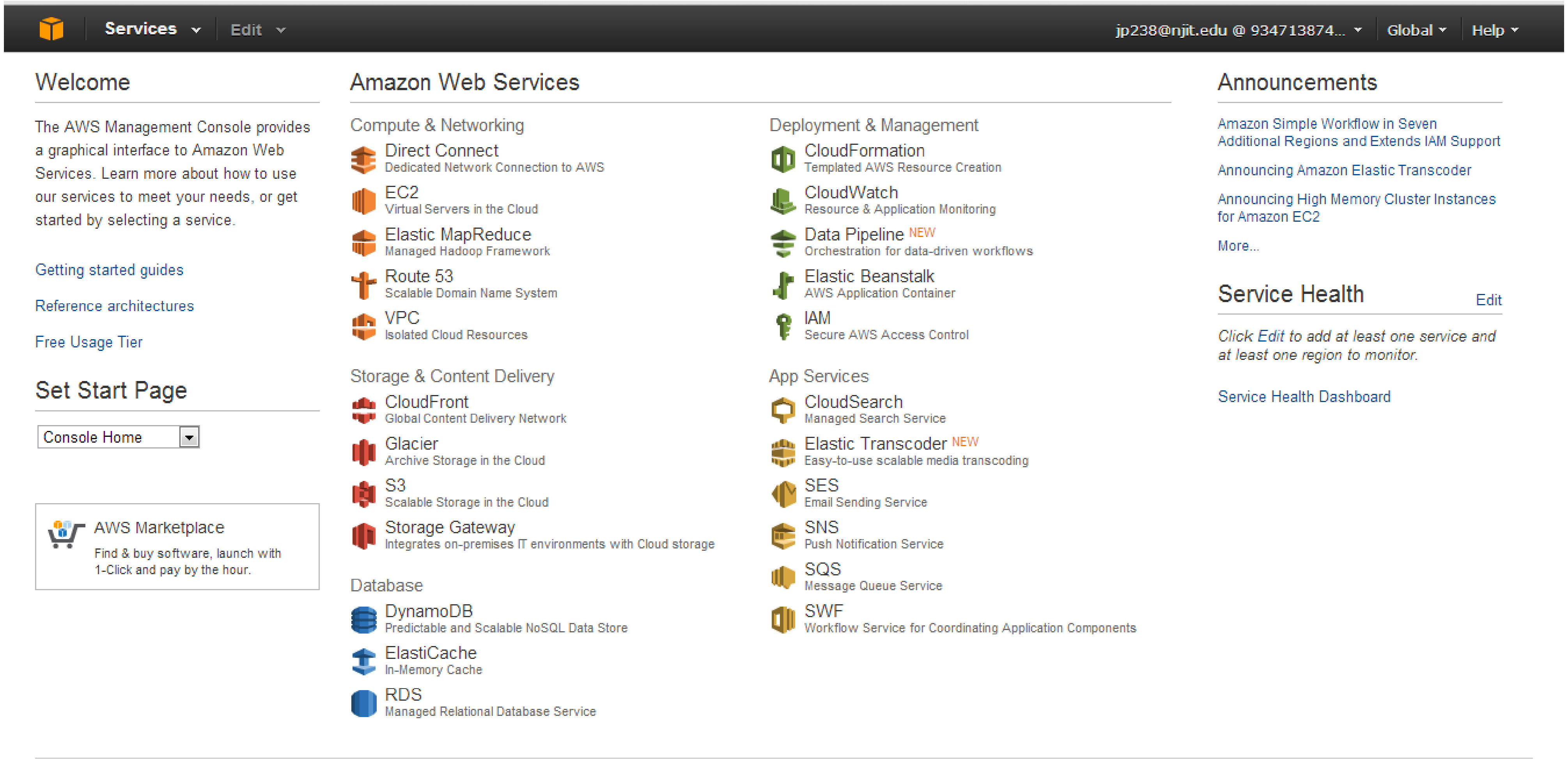
- Microsoft Windows Azure
  - https://azure.microsoft.com
- Google Cloud
  - https://cloud.google.com/
- Amazon EC2
  - https://aws.amazon.com/ec2/
- Eucalyptus (first open-source platform for private clouds, 2008)
  - A software platform for the implementation of private cloud computing on computer clusters
  - https://github.com/eucalyptus
- Many others



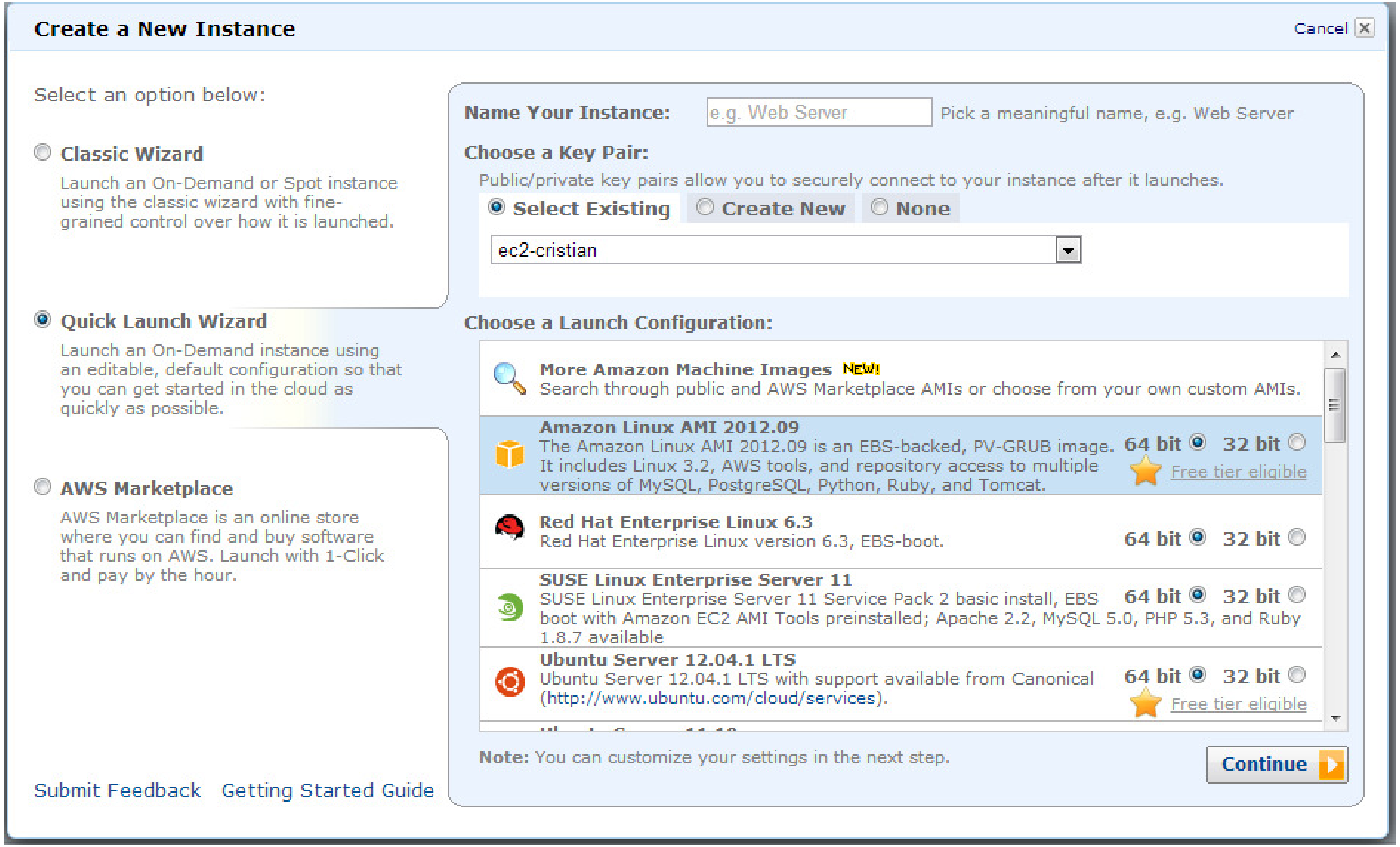
Managing Amazon EC2 Instances

- AWS management console
  - Web-based, most powerful
  - http://aws.amazon.com/console/
  - Command line tools
  - http://aws.amazon.com/developertools/351?_encoding=UTF8&jiveRedirect=1
- Third-party UI tools
  - Example: ElasticFox browser add on

Login AWS Management Console



Select AMI to create instance(s)

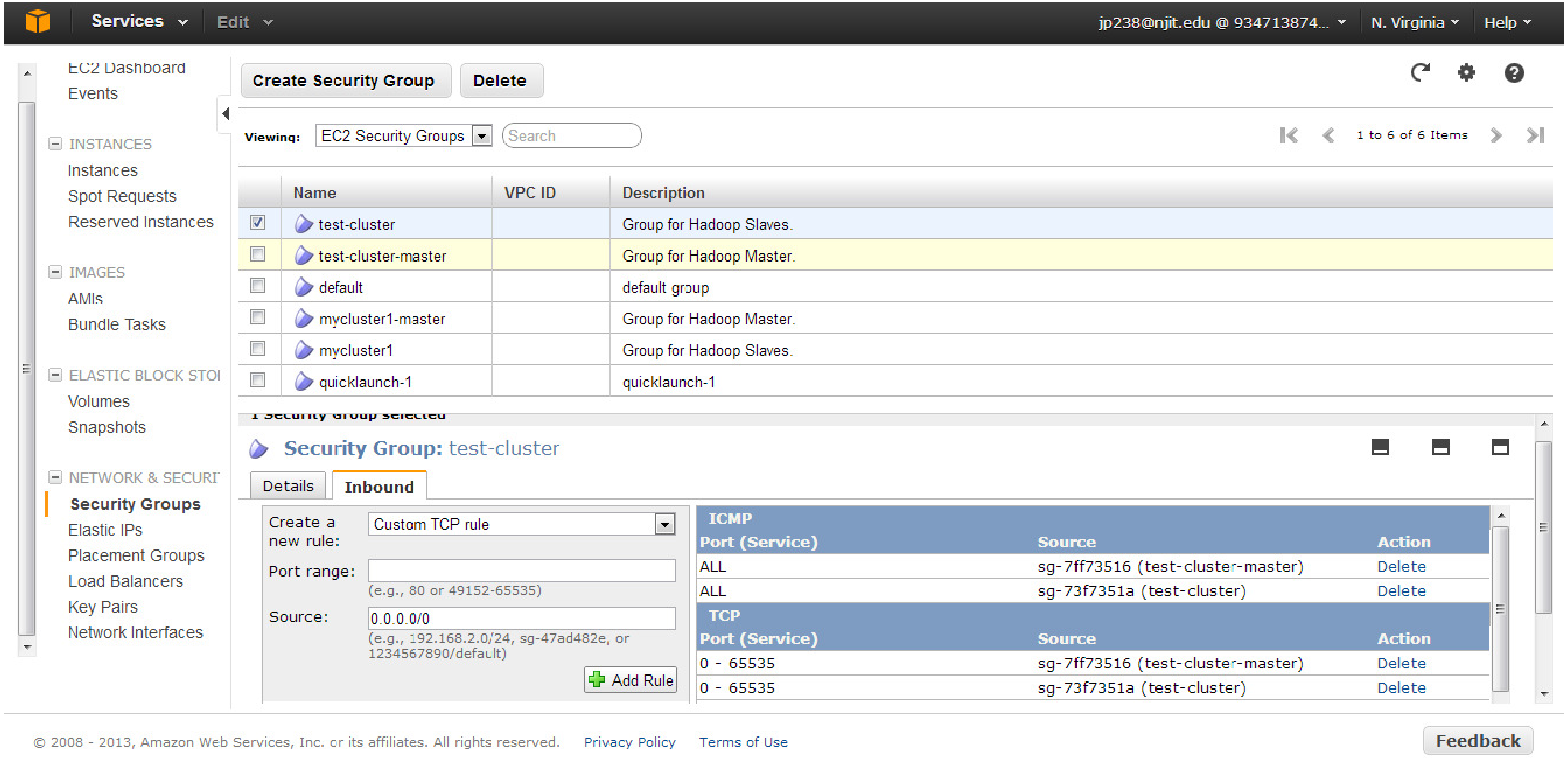


Select instance type: http://aws.amazon.com/ec2/instance-types/

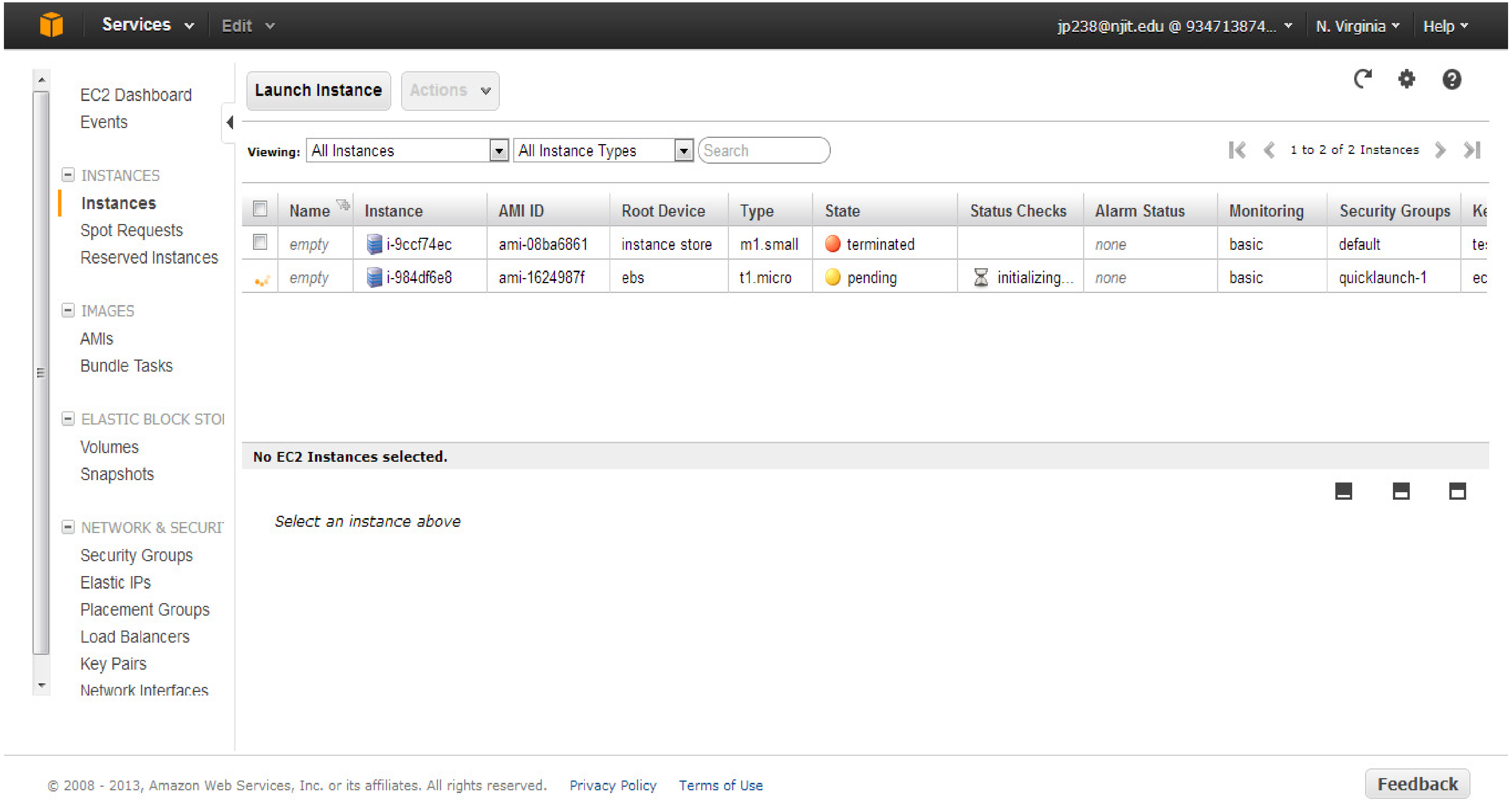
Assign instance to security group(s)

- A **security group** defines firewall rules for instances
- At launch time, instance can be assigned to multiple groups
- Default group doesn’t allow any network traffic
- Once an instance is running, it can't change to which security group(s) it belongs
- Can modify rules for a group at any time
- New rules automatically enforced for all running instances and instances launched in the future

Illustration of security group



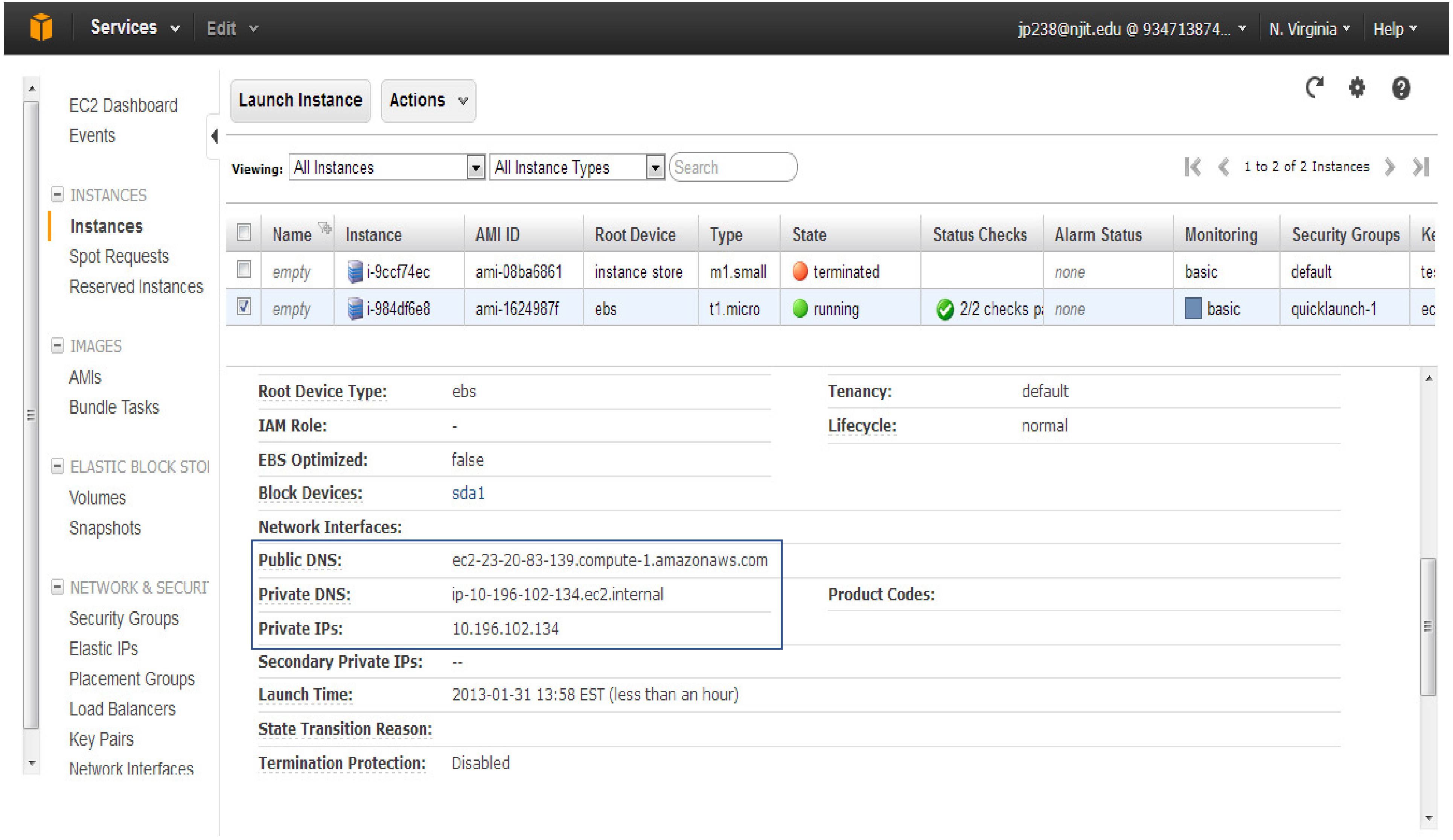
Launch instance



Instance IP addresses

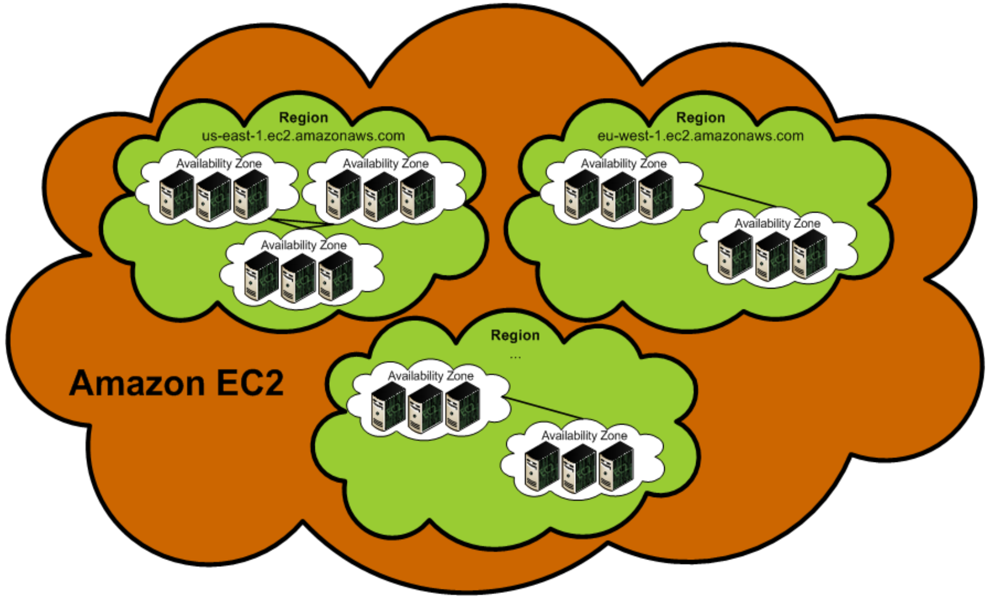
- Public IP and DNS
  - Public addresses are reachable from the Internet
- Private IP and DNS
  - Private addresses are only reachable from within the Amazon EC2 network
- Elastic IPs
  - Static IP addresses associated with account, not specific instances
  - If instance using elastic IP fails, this address can be quickly remapped to another instance
    - DNS propagation may take a long time if remapping the name to another IP address

Checking instance IP/DNS



Region and availability zones

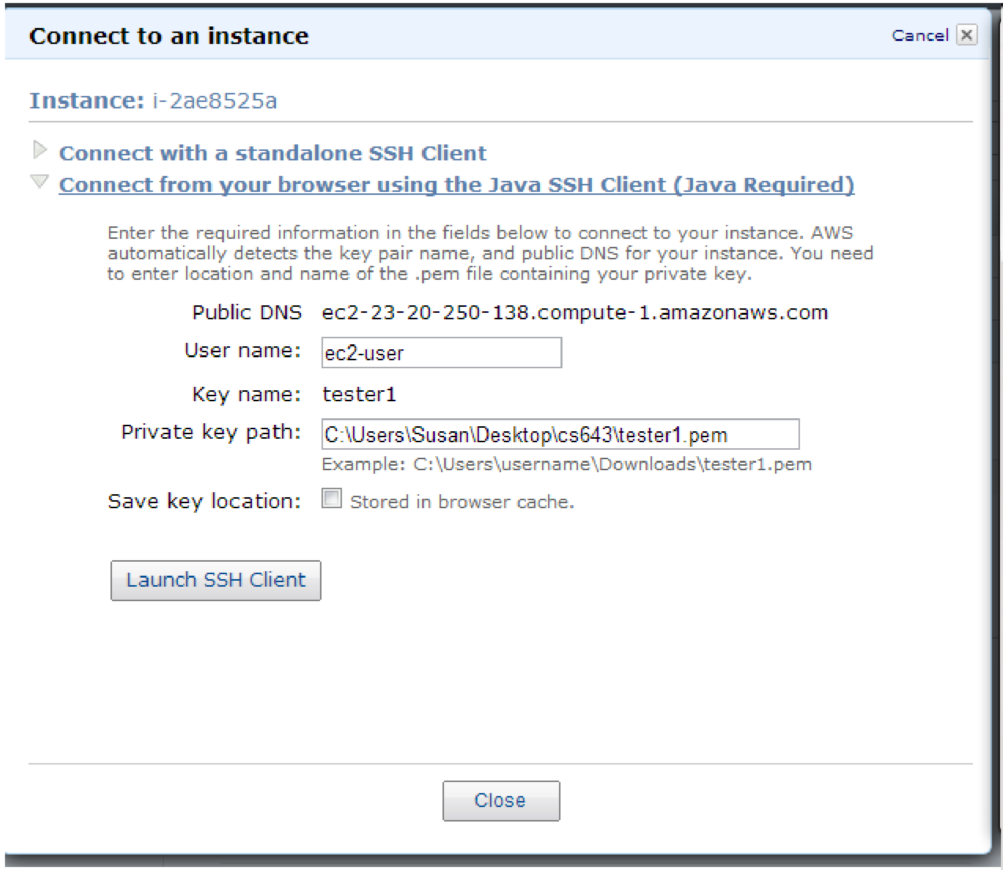
- Regions are located in separate geographic areas (US: Virginia & California, Ireland, Singapore, etc.)
  - Each Region is completely isolated
  - Failure independence and stability
- Availability Zones are distinct locations within a Region
  - Isolated, but connected through low-latency links
  - Failure resilience
- Current pricing: http://aws.amazon.com/ec2/pricing/

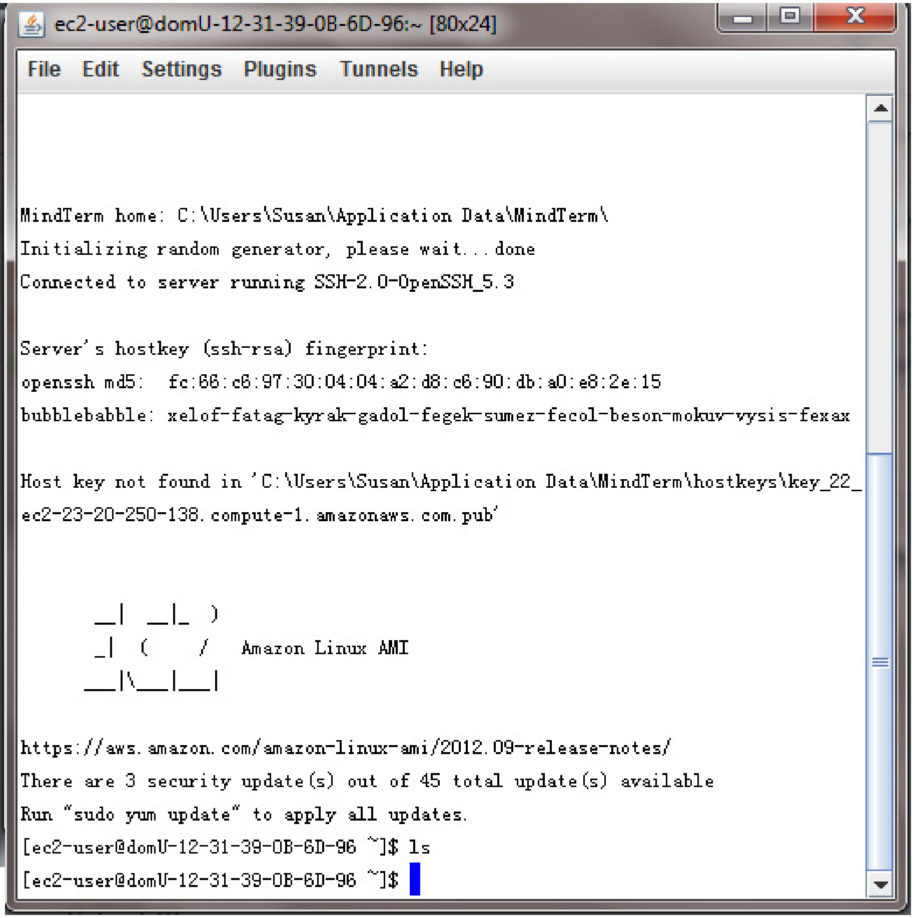


Connecting to instances

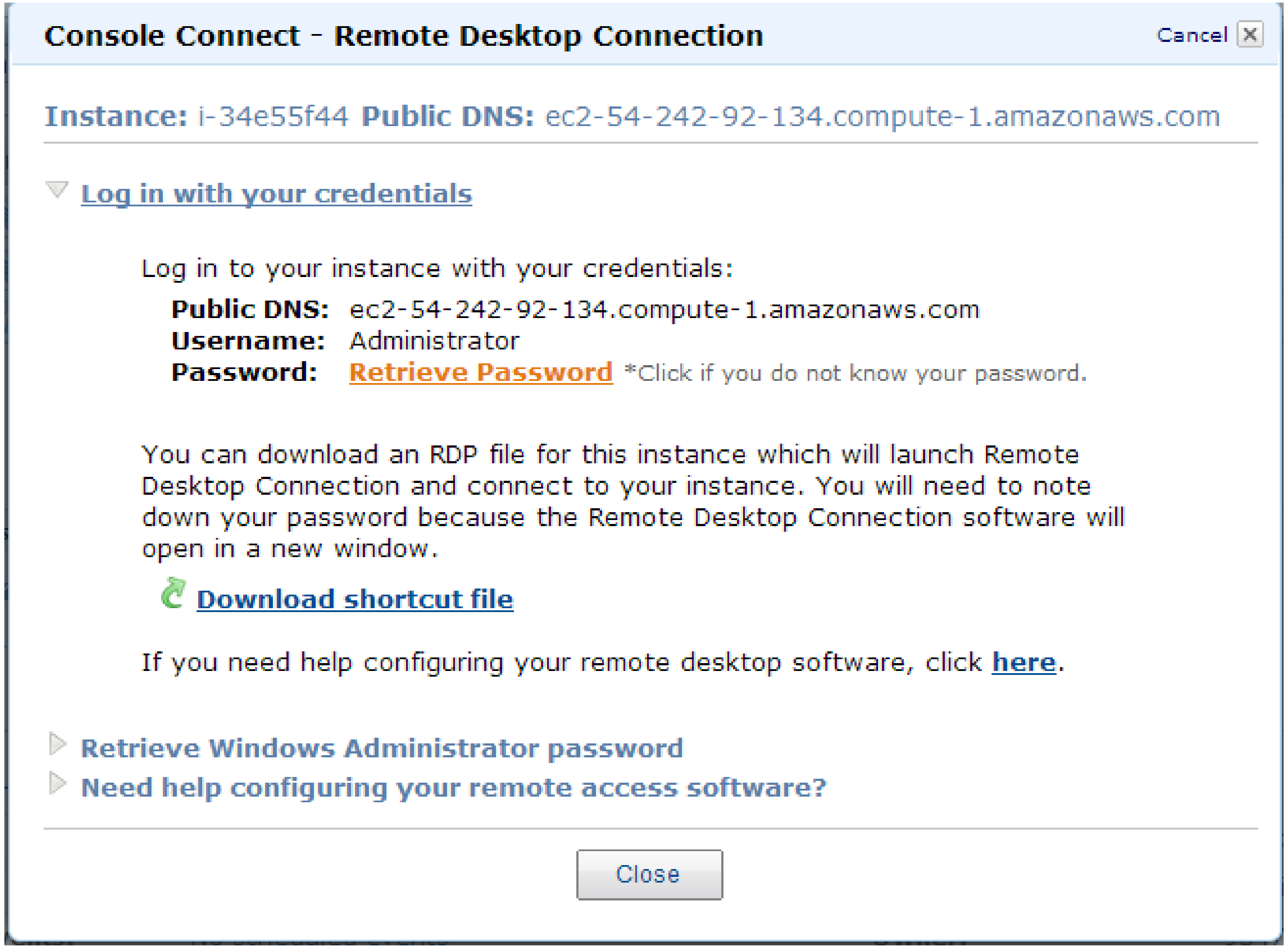
- Windows instance
  - Connect from your browser using the Java SSH Client
  - Connect using Remote Desktop
- Linux Instance
  - Connect from your browser using the Java SSH Client
  - Putty.exe/putty key generator
  - SSH command on linux machine
  - ssh -i key.pem ec2-user@ec2-23-20-83-139.compute-1.amazonaws.com

Connecting to Linux instance

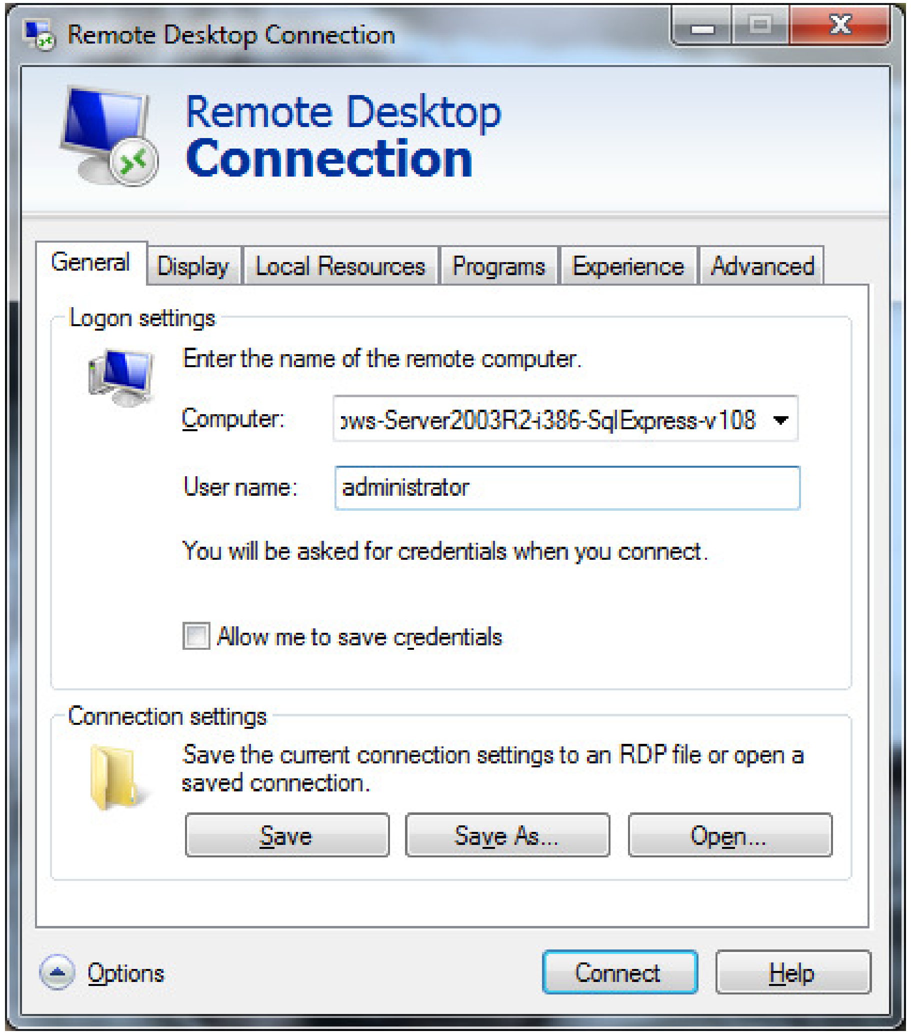




Connecting to Windows instance: get administrator password



Connecting to Windows instance



- Type in public DNS name of instance
- Use the retrieved administrator password

IAM – Identity Access Management

- “AWS Identity and Access Management (IAM) helps to securely control access to AWS resources

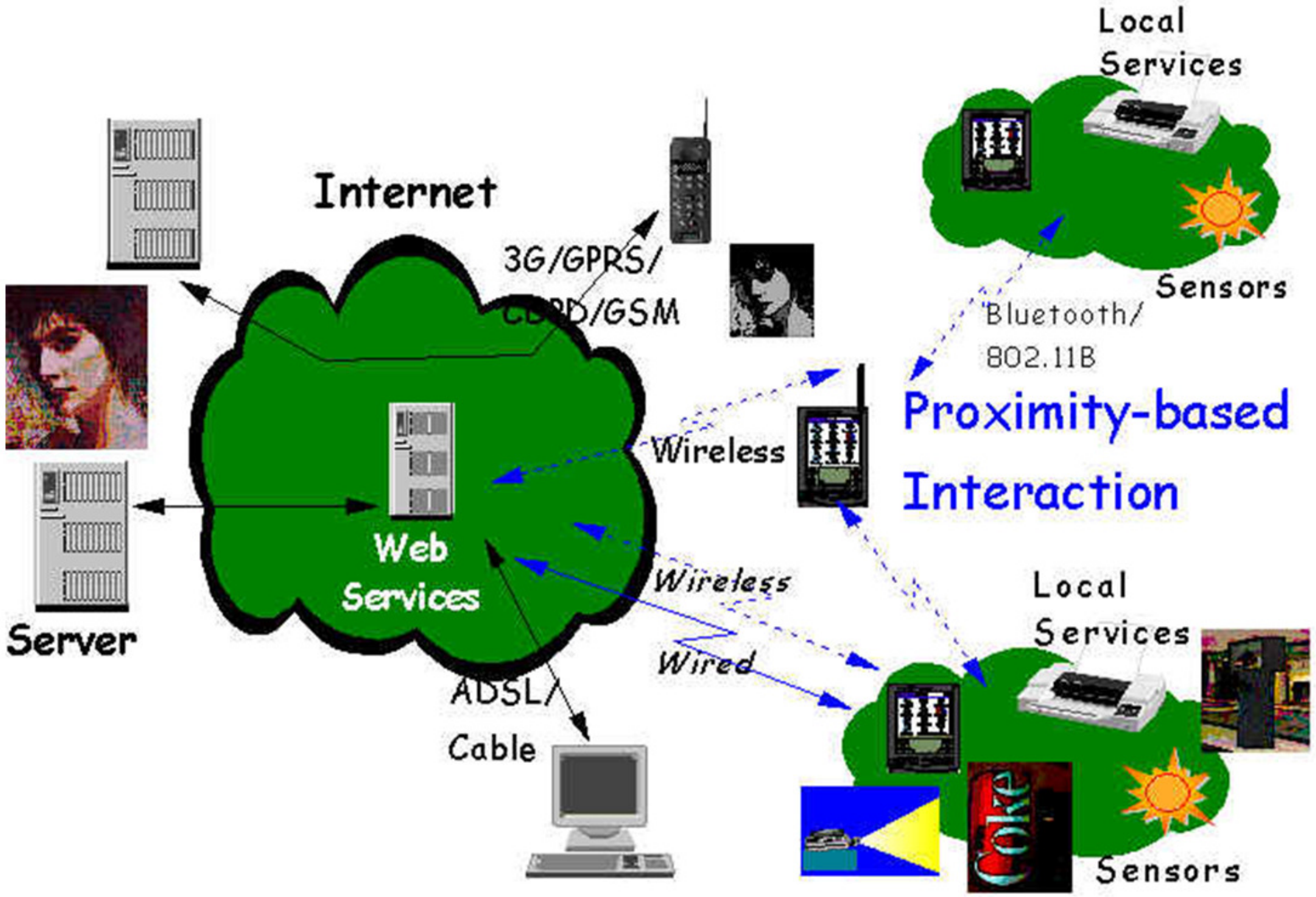
- IAM is used to control who can use your AWS resources (authentication) and what resources they can use and in what ways (authorization).”

Mobile and Ubiquitous Computing

Mobile and Ubiquitous Computing

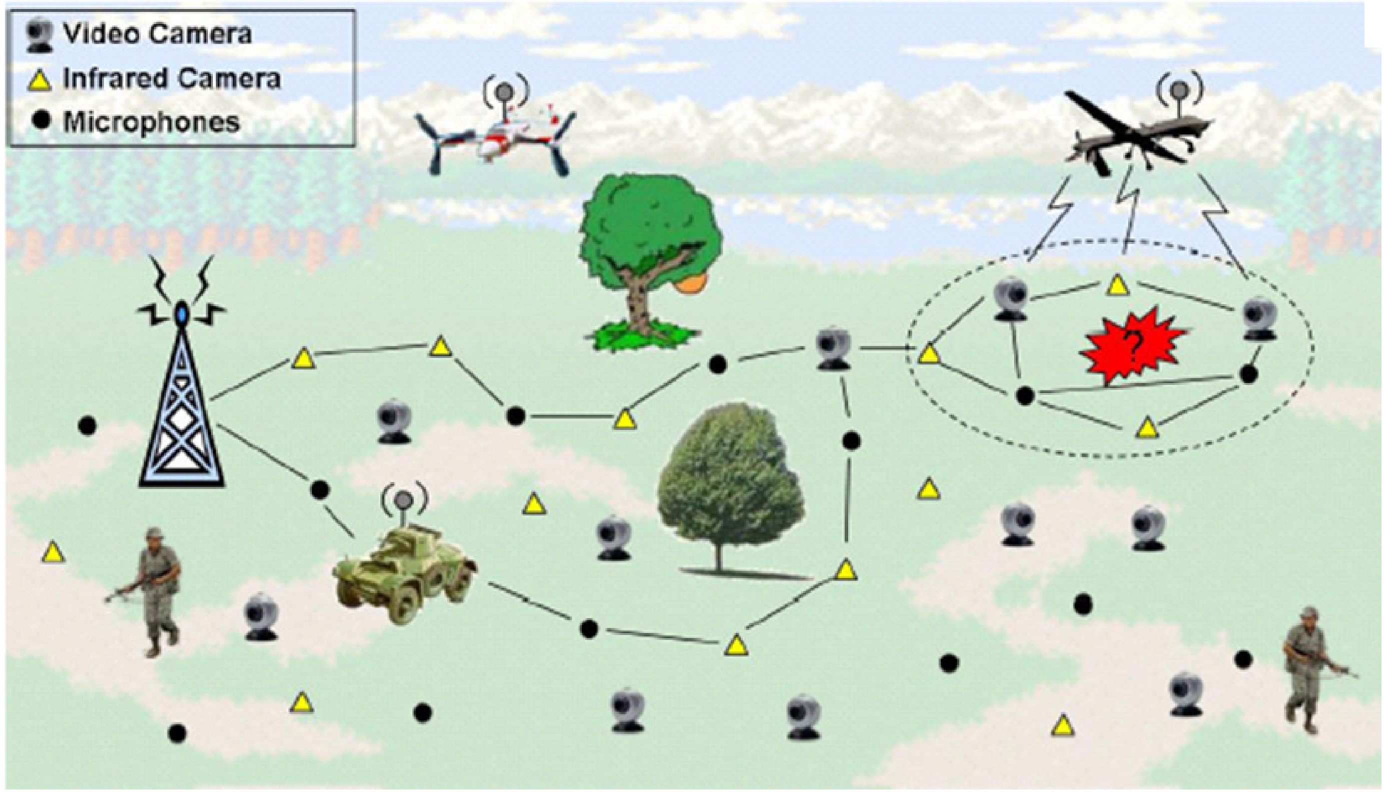
Mobile and Ubiquitous Computing Internet of Things (IoT)

- GPRS: General Packet Radio Service
- WTP: Wireless Transport Protocol
- WAP: Wireless Application Protocol with 2 components: WML and WMLScript
- WML: Wireless Markup Language
- cHTML: Compact HTML
- HDML: Handheld Device Markup Language



Wireless Sensor Networks

- Pervasive applications
    - Agricultural
    - Military
    - Industrial



Ongoing Research in Our HPNC Group

Data-intensive Computing

- Scientific Workflow Optimization: mapping, scheduling, modeling
- Various network environments HPN, grid, cloud

High-performance Networking

- Bandwidth scheduling
- Transport control/profiling
- Control plane design

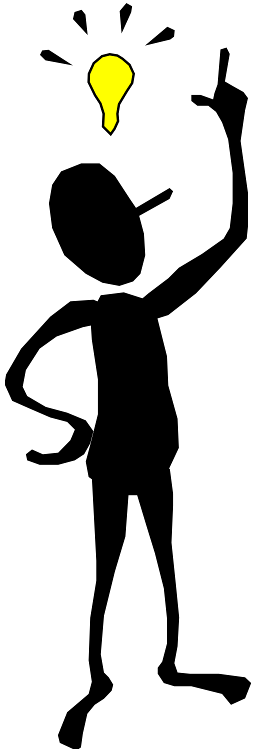
Distributed Sensor Networks

- Deployment, routing, fusion

Cyber Security

- Monitoring, game theory

Visualization and Image Processing



Thanks ! ☺

Questions ?