Introduction

Mirek Riedewald

Key Learning Goals

- What are the three Vs of Big Data?
  - Can a 1 GB dataset cause a Big-Data problem?
- What do we mean by “data center as computer” and “warehouse-scale computer”?
  - Is this about an architecture or a programming model or both?
- What are the two main performance concerns when designing programs that access data at different levels of the storage hierarchy: {memory, SSD/disk} × {local, same rack, across the data center}?

Key Learning Goals

- What is the impact of Moore’s Law for scalable Big-Data processing?
- Why do businesses migrate their computation to the Cloud?
- Why might some businesses decide to not move all their data and computation to the Cloud?
- Name major Cloud providers.

Why Parallel Data Processing?

- Answer 1: Big Data

What is “Big Data”?

- “Big Data” means different things to different people. It usually refers to (i) our ability to collect large amounts of data and (ii) the promise that analyzing it will create new insights, e.g., scientific discoveries, more effective governance, or better business decisions.
- While most people probably associate Big Data with high volume, e.g., petabytes, “small” data can pose Big-Data problems if it is produced at high velocity or shows high variety. These are known as the **three Vs** of Big Data as introduced by Gartner [Laney, Douglas. "3D Data Management: Controlling Data Volume, Velocity and Variety". Gartner. Retrieved 6 February 2001].
- Intuitively, Big Data refers to problems where the data—due to sheer volume, the high rate at which it is generated, or its complexity—overwhelms traditional approaches for analyzing or storing it.

How Much Data is Produced Annually?

- This is difficult to estimate accurately. Probably the most thorough analysis of the amount of data generated world-wide was undertaken in 2003 by a team at UC Berkeley [http://www2.sims.berkeley.edu/research/projects/how-much-info-2003/].
- While those numbers are by now outdated, they make an impressive case for Big-Data analysis, because our ability to generate and collect data has rapidly increased since then.
- Look at selected findings next (for details consult the report).

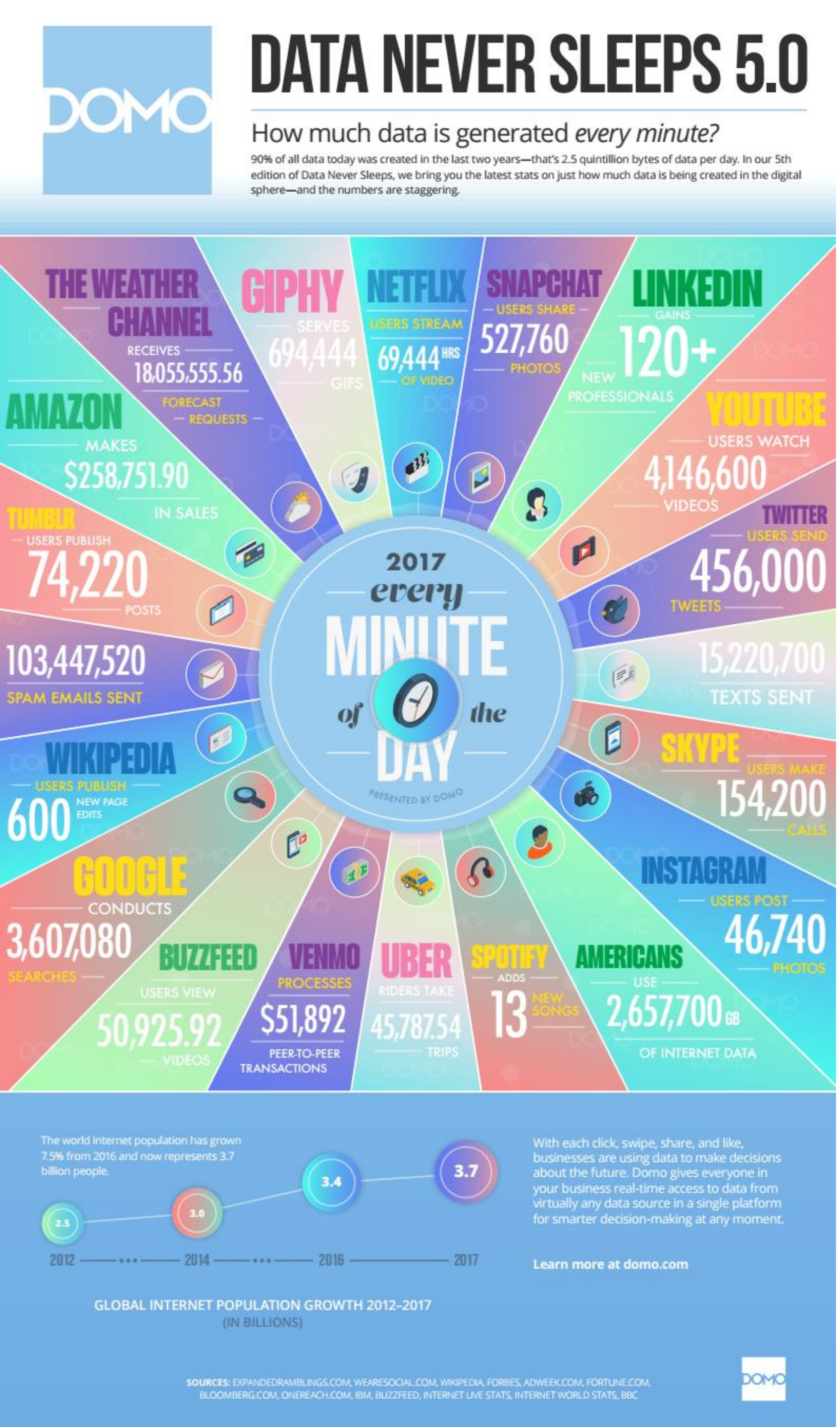
How Much Information Report 2003

- Print, film, magnetic, and optical storage media produced 5 exabytes (10^{18} bytes) of new information in 2002.
  - This was equivalent to half a million times the size of all print collections of the US Library of Congress!
- New information stored on paper, film, magnetic, and optical media doubled between 2000 and 2003.
- Information flows through electronic channels—telephone, radio, TV, Internet—contained 18 exabytes of new information in 2002.

Stop and Think

- How have things changed since 2003 and what might these numbers look like today?
- Which of the media do you think lost and which won market share?
- Can you think of new media that did not exist in 2003 or did not play a major role then?
- Which of the above numbers are affected significantly by the rise of tablets/smartphones and by social networks, e.g., Facebook?

Let us now look at some newer numbers.



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DATA NEVER SLEEPS 5.0

How much data is generated *every minute?*

90% of all data today was created in the last two years—that's 2.5 quintillion bytes of data per day. In our 5th edition of Data Never Sleeps, we bring you the latest stats on just how much data is being created in the digital sphere—and the numbers are staggering.

THE WEATHER CHANNEL RECEIVES 18,055,555.56 FORECAST REQUESTS

GIPHY SERVES 694,444 GIFS

NETFLIX USERS STREAM 69,444 HRS OF VIDEO

SNAPCHAT USERS SHARE 527,760 PHOTOS

LINKEDIN GAINS 120+ NEW PROFESSIONALS

YOUTUBE USERS WATCH 4,146,600 VIDEOS

TWITTER USERS SEND 456,000 TWEETS

15,220,700 TEXTS SENT

SKYPE USERS MAKE 154,200 CALLS

INSTAGRAM USERS POST 46,740 PHOTOS

AMERICANS USE 2,657,700 GB OF INTERNET DATA

SPOTIFY ADDS 13 NEW SONGS

UBER RIDERS TAKE 45,787.54 TRIPS

VENMO PROCESSES $51,892 PEER-TO-PEER TRANSACTIONS

BUZZFEED USERS VIEW 50,925.92 VIDEOS

GOOGLE CONDUCTS 3,607,080 SEARCHES

WIKIPEDIA USERS PUBLISH 600 NEW PAGE EDITS

103,447,520 SPAM EMAILS SENT

TUMBLR USERS PUBLISH 74,220 POSTS

AMAZON MAKES $258,751.90 IN SALES

2017 *every* MINUTE *of the* DAY

PRESENTED BY DOMO

The world internet population has grown 7.5% from 2016 and now represents 3.7 billion people.

GLOBAL INTERNET POPULATION GROWTH 2012–2017
(IN BILLIONS)

With each click, swipe, share, and like, businesses are using data to make decisions about the future. Domo gives everyone in your business real-time access to data from virtually any data source in a single platform for smarter decision-making at any moment.

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SOURCES: EXPANDEDRAMBLINGS.COM, WEARESOCIAL.COM, WIKIPEDIA, FORBES, ADWEEK.COM, FORTUNE.COM, BLOOMBERG.COM, ONEREACH.COM, IBM, BUZZFEED, INTERNET LIVE STATS, INTERNET WORLD STATS, BBC

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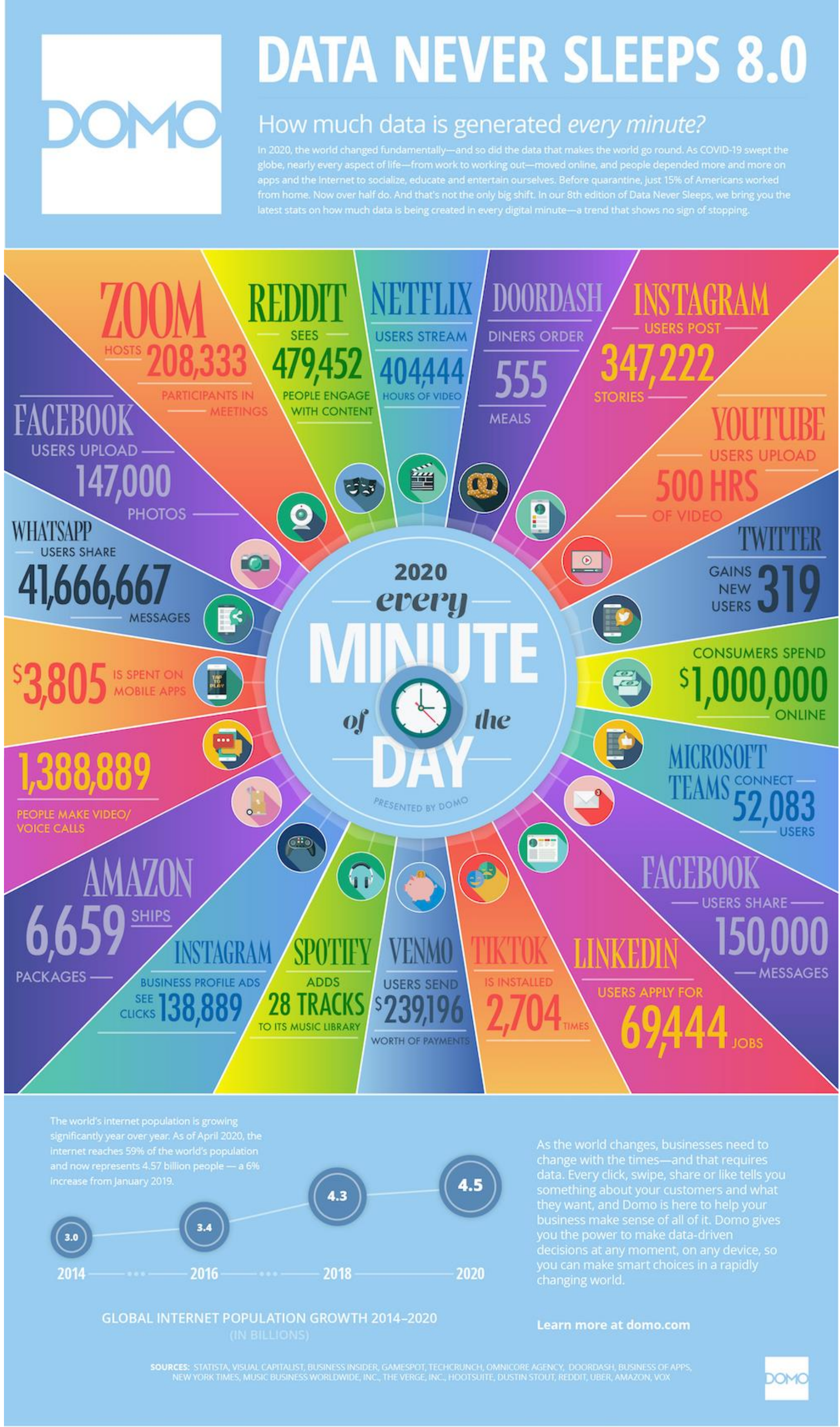

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DATA NEVER SLEEPS 8.0

How much data is generated *every minute?*

In 2020, the world changed fundamentally—and so did the data that makes the world go round. As COVID-19 swept the globe, nearly every aspect of life—from work to working out—moved online, and people depended more and more on apps and the Internet to socialize, educate and entertain ourselves. Before quarantine, just 15% of Americans worked from home. Now over half do. And that's not the only big shift. In our 8th edition of Data Never Sleeps, we bring you the latest stats on how much data is being created in every digital minute—a trend that shows no sign of stopping.

ZOOM HOSTS 208,333 PARTICIPANTS IN MEETINGS

REDDIT SEES 479,452 PEOPLE ENGAGE WITH CONTENT

NETFLIX USERS STREAM 404,444 HOURS OF VIDEO

DOORDASH DINERS ORDER 555 MEALS

INSTAGRAM USERS POST 347,222 STORIES

YOUTUBE USERS UPLOAD 500 HRS OF VIDEO

TWITTER GAINS 319 NEW USERS

CONSUMERS SPEND $1,000,000 ONLINE

MICROSOFT TEAMS CONNECT 52,083 USERS

FACEBOOK USERS SHARE 150,000 MESSAGES

LINKEDIN USERS APPLY FOR 69,444 JOBS

TIKTOK IS INSTALLED 2,704 TIMES

VENMO USERS SEND $239,196 WORTH OF PAYMENTS

SPOTIFY ADDS 28 TRACKS TO ITS MUSIC LIBRARY

INSTAGRAM BUSINESS PROFILE ADS SEE 138,889 CLICKS

AMAZON SHIPS 6,659 PACKAGES

1,388,889 PEOPLE MAKE VIDEO/VOICE CALLS

$3,805 IS SPENT ON MOBILE APPS

WHATSAPP USERS SHARE 41,666,667 MESSAGES

FACEBOOK USERS UPLOAD 147,000 PHOTOS

2020 *every* MINUTE *of the* DAY

PRESENTED BY DOMO

The world's internet population is growing significantly year over year. As of April 2020, the internet reaches 59% of the world's population and now represents 4.57 billion people — a 6% increase from January 2019.

GLOBAL INTERNET POPULATION GROWTH 2014–2020
(IN BILLIONS)

As the world changes, businesses need to change with the times—and that requires data. Every click, swipe, share or like tells you something about your customers and what they want, and Domo is here to help your business make sense of all of it. Domo gives you the power to make data-driven decisions at any moment, on any device, so you can make smart choices in a rapidly changing world.

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SOURCES: STATISTA, VISUAL CAPITALIST, BUSINESS INSIDER, GAMESPOT, TECHCRUNCH, OMNICORE AGENCY, DOORDASH, BUSINESS OF APPS, NEW YORK TIMES, MUSIC BUSINESS WORLDWIDE, INC., THE VERGE, INC., HOOTSUITE, DUSTIN STOUT, REDDIT, UBER, AMAZON, VOX

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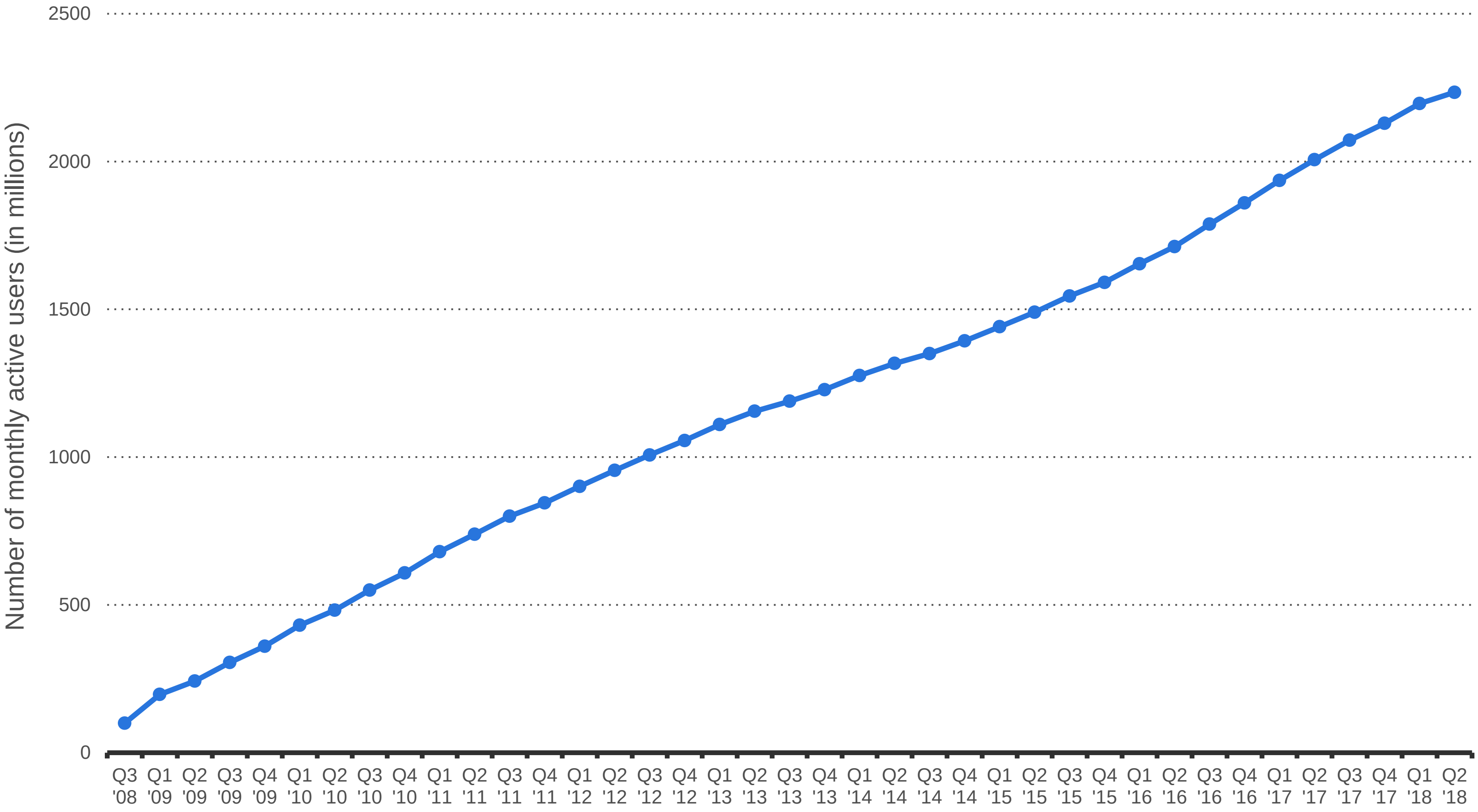
Facebook Growth



Facebook. n.d. Number of monthly active Facebook users worldwide as of 2nd quarter 2018 (in millions). Statista. Accessed August 14, 2018. Newer version available from https://www.statista.com/statistics/264810/number-of-monthly-active-facebook-users-worldwide/

Social-Network Analysis

- As a larger fraction of the world’s population spends more time online, massive amounts of data about social interactions and opinions are produced, for example:
  - Homepages on the Web, personal pages in online social networks
  - Blogs, tweets, online product reviews, emails
  - Companies and governments also collect data about site visits and purchases
- We can use this data to answer questions about humanity and society:
  - How does information spread and how is this affected by connections between people?
  - How do my friends affect my product reviews, purchases, or choice of new friends?
  - Will the first reviews for a product influence my own review?
  - What are friendship patterns? A famous result is the *small-world phenomenon*, which intuitively states that even in a very large and sparse network, any two individuals are likely to be connected through a short sequence of acquaintances (“six degrees of separation”).
- This data also helps governments to identify dangerous organizations or to spy on their citizens.

Big Data in Business

- Big Data holds great promise for improving the way we do business as the following examples illustrate.
- Detecting criminal activities for bank accounts and credit cards:
  - As companies collect data about legitimate and fraudulent transactions, they can construct prediction models using machine learning. For an incoming transaction, these models predict in real-time if it is legitimate or should be flagged as potentially fraudulent.
  - Model training is often difficult due to data volume (high training time) and variety (making it difficult to identify actionable patterns). Keeping models up to date and making real-time predictions is challenging due to data velocity as transactions are coming in at high rates.
- Retailers analyze purchase behavior to determine which products are frequently bought together. Established techniques, e.g., association-rule mining, often struggle to scale to Big Data.
- Companies can customize ads based on user profiles built from social-network data (interests, behaviors, friends), browsing history, email content, and purchase history. Notice how after you search for something, you will often see related ads soon after.
- The same data can also be used to identify key groups of customers, e.g., by identifying clusters of similar users.

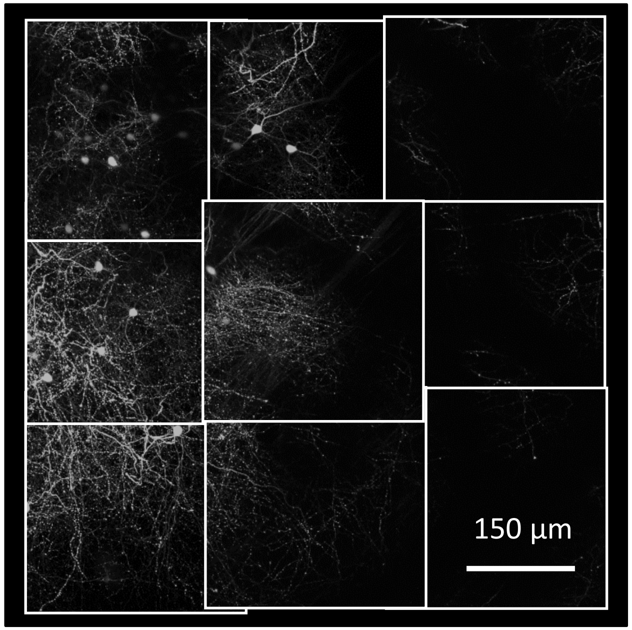
Data-Driven Science

- The human genome has about 3 billion base pairs. Imagine how much data we would have to manage for Boston, the US, India, or China.
- The Large Hadron Collider (LHC) in Europe is the world’s largest and most powerful particle accelerator. It performs high-energy physics experiments to answer questions related to our understanding of the Universe, e.g., verify the existence of the Higgs boson. The LHC produces about 15 petabytes of raw data annually. [http://home.web.cern.ch/about/computing accessed November 18, 2013]
- The Sloan Digital Sky Survey’s goal is to “map the universe.” Between 2000 and 2008, it obtained deep, multi-color images covering more than a quarter of the sky and created 3-dimensional maps containing more than 930,000 galaxies and more than 120,000 quasars. [http://www.sdss.org/ accessed November 18, 2013]
- Citizen-science projects such as eBird (http://ebird.org/content/ebird/) are collecting and integrating tens of millions of reports about bird sightings from all over the world. Joining these reports with data about climate, weather, human presence, habitat, elevation, etc. creates a massive data resource for exploring how bird populations are impacted by human activity or climate change.

Science Highlight: NCTracer

DATALAB
@Northeastern

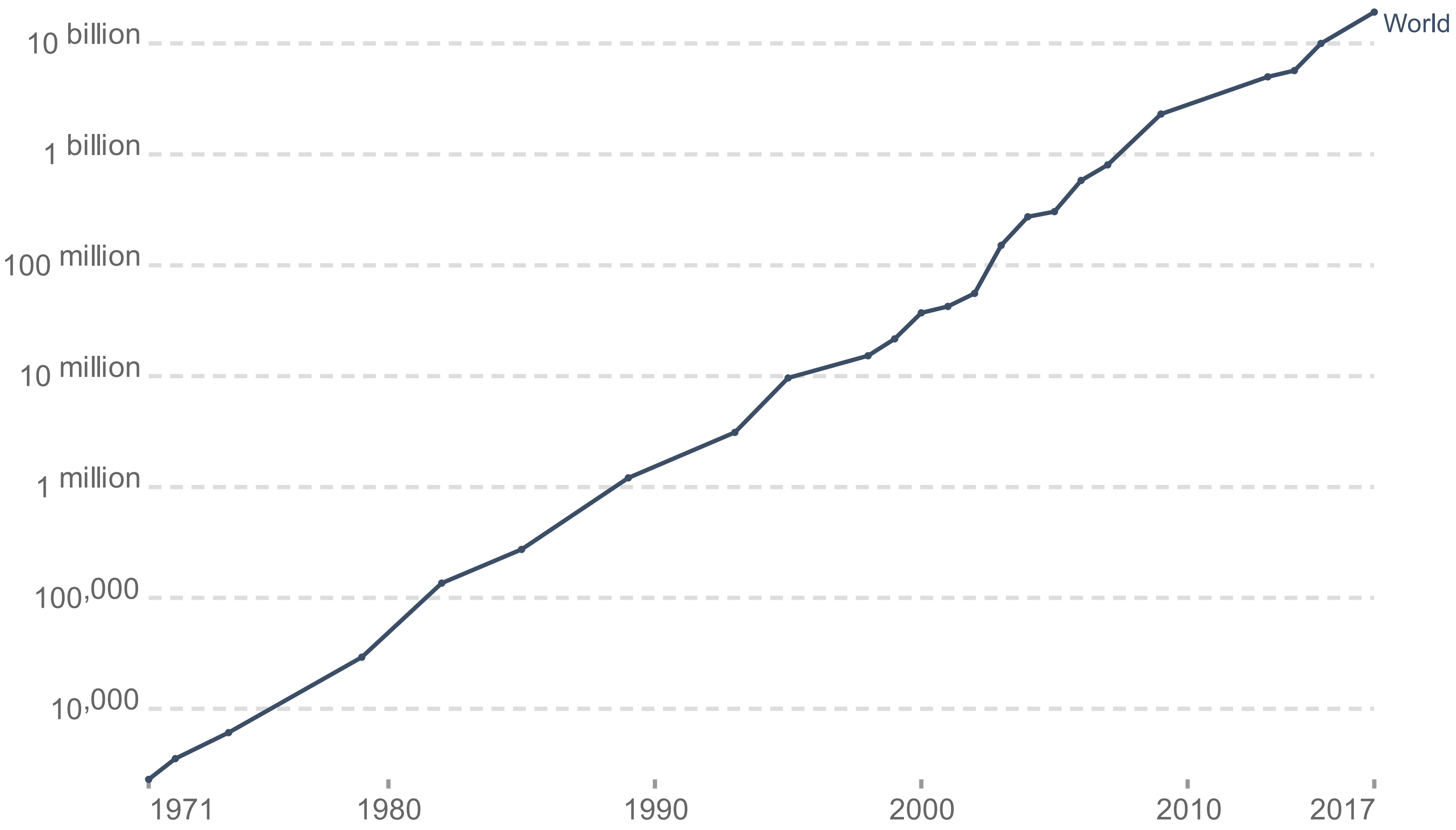
- Prof. Riedewald and his students at the DATA Lab collaborate with scientists—Prof. Stepanyants' group in COS—on a project whose goal is to map connectivity in the brain.
- A mouse-brain scan produces about 20 terabytes of raw image data, which must be cleaned, aligned, and turned into a graph.
- Then we want to identify interesting structural patterns and pattern changes over time. (For the latter, data covers only outer brain layers in a limited region of the skull.)



Why Parallel Data Processing?

- Answer 1: Big Data
- Answer 2: hardware trends
  - Multi-core CPUs and GPUs

Moore’s Law: Still Going Strong



Moore's Law: Transistors per microprocessor

Our World in Data

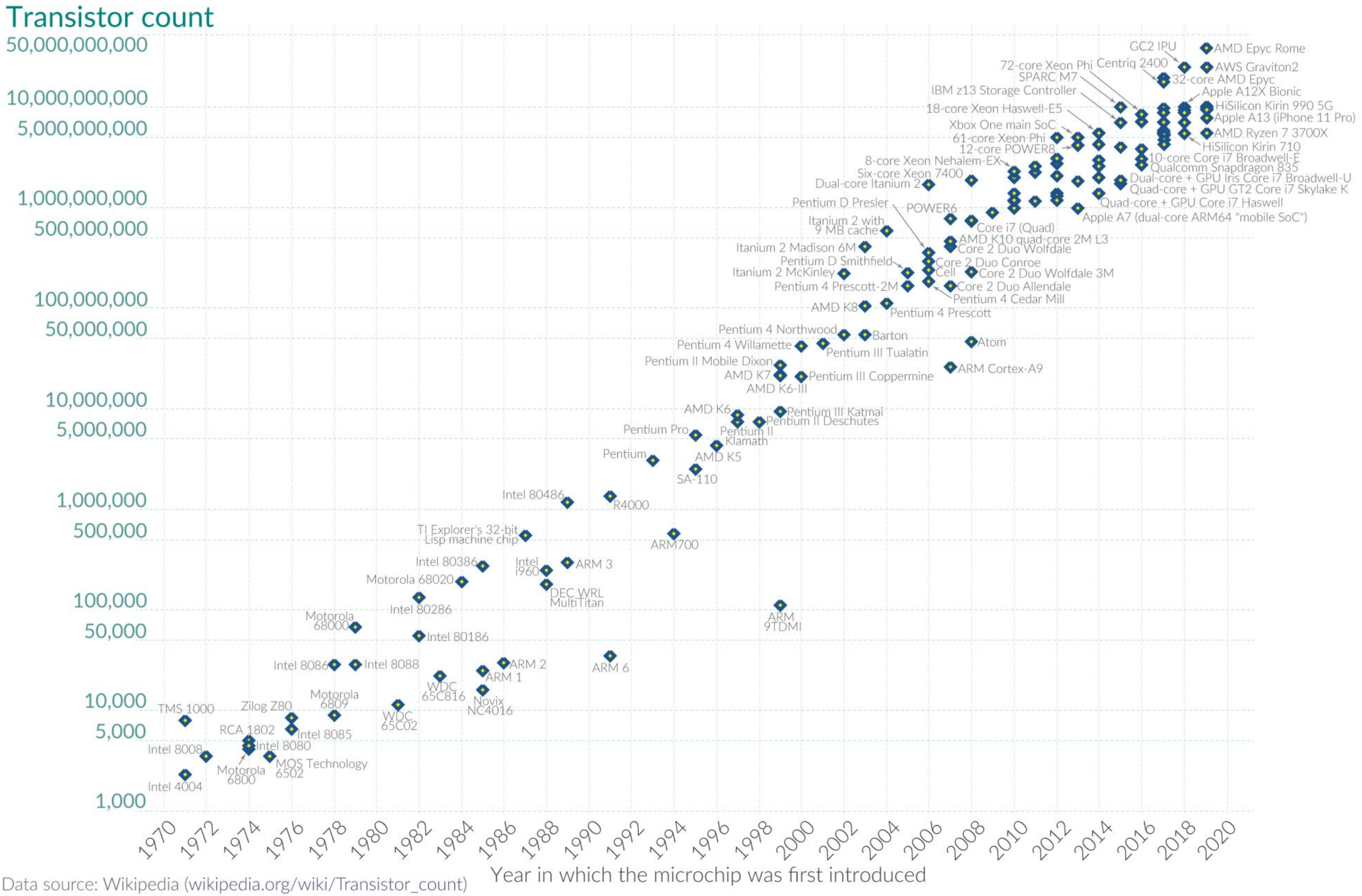
Number of transistors which fit into a microprocessor. This relationship was famously related to Moore's Law, which was the observation that the number of transistors in a dense integrated circuit doubles approximately every two years.

Source: Karl Rupp. 40 Years of Microprocessor Trend Data.

Moore's Law: The number of transistors on microchips doubles every two years

Our World in Data

Moore's law describes the empirical regularity that the number of transistors on integrated circuits doubles approximately every two years. This advancement is important for other aspects of technological progress in computing – such as processing speed or the price of computers.



Data source: Wikipedia (wikipedia.org/wiki/Transistor_count)

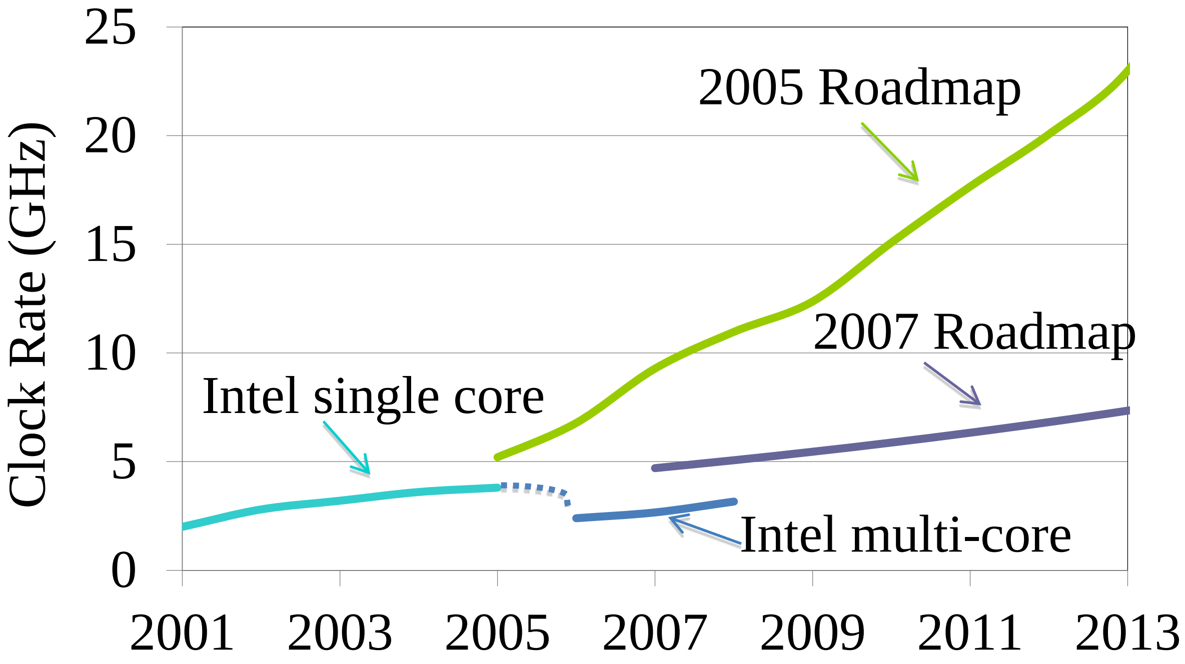
OurWorldinData.org – Research and data to make progress against the world's largest problems.

Moore’s Law: The Good Old Days

- Moore’s Law: the number of transistors that can be placed inexpensively on an integrated circuit doubles about every 2 years. More transistors on a chip means more computational resources.
- Until the early 2000s, this also meant that existing sequential programs automatically became faster at a similar rate. As a rule of thumb, you essentially just had to wait for 2 years and your program would run twice as fast.
- Hence there was little motivation to master the complex art of parallel programming. Parallel computing never entered the mainstream and was limited to (high-impact) niche applications, e.g., military tasks, high-energy physics, and weather forecasting.

“New” Realities

- The “party” ended around 2004 due to heat and energy-related issues, causing CPU clock rate to remain below 5 GHz since 2005.
- The graph below shows Intel’s 2005 roadmap for CPU clock rates. As problems were discovered, Intel corrected the roadmap in 2007. However, even the corrected roadmap proved overly optimistic. [Source: Dave Patterson, UC Berkeley]
- In the end, multi-core CPUs emerged as the preferred way to leverage the still-increasing transistor density while avoiding cooling problems. (Note: There exist other solutions such as water-cooled CPUs. However, it is unlikely that end-users will see water-cooled CPUs in their commodity machines any time soon.)



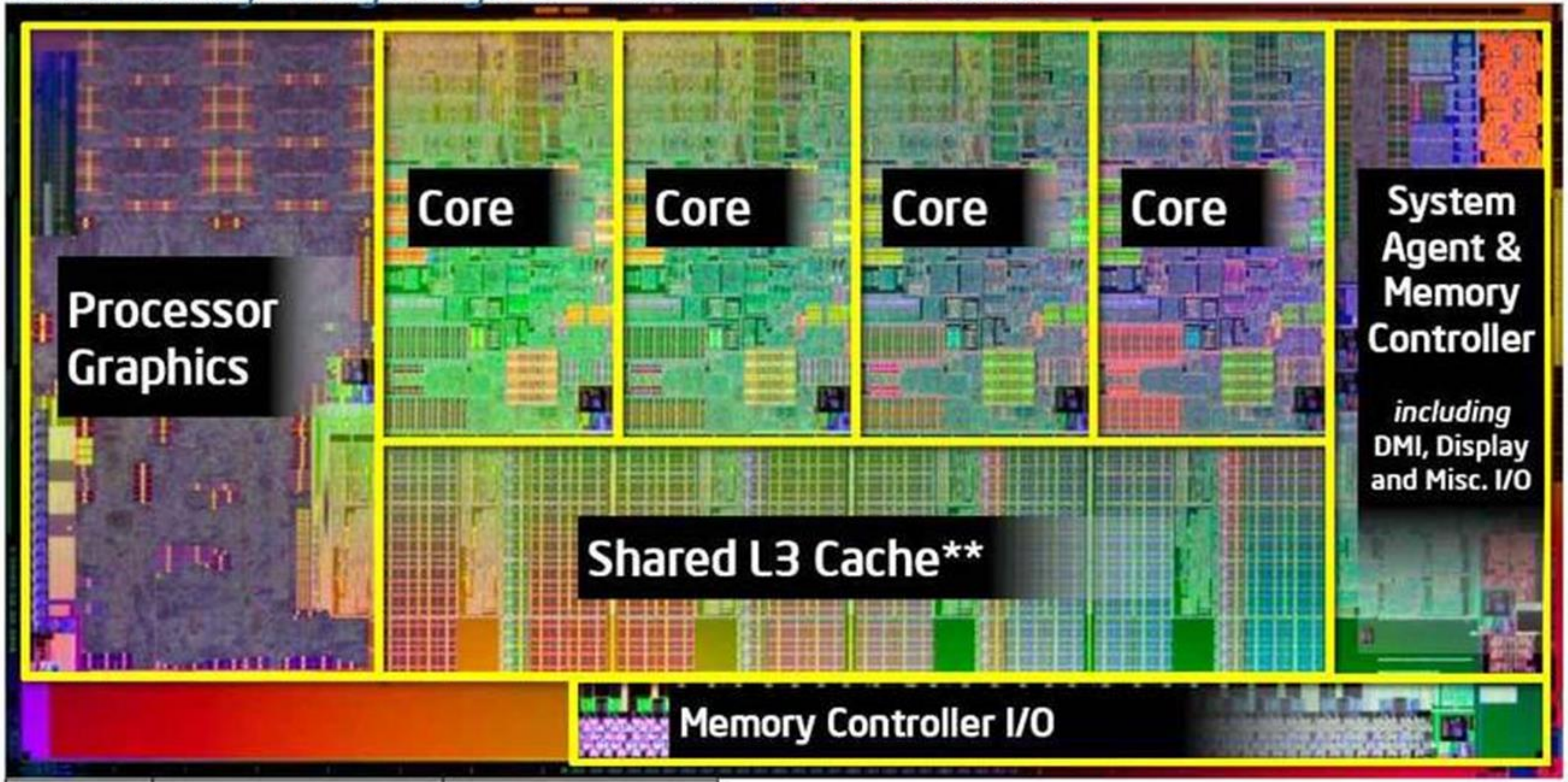
Multi-Core CPUs

- A multi-core CPU consists of several "mini-CPUs" on the same chip, called cores.
- Cores typically share some cache, the memory bus, and access to the same main memory.
- To take advantage of Moore's Law, a program needs to utilize multiple cores to exploit the additional transistors on a chip. This can be done by running multiple applications concurrently or by making applications multi-threaded.
  - Unfortunately, it is not easy to re-write existing software and make it multi-threaded.

Processor Example [Source: Intel]

2nd Generation Intel® Core™ Processor Die Map

32nm Sandy Bridge High-k + Metal Gate Transistors



Die	Number of Transistors (mio)	Die size with Scribe (mm2)
4+2	995	216
2+2	624	149
2+1	504	131

** Cache is shared across all 4 cores and processor graphics

Typical Multi-Core Properties

- Each core has some local cache (e.g., L1, L2).
- The cores on the same chip share some cache (e.g., L3).
- All cores access the same memory through a shared bus.
- Misses become much more expensive from L1 to L3.
- Beyond L3, access times grow rapidly as we show next.

Important Numbers [Source: Google's Jeff Dean @LADIS'09]

L1 cache reference	**0.5**
Branch mispredict	5
L2 cache reference	**7**
Mutex lock/unlock	25
Main memory reference	**100**
Compress 1 KB with Zippy	3,000
Send 2 KB over 1 Gbps network	20,000
Read 1 MB sequentially from memory	**250,000**
Round trip within same data center	500,000
Disk seek	**10,000,000**
Read 1 MB sequentially from disk	**20,000,000**
Send packet CA -> Holland -> CA	150,000,000

All times in nano seconds.

Discussion of the Numbers: Latency

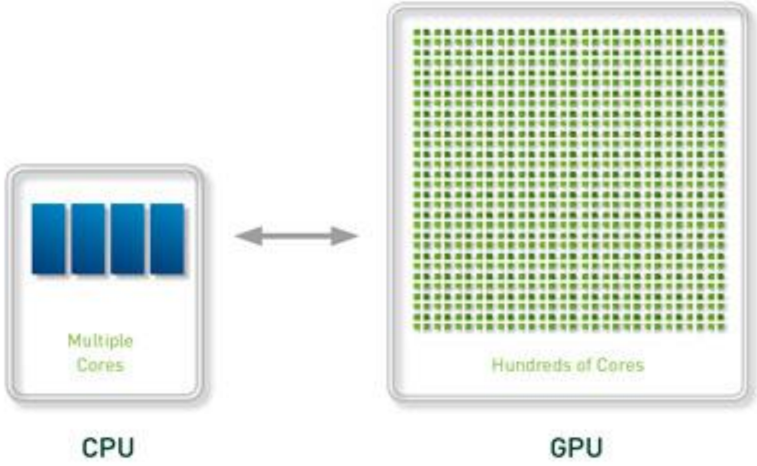
- The numbers on the previous page illustrate how dramatically access time increases for data located farther away from a core:
  - It takes about ten times longer to access L2 cache than L1 cache.
  - When a record is not in cache and must be fetched from memory, it takes 200 times longer than L1 cache.
  - Accessing a data record on a traditional spinning hard disk takes another 100,000 times longer than a memory reference.
  - If data is accessed in a data center across the globe, wait time increases by another factor of 15.
- However, notice that the numbers discussed so far refer to the latency of access, i.e., the time from a core issuing a request until “the first bit” arrives at the core.

Discussion of the Numbers: Data Rate

- When transferring larger blocks of data, the data rate of the channel will also affect the time it takes until the *entire block* has been transferred.
  - The example disk has a latency of 10 milliseconds (msec) and a data transfer rate of 100 MB per second.
  - Latency means that it takes about 10 msec for the disk to position its head over the first relevant disk sector, no matter how much data will be read from there.
  - Reading 1 MB sequentially from disk takes 20 msec: 10 to position the head plus 10 to read 1 MB of data.
  - Reading 10 KB of data takes 10.1 msec, while reading 10 MB takes 110 msec. The dominating factor is latency for the former, but data transfer time for the latter.
  - When reading 1 MB from disk, it is much faster to read a single 1 MB chunk in 20 msec than 100 separate 10 KB fragments of it. The latter could take 100 times 10.1 msec, i.e., 50 times longer! This is one of the reasons for defragmenting a hard disk.

GPU vs. CPU

- GPUs are optimized for massively parallel graphics processing. They have many more cores than a CPU, but each core is simpler and supports a comparably limited set of operations.
- Due to the popularity of computer games, GPUs are commodity chips with an excellent performance-to-price ratio. Hence, they attracted interest in academia and industry for general computations.
- While many graphics-processing tasks are easy to parallelize, for general-purpose computational use it is challenging to write code that effectively leverages 100s of “simple” cores. Parallel computing platforms and programming models were proposed to address this challenge, e.g., NVIDIA’s CUDA.



Source: NVIDIA

Why Parallel Processing?

- Answer 1: Big Data
- Answer 2: hardware trends
  - Multi-core CPUs and GPUs
  - Data center as a computer

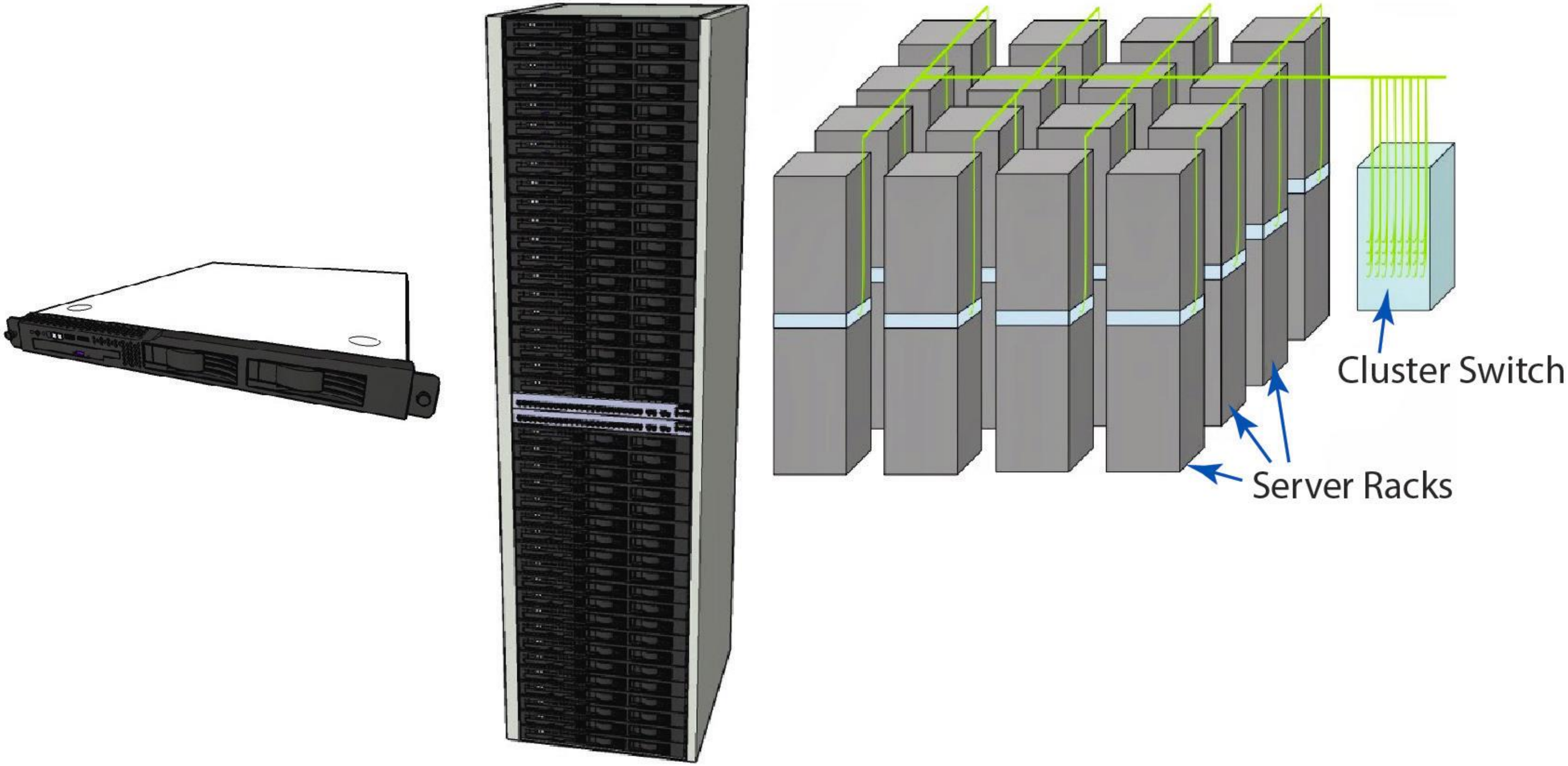
Data Center as a Computer

- Data Center as a Computer, also known as **Warehouse-Scale Computer (WSC)**, is the most relevant hardware-driven trend that motivated Google to propose MapReduce.

- Large companies such as Google, Microsoft, Facebook, and Amazon are already managing hundreds to tens of thousands of servers in their data centers. Many of those servers are commodity PCs, which deliver a better cost per unit of computational capability than specialized hardware due to economies of scale. It is also easy to "scale out" by adding more machines as demand increases.

- With access to thousands of machines linked to each other via high-speed networks, how can one use those machines to solve Big Data analysis problems?
  - The idea behind Data Center as a Computer and Warehouse-Scale Computer is to create an environment that enables programming of large clusters of machines as if they were a single huge computer.

Basic Architecture

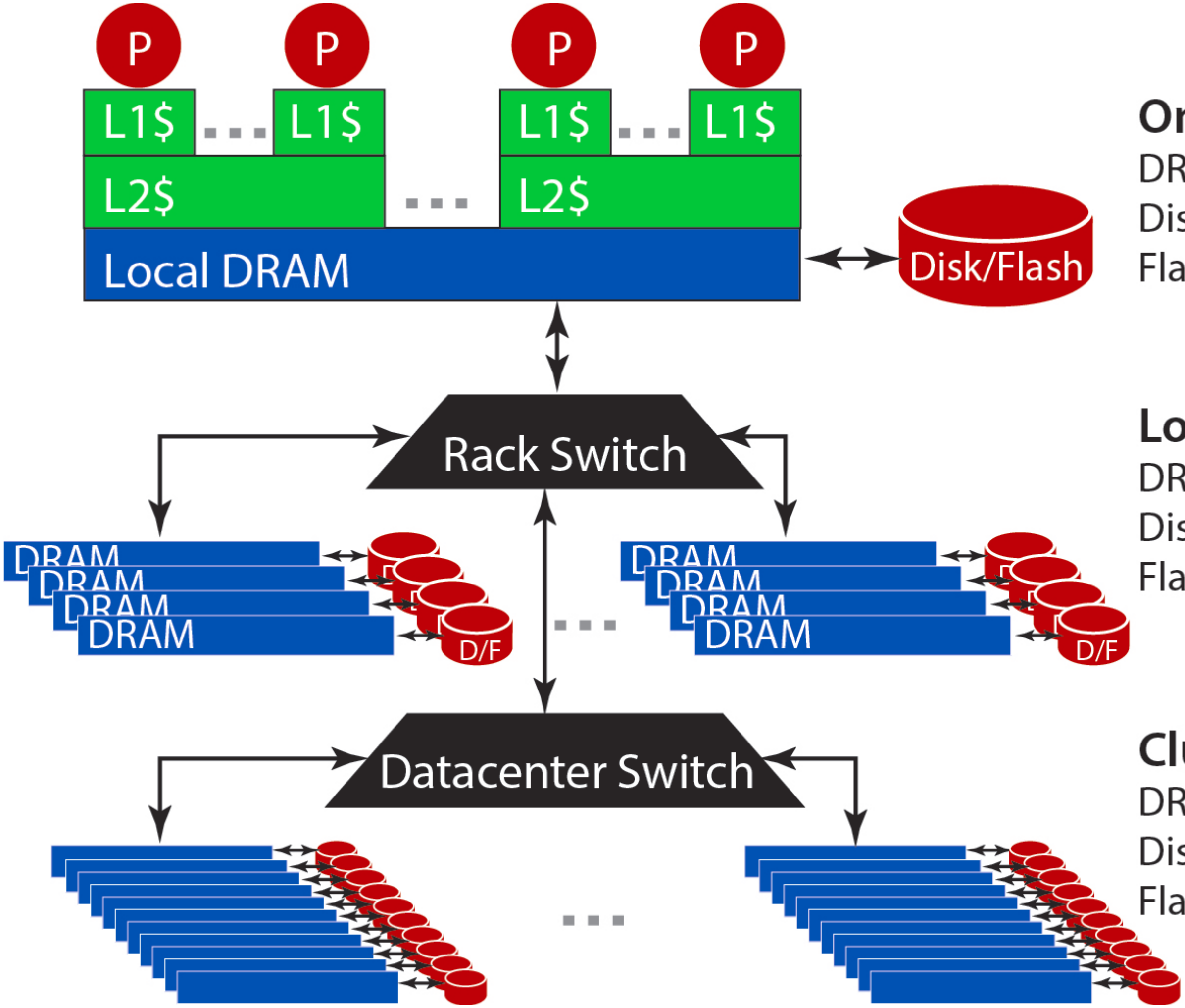


Source: Barroso, Clidaras, Holzle (2013)

Typical Specs (Barroso et al, 2013)

- Each individual machine is a low-end server in a 1U ("single unit" of height 1.75 inches/44.45 mm) enclosure in a 7' rack.
- All machines in a rack are connected to a rack-level switch with 1- or 10-Gbps links
- The different rack-level switches are connected by one or more cluster switches. Overall, more than 10,000 servers could be connected with each other this way.
- There are local (cheap) disks on each server. Disk space across machines is managed by a global distributed file system. (Discussed in another module)
- There might be Network Attached Storage (NAS) devices for a more centralized storage solution.

Storage Hierarchy



One Server

DRAM:	16 GB, 100 ns, 20 GB/s
Disk:	2T B, 10 ms, 200 MB/s
Flash:	128 GB, 100 us, 1 GB/s

Local Rack (80 servers)

DRAM:	1 TB, 300 us, 100 MB/s
Disk:	160 TB, 11 ms, 100 MB/s
Flash:	20 TB, 400 us, 100 MB/s

Cluster (30 racks)

DRAM:	30 TB, 500 us, 10 MB/s
Disk:	4.80 PB, 12 ms, 10 MB/s
Flash:	600 TB, 600 us, 10 MB/s

Source: Barroso, Clidaras, Holzle (2013)

Storage Hierarchy Discussion

- A single server's specs look very similar to those of a laptop a student might own. There are 16 GB of main memory (DRAM) that have an access latency of 100 nanoseconds. Data from memory can be transferred to the local CPU at a rate of 20 GB/sec. Traditional rotating hard disks can provide up to 2 TB of storage, but latency is 100,000 times slower and bandwidth for data transfer is about 100 times lower than for memory. Flash offers a middle ground for non-volatile storage: latency and bandwidth are "only" 1000 and 20 times slower, respectively, than memory.
- Instead of reading data only from devices on the same server, a CPU could also request it from another machine in the same rack or even a different rack. As the numbers indicate, the farther away the data, the higher the latency and lower the bandwidth. Interestingly, since the network switches and links determine the maximal possible bandwidth for transferring data from a different machine, these numbers are identical for memory, disk, and flash.
- Also notice that the combined memory in the same rack is similar to the disk capacity of a single machine. However, access latency is better, while bandwidth is worse compared to the local disk.

Programming WSCs

- To achieve the greatest possible performance, an application should be aware of these tradeoffs.
- Asking a programmer to optimize the code “manually” is impractical. Furthermore, code optimized for one cluster would have to be rewritten for another with different parameters. On the other hand, completely ignoring these numbers and simply programming for a giant machine with 30 TB of RAM would most likely result in poor performance.
  - Just moving a terabyte of data between machines would take a huge amount of time.
- Several aspects are relevant for striking the right balance between high program performance and low programming complexity for WSCs.

WSC Programming Principles

1. A WSC should consist of relatively homogenous hardware and should have a system software platform with a common system management layer. The common infrastructure and services hide architectural complexity from the programmer.
2. Since the servers are commodity machines, they tend to fail. With thousands of machines, failures are the norm, not the exception. Those failures should be handled transparently by the infrastructure. This avoids cluttering user code with failure handlers.
3. The programmer needs a simple way for making thousands of CPUs do productive work. It would be too complex to write code that explicitly manages the behavior of individual machines. Instead, the programmer should be able to focus on the algorithm. Task scheduling and resource management should be provided by the WSC infrastructure. Similarly, programs running on a WSC need to be aware of data location, but the programmer should not have to reason about data locations when writing a program.

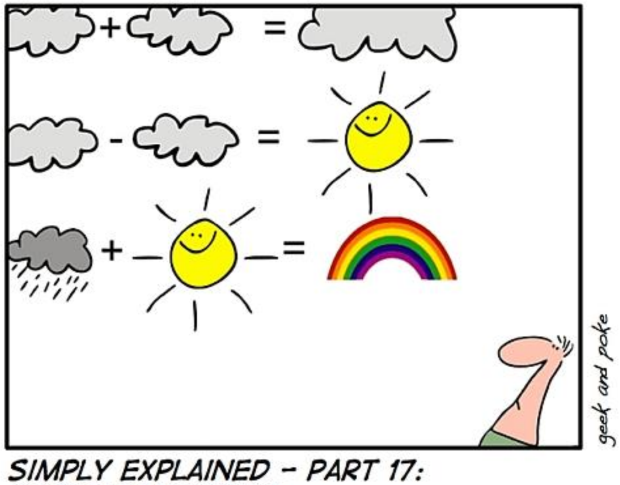
This is where systems like Hadoop MapReduce and Spark really shine! They simplify parallel programming, but still achieve high performance when executing a job in parallel on tens or thousands of machines.

More and more, parallel data processing is performed in the “Cloud”. What is the “Cloud”?

Some content based on [Brian Hayes. Cloud Computing. *Communications of the ACM* 51(7), 2008]

Cloud Overview

- There are many variations on cloud computing, but all offload some computation or service to a remote provider. The cloud user accesses remote resources and services without knowing details about underlying hardware. Relevant concepts include on-demand computing, software as a service (SaaS), and Internet as platform.
- As Cloud offerings gain popularity, they replace traditional "shrink-wrap" software, e.g., compare MS Word on a desktop PC to Google Docs or Office 365. This goes along with a change in pricing models. Instead of purchasing a software license once and then using the software "for free," Cloud users often have no initial cost but pay for usage.



SIMPLY EXPLAINED – PART 17:
CLOUD COMPUTING

Cloud Computing Variants

There are three major types of Clouds and Cloud usage. (For all examples, note that Cloud offerings keep changing. Check which ones are still around and which others have been added.)

1. Reserve virtual machines to create a virtual cluster. Then run your own application(s) there.
   - Examples: Amazon Web Services (including Elastic MapReduce), IBM SmartCloud, Google App Engine, Microsoft Azure, Force.com
2. Connect through a Web browser to an existing application running in the Cloud.
   - Examples: Google Docs, Acrobat.com, Microsoft Office 365
3. Build your own application on top of services offered by a Cloud provider. Typical services include database, document management, Web design, workflow management, and data analytics. This type of Cloud usage lies between the first two “extreme” points.
   - Examples: Salesforce.com, Microsoft Dynamics, IBM Tivoli Live

Cloud History: Back to the Future?

Source: Wikipedia article on IBM Mainframe (accessed 09/2019)

- In many ways, it seems as if Cloud computing is a step back to the 1960s world of hub-and-spoke mainframe configurations. Then “dumb” terminals were used to access a mainframe machine through phone lines.
- This all changed in the 1980s when the client-server model let PCs take over functionality and data from the mainframe. Companies such as SAP who realized this trend early on and designed their business software accordingly became global powerhouses.

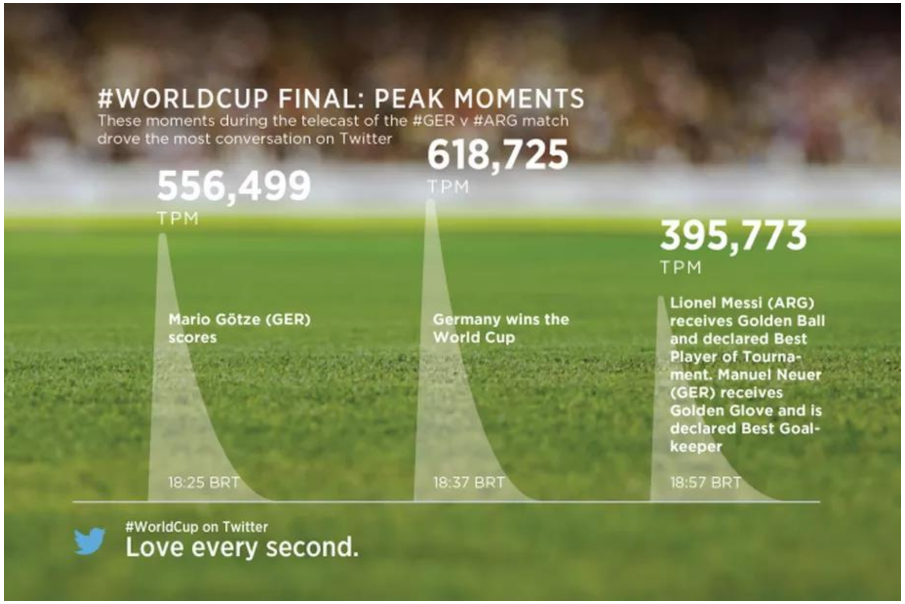
So, why is it in fashion to go back to an old model?

Or Not Back to the Future?

- Despite the obvious similarities, the Cloud is not the same as a 1960s hub. First, clients can communicate with many servers at the same time and are more powerful than the old terminals. Second, servers also can communicate with each other.
- Still, with Cloud computing, functionality migrates away to data centers. Storage, computing, high bandwidth, and careful resource management are characteristics of the core, while end users initiate requests from the fringe.

Driving Forces of Cloud Computing

- Clouds leverage economies of scale in several ways:
  - Software installation, configuration, and maintenance become easier in a more homogeneous environment.
  - Less personnel is needed for hardware maintenance compared to each company running their own IT department.
  - A single instance of a text processor or spreadsheet program cannot utilize 100 cores, but 100 instances can!



- The Cloud enables elasticity, i.e., the ability to grow and shrink capacity on demand. In many businesses there is a great difference between average and peak demand.
- Sizing infrastructure for peak demand wastes resources most of the time.
- On the other hand, not being able to handle the load could result in lost business opportunity or customers. Just imagine you want to buy a product and the Web site says “sorry, you cannot spend your money because our servers are overloaded.”

- With Cloud computing, there is no major initial investment cost and the customer pays according to usage.

Cloud Challenges

- Scalability: Cloud providers must support many users and many applications
- Complex interactions: a client might invoke programs on multiple servers and each server might interact with multiple clients.
- A browser is limited in functionality compared to a traditional operating system. Hence applications accessed through a browser are inherently limited in the way they interact with the user and manage data.
- Despite economies of scale, a Cloud provider might have to deal with a more heterogeneous environment than any single company. It might have to support a database backend running SQL, and JavaScript and HTML at the client. A server app might be written in PHP, Java, or Python.

The Cloud’s Biggest Problem

- Arguably the biggest challenges for Cloud computing are related to privacy, security, and reliability.
  - What happens if the service is not accessible?
  - Who owns the data? Will the Cloud user lose access to the data if the bill is not paid?
  - Can the Cloud provider guarantee that deleted documents are really gone?
  - How well does the Cloud provider protect the data, e.g., against leaking to a third party or against government access? For instance, if software by competing companies runs on the same physical machines, could an infrastructure bug allow data to be shared? Would a Cloud provider contest government requests for private data as much as the company whose customers are affected? With events such as the revelations by Edward Snowden, such questions are more relevant than ever.

References

- Barroso, L.A., Clidaras, J., Hölzle, U.: The Datacenter as a Computer: An Introduction to the Design of Warehouse-Scale Machines. Synthesis Lectures on Computer Architecture **8**(3), 1—154 (2013)
  - https://scholar.google.com/scholar?cluster=16215025499256569000&hl=en&as_sdt=0,22