Northeastern University - Seattle

CS6650 Building Scalable Distributed Systems

Professor Ian Gorton

Building Scalable Distributed Systems

Week 1 – Introduction to Scalable Systems

Introductions

- Before we begin let’s quickly introduce ourselves
- Can you briefly indicate:
  - Write your name and
  - a hint on how to pronounce it (be creative!!)
  - Something about you that no one else in class knows

Outline

- A brief history of how we got here
  - Internet Scale Systems
- Modern Web Sites and Scale
- What is Scalability?
- Course Topics
- Course Structure

Learning objectives

1. Describe the evolution of software systems to achieve web scale
2. Explain the difficulties inherent in achieving linear scalability
3. Explain performance, availability and scalability
4. Lab: Get up and running on AWS

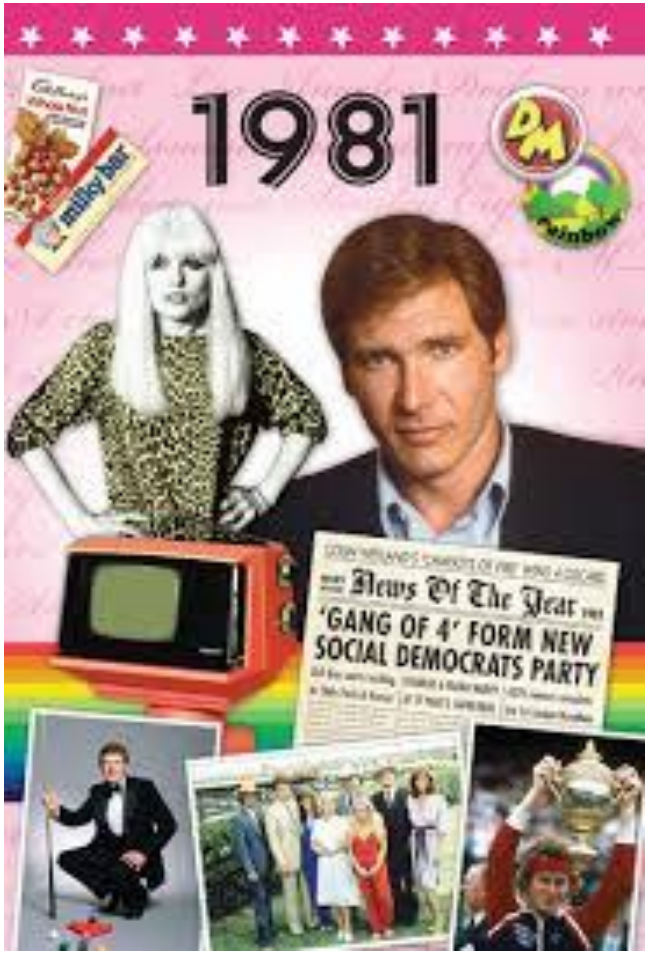
Internet Scale Systems – Some History

The first computer I used (similar anyway)

crepe jumpsuit. Mandarin collar, diagonal front buttoning. French Fact. (3) Burgundy cotton velvet evening jacket worn with black wool cuffed pants. Michel Robichaud for Burtuar Clothes. (4) Royal purple jumpsuit with white floral pattern in acetate/nylon. Algo Industries. (5) Purple/black acetate/metallic tunic and black acetate pants. Michel Robichaud for Fendi Fashions. (6) Black polyester jumpsuit with double spaghetti straps and multicolour polyester jacket. Etc. . . Stanley Sklar.

De gauche à droite: (1) Jaquette de triacétate à carreaux noir/argent/mauve portée sur une combinaison-pantalon fuseau noire en acétate/nylon. Lilly Dee. (2) Combinaison-pantalon en crêpe de cayenne rouge et blanc, col chinois, boutonnage en diagonale sur le devant. French Fact. (3) Veste bulldier en velours de coton Bordeaux portée sur pantalon de laine noir à revers. Michel Robichaud pour Burtuar Clothes. (4) Combinaison-pantalon pourpre royale à motif floral blanc, acétate/nylon. Algo Industries. (5) Tunique d'acétate métallisé violet/noir et pantalon d'acétate noir. Michel Robichaud pour Fendi Fashions. (6) Combinaison-pantalon de polyester, noire à bretelles double-cordon genre "spaghetti" et jaquette de polyester multicolore. Etc. . . Stanley Sklar.

PHOTO: ROBERT COSBOT


1981
DM
Rainbow
milky bar
News Of The Year
'GANG OF 4' FORM NEW SOCIAL DEMOCRATS PARTY


1984


THE
CHESTER
GROSVENOR
next
Thornton's
Russell
Bromley

Cheshire County Council IT Department 1984

```
SV                MSS-21 Management of Sales and Service      Production Files
                            Clear Communications

                              Service Management
   1. Job Ticket Entry/Update              16. Recurring Scheduling History
   2. Job Ticket Parts/Labor               17. Weekly Calendar
   3. Job Ticket Ready to Price            18. Quick Parts Scan
   4. Job Ticket Ready to Invoice          19. Invoice Number Inquiry
   5. Job Ticket Inquiry                   30. Customer Service Inquiry
   6. Job Ticket Profit Analysis           31. Item Inquiry
   7. Scheduling                           32. Serial Number Inquiry
   8. Job Ticket Release from Crd Hold     33. Serial Num Inq By Sys/Dec/Hex Id
   9. Tech Hours Worked Inquiry            35. Summary Sales Analysis
  10. Hours Worked Inquiry                 40. Customer Maintenance
  11. Contract Management Menu             41. Ship To Maintenance
  12. Tech Scheduling                      43. Item Maintenance
  14. Job Ticket Invoicing                 49. Technician Maintenance
  15. Recurring Scheduling                 51. Sales Order Management Menu
                                                                    More...
Selection or command
===>
F3=Exit  F4=Prompt  F6=Messages  F9=Retrieve  F10=Goto Menu  F12=Previous
                F18=Spool Files  F21=Search Menu  F22=Initial Menu
                          (C) copyright systems implementation, inc., 2009
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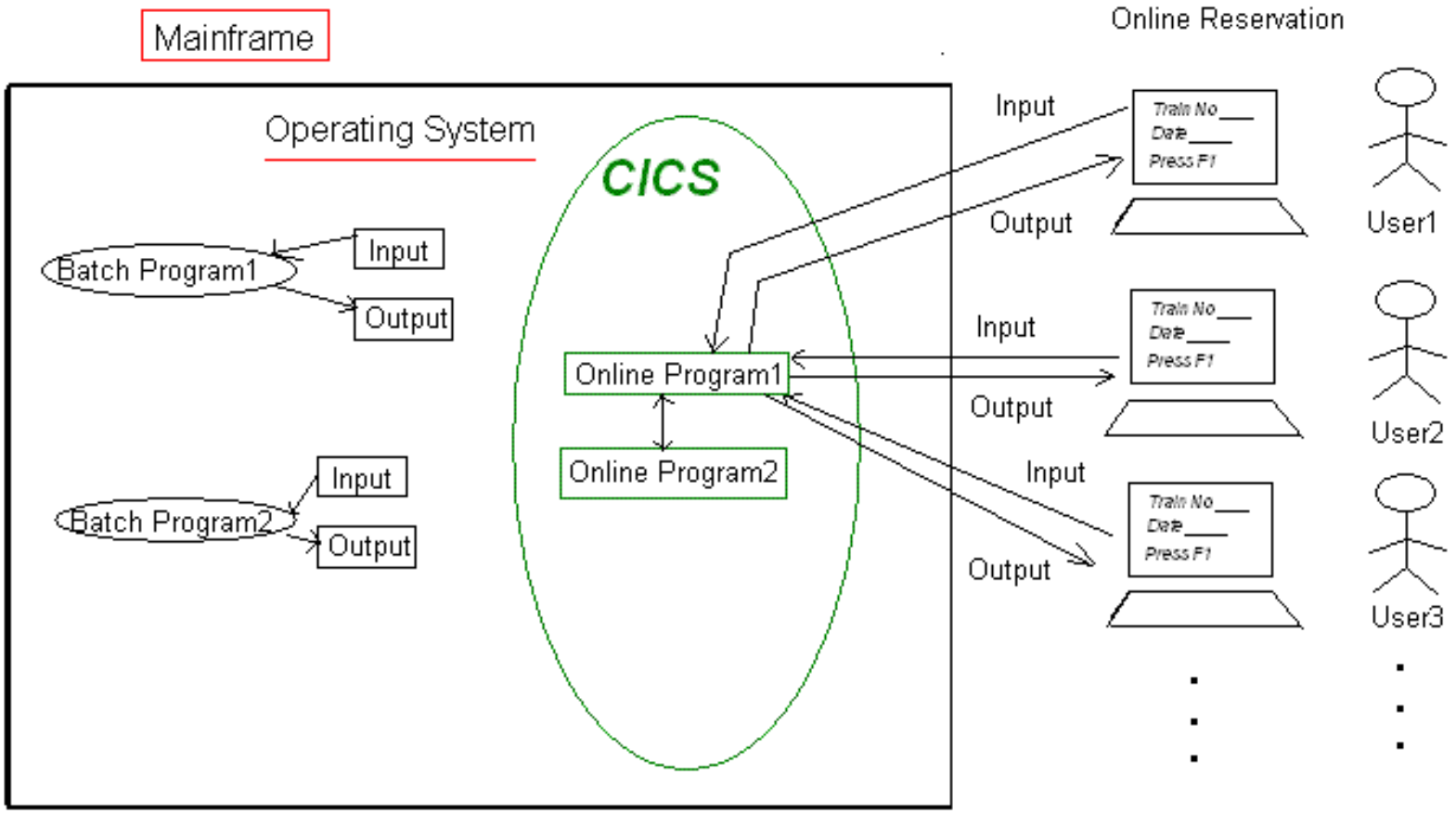
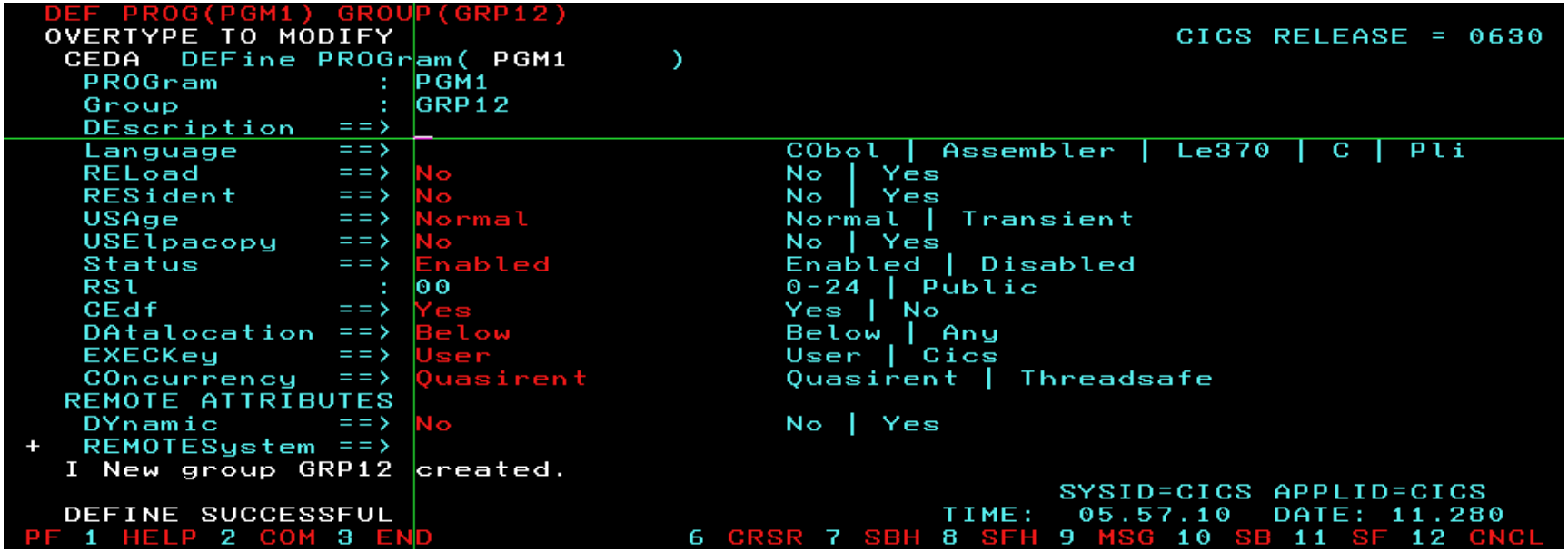
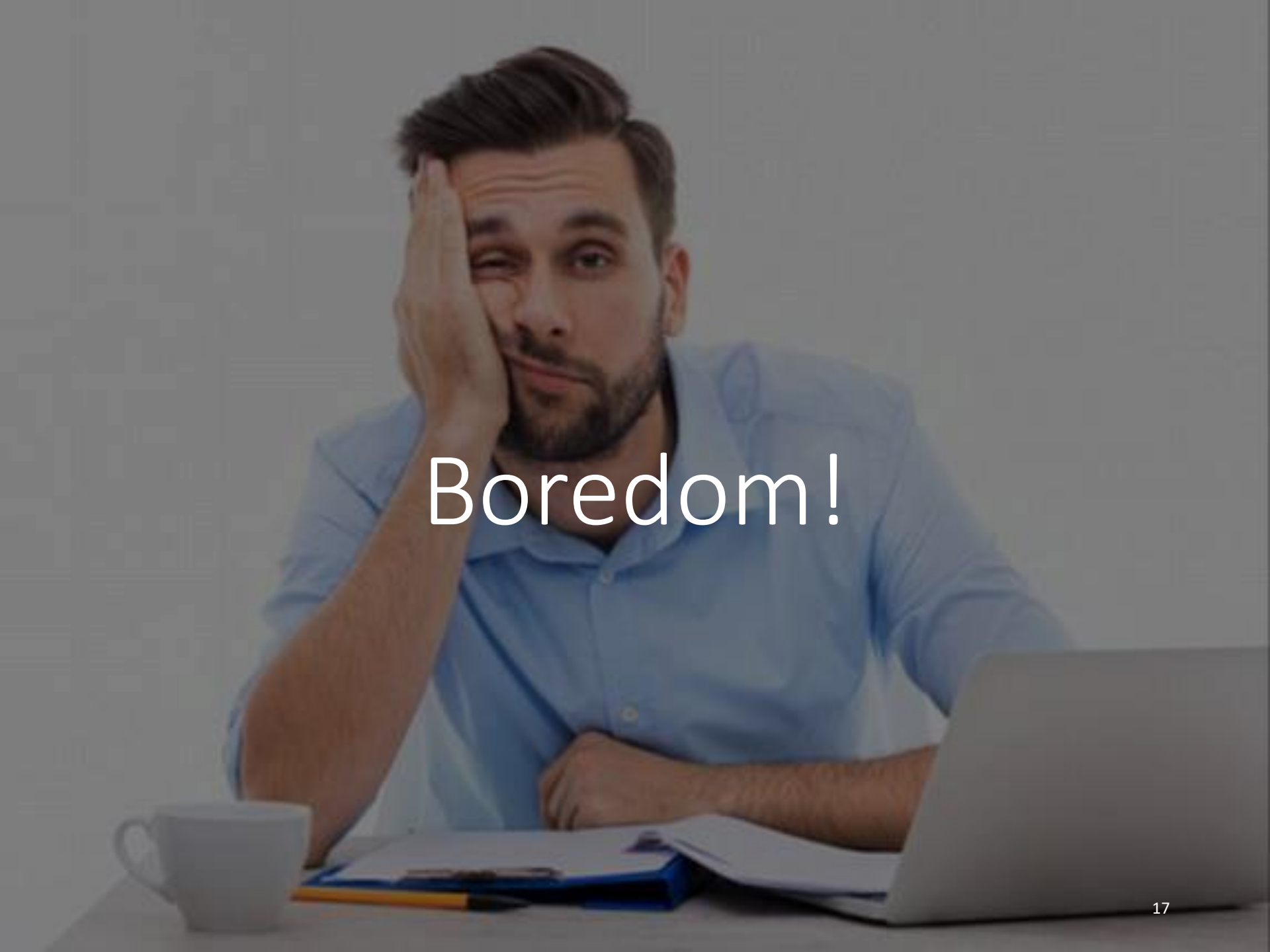
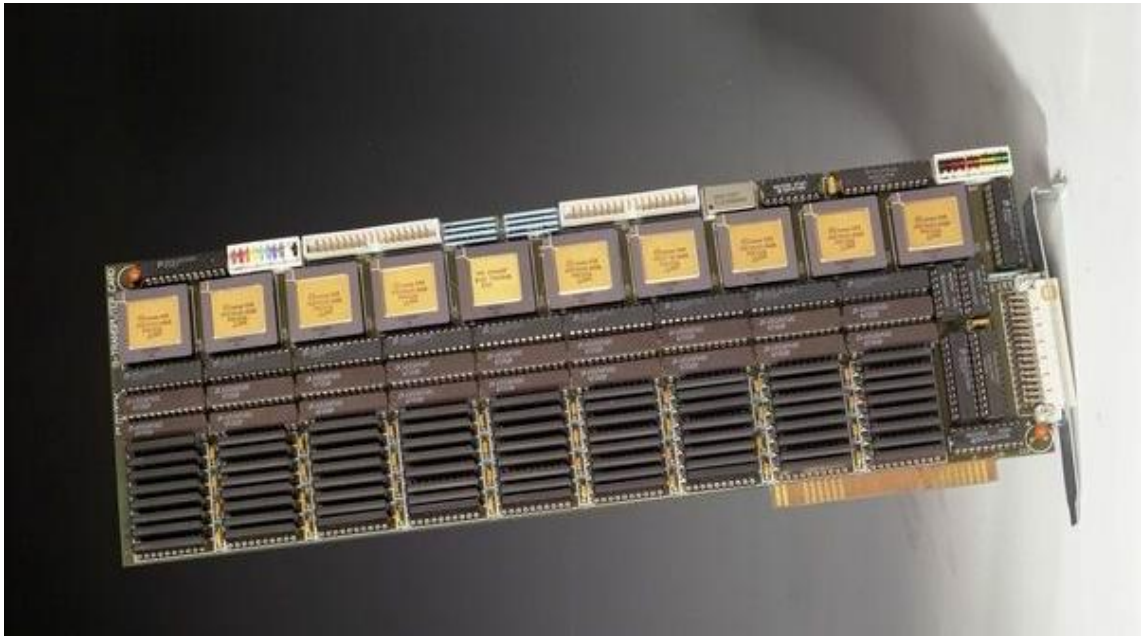
Mainframegurukul.com

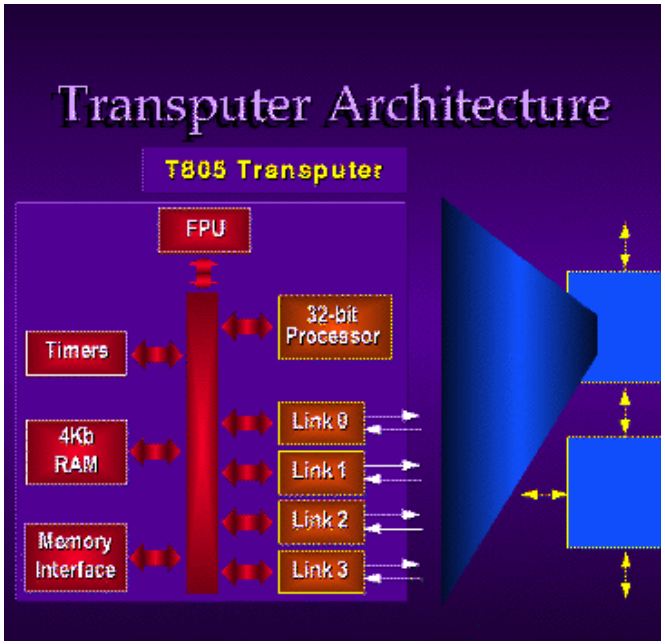



DEF PROG(PGM1) GROUP(GRP12)
OVERTYPE TO MODIFY
CICS RELEASE = 0630
CEDA DEFine PROGram(PGM1)
PROGram : PGM1
Group : GRP12
DEscription ==>
Language ==> COBol | Assembler | Le370 | C | Pli
RELoad ==> No No | Yes
RESident ==> No No | Yes
USAge ==> Normal Normal | Transient
USElpacopy ==> No No | Yes
Status ==> Enabled Enabled | Disabled
RSl : 00 0-24 | Public
CEdf ==> Yes Yes | No
DAtalocation ==> Below Below | Any
EXECKey ==> User User | Cics
COncurrency ==> Quasirent Quasirent | Threadsafe
REMOTE ATTRIBUTES
DYnamic ==> No No | Yes
+ REMOTESystem ==>
I New group GRP12 created.
SYSID=CICS APPLID=CICS
DEFINE SUCCESSFUL
TIME: 05.57.10 DATE: 11.280
PF 1 HELP 2 COM 3 END 6 CRSR 7 SBH 8 SFH 9 MSG 10 SB 11 SF 12 CNCL


IBM
Cloud Enabling
IBM CICS
Redbooks


Boredom!

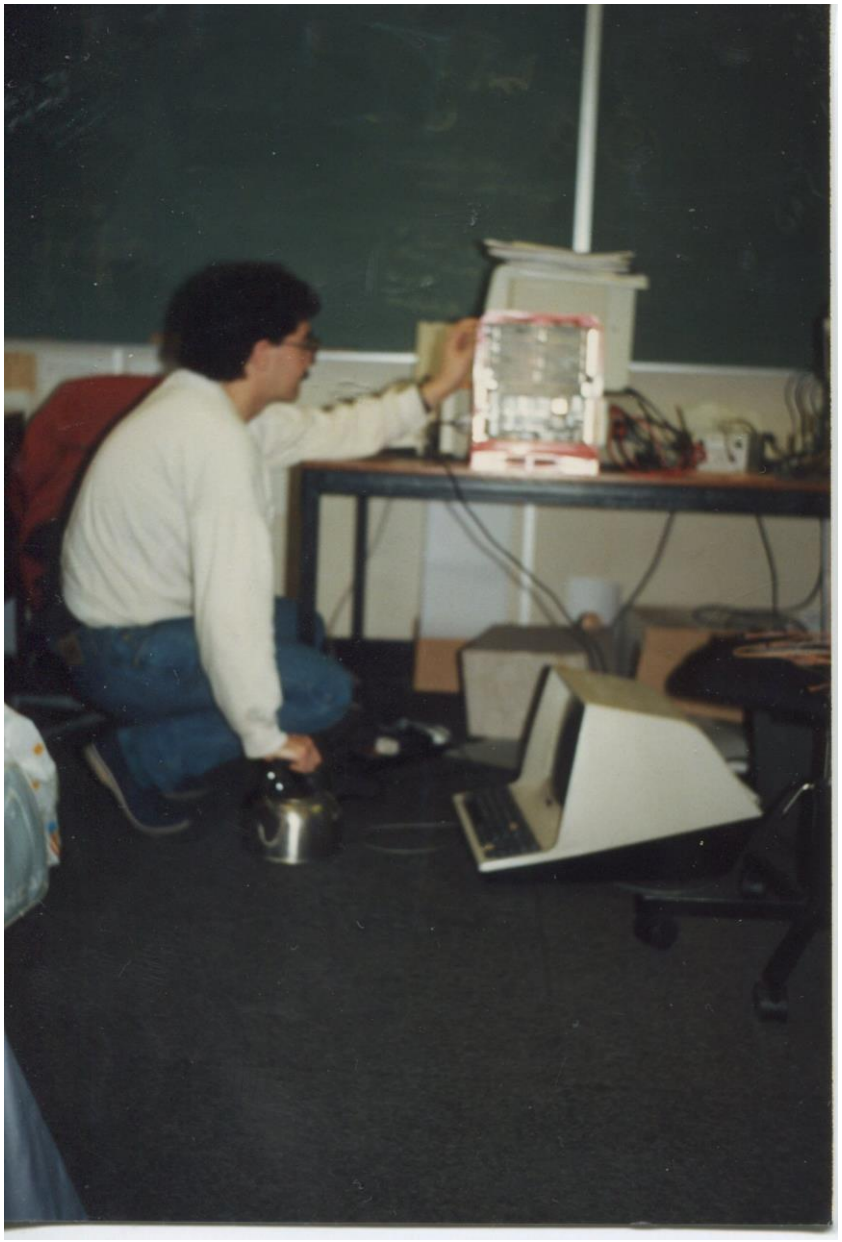



Transputer Architecture
T805 Transputer
FPU
32-bit Processor
Timers
4Kb RAM
Memory Interface
Link 0
Link 1
Link 2
Link 3

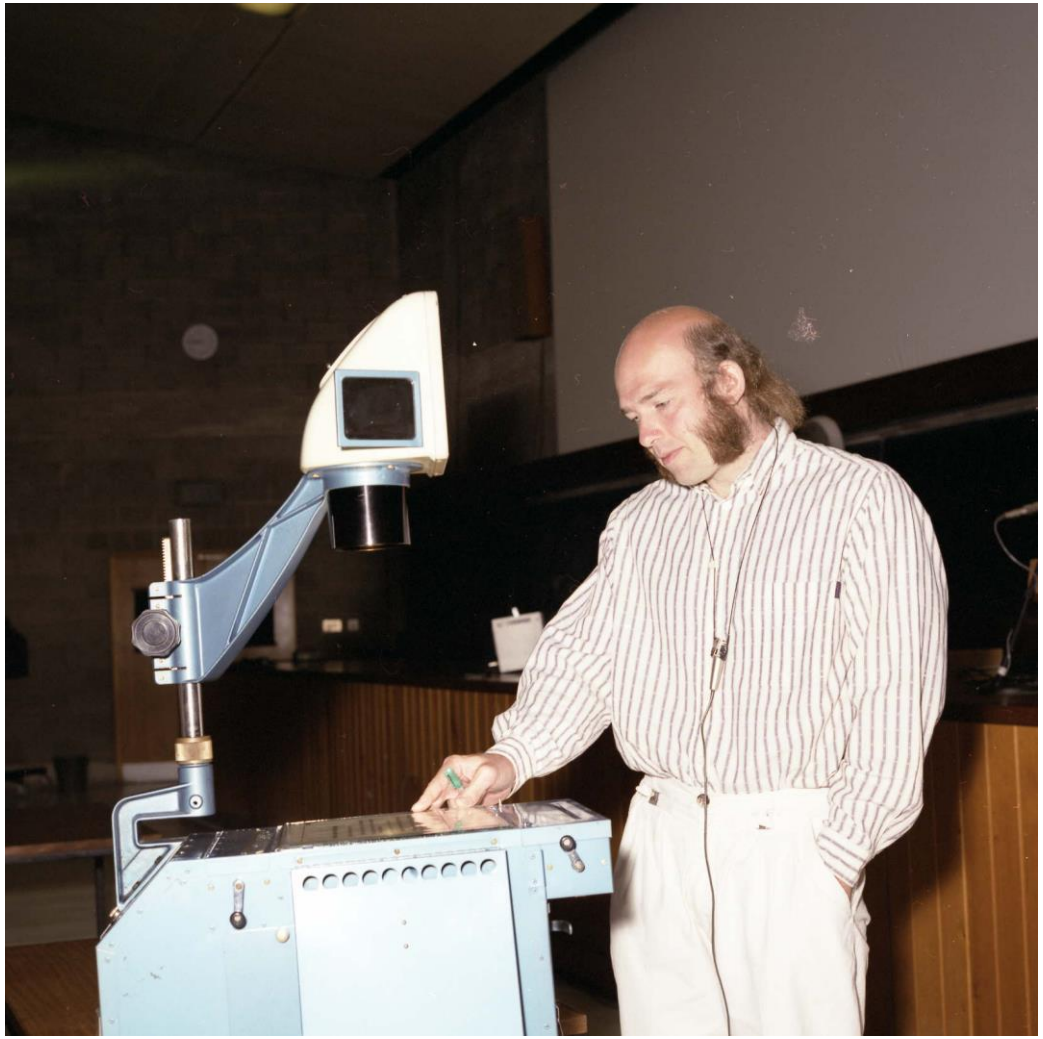
Grad School!!

Multiprocessor Transputer Systems

It really is me!



David May, Inmos Chief Scientist and Occam guru

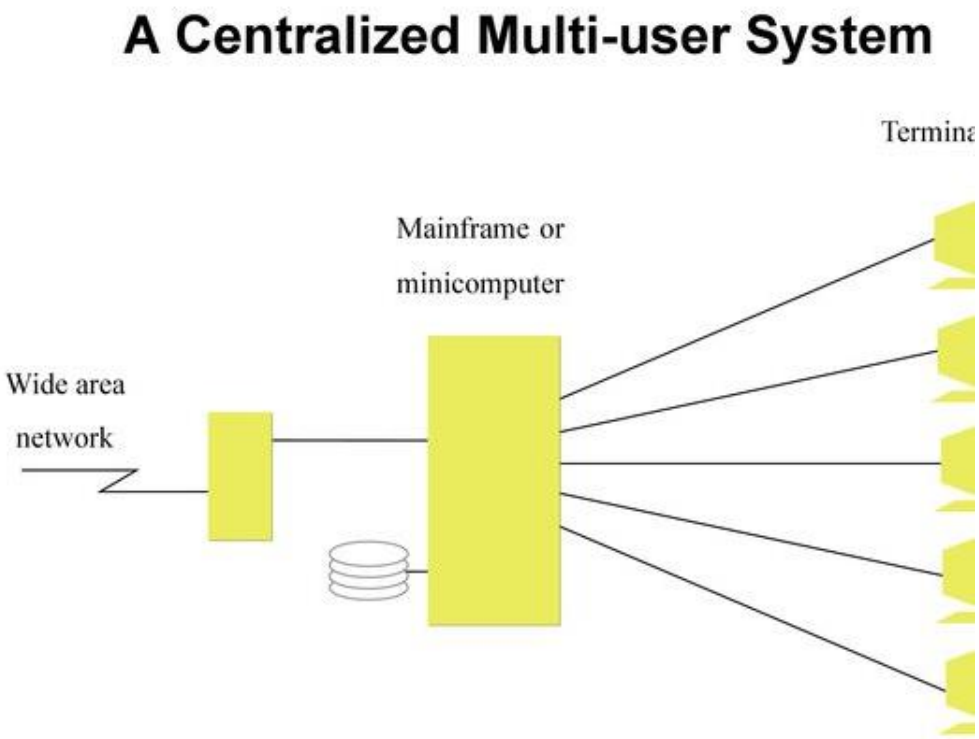


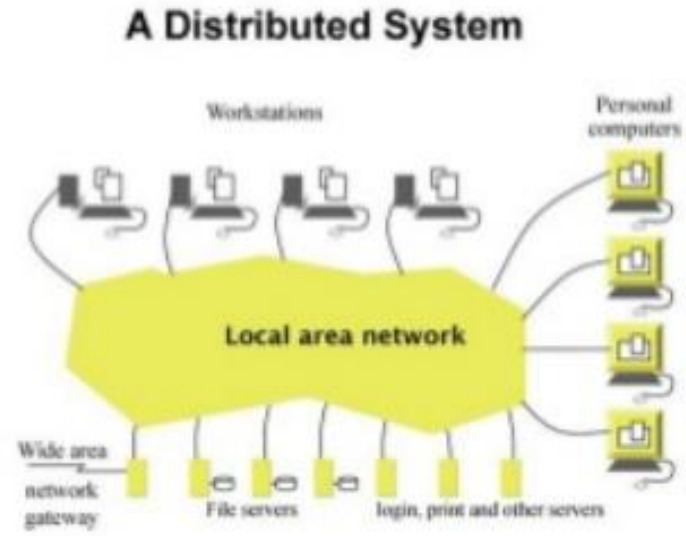
Next Stop – Australia!

1990

What about distributed systems?

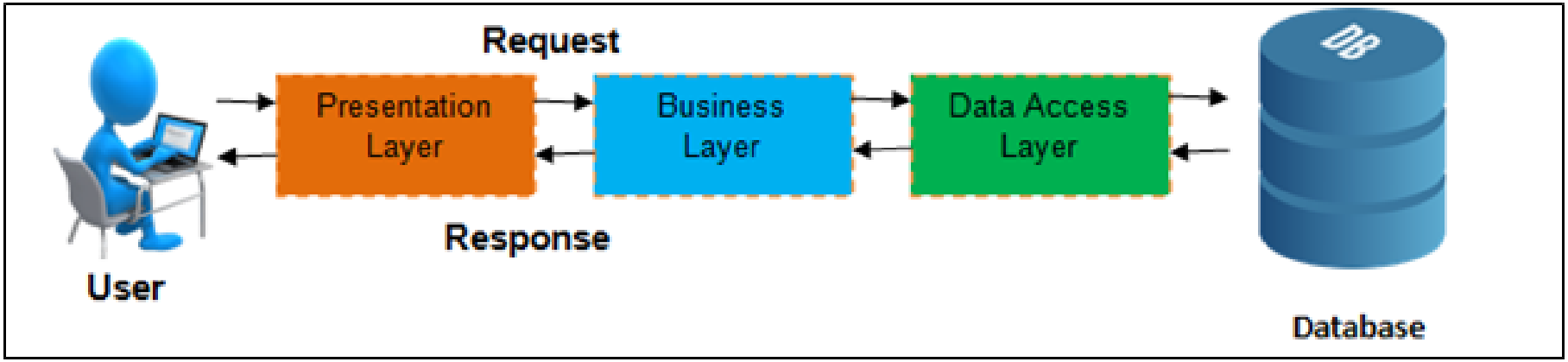
- Rare until basically early 1990s …
- Networks slow …
- Protocols slow
- Computers slow ☺





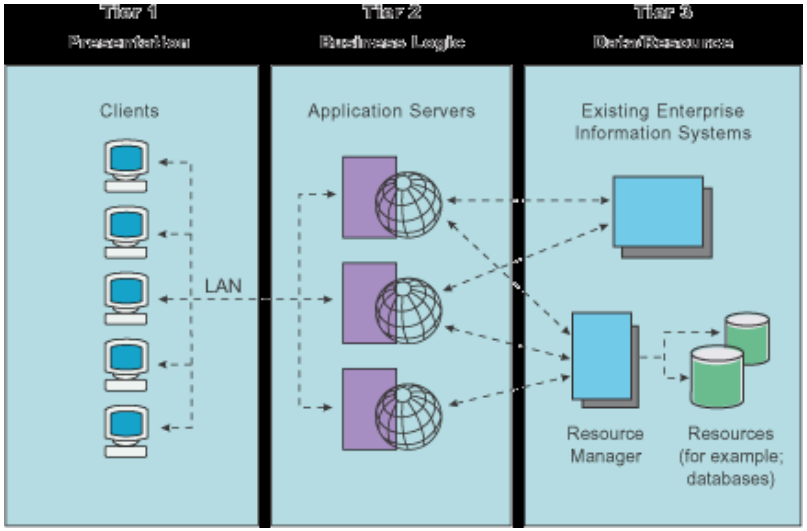
Early 1990s - the internet went mainstream-ish

- PCs and work stations become connected
  - LANs
  - WANs
- Global internet backbone
  - Corporate networks
  - Dial up at home
- Client software
  - Program
  - Browsers very simple static content serving



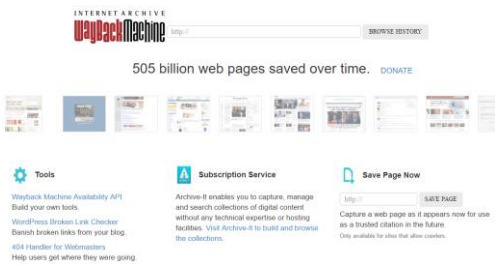
Three tier system becomes common

As the internet grew (mid 1990s onwards)



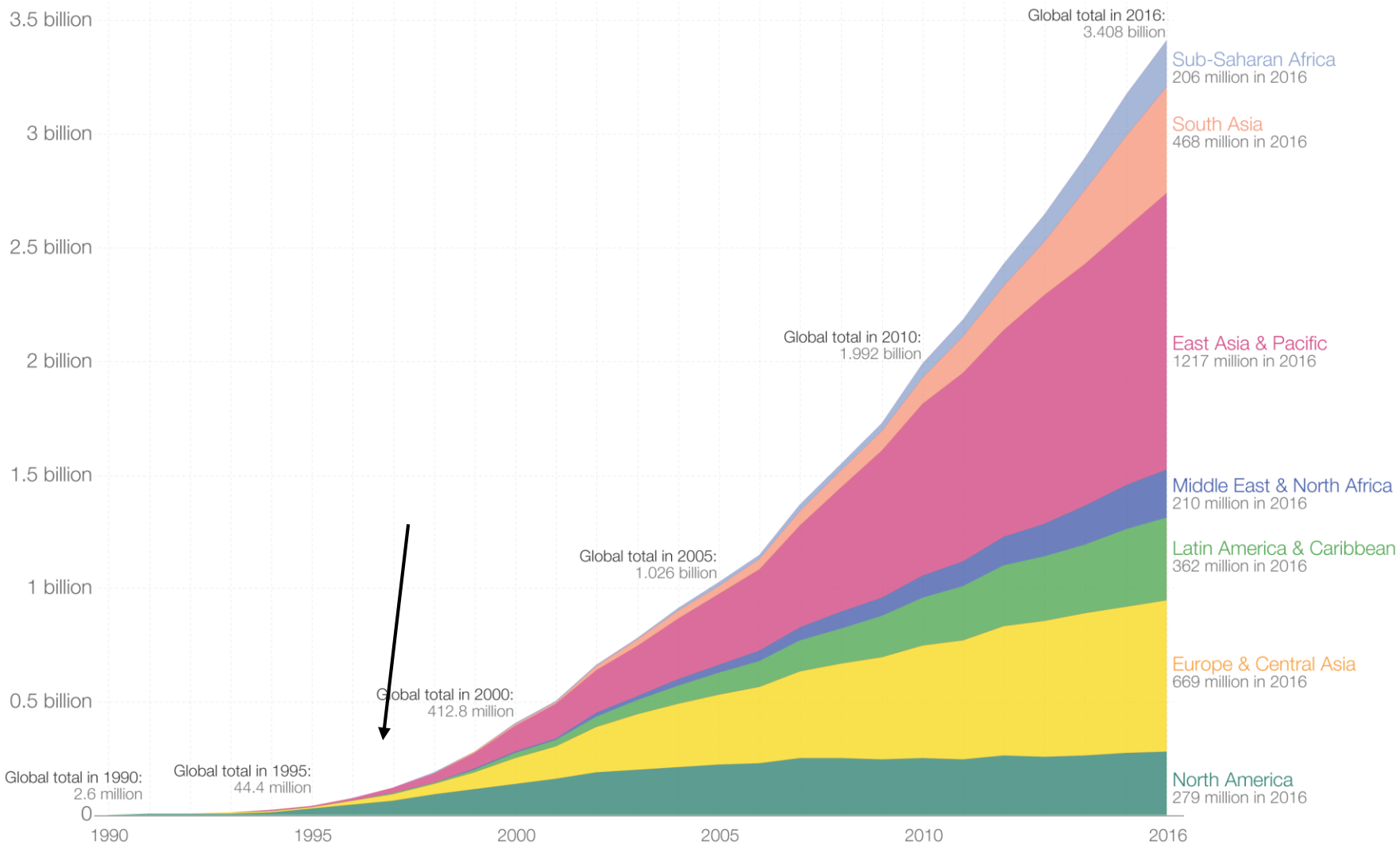
- Step change – business systems opened up to the internet
  - Eg internet banking
- Scalability achieved by
  - replication at middle tier (scale out)
    - Stateless services
  - Scaling up at database tier

What Led to Growth?



- The advent of the WWW was the backbone for the growth
- Obviously, it allowed for access by an increasing number of users
  - Potentially every person in the world can see a Web app
- It also allowed for a new service model for:
  - Enterprises
  - Consumer products
  - eGovernment
- Poke around the Wayback Machine to see the Web-past
  - https://archive.org/web/

Internet users by world region since 1990

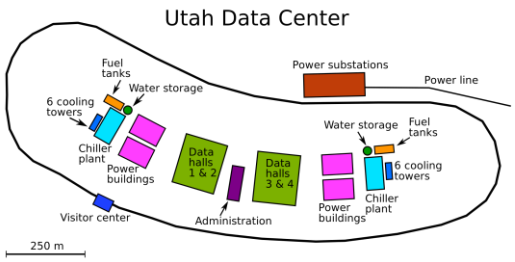


Data source: Based on data from the World Bank and data from the International Telecommunications Union. Internet users are people with access to the worldwide network.
The interactive data visualization is available at OurWorldinData.org. There you find the raw data and more visualizations on this topic.


Google


ebay


amazon



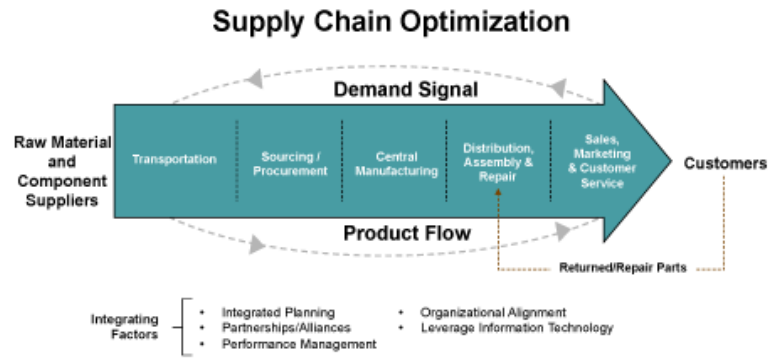
Unprecedented Data Collection and Distribution

- New service models allow for collection of data that wasn't previously available
- This knowledge can provide competitive advantage
  - If they can manage and analyze the data effectively
  - The realm of data sciences
    ….

Wal-Mart

- Wal-Mart knows what will happen when we have inclement weather
- What items do you think are impacted by an impending hurricane?
  - Certainly water and flashlights
  - The sales of Strawberry Pop Tarts increases seven fold
  - The largest selling item, however, is beer …
- What does knowing this allow Wal-Mart to do?

Knowledge is Profit



- Predict sales
- This allows them to have sufficient stock on hand
  - Otherwise they could sell out of items
- It also allows them to minimize the surplus stock that they need
  - Thus reducing the overhead by adopting a “leaner” ***just in time*** approach

Significant Competitive Advantage

- Wal-Mart uses this data to it's advantage
- 20 years ago Wal-Mart trailed K-Mart
  - K-Mart had more collective bargaining power and was able to negotiate a lower wholesale price
- Wal-Mart used data to streamline operations
  - They were able to reduce the percentage of the store that was used to stock surplus from the normal 25% to 10%
  - They are able to better coordinate with suppliers (resulting in more efficient production runs)
- Wal-Mart is now the largest retailer in the world

Distributed frameworks

- Sockets – Berkeley, 1983 (earlier implementations existed), became POSIX implementation
- ONC/Sun RPC – 1984-onwards
- OSF DCE – 1989-onwards
- CORBA – early 1990s-onwards
- Java RMI mid 1990-s onwards
- XML Web Services – SOAP 2000-ish
- Http – REST – Fielding thesis 2000
- WebSockets - 2001

Modern web sites and scale

21ST CENTURY APPLICATIONS

Some numbers

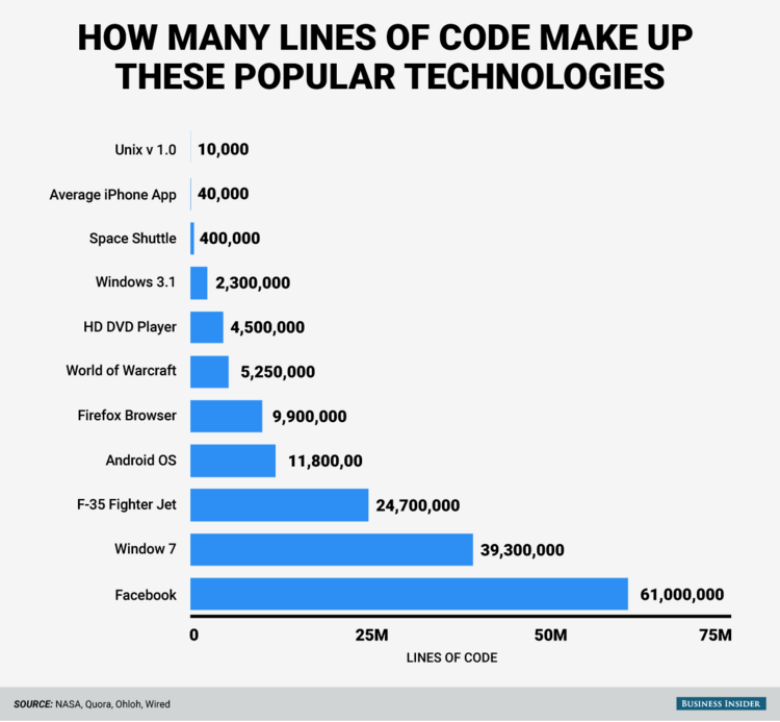
Dropbox – exascale storage system, millions of new files per hour, from 2012-16 seen over 12x growth.

Gmail – 1.2 billion users, blocks 10M spam messages every minute

Netflix – runs on AWS, took 7 years to migrate, uses 15% of global downstream internet traffic

Facebook - More than 300 million photos uploaded per day and 510,000 comments posted and 293,000 statuses updated per minute

Youtube - Users watch 4,146,600 YouTube videos every minute



Google repository statistics, January 2015.

Total number of files	1 billion
Number of source files	9 million
Lines of source code	2 billion
Depth of history	35 million commits
Size of content	86TB
Commits per workday	40,000

https://www.businessinsider.com/google-runs-on-5000-times-more-code-than-the-space-shuttle-2016-7?international=true&r=US&IR=T

- **Anatomy**
- **Of a**
- **21st Century**
- **Software Systems**

Transactions
User interactions
Sensors
Internet of Things

Massive
Cloud Scale
Processing

Distributed
Globally

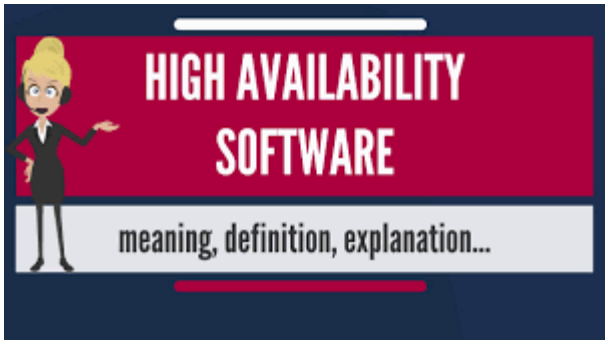
CAP Theorem

GLOBAL USER BASE

- COMPLEX BIG DATA ANALYTICS
- BUSINESS INSIGHTS
- SYSTEMS OPERATIONS

Building Massive Scale Systems is difficult

Software Architecture
Quality Attributes

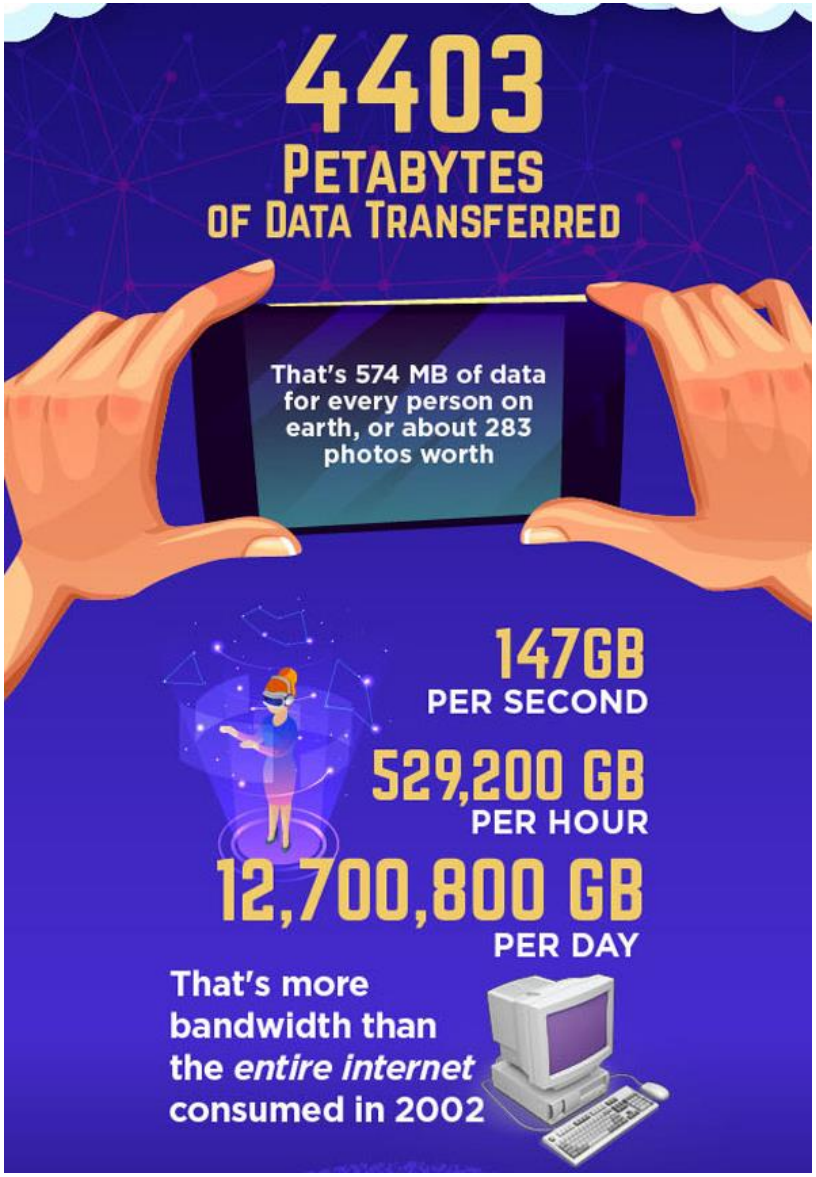


- Only one large internet site publish detailed usage statistics every year

- So let's look at some usage numbers ….


Pornhub
2018
33.5
BILLION
VISITS TO PORNHUB
92 MILLION
DAILY AVERAGE VISITS
=
THE POPULATIONS OF
CANADA, POLAND AND AUSTRALIA
EVERY DAY


30.3
BILLION
SEARCHES
962
SEARCHES
PER SECOND
4,791,799
VIDEOS UPLOADED
1 MILLION
HOURS OF VIDEO
/
115 YEARS
OF VIDEO
1903
2018
If you started watching 2018's videos after the Wright brother's first flight, you would still be watching today!

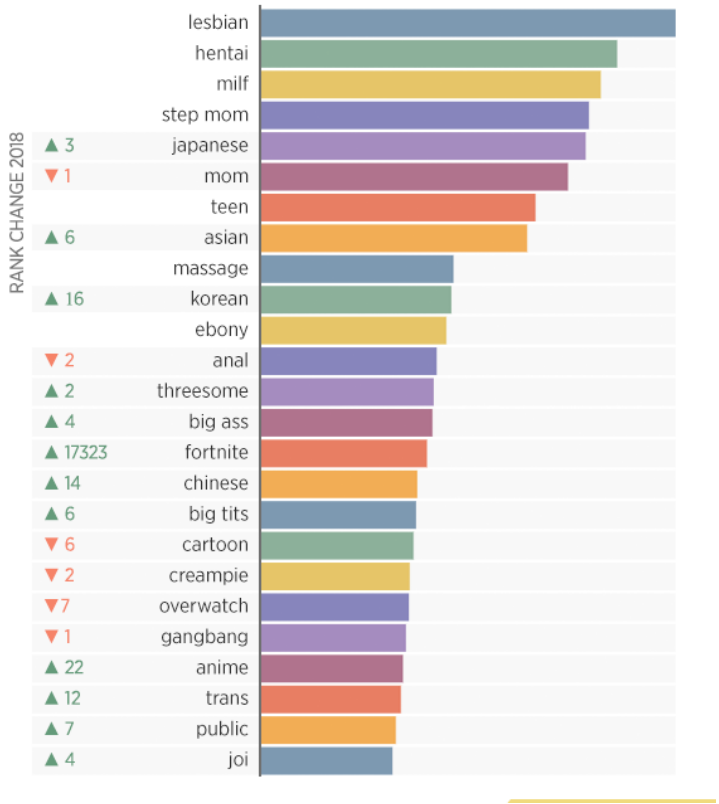

4403
PETABYTES
OF DATA TRANSFERRED
That's 574 MB of data for every person on earth, or about 283 photos worth
147GB
PER SECOND
529,200 GB
PER HOUR
12,700,800 GB
PER DAY
That's more bandwidth than the *entire internet* consumed in 2002


EVERY MINUTE ON Pornhub
207,405
Videos Viewed
63,992
Visitors
10,498
Hours of Videos Watched
7708
GB of Data Transfered
57,750
Searches
55
Views of Kim K's Sex Tape
12
Videos Uploaded & 2 Hours of Content
122
Messages Sent
13,962
User Profiles Viewed
22
New Video Comments
593
Users Followed
528
Videos Added to Playlists
271
Videos Rated
167
Friend Requests Accepted
2018 YEAR IN REVIEW

2018 YEAR IN REVIEW

Pornhub

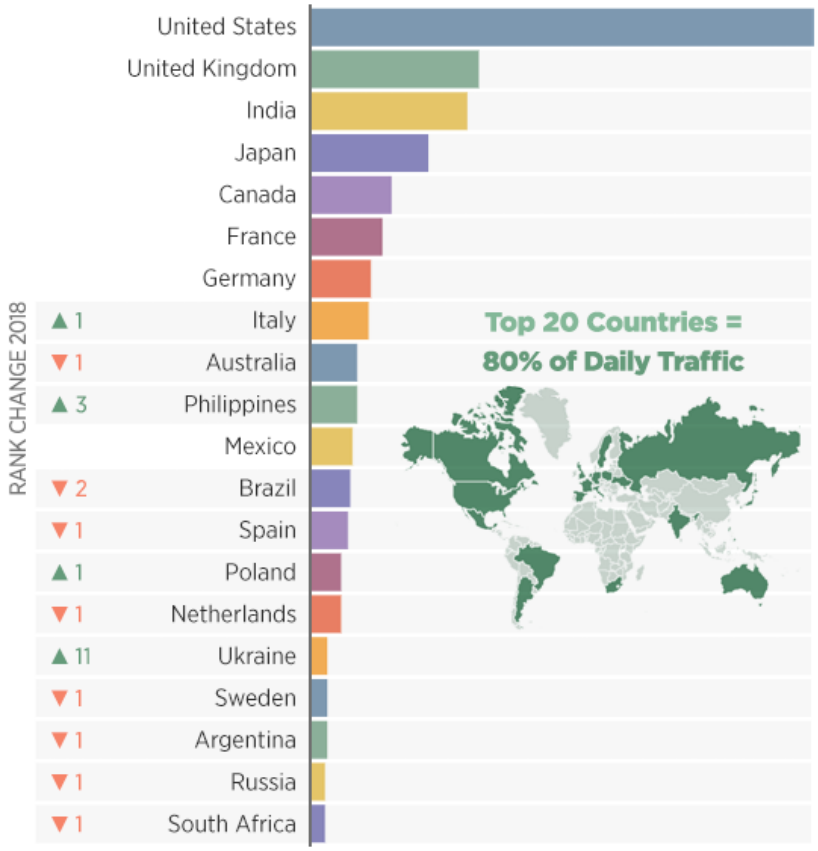
Most Searched for Terms of 2018



2018 YEAR IN REVIEW

Pornhub

Top 20 Countries by Traffic

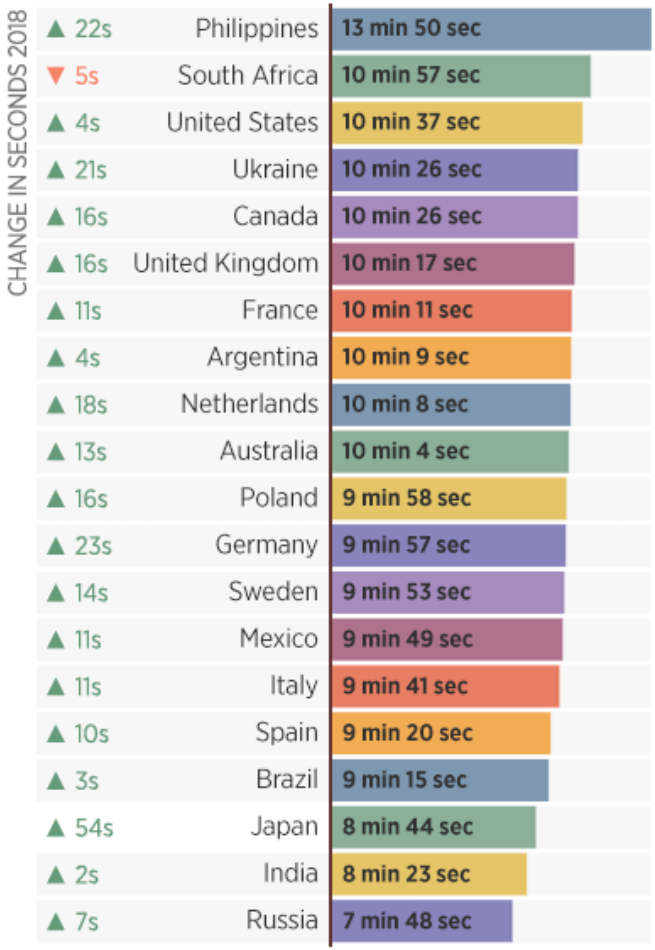


Largest Rank Changes of 2018				
	▲33 Kazakhstan	▲26 Cuba	▲15 Czechia
	▲31 Syria	▲17 Colombia	▲12 Turkey

2018 YEAR IN REVIEW

Pornhub

Time Spent Per Visit



10 min 13 sec

Average Visit Duration Worldwide

▲14 sec

Increase in 2018

Largest Duration Increases of 2018

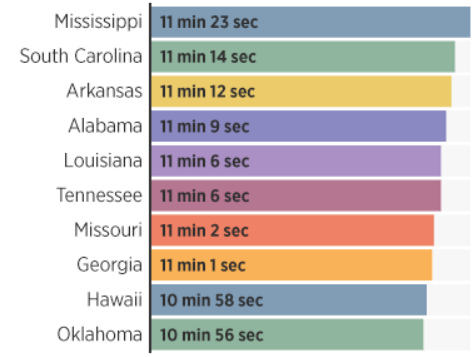
Czech Republic	▲ 112s
Algeria	▲ 80s
Morocco	▲ 56s
Sri Lanka	▲ 55s
Japan	▲ 54s
Latvia	▲ 50s
Fiji	▲ 47s
Ethiopia	▲ 52s
Moldova	▲ 40s
Hong Kong	▲ 37s

2018 YEAR IN REVIEW

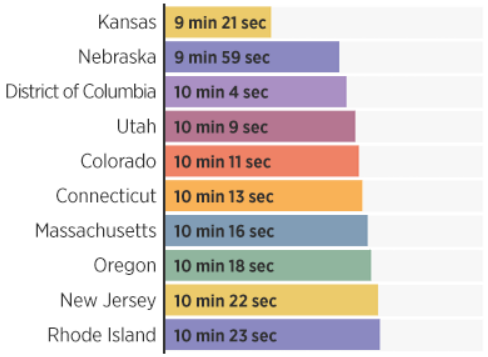
Pornhub

Time Spent Per Visit - United States

States That Last the Longest



States That Last the Shortest



10 min 37 sec

Average Visit Duration in the United States

▲4 sec

Increase in 2018

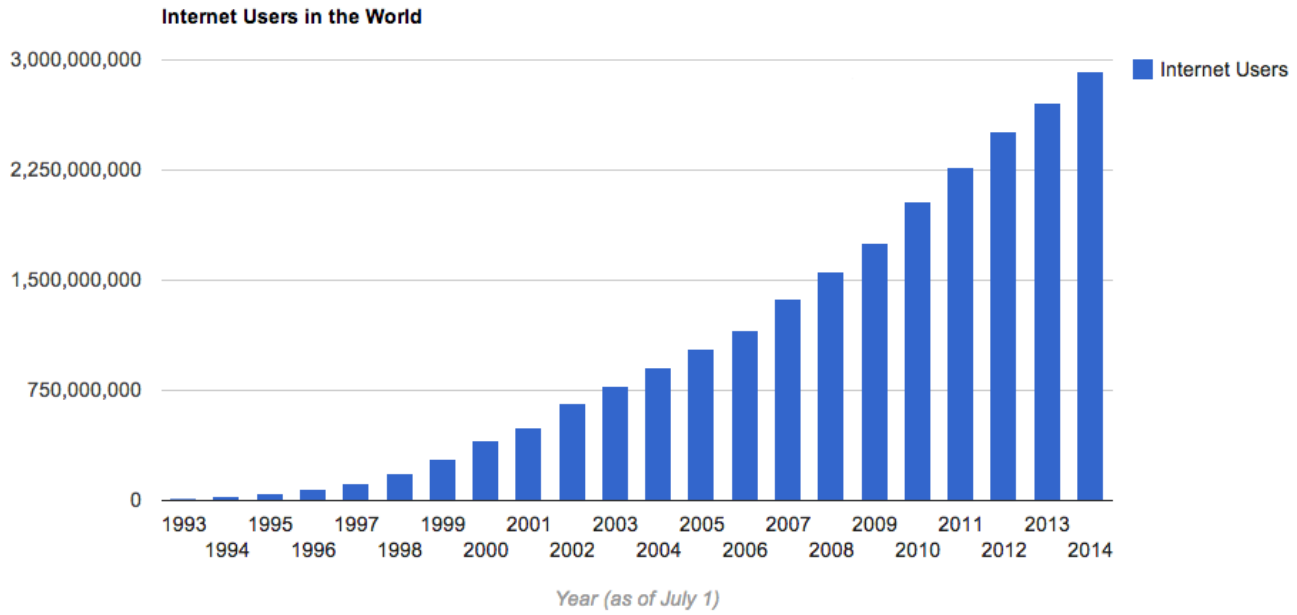
Largest Duration Changes of 2018

Idaho	▲54s
Oregon	▲23s
District Colombia	▼20s
Nebraska	▼19s
Kansas	▲16s
New Hampshire	▲14s
Maine	▲13s
Montana	▲12s
South Dakota	▲11s
Vermont	▲11s
Mississippi	▼11s

What is Scalability?

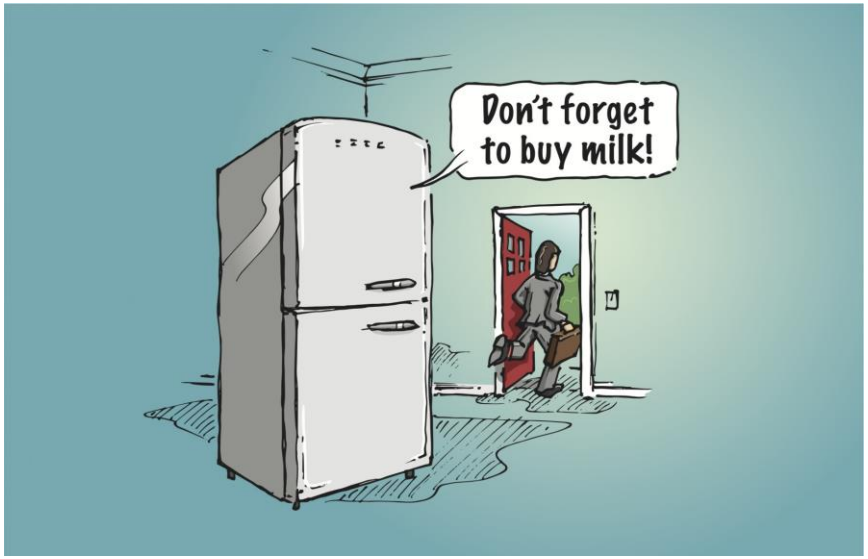
Scale is being driven by …

Around 40% of the world population has an internet connection today (view all on a page). In 1995, it was less than 1%.
The number of internet users has increased tenfold from 1999 to 2013.
The **first billion** was reached in 2005. The **second billion** in 2010. The **third billion** in 2014.
The chart and table below show the number of global internet users per year since 1993:

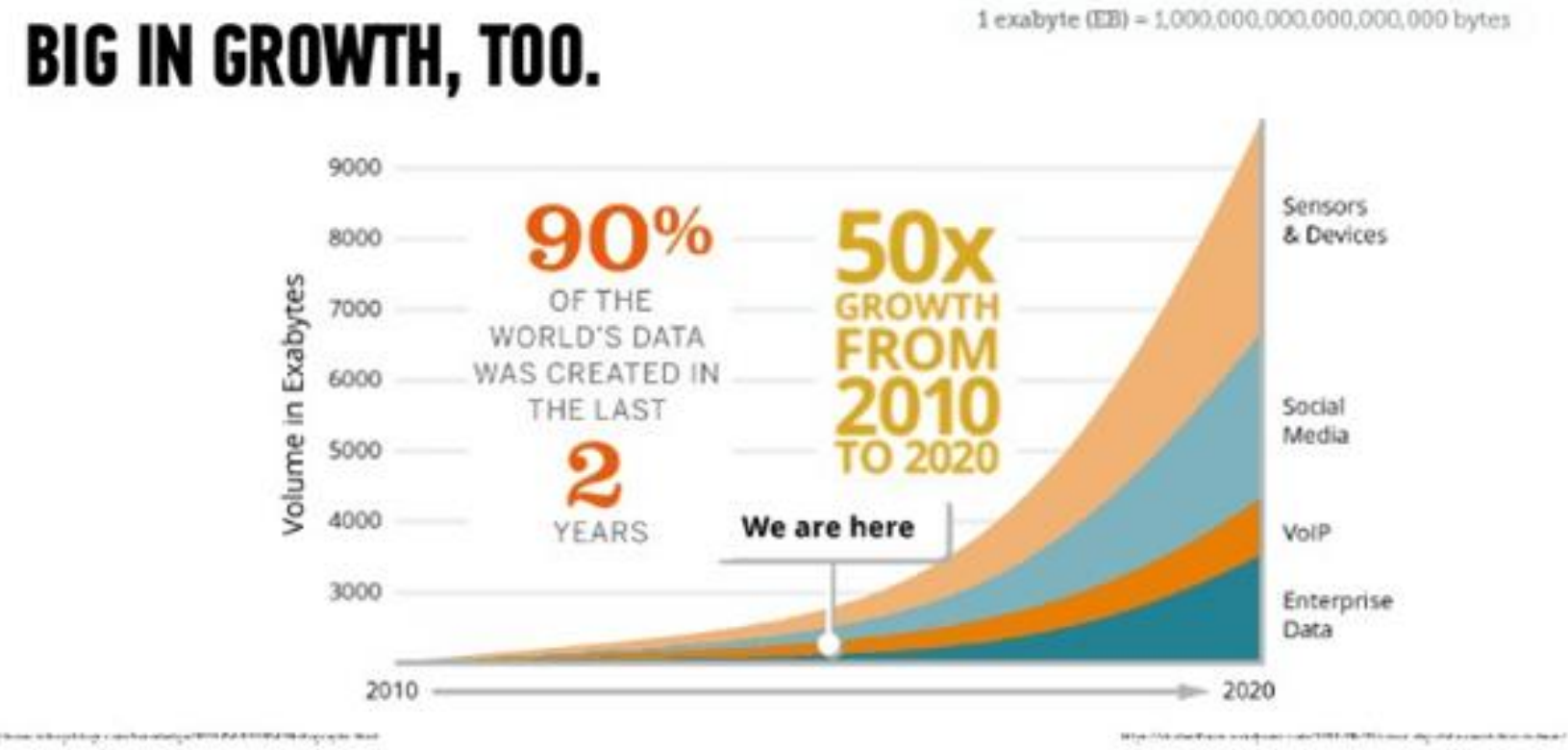


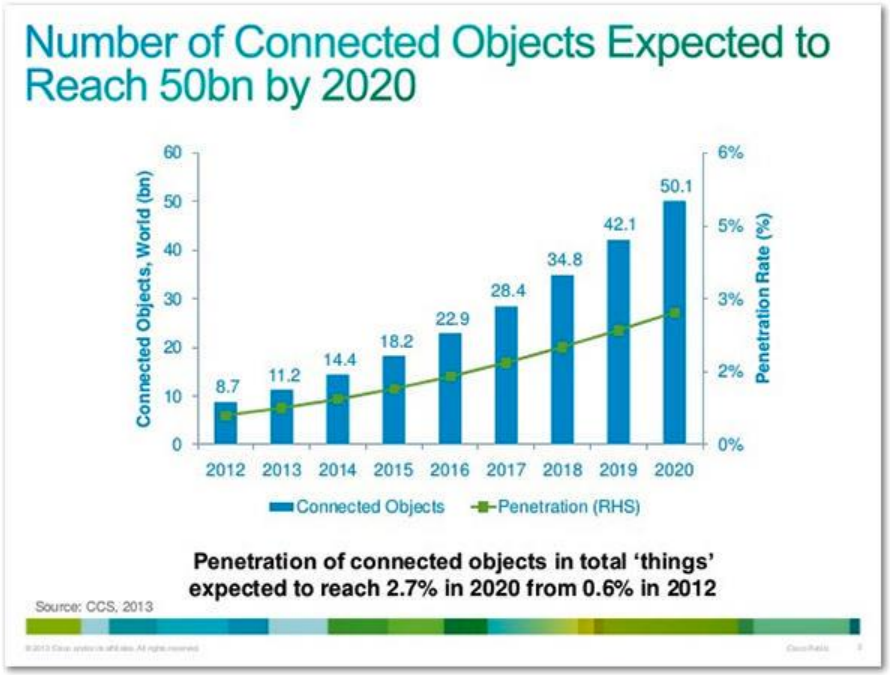
As well as ….


I LOVE IT WHEN
YOU CALL ME BIG DATA
memegenerator.net


Don't forget to buy milk!

Data Volumes





2025???

http://www.zdnet.com/article/the-internet-of-things-and-big-data-unlocking-the-power/

Question

- How are usage statistics derived in a scalable system?
- Information must be gathered about every single request
  - Session length
  - Session origin
  - Session behavior
- In pornhub.com's case, billions of visits a year
- Lot of data …..
  - A big data system?


The future is about
Big Data
Big Problems
@Web Scale

Web scale

Globally accessible

(Practically) infinite user base

Constant usage (24x7)

Ability to handle surges and spikes in requests

Controllable costs

Scalability

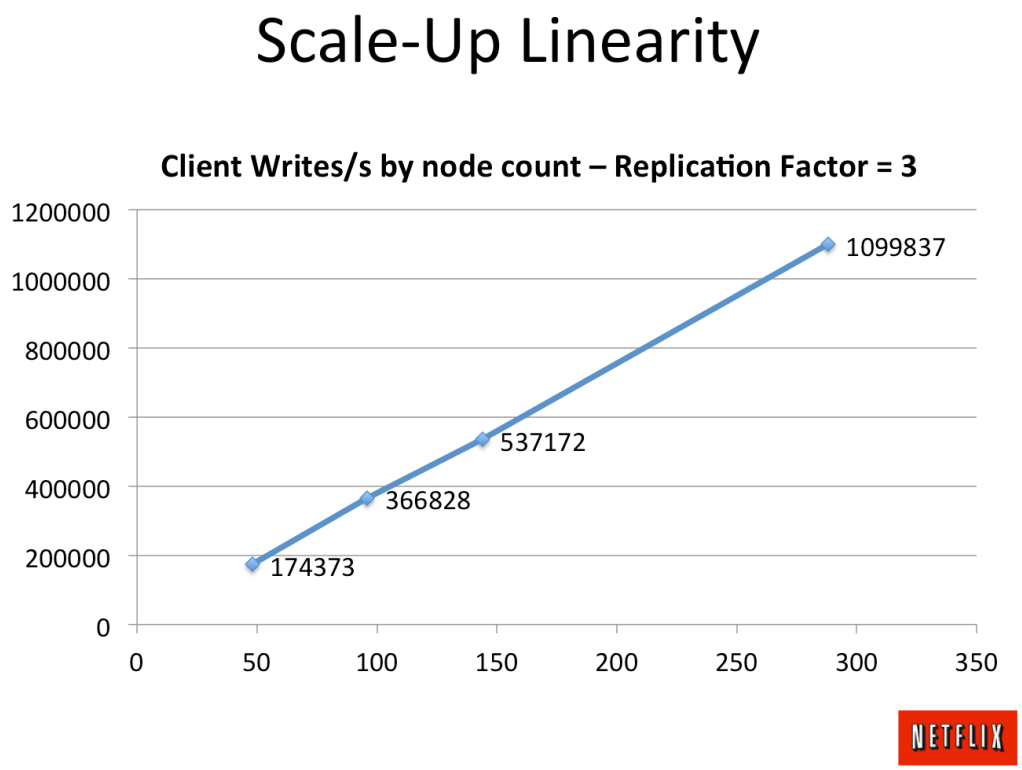
- The ability of a system to increase or decrease capacity in response to changing demands, while continuing to satisfying service level agreements for latency and availability
- Hyperscalability – as above, while supporting exponential growth with linear costs

Just need more machines and disks?

2025???

Major Internet Companies have 1m+ servers in 2013

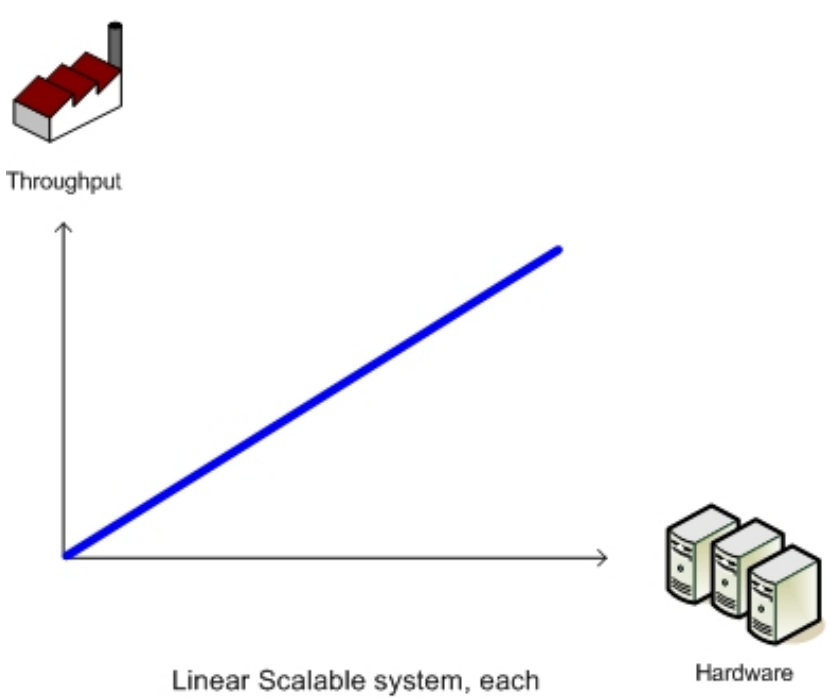
And Scale Linearly ….



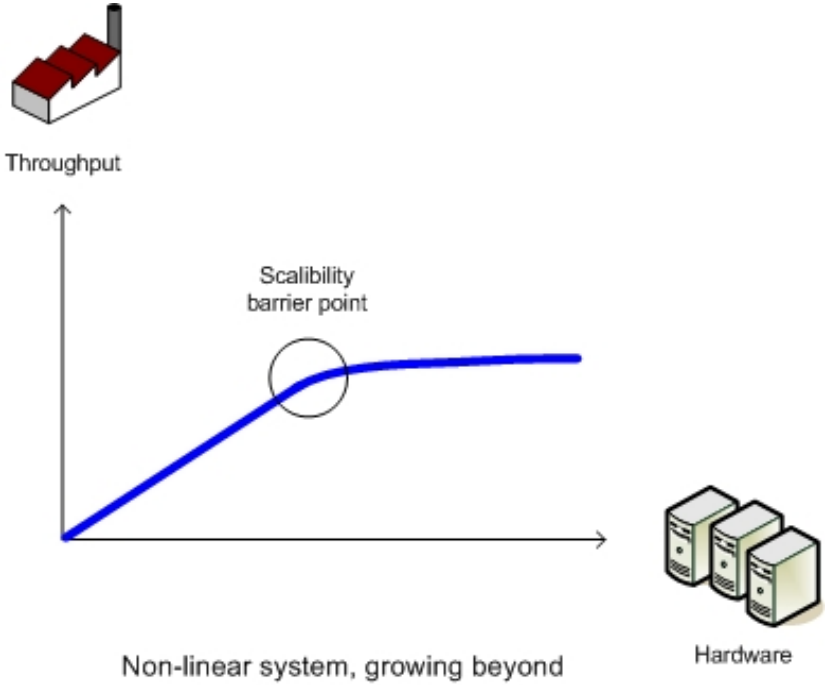
http://www.datastax.com/2012/01/choosing-the-right-architecture-for-big-data-scale


IT'S
Easy

Anyone heard of Amhdahl's law?

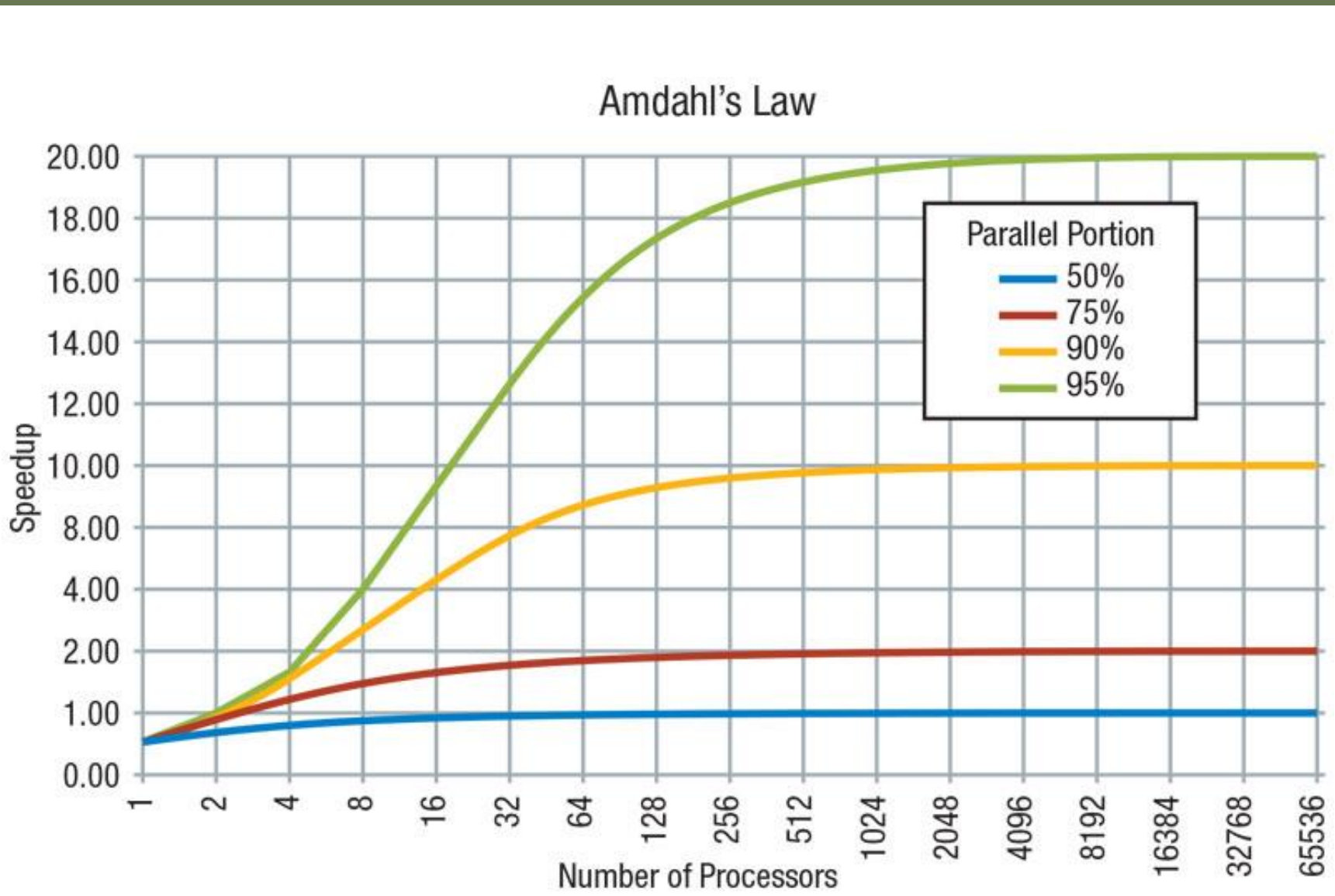


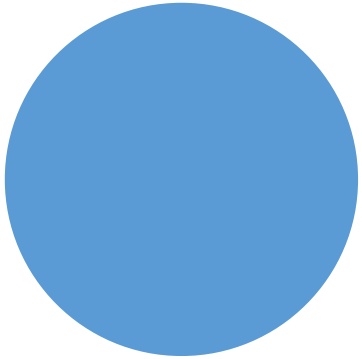
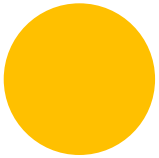
Linear Scalable system, each addition of an hardware unit adds a throughput unit



Non-linear system, growing beyond a certain barrier point adds complexity that hinders throughput increase

Amhdahl's Law

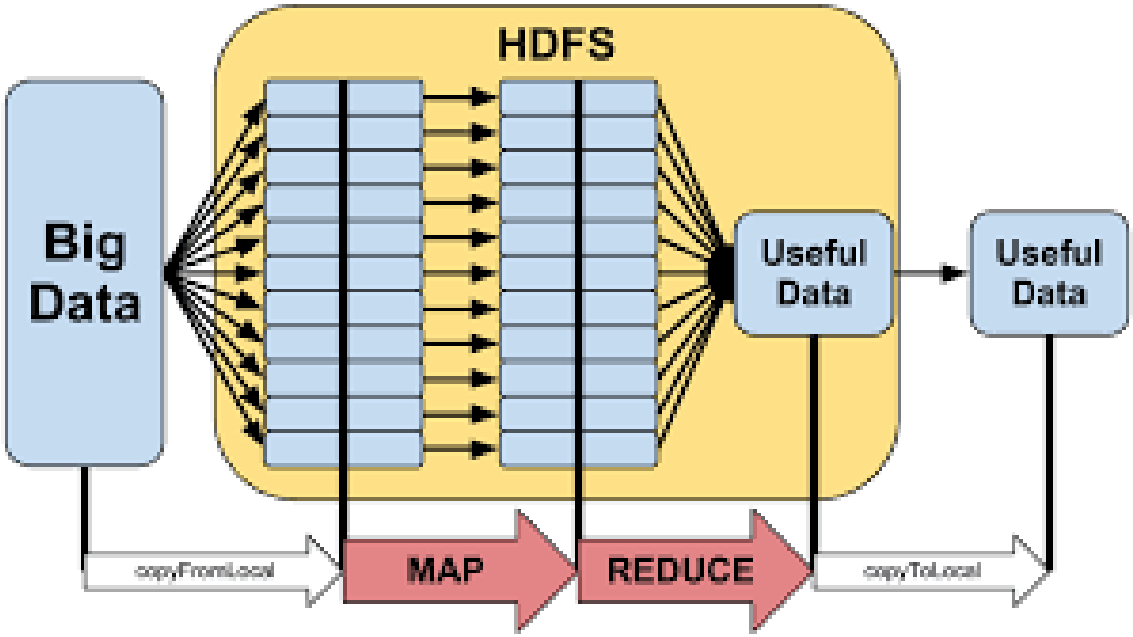

Amdahl's Law
Speedup
20.00
18.00
16.00
14.00
12.00
10.00
8.00
4.00
2.00
1.00
0.00
1
2
4
8
16
32
64
128
256
512
1024
2048
4096
8192
16384
32768
65536
Number of Processors
Parallel Portion
50%
75%
90%
95%

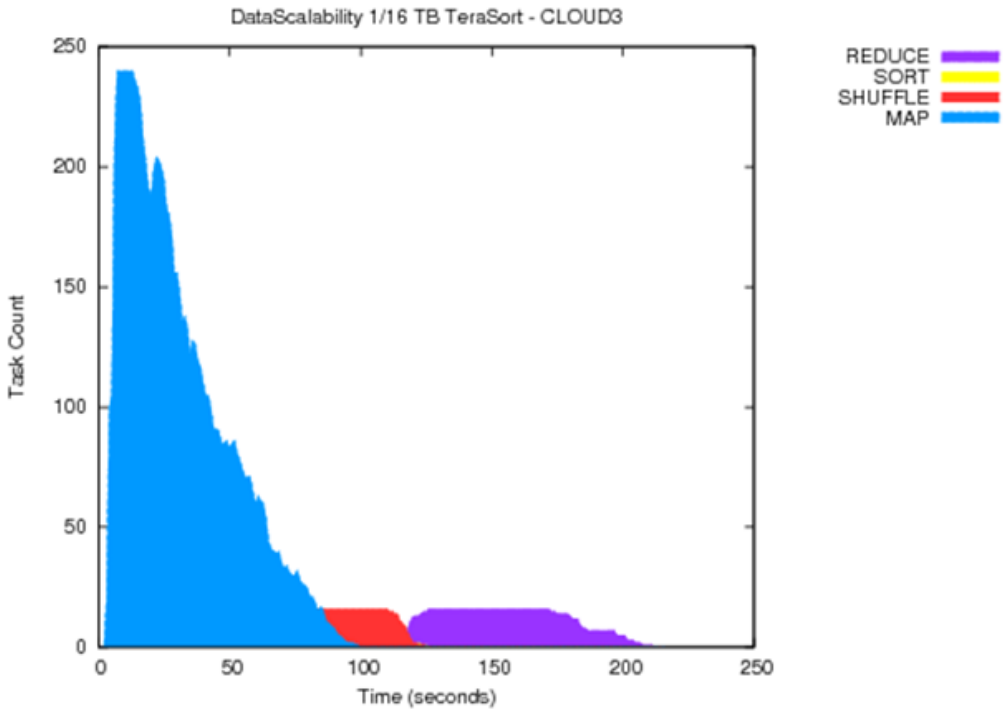
Amhdahl's Law in 2025???


NO
CHANGE

Many
problems
are
easily
parallelized
though?


HDFS
Big Data
Useful Data
Useful Data
copyFromLocal
MAP
REDUCE
copyToLocal

Data Skew???


DataScalability 1/16 TB TeraSort - CLOUD3
Task Count
Time (seconds)
0
50
100
150
200
250
REDUCE
SORT
SHUFFLE
MAP

The future is Big Problems

That are difficult to design

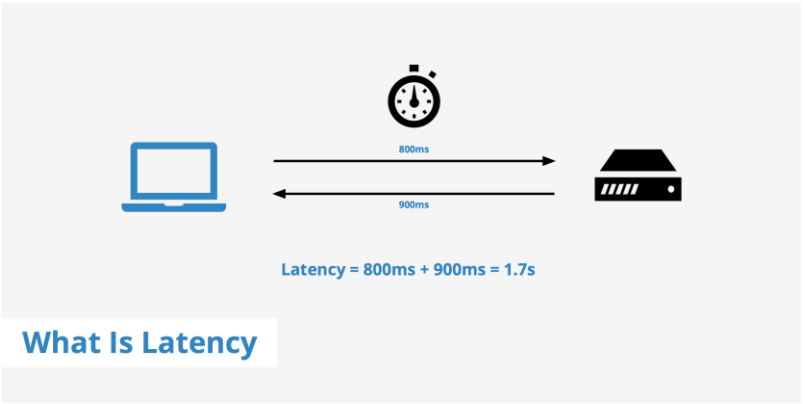
And difficult to build

And difficult to deploy

Engineering Challenges

- High traffic:
  - Consider ad exchanges that are responding to 1,000,000 requests/second
- Huge volumes of data:
  - Often terabytes or petabytes of data
- Strict requirements for systemic properties:
  - Response time, throughput, security, availability, compute cost, …

Response time



- Also known as latency
- Round trip time from when a request sent until a response is received

Response Time

Response time has an impact on user behavior

Many studies show a decrease in sales and customer retention as the response time increases

http://www.martinlugton.com/page-load-speed-important-impact-site-speed-conversions-revenue/

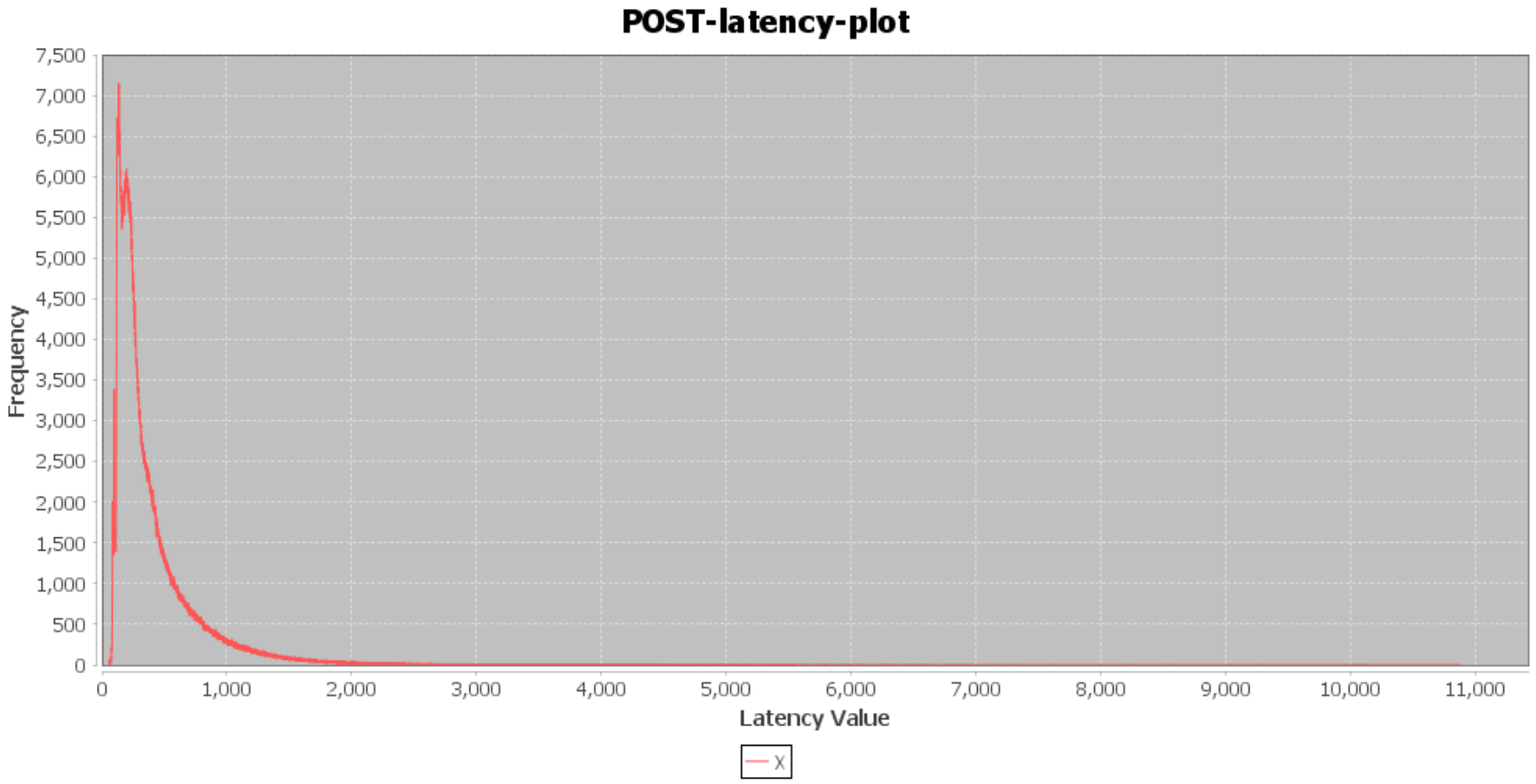
“Google: increasing page load time from 0.4 seconds to 0.9 seconds decreased traffic and ad revenues by 20%”

In some cases it’s required by contract

Responses to ad-exchanges for example need to be within 40 milliseconds

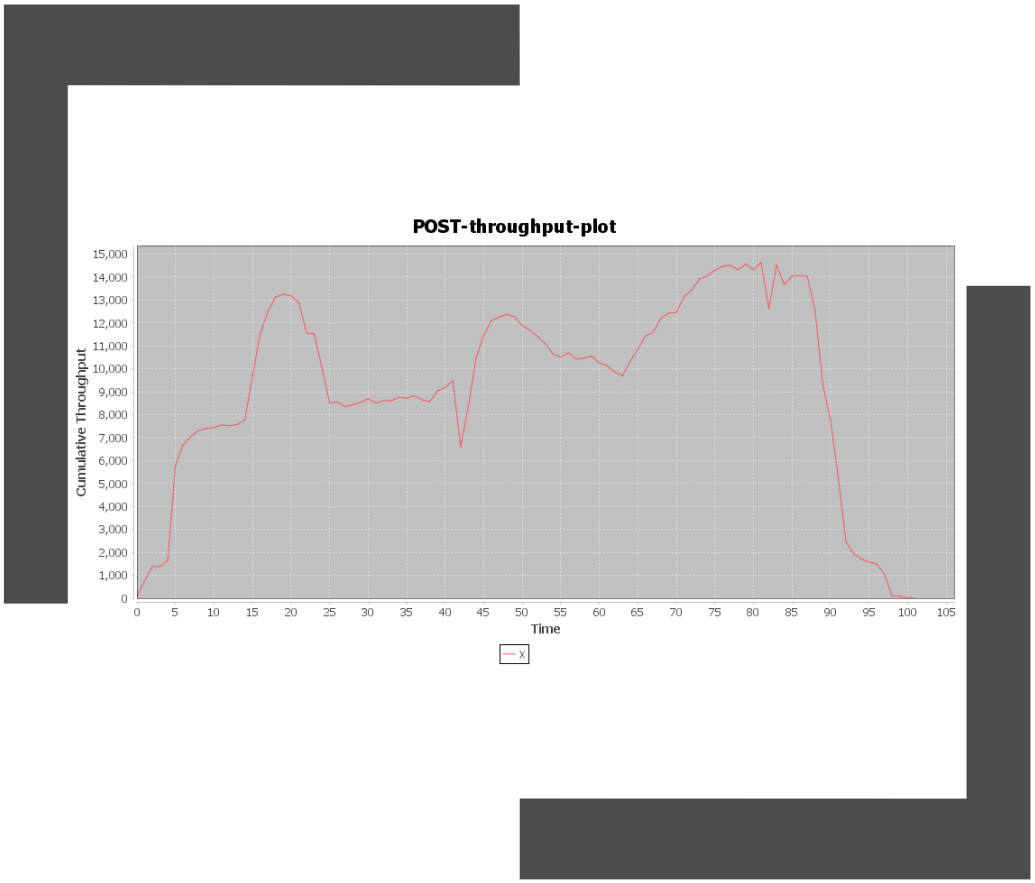
Website response time impacts google rankings

One factor google uses when determining ad listings



Typical Response Time – Long Tail

Throughput



- The capacity of a system to process requests
- Typically measured as number of requests/second
- Cf latency:
  - Latency is a measure for a single request
  - Throughput is a bulk measure of many requests

Throughput

Massive throughput is needed at scale

Millions of requests per second

Before web scale systems, we just used bigger more powerful systems

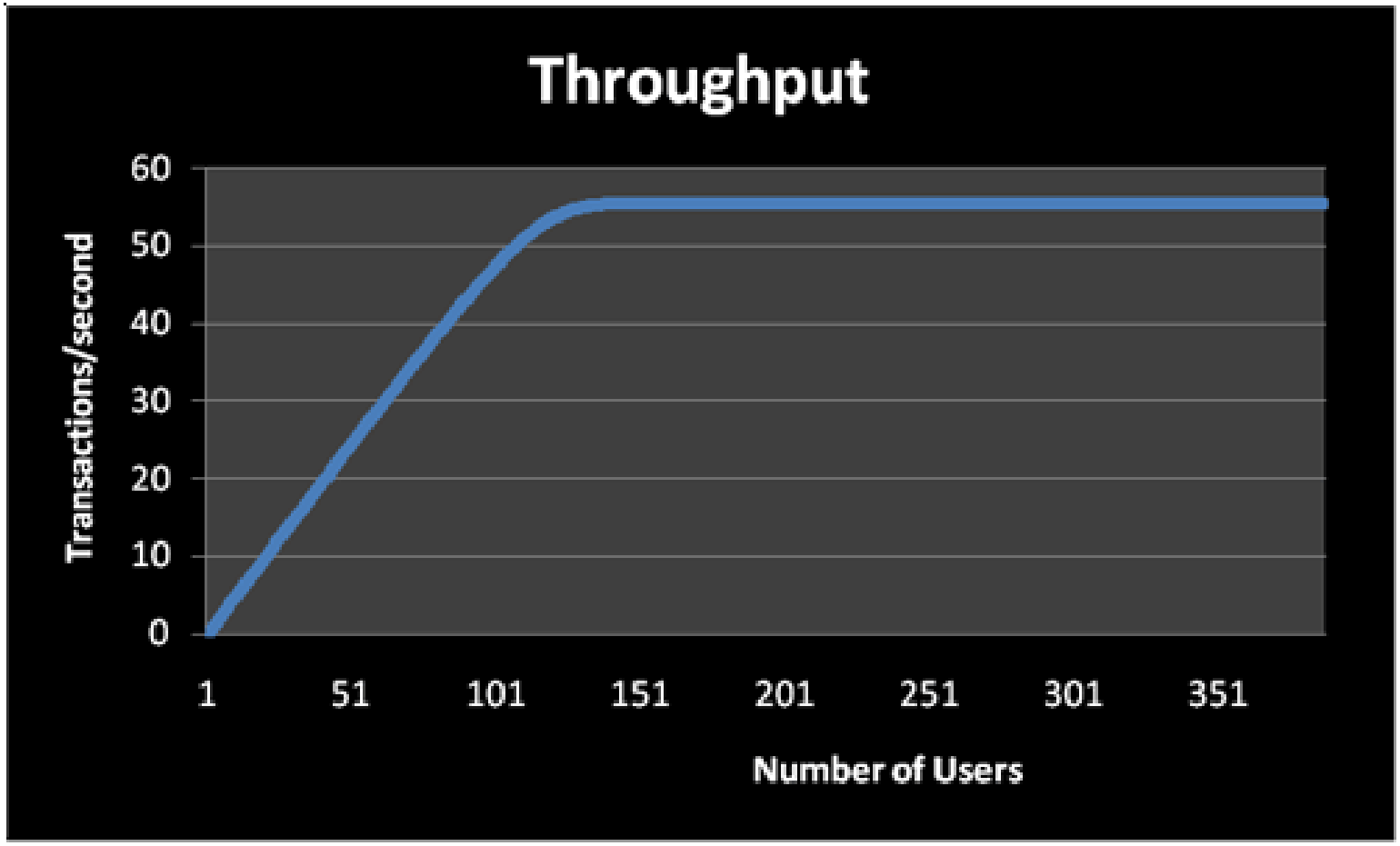
Particularly for the database server

That's no longer an option at web scale

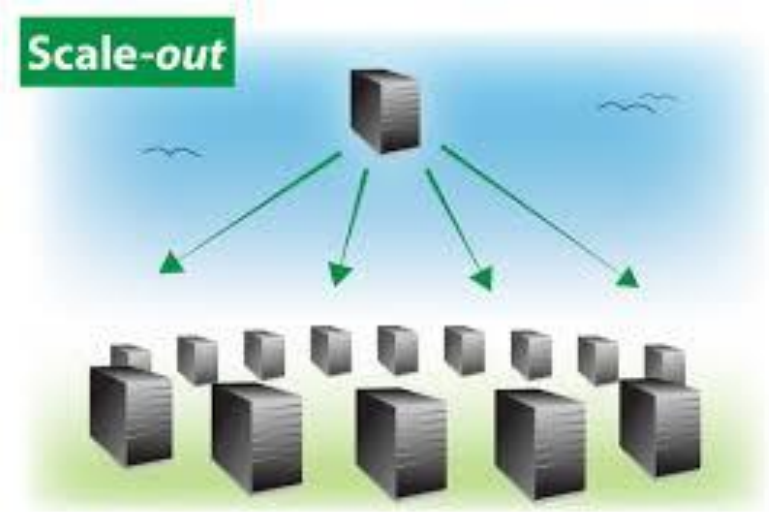
We need to be able to efficiently scale out

In other words be able to split the load across multiple nodes

Throughput with fixed capacity



Scale Out



- **Scale** horizontally (or **scale out**) means adding more nodes to a system
- Increases capacity and hence throughput
- 100s to 1000s of nodes needed at scale
- Scale in/down equally important
  - Why???

Availability

The percentage of time a system is accessible to user

At web scale

Global customer base

High availability required

How high?

99%

99.999%

99.999999%

Availability

- If a system has 1 component
  - It if not available if the element (software/hardware) fails
  - Single Point of Failure (SPoF)
  - So need very highly reliable component
- To achieve scalability, we need to scale out
  - 100s and 1000s of components
  - Do they all need to be always available?
- At scale *everything* breaks …
- Systems need to be able to deal with regular component failures
  - In other words, *fault tolerant*
  - ***Built to handle problems as failure is expected***

Question

- If my system runs on 10,000 nodes (machines), each with its own disk, how many disk crashes might my system experience every year?
- What information do we need to estimate this?

Annualize Failure Rate

- AFR (%) = (8760/MTBF)*100
- a common drive may have a 300,000 hours MTBF,
- gives a theoretical 2.92% annualized failure rate
  - i.e. a 2.92% chance that a given drive will fail during a year of use.
- A CMU 2007 study showed an estimated 3% mean AFR over 1–5 years
  - https://www.usenix.org/legacy/events/fast07/tech/schroeder.html

Managing Tradeoffs

- There is not one way to build such systems
- Requirements and context are going to differ from one system to another
- Optimizing on one system property is inevitably going to compromise another concern, eg
  - Throughput versus cost
  - Performance versus availability
- As an engineer you need to be able to understand:
  - the concerns and context of a given system
  - the nature of the tradeoff that results from a set of decisions
  - And use metrics to guide your designs

Course Outline

Course Overview

- Web site: https://gortonator.github.io/bsds-6650/
- In this course you'll learn both theory and practical knowledge
  - To be able to engineer robust, scalable, efficient internet scale systems
- The theory will be learned by:
  - Reading relevant materials/seminar
  - Lectures
  - Quizzes
- The practical knowledge will be gained by:
  - In class exercises
  - Projects

Course Outline

Course Content

Modules

Week	Topic	Date
1	Introduction to Distributed Systems	9/10
2	Concurrency	9/17
3	Distributed Systems Fundamentals	9/24
4	Data Layer: Replication, Partitioning and Consistency	10/1
5	Data Layer: NoSQL Databases	10/8
6	Scalable Request Processing: APIs and State Management	10/15
7	Caching and Load Balancing	10/22
8	Asynchronous Systems	10/29
9	Microservices	11/5
10	Data Processing Architectures - Lambda/etc	11/12
11	Scalable Data Analytics	11/19
12	Stream Processing	11/26
13	Security	12/3
14	Final Project Presentations	12/10

Grading

- There will be three components to the grades
  - 4 programming assessments (72%)
  - 4 in class Quizzes (24%)
  - Short paper (4%)

Final Stuff

All course materials will be distributed through web site/blackboard

We have a Piazza site for questions/discussions

We won't be taking attendance, but you are expected to attend and actively participate in class

Discussion is welcome

Assignments overview

Project 1 – Using AWS

Client

Multithreading
Measurement
Presentation

Server

Project 2

Client

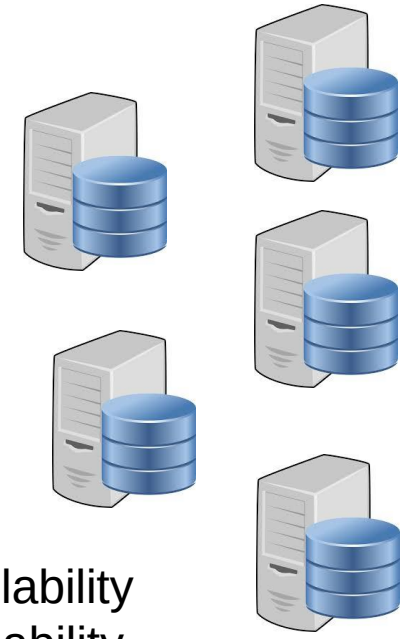
Server

Server thread models
State management
Data storage schemas

Project 3

Client

Server



Availability
Scalability
Caching
Monitoring

Project 4

How to succeed in this course

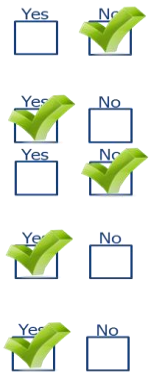
- Do the reading
- Study for the quizzes
- Start the assignments early
  - Really …. #notkidding
- Work consistently
- Experiment
- Be inquisitive and have fun
- Expect to work hard!!!

At the end of the course

- You will acquire a set of skills that is in very high demand right now
  - At Amazon, Google, Facebook, Microsoft and, well, everywhere really!
  - Projects should be useful in interviews
- You will learn a lot about how computer systems really work

A disclaimer…

- This is a “bleeding edge” course!
  - We are somewhat unique in offering such a course
  - The subject of this course is always evolving and is too broad for a single existing text book
- Some of the material in the course will result in pain, suffering, and a strong desire in some of you for alcohol!!
  - Debugging distributed systems is hard!
- We will be using some really complex technology
  - You will be confused and finding help is not easy
- But it will be fun – honestly!!
  - If you are into that kind of thing ☺



- Can we work on assignments together?
- Can I discuss the assignment with others (in general terms)?
- Can I use code I copied from the web?
- Can I ask questions about the assignments on Piazza?
- I just happened to leave my svn password on my table, and XYZ just happened to find it. Will I be penalized for this?

Policies - Collaboration