CS 744: BIG DATA SYSTEMS

Shivaram Venkataraman Fall 2021

WHO AM I?

Assistant Professor in Computer Science

PhD at UC Berkeley: System Design for Large Scale Machine Learning

Industry: Google, Microsoft Research

Open source: Apache Spark committer

Call Me: Shivaram or Prof. Shivaram

COURSE LOGISTICS

Shivaram Venkataraman

Office hours: Thursday 11-noon, CS 7367 (or Zoom?)

TA:Yien Xu

Office hours: Mon 5-6pm, Zoom?

Discussion, Questions: Use Piazza!

TODAYS AGENDA

What is this course about?

Why are we studying Big Data systems?

What will you do in this course?

BRIEF HISTORY OF BIG DATA

G00GLE 1997



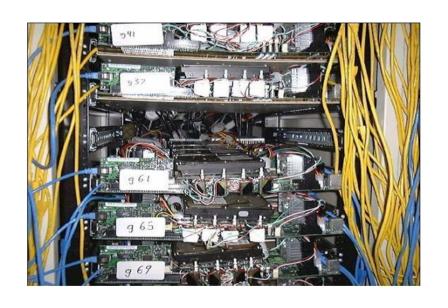
DATA, DATA, DATA

"...Storage space must be used efficiently to store indices and, optionally, the documents themselves. The indexing system must process hundreds of gigabytes of data efficiently..."

The Anatomy of a Large-Scale Hypertextual Web Search Engine

Sergey Brin and Lawrence Page

G00GLE 2001



Commodity CPUs

Lots of disks

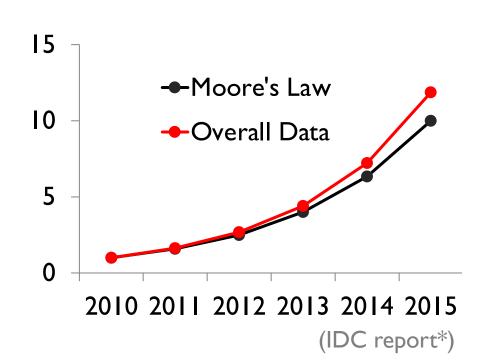
Low bandwidth network

Cheap!

DATACENTER EVOLUTION

Facebook's daily logs: 60 TB

Google web index: 10+ PB





FOURTH
PARADIGM

DATA-INTENSIVE SCIENTIFIC DISCOVERY

"scientific breakthroughs will be powered by advanced computing capabilities that help researchers manipulate and explore massive datasets"

-- Jim Gray

EDITED BY TONY HEY, STEWART TANSLEY, AND KRISTIN TOLLE



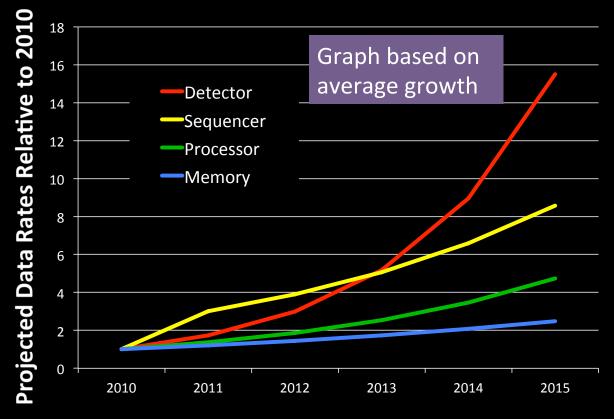
SOLAR FLARE PREDICTION

~ 2 PB

Working with data from Solar Dynamics Observatory
[Brown et. al SDO Primer 2010]

Solar Flare Prediction Using Photospheric and Coronal Image Data.

[Jonas et. al American Geophysical Union, 2016]



Source: More Data, More Science and... Moore's Law [Kathy Yellick]

DATACENTER EVOLUTION



Google data centers in The Dulles, Oregon

DATACENTER EVOLUTION

Capacity:

~10000 machines



Bandwidth: 12-24 disks per node

Latency: 256GB RAM cache

Outage in Dublin Knocks Amazon, Microsoft Data Centers Offline

By: Rich Miller

August 7th, 2011





Official Gmail Blog

News, tips and tricks from Google's Gmail team and friends.

A lightning strike has cau for Amazon and Microso Microsoft's BPOS (Busin

many sites using Amazo More on today's Gmail issu

Posted: Tuesday, September 01, 2009

Posted by Ben Treynor, VP Engineering and Sit

Gmail's web interface had a widespread outage Amazon EC2 and Amazon RDS Service Disruption people rely on Gmail for personal and profession problem with the service. Thus, right up front, I'd and we're treating it as such. We've already thor

a list of things we intend to fix or improve as a re



Sign Up

nctionality to all affected services, we would like to share more details with our customers about the events th our efforts to restore the services, and what we are doing to prevent this sort of issue from happening again. pted by this event, and as with any significant service issue, our intention is to share the details of what happe

The Joys of Real Hardware

Typical first year for a new cluster:

- ~0.5 overheating (power down most machines in <5 mins, ~1-2 days to recover)
- ~1 PDU failure (~500-1000 machines suddenly disappear, ~6 hours to come back)
- ~1 rack-move (plenty of warning, ~500-1000 machines powered down, ~6 hours)
- ~1 network rewiring (rolling ~5% of machines down over 2-day span)
- ~20 rack failures (40-80 machines instantly disappear, 1-6 hours to get back)
- ~5 racks go wonky (40-80 machines see 50% packetloss)
- ~8 network maintenances (4 might cause ~30-minute random connectivity losses)
- ~12 router reloads (takes out DNS and external vips for a couple minutes)
- ~3 router failures (have to immediately pull traffic for an hour)
- ~dozens of minor 30-second blips for dns
- ~1000 individual machine failures
- ~thousands of hard drive failures

slow disks, bad memory, misconfigured machines, flaky machines, etc.

Long distance links: wild dogs, sharks, dead horses, drunken hunters, etc.

JEFF DEAN @ GOOGLE



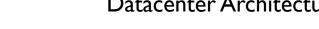
How do we program this?



BIG DATA SYSTEMS

Big Data Landscape 2016 (Version 3.0) Infrastructure Analytics **Applications** Analyst Data Science Human Hadoop Hadoop in Analytics Sales & Marketing Customer Service Spark **Cluster Services** Visualization Legal On-Premise the Cloud Platforms Platforms Platforms RADIUS' Gainsight' Capital MEDALLIA amazon 🔆 + a b | e a ı context relevant databricks RAVEL **Q** Palantir Microsoft 6 bloomreach Zeta ğıld CONTINUUM To DataRobot ATTENJITY 🐵 LEVERSTRING livefyre Hortonworks O Google Cloud Platform CLARABRIDGE JUDICATA AYASDI quavus Qlik @ looker MAPR Pivotal blue yonder Lattice ₩ CLICKFOX GridGain 4 **d**ockei IBM InfoSphere Connectifie Datameer Quid enigma MODE plotly Roamb @kahuna Infer SAILTHRU Everlay STELLAService MESOSPHERE textic IBM InfoSphere SISENSE TOOMDATA **TACHYON** Core OS pepperdata. Digital Reasoning IG&DATA Preact Bottlenose. persado AVISO Ósense ODMINO Sense @Brevia entelo 🐧 altiscale 🔲 bole bluedata jethro Stack IQ ORBITAL INSIGHT inter ana ŷhat ▲ ALGORITHMIA CHARTIO QUANTIFIND ACTIONIC **DigitalGenius** hi□ PREM®NITION fuse|machines #NGAGIO appuri Wiseio Social **NoSQL Databases** NewSQL Databases BI Platforms Statistical Log Analytics Ad Optimization Security Vertical AI Computing Analytics Power BI amazon amazon Google Cloud Platform Clustrix Pivotal splunk> Hootsuite ■ CYLANCE Applications AppNexus MediaMath **S**sas **ORACLE** sumologic CounterTack cybereason Microsoft Azure MarkLogic NETB^SE criteo. Threat Metrix. **A DATASIFT** kıbana splice **℀** birst **SPSS** OpenX ∞rocketfuel mongoDB DATASTAX GoodData AREA 1 SentinelOne tracx bitly Recorded Future Guardian Integral () the Trade Desk Clara **∢E**ROSPIKE **citusdata** Couchbase platfora ♠ MATLAB **synthesio** Adgorithms dstillery deepdb Trafodion Cockroach LABS SequoiaDB redislabs @ influxdata loggly **KASIST** (D) atscale FORTSCALE *sift science TAPAD Data**X□ Oppier** MOA SICNIFY: Graph MPP Data Speech & NLP Horizontal AI Cloud EDW Real-Time Machine Learning Databases Databases Transformation Integration Watson amazon Publisher Govt / Regulation Finance amazon informatica sentient alteryx **⊿ffirm iiiLending**Club meo4j Google Cour Tools T METAMARKETS H₂O NUANCE W Socrata **VERTICA** vicarious talend **Outbrain** OnDeck> ...Kreditech MuleSoft Dato NETEZZA Pivotal (7) OPENGOV TRIFACTA ngro 🕞 🕰 Numenta Tab99la zesifinance LendÜp 💔 Kabbage snapLogic confluen Oction tamr 🐅 🧞 quantcast FN FiscalNote tidemark. (2007) INSIKT **BedrockData** Descartes clarifai OrientDB DATATORRENT kognitio StreamSets Chartbeat Z UOra : Dataminr : 100 Lenddo EXASOL Odremio dataArtisans PREDPOL Infoworks △ Alation xplenty IDIBON (%) a yieldbot mark43 **ISENTIUM** Management Security Storage App Dev Crowd-Search Data Services For Business Web / Mobile "##" OpenDataSoft Quantopian sentient Yieldmo / Commerce / Monitoring TANIUM" sourcing Analysts apigee UO OPERA × illumio Google Analytics New Relic. 35 EXALEAD OrigamiLogio Life Sciences Industries Education/ CODE42 mixpanel Microsoft Azu Lucidworks amazon octifio PATHWAY GENOMICS CASK Keen IO **EXL** Learning OP@WER eHarmony ClearStory DataGravity panasas/ RJMetrics BLUECOR Counsul elastic ThoughtSpot RetailNext **Numerify KNEWTON duetto splunk> X Recombine CipherCloud' nimblesto **-** Typesafe AMPLITUDE 69 granify CrowdFlower DATA SCIENCE CIRRO **S**VECTR∧ M∧∧N∧ 💋 swiftype KYRUUS FLATIRON STITCH FIX 0 Clever соно sumAll Airtable oe⊘ezymergen HealthTap® retention custora Procono DRIVEN Qumulo import (i) TACHYUS Seeo FarmLogs @eclara Cross-Infrastructure/Analytics PANORAMA HowGood celect CMACHINE Ginger.io * transcriptic Glow enlitic AiCure A. Ato statmuse B@XEVER Manazon Google H Microsoft IBH SAP SSAS III (I) Among VERTICA VMWARE TIBC TERADATA ORACLE II Netapp **Open Source** Stat Tools Framework Query / Data Flow Data Access Coordination Real-Time Machine Learning 1 Search Security HBASE mongoDP Apache SINGA MADlib. Spark Spark Apache Ranger talend ogama cassandra YARN A MESOS ScalaLab Apache Zookeeper Caffe CNTK TensorFlo Visualization CouchDB **riak | PPENTS Flink Solr SLAMDATA APACHE Spark TEZ VELES WEKA DIMSUM Jupyter DL4J Flink QCDAP Apache Ambari ** TACHYON - druid Data Sources & APIs Incubators & Schools Location / People / Entities Health IOT Financial & Economic Data Air / Space / Sea Other Bloomberg D | DOW JONES PLURALSIGHT IAWBONE GARMIN **△** spire acxiem Experian Epsilon InsideView ThingWorx Y-DLEE PREMISE CAPITAL IQ DataCamp INSIGHT GARMIN COURSELLORO WINDWARD 🎠 STREETLINE 🍓 **esri** practice fusion : fitbit malium samsara A DataElite panjiva Withings VALIDIC netatmo Crimson Hexagon CARTODB factual. Place quandl xignite CBINSIGHTS The Data Incubator WETIS Human API SteckTwits @estimize PLAID Airware Torone Deploy CIRCULATE placemeter BASIS Sense ■ ĐATA.GOV kinsa Last Updated 3/23/2016 © Matt Turck (@mattturck), Jim Hao (@ijmrhao), & FirstMark Capital (@firstmarkcap) FIRSTMARK

Applications Machine Learning SQL Streaming Graph Computational Engines Scalable Storage Systems Resource Management **Datacenter Architecture**

















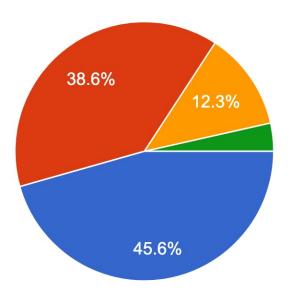






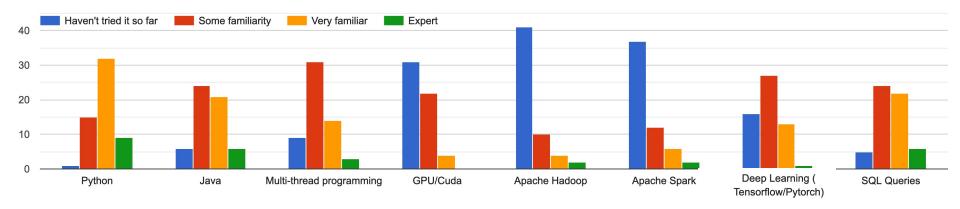
COURSE SYLLABUS

BACKGROUND SURVEY: PAPER READING

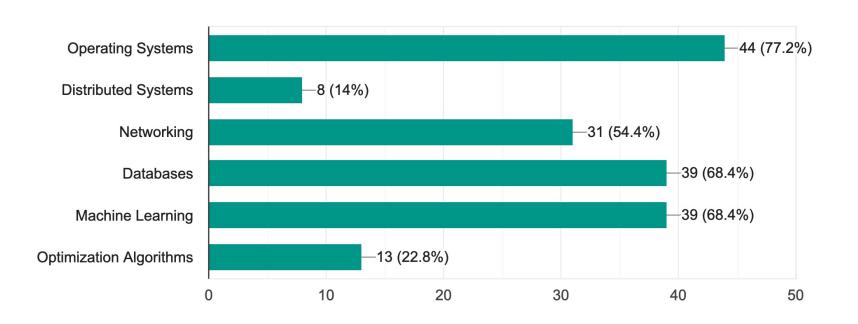


- I am new to this!
- I have evaluated a few papers before but I am still learning how to do this
- I have some experience in critically reading papers but I can learn more
- I have significant experience!

FAMILIARITY WITH TOOLS



PRIOR COURSES



WHAT DO YOU HOPE TO LEARN FROM THE COURSE?

Understanding of Big Data system architectures and approach towards their design

I hope to be able to design and deploy end to end machine learning pipelines that are designed keeping the tenets of low latency and high throughput in mind.

Tools and techniques to handle big data! My current research project has me handling large computations that I'm woefully unprepared for.

I want to learn about different systems and see if I can get a Data Science job.

I am interested in Systems research and would like to read and understand advanced papers related to it.

. . .

LEARNING OBJECTIVES

At the end of the course you will be able to

- Explain the design and architecture of big data systems
- Compare, contrast and evaluate research papers
- Develop and deploy applications on existing frameworks
- Design, articulate and report new research ideas

LEARNING OBJECTIVES

At the end of the course you will be able to

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Paper Review

Discussion

Assignment

Project

CLASS FORMAT

Schedule: http://cs.wisc.edu/~shivaram/cs744-fa21

Reading: ~ I paper per class

Review: Fill out review form (link posted on Piazza) by 9am

Discussion: In-class group discussion, submit responses within 24 hours

What if you cannot attend?

Best 15 responses (out of ~22)

Discussion: Student/TA/Prof (write their name!) and submit

HOW TO READ A PAPER: EXAMPLE

The Google File System

Sanjay Ghemawat, Howard Gobioff, and Shun-Tak Leung Google*

ABSTRACT

We have designed and implemented the Google File System, a scalable distributed file system for large distributed data-intensive applications. It provides fault tolerance while running on inexpensive commodity hardware, and it delivers high aggregate performance to a large number of clients.

While sharing many of the same goals as previous distributed file systems, our design has been driven by observations of our application workloads and technological environment, both current and anticipated, that reflect a marked departure from some earlier file system assumptions. This has led us to reexamine traditional choices and explore rad-

1. INTRODUCTION

We have designed and implemented the Google File System (GFS) to meet the rapidly growing demands of Google's data processing needs. GFS shares many of the same goals as previous distributed file systems such as performance, scalability, reliability, and availability. However, its design has been driven by key observations of our application workloads and technological environment, both current and anticipated, that reflect a marked departure from some earlier file system design assumptions. We have reexamined traditional choices and explored radically different points in the design space.

PRACTICE DISCUSSION!

https://forms.gle/KFG7Xd1CZm6bZcRp7

What are your goals in taking the Big Data Systems course? How similar / different are goals among students in the group?

What were your main takeaways from "How to Read a Paper"?

PRACTICE DISCUSSION SUMMARY

ASSESSMENT

- Paper reviews: 10%
- Class Participation, Discussion: 10%
- Assignments (in groups): 20% (2 @ 10% each)
- Midterm exams: 30% (2 @15% each)
- Final Project (in groups): 30%

ASSIGNMENTS

Two homework assignments in Python using NSF CloudLab

- Assignment 0: Setup CloudLab account
- Assignment I: Data Processing
- Assignment 2: Machine Learning

Short coding based assignments. Preparation for course project Work in groups of three

EXAMS

- Two midterm exams
- Open book, open notes
- Synchronous, in-class
- Focus on design, trade-offs

More details soon

COURSE PROJECT

Main grading component in the course!

Explore new research ideas or significant implementation of Big Data systems

Research: Work towards workshop/conference paper

Implementation: Work towards open source contribution

COURSE PROJECT EXAMPLES

Example: Research

How do we scheduling distributed machine learning jobs while accounting for performance, efficiency, convergence ?

Example: Implementation

Implement a new module in Apache YARN that allows GPUs to be allocated to machine learning jobs.

COURSE PROJECT

Project Selection:

- List of course project ideas posted
- Form groups of three
- Bid for one or more ideas or propose your own!
- Instructor feedback/finalize idea

Assessment:

- Project introduction write up
- Mid-semester check-in
- Poster presentation
- Final project report

WAITLIST

- Class size is limited to ~75 for this semester
- Focus on research projects, discussion
- Limited undergraduate seats

If you are enrolled but don't want to take, please drop ASAP!

If you are on the waitlist, we will admit students as spots open up

If you want to audit the class:

BEFORE NEXT CLASS

Join Piazza: https://piazza.com/wisc/fall2021/cs744

Complete Assignment 0 (see website)

Paper Reading: The Datacenter as a Computer