Distributed Systems

15-440 / 15-640

Fall 2018

Welcome! Course Staff


Yuvraj Agarwal


Daniel Berger

Instructors

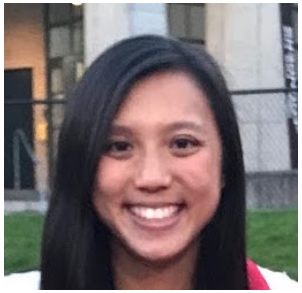
10 TA's

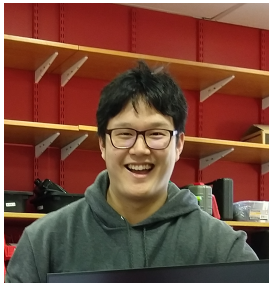

Tushar Agarwal


Chelsea Chen


Karan Dhabalia

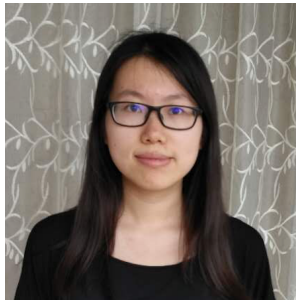

Guoyao (Freddie) Feng


Zeleena Kearney


Dohyun Kim


Samuel Kim


Amadou Latyr Ngom


Tian Zhao


(TBD!)

Course Logistics

- Course Policies
  - Website: https://www.synergylabs.org/courses/15-440
  - Piazza: piazza.com/cmu/fall2018/1544015640/home
  - Obligatory discussion of {late days, cheating, etc.}
- Waitlist!
- Optional Recitations: Primarily for project support
- Office hours / TAs are on class web page (check often)
- Go work through the Tour of Go!
  - https://tour.golang.org/welcome/1

Waitlist

- Waitlist of unprecedented size.
- Registered: 440 (106) + 640 (87) => 193 (+12 invited)
- Waitlisted: 440 (23) + 640 (80) => 103
- The bad news: We are already full. We are by law limited to physical class size, not subject to negotiation. Section A (200 people max)
- The plea: Not serious? PLEASE DROP SOON.
- The strategy:
  - 1st week, add a few more people (in 640) - Attend class!
  - Follow WL order (SCS, ECE/INI) – Estimate maybe ~20
    - These get enrolled **only** if someone drops (we will email you)

Processing WL/Enrollment

- Unable to able to take the class if:
  - If not taken 213/513 at CMU *before*
  - If you are an UGRAD and lower than a “C” in 213
  - If you are a Grad and lower than a “B-” in 213/513
- Priority order
  - Required: CS UGrad, MS in SCS (MSCS, MSDC, MITS,..)
  - .. then WL rank + 213 Grade for ECE and INI students

- Our apologies: Resource Limitations (Room, TAs, ..)
- Questions? Tracy Farbacher (tracyf@cs.cmu.edy)

Recitations & TA hours

- Optional Recitations this year
  - Two 1hr sessions: 6pm – 9pm (most likely Tuesday/Wednesday)
  - Best effort: room availability, non overlap with classes
  - TAs will strictly enforce room size limit, if you find no seats please come to the next session (Overflow disallowed by fire code!).

- Recitations (6 or 7) primarily to support Programming Projects
  - Introduction to GO (9/5)
  - Introduction to P0, P1, P2, P3 + Discussion after projects due
  - Lead by TAs, are not meant to go over class lectures

- TA Office Hours (7 days / week, spread out during the day)
  - No office hours the day before projects or homeworks are due

Course Goals

- Systems requirement:
  - Learn something about distributed systems in particular;
  - Learn general systems principles (modularity, layering, naming, security, ...)
  - Practice implementing real, larger systems; in teams; must run in nasty environment;

- One consequence: Must pass homeworks, exams, and projects independently as well as in total.
  - Note, if you fail either you will not pass the class

Course Format

- ~24 lectures: Tu/Th 10:30am – 11:50am in GHC 4401
- Office hours: Practical issues for implementing projects; general questions and discussion
- 4 projects; 2 solo (p0, p2), 2 person team (p1,p3)
  - P0 – warm up project, learn syntax of GO
  - P1: Distributed (internet-wide) bitcoin miner
  - P2: Project with distributed systems concepts like distributed commit/consensus (e.g. PAXOS/RAFT)
  - P3: Building Tribbler (or something, TBD)

Course Format – Midterms

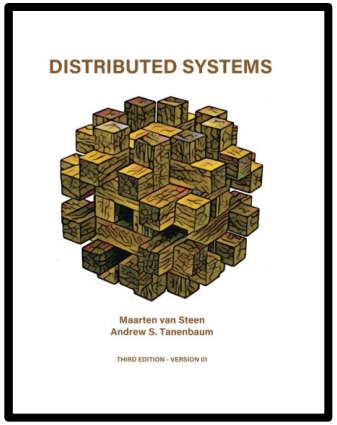
Everything on this slide is tentative, check website

- Plan: Two Mid-terms *during class times*
  - Tentative: Oct 18th and Dec 6th, subject to change
  - *May* have to move 2nd midterm to finals week

- Registrar: Please do not make any plans to leave for winter break before the final exam schedule is out.
  - If you must, then earliest day you can safely leave: Dec 18th

Study Material

- Slides and notes on course website
  - Not identical to prior 15-440 instances
- Distributed Systems 3.0.1 (2017)
  - Free download
  - Link to purchase ($25) from syllabus page
- Several useful references on web page



About Projects

- Systems programming somewhat different from what you've done before
  - Low-level (C / GO)
  - Often designed to run indefinitely (error handling must be rock solid)
  - Must be secure - horrible environment
  - Concurrency
  - Interfaces specified by documented protocols
- Office Hours & "System Hacker's View of Software Engineering"
  - Practical techniques designed to save you time & pain
- WARNING: Many students dropped during Project 1

  => started too late!

Collaboration

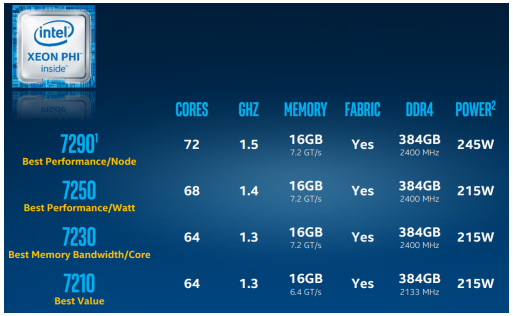
- Working together important
  - Discuss course material
  - Work on problem debugging
- Parts must be your own work
  - Homeworks, midterm, final, solo projects
- Team projects: both students should understand entire project
- What we hate to say: we run cheat checkers...
- Please *do not* put code on *public* repositories
- Partner problems: *Please address them early*

Late Work

- 10% penalty per day
- Cannot be more than 2 days late
  - (no exceptions after 48 hours of due date/time)
- Usual exceptions:
  - documented medical, emergency, etc.
- Talk to us early if there's a problem!
- Regrade requests in writing to course admin

Why take this course?

- Huge amounts of computing are now distributed...
  - A few years ago, Intel threw its hands up in the air: couldn't increase GHz much more without CPU temperatures reaching solar levels
  - But we can still stuff more transistors (Moore's Law)
  - Result: Multi-core and GPUs.
  - Result 2: Your computer has become
  - a parallel/distributed system



- Oh, yeah, and that whole Internet thing...
  - my phone syncs its calendar with google, which I can get on my desktop with a web browser, ...
    - (That phone has the computing power of a desktop from 10 years ago and communicates wirelessly at a rate 5x faster than the average american home could in 1999.)
  - Stunningly impressive capabilities now seem mundane. But lots of great stuff going on under the hood...
  - Most things are distributed, and more each day

If you find yourself …

- In Hollywood….
  - … rendering videos on clusters of 10s of 1000s of nodes?
  - Or getting terabytes of digital footage from on-location to post-processing?
- On Wall Street…
  - tanking our economy with powerful simulations running on large clusters of machines
  - For 11 years, the NYSE ran software from Cornell systems folks to update trade data
- In biochem…
  - using protein folding models that require supercomputers to run
- In gaming…
  - Writing really bad distributed systems to enable MMOs to crash on a regular basis
- Not to mention the obvious places (Internet-of-Things Anyone?)

What Is A Distributed System?

"A collection of independent computers that appears to its users as a single coherent system."

- Features:
  - No shared memory – message-based communication
  - Each runs its own local OS
  - Heterogeneity
- Ideal: to present a single-system image:
  - The distributed system "looks like" a single computer rather than a collection of separate computers.

Characteristics of a DS

- Present a single-system image
  - Hide internal organization, communication details
  - Provide uniform interface
- Easily expandable
  - Adding new servers is hidden from users
- Continuous availability
  - Failures in one component can be covered by other components
- Supported by middleware

Distributed System Layer

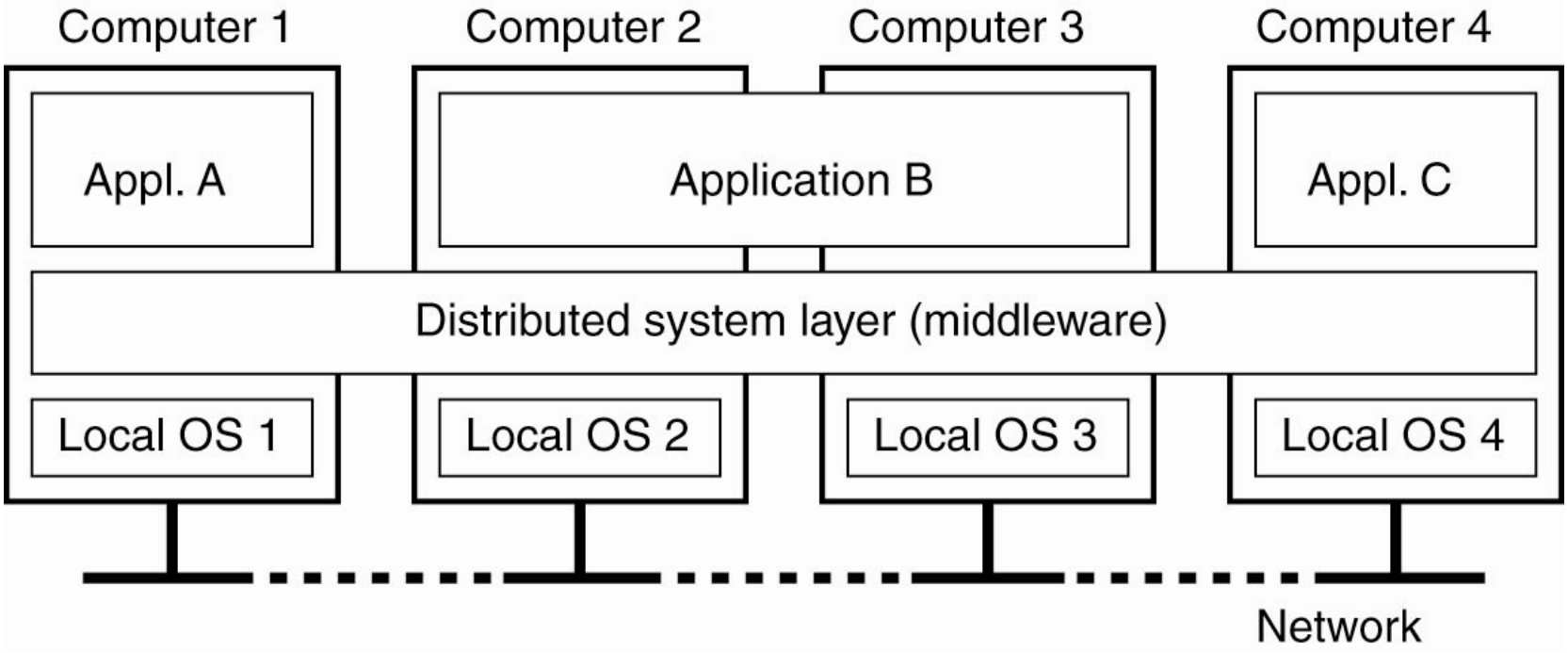


Figure 1-1. A distributed system organized as middleware. The middleware layer runs on all machines, and offers a uniform interface to the system

Goal 1 – Resource Availability

- Support user access to remote resources (printers, data files, web pages, CPU cycles) and the fair sharing of the resources
- Economics of sharing expensive resources
- Performance enhancement – due to multiple processors; also due to ease of collaboration and info exchange – access to remote services
- Resource sharing introduces security problems.

Goal 2 – Transparency

- Software hides some of the details of the distribution of system resources.
  - Makes the system more user friendly.
- A distributed system that appears to its users & applications to be a single computer system is said to be transparent.
  - Users & apps should be able to access remote resources in the same way they access local resources.
- Transparency has several dimensions.

Types of Transparency

Transparency	Description
Access	Hide differences in data representation & resource access (enables interoperability)
Location	Hide location of resource (can use resource without knowing its location)
Migration	Hide possibility that a system may change location of resource (no effect on access)
Replication	Hide the possibility that multiple copies of the resource exist (for reliability and/or availability)
Concurrency	Hide the possibility that the resource may be shared concurrently
Failure	Hide failure and recovery of the resource. How does one differentiate betw. slow and failed?
Relocation	Hide that resource may be moved during use

Transparency to Handle Failures?

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.

slide from Jeff Dean, Google

Goal 2: Degrees of Transparency

- Trade-off: transparency versus other factors
  - Reduced performance: multiple attempts to contact a remote server can slow down the system – should you report failure and let user cancel request?
  - Convenience: direct the print request to my local printer, not one on the next floor
- Too much emphasis on transparency may prevent the user from understanding system behavior.

Goal 3 - Openness

- An **open distributed system** "…offers services according to standard rules that describe the syntax and semantics of those services." In other words, the interfaces to the system are clearly specified and freely available.
  - Compare to network protocols, Not proprietary
- **Interface Definition/Description Languages (IDL)**: used to describe the interfaces between software components, usually in a distributed system
  - Definitions are language & machine independent
  - Support communication between systems using different OS/programming languages; e.g. a C++ program running on Windows communicates with a Java program running on UNIX
  - Communication is usually RPC-based.

Examples of IDLs

- IDL: Interface Description Language
  - The original
- WSDL: Web Services Description Language
  - Provides machine-readable descriptions of the services
- OMG IDL: used for RPC in CORBA
  - OMG – Object Management Group
- …

Open Systems Support …

- **Interoperability**: the ability of two different systems or applications to work together
  - A process that needs a service should be able to talk to any process that provides the service.
  - Multiple implementations of the same service may be provided, as long as the interface is maintained
- **Portability**: an application designed to run on one distributed system can run on another system which implements the same interface.
- **Extensibility**: Easy to add new components, features

Goal 4 - Scalability

- Dimensions that may scale:
  - With respect to size
  - With respect to geographical distribution
  - With respect to the number of administrative organizations spanned

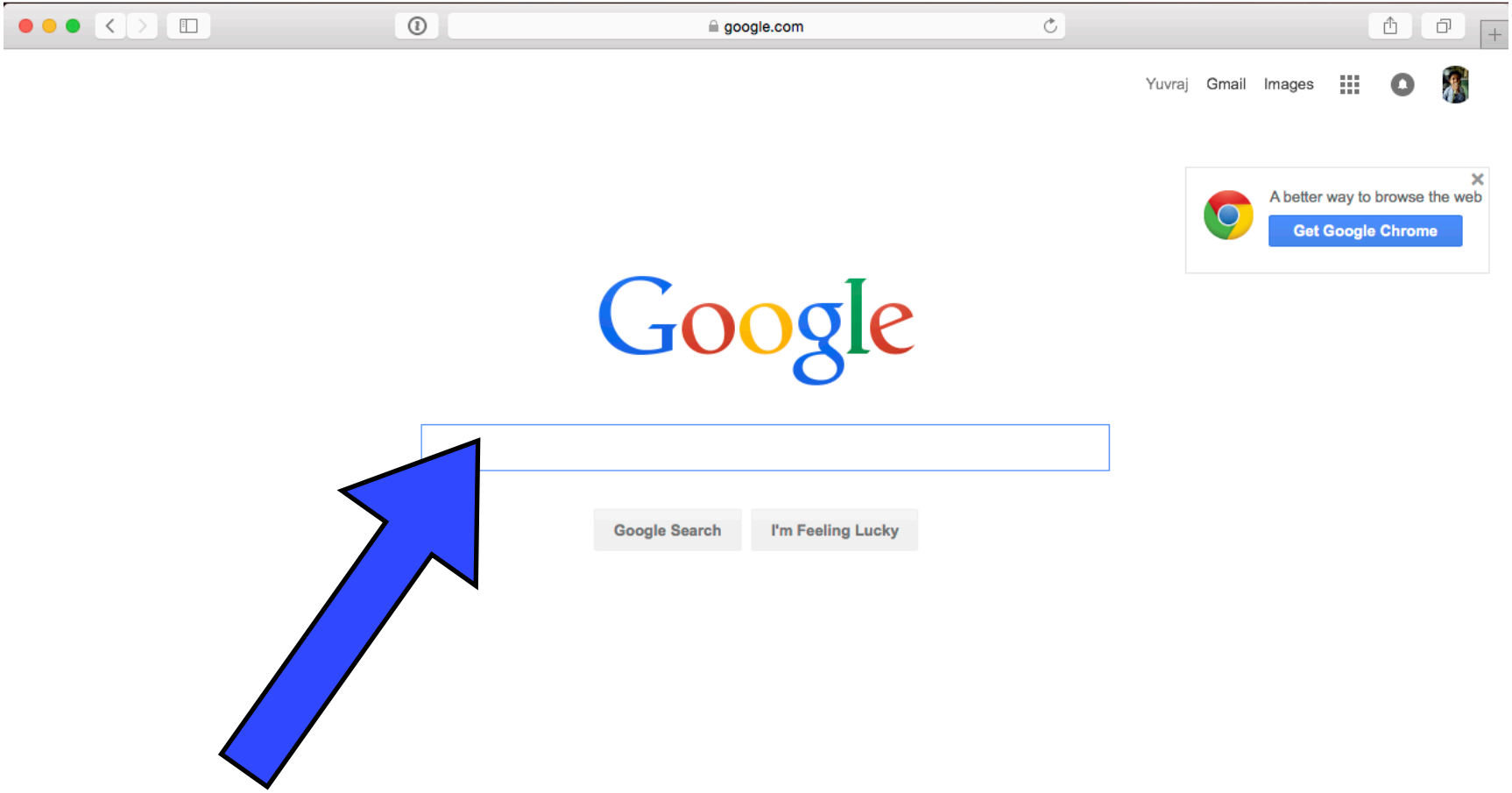
- A scalable system still performs well as it scales up along any of the three dimensions.

Summary: Goals of DS

- Resource accessibility
  - For sharing and enhanced performance
- Distribution transparency
  - For easier use
- Openness
  - To support interoperability, portability, extensibility
- Scalability
  - With respect to size (number of users), geographic distribution, administrative domains

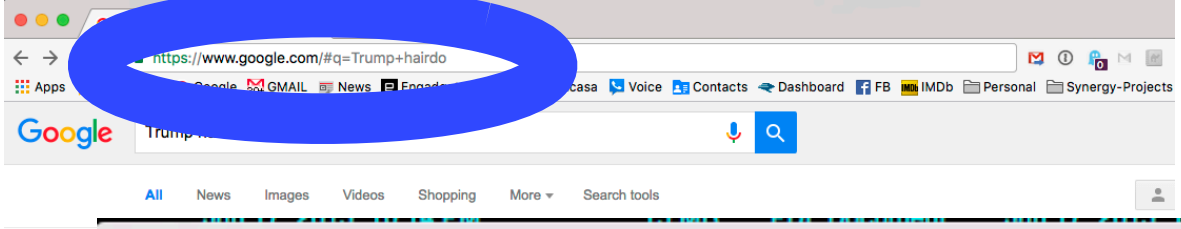
Enough advertising

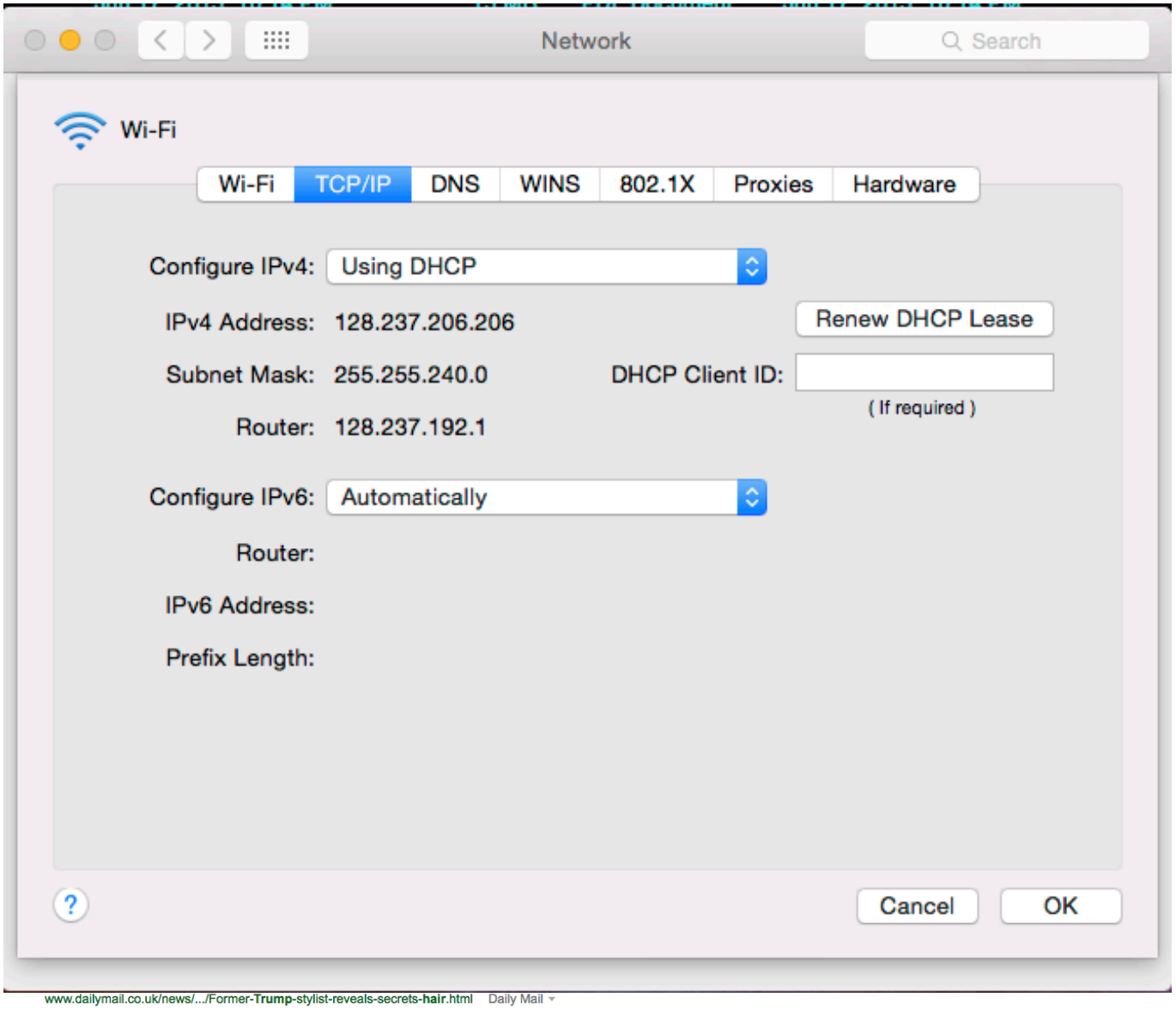
- Let’s look at one real distributed system
- That’s drastically more complex than it might seem from the web browser...



Lets say you were wondering what President Trump is upto today … ?!?

… wonder what the secret is of his amazing hairdo! ..

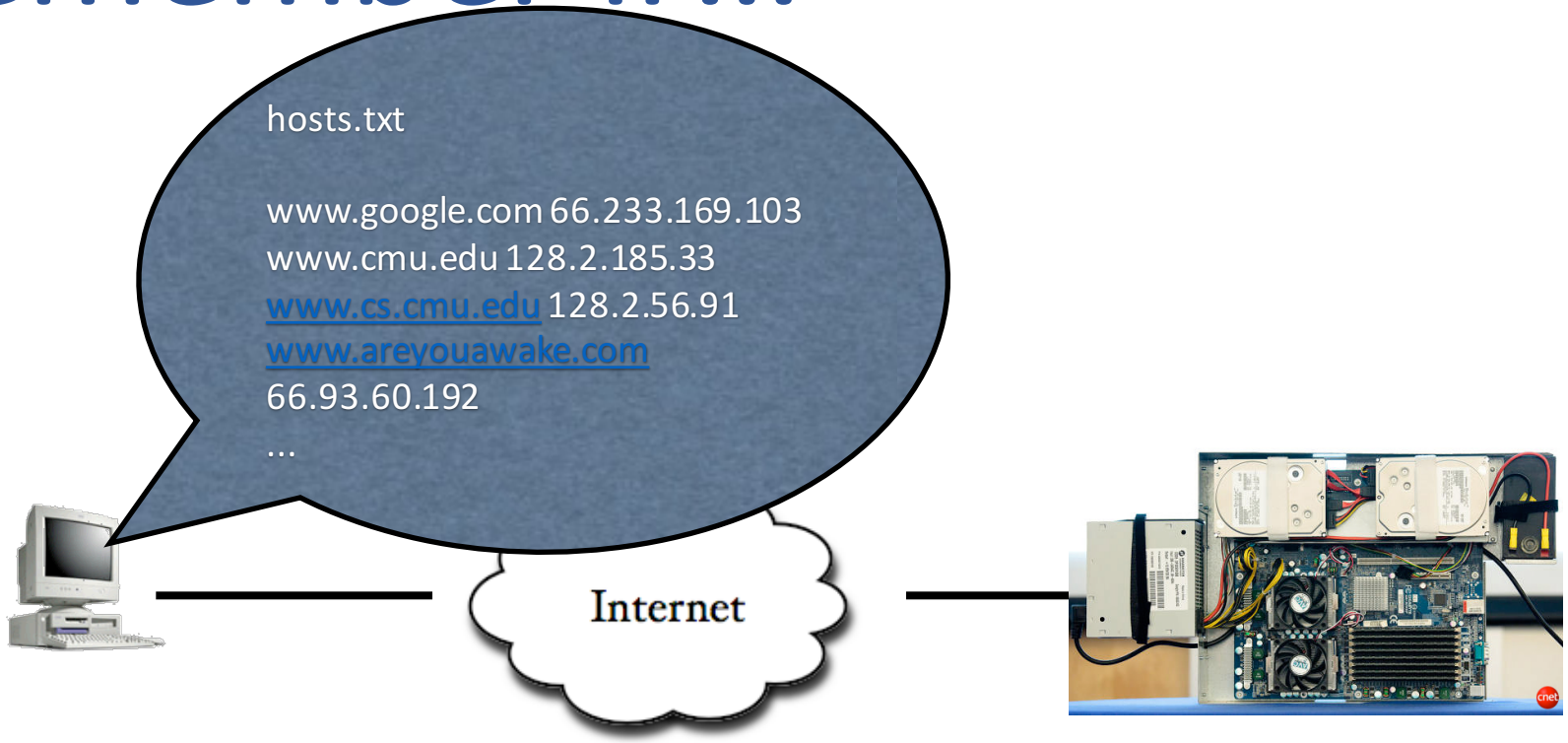




www.dailymail.co.uk/news/.../Former-**Trump**-stylist-reveals-secrets-**hair**.html Daily Mail

Jul 20, 2016 - The secrets behind **Trump's hair**: Former stylist reveals the Donald covers it with gel, avoids professional salons... oh, and it's 100 percent REAL.

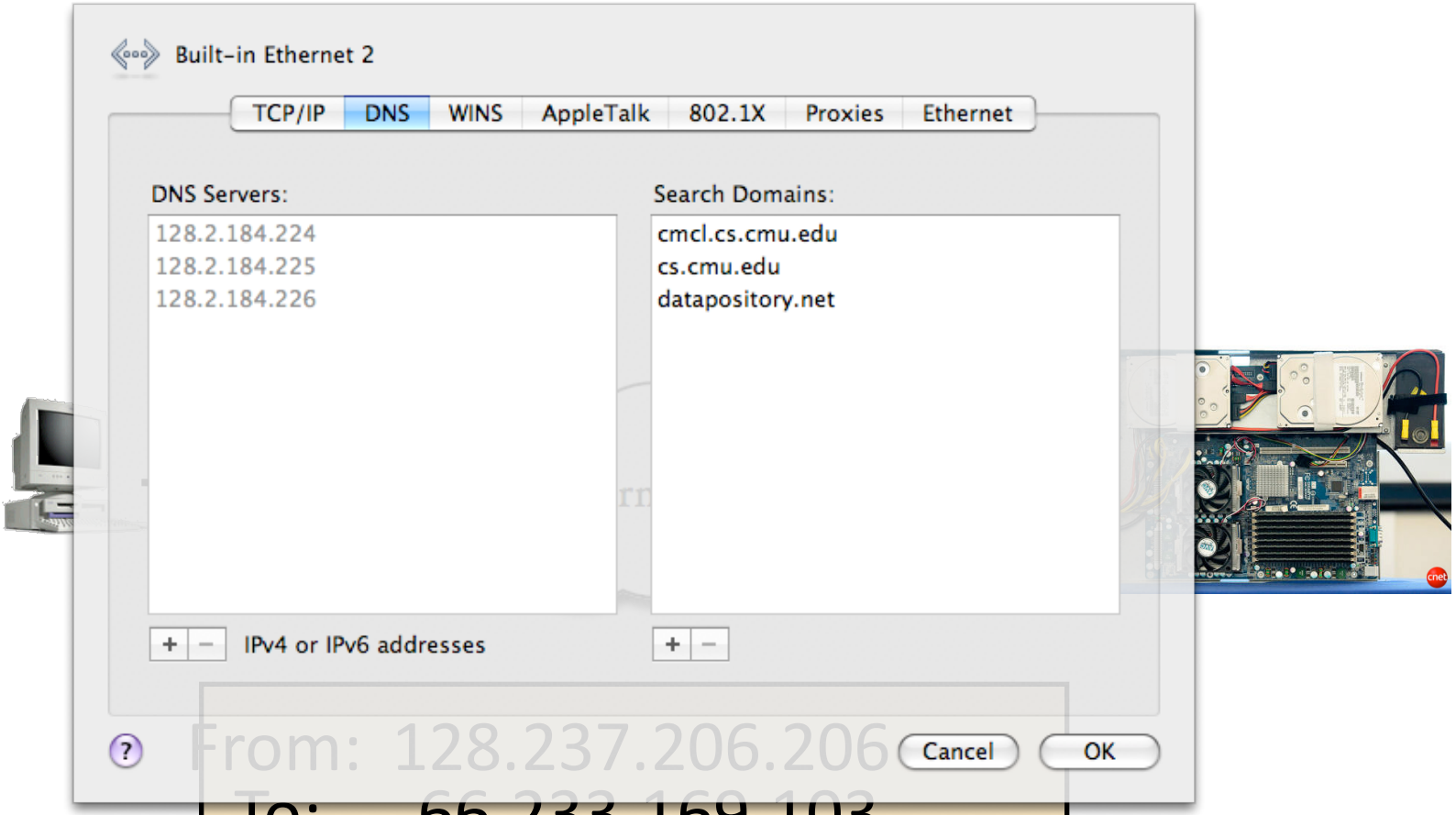
Remember IP…



From: 128.237.206.206
To: 66.233.169.103

<packet contents>

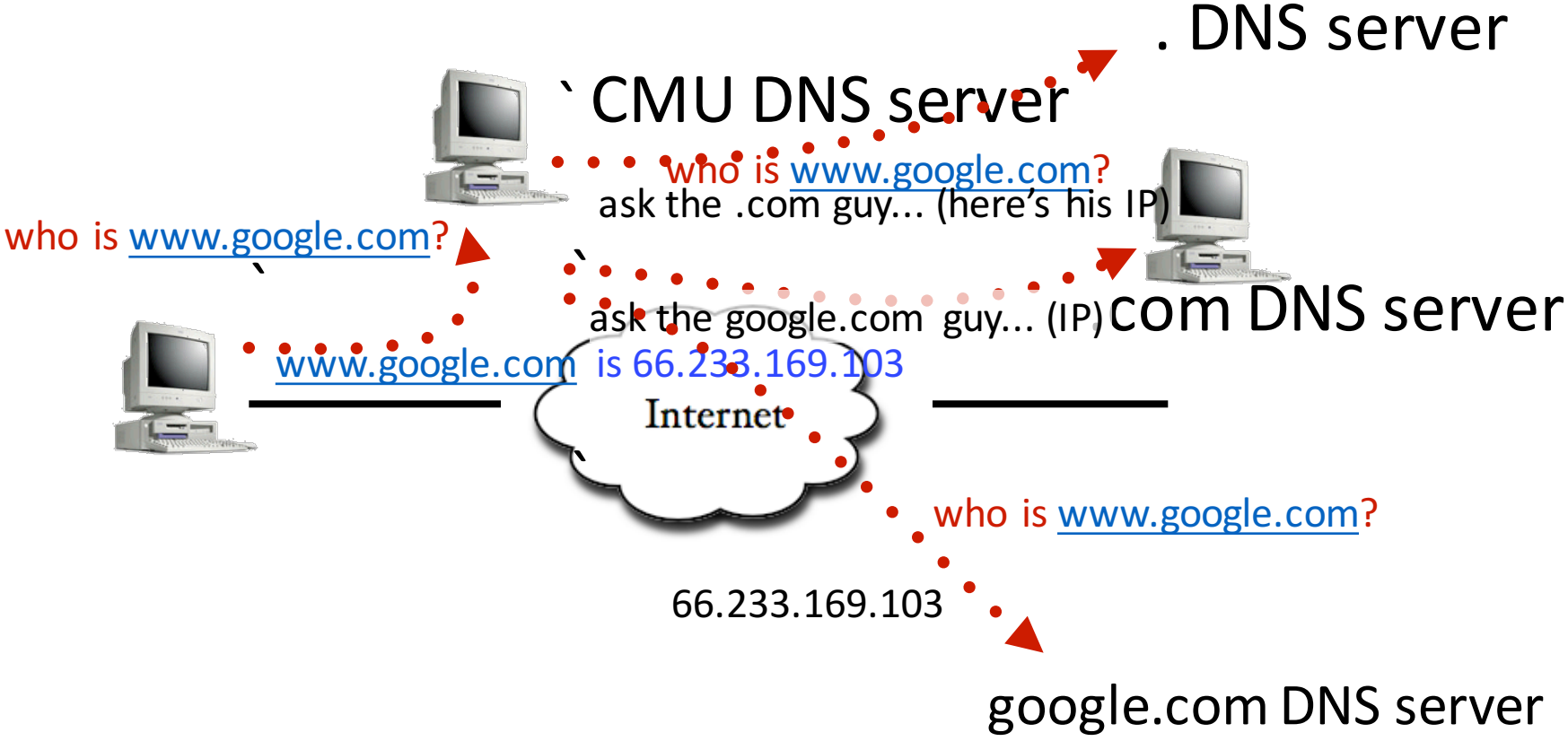
Remember IP…


Built-in Ethernet 2
TCP/IP
DNS
WINS
AppleTalk
802.1X
Proxies
Ethernet
DNS Servers:
128.2.184.224
128.2.184.225
128.2.184.226
Search Domains:
cmcl.cs.cmu.edu
cs.cmu.edu
datapository.net
IPv4 or IPv6 addresses
Cancel
OK
From: 128.237.206.206
To: 66.233.169.103
<packet contents>

The Google Example

- Note that URL: www.google.com
- But your computer has an IP address...
- Naming! The "Domain Name System", or DNS, translates names to IP addresses
  - In the days of yore, this was a text file called "hosts.txt" that everyone periodically downloaded
  - Today, with hundreds of millions of domains...
  - It's a big distributed system that allows people to update small parts ("moo.cmcl.cs.cmu.edu") without coordinating with the owners of other parts. We'll see this soon.

Domain Name System



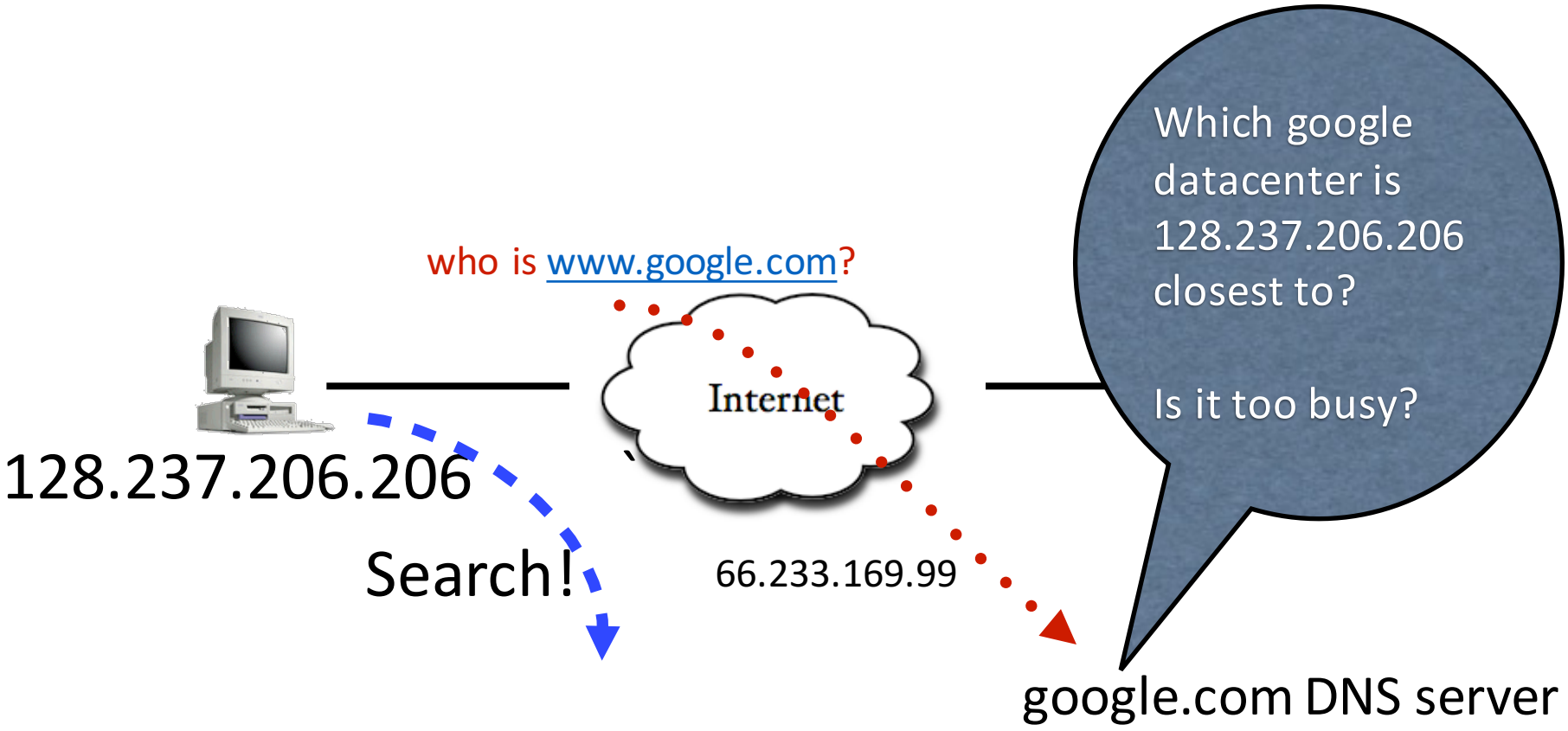
Domain Name System

Decentralized - admins update own domains without coordinating with other domains

Scalable - used for hundreds of millions of domains

Robust - handles load and failures well

But there's more…



A Google Datacenter

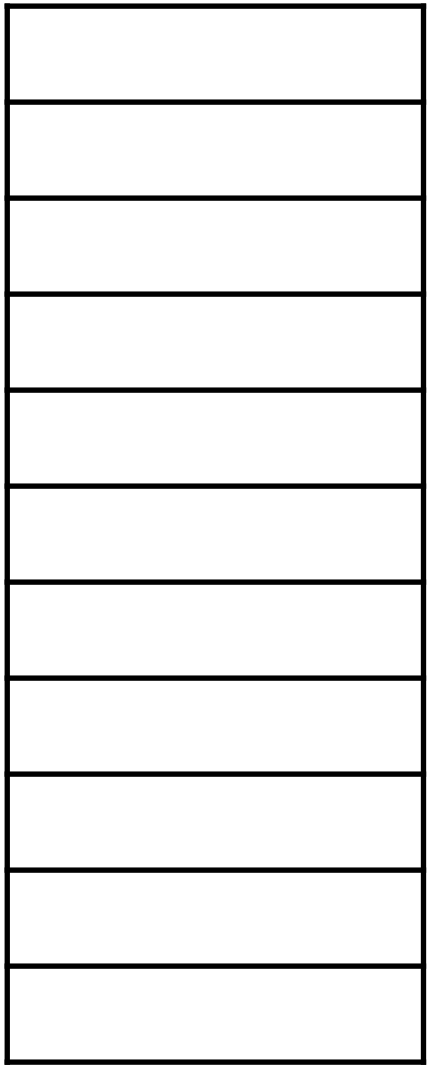
How big? Perhaps one million+ machines

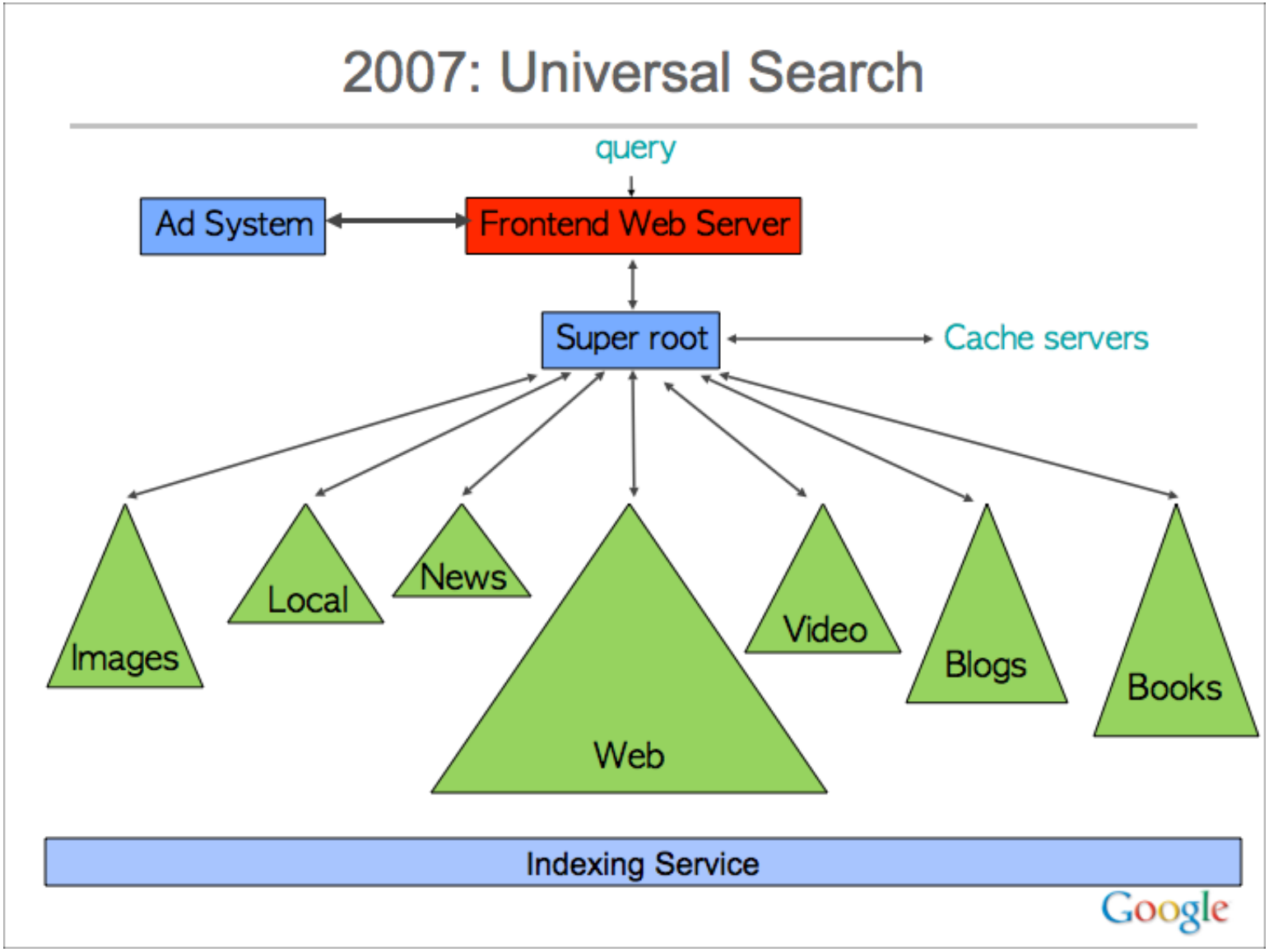
but it's not that bad...

usually don't use more than **20,000** machines to accomplish a single task. [2009, probably out of date]

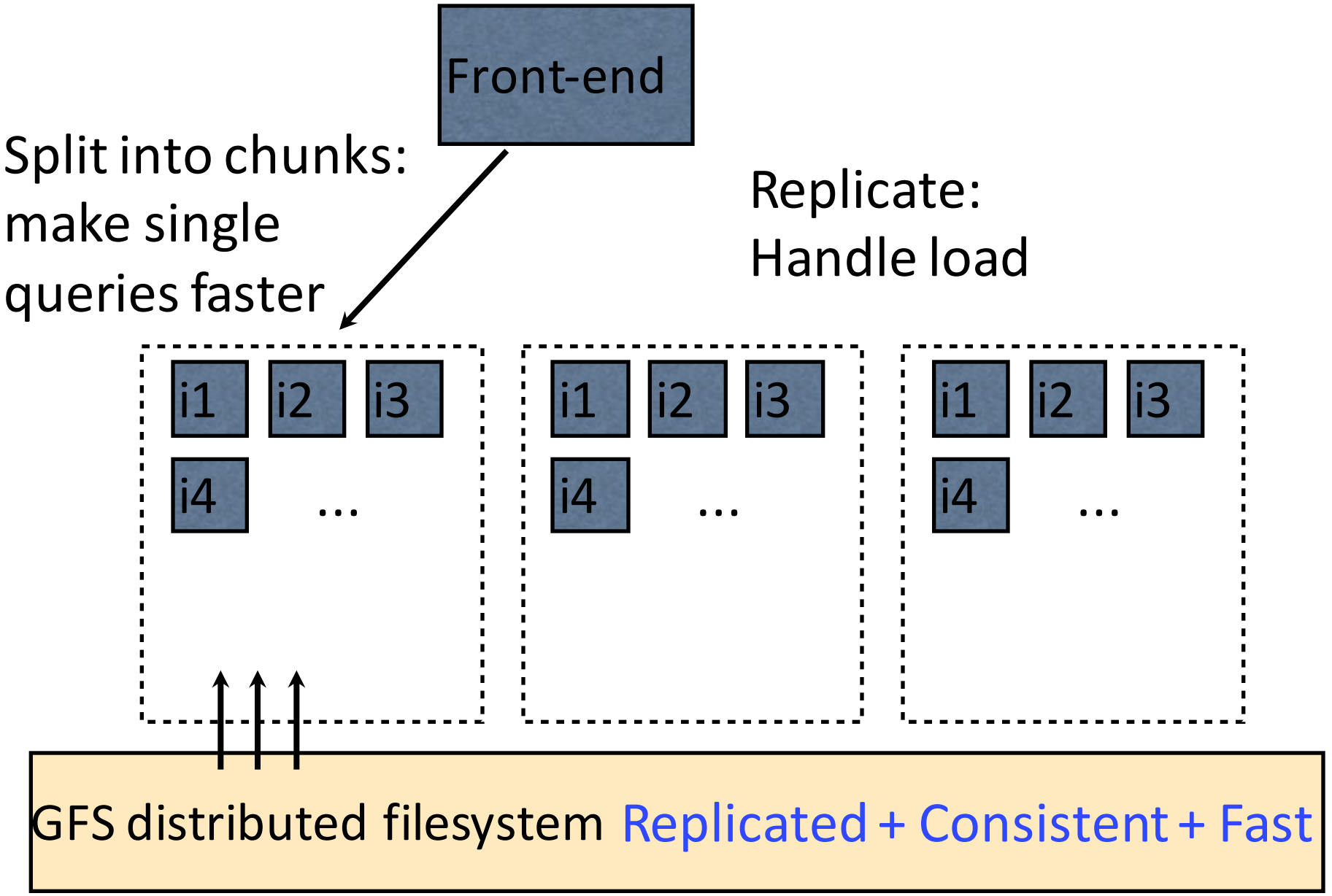
Search for “Trump hairdo”

Front-end





slide from Jeff Dean, Google


Front-end
Split into chunks:
make single
queries faster
Replicate:
Handle load
i1
i2
i3
i4
...
i1
i2
i3
i4
...
i1
i2
i3
i4
...
GFS distributed filesystem Replicated + Consistent + Fast

How do you index the web?

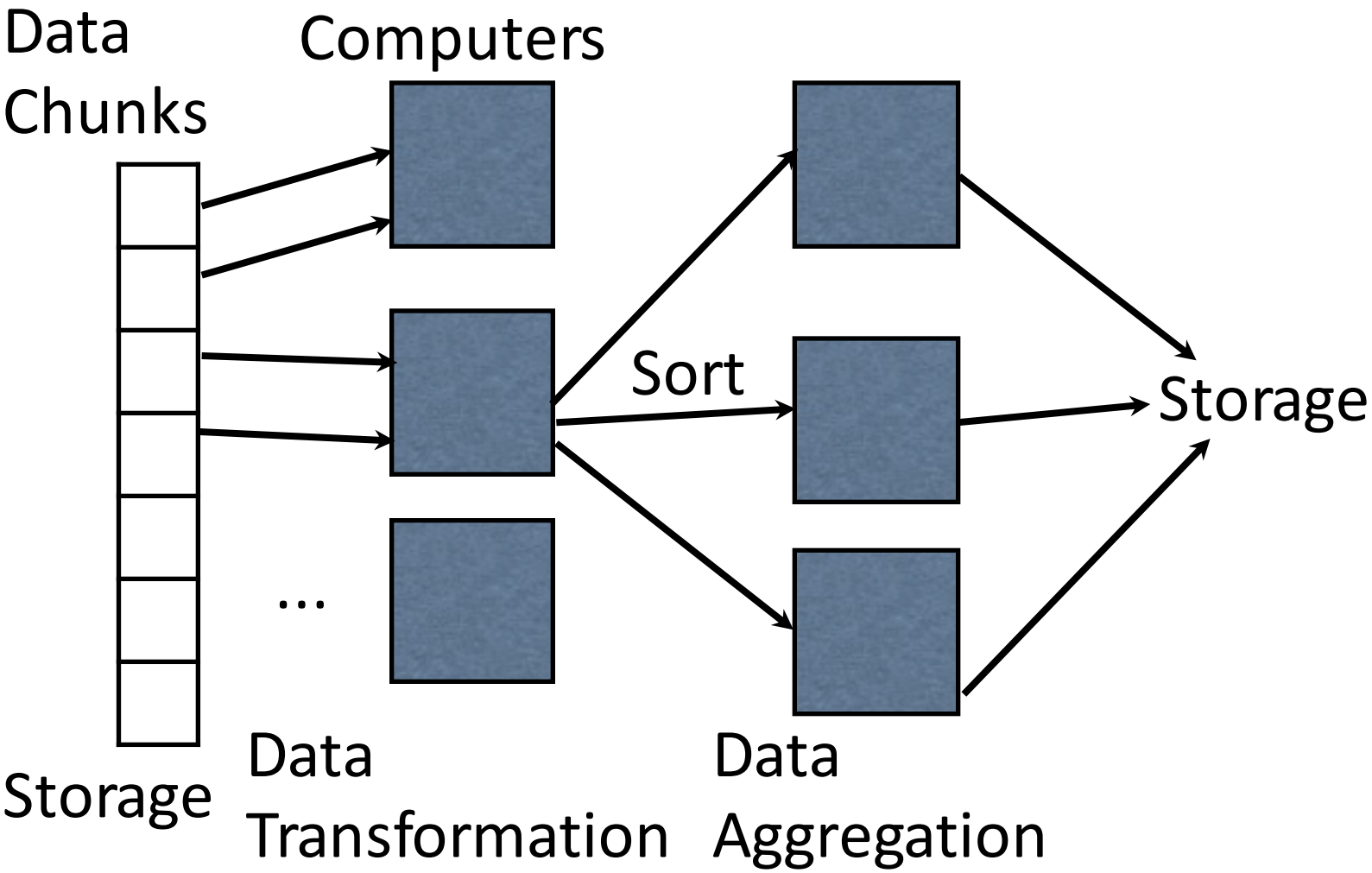
- Get a copy of the web.
- Build an index.
- Profit.

There are over 1 trillion unique URLs
Billions of unique web pages
Hundreds of millions of websites
30?? terabytes of text

- Crawling -- download those web pages
- Indexing -- harness 10s of thousands of machines to do it
- Profiting -- we leave that to you.

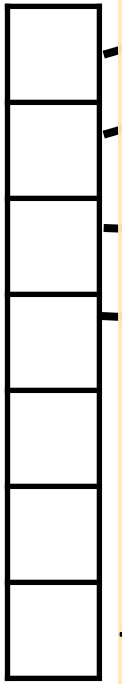
- “Data-Intensive Computing”

MapReduce / Hadoop



MapReduce / Hadoop

Data Chunks



Storage

Why? Hiding details of programming 10,000 machines!

Programmer writes two simple functions:

map (data item) -> list(tmp values)
reduce (list(tmp values)) -> list(out values)

MapReduce system balances load, handles failures, starts job, collects results, etc.

Data Transformation

Data Aggregation

All that...

- Hundreds of DNS servers
- Protocols on protocols on protocols
- Distributed network of Internet routers to get packets around the globe
- Hundreds of thousands of servers
- ... to find out what's the deal with Trump's hair!

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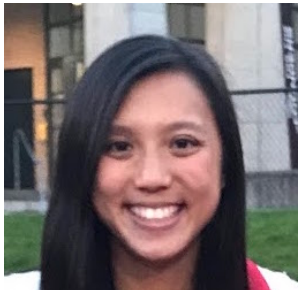
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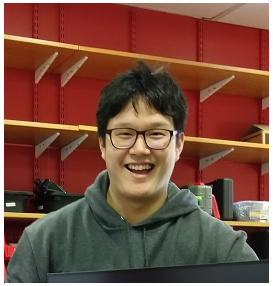
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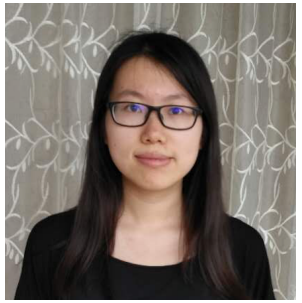
Tian Zhao


(TBD!)

Thanks!


Tuesday September 08, 1992
WHEN I STARTED PROGRAMMING, WE DIDN'T HAVE ANY OF THESE SISSY "ICONS" AND "WINDOWS."
ALL WE HAD WERE ZEROS AND ONES -- AND SOMETIMES WE DIDN'T EVEN HAVE ONES.
I WROTE AN ENTIRE DATABASE PROGRAM USING ONLY ZEROS.
YOU HAD ZEROS? WE HAD TO USE THE LETTER "O."
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J.Adams
9-8