Distributed Systems Fundamentals [Fall 2013]

Lec 1: Course Introduction

Know your staff

- Instructor: Prof. Roxana Geambasu (me)
  - Office hour: Thursday 1-2pm (CSB 461)
  - roxana@cs.columbia.edu
  - http://www.cs.columbia.edu/~roxana/

- Teaching assistants:
  - Peter Du (peter@cs.columbia.edu)
  - Yu Qiao (yq2145@columbia.edu)
  - Their office hours on the website

Important addresses

- Website: **https://www.cs.columbia.edu/~du/ds/**
  - Check regularly for schedules and deadlines!
- Discussions: **Piazza**
  - Please sign up ASAP
- Staff contact:
  - **distributed-systems-class@lists.cs.columbia.edu**
  - If you have a homework-related question, post it on Piazza, as it might help others
  - If you need to communicate something more privately, use the above mailing list or our email addresses

This class will teach you …

1. Core concepts of distributed systems
   – Abstractions, algorithms, implementation techniques

2. Popular distributed systems and tools used by big companies today
   – E.g.: Google's protobuf/Bigtable/Spanner/MapReduce, Sun's NFS, Yahoo's Hadoop, Amazon's Dynamo, etc.

3. How to build a real distributed system yourself
   – Via a series of coding assignments, you will build your very own distributed file system

Relationship with other CU classes

- Multiple "cloud computing" classes are offered @CU
  - Those classes teach you how to use various popular distributed systems (particularly Hadoop)
  - This class will teach you the how those and other systems are built, so you can build and use them better in the future
- Similar to the OS class, but for the distributed environment
  - And in the "cloud" era, everything is distributed!
    - If you want to do data mining you need to build a DS
    - If you want to do mobile apps, you need to build a DS
- Class has distinctive focus on state-of-the-art systems being used today by big companies
  - Concepts classes followed by real-world practice classes

Prerequisites: C/C++!

- Pre-requisites:
  - You must have a <u>solid</u> working experience in C
  - Some knowledge of C++
  - Columbia courses (or equivalents):
    - COMS W3137 Data Structures and Algorithms
    - COMS W3157 Advanced Programming
    - COMS W3827 Fundamentals of Computer Systems
    - Optional, but <u>very</u> useful: COMS 4118 Operating Systems

- If you lack these prerequisites, do <u>**not**</u> take the class
  - Heavy coding accounts for a large portion of the grade!
  - Use first assignment to figure out if you have sufficient experience

Course readings

- Official textbook:
  - Distributed Systems (Tanenbaum and Steen)
  - Fairly outdated (compared to the modern focus of this class), but great for understanding core issues

- Very useful references:
  - The C++ Programming Language (Bjarne Stroustrup)
  - Principles of Computer System Design (Saltzer and Kaashoek)
  - Advanced Programming in the UNIX environment (Stevens)
  - UNIX Network Programming (Stevens)
  - Google's C++ Coding Style Guide

Course structure

- Lectures
  - Read assigned chapters from Tanenbaum before class
  - Participate in class (ask and answer questions)

- Assignments
  - Six graded assignments (HW2-7) plus one pass/fail assignment (HW1)
  - Each assignment has two parts: writing and coding
  - Coding component is a.k.a. a “lab”

Assignments

- Homework 1 is a “sample” homework to help you figure out if you should take course
  - It will be graded pass/fail and will not count to final grade
    - Pass means we welcome you to the course
    - Fail means drop this course and take a prerequisite
  - Assigned today and due Sept 11, 2013
- Homeworks 2-7 build a networked file system with detailed guidance
- All homeworks have written and coding parts
  - Written parts: loosely follow the coding portions and course concepts, and help you understand those better
  - Coding parts: heavy coding, need lots of time!
  - Start with written part then do coding part

Grading

- Grading formula
  - 70%: six graded homeworks
  - 15%: final exam
  - 15%: class participation

- Grading policies
  - No deadline extensions: late submissions will get a 0!
  - Can discuss, but *not* look at others' code or answers
  - For coding: be as clean as you can possibly be
    - Test thoroughly, comment your code, and adhere to a strict coding style (we recommend one on website)
  - More policies on website, read them in detail

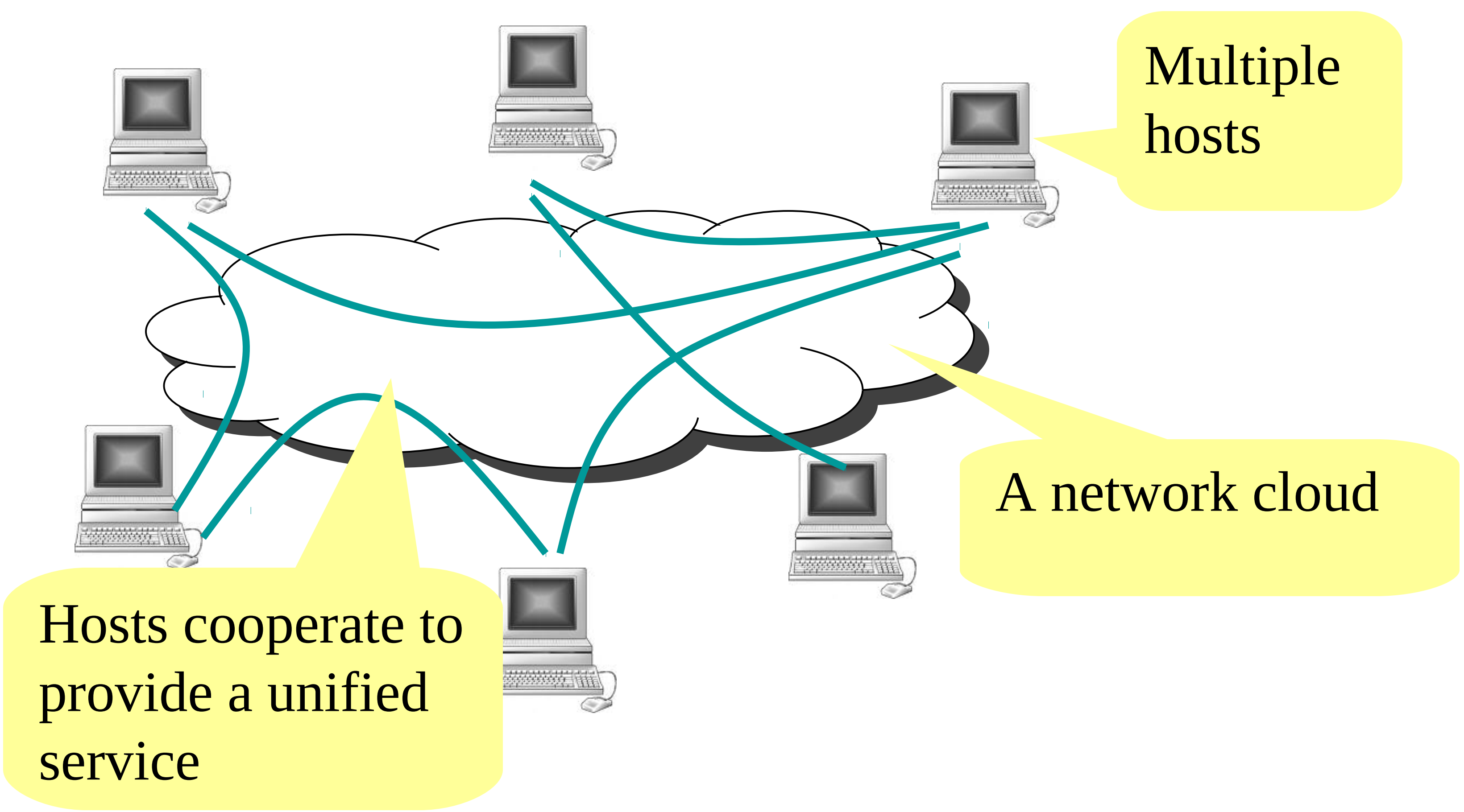
Acknowledgements

- Course builds on several other distributed systems courses:
  - MIT's 6.824 (Robert Morris and Frans Kaashoek)
  - NYU's G22.3033 (Jinyang Li)
  - CMU's 15-440 (David Andersen)

- Lab assignments are taken from MIT, NYU courses
- Lectures are adapted from all three courses
- Website structure is adapted from NYU course
- This lecture is adapted from MIT and NYU lectures 1

Questions?

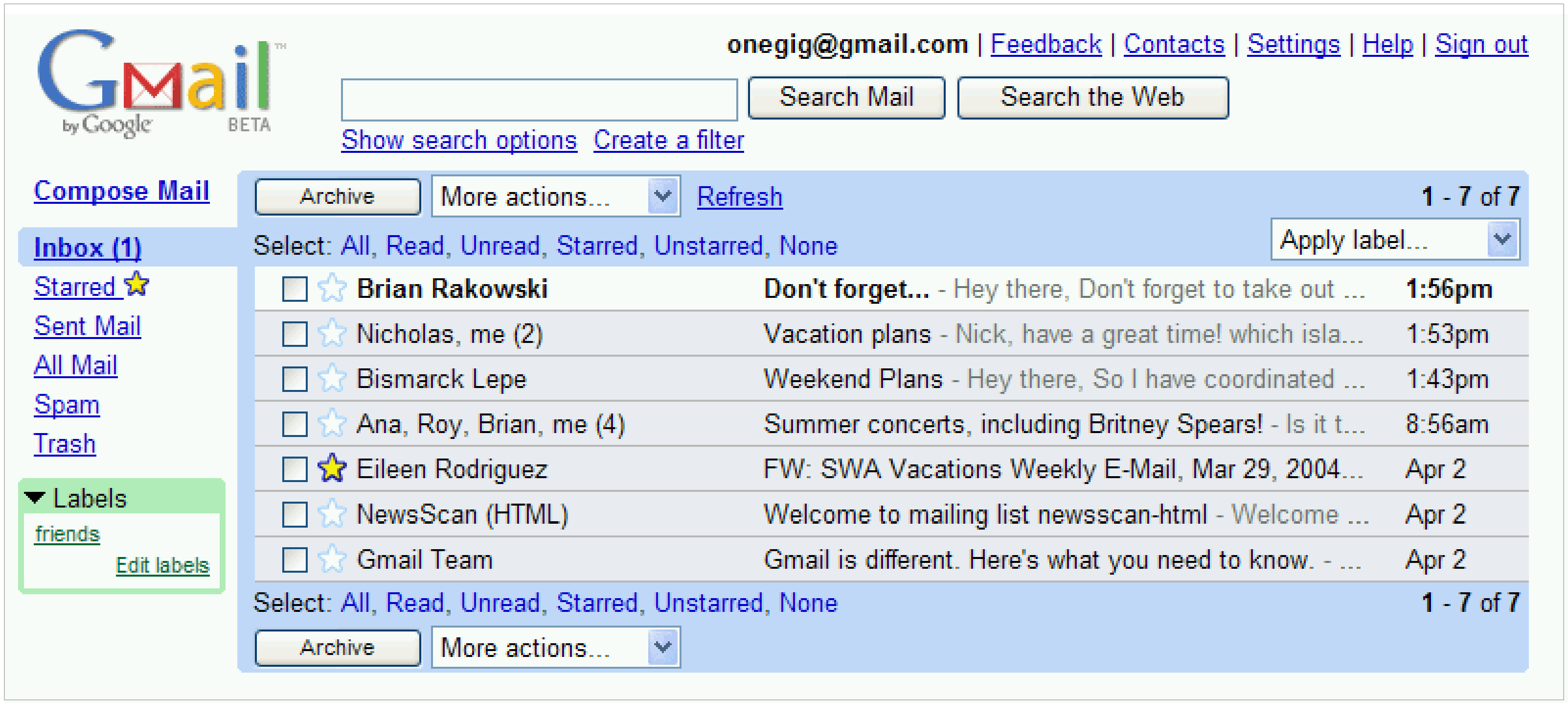
What are distributed systems?



- Examples? Counter-examples?

Example: Gmail

- What do you think happens when you click on “Inbox”?



(screenshot found through google images)

Example: Gmail

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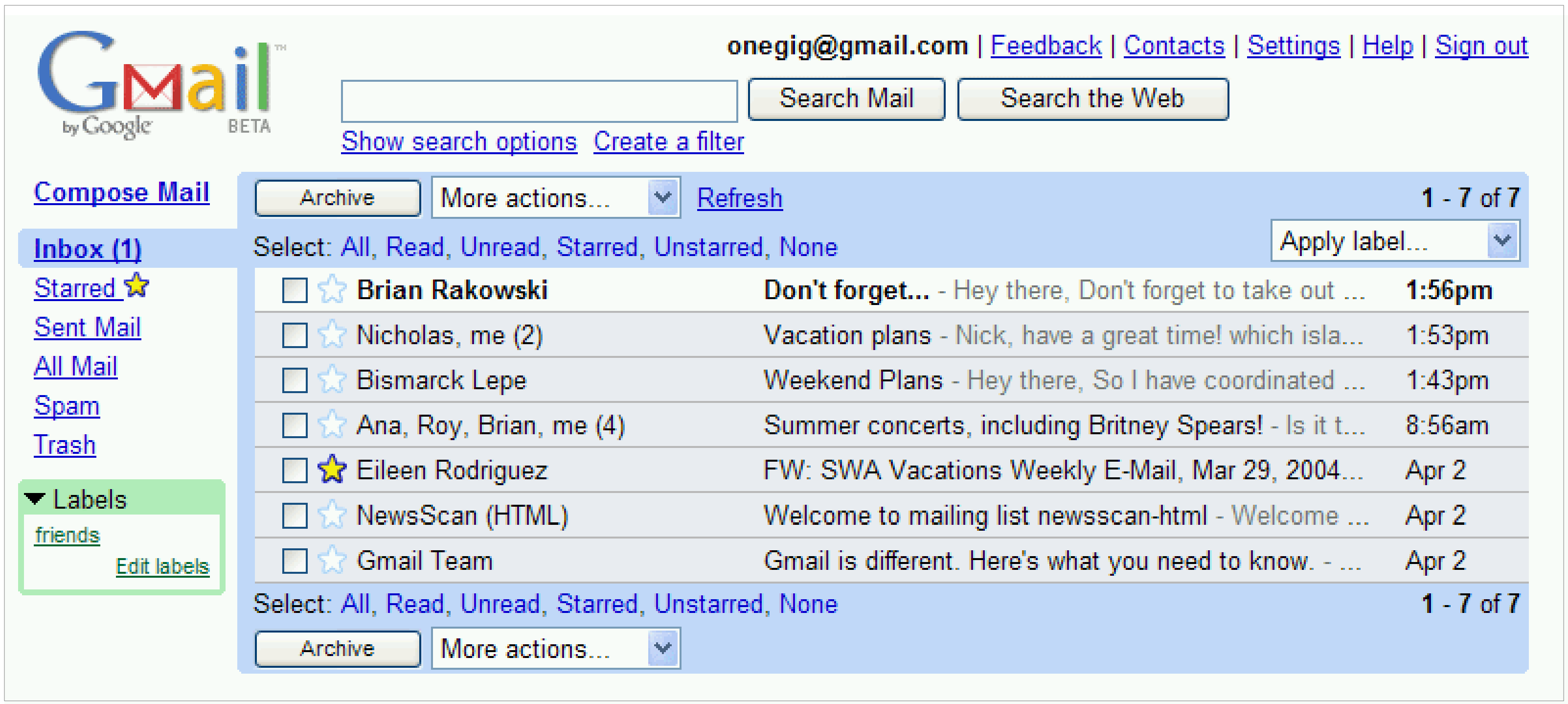
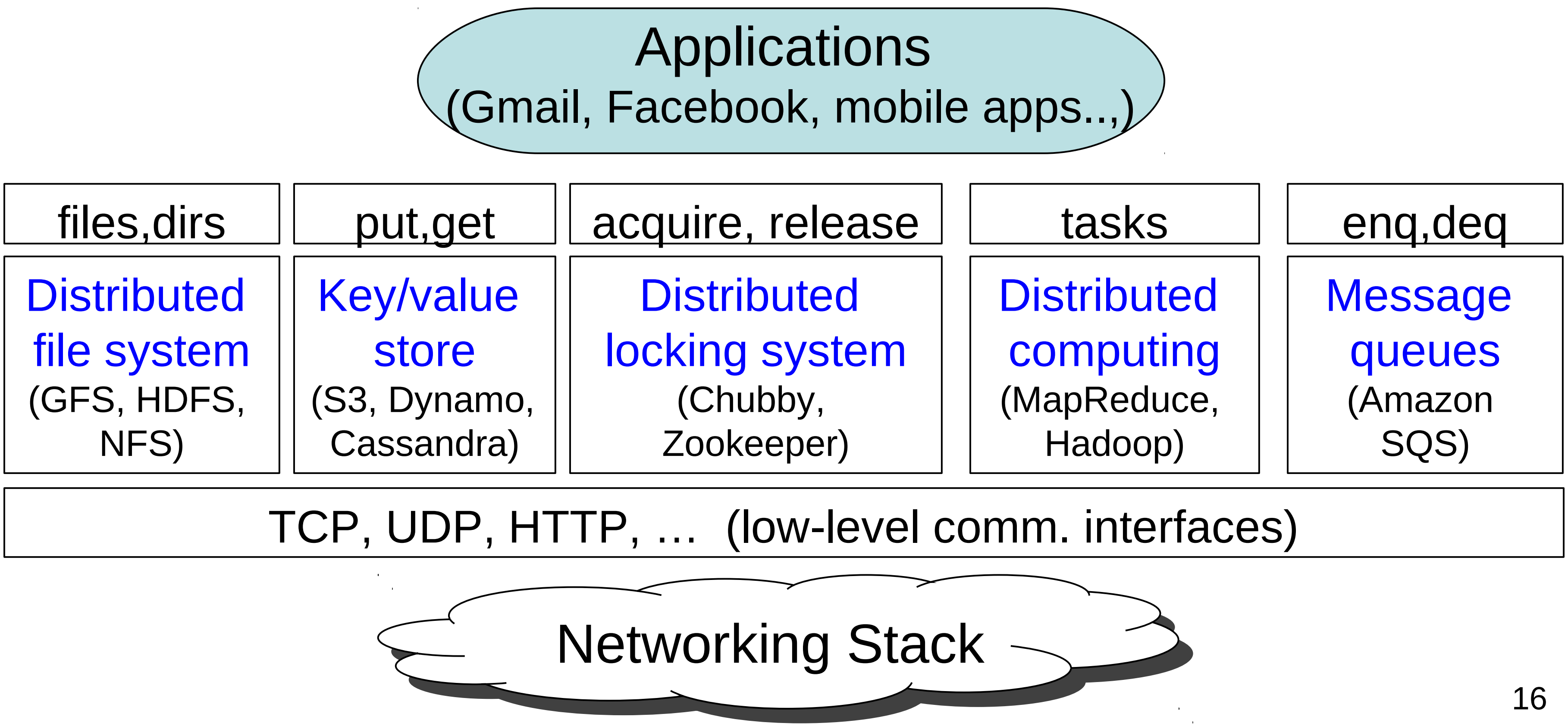


- Lots of components accessed: load balancer, auth service, mem cache, gmail front end, storage service, ads service, batch computations to build profile, etc.

Distributed systems vs. networks

- Distributed systems raise the level of abstraction
- Hide many complexities and make it easier to build applications



Why distributed systems?
for location transparency

- Examples:
  – Your browser doesn’t need to know which Google servers are serving Gmail right now
  – Your Amazon EC2-based mobile app doesn’t need to know which servers in S3 are storing its data

- Why is location transparency important?

Why distributed systems? for scalable capacity

- Aggregate resources of many computers
  - CPU: MapReduce, Dryad, Hadoop
  - Disk: NFS, the Google file system, Hadoop HDFS
  - Memory: memcached
  - Bandwidth: Akamai CDN

- What scales are we talking about?
  - Typical datacenters have 100-200K machines!
  - Each service runs on more like 20K machines, though

Why distributed systems?
for availability

- Build a reliable system out of unreliable parts
  - Hardware can fail: power outage, disk failures, memory corruption, network switch failures…
  - Software can fail: bugs, mis-configuration, upgrade …
  - To achieve 0.9999 availability, replicate data/computation on many hosts with automatic failover

Why distributed systems?
for modular functionality

- Your application is split into many simpler parts, which may already exist or are easier to implement
  - Authentication service
  - Indexing service
  - Locking service

- This is called the service-oriented architecture (SOA) and much of the Web is built this way
  - E.g.: one request on Amazon’s website touches tens of services, each with thousands of machines (e.g., pricing service, product rating service, inventory service, shopping cart service, user preferences service, etc…)

Challenges

- Achieving location transparency, scalability, availability, and modularity in distributed systems is really hard!

- System design challenges
  - What is the right interface or abstraction?

- Achieving scalability is challenging
  - How to partition functions for scalability?

- Consistency challenges
  - How do machines coordinate to achieve the task?

Challenges (Continued)

- Security challenges
  - How to authenticate clients or servers?
  - How to defend against misbehaving servers?
- Fault tolerance challenges
  - How to keep system available despite machine or network failures?
- Implementation challenges
  - How to maximize concurrency?
  - What's the bottleneck?
  - How to reduce load on the bottleneck resource?

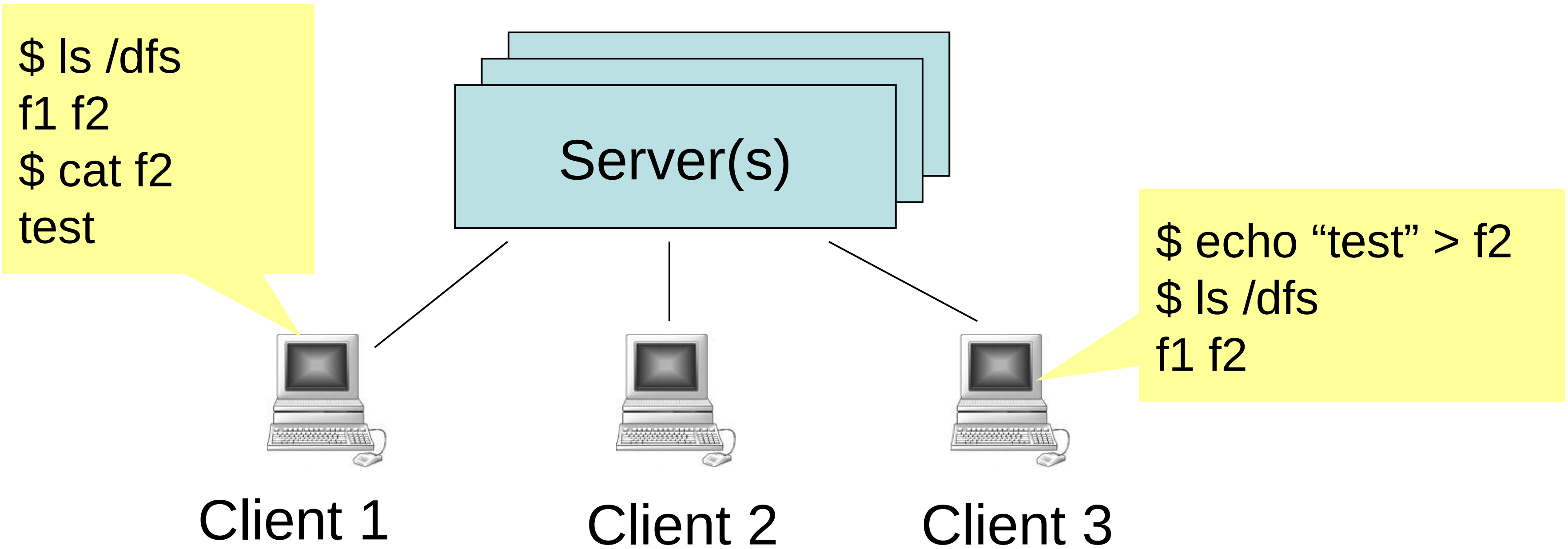
A word of warning

"A distributed system is a system in which I can't do my work because some computer that I've never even heard of has failed."

-- Leslie Lamport

Topics in this course

Case Study:
Distributed file system



- Single shared file system, so users can cooperate
  – Lots of client computers
  – One or more servers
- Examples: NFS (single server), GFS (multi-server)

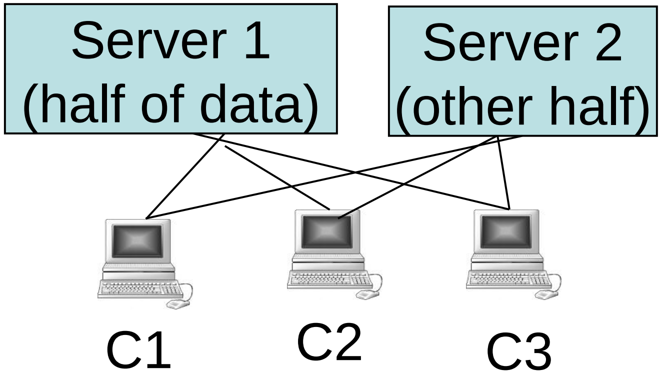
Topic: System Design

- What is the right interface?
  - File interface: relay FS requests to server (NFS, GFS)
  - Block interface: expose disk blocks from server(s) and have FS logic in clients (Storage Area Networks)
  - Key/value: expose put/get interface (Amazon S3)
  - Database: expose a DB interface from the server (Google's Bigtable, distributed RDBMS)

- There is no right answer
  - There are always tradeoffs: performance, ease of programming, scalability
  - Choice depends on the application
  - This will be a theme in this course

Topic: Scalability

- How to scale the distributed file system?
  - Lots of users with lots of data (e.g., all CU students/faculty)
- Ideally: having N servers supports Nx as many users as having one server
- Idea: Partition data across servers
  - By user
  - By file name

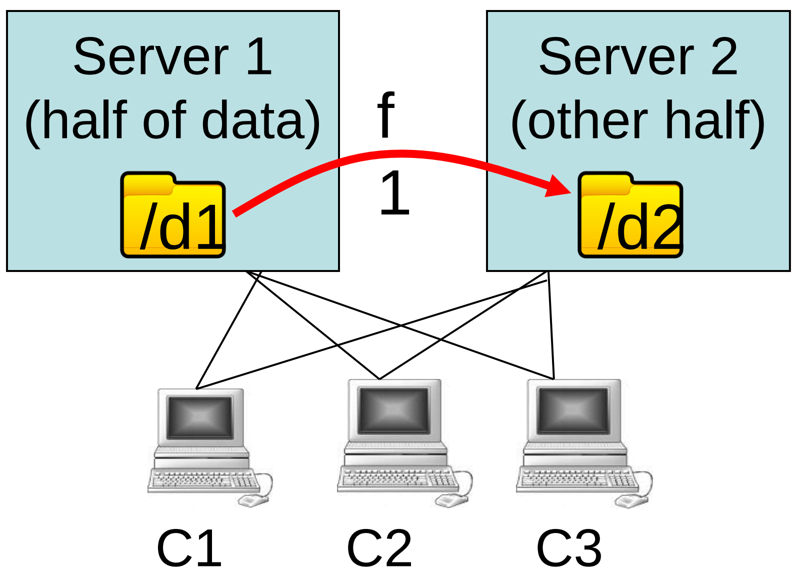


- But you rarely get the ideal… Why?
  - Load imbalance: one very active user, one very popular file
  - One server gets 99.9% of requests; N-1 servers mostly idle

Topic: Consistency

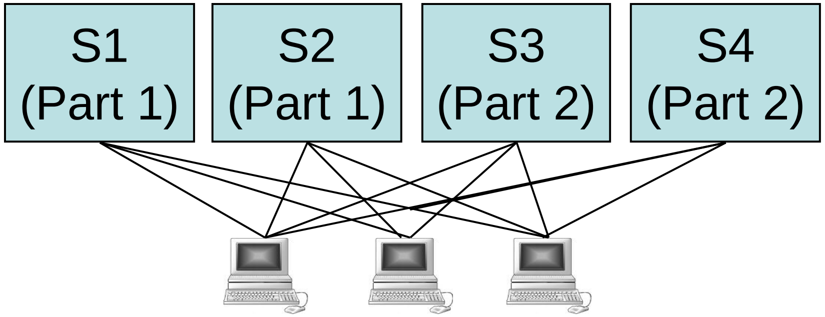
- When C1 moves file f1 from /d1 to /d2, do other clients see intermediate results?
  - f1 in both directories, f1 in neither

- What if both C1 and C2 want to move f1 to different places?



Topic: Fault Tolerance

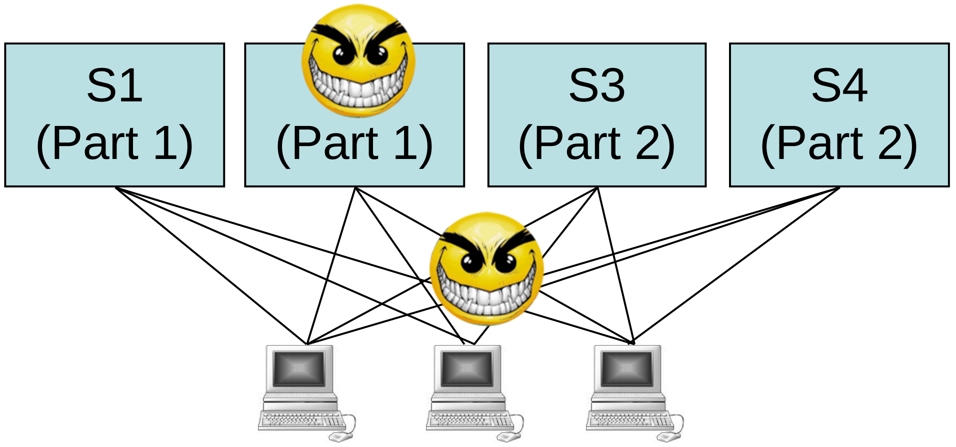
- Can I use my files if server / network fails?
- Idea: replicate data at multiple servers



- But how to maintain consistency despite faults?
  - S1 misses updates while it reboots, so S2 must update it
  - If network's down, S1 can't get updates – should it resume execution?
- In general, consistency is tough and expensive
  - Hence, many applications opt for "weak consistency"

Topic: Security

- Adversary can manipulate or sniff messages to corrupt or access files
  - How to authenticate?
- Adversary may compromise machines
  - Can the FS remain correct despite a few compromised nodes?



Topic: Implementation

- How do clients/servers communicate?
  - Direct network communication is painful
  - Want to hide network stuff from application logic (e.g., RPC, RMI)
- The file server should serve multiple clients concurrently
  - Keep (multiple) CPU(s) and network busy while waiting for disk
  - But concurrency is hard to get right (e.g., race conditions, live locks, deadlocks)

Overview of Homework 1: C++ Warm-up

(Yu Qiao)

About Homework 1

- A warm up exercise.
- Determine whether you are comfortable with this class.
- Will be graded pass/fall. Will NOT be counted towards final grade.
- Read the submission instructions very carefully. It may be complicated.
- Always post your question at Piazza

Next Time

- TODO for you: Homework 1
- We'll do a couple of case studies to understand what distributed systems really are:
  - Web architectures
  - A short history of cloud computing