CS 455: Introduction To Distributed Systems [Introduction]

The Road Ahead

Winds from ports to packets
and thence onto sockets
Over which all data must traverse

Intricacies of threads unraveled
To prod CPUs along roads less traveled

Relegate the bane of insights tardy and stale
By writing code that will scale

Of programs adept at coordination
With nary a dash of intervention

Shrideep Pallickara
Computer Science
Colorado State University

Topics covered in this lecture

- Introduction
- Course overview and expectations
- Communications

DISTRIBUTED SYSTEMS
QUICK OVERVIEW

COMPUTER SCIENCE DEPARTMENT

COLORADO STATE UNIVERSITY

3

What is a distributed system?

- *A distributed system is one in which hardware and software components located at networked computers communicate and coordinate their actions only by passing messages.*

  Coulouris, Dollimore, Kindberg and Blair

- *A distributed system is one in which the failure of a computer you didn't even know existed can render your own computer unusable.*

  Leslie Lamport

COLORADO STATE UNIVERSITY Professor: SHRIDEEP PALLICKARA COMPUTER SCIENCE DEPARTMENT INTRODUCTION L1.4

4

Why Distributed Systems?

- Your hard-drive's primacy has been eroding
- Data and programs are delivered over the network
  - No single hard drive can hold all the data you need
- Services themselves are distributed
  - Google search is backed by a massive distributed cloud

Distributed systems builds on a diverse set of areas

- Networking
- Concurrency
- Algorithms and Graph Theory
- Cryptography
- Failure recovery and consistency models
- Probability theory
- Machine learning
- Information Retrieval
- Transactional Systems

Distributed Systems: CHALLENGES [1/2]

- Scale with increases in data and users
- Responsiveness
  - Regardless of data size, responses must be prompt
- Intelligent
  - Correlate all sorts of information

Distributed Systems: CHALLENGES [2/2]

- Dealing with system conditions
  - Murphy's Law
  - Malicious Users
  - Byzantine failures
- Security
  - Detection
  - Privacy and Accountability
  - Authorizations

ABOUT ME

9

About me

- I do research in this area
- Areas that I have worked or actively work in include:
  - Cloud computing and analytics
  - Internet-of-Things (IoT)
  - Big Data
  - Content dissemination and streaming systems
  - Grid computing
  - P2P systems
  - Object Request Brokers

10

My research has been deployed in

- Urban sustainability
- Epidemic modeling
- Agriculture
- Commercial internet conferencing systems
- Defense applications
- Earthquake sciences
- Environmental monitoring
- Healthcare informatics
- High energy physics
- Visualizations

COURSE LOGISTICS, EXPECTATIONS, AND SUCH

Course webpage

- All course materials will be delivered through **Canvas**
  - Lectures [Slide sets and Video recordings]
  - Assignments
  - Syllabus and Announcements
  - Grades

Office Hours

- Professor: **Shrideep Pallickara**

  Via Zoom

  Office Hours: 9:00 – 10:00 AM Friday
- GTA: Office hours will be via MS Teams

  Miller Ridgeway

  Nishant Kashiv
- Lab/Help Sessions: MS Teams from 4:00 – 5:00 pm on Friday
- Please send all e-mails to: **compsci_cs455@colostate.edu**

Course textbook

- This class has two **optional** textbooks

  Distributed Systems: Principles and Paradigms. *Andrew S. Tanenbaum and Maarten Van der Steen*. 3rd Edition. Createspace, ISBN 9781530281756

  Distributed Systems: Concepts and Design. George Coulouris, Jean Dollimore, Tim Kindberg, Gordon Blair. 5th Edition. Addison Wesley. ISBN: 978-0132143011

When I make slides …

- I usually refer to several texts
  - And technical papers and articles (with URLs)
- I always list my references at the end of every slide set

Textbooks that I will refer to during the course include … (1/2)

- Distributed Systems: Principles and Paradigms. *Andrew S. Tanenbaum and Maarten Van der Steen. 2nd Edition. Prentice Hall. ISBN: 0132392275/978-0132392273.*
- Distributed Systems: Concepts and Design. George Coulouris, Jean Dollimore, Tim Kindberg, Gordon Blair. 5th Edition. Addison Wesley. ISBN: 978-0132143011
- Distributed Computing: Principles, Algorithms, and Systems. *Ajay Kshemkalyani and Mukesh Singhal. 1st edition. Cambridge University Press. ISBN: 0521876346/ 978-0521876346*
- Computer Networks: A Systems Approach. *Larry Peterson and Bruce Davie. 4th edition. Morgan Kaufmann. ISBN: 978-0-12-370548-8.*
- *Java Concurrency in Practice*. Brian Goetz, Tim Peierls, Joshua Bloch, Joseph Bowbeer, David Holmes, and Doug Lea. Addison-Wesley Professional. ISBN: 0321349601/978-0321349606.
- *Java Threads*. Scott Oaks and Henry Wong. . 3rd Edition. O'Reilly Press. ISBN: 0-596-00782-5/978-0-596-00782-9

Textbooks that I will refer to during the course include … (2/2)

- *Hadoop: The Definitive Guide*. Tom White. 3rd Edition. Early Access Release. O'Reilly Press. ISBN: 978-1-449-31152-0
- Concurrent Programming in Java(TM): Design Principles and Pattern. *Doug Lea. 2nd Edition. Prentice Hall. ISBN: 0201310090/978-0201310092.*
- Cloud Application Architectures: Building Applications and Infrastructure in the Cloud. *George Reese.1st edition. O'Reilly. ISBN: 0596156367/978-0596156367.*
- Practical Cryptography. *Niels Ferguson and Bruce Schneier. 1st edition. Wiley Publishing. ISBN: 0-471-22894-X/0-471-22357-3.*
- *Unix Systems Programming. Kay Robbins & Steve Robbins, 2nd edition. Prentice Hall. ISBN: 978-0-13-042411-2.*
- *Operating Systems Concepts. Avi Silberschatz, Peter Galvin, Greg Gagne. 8th edition. John Wiley & Sons, Inc. ISBN-13: 978-0-470-12872-5.*

Infospaces (https://infospaces.cs.colostate.edu)

- New **knowledge repository** that we are building to enhance learning
- All videos are designed to be less than 2 minutes
- Improving Infospaces
  - Let us know what you would like to see
  - If you'd like to contribute to this repository let us know!

GRADING

Grading breakdown

- Assignments: 55%
  - HW1: 15%; HW2: 20%; HW3: 20%
- Term project and paper: 10%
- Term project presentation: 5%
- Quizzes (10 best) : 10%
- Midterm: 10%
- Final exam: 10%

Grading Policy [1/3]

- Letter grades will be based on the following standard breakpoints:
  - >= 90 is an A, >= 88 is an A-,
  - >= 86 is a B+, >=80 is a B, >=78 is a B-,
  - >= 76 is a C+, >=70 is a C,
  - >= 60 is a D, and <60 is an F.
- I will not cut higher than this, but I *may* cut lower.

Grading Policy [2/3]

- Every assignment will be posted at least 4 weeks before the due date.
- Every assignment will include information about:
  - How much it will count towards the course grade
  - How it will be graded
- Late submission penalty: 7.5% per-day for the first 2 days
  - Submissions after the late submission period will have an automatic ZERO
  - If you submit the wrong files and notice after 2 days? 40% deduction
  - Detailed submission instructions posted on the course website.
  - Assignments will be graded within 2 weeks of submission

Grading Policy [3/3]

- If you have problems with the grading
  - Talk to the GTAs first
- The GTAs strive to ensure that the grading is consistent across the board

Quizzes, midterm, and final

- Each component accounts for **10%** of the course grade
- Final is comprehensive
- There will be 13 quizzes
  - 3 quizzes where you had your lowest scores will be dropped
    - We will take your 10 highest scores
  - Quizzes, midterms, and final are Open Book and administered via Canvas
  - There will be at least a 48-hour window to take the exam
    - There will be no make-up exam

Quizzes, mid term, and final

- I will only ask questions about what I teach
- If the concepts were covered in my slides
  - You should be be able to answer the questions

ASSIGNMENTS

27

Assignments: What to expect

- There will be no busy work
  - No GUI
- Complexity will not be through obfuscation
- You will be able to look back and feel good about them
  - Delayed gratification

28

There will be 3 assignments [Java]

- Networking assignment
- Threading Assignment
- Scalable programs using MapReduce (Hadoop)

Assignments

- You will have about **4 weeks** to complete each assignment
- The assignments will include **milestones** that should be achieved for each week

Term project [1/2]

- This will be based on Apache SPARK
- Term project deliverables
  - Source codes [7 points]
  - Term Project Report [3 points]
  - Term Project Presentation [5 points]

Term project [1/2]

- The term project is a group effort
  - Team size = 2-3 and you can choose your teammate.
  - Please **respond** to your teammate's e-mails on time!
    - Make sure he/she has the e-mail that you check regularly
  - If you have problems finding a teammate, please let us know

Assignments: Logistics

- Assignments will be due **at 5:00 pm**
  - **Programming** assignments are due on **Wednesdays**
- You are allowed to submit up to 2 days late
  - There is a **7.5%** deduction for each day that you are late
- All assignments (except the term project) are **individual** assignments

WHAT IT TAKES TO SUCCEED

What it takes to succeed [1/3]

- You are required to work **~12 hours** per-week outside of class
  - Coding and reviewing material from class
- If you miss a lecture
  - Add about 3 hours per missed lecture

What it takes to succeed [2/3]

- Work on the assignments **every day**
  - There is no such thing as waiting for inspiration to strike!
- **Reflect** about how you could have designed things differently for better performance
  - Even after you have submitted an assignment
  - It will improve the choices you make in the next assignment

What it takes to succeed [3/3]

- Work in bigger-sized chunks
  - Too many short bursts = Too many context switches
    - You will be busy doing nothing
- Document your code

Other pitfalls

- Poor management of **course loads**
  - Plan the number and type of courses you take
  - Don't spread yourself so thin that you do not give yourself the opportunity to succeed
- Not attacking the problem and working on the fringes
  - Spend your time wisely on critical paths

Interactions

- You can have discussions with me, the GTAs, and your peers
- There are **two constraints** to these discussions
  1. No code can be exchanged under *any* circumstances
  2. No one takes over someone else's keyboard
- Bumps are to be expected along the way
  - But you should get over this yourself
  - It will help you with the next problem you encounter

TOPICS COVERED IN CS455

Topics covered in CS455 [1/2]

- Communications
- Threads: Safety and Concurrency
- Building scalable servers
- MapReduce
- Spark

Topics covered in CS455 [2/2]

- Distributed mutual exclusion
- Election algorithms
- File systems and network storage
- Distributed server topologies
- Distributed storage systems

COMMUNICATIONS & NETWORKING

43

Example:
Setting up connections to a server

- Programs open a **socket** to a server that's *listening* for connections
- To create a `Socket` you need to know the Internet host you want to connect to
- Servers don't know *who* will contact them
  - If it did, difficult to synchronize *when* this would happen

44

An analogy

- Server is like a person sitting by the phone
  - Doesn't know *who* will call and *when*
  - When the phone rings?
    - Talk to whoever is on the other line

Java provides a `ServerSocket` to enable writing servers

- `ServerSocket` runs on the server
  - **Listens** for *incoming* network connections on a particular **port** on the host that it runs on
- When a client socket on a remote host attempts to connect to that server port
  1. Server **wakes** up
  2. **Negotiates** a connection between the client and server
  3. **Opens** a regular `Socket` between the two hosts

Some more about the two types of sockets

- `ServerSockets` **wait** for connections
- Client `Sockets` **initiate** connections
- Once the `ServerSocket` has set up the connection?
  - **Data always travels over the regular `Socket`**

Using the `ServerSocket`

- Created on a particular **port** using the `ServerSocket(port)` constructor
- Listen for communications on that port using `accept()`
  - **Blocks** *until* a client attempts to make connection
  - Returns a `Socket` object that **connects** the client to the server
- Use the `Socket`'s `getInputStream()` and `getOutputStream()` to communicate

Creating the `ServerSocket`

- `ServerSocket serverSocket = new ServerSocket(5000);`
  - Tries to create a server socket on port 5000
- `ServerSocket serverSocket = new ServerSocket(5000, 100);`
  - Can hold up to 100 incoming connections
- `ServerSocket serverSocket = new ServerSocket(5000, 100, InetAddress.getHostByName ("address2.cs.colostate.edu"));`
  - On a **multi-homed** host, specify the network-address over which connections should be accepted

Accepting network connections

```
ServerSocket serverSocket =
     new ServerSocket(portNum);
while(true) {
   Socket socket = serverSocket.accept();
   ...
}
```

Closing the client and server sockets

- Closing a `ServerSocket` **frees** a port on the host that it runs on
- Closing a `Socket` **breaks** the connection between the local and remote hosts

We exchange byte streams over the socket

- The `java.io` package contains the `DataInputStream` and `DataOutputStream` that lets you do this elegantly
- `DataInputStream din =`
  `new DataInputStream(socket.getInputStream());`
- `DataOutputStream dout =`
  `new DataOutputStream(socket.getOutputStream());`

Elements that play a role in communications

- **Transmission media**
  - Wire, cable, fiber, and wireless channels
- **Hardware devices**
  - Routers, switches, bridges, hubs, repeaters, and network interfaces
- **Software components**
  - Protocol stacks, communication handlers, and drivers

Communications & Networking: Topics that we will cover

- Data transmission
- Switched Networks
- Bandwidth and Latency
- Multiplexing
- Internet Architecture
- IP routing (IPv4 and IPv6)
- The TCP and UDP protocols

COMMUNICATIONS & NETWORKING {HOW DATA IS SENT}

COMPUTER SCIENCE DEPARTMENT

COLORADO STATE UNIVERSITY

55

How is the data sent?

- Are we sending **1**'s and **0**'s?
- Whatever the physical medium, we use **signals**
  - Electromagnetic waves traveling at the speed of light
    - Speed of light is different in different mediums

COLORADO STATE UNIVERSITY Professor: SHRIDEEP PALLICKARA COMPUTER SCIENCE DEPARTMENT INTRODUCTION L1.56

56

Components of encoding binary data in a signal

- Modulation
- Duplexity

Encoding binary data: Modulation

- Objective is to send a ***pair*** of **distinguishable** signals
- Vary frequency, amplitude, or phase of the signal to transmit information
  - E.g. vary the power (amplitude) of signal
  - $x(t) = A \sin(2\pi ft + \theta)$

Encoding binary data: Duplexity

- *How many* bit streams can be encoded on a link at a time?
  - If it is one: nodes must share access to link
- Can data flow in both **directions** at the same time?
  - Yes ➔ full-duplex
  - No ➔ half-duplex

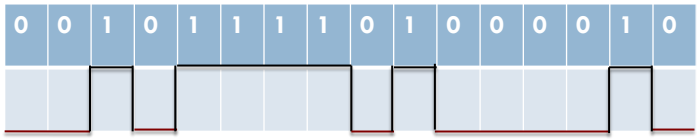
For our purposes, let's ignore details of modulation

- Assume we are working with two signals
  - High and low
- In practice:
  - Different voltages on a copper-based link
  - Different power-levels on an optical link

Let's do the obvious thing

- Map **1** to a high signal
- Map **0** to a low signal

Non-return to zero (NRZ)



Problems with NRZ because of consecutive 1's and 0's: **BASELINE WANDER**

- Receiver keeps **average** of the signal seen so far
- Average is used to *distinguish* between low and high
- Lots of consecutive **1**/**0**'s will make it difficult to detect a significant change

Problems with NRZ because of consecutive 1's and 0's: **CLOCK RECOVERY**

- Every clock cycle, sender transmits and the receiver receives
- Sender and receiver's clocks must be perfectly **synchronized**
  - Otherwise, it is not possible to decode the signal

The contents of this slide-set are based on the following references

- *Computer Networks: A Systems Approach. Larry Peterson and Bruce Davie. 4th edition. Morgan Kaufmann. ISBN: 978-0-12-370548-8. [Chapter 1, 2]*
- *Java Network Programming, Third Edition. Elliotte Rusty Harold. O'Reilly. ISBN-10: 0596007213 / 978-0596007218.* [Chapter 7]