CS 555: Distributed Systems [Introduction]

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Topics covered in this lecture

- Course overview and expectations
- Broad brushstroke coverage of distributed systems

COURSE OVERVIEW AND SUCH

Course webpage

- All course materials will be on the course webpage **http://www.cs.colostate.edu/~cs555**
  - Schedule
  - Lectures
  - Assignments
  - Announcements
- Grades will be posted on **Canvas**
- **Piazza**: For discussions

On the schedule page

- You will see the **topics** that will be covered and the **order** in which I will cover them
- The readings section will list the books (and the chapters therein) that form the basis for the materials
- You will also see the schedule for when the **assignments** will be posted and when they are due

Office Hours

- Shrideep Pallickara
  Computer Science (CSB 364)
  Office Hours: 2:00-3:00 pm Friday or by appointments
- GTA: Daniel Rammer
  Office Hours: Will be finalized soon.

Why Distributed Systems?

- Your hard-drive's primacy has been eroding
- Data sources 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

- Algorithms and Graph Theory
- Cryptography
- Networking
- 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
- Dealing with system conditions
  - Murphy's Law
  - Malicious Users
  - Byzantine failures

Distributed Systems: Challenges [2/2]

- Security
  - Detection
  - Privacy and Accountability
  - Authorizations

About me

- I do research in this area
- Areas that I have worked or actively work in include
  - Cloud computing
  - Internet of Things, Edge/Fog Computing
  - Grid computing
  - Peer-to-Peer systems
  - Content dissemination systems
  - Object Request Brokers
  - Collaborative systems

EXPECTATIONS

Expectations

- You will attend all classes
- You will focus on the discussions, and not on …
  - Other assignments
  - Social networking updates
- Programming Assignments have to be done **individually**
- You will be **challenged** in this course
  - Assignments are geared toward real systems

ASSIGNMENTS

Programming Assignments: Logistics

- Programming assignments will be due **at 5:00 pm on a Wednesday**
- You are allowed to submit up to 2 days late
  - There is a **7.5%** deduction for each day that you are late
- All programming assignments are **individual** assignments

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

There will be 3 programming assignments and a Term Project

- Contrasting replication and erasure coding in a distributed file system
- Structured P2P system
- Cloud computing assignment
- Term Project & Report [35]
  - Team Effort: Groups of 2-3 (Must include at least one on-campus and distance student)

WHAT IT TAKES TO SUCCEED

What it takes to succeed (1/2)

- You are required to work at least **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 (2/2)

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

How to fail this course?

- Believing that you can learn via osmosis
- **Missing lectures**
  - If you don't have the discipline to show up, you will most likely not have the discipline to catch up
- **Procrastinating**
  - The assignments cannot be done in a week
  - *Organize your schedule* so that you can succeed

Use of laptops, cell phones, tablets, and other electronic devices

- **Is not allowed**
- If you must use a laptop you will have to:
  - Turn off wireless
  - And use it only for taking notes
- Authorized laptop users
  - Will sit in the back row starting at the corners

Why attend lectures if all the slides are posted?

- Slides are only part of the story
  - They anchor the discussion
- Any field has a *language* associated with it
- People who have worked in an area for a long time speak the language (*and do so subconsciously*)
  - Sitting in classes helps you learn how to frame questions and responses
- Often there are surprising questions
  - Some of these may be asked by interviewers

Help me help you

- We will have **surveys** at the end of every class
- You will provide a list of
  - 3 concepts you followed clearly
  - 3 concepts you had problems keeping up with
- Problem areas for the majority of the class will be addressed in the next class

Interactions

- You can have discussions with me and your peers
- There are **two constraints** to these discussions
  - No code can be exchanged under any circumstances
  - 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

GRADING

Grading Breakdown

- Programming Assignments: 55%
- Term Project & Report: 35%
- Quizzes: 10%

Grading: Letter Grades

- 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 and Late Submissions

- There is **no extra-credit**
  - Any credit you earn must be on a level-playing field with your peers
- There will be **no make-up exams**
- Assignments will have an interview portion

For the Quizzes

- I will only ask questions about what I teach
  - If I didn't teach it, I won't ask from that portion
- If the concepts were covered in my slides
  - You should be be able to answer the questions

When I make slides

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

There is no textbook for this course, but we will rely on several texts/papers

- *Distributed Systems: Principles and Paradigms. Andrew S. Tanenbaum and Maarten Van der Steen. 2nd Edition. Prentice Hall. ISBN: 0132392275/978-0132392273.*
- *Distributed Computing: Principles, Algorithms, and Systems. Ajay Kshemkalyani and Mukesh Singhal. 1st edition. Cambridge University Press. ISBN: 0521876346/ 978-0521876346*
- *Concurrent Programming in Java(TM): Design Principles and Pattern. Doug Lea. 2nd Edition. Prentice Hall. ISBN: 0201310090/978-0201310092.*
- *Distributed Algorithms. Nancy Lynch. 1st edition. Morgan Kaufman. ISBN: 1558603484/978-1558603486.*
- *Cloud Application Architectures: Building Applications and Infrastructure in the Cloud. George Reese.1st edition. O'Reilly. ISBN: 0596156367/978-0596156367.*

There is no textbook for this course, but we will rely on several texts/papers

- *Computer Networks: A Systems Approach. Larry Peterson and Bruce Davie. 4th edition. Morgan Kaufmann. ISBN: 978-0-12-370548-8.*
- *Practical Cryptography. Niels Ferguson and Bruce Schneier. 1st edition. Wiley Publishing. ISBN: 0-471-22894-X/0-471-22357-3.*
- *Cryptography and Network Security: Principles and Practice. William Stallings. 5th Edition. Prentice Hall. ISBN: 0136097049/978-0136097044*
- *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.*

TOPICS TO BE COVERED IN CS555

Topics covered in CS555

- Time
- Threads and Processes
- Role of Order
- Content Dissemination Systems
- Peer to Peer Systems
- Data intensive computing
  - MapReduce
- Stream Processing Systems
  - Spark

Topics covered in CS555

- Replication and Consistency Models
  - Brewers CAP
- Cloud Storage Systems
  - Google File System, Amazon Dynamo
- Distributed Objects and RPCs
- Virtualization
  - Server Consolidation

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BROAD BRUSHSTROKE COVERAGE OF DISTRIBUTED SYSTEMS

Distributed systems definition

- *A distributed system is a collection of independent computers that appears to its users as a single coherent system*
  - Andrew Tanenbaum
- *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

Distributed Systems: GOALS

- Making resources accessible
- Distribution transparency
- Openness
- Scalability

GOAL 1: Making resources accessible

- **Share resources** in a controlled and efficient fashion
  - Printers, computers, storage facilities, etc.
- Reasons for sharing?
  - Economics: Often *cheaper* to share than to have copies
  - Easy to *collaborate* and exchange information

As connectivity and sharing increase security issues become important

- Protection against intrusion and eavesdropping of communications
- Entities can track communications to build profiles of users
  - Violates privacy
  - Unwanted communications
    - Spam?

GOAL 2: Distribution transparency

- **Hide** the fact that the the constituent processes and resources are physically distributed
  - Across multiple computers
- System should present itself to the application & users as if it were a single computer system
  - **Transparency**

Types of transparency

Transparency	Description
Access	Hide differences in data representation and how a resource is accessed
Location	Hide where a resource is located
Migration	Hide the fact that a resource may move to another location
Relocation	Hide that a resource may be moved to another location while in use
Replication	Hide that a resource is replicated
Concurrency	Hide that a resource may be shared by several competitive users
Failure	Hide the failures and recovery of a resource

Degree of transparency: Sometimes we cannot hide all distribution aspects from users

- Time zone variations
- Communications are not instantaneous
  - Signal transmission is limited by the
    - Speed of light
    - Limited processing capabilities of intermediate switches

Trade-off between transparency and performance of system

- EXAMPLE: Mask transient server failure by *retrying* connections periodically
  - Maybe better to give up earlier or try another server
- EXAMPLE: Several replicas need to be kept *consistent* at all times
  - If change is made to one copy, it must be propagated to all copies *before* a new change can be made

GOAL 3: Openness

- Offer services according to standard rules that describe **syntax** and **semantics** of those services
  - E.g., in networks, rules govern: format, content, and meaning of messages
  - Formalized in **protocols**
- Services are generally specified through interfaces

What are these interfaces?

- Specify names of functions
  - Along with types of parameters, return values, possible exceptions, etc.
  - IDL (Interface Definition Language), WSDL (Web Services Description Language)
- Hardest part is specifying the semantics of these interfaces
  - What exactly does the service do?

Interoperability

- The extent to which two implementations of components from different manufacturers
  - **Coexist** and *work together*
  - Merely by relying on each other's interfaces

Portability

- Extent to which application developed for distributed system **A**
  - Can be executed, *without modification*, on a different distributed system **B** that implements the same interfaces as **A**

Extensibility

- Configure system out of *different* components
  - Possibly from different developers
- Add new components, replace existing ones
  - Without affecting components that stay in place
- Examples:
  - Add parts that run on a different OS
  - Replace an entire file system

Achieving flexibility

- System must be organized as a collection of **small**, replaceable or adaptable components
- Definitions for not only highest-level interfaces but also for internal parts of the system
  - Describe how these interact

Flexibility example: Caching within a browser

- Browsers allow you to *adapt* caching policy
  - Specify size of the cache
  - Consistency check of cached document
- However you cannot influence other parameters such as
  - *How long* can a document remain in the cache?
  - Which document should be removed when the cache fills up?
  - Cannot make caching decisions based on content
    - For e.g., metro train timetables rarely change

What we need is a separation of policy and mechanism

- Browser should ideally provide facilities *only* for storing documents
  - Users decide which documents are stored and for how long
  - Perhaps user can implement policy as a pluggable browser component

GOAL 4: Scalability Dimensions

- **Size**
  - Should be possible to add *more users and resources* to the system
- **Geographically scalable**
  - Users and resources may be spatially far apart
- **Administrative scalability**
  - Should be easy to manage even if it spans many independent administrative domains

Examples of scalability limitations

Concept	Example
Centralized services	A single server for all users
Centralized data	A single on-line telephone book
Centralized algorithms	Doing routing based on complete information

Characteristics of decentralized algorithms

- No machine has complete information about system
- Machines make decisions based only on local information
- Failure of one machine does not ruin algorithm
- No implicit assumption that a global clock exists

Scaling techniques: Asynchronous communications

- **Avoid waiting** for responses to requests that were issued
  - Works well in WAN and geographically dispersed settings
- Alternatively, use a **separate thread** of control for requests
- Does not work well in interactive applications

Scaling techniques: Distribution

- Take a component and **split** them into smaller parts
  - **Disperse** these parts across the system
- Examples:
  - Domain Name System (DNS)
  - World Wide Web

Scaling techniques: Replication

- Scaling problems usually manifest themselves as performance problems
  - Slow responses, and such
- Replication involves having dispersed copies
  - Increases **availability**
    - Better fault tolerance
  - **Balances load** between components
    - Leads to better performance

Pitfalls: False assumptions made during development of a distributed application

- The network is reliable
- The network is secure
- The network is homogeneous
- The topology does not change
- Latency is zero
- Bandwidth is infinite
- Transport costs is zero
- There is one administrator

List by:
Peter Deutch
Sun Microsystems

Trade-off space in distributed systems

1. CPU and memory utilization
2. Synchronization overhead
   - Number, type, and size of messages exchanged
3. Consistency
   - Brewers CAP theorem
4. Time
   - Completion time, response times, etc
5. Costs

ONTOGENY RECAPITULATES PHYLOGENY

After Charles Darwin's book ON THE ORIGIN OF SPECIES was published

- German zoologist Ernst Haeckl stated
  - Ontogeny recapitulates Phylogeny

Development of an embryo — *repeats* — *the evolution of the species*

- i.e. human egg goes through stages of being a fish, … , before becoming human baby
- Modern biologists think this is a gross simplification!

Something vaguely similar has happened in the computer industry

- Each new species (*type of computer*) goes through the development that its ancestors did
  - Both in hardware and software
  - Mainframe, mini computers, PC, handheld, etc

Much of what happens in computing and other fields is technology driven

- Ancient Romans lacked cars not because they liked walking
  - It is because they didn't know to build cars
- PCs exist not because people have a centuries-old pent-up desire to own one
  - It is now possible to manufacture them cheaply

Technology affects our view of systems

- A **change** in technology renders some idea obsolete
  - Another change could revive it
- Especially true when change has to do with **relative performance**
  - Of different parts of the system

Let's look at this relative performance

- When CPUs become faster than memories?
  - Caches become important to speed-up slow memory
- If new memory technology makes memories much faster than CPUs?
  - Caches will vanish!
- In biology extinction is forever
  - In computer science it is sometimes only for a few years

Systems stand on the shoulders of those that have come before it

- Client-Server
- 3-tier (or N tiers)
- Distributed Objects (DCOM, CORBA, RMI)
- Message Passing based
  - Queuing, Publish/Subscribe, Peer-2-Peer
- Grid Computing
- Service Oriented Architectures (XML)
- Cloud Computing

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

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- Andrew S Tanenbaum and Herbert Bos. *Modern Operating Systems*. 4th Edition, 2014. Prentice Hall. ISBN: 013359162X/978-0133591620