Introduction

PEC-CS-601G Parallel & Distributed System

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Outline of the Course

- Course Webpage: https://soumadip.github.io/courses/DS/
- Broad overview
  - **Introduce you to distributed system design**
  - **Algorithms and system design issues**
  - **Real world Examples**
- Internals evaluation
  - Term projects, Case studies
- Reference books
  - Advanced Operating Systems by Mukesh Singhal and Niranjan Shivaratri
  - Distributed Systems: Principles and Paradigms by Andrew Tanenbaum and Maarten van Steen
  - Distributed Database Systems by D.Bell and J. Grimson, Addison

What is a Distributed System?

“A distributed system is a system where I can’t get my work done because a computer has failed that I’ve never even heard of.”

- Leslie Lamport

What is a Distributed System?

A network of autonomous machines/devices that communicate to perform some task

Modes of communication

- Message passing
- Distributed Shared Memory

Major Components

- Machines, Devices
  - PCs, servers, specialized devices
  - Commonly called **nodes**
- Network
  - links, switches, routers
- Storage
  - local, distributed

- Systems software/ applications/ tools
  - Distributed OS, databases, filesystems, load balancer, event, performance monitoring tools, security software…
  - Not all distributed system will need all
- Middleware
- User applications

Advantages

- Resource Sharing
  - Example: share devices, software, services…across networks
- Better Performance
  - Example: Parallel execution of tasks, load sharing between multiple servers, data replication closer to user….
- Fault Tolerance
  - Example: Increase system availability by putting redundant/backup servers
- Handle inherently distributed data
  - Example: Internet routing, distributed data mining
- Scalability
  - Example: add more servers as needed if load increases

Common Characteristics

- Heterogeneous in many cases
  - Different architectures, operating systems….
- Can be geographically distributed
  - Network delays play an important role
- Faults are common
  - Larger the system is, more chance of something failing at any one time

- Replication is very widely used for better availability and performance
  - Need for maintaining data consistency
  - Trade-off between performance and consistency

Examples of Distributed Systems

- Almost every large system that you use is distributed
  - Online stores like Amazon, Flipkart,….
  - Content delivery services like Netflix, Hotstar,…..
  - Social networks like Facebook, Twitter,…
  - Google and its services
  - Cloud Services like Amazon AWS, Microsoft Azure
  - Travel/Ticket booking services like IRCTC, makeMyTrip, …
  - Internet!
  - IEM CRP

- Not all build/manage their own distributed systems, rather use services provided by others.
- We will learn more later

Why are They Harder to Design?

- Lack of global shared memory
  - Hard to find the global system state at any point
- Lack of global clock
  - Events cannot be started at the same time
  - Events cannot be ordered in time easily
- Hard to verify and prove
  - More complex atomicity issues
  - Arbitrary interleaving of actions makes the system hard to verify

- Same problem is there for multi-process programs on a single machine
- Harder here due to communication delays

Example: Lack of Global Memory

- Problem of Distributed Search
  - A set of elements distributed across multiple machines
  - A query comes at any one machine A for an element X
  - Need to search for X in the whole system

- Sequential algorithm is very simple
  - Search and update done on a single array in a single machine
  - No. of elements also known in a single variable

Example: Lack of Global Memory (contd.)

- How to send the query to all other machines?
- Do all machines even know all other machines?
- How to get back the result of the search in each machine?
- Handling updates (both add/delete of elements at a machine and add/remove of machines) – adds more complexity

- **Main problem**

No one place (*global memory*) that a machine can look up to see the current system state (*what machines, what elements, how many elements*)

Example: Lack of Global Clock

- Problem of Distributed Replication
  - 3 machines A, B, C have copies of a data X, say initialized to 1
  - Query/Updates can happen in any m/c
  - Need to make the copies consistent within short time in case of update at any one machine

- Naïve algorithm
  - On an update, a machine sends the updated value to the other replicas
  - A replica, on receiving an update, applies it

Example: Atomicity Issues

- Problem of Symmetry Breaking
  - 2 nodes, each with a value 1
  - Need to get to a final state with one node having value 0 and one node having value 1

Algorithm

- Each node sends a message to the other to know its value
- Each node sets its own value to the complement of the value received from the other node if the two values are the same

– May never terminate if send-receive-set is not atomic

Distributed Scheduler (not atomic) vs. Central Scheduler (atomic)

– Is a central scheduler in a distributed system practical?

Distributed Algorithms

- Algorithms that run on distributed systems
  - Algorithms in which every node executes some program to cooperatively do something
  - Program run by each node may or may not be the same
- Distributed algorithms have been designed for many many problems
  - For any problem you know, you can ask “is there a distributed algorithm for it?

- Systems can not run without algorithms, so in any distributed system you see, there are distributed algorithms
- We will look at both algorithms and system issues

Models for Distributed Algorithms

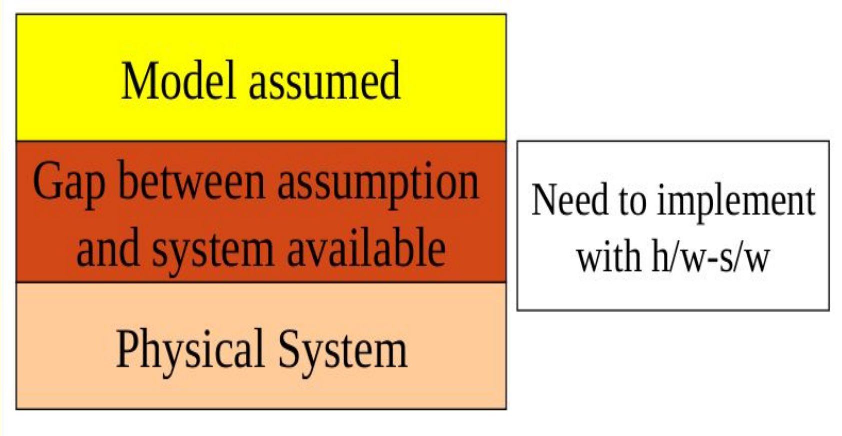
Informally, guarantees that one can assume the underlying system will (or will not!) give

- **Topology** : completely connected, ring, tree, arbitrary,…
- **Communication** : shared memory/message passing (Reliable? Delay? FIFO?
- **Broadcast** / **multicast**?…)
- **Synchronous** / **asynchronous**

- **Failure** possible or not
  - What all can fail?
  - Failure models (crash, omission, Byzantine, timing,…)
- **Unique Ids**
- Other Knowledge : no. of nodes, diameter
- **Scheduler**: Distributed, Central

Models for Distributed Algorithms (contd.)

- Less assumptions ⇒ weaker model
- A distributed algorithm needs to specify the model on which it is supposed to work
- The model may not match the underlying physical system always



Complexity Measures

- Message complexity
  - Total no. of messages sent
- Communication complexity (aka. Bit Complexity)
  - Total no. of bits sent
- Time complexity
  - For synchronous systems, no. of rounds.
  - For asynchronous systems, different definitions are there
- Space complexity
  - total no. of bits needed for storage at all the nodes