

Distributed Software Development
Fundamentals of Distributed Systems

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2-2: TCP/IP in 30 minutes

- Goal: Understand how a network transmits messages at different layers.
- How is a network composed?
- What really happens when Firefox opens a connection to a web server?
- Note: this will be an overview: For more details, you should take Prof. Buckwalter's class.

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2-3: Layering

- Modern network design takes advantage of the idea of *layering*.
- A particular service or module is constructed as a black box.
- Users of that service do not need to know its internals, just its interface.
- This makes it easy to later build new modules (or layers) that use the lower layers.
- For example, HTTP is built on top of TCP.
 - A web browser does not typically need to worry about the implementation of TCP, just that it works.
- Unlike modules in a typical OO system, the layers in a networked system comprise protocols that span multiple machines.

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2-4: The OSI seven-layer model

- ISO (a standards body) developed a reference model called OSI that defines the different layers needed for communication, and specifies which should do each job.
- The goal is to produce an open protocol that allows for heterogeneous, extensible systems.
- A *protocol* is a specification describing the order and format of messages.
- An open protocol is one in which all of this information is publicly available.

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2-5: The OSI seven-layer model

- Application
- Presentation
- Session
- Transport
- Network
- Data Link
- Physical

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2-6: Message transmission across layers

- An application (such as a web browser) wants to send a message to another computer.
- That application constructs a message and passes it to the application layer.
- The application layer attaches a header to the message and passes it to the presentation layer.
- The presentation layer attaches a header and passes it to the session layer, and so on.
- On the other end, the message is received by the physical layer, who strips off the appropriate header and passes the message up to the data link layer.
- This continues until the message reaches the application layer of the receiving machine.
- High-level layers don't need to worry about lower-level layers.
- Lower-level layers treat everything from higher layers as data to be sent.

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2-7: Layers and packets

- Each layer constructs a packet containing a portion of the data to be transmitted.
- This packet has a data section, and a header.
 - The header contains origin and destination information, checksums, sequence numbers, and other identifying information.
- When a message is sent by (for example) TCP, a packet is constructed and passed down to the IP layer.
- This entire packet then becomes the data portion of the IP packet, which is passed down to the network layer, and so on.
- On the other end, the lowest layer removes the header and checks the data integrity, then passes the data portion up to the next layer.

2-8: Physical Layer

- This is the lowest-level layer, responsible for transmitting 0s and 1s.
- Governs transmission rates, full or half-duplex, etc.
- A modem works at the physical layer.
- Lots of interesting problems at this level that we won't get into ...

2-9: Data Link Layer

- The data link layer provides error handling for the physical layer.
- Individual bits are grouped together into frames.
- A checksum is then computed to detect transmission errors.
- The data link layer can then request a retransmission of an error is detected.
- Messages are numbered; receiver can request re-transmission of any message in a sequence.
- Each frame is a separate, distinct message.
- The Data link layer provides error-free transmission to upper-level layers.

2-10: Network Layer

- The network layer is responsible for routing and flow control.
- The network layer removes the data link header and examines the resulting packet for a destination, and then forwards it as appropriate.
- the Internet Protocol (IP) is one of the best-known network-layer protocols.
- Primary role: move packets from a sending host to a receiving host. This involves:
 - Routing: determine the path that a packet should take to get to its destination.
 - Forwarding: When an incoming packet is received, place it on the output link that takes it to the next hop in its route.

2-11: Network Layer

- A router contains a *forwarding table* - when an incoming packet is received, the router compares it to this table to determine where to send it next.
 - This is forwarding.
- These forwarding tables are configured by means of a routing algorithm.
- For example, the link-state algorithm is a version of Dijkstra's algorithm - this computes a global routing table.
- Internet routing algorithms (such as BGP) are more complex, and use a decentralized routing table.
- In a nutshell, BGP lets subnets figure out how to reach other subnets via a gateway. That gateway is then responsible for routing within the subnet.

2-12: Transport Layer

- The network layer still operates at the level of individual packets, or datagrams.
- Packets may get lost, or arrive out of order.
- TCP is a transport-level protocol that provides *connection-oriented* service.
 - Guaranteed, in-order delivery.
 - State is maintained.
- This layer will also manage quality-of-service and some congestion control.
- UDP is also a transport level protocol, albeit one that does not provide connection-oriented delivery.

2-13: Session Layer

- The session layer was designed to provide support for access rights and synchronization.
- In practice, it is not widely used, and is not present in the TCP/IP suite.

2-14: Presentation Layer

- The presentation layer controls display of packet information.
- This may include encryption/decryption, compression, translation between character formats.

2-15: Application Layer

- This is the layer that most of us are most familiar with.
- It consists of user-level protocols built on top of the existing layers.
 - HTTP
 - FTP
 - SMTP
 - P2P protocols
 - Instant messaging
 - RTSP/streaming video
 - etc.

2-16: An example: HTTP

- HTTP is the protocol that drives the Web.
 - A side note/axe to grind: WWW != Internet!!
- It is a stateless protocol that uses TCP as its underlying protocol.
 - The client sends a request, which is processed by the server.
 - The server sends a reply, and the exchange is ended.

2-17: HTTP requests

- HTTP has a very simple message format.

```
GET /~brooks/index.html HTTP/1.1
Host: www.cs.usfca.edu
Connection: close
User-agent: Mozilla/4.0
Accept-language: en
```

- You can try this out for yourself with telnet ...

2-18: HTTP

- There are lots of wrinkles and extensions to HTTP
 - Cookies to help save state
 - CGI, SOAP to execute code as the result of an HTTP request.
 - Web caching to store data closer to clients.
- These are all possible because HTTP is an open protocol.
- This is also what makes it possible for different companies to write web browsers and web servers that seamlessly work together.

2-19: Summary

- the modern networking stack can be conceptually broken into a set of layers.
- Each layer has a specific, well-defined function.
 - Acts as a black box
- Higher-level layers build on the functionality of lower-level layers.
- We'll be primarily concerned with the Transport and Application layers.

2-20: What is a Distributed System?

- What is a distributed system?
 - (Coulouris) "A distributed system is one in which hardware or software components communicate or coordinate their actions only by passing messages."
 - (Tanenbaum) "A distributed system is a collection of independent computers that appear to the users of the system as a single computer."
 - (Lamport) "You know you have one when the crash of a computer you've never heard of stops you from getting any work done."
- All of these get at different aspects of the issue ...

2-21: Advantages of a distributed system

- Can share expensive resources or data
- Economics
 - A collection of PCs can provide better price/performance than a single mainframe.
- Speed
 - A distributed system will often have more computing power than a single mainframe.
- Inherent distribution
 - Often, your data/users/resources are geographically distributed

2-22: Advantages of a distributed system

- Reliability
 - If one node fails, the rest of the system can continue
- Incremental growth
 - Components can be added or replaced in small increments..

2-23: Disadvantages of distributed systems

- Software design is much more complicated.
 - Lack of appropriate tools/languages
 - Disagreement on principles: how much should users know about the system? How much the system handle on a user's behalf?
- Potential network saturation
- Privacy and security issues
 - Allowing resources to be shared can lead to data leakage
- Extra sysadmin work

2-24: Design Issues

- Transparency
- Flexibility
- Dependability
- Performance
- Scalability

2-25: Transparency

- The goal of transparency is a *single-system image*
 - From the user's POV, it looks like a single machine.
- Types of transparency:
 - Location transparency - Users cannot tell where their resources are actually located.
 - Migration transparency - Resources can move without changing their names.
 - Replication transparency - the number of copies of a resource is hidden from users.
 - Concurrency transparency - Users can share resources without being aware of the presence of other users.
 - Parallelism transparency - A task can be run on multiple machines without the user being aware of it.

2-26: Transparency

- Is transparency always a good thing? What is the downside?

2-27: Flexibility

- Flexibility refers to how easy or difficult it is to change or reconfigure a system.
- The research question is how to best provide flexibility.
- In the OS world, this debate shows up in the comparison of monolithic kernels and microkernels.
 - Monolithic kernel - Provides most services on its own
 - Microkernel - Only handles a simple set of services. Most other services are implemented at the user level.
- Microkernel is very flexible and modular; services can be added, deleted, or moved without much reconfiguration.
- Monolithic kernel gives better performance.

2-28: Reliability

- There are several different aspects of reliability:
 - Availability: what fraction of the time is the system usable?
 - Integrity: Data must be kept consistent. (this sometimes clashes with availability)
 - Security: Unauthorized usage must be prevented.
 - Fault tolerance: How unpleasantly does the system fail? Is data lost? Can recovery happen?

2-29: Performance

- Performance is trickier than it appears.
- lots of possible metrics
 - Response time
 - Throughput
 - System utilization
 - Network capacity
- Typically, communication costs dominate
- This leads to a *coarser-grained* parallelism that we would see in a parallel computer.

2-30: Types of process failure

- In looking at different protocols and algorithms, we'll want to know what types of failure they are resistant to.
 - Failstop (or crash): Process halts and remains in that state; failure can usually be detected.
 - Send omission: a process fails to send messages, or halts in the middle of sending.
 - Receive omission: a process fails to receive a message properly, or halts while receiving.
 - General omission: combination of send and receive omission
 - Byzantine failure: Process behaves in an arbitrarily incorrect way.
 - Timing failure: process commits a general omission failure, or its clock drift exceeds allowable bounds.

2-31: Types of Communication Failure

- We also must consider failures that happen in the network:
 - Crash: a link stops completely.
 - Omission: A link fails to transmit some of its messages.
 - Byzantine: A link can exhibit any possible behavior, including generating spurious messages.
- Note: A Byzantine failure can be treated the same as an attacker/intruder.

2-32: Communication paradigms

- Reliable communication: messages are guaranteed to eventually arrive.
- In-order: messages are guaranteed to arrive in the order they are sent.
- Asynchronous: there is no bound on message delay
- Synchronous:
 - Known upper bound b on message delay
 - Every process p has a local clock C_p which drifts at a rate of $r > 0$ and $\forall p$ and $\forall t > t'$:
$$(1 + r)^{-1} \leq \frac{C_p(t) - C_p(t')}{t - t'} \leq (1 + r)$$
 - In English, clock drift has an upper and lower bound.
 - Also, bounds on the amount of time needed for a process to execute a single step.
- Synchronous communication allows you to implement approximately synchronized clocks, even in the presence of failure.

2-33: Dealing with time

- One of the fundamental problems in distributed systems is dealing correctly with time.
- Not only when things happened, but what order things happened in.
- We would like for all processes to see *relevant* changes in the same order.
 - Example: updating a replicated database.
- Depending on the communication model, this may be quite difficult.
- Insight: often, it doesn't matter exactly what time an operation happens, but what order events occur in.
- (exception: hard real-time systems)

2-34: Global time servers

- NTP is an Internet Protocol that allows your machine to synchronize its clock with a remote source, thereby keeping it accurate.
- Is that all we need to do?

2-35: Global time servers

- NTP is an Internet Protocol that allows your machine to synchronize its clock with a remote source, thereby keeping it accurate.
- Is that all we need to do?
- Maybe, maybe not.
 - What if we don't have an Internet connection, or NTP is blocked by our firewall?
 - Can we guarantee that all users use the same remote time server?
 - How often should they update?
 - What if users don't do this?

2-36: Logical time

- The algorithms we'll look at in this class will not need to depend on the *absolute* time that something happens.
- Instead, we'll be interested in the *logical* time, or *causal order* in which events occur.
- As long as all processes agree on the order in which a set of events that influence each other occurs, we're OK.
- We'll spend time next week looking at this problem.

2-37: Summary

- There are lots of desirable properties and design issues for distributed systems.
 - Performance, scalability, reliability, flexibility, transparency
 - Often, we must sacrifice one for another
 - Some (e.g. Parallel transparency) are not possible with today's technology.
- Communication can be either *synchronous* or *asynchronous*
- Time is a very sticky problem to deal with in distributed systems.
- Characterizing types of failure will help us identify what our algorithms and systems can and cannot stand up to.