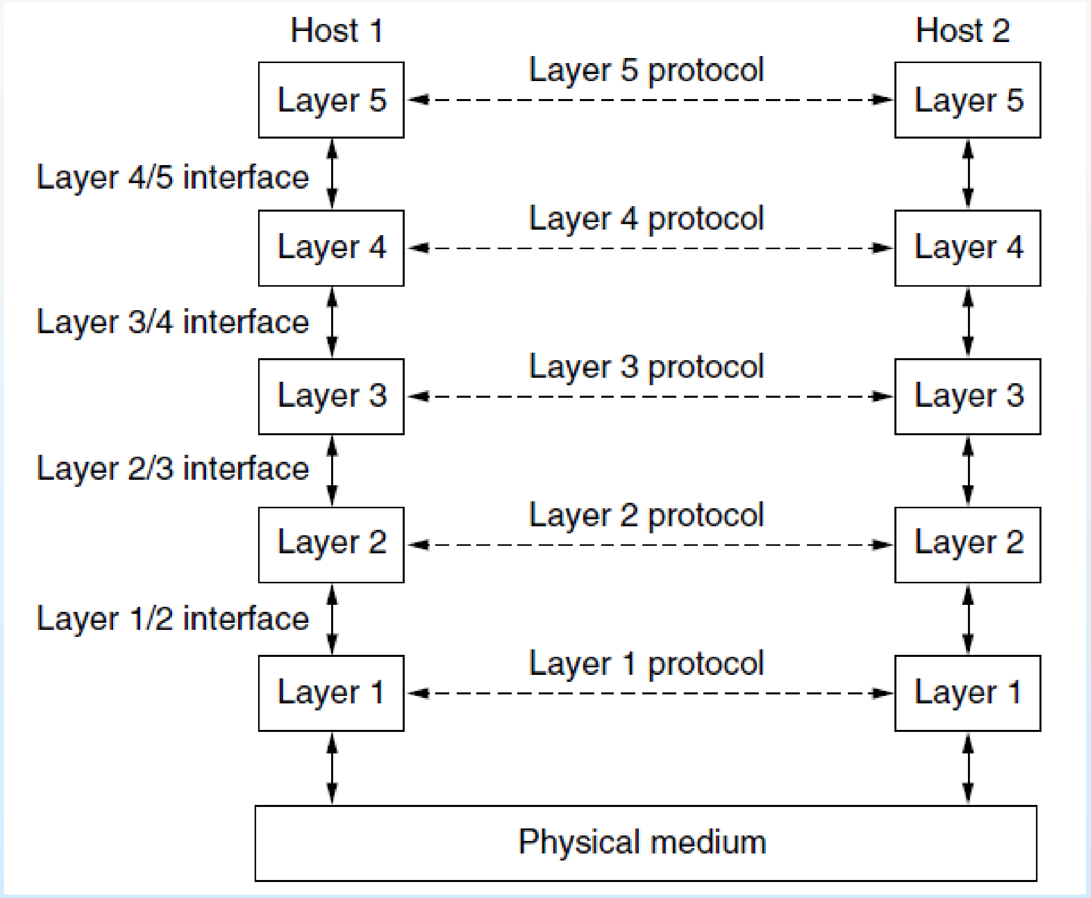
Network Software

- Communication Protocol Hierarchies
- Design Issues for the Layers (OSI Model)
- Connection-Oriented and Connectionless Services
- Service Primitives
- The Relationship of Services to Protocols

Protocol Hierarchies

- *"Abstraction—the hiding of details behind a well-defined interface—is the fundamental tool used by system designers to manage complexity"*
  Larry L. Peterson and Bruce S. Davie, Computer Networks
- To reduce design complexity networks are organized as a stack of layers
- The purpose of each layer is to offer certain services to the higher layers while shielding those layers from the details of how the offered services are actually implemented
- AKA: information hiding, abstract data types, data encapsulation, and object-oriented programming
- Conversation between layer *n* on one machine with layer *n* on another machine: the rules and conventions used in this conversation are collectively known as the **layer *n* protocol**

Layers, protocols, and interfaces

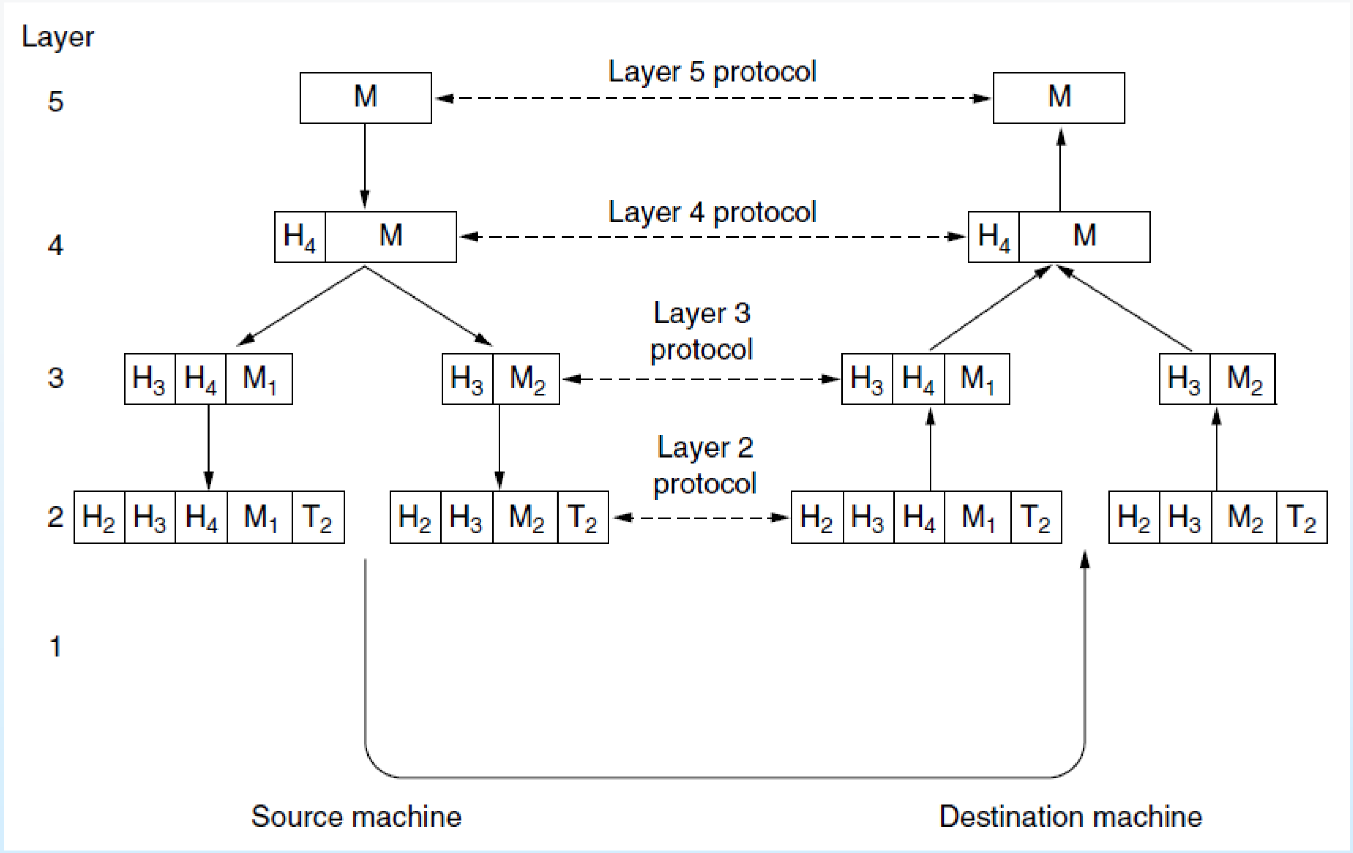


Real data is transfered only at the physical layer!
All other dotted lines are virtual!

Network Architecture

- A set of layers and protocols is called a **network architecture**
- Neither the details of the implementation nor the specification of the interfaces is part of the architecture
- A list of the protocols used by a certain system, one protocol per layer, is called a **protocol stack**
- **Typical flow:**
  - A message, *M*, is produced by an application process running in layer 5 and given to layer 4 for transmission
  - Layer 4 puts a **header** in front of the message to identify the message and passes the result to layer 3
  - The header includes control information, such as address/port, to allow layer 4 on the destination machine to deliver the message
  - Other examples of control information used in some layers are sequence numbers, sizes, and times
  - layer 3 must break up the incoming messages into smaller units, packets, prepending a layer 3 header to each packet

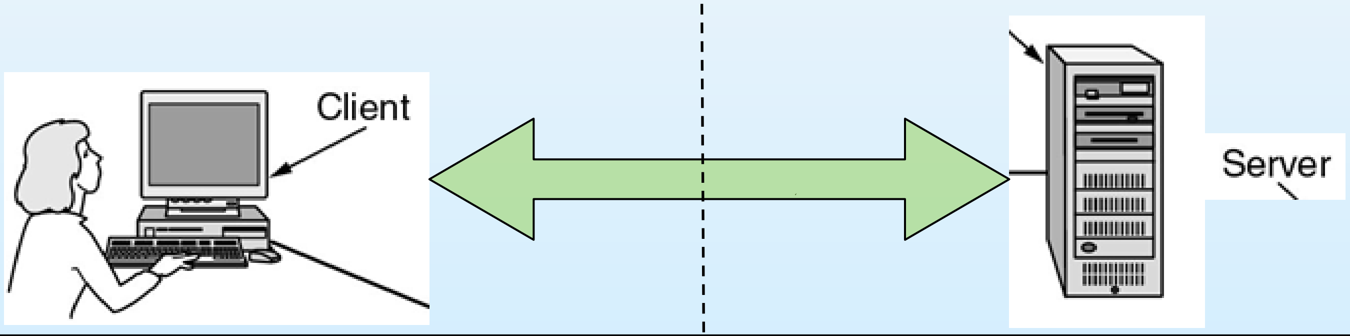
Communication Flow



- Layer 3 decides which lines to use and passes the packets to layer 2
- Layer 2 adds to each piece not only a **header** but also a **trailer**, and gives the resulting unit to layer 1 for physical transmission
- At the receiving machine the message moves upward, from layer to layer, with headers being stripped off as it progresses

Communication Protocol

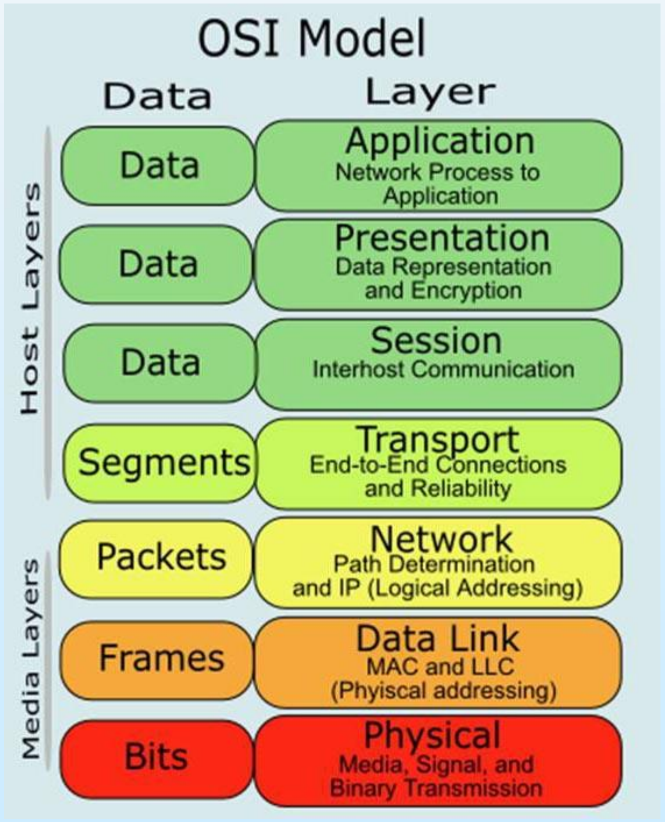
- Definition 1: A **protocol** is an agreement between the communicating parties on how communication is to proceed
- Definition 2: A **protocol** is a set of communication "rules" between two processes.
- Example: A "grades database query" protocol
  - (We may make a small project out of it later …)

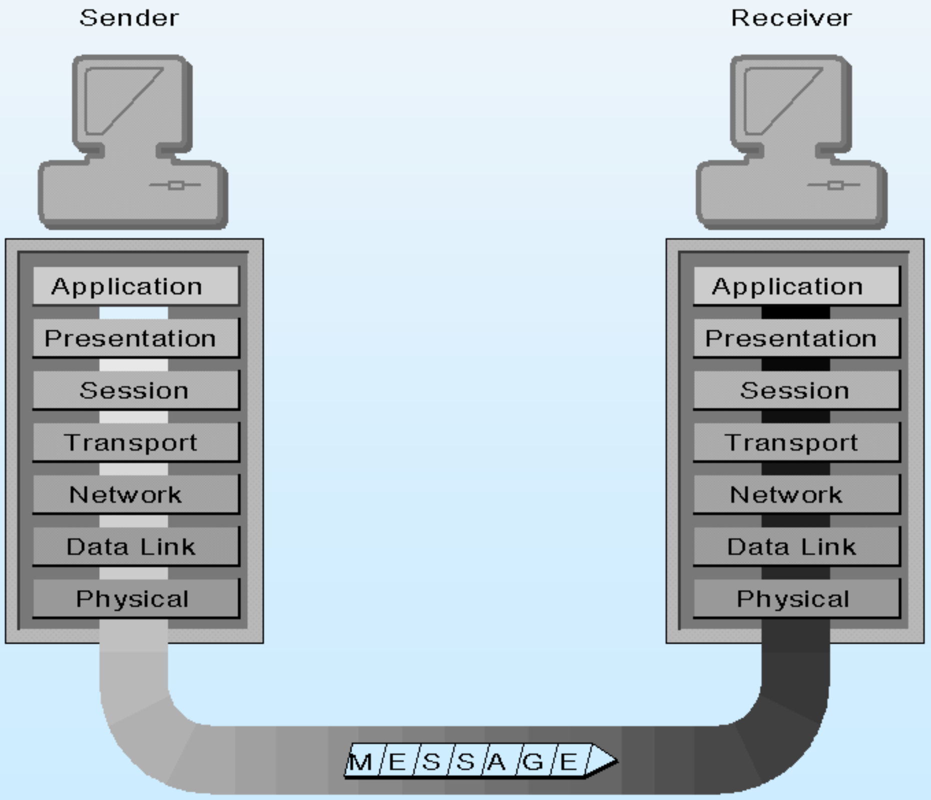


```
Client:  HELLO                     Server:  READY
Client:  NAME 051883261\n          Server:  DAN HACKER\n
Client:  GRADE MATH\n              Server:  87\n
Client:  GRADE HISTORY\n           Server:  93\n
Client:  END                       Server:  BYE
```

OSI Model

- **Open Systems Interconnection (OSI)**
- Proposed by the **International Standards Organization** (ISO)
- The OSI model has seven layers


OSI Model
Data
Layer
Host Layers
Media Layers
Data
Application
Network Process to Application
Data
Presentation
Data Representation and Encryption
Data
Session
Interhost Communication
Segments
Transport
End-to-End Connections and Reliability
Packets
Network
Path Determination and IP (Logical Addressing)
Frames
Data Link
MAC and LLC (Phyiscal addressing)
Bits
Physical
Media, Signal, and Binary Transmission



Application Layer

- The closest layer to the user: Outlook, Explorer, Firefox, Skype (HTTP, POP, SMTP, FTP, TELNET).
- In this layer that a user interacts with the software application that does data transfer
- The main tasks:
  - Identify/authenticate the user who wants to communicate
  - determine whether the data and networks sources are available
  - synchronize communication between the two nodes

Presentation Layer

- Convert the data into a format that could be easily recognized by the application layers of other end users.
- For example: translation between ASCII and EBCDIC machines as well as between different floating point and binary formats. Integer size (16,32, or 64 bit?). Floating point representations.
- Compression/decompression, conversion, encryption/decryption, coding, decoding, etc.
- Converts the data obtained from the application layer into a format that can be easily identified by other network layers.

Session Layer

- In practice, this layer is often not used or services within this layer are sometimes incorporated into the transport layer
- Establishing, maintaining and terminating the connection between two end nodes (not used in TCP/IP)
- Controls the communication between the source user and the destination user and also decides the time of communication
- It determines one-way or two-way communications and manages the dialog between both parties; for example, making sure that the previous request has been fulfilled before the next one is sent
- Any error report related to application layer, presentation layer and session layer, are provided by this layer

Transport Layer

- Responsible for delivering the data or the messages between the two nodes
- Divide the data in packets at the sender side
- Re-assemble packets at the receiver side
- Third task: error free data transmission
  - Uses checksums for error correction or rejection
  - Drop corrupt packets and requests retransmission
- Fourth task: guarantee data integrity
  - Make sure all packets have arrived
- UDP, SPX, TCP are some of the protocols that operate on this layer with one exception: UDP is unreliable

Network Layer

- Provide switching technologies and routing technologies:
  It is the *network* layer's job to figure out the *network* topology, handle routing and to prepare data for transmission
- Establishes the route between the sending and receiving nodes for data transmission (also known as virtual circuits)
- Encapsulation of transport data into network layer protocol data units
- Also responsible for handling errors, packet sequencing, controlling network congestion and addressing
- In short: this layer is responsible for the setting up the required network for transferring data from one node to other.

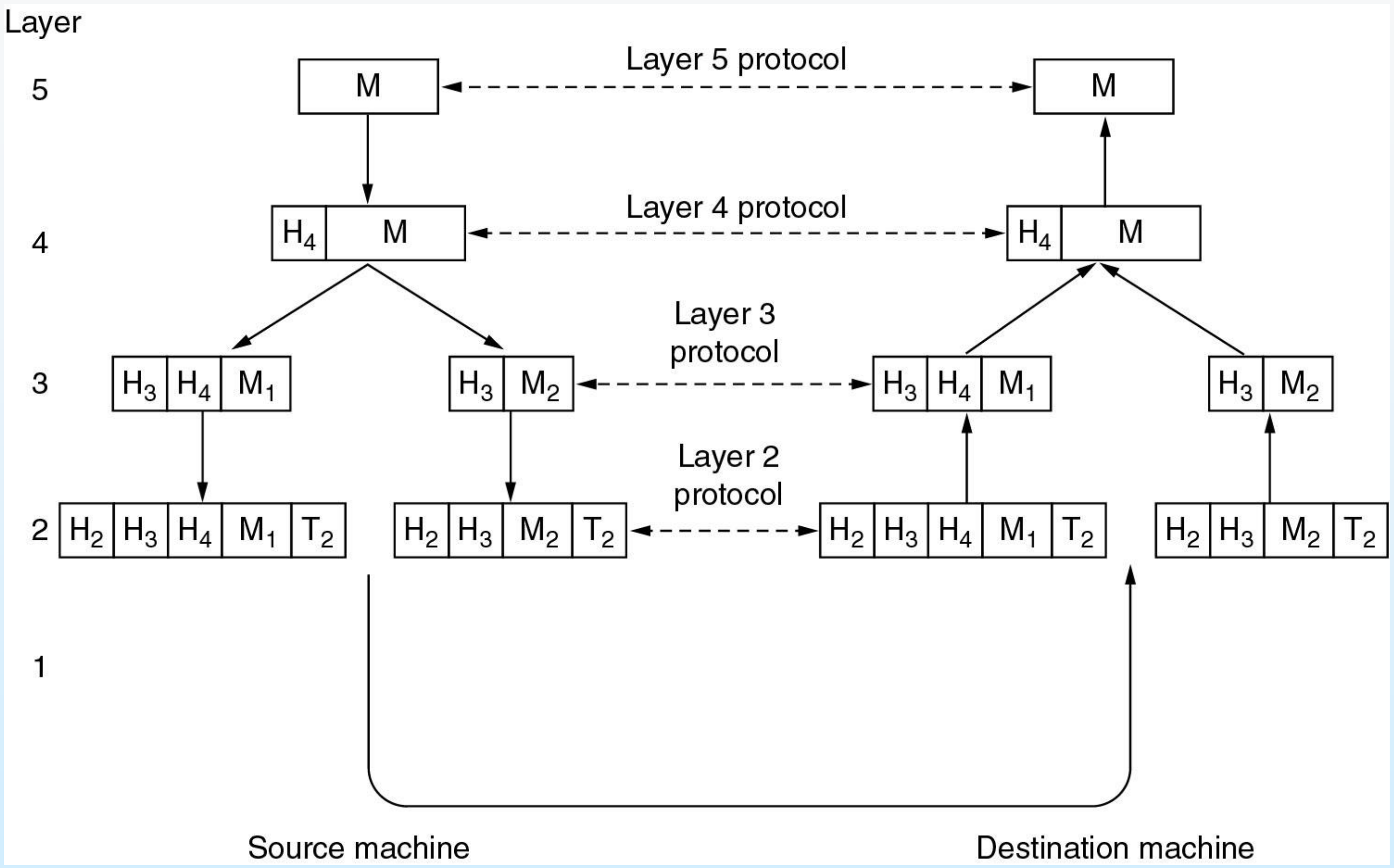
Data Link Layer

- Encoding and decoding of data frames into bits (as the physical layer may use waves or other type of media). At the receiving side: Collects a stream of bits into a larger aggregate called a *frame.*
- Segmentation of upper layer datagrams (packets) into frames in sizes that can be handled by the communications hardware
- Takes care of any errors in the physical layer (electricity presence, voltage drop, no power, connection, etc.)
- Provides reliable transit of the data through a physical network
- Synchronization of various physical devices that will transmit the data
- It makes sure that the frames are transferred in correct order and asks for retransmission in case of error
- The frame formatting issues such as stop and start bits, bit order, parity and other functions are handled here. Management of big-endian/little-endian issues are also managed at this layer.
- Usually implemented on Hardware (network interface card):

Physical Layer

- Deals with the physical components of a network
- Activation, maintenance and deactivation of various physical links that act in data transmission
- Electrical signals, voltage levels, cables, data transmission rates, etc., are some of the major elements defined by the physical layer
- It is also responsible for passing and receiving bytes from the physically connected medium
- Implemented on hardware (network interface card)

Information Flow



The peer processes in layer 4 (for example) conceptually think of their communication as being "horizontal," using the layer 4 protocol
Each one is likely to have procedures called something like *SendToOtherSide* and *GetFrom-OtherSide*, even though these procedures actually communicate with lower layers across the 3/4 interface, and not with the other side.

Design Issues - Accuracy

- Packet traveling through the network: there is a chance that some bits will be flipped, or even get lost, or new ones will be added:
  - fluke electrical noise
  - random wireless signals
  - hardware flaws
  - software bugs (and so on …)
- Is it possible to detect and even fix these errors?
- Must separate between two targets:
- **Error Detection**
  - Easy mechanisms for detecting errors (with very high probability)
- **Error Correction**
  - This is possible but very costly (space, time, resources)

Design Issues - Reliability

- Finding a working path through a network:
  - Usually there are multiple paths between a source and destination
- In a large network, there may be broken links, hosts, and routers
- If the network is down in Germany: packets sent from London to Rome via Germany will not get through, but packets from London to Rome via Paris may get through … ?
- A network should automatically detect the problem and make this decision. This topic is called **routing**. How this is done? We'll see later …
- Not all communication channels preserve the order of packets sent on them, and packets can also get completely lost

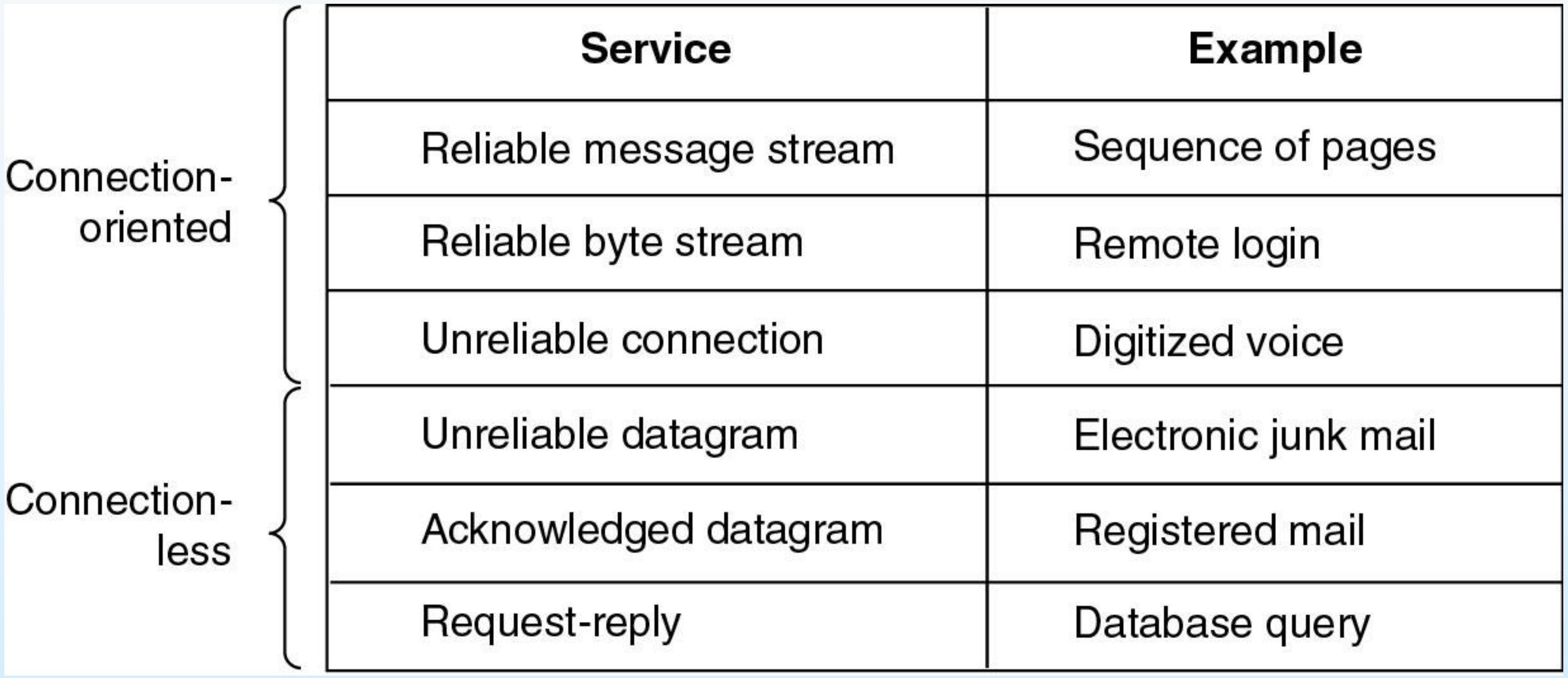
Design Issues – Flow Control

- **Congestion**: how to keep a fast sender from swamping a slow receiver?
- Overloading of the network is called **congestion:** too many computers want to send too much traffic, and the network cannot deliver it all
- One strategy is for each computer to reduce its demand when it experiences congestion
- **Starvation**: fast receivers against slow senders (fast clients vs. slow server)
- **Quality of service** is the name given to mechanisms that reconcile these competing demands
- Applications: video streaming, VOIP, media recorders (“buffer overrun”)
  - Balancing senders and receivers speeds in such cases is very crucial

Design Issues – Security

- Network must be secured by defending it against different kinds of threats:
- **Confidentiality:** prevent unauthorized access to information (snooping)
- **Authentication:** prevent someone from impersonating someone else (Phishing)
- **Integrity:** prevent surreptitious changes to messages:
  "debit my account $10" → "debit my account $1000"
- Solution designs are heavily based on **cryptography**

Connection-Oriented and Connectionless Services



	Service	Example
Connection-oriented	Reliable message stream	Sequence of pages
	Reliable byte stream	Remote login
	Unreliable connection	Digitized voice
Connection-less	Unreliable datagram	Electronic junk mail
	Acknowledged datagram	Registered mail
	Request-reply	Database query

Connection-Oriented

- Connection is established, the sender, receiver, and subnet conduct a **negotiation** about the parameters to be used, such as
  - Maximum message size
  - Quality of service required, and other issues
- Typically, one side makes a proposal and the other side can accept it, reject it, or make a counter proposal.
- A **circuit** is another name for a connection with associated resources (after the telephone model …)
- Reliability: do not lose data – e.g., the receiver acknowledge the receipt of each message
- so the sender is sure that it arrived
- TCP – Transmission Control Protocol is connection oriented
- Text documents, email, image attachments

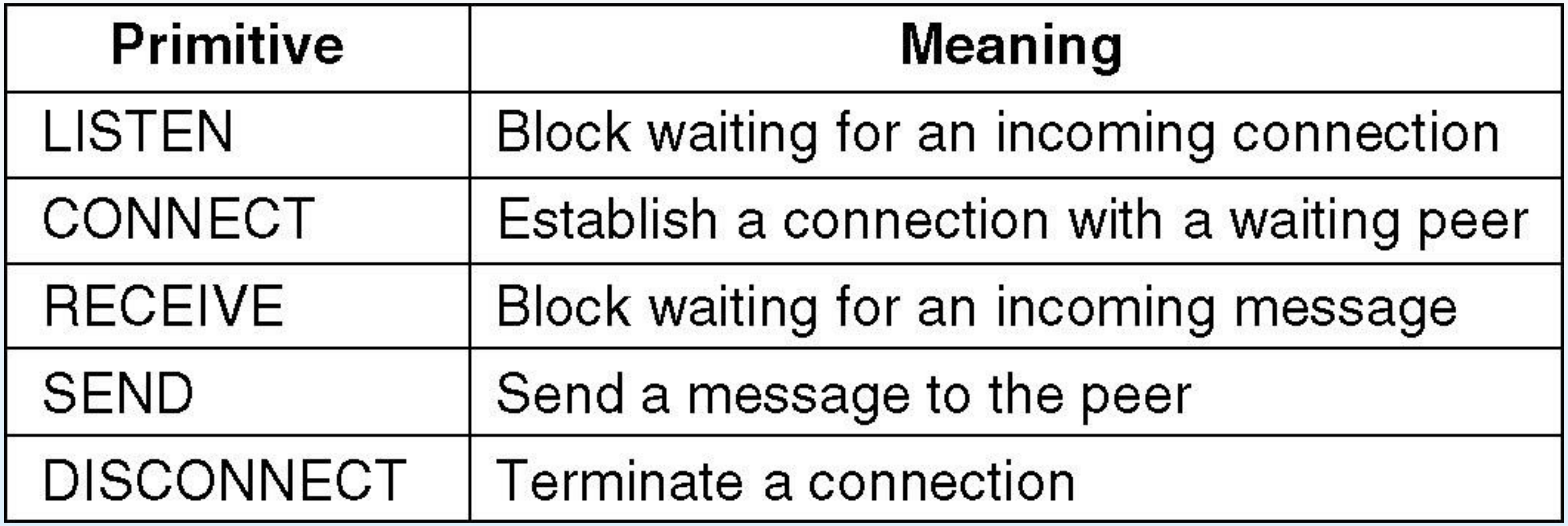
Connectionless Service

- In contrast to connection-oriented service, **connectionless** service is modeled after the postal system
- Each message (letter/package) carries the full destination address and each one is routed through the intermediate nodes inside the system independent of all the subsequent messages
- UDP – User Datagram Protocol – unreliable
- Unreliable (meaning not acknowledged) connectionless service is often called **datagram** service, in analogy with telegram (service, which also does not return an acknowledgement to the sender)
- Video streaming, Video conference, VOIP, Digital TV transmission (Idan+)

Co-existence of both kinds

- reliable communication may not be available in a given layer
- For example, Ethernet does not provide reliable communication. Packets can occasionally be damaged in transit
- It is up to higher protocol levels to recover from this problem. In particular, many reliable services are built on top of an unreliable datagram service. Second,
- Both reliable and unreliable communication usually coexist.

Connection-oriented Service Primitives



Primitive	Meaning
LISTEN	Block waiting for an incoming connection
CONNECT	Establish a connection with a waiting peer
RECEIVE	Block waiting for an incoming message
SEND	Send a message to the peer
DISCONNECT	Terminate a connection

- Minimal example of service primitives that provide a reliable byte stream
- A service is formally specified by a set of **primitives** (operations) available to user processes to access the service
- These primitives tell the service to perform some action or report on an action taken by a peer entity (usually as operating system calls)
- Modeled after the Berkeley socket interface

Service Primitives (2)

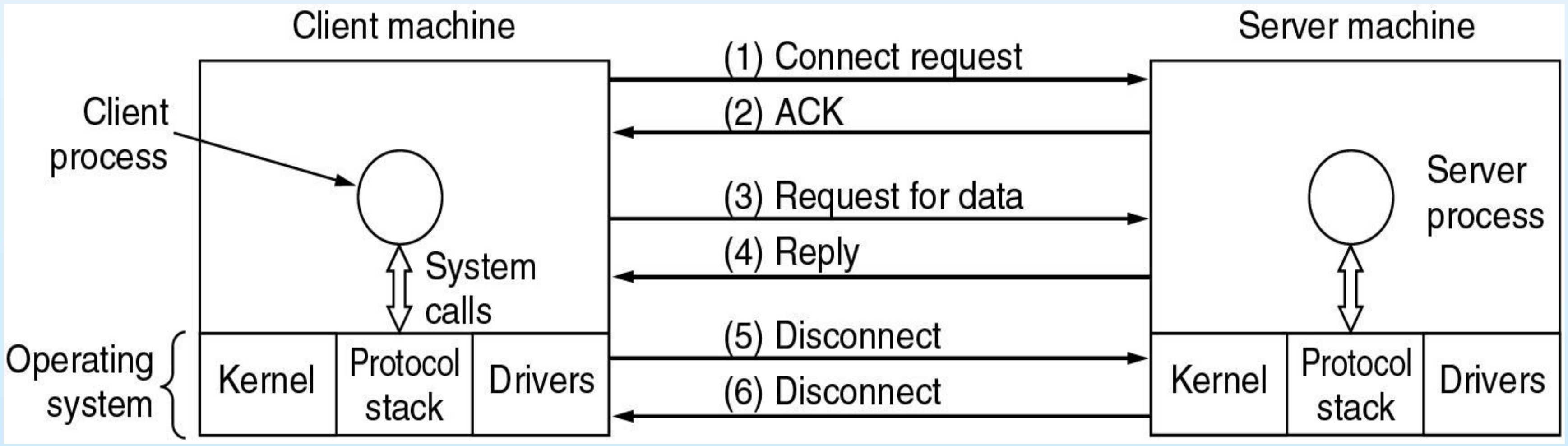
- **LISTEN** is usually implemented by a block system call - the server process is blocked until a request for connection appears
- **CONNECT** is usually implemented by a connection request to a server
  - The **CONNECT** call may need to specify the server’s address
  - The operating system then typically sends a packet to the peer asking it to connect
- The client process is suspended until there is a response
- When the packet arrives at the server, the operating system sees that the packet is requesting a connection
  - It checks to see if there is a listener
  - If so it unblocks the listener (wake-up call)
  - The server process may accept the connection with the **ACCEPT** call
- This sends a response back to the client process to accept the connection

Service Primitives (3)

- Next step: **RECEIVE**
  - The server prepares to accept the first client request
  - The **RECEIVE** call blocks the server
- Then the client executes **SEND** to transmit its request (data or action) followed by the execution of **RECEIVE** by the server (and then blocks)
- The arrival of the request packet at the server machine unblocks the server so it can handle the request
- After it has done the work, the server uses **SEND** to return the answer to the client
- The arrival of this packet unblocks the client, which can now inspect the answer. If the client has additional requests, it can proceed immediately.
- When the client is done, it executes **DISCONNECT** to terminate the connection. Usually, a **DISCONNECT** is a blocking call, suspending the client and sending a packet to the server saying that the connection is no longer needed

Service Primitives (4)

- When the server gets the client disconnect packet, it also issues a server **DISCONNECT** of its own, acknowledging the client and releasing the connection
- When the server's packet gets back to the client machine, the client process is released and the connection is broken
- In a nutshell, this is how connection-oriented communication works:


Client machine
Server machine
Client process
Server process
System calls
Operating system
Kernel
Protocol stack
Drivers
Kernel
Protocol stack
Drivers
(1) Connect request
(2) ACK
(3) Request for data
(4) Reply
(5) Disconnect
(6) Disconnect