UNIVERSITY OF PADOVA
DEPARTMENT OF INFORMATION ENGINEERING

Biomedical Wearable Technologies
for Healthcare and Wellbeing

Fundamentals of computer networks

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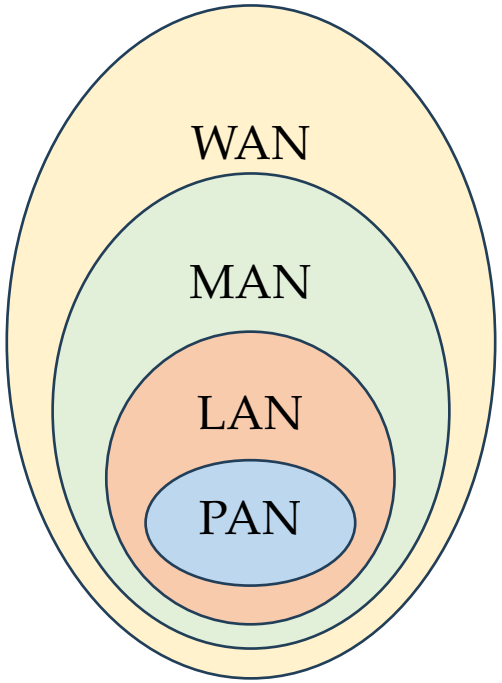
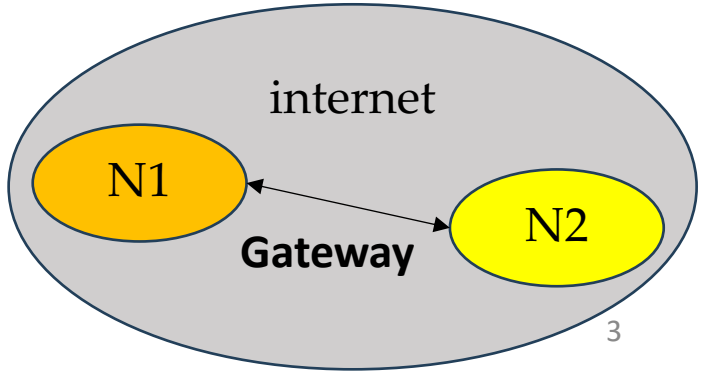
Computer networks

- Data collected by wearable IoT sensors are shared among different devices running over a computer network, typically the Internet.
- **Computer network:** a collection of autonomous computers (**hosts**) interconnected by a single technology.
- Two computers are said to be interconnected if they are able to exchange information.
- Purpose of computer networks: to **share resources** (e.g. data and applications).

Types of computer networks by their extention

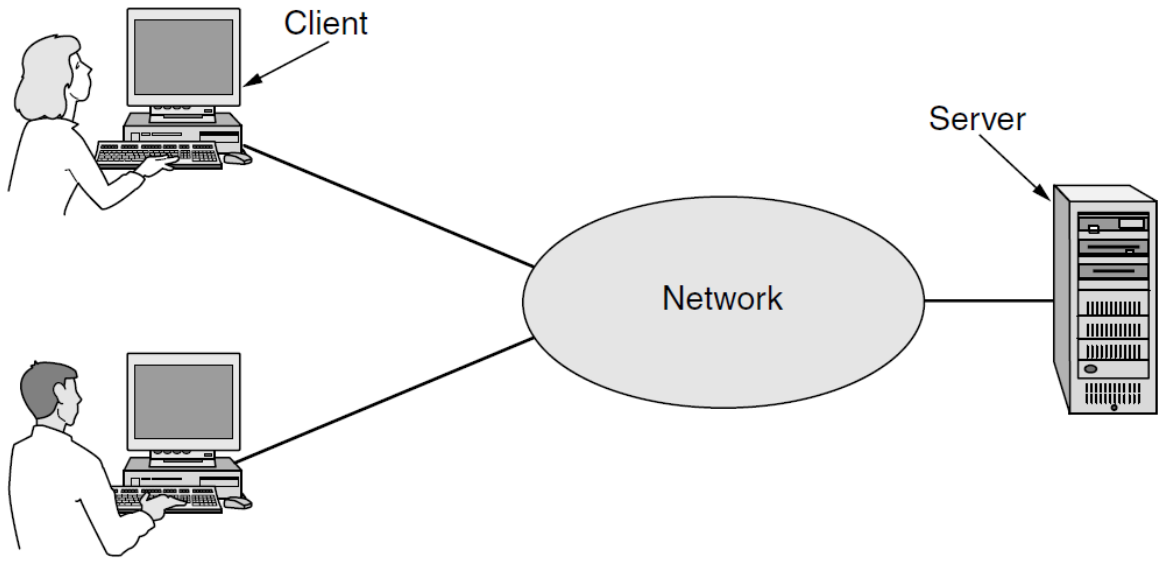
- **Personal Area Network (PAN)**: it lets devices communicate over the range of a person (e.g., short-range Bluetooth networks).
- **Local Area Network (LAN)**: a privately owned network that operates within and nearby a single building (e.g., the network of a company).
- **Metropolitan Area Network (MAN)**: it covers a city (e.g. cable television networks available in many cities with poor over-the-air television reception).
- **Wide Area Network (WAN)**: it spans a large geographical area, often a country or continent (e.g., a network of a company that has offices in different cities)
- **Internetworks (internet):** a collection of interconnected networks, in which devices of different networks can exchange messages regardless of their underling network hardware
  - **Gateway**: a machine that makes a connection between two or more networks and provides the necessary translation, both in terms of hardware and software
  - The worldwide **Internet** (with capital I) is the most popular example of internet





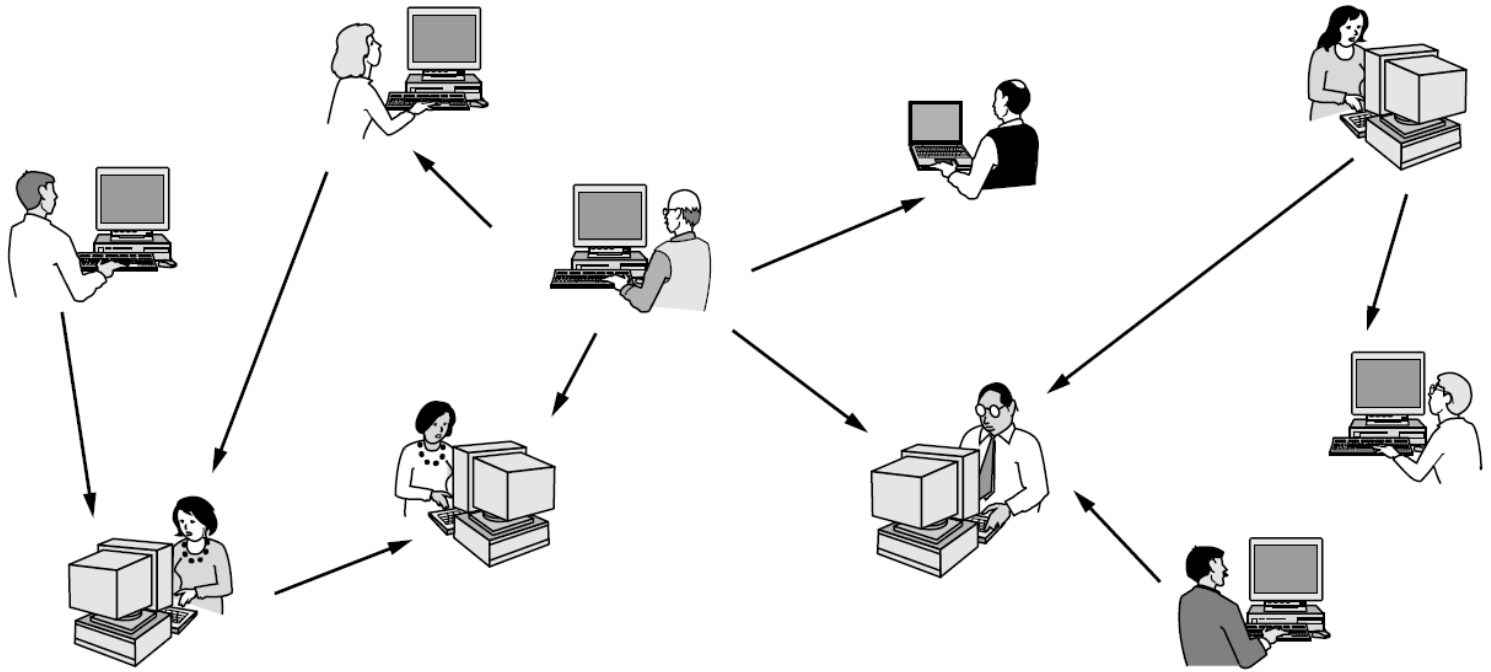
Client-server model

- **Client-server model:** a network structure that partitions tasks between the providers of a resource or service, called servers, and service requesters, called clients.
- The server is often designed to operate as a centralized system that serves many clients. The computing power, memory and storage requirements of a server must be scaled appropriately to the expected workload.



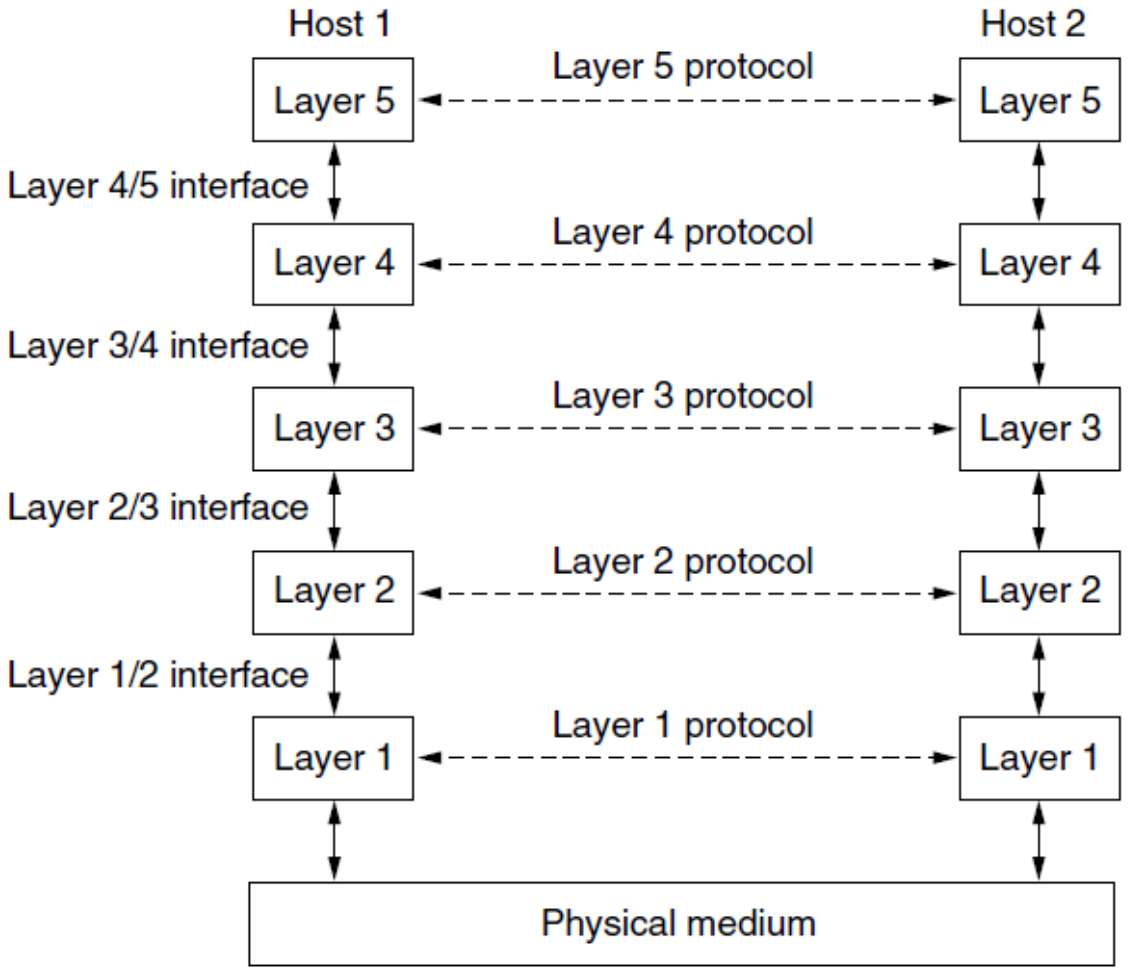
Peer-to-peer model

- **Peer-to-peer model:** a network structure that partitions tasks or workloads between peers. Peers are equally privileged, equipotent participants in the application.
- Every hosts can communicate with one or more other hosts.
- No fixed division into clients and servers (they are all peers).



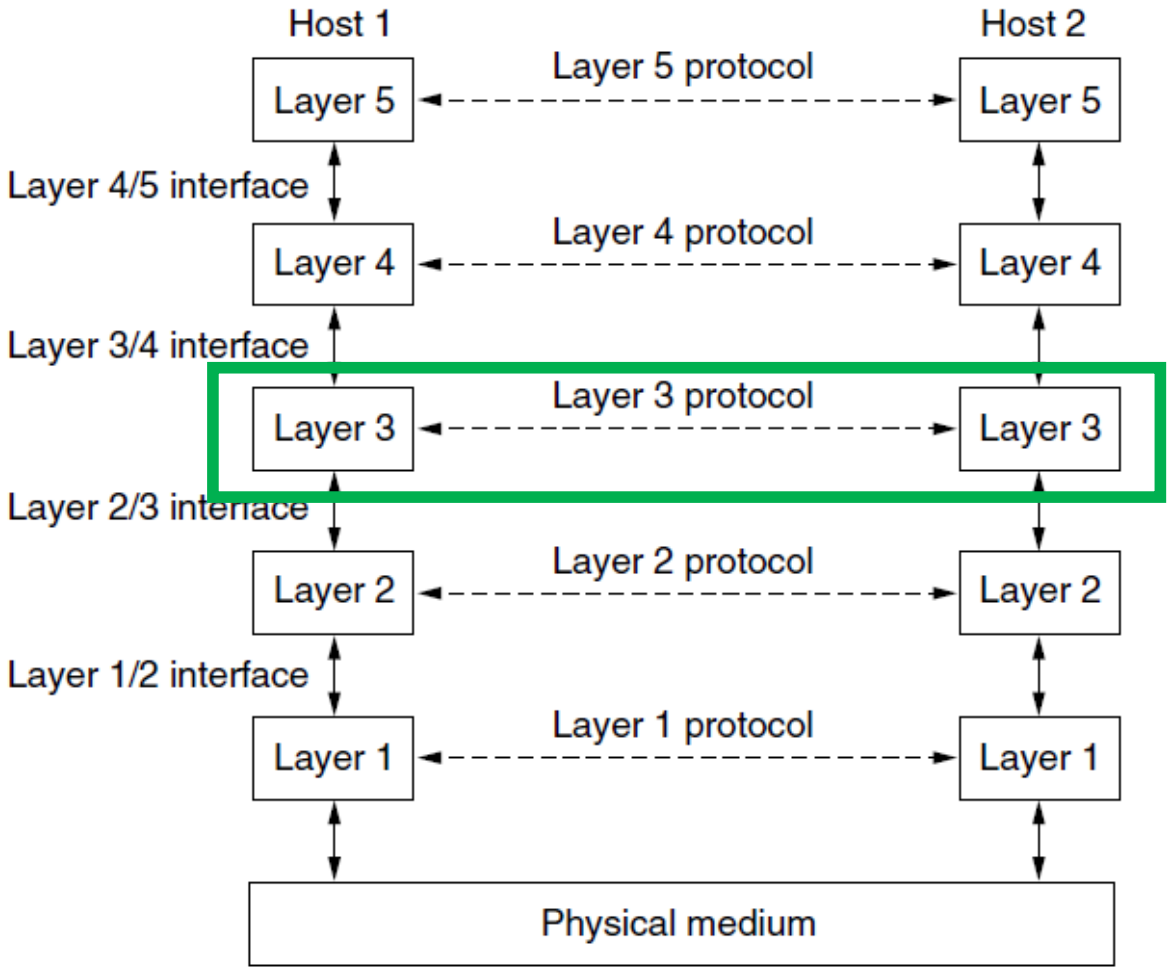
Network software: protocol hierarchies

- To reduce their design complexity, most networks are organized as a stack of **layers** or **levels**, each one built upon the one below it.
- 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.



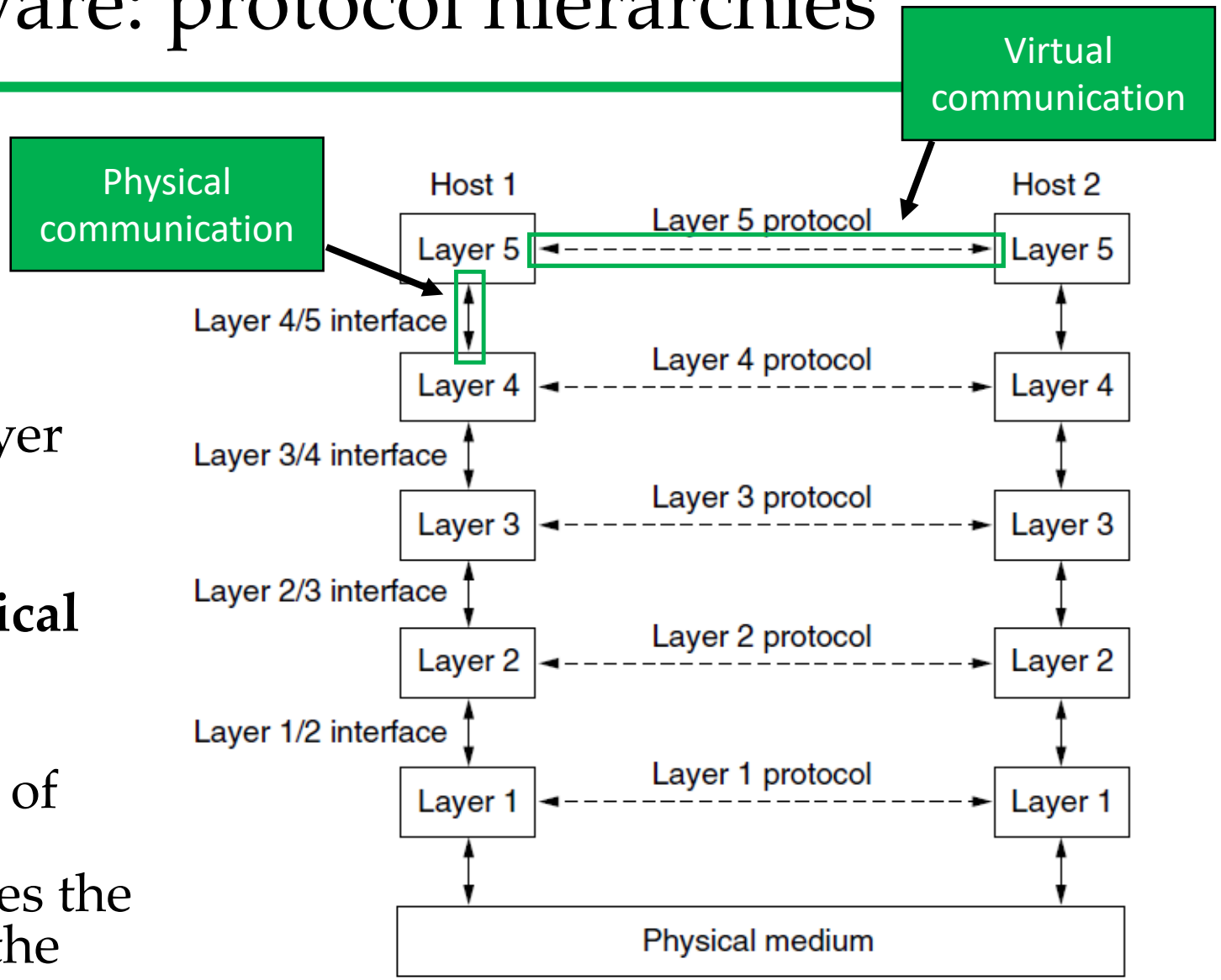
Network software: protocol hierarchies

- Two entities of the same layer on different machines are called **peers.**
- When two peers of layer n communicate, the rules and conventions used in this conversation constitute the layer n protocol.
- **Protocol:** agreement between the communicating parties on how communication is to proceed.
- Layers and protocols form the **network architecture**.



Network software: protocol hierarchies

- In reality, no data are directly transferred from layer *n* on one machine to layer *n* on another machine.
- Each layer passes data to the layer immediately below it, until the lowest layer is reached.
- Layer 1 passes data to the **physical medium** through which actual communication occurs.
- An **interface** between each pair of adjacent layers defines which primitive operations and services the lower layer makes available to the upper one.



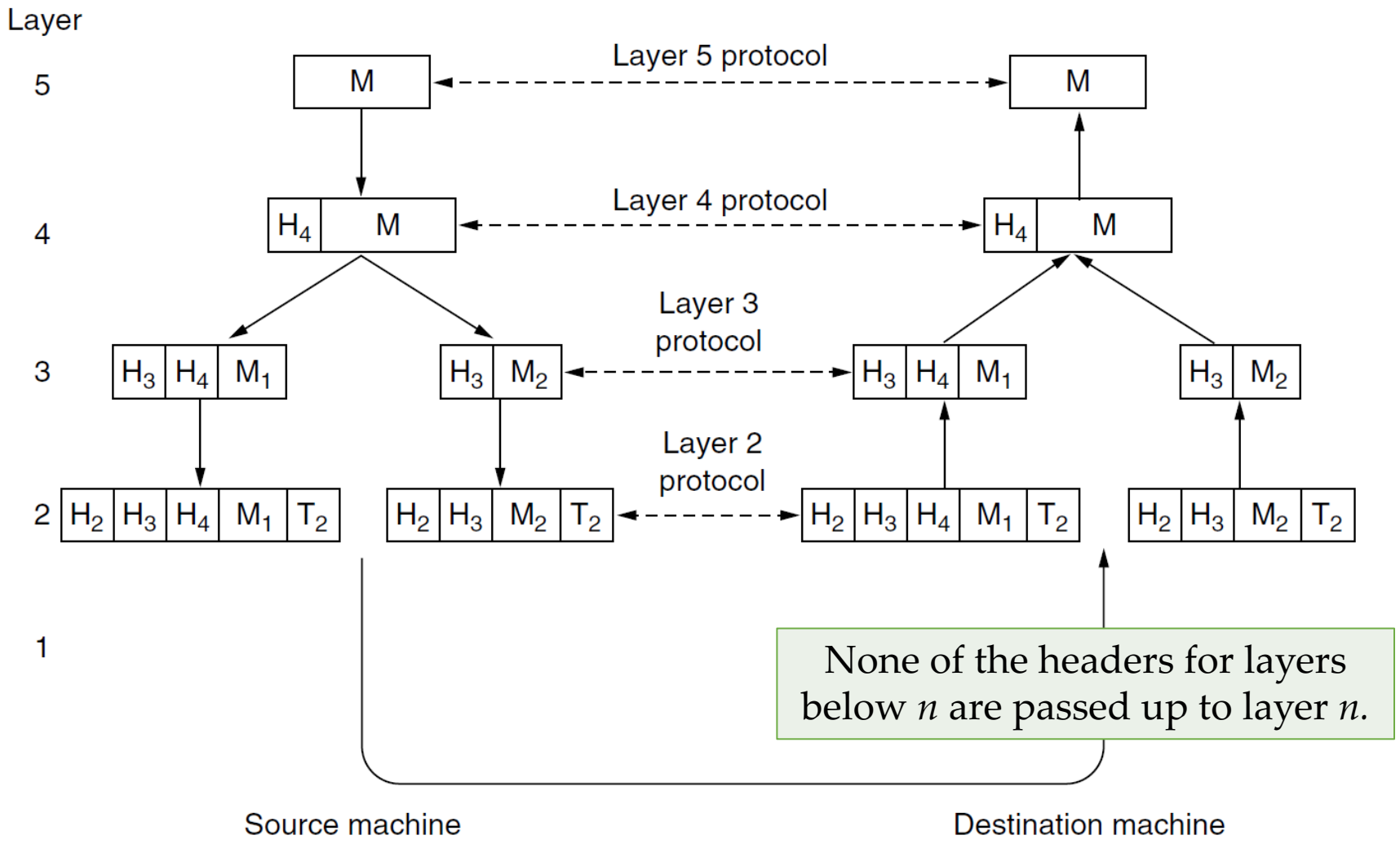
Example of network architecture

A message M is produced by an application running on layer 5 and given to layer 4 for transmission.

Layer 4 puts a header (e.g. address) in front of M to identify it and then pass it to layer 3.

Layer 3 breaks M into smaller packets (M1 and M2) and add headers to each packet which are passed to layer 2.

Layer 2 adds a header and a trailer to each packet and then pass them to layer 1 for physical transmission to the destination machine.



Services and primitives

- **Service:** a set of primitives (operations) that a layer provides to the layer above.
  - What operations the layer is prepared to perform on behalf of its users
  - No information about how these operations are implemented.
  - It relates to an interface between two layers, with the lower layer being the service provider and the upper layer being the service user.

Examples of primitives for a simple connection-oriented service

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

Connection-oriented vs connectionless services

Two types of service:

- **Connection-oriented service:** the service user first establishes a connection with the receiver, then it uses the connection to send data, and finally it releases the connection (like in a telephone communication).
  - In most cases the order of data bits is preserved → bits arrive in the same order they were sent.

- **Connectionless service**: each message carries the full destination address and each one is sent independently on the subsequent messages (like in postal system).
  - Normally, when two messages are sent to the same destination, the first one sent will be the first one to arrive. However, it is possible that the first one sent can be delayed so that the second one arrives first.
  - The messages in a connectionless service are also called **datagram**.

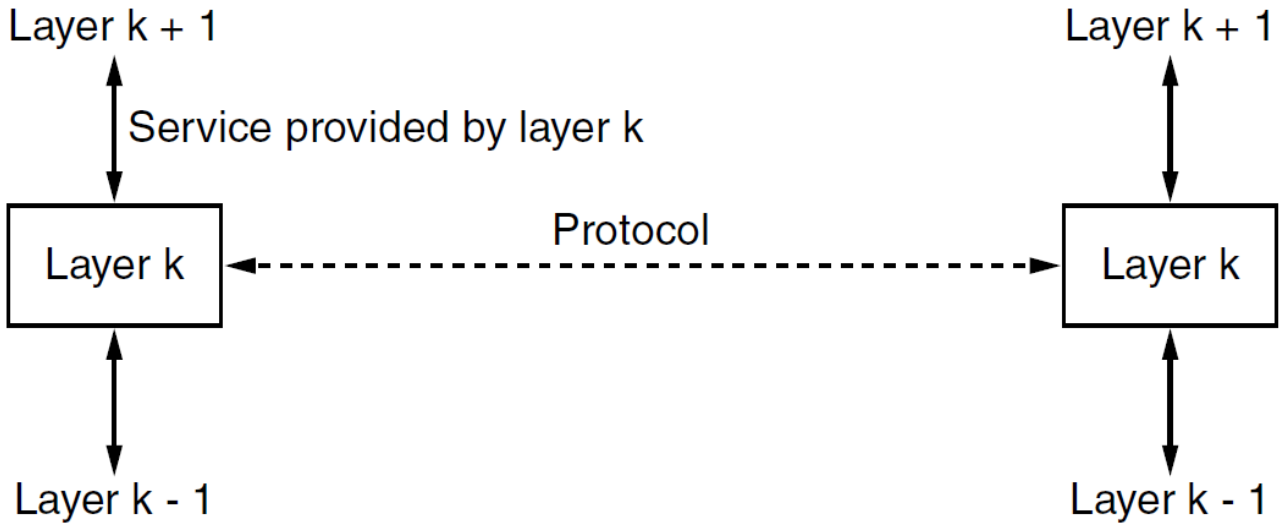
Reliable vs. unrealiable services

- A **reliable** service never looses data: the receiver acknowledges the receipt of each message so the sender is sure that it arrived.
- The acknowledgement process introduces overhead and delays, sometimes undesirable.
  - E.g. in a telephone communication it is less disruptive to hear a bit of noise on the line from time to time than to experience a delay waiting for acknowledgements.
- An **unreliable** service does not return an acknowledgement to the sender

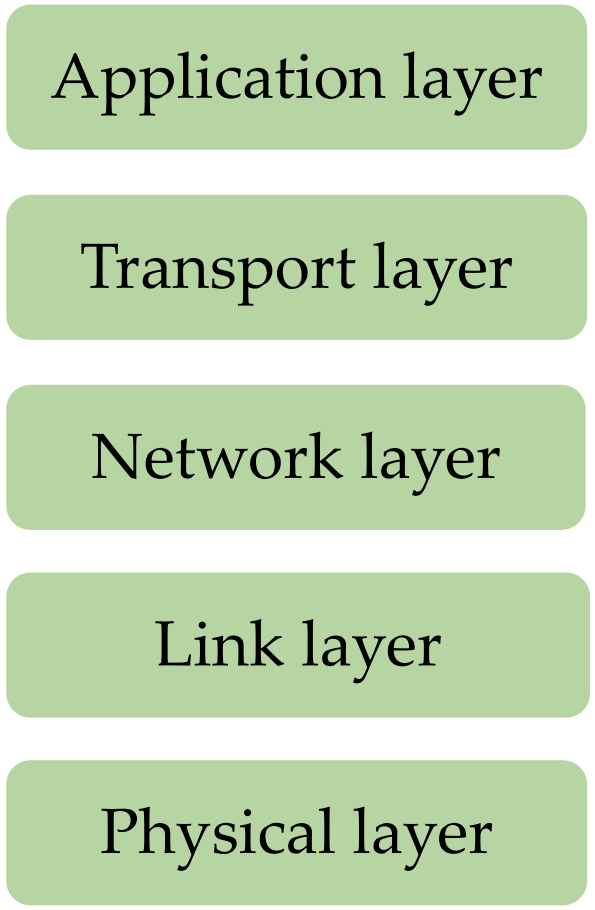
	Service	Example
Connection-oriented	Reliable message stream	Sequence of pages
	Reliable byte stream	Movie download
	Unreliable connection	Voice over IP
Connection-less	Unreliable datagram	Electronic junk mail
	Acknowledged datagram	Text messaging
	Request-reply	Database query

Protocol vs. service

- **Protocol**: The set of rules governing the format and meaning of the packets, or messages that are exchanged by the peer entities within a layer.
- **Service:** the set of primitives (operations) that a layer provides to the layer above it. They are related to the interfaces between layers.
- The protocol of layer k defines the implementation details of services which layer k provides to users of layer k+1; such details are not visible to users of layer k+1.



The TCP/IP reference model



- **Worldwide Internet**: the global system of interconnected computer networks that uses the Internet protocol suite (TCP/IP) to communicate between networks and devices.
- The reference model used by the worldwide Internet is called **TCP/IP reference model** and it was introduced by Cerf and Kahn in 1974.

The TCP/IP reference model

Application layer

Transport layer

Network layer

Link layer

Physical layer

- It includes the protocols used by applications running on different hosts to communicate
- Example: A Web browser can send requests to a Web server using the **HTTP protocol**, which is a protocol of the application layer

The TCP/IP reference model

Application layer

Transport layer

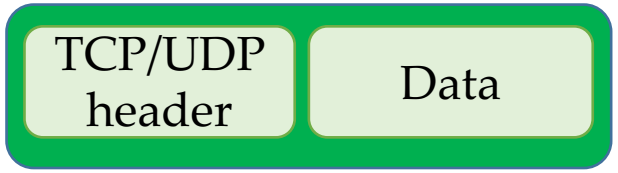
Network layer

Link layer

Physical layer

- It creates and maintain conversations between applications on two hosts
- Two transport protocols have been defined:
  - **Transmission control protocol (TCP)**: a reliable connection-oriented protocol that allows a byte stream delivery without errors.
  - **User Datagram Protocol (UDP)**: an unreliable, connectionless protocol for applications in which prompt delivery is more important than accurate delivery (e.g., speech or video).

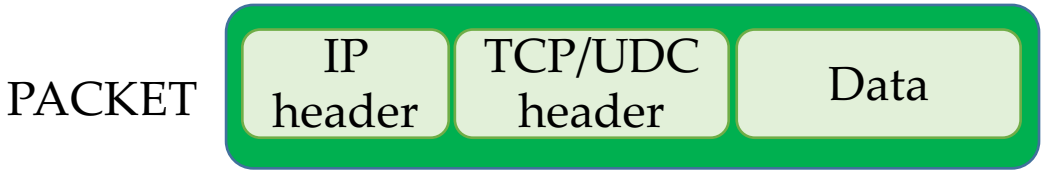
SEGMENT



The TCP/IP reference model

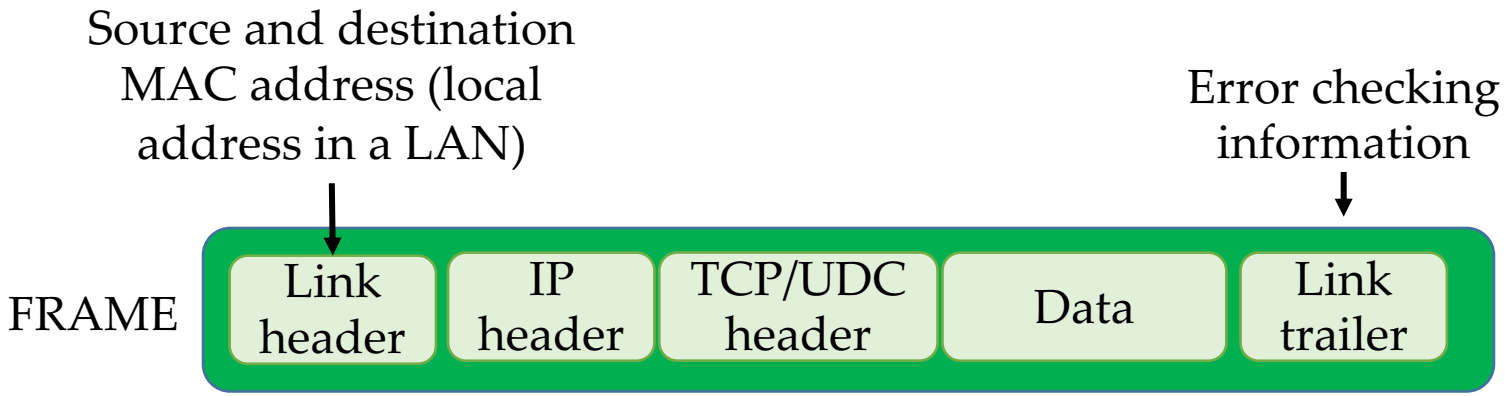
- Application layer
- Transport layer
- **Network layer** →
- Link layer
- Physical layer

- Unreliable connectionless data transmission.
- Packets are sent independently to the destination by a certain path.
- This layer works with two protocols:
  - **Internet protocol (IP):** it defines the IP addresses, i.e,. that label (e.g., 192.0.2.1) that uniquely identifies a host connected to a computer network using the IP protocol.
  - **Internet Control Message Protocol (ICMP)**: it sends error and control messages.



The TCP/IP reference model (revised)

- Application layer
- Transport layer
- Network layer
- **Link layer**
- Physical layer



- It moves packets between the network layer and the physical layer.
- Not really a layer at all, but rather an interface between hosts and physical transmission links.

The TCP/IP reference model

- Application layer
- Transport layer
- Network layer
- Link layer
- **Physical layer**

0001010111011010100110011010111010101

- It physically receives and transmit raw bits over a communication channel.
- A standardized interface to the transmission medium (electrical, optical, or wireless communication).

World Wide Web

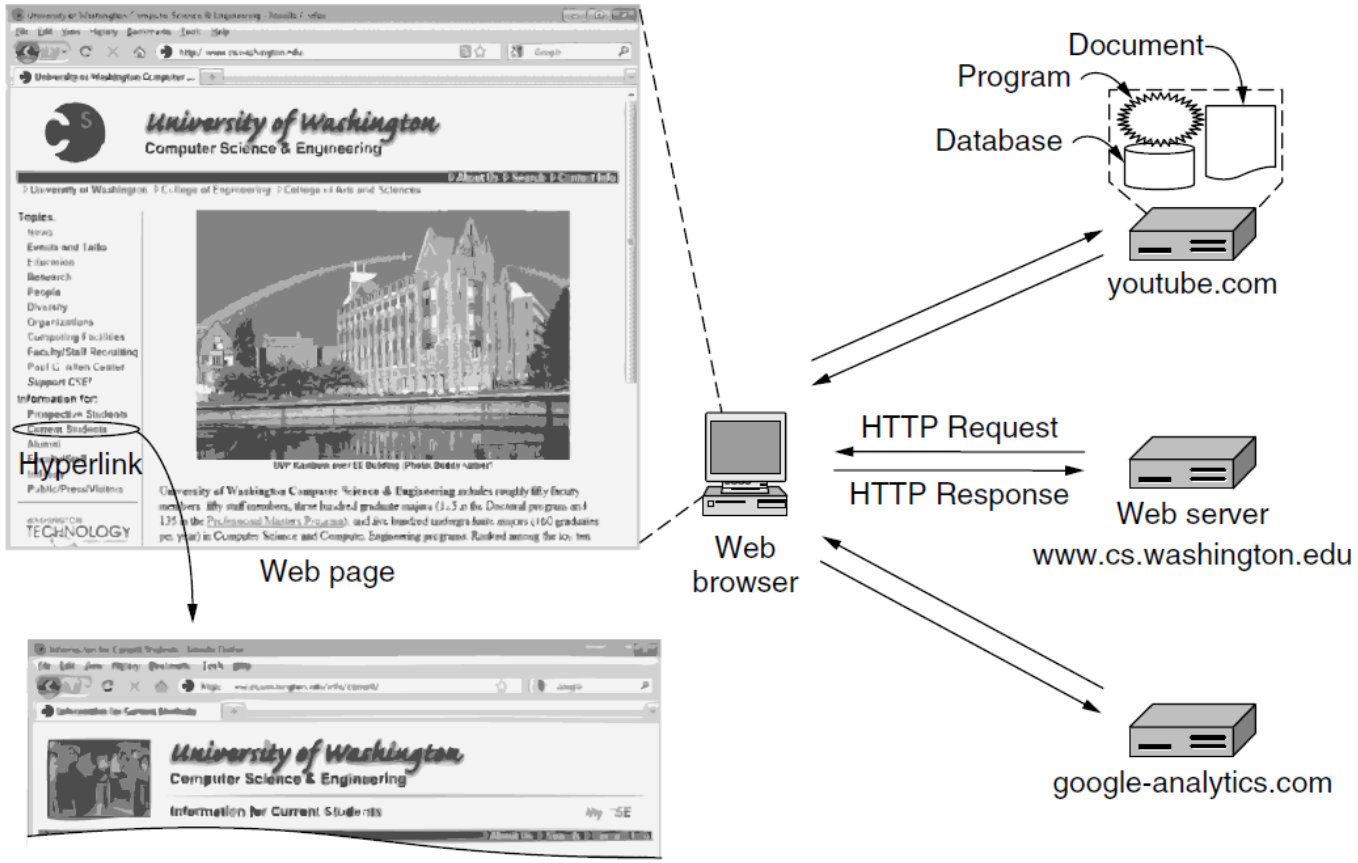
- An architectural framework for accessing linked content spread out over millions of machines all over the Internet.
- How the Web was born:
  - 1989, Geneva, CERN: the physicist Tim Berners-Lee proposed to develop a web of linked documents to help large research teams
  - 1991, San Antonio, Texas: First prototype of Web presented at the Hypertext '91 conference
  - 1993, Champaign, Illinois: First graphical browser (Mosaic) developed by Marc Andreessen (University of Illinois).
  - 1994, Mountain View, California: Marc Andreessen found the company Netscape Communications Corp., whose goal was to develop Web software.
  - 1994: CERN and M.I.T. Foundation of the World Wide Web Consortium (W3C), an organization devoted to further developing the Web, standardizing protocols, and encouraging interoperability between sites.
  - 1994 - today: The Web has grown exponentially…

Architectural overview

- The Web is a vast, worldwide collection of contents in the form of **Web pages**, accessed and shared through the Internet according to a **client-server architecture** model.
  - Pages can contain text, images, videos, programs that produce a graphical interface with which users can interact, etc.
- Each page may contain **links** to other pages. A piece of text, icon, image, etc. associated with another page is called a **hyperlink.**
- A page can be static or dynamic.
  - **Static page**: a document that is the same every time it is displayed.
  - **Dynamic page**: a page that contains a program generating dynamic content or that is generated on demand by a program.
- A **Web site** is a collection of Web pages.

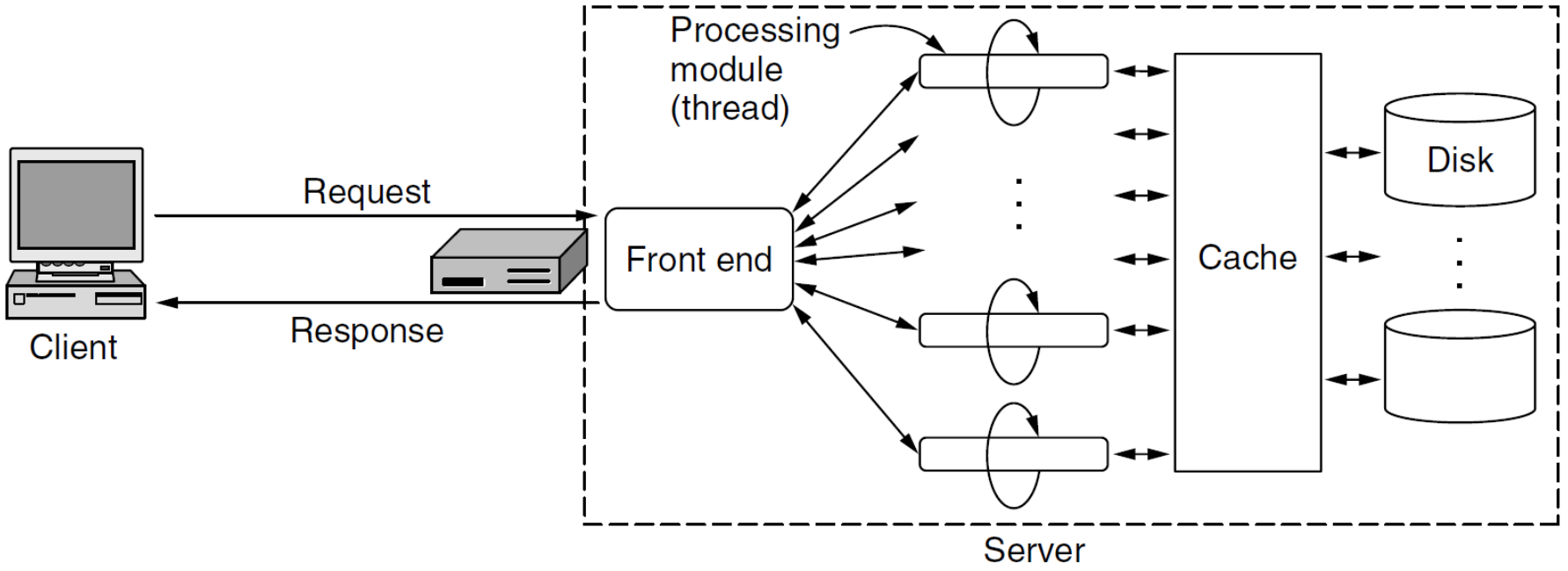
Architectural overview

- **Browser**: program running on the client to view Web pages
- The browser requests the page to the server, receives it, interprets the content, and displays the page, properly formatted, on the screen.
- The request-response protocol for fetching pages is a simple text-based protocol that runs over TCP, called **HyperText Transfer Protocol (HTTP).**



The server structure

- Web servers are designed with a **multithreaded design** to manage multiple requests at a time.
  - A front-end module that accepts all incoming requests and *k* parallel processing modules.
  - The cache stores the most-recently read files.

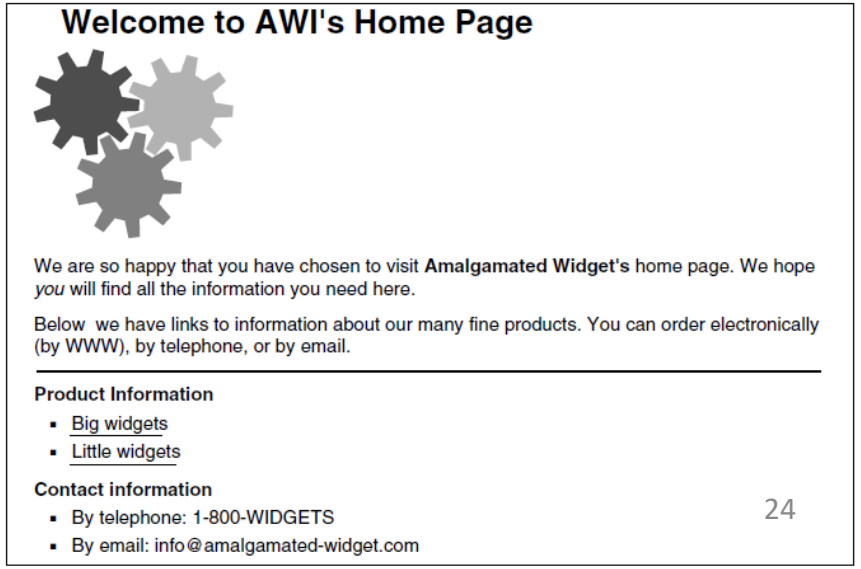


HyperText Markup Language (HTML)

- Web pages are written in a **HTML (HyperText Markup Language).** HTML is a markup language: language for describing how documents are to be formatted.
- A browser is basically an HTML interpreter
- HTML pages can contain text and rich content elements (e.g., MPEG, JPEG, mp3).
- When a server returns a page, it also returns some information about the type of contents in the page (MIME type).
- If the page content is different from text/html, the browser resorts to a **plug-in**, i.e., a third-party code module that is installed as an extension to the browser, to interpret that content (e.g., plug-in for PDF).

```
<html>
<head> <title> AMALGAMATED WIDGET, INC. </title> </head>
<body> <h1> Welcome to AWI's Home Page </h1>
<img src="http://www.widget.com/images/logo.gif" ALT="AWI Logo"> <br>
We are so happy that you have chosen to visit <b> Amalgamated Widget's</b>
home page. We hope <i> you </i> will find all the information you need here.
<p>Below we have links to information about our many fine products.
You can order electronically (by WWW), by telephone, or by email. </p>
<hr>
<h2> Product information </h2>
<ul>
   <li> <a href="http://widget.com/products/big"> Big widgets </a> </li>
   <li> <a href="http://widget.com/products/little"> Little widgets </a> </li>
</ul>
<h2> Contact information </h2>
<ul>
   <li> By telephone: 1-800-WIDGETS </li>
   <li> By email: info@amalgamated-widget.com </li>
</ul>
</body>
</html>
```

(a)



The client side

- How can the browser retrieve a page?
- Each page is assigned an identifier called **Uniform Resourse Locator (URL)**
- The URL includes three components:
  - the communication protocol to access to the page
  - the name of the server where the page is located
  - the path identifying the page file on the server

Remember: The **IP address** is that label (e.g. 192.0.2.1) which uniquely identifies a host connected to a computer network using the IP protocol.

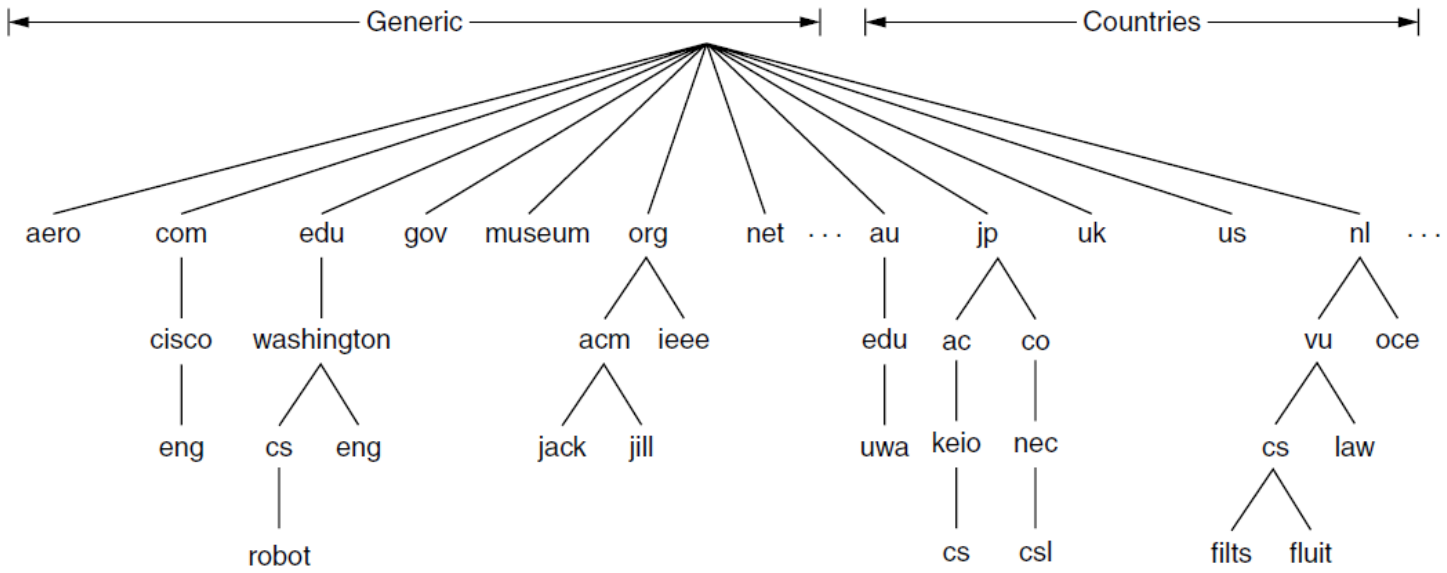
http://www.dei.unipd.it/index.html

http	www.dei.unipd.it	index.html
Protocol	Name of the server	Path of the page

- But in order to send the request the browser needs to know the IP address of the server.
- This information is stored in a **name server**…

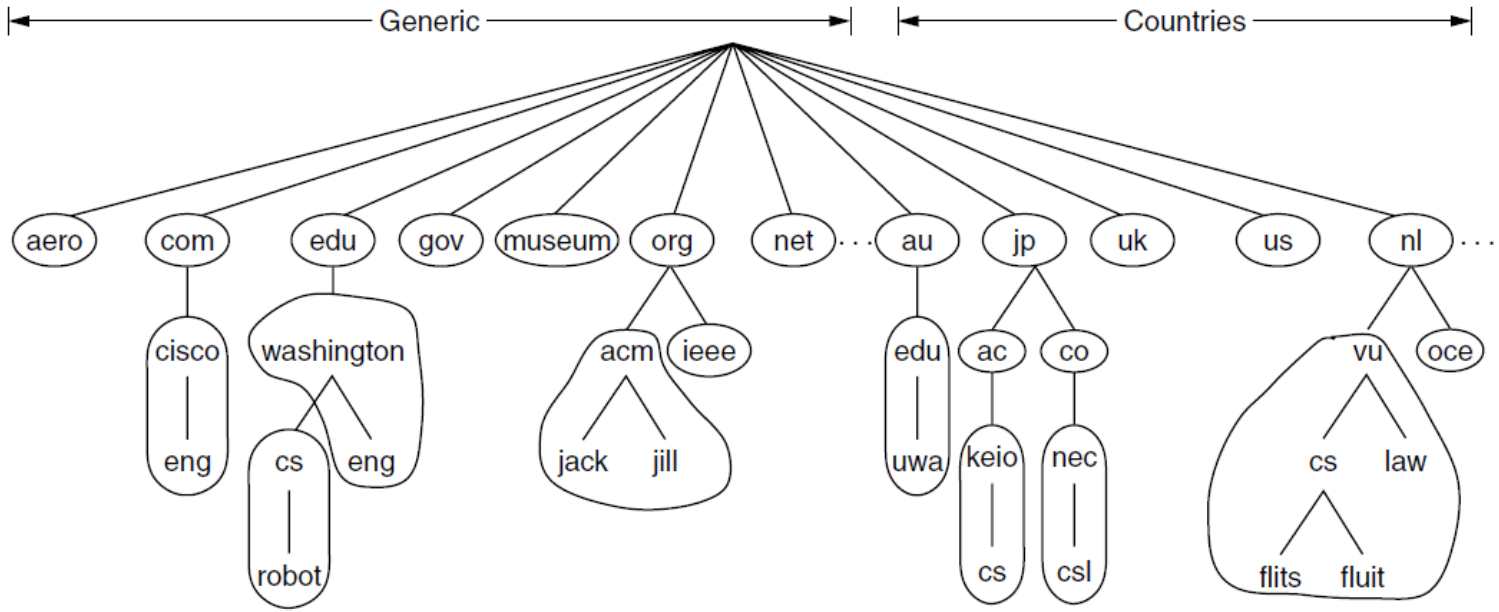
Domain Name Space (DNS)

- The **Domain Name Space (DNS)** is a hierarchical, domain-based naming scheme and a distributed database system used for mapping server names with their IP address.
- The DNS is managed by an organization called **ICANN** (**Internet Corporation for Assigned Names and Numbers**).
- There are 250 top-level domains, each divided into subdomains according to a hiearchical structure.



The DNS database

- The DNS database stores information about each registered domain, including the IP address.
- The DNS database is not stored in a single server. It is divided into non-overlapping **zones** and each zone is associated to multiple servers.
- The process of looking up a domain name in the DNS database and finding its resource records (e.g., IP address) is called **name resolution** and it is performed by a program called **resolver**.



Browsing - the client side

When the user click on a hyperlink linking the URL:

http://www.dei.unipd.it/index.html

- The browser determines the linked URL (by seeing what was selected).
- The browser asks to the DNS resolver the IP address of the server *www.dei.unipd.it*
- The resolver replies with 147.162.2.199.
- The browser makes a TCP connection to 147.162.2.199 on port 80 (port for HTTP).
- It sends over an HTTP request asking for the page */index.html*.
- The server *www.dei.unipd.it* sends the page */index.html* as an HTTP response.
- If the page includes URLs that are needed for display, the browser fetches the other URLs using the same process.
- The browser displays the page.
- The TCP connection with *www.dei.unipd.it* is closed if there are no other requests for the same server for a short period.

Browsing – The server side

When the client sends a connection request to a server, the server:

- Accepts a TCP connection from a client (a browser).
- Resolves the name of the Web page requested (some incoming paths may contain build-in shortcuts that need to be parsed, e.g., empty file names to be expanded to a default file name).
- Performs access control on the Web page → checking access restrictions for the requested page.
- Fetches the requested page from disk or run a program to build it.
- Returns the response to the client.
- Makes an entry in the server log for administrative purposes.

To increase performance, a single TCP connection may be used by a client and server for multiple page fetches.

References

- Tanenbaum, Wetherall – Computer Networks – Fifth Edition
  - Chapter 1 – Introduction
  - Chapter 7 – The application layer