Protocol Architectures

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- Open Systems for Interconnection (OSI)
- TCP/IP
- Multimedia Traffic and Performance

Need For Protocol Architecture

- Example: File Transfer from one computer to another
  - Require path between two computers: either direct link or communication network
  - But more is needed to transfer the file:
    - Source must activate the link/network in preparation for transmission
    - Source must know that destination is ready to receive
    - Source file transfer application must know that destination application is prepared to accept
    - File formats may need to be translated
- High degree of cooperation is needed between two computer systems
- Data exchange is a complex task – it is very hard!
- So apply the divide-and-conquer principle:
  - Break the communication tasks into subtasks
  - Implement tasks separately in layers in stack
  - Each layer provides functions needed to perform communications for layers above
  - Each layer uses functions provided by layers below
  - Peer layers communicate with a protocol

Key Elements of a Protocol

- What is a protocol?
  - Set of rules (or conventions) that two (or more) peer entities obey in order to communicate
- Elements of a protocol:
  - Syntax: the types of messages that can be exchanged, and the format of each message
  - Procedures (or rules): the set of rules that each entity must follow
    - E.g. what to do when receive a message of type X; what to do when a timer expires
    - Includes information and the meaning of messages and timing of events
  - Other parts:
    - Service provided to higher layer
    - Assumptions about environment and lower layers

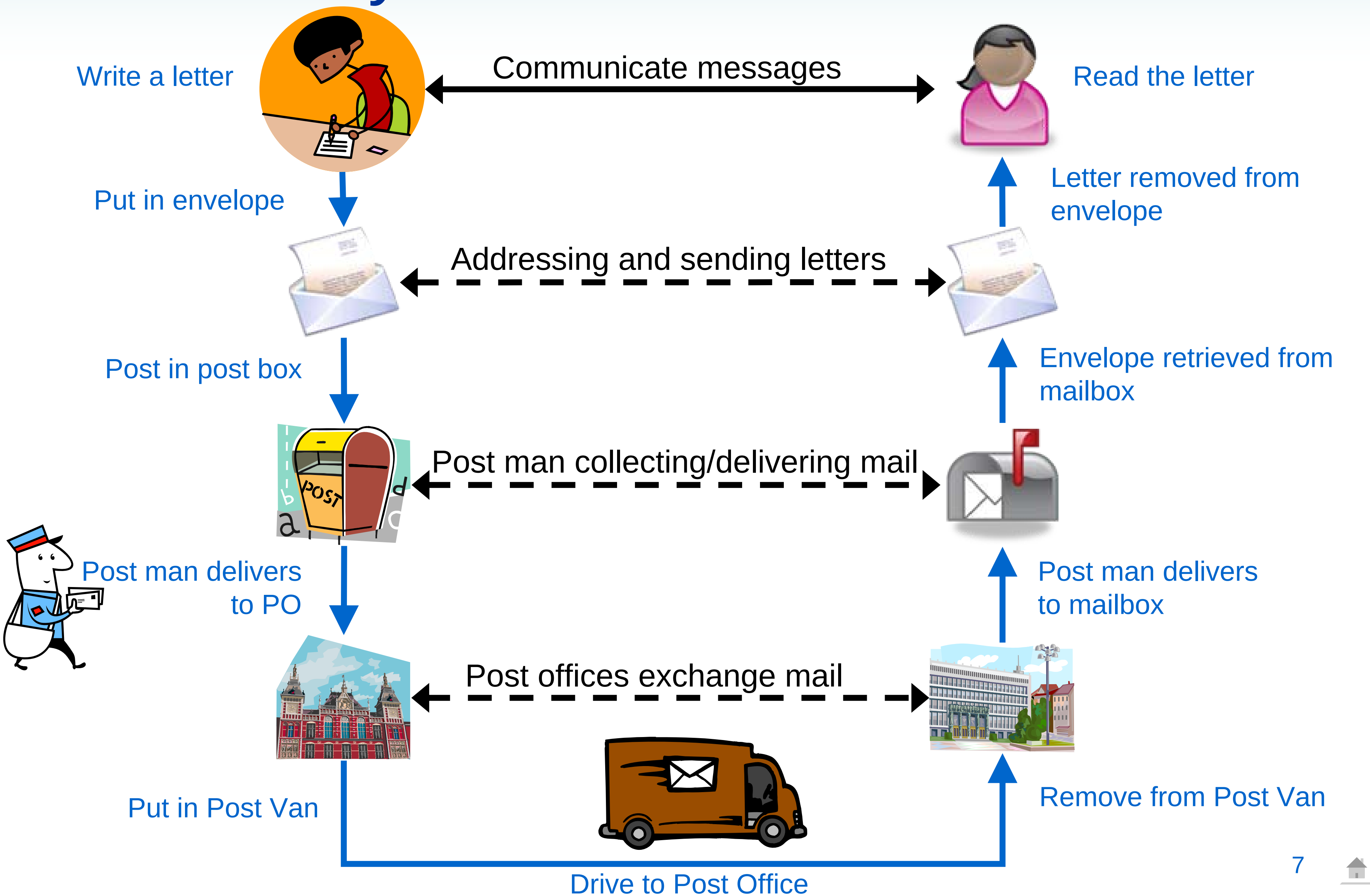
Protocol and Standards

- Protocols are rules that communicating entities follow
  - Protocols are implemented in hardware and software on computing devices
- Standards are agreed-upon rules, i.e. protocols that some organisation has agreed upon
  - Standards are essential in creating open and competitive market
    - If all equipment manufacturers follow one standard, then you, as a purchaser, can select the equipment that best suites your need and know that it will interoperate with other equipment
  - Guarantee national and international interoperability
  - De jure standards: standards that have been officially recognised or are part of law
  - De facto standards: not approved by standards organisation, but in widespread use

Standards Organisations

- *International Organisation for Standardisation (ISO)* – formed from national standards bodies to create global standards
- *International Telecommunication Union – Telecommunication Sector (ITU-T)* – formed from national telecom operators and other organisations to create global standards for telecoms
- *Institute of Electrical and Electronics Engineers (IEEE)* – professional engineering society that develops standards in electronics, radio and electrical engineering
- *American National Standards Institute (ANSI)* – US standards organisations
- *Electronic Industries Association (EIA)* – electronics manufacturing standards
- *Internet Engineering Task Force (IETF)* – part of the Internet Society, develops most standards for the Internet
- *World Wide Web Consortium (W3C)* – develops web based standards (e.g. HTML)
- Others:
  - Forums and Special Interest Groups: usually companies get together to work on specific technologies
  - Regulatory agencies: government agencies that set regulations on use of communication technologies

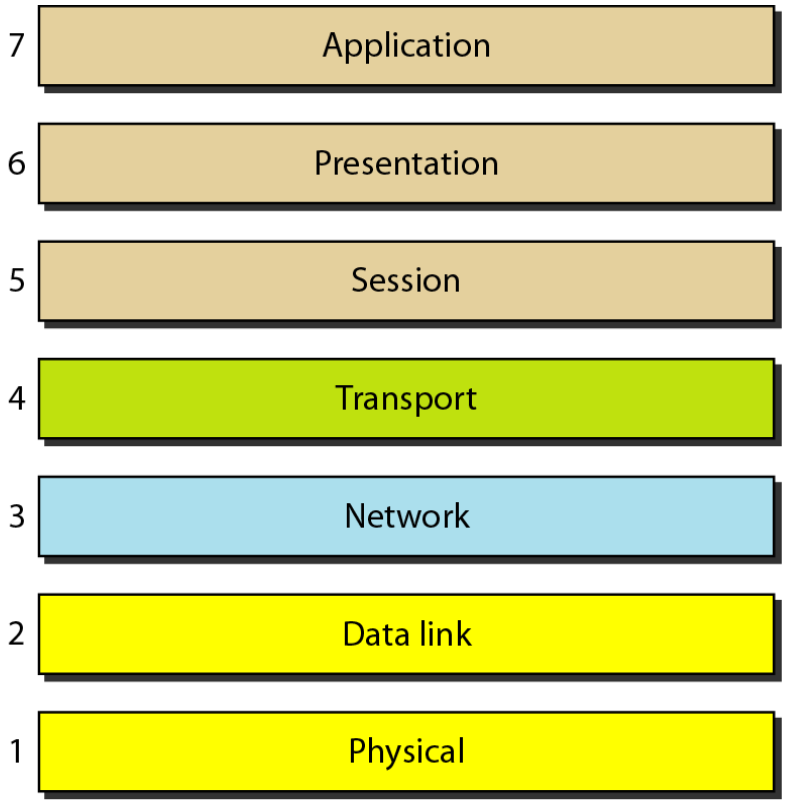
A Layered Architecture: Post



Open Systems for Interconnection

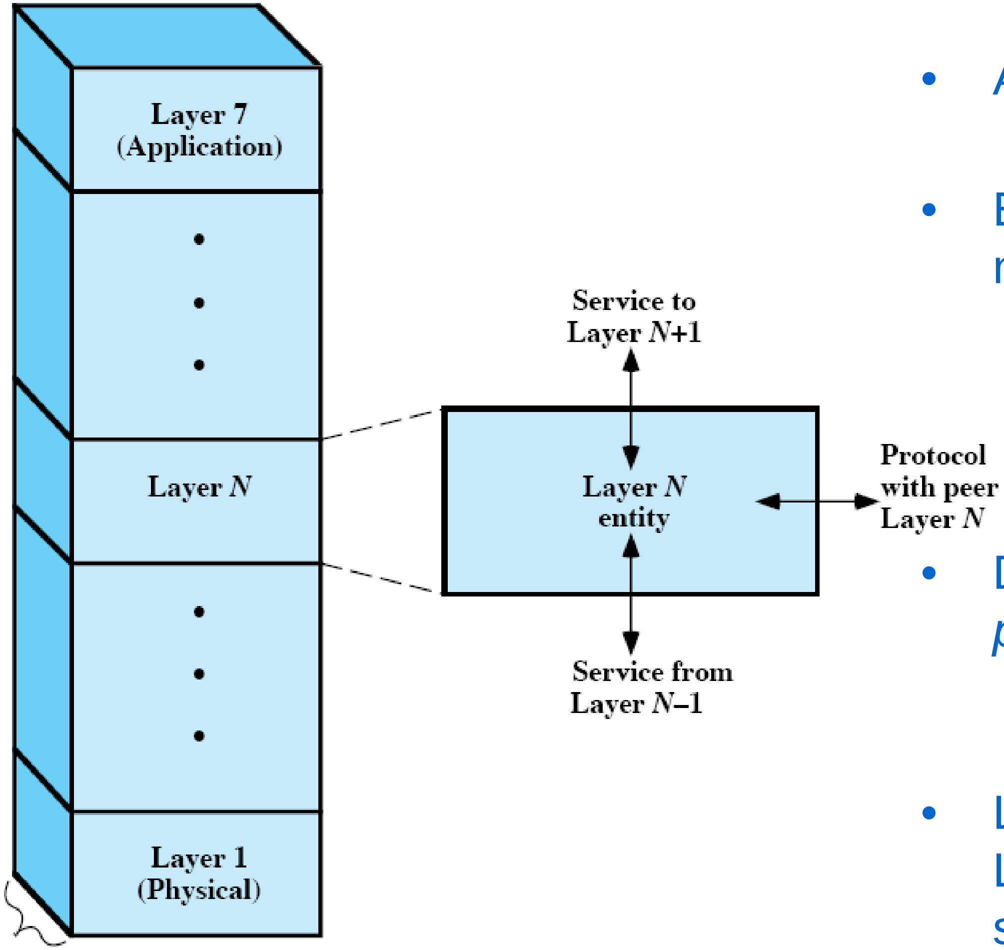
- Open Systems for Interconnection (OSI)
  - Developed by the International Organization for Standardization (ISO), introduced in late 1970's
- The OSI 7-layer reference model
  - Defines concepts that are helpful in thinking about layering, architectures and describing protocols
  - Within each layer, one or more protocols are standardized
- Not used in practice today!
  - Implementations of TCP/IP were mature before OSI implementations were available
  - Overly complex compared to TCP/IP

OSI 7-Layer Model



- Application: allows users (human or software) to access network; provides user interfaces and support for applications
- Presentation: translation, encryption and compression of data formats
- Session: creates and manages connections (sessions) between applications
- Transport: reliable transfer of data between end-points (processes)
- Network: delivery of data across networks; establish connections between end-points
- Data Link: reliable transfer across a link, including addressing and error control
- Physical: mechanical, electrical and functional means of transferring bits over medium

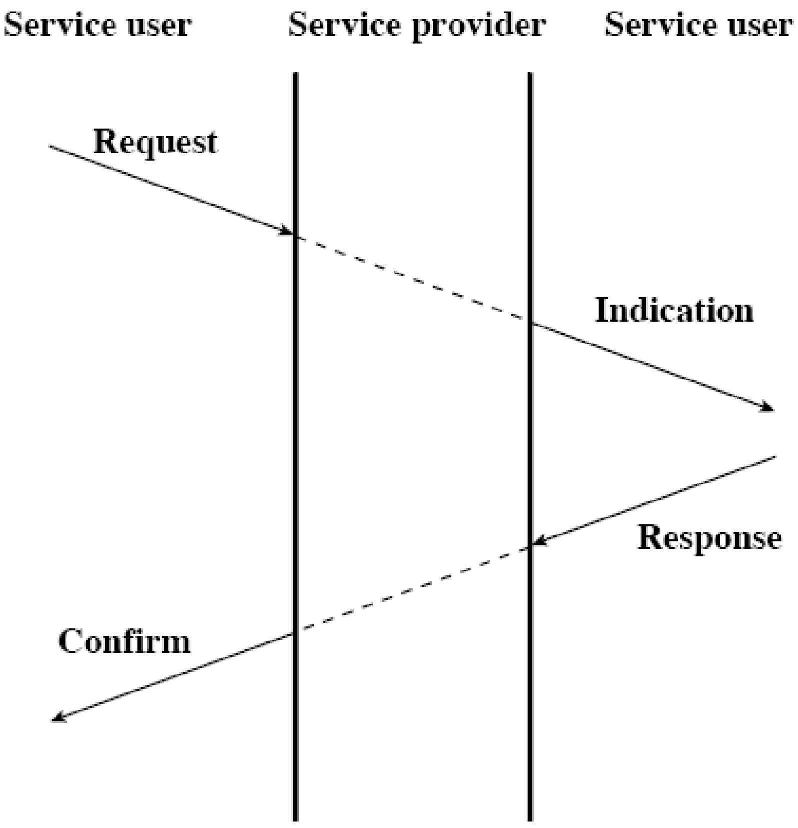
OSI Layering Concepts



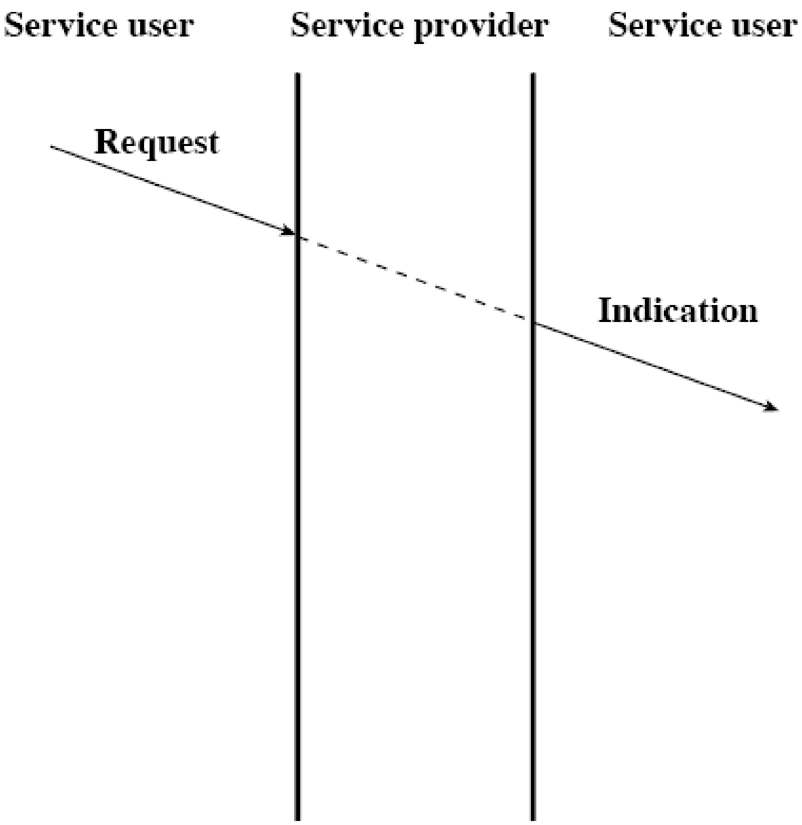
- Architecture is divided into n layers
  - OSI: n=7; TCP/IP: n=5
- Each layer provides a service to the next higher layer
  - Formally designed as a *service definition*
  - Similar to interface
  - Defined using *service primitives*
- Details of each layer are defined in *protocol specification*
  - Other layers are not concerned with these details
- Layer N uses the service provided by Layer (N-1); Layer N provides a service to Layer (N+1)

Service Primitives

- Interface (or service) provided by a layer is defined by a sequence of *primitives* (which also have parameters)



(a) Confirmed Service



(b) Nonconfirmed Service

Service Primitive Types

REQUEST	A primitive issued by a service user to invoke some service and to pass the parameters needed to specify fully the requested service
INDICATION	A primitive issued by a service provider either to: indicate that a procedure has been invoked by the peer service user on the connection and to provide the associated parameters, or notify the service user of a provider-initiated action
RESPONSE	A primitive issued by a service user to acknowledge or complete some procedure previously invoked by an indication to that user
CONFIRM	A primitive issued by a service provider to acknowledge or complete some procedure previously invoked by a request by the service user

TCP/IP Protocol Architecture

- Developed by US Defense Advanced Research Project Agency (DARPA)
  - For ARPANET packet switched network
- Used by the global Internet today
- Protocol suite comprises a large collection of standardized protocols
- There is no official layered model (unlike 7-layer OSI)
  - But many people (textbook authors, lecturers) have tried to characterize Internet protocols into a layered model
  - Usually 5 layers (sometimes the names and functionality differ)
  - We will use this layered architecture in remainder of course

- Note: TCP is a protocol; IP is a protocol; but TCP/IP most often refers to a set (or suite) of protocols used on the Internet
  - E.g. TCP, IP, UDP, ICMP, IGMP, ARP, …
  - TCP/IP does not mean “only TCP and IP”
  - TCP/IP architecture may also be called “Internet Architecture” or “Internet Stack”

TCP/IP Layered Model

- 5 Layered Model (from bottom)

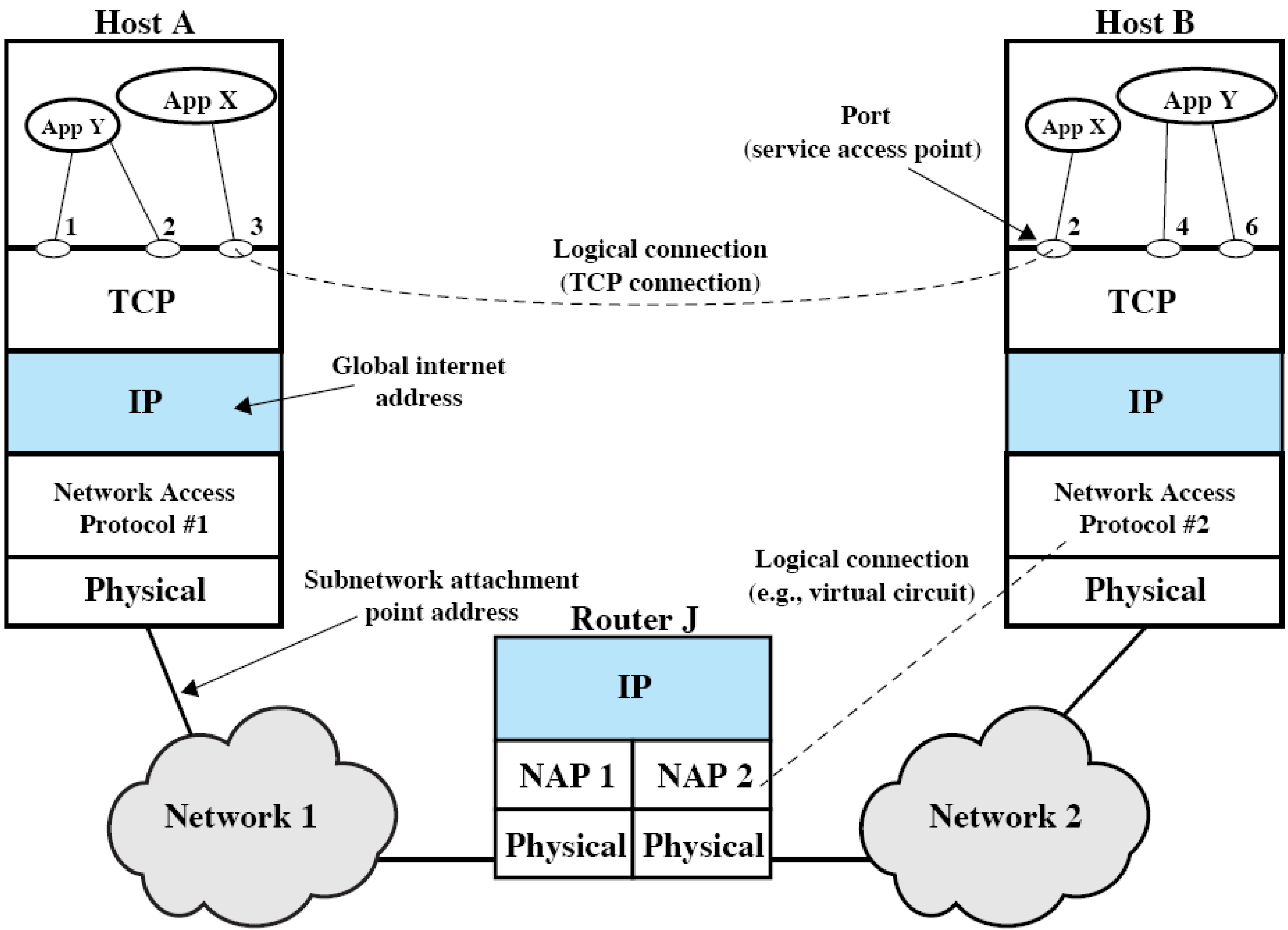
1. Physical Layer
   - Physical interface between transmission device and medium
   - How to send bits over transmission medium: data rate, signalling, electrical signals, codecs, modems, …
2. Data Link Layer
   - Sometimes called: “Network Access”, “MAC”, “Link”, “Hardware”
   - Transmission of data over link or network to which the device is attached
   - Addressing scheme of destination device
   - Allows layers above to ignore details of links
3. Network Layer
   - Sometimes called: “Internet” or “IP” layer
   - Core of the Internet; uses the Internet Protocol
   - Allows hosts to communicate across different networks
   - Provides routing across the Internet; determine the path to take
   - Provides unreliable, connectionless deliver of packets

TCP/IP Layered Model

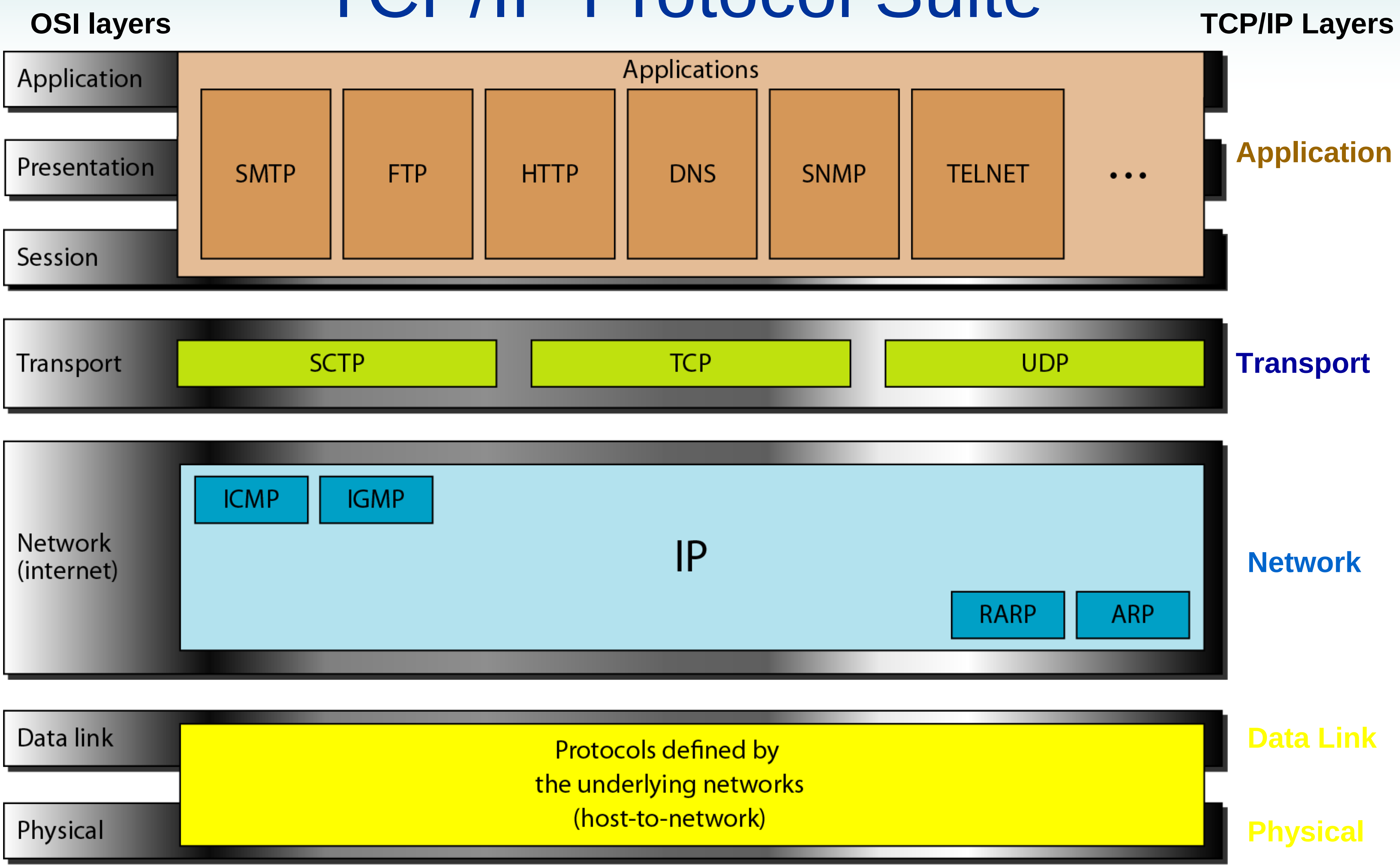
- 5 Layered Model (from bottom)

4. Transport Layer
    - Provides connections between applications (processes) running on the end hosts. Three standardised protocols:
        - User Datagram Protocol (UDP): unreliable, connectionless sending of packets
        - Transmission Control Protocol (TCP): reliable, connection-oriented sending of packets
        - Stream Control Transmission Protocol (SCTP): combines features of TCP and UDP to better support voice and other applications
5. Application Layer
    - Everything else!
    - Contains functionality needed for various applications used on the Internet
        - E.g. for web browsing (HTTP), file transfer (FTP), email (SMTP), …

TCP/IP Concepts



TCP/IP Protocol Suite



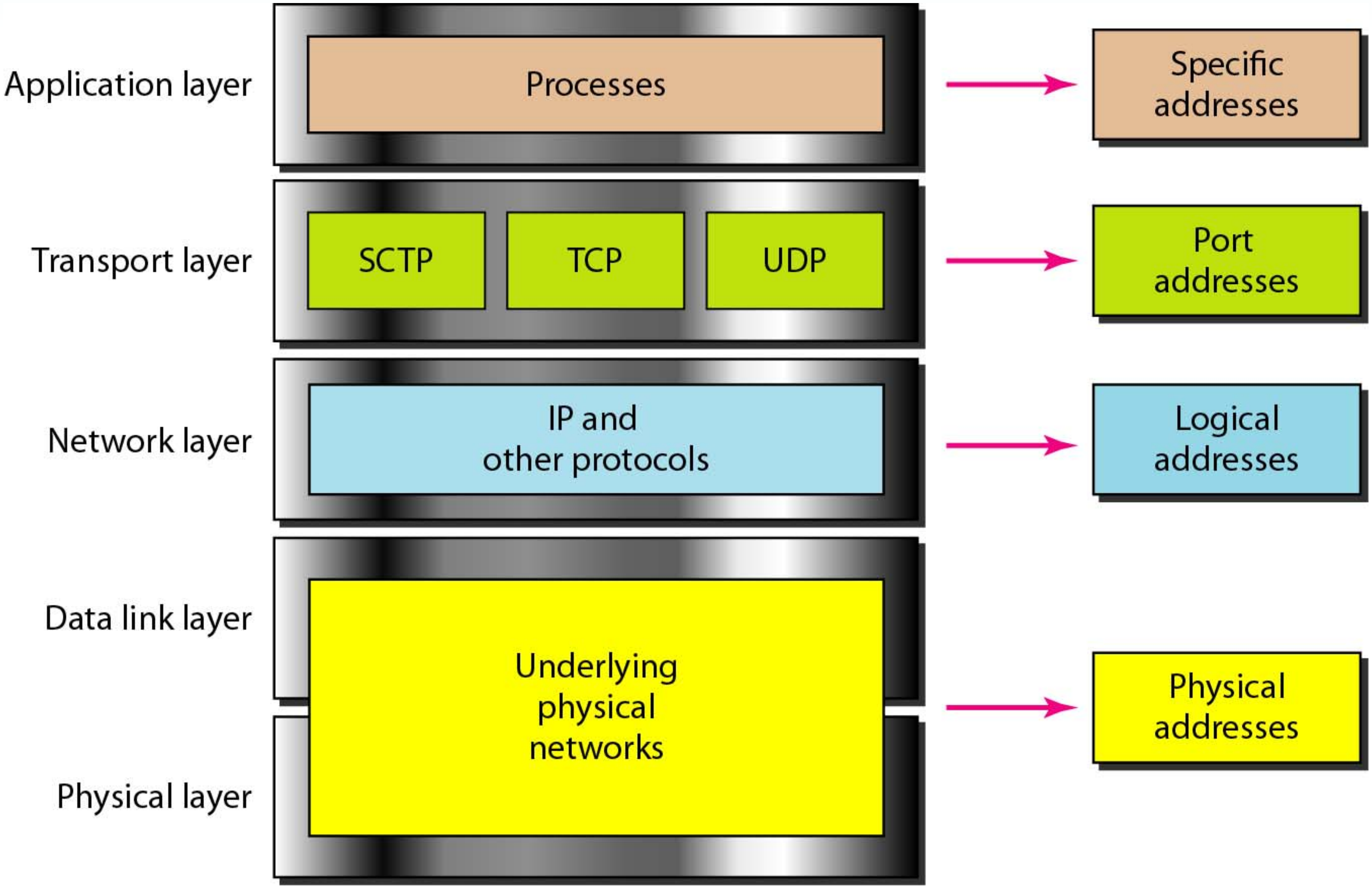
Addressing in TCP/IP

- Physical Addresses
  - Also referred to as “Data Link”, “Link”, “MAC”, “Hardware” addresses
  - Address of a physical interface on a device
  - Address type depends on the LAN/WAN technology being used
    - E.g. IEEE 48-bit addresses are used in Ethernet LANs; some Apple protocols use 8-bit dynamic addresses
  - Example: 07:01:02:01:2C:4B (48-bit IEEE address in hexadecimal)
- Logical Addresses
  - Also referred to as “Network” address
  - IP addresses are the format used in TCP/IP
    - Currently IP addresses are 32-bit addresses
    - In theory, all hosts (interfaces) on the Internet should have a unique IP address
    - Therefore, although hosts may use different physical address types, they use a common logical address type
  - Example: 125.25.71.189 (32-bit IP address in dotted decimal notation)

Addressing in TCP/IP

- Port Addresses
  - Also referred to as a “Transport” address
  - IP address identifies a computer (or a interface on a computer)
  - Port addresses identify software processes on that computer
  - Allows multiple Internet applications to run on the one computer at the same time
  - Example: 80 (port number used by web servers); 41067 (random port number used by a client application)
- Other Addresses
  - Applications may use specific addresses
    - URLs, Email, P2P application addresses, …
  - Example: http://www.google.co.th/; steve@siit.tu.ac.th

Layers and Addresses in TCP/IP

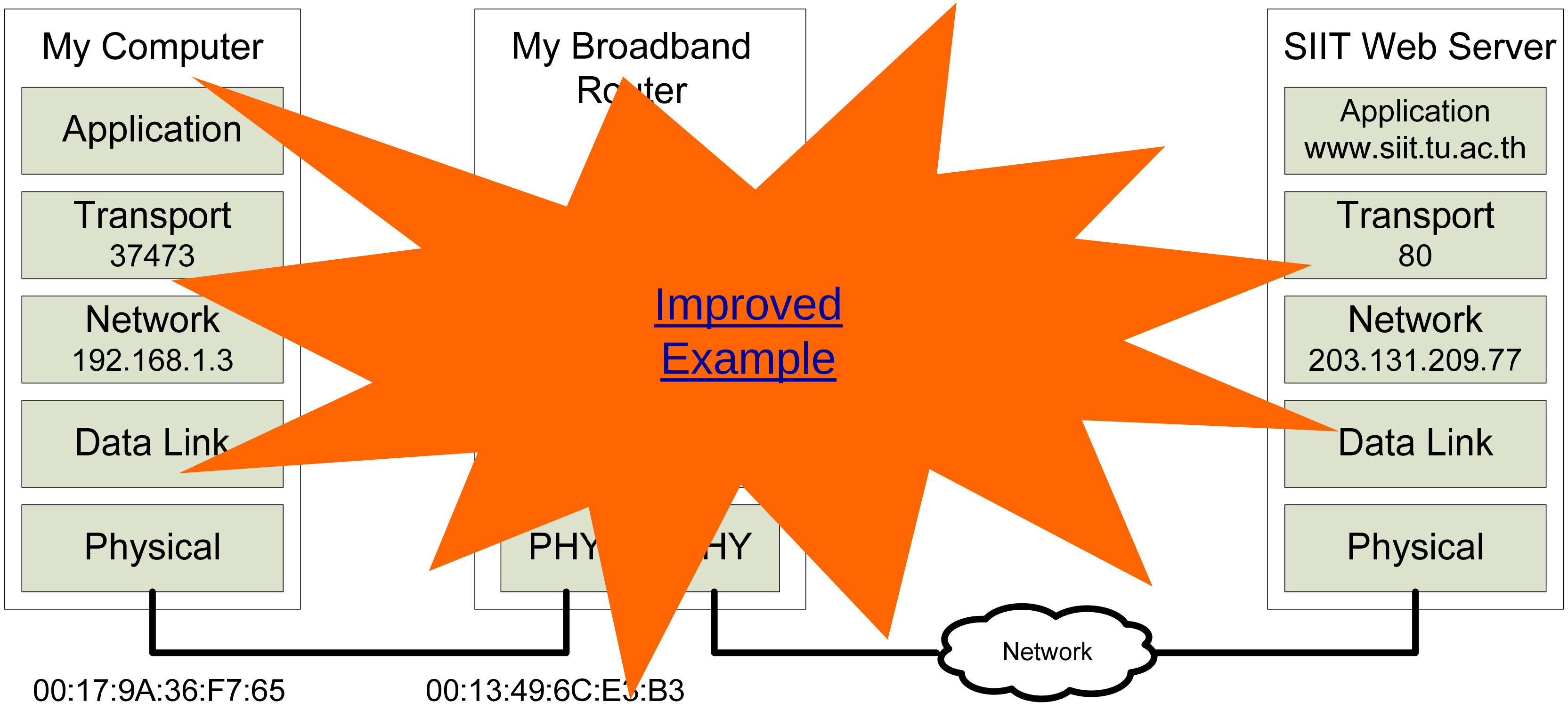


Addressing Example

Networking configuration from my home computer

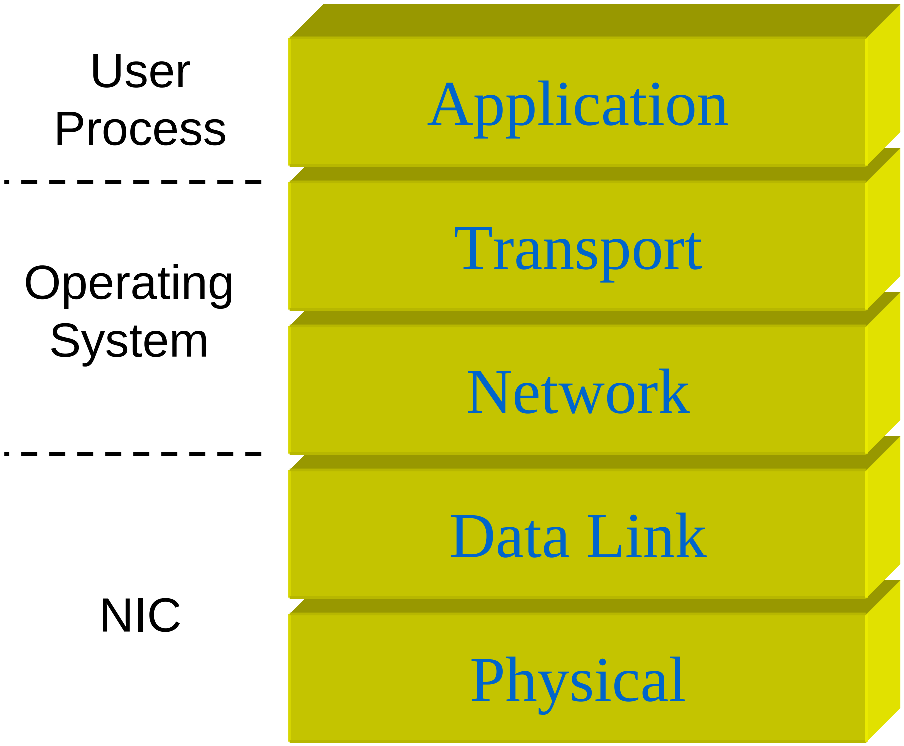
```
sgordon@basil:~/its323$ ifconfig eth1
eth1      Link encap:Ethernet  HWaddr 00:17:9A:36:F7:65
          inet addr:192.168.1.3  Bcast:192.168.1.255  Mask:255.255.255.0
          inet6 addr: fe80::217:9aff:fe36:f765/64 Scope:Link
          UP BROADCAST RUNNING MULTICAST  MTU:1500  Metric:1
          RX packets:105041 errors:0 dropped:0 overruns:0 frame:0
          TX packets:128616 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:1000
          RX bytes:12129260 (11.5 MiB)  TX bytes:56865017 (54.2 MiB)
          Interrupt:12 Base address:0xcf00

sgordon@basil:~/its323$ arp -n
Address                  HWtype  HWaddress           Flags Mask            Iface
192.168.1.1              ether   00:13:49:6C:E3:B3   C                     eth1

sgordon@basil:~/its323$ nslookup www.siit.tu.ac.th
Server:         192.168.1.1
Address:        192.168.1.1#53
Non-authoritative answer:
Name:   www.siit.tu.ac.th
Address: 203.131.209.77

sgordon@basil:~/its323$ netstat -t -n
Active Internet connections (w/o servers)
Proto Recv-Q Send-Q Local Address           Foreign Address         State
tcp        1      1 192.168.1.3:37473       203.131.209.77:80       CLOSING
tcp        1      1 192.168.1.3:37474       203.131.209.77:80       CLOSING
tcp6       0    368 ::ffff:192.168.1.3:22   ::ffff:61.19.242.1:2109 ESTABLISHED
```

Addressing Example



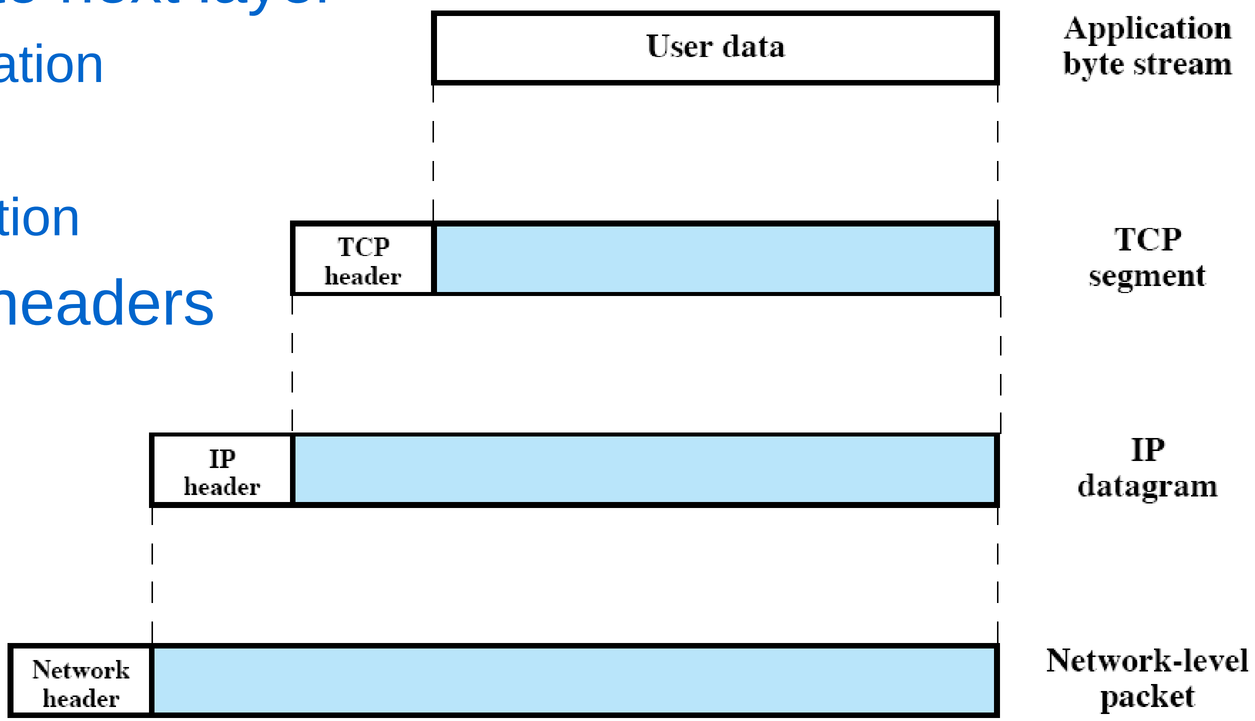
Implementing Layers

- Layers in a computer are called *(protocol) stack*
- Protocols are sets of rules
- Protocols are implemented in software and/or hardware
- Common implementation of a stack in a PC:
  - Application: user level processes (e.g. Firefox – HTTP)
  - Transport, Network: operating system (e.g. WinXP – TCP/IP)
  - Data Link, Physical: network interface card (NIC) (e.g. Ethernet card – IEEE 802.3)



Data and Layers

- A message at each layer is called *Protocol Data Unit (PDU)*
- Each layer normally attaches a header to the PDU before sending to next layer
  - Address information
  - PDU identifiers
  - Control information
- On receipt, the headers are removed



Traditional vs Multimedia Applications

- Traditionally network and Internet dominated by information retrieval applications
  - typically using text and image transfer
  - eg. email, file transfer, web
- An increasing growth in multimedia applications
  - involving massive amounts of data
  - such as streaming audio and video
- What is Multimedia?
  - Media: text, audio, graphics, video
  - Multimedia originally referred to combinations of media types
    - But now refers to applications that require real-time processing or communication of video or audio
      - E.g. Voice over IP is multimedia (but only 1 media - audio)

Elastic and Inelastic Traffic

- Elastic traffic
  - Can adjust to delay and throughput changes over a wide range
  - E.g. traditional “data” style TCP/IP traffic
  - Some applications more sensitive though
    - Email insensitive to changes in delay
    - File transfer is sensitive to throughput (expect transfer time proportional to file size)
- Inelastic traffic
  - Does not easily adapt to such changes
  - E.g. “real-time” voice and video traffic
  - Need minimum requirements on network:
    - Throughput
    - Delay
    - Delay variation (jitter)
    - Packet loss
  - Need to be able to give preferential treatment to traffic and applications must be able to state their requirements - Quality of Service (QoS)

Performance of Networks

- Bandwidth
  - Bandwidth in Hertz (Hz): range of frequencies a channel can pass (next lecture)
    - E.g. the bandwidth of a telephone line is 4kHz
  - Bandwidth in bits per second (bps): number of bits a channel (or network) can transmit
    - E.g. the bandwidth of Fast Ethernet is 100Mb/s
  - Relationship between the two depends on transmission system and modem (covered in next lectures)
- Throughput
  - How fast we can actually send data
  - Bandwidth is capacity of link/network; throughput is real data rate we achieve
    - Bandwidth and throughput are different because there are often overheads and other limiting factors on throughput
    - E.g. Fast Ethernet throughput may be 40Mb/s

Performance of Networks

- Delay (or Latency)
  - How long it takes for entire message to arrive at destination (from when first bit is sent)
    - Propagation time + Transmission time + Queuing time + Processing time
  - Propagation time = Distance / Speed
    - Speed of light (3 x 10^8m/s) is the best; air is slower, and cable is much slower
    - E.g. 12,000km across Atlantic ocean at 2.4 x 10^8 gives 50ms
  - Transmission time = Message Size / Bandwidth
    - E.g. 2.5KB email over 1Gb/s channel: 0.020ms
  - Queuing time: intermediate devices hold messages in queues in a network. Not a fixed factor
  - Processing time: end computers and intermediate devices process each message in CPU
    - Usually very small compared to propagation/transmission time (so we often ignore it)
- Jitter (or Delay Variance)
  - The difference in delay between subsequent packets

Delay Example