• **Point to point connections**
  – Representing information
    » Analog vs digital
    » Representing words and pictures
  – Communications media and bandwidth

• **Networks**
  – LANs vs WANs
  – Circuit switched vs packet switched

• **Example: The Internet**
A simple point-to-point connection

- processors convert data into signals
- signals are transported through channels
- channels utilize one or more connection media
Data: Analog vs. Digital

• Analog data
  – can take on any value within a continuous range
  – Examples:
    » human voice
    » Boston’s temperature

• Digital data
  – can take on only a finite set of discrete values
  – Examples:
    » data stored in binary computers
    » the US standard sizes of clothes
Representing Numbers

1 0 1 1

$1 \times 2^3 + 0 \times 2^2 + 1 \times 2^1 + 1 \times 2^0$

$1 \times 8 + 0 \times 4 + 1 \times 2 + 1 \times 1$

11

<table>
<thead>
<tr>
<th>Number</th>
<th>4-bit binary representation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0001</td>
</tr>
<tr>
<td>2</td>
<td>0010</td>
</tr>
<tr>
<td>3</td>
<td>0011</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>
## Representing Characters

<table>
<thead>
<tr>
<th>Character</th>
<th>ASCII* representation</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1010 0001</td>
</tr>
<tr>
<td>B</td>
<td>1010 0010</td>
</tr>
<tr>
<td>C</td>
<td>1010 0011</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0101 0000</td>
</tr>
<tr>
<td>1</td>
<td>0101 0001</td>
</tr>
</tbody>
</table>

* American Standard Code for Information Interchange
Formatted Documents

• In addition to text, must contain information about how it appears on paper
  » bold, italic, underlined text
  » different sizes of type
  » page breaks

• “Invisible” formatting characters are embedded in text
  » special “begin formatting” character
  » format specification character (i.e. “bold type”)
  » text string for which formatting applies
  » special “end formatting” character

• Same character codes have different meaning when interpreted as letters and when as format specifications
  » 65 could mean either ‘A’ or ‘bold’ depending on context
Example:
- This is a nicely formatted line.

Could be stored internally as:
- `<BG PAR> 'T' 'h' 'i' 's' ' ' 's' ' ' 'a' <BG UNDERLINE> 'n' 't' 'c' 'e' 'l' 'y' 'f' 'o' 'r' 'm' 't' 't' 'e' 'd' <EN COLOR> ' ' 'n' 'e' '.' <CR>`

Where:
- `<BG PAR>, <BG UNDERLINE>, <EN UNDERLINE>, <BG COLOR>, <EN COLOR>, <CR>` are special byte sequences that denote the beginning and end of various formatting features
- Different word processors use different byte sequences, that’s why documents require conversion to be used by a different wp
Thomas W. Malone is the Patrick J. McGovern Professor of Management at the MIT Sloan School of Management. He is also the founder and director of the MIT Center for Coordination Science and was one of the two founding co-directors of the MIT Initiative on "Inventing the Organizations of the 21st Century". Professor Malone teaches classes on leadership and information technology, and his research focuses on how new organizations can be designed to take advantage of the possibilities provided by information technology.


Professor Malone has also published over 75 articles, research papers, and book chapters;
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For example, Professor Malone predicted, in an article published in 1987, many of the major developments in electronic business over the
Bitmapped graphics

- **Numbers, letters, and words are not enough: we want pictures**

- **Representing a picture**
  - Draw a very fine grid on it
    - grid cells are called pixels or dots
  - See what is in each grid cell
    - bitmap: is cell empty or full?
    - grayscale: how dark is the cell?
    - color: what color is the cell?
  - Represent each cell with a prespecified # of bits (how many?)
  - Store the bits for the cells in a prespecified order
    - e.g., all the cells for the top row, then the next row, etc.
Movement Towards Digital

Boston (MIT)

NYSEX

Pactel

AT&T

L.A.

UCLA

digital

analog

digital

digital
Today

Over-the-air TV
Radio (am/fm)
Cable TV
Telephone
FAX
Computer/modem
Wireless telephone
Meter readings

Future?

single digital “pipe” to deliver all services

Residence

Digital Convergence
## Connection media – Examples

<table>
<thead>
<tr>
<th>Medium</th>
<th>Speed</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Twisted wire</td>
<td>300 BPS – 10 MBPS</td>
<td>Low</td>
</tr>
<tr>
<td>Microwave</td>
<td>256 KBPS – 100 MBPS</td>
<td></td>
</tr>
<tr>
<td>Coaxial cable</td>
<td>56 KBPS – 200 MBPS</td>
<td></td>
</tr>
<tr>
<td>Optical fiber</td>
<td>500 KBPS – 10 GBPS</td>
<td>High</td>
</tr>
</tbody>
</table>

BPS = bits per second

What is bandwidth?

• **Technically:**
  – The range of usable frequencies in a communications medium

• **Practically:**
  – The amount of information that can be carried by a communications medium per unit of time
Multiplexing: Squeezing many channels into one

Frequency Division Multiplexing (FDM)

Time Division Multiplexing (TDM)

Multiplexer  Multiplexer
Why build networks?

Full Connectivity doesn't scale!
Networks are about sharing

- The network allows an entity to switch its attention among a large number of others
- Permits sharing of resources attached to the network, including the resources of the network itself.
Local and Wide Area Networks

• **Local Area Networks (LANs)**
  – Short distances
  – Within organizations
  – Typical technology: Ethernet or Token Ring

• **Wide Area Networks (WANs)**
  – Long distances
  – Across organizations (typically multiple LANs)
  – Typical technology: Public Switched, Leased Line
Two forms of network connection

- **Circuit switching**
  - A dedicated end-to-end connection is established for the duration of the connection
  - Used in telephone network

- **Packet switching**
  - Messages are divided into small packets
  - Each packet is separately routed to the destination
  - Different packets can take different paths and times
  - Missing or garbled packets are retransmitted, if necessary
  - Packets are reassembled into messages at the destination
<table>
<thead>
<tr>
<th>Circuit switching</th>
<th>Packet switching</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum delay</td>
<td>Variable delay</td>
</tr>
<tr>
<td>Very inefficient use of connection capacity</td>
<td>Much more efficient use of connection capacity</td>
</tr>
<tr>
<td>When overloaded, unable to make connection at all</td>
<td>Can almost always connect, but may be long delays</td>
</tr>
<tr>
<td>Both ends of connection must use same data rate</td>
<td>Data-rate conversion is easy</td>
</tr>
</tbody>
</table>
The Internet

• What is the Internet?
  – Outgrowth of ARPANET
  – Based on TCP/IP
  – A collection of interconnected networks
  – Provides appearance of widespread connectivity

• What is it used for?
  – E-mail, file transfer, terminal access, client-server traffic, information browsing (aka Web), distributed work, electronic commerce, etc.
Hierarchy of networks

- End User
  - Local Area Network #1 (LAN#1) [MIT]
  - LAN #2
  - MIT
  - End User
    - Internet Service Provider #1 (ISP#1)
      - MIT
      - LAN #3
      - Harvard
      - Backbone Network #2
        [Worldcom, Sprint, Genuity (Level 3), Cable & Wireless, ...]
      - IPT#3
      - UCLA
      - For further info, see: navigators.com/isp.html
    - Backbone Network #1 [ATT]
      - MIT
      - ISP#2
      - gateway
      - AOL
      - MIT
      - End User
        - Local Area Network #n
Internet Addresses (IP addresses)

Host 155.22.11.250

Host 12.34.23.40

Host 18.171.0.30

Host 192.37.40.51
Understanding Internet Addresses

• 18.154.0.27
  – uniquely assigned to a specific Internet connection point
  – 32-bit address
  – each number between dots is the decimal representation of 8 bits in the address
  – In this case:
    » 18 specifies MIT (MIT owns all addresses 18.xxx.yyy.zzz)
    » 154 specifies the subnet corresponding to building E56
    » 0.27 is host number within the subnet
  – Every internet address can optionally have a descriptive host name (e.g.LASAGNA.MIT.EDU)
Who controls the Internet?