New human-like robots that can recognize faces, hold simple conversations and even play hide and seek will sell for $3000 next year.

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I/O Review

- I/O gives computers their 5 senses
- I/O speed range is 12.5-million to one
- Differences in processor and I/O speed synchronize with I/O devices before use
- Polling works, but expensive
  - Processor repeatedly queries devices
- Interrupts works, more complex
  - Device causes an exception, causing OS to run and deal with the device
- I/O control leads to Operating Systems

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Why Networks?

- Originally sharing I/O devices between computers
  - Ex: printers
- Then communicating between computers
  - Ex: file transfer protocol
- Then communicating between people
  - Ex: e-mail
- Then communicating between networks of computers
  - Ex: file sharing, www, ...

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How Big is the Network (2006)?

- ~30 in 273 Soda
- ~525 in inst.cs.berkeley.edu
- ~6,400 in eecs & cs.berkeley.edu
- (1999) ~50,000 in berkeley.edu
- ~10,000,000 in .edu (2005: ~9,000,000)
- ~286,500,000 in .us (2005: ~217,000,000)
- (net.com.edu.arpa.us.mil.org.gov)
- ~439,000,000 in the world (2005: ~317,000,000)

Source: Internet Software Consortium: www.isc.org

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Growth Rate

<table>
<thead>
<tr>
<th>Year</th>
<th>Domain Survey Host Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>1983</td>
<td>3 mb/s</td>
</tr>
<tr>
<td>1990</td>
<td>10 mb/s</td>
</tr>
<tr>
<td>1997</td>
<td>100 mb/s</td>
</tr>
<tr>
<td>1999</td>
<td>1000 mb/s</td>
</tr>
<tr>
<td>2006</td>
<td>10 Gig E</td>
</tr>
</tbody>
</table>

Source: Internet Software Consortium (www.isc.org)

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Shared vs. Switched Based Networks

- Shared vs. Switched:
  - Switched: pairs ("point-to-point" connections) communicate at same time
  - Shared: 1 at a time (CSMA/CD)
- Aggregate bandwidth (BW) in switched network is many times shared:
  - Point-to-point faster since no arbitration, simpler interface

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Shared

- Node
- Node
- Node

Switch

- Crossbar

- Node
- Node
What makes networks work?
- links connecting switches to each other and to computers or devices
- ability to name the components and to route packets of information - messages - from a source to a destination
- Layering, redundancy, protocols, and encapsulation as means of abstraction (61C big idea)

Typical Types of Networks
- Local Area Network (Ethernet)
  - Inside a building: Up to 1 km
  - (peak) Data Rate: 10 Mbits/sec, 100 Mbits/sec, 1000 Mbits/sec (1.25, 12.5, 125 MBytes/s)
  - Run, installed by network administrators
- Wide Area Network
  - Across a continent (10km to 10000 km)
  - (peak) Data Rate: 1.5 Mb/s to 10000 Mb/s
  - Run, installed by telecommunications companies (Sprint, UUNet[MCI], AT&T)
- Wireless Networks (LAN), ...

The Sprint U.S. Topology (2001)

Administrivia
- It’s the final countdown…
  - <2 weeks left!
  - Last Lecture and Course Surveys on Friday 12/08
  - Final Review Session on Sunday 12/10
  - Final Exam on Thursday 12/14
- Project 3 grading this week
  - Wednesday, Thursday, Friday
  - Sign up for time slot online

ABCs of Networks: 2 Computers
- Starting Point: Send bits between 2 computers
- Queue (First In First Out) on each end
- Can send both ways ("Full Duplex")
  - One-way information is called "Half Duplex"
- Information sent called a "message"
  - Note: Messages also called packets

A Simple Example: 2 Computers
- What is Message Format?
  - Similar idea to Instruction Format
  - Fixed size? Number bits?
  - Header (Trailer): information to deliver message
  - Payload: data in message
  - What can be in the data?
    - anything that you can represent as bits
    - values, chars, commands, addresses...
Questions About Simple Example

- What if more than 2 computers want to communicate?
  - Need computer “address field” in packet to know:
    - which computer should receive it (destination)
    - which computer to reply to (source)
  - Just like envelopes!

Dest. Source Len
Net ID | Net ID | CMD/ Address /Data
8 bits | 8 bits | 8 bits | 32*n bits
Header | Payload

Questions About Simple Example

- What if message is garbled in transit?
  - Add redundant information that is checked when message arrives to be sure it is OK
  - 8-bit sum of other bytes: called “Check sum”; upon arrival compare check sum to sum of rest of information in message. xor also popular.

Checksum
Net ID | Net ID | Len | CMD/ Address /Data
8 bits | 8 bits | 32 bits
Header | Payload | Trailer

Questions About Simple Example

- What if message never arrives?
  - Receiver tells sender when it arrives
  - Send an ACK (ACKnowledgement) [like registered mail]
  - Sender retries if waits too long
  - Don’t discard message until it is ACK’ed
  - If check sum fails, don’t send ACK

Checksum
Net ID | Net ID | Len | ACK | CMD/ Address /Data
8 bits | 8 bits | 32 bits | 1 bit
Header | Payload | Trailer

Observations About Simple Example

- Simple questions (like those on the previous slides) lead to:
  - more complex procedures to send/receive message
  - more complex message formats

- Protocol: algorithm for properly sending and receiving messages (packets)

Software Protocol to Send and Receive

- SW Send steps
  1: Application copies data to OS buffer
  2: OS calculates checksum, starts timer
  3: OS sends data to network interface HW and says start

- SW Receive steps
  3: OS copies data from network interface HW to OS buffer
  2: OS calculates checksum, if OK, send ACK; if not, delete message (sender resends when timer expires)
  1: If OK, OS copies data to user address space, & signals application to continue
Protocol for Networks of Networks?

- **Abstraction** to cope with complexity of communication (compare to Abstraction for complexity of computation)

- Networks are like onions
  - Hierarchy of layers:
  - Application (chat client, game, etc.)
  - Transport (TCP, UDP)
  - Network (IP)
  - Physical Link (wired, wireless, etc.)

Protocol Family Concept

- Key to protocol families is that communication occurs logically at the same level of the protocol, called peer-to-peer...
  ...but is implemented via services at the next lower level
- Encapsulation: carry higher level information within lower level "envelope"
- Fragmentation: break packet into multiple smaller packets and reassemble

Transmission Control Protocol/Internet Protocol (TCP/IP)

- This protocol family is the basis of the Internet, a WAN protocol
- IP makes best effort to deliver
- TCP guarantees delivery
- TCP/IP so popular it is used even when communicating locally: even across homogeneous LAN

TCP/IP packet, Ethernet packet, protocols

- Application sends message
- TCP breaks into 64KiB segments, adds 20B header
- IP adds 20B header, sends to network
- If Ethernet, broken into 1500B packets with headers, trailers (24B)
- All Headers, trailers have length field, destination, ...

Overhead vs. Bandwidth

- Networks are typically advertised using peak bandwidth of network link: e.g., 100 Mbits/sec Ethernet (“100 base T”)
- Software overhead to put message into network or get message out of network often limits useful bandwidth
- Assume overhead to send and receive = 320 microseconds (μs), want to send 1000 Bytes over “100 Mbit/s” Ethernet
  - Network transmission time: 1000Bx8b/B /100Mb/s = 8000b / (100b/μs) = 80 μs
  - Effective bandwidth: 8000b/(320+80)μs = 20 Mb/s
And in conclusion…

- Protocol suites allow networking of heterogeneous components
- Another form of principle of abstraction
- Protocols ⇒ operation in presence of failures
- Standardization key for LAN, WAN
- Integrated circuit (“Moore’s Law”) revolutionizing network switches as well as processors
- Switch just a specialized computer
- Trend from shared to switched networks to get faster links and scalable bandwidth

[Bonus] Example: Network Media

Twisted Pair (“Cat 5”):
- Copper, 1mm thick, twisted to avoid antenna effect
- 3 parts are cable, light source, light detector

Fiber Optics
- Transmitter is L.E.D or Laser Diode
- Silica: glass or plastic; actually < 1/10 diameter of copper
- Total internal reflection
- Air
- Light: 3 parts are cable, light source, light detector
- Buffer
- Cladding
- Transmitter
- Receiver
- Photodiode

[Bonus] Backbone Link App Composition

File-sharing is the dominant application on many links!