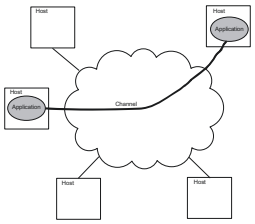
Requirements: (3) Process-to-Process Channels



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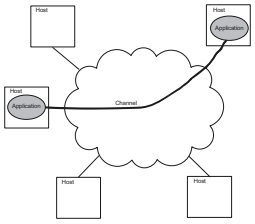
Requirements: (3) Process-to-Process Channels

- The application programs running on the hosts connected to the network must be able to communicate in a meaningful and efficient way
- Network supports common process-to-process channels; e.g.,
  - Reliable (no loss, no errors, no duplication, in-order): for file access and digital libraries
  - Secure (privacy, authentication, message integrity)
  - Delay-bounded: for real-time voice and video



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Requirements: (3) e2e Channels

- What Goes Wrong in the Network?
  - Bit-level errors (electrical interference)
  - Packet-level errors (bit errors, congestion)
  - Link and node failures
  - Packets are delayed
  - Packets are delivered out-of-order
  - Third parties eavesdrop

error detection & correction ⊆ error control

The key problem is to fill in the gap between what applications expect and what the underlying technology provides

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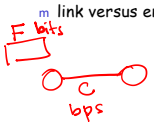
Requirements: (3) e2e Channels

- Performance: Bit Rate (throughput)
  - Amount of data that can be transmitted per time unit
  - Example: 10Mbps
  - link versus end-to-end



Delivery rate (bit rate) = $\frac{F}{F/C + X}$ = C

effective capacity ≜ throughput

X: extra delays

$\frac{1}{C\ (b/s)}$ ≜ time to transmit one bit $\left(\frac{sec}{bit}\right)$

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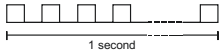
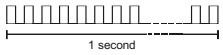
Requirements: (3) e2e Channels

- Performance: Bit Rate (throughput)
  - Amount of data that can be transmitted per time unit
  - Example: 10Mbps
  - link versus end-to-end
  - Notation
    - KB = 2^{10} bytes
    - Mbps = 10^6 bits per second
  - Bit rate (aka capacity) related to ``bit width''



1Mbps
(each bit 1 microseconds wide)



2 Mbps
(each bit 0.5 microseconds wide)

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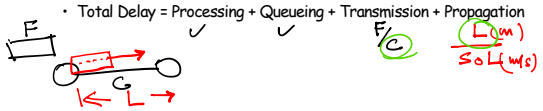
Requirements: (3) e2e Channels

- Performance: Delay
  - Time it takes to send message from point A to point B
  - Example: 24 milliseconds (ms)
  - Sometimes interested in round-trip delay (response time)
  - Components of delay
    - Total Delay = Processing + Queueing + Transmission + Propagation



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Requirements: (3) e2e Channels

- Performance: Delay
  - Time it takes to send message from point A to point B
  - Example: 24 milliseconds (ms)
  - Sometimes interested in round-trip delay (response time)
  - Components of delay
    - Total Delay = Processing + Propagation + Transmit + Queue
    - Propagation Delay = Distance / SpeedOfLight
    - Transmission = Size / Bit Rate
  - Speed of light
    - 3.0 x 10^8 meters/second in a vacuum
    - 2.3 x 10^8 meters/second in a cable
    - 2.0 x 10^8 meters/second in a fiber

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Requirements: (3) e2e Channels

- Relative importance of bit rate and propagation delay
  - small message (e.g., 1 byte): 1ms vs 100ms dominates 1Mbps vs 100Mbps
  - large message (e.g., 25 MB): 1Mbps vs 100Mbps dominates 1ms vs 100ms

$\frac{1B*8}{1Mbps} = 8\mu s$ vs $\frac{1B}{100Mbps} = 0.08\mu s$ ⇒ propagation delay dominates

$\frac{25MB*8}{1Mbps} = 200s$ vs $\frac{25MB}{100Mbps} = 2 sec$ ⇒ transmission delay dominates total delay

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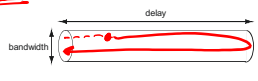
Requirements: (3) e2e Channels

- Relative importance of bit rate and propagation delay
  - small message (e.g., 1 byte): 1ms vs 100ms dominates 1Mbps vs 100Mbps
  - large message (e.g., 25 MB): 1Mbps vs 100Mbps dominates 1ms vs 100ms
- Bandwidth (Bit Rate) x Delay Product (BxD)

bps * RTT min (Round trip propagation delay)



- Example: 100ms round-trip propagation delay/time (RTT) and 45Mbps Bit Rate = 4,500,000 bits ~ 550 KB of data

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Where do we go from here?

"The secret of getting ahead is getting started. The secret to getting started is breaking your complex overwhelming tasks into small manageable tasks and then starting on the first one."

--Mark Twain

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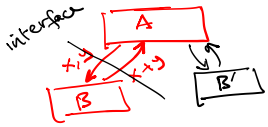
Standards

- By having computers comply to the same standards, they can ``interoperate'' even if they are of different type or connected to different types of networks



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Standards

- By having computers comply to the same standards, they can ``interoperate'' even if they are of different type or connected to different types of networks
- Standards Organizations
  - In Europe:
    - ITU-T (formerly CCITT), e.g. publications X.25, V.24, etc.
      - X-series define how to connect a host to PSDN (Data)
      - V-series define how to connect a host to PSTN (Telephone)
      - I-series define how to connect a host to ISDN (Integrated)
    - ISO, developed OSI architecture — Open Systems Interconnection
  - In US: IETF, IEEE, ANSI, NIST, ...
    - IETF RFCs define Internet standards
    - IEEE 802 define standards for links, e.g. Ethernet, WiFi

RFC = Request for Comments

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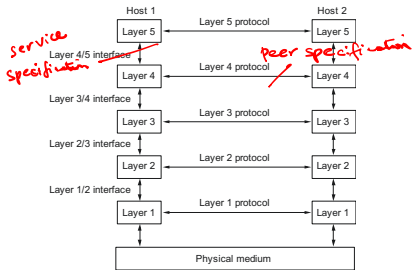
ISO/OSI Architecture

- Based on divide-and-conquer concept



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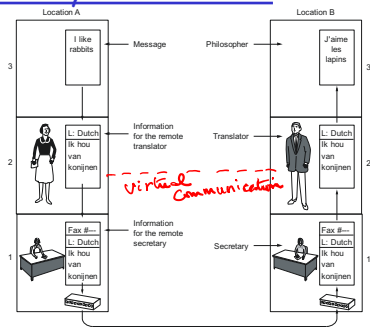
The Philosopher-translator-secretary Architecture



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