System Design and Performance Analysis Concepts

Shivkumar Kalyanaraman
Rensselaer Polytechnic Institute
shivkuma@ecse.rpi.edu
http://www.ecse.rpi.edu/Homepages/shivkuma

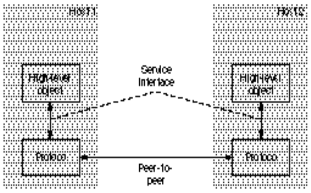
Based in part upon the textbook by S.Keshav,
and slides of Raj Jain (OSU), L. Peterson (Uarizona)

Overview

- ❑ Protocols, layering, encapsulation
- ❑ General System Design techniques
    - ❑ Multiplexing, virtualization
    - ❑ Parallelization & pipelining
    - ❑ Batching, Randomization,
    - ❑ Locality and hierarchy,
    - ❑ Separating data & control, Extensibility
- ❑ Performance

Protocols

- Building blocks of a network architecture
- Each protocol object has two different interfaces
  - *service interface*: defines operations on this protocol
  - *peer-to-peer interface*: defines messages exchanged with peer



- Term “protocol” is overloaded
  - specification of peer-to-peer interface
  - module that implements this interface

Layering

- *Layering:*
  - Use abstractions to hide complexity
  - Allows a subroutine abstraction between a layer and its adjacent layers.
  - Interface between layers is also called the architecture.
    - Interface design crucial because <u>interface outlives the technology</u> used to implement the interface.

Layering

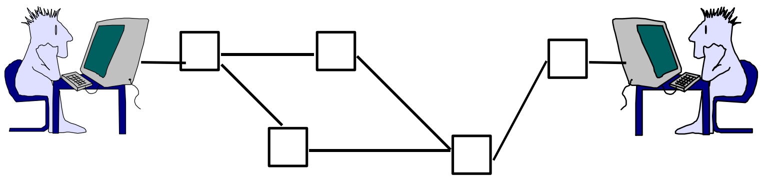
<table>
<tr><td>FTP</td><td>Telnet</td><td>Web</td><td>Email</td></tr>
<tr><td colspan="2">TCP</td><td colspan="2">UDP</td></tr>
<tr><td colspan="2">IP</td><td colspan="2">IPX</td></tr>
<tr><td colspan="2">Ethernet</td><td colspan="2">Token Ring</td></tr>
<tr><td colspan="2">Twisted Pair</td><td colspan="2">Fiber</td></tr>
</table>

← Same Interfaces

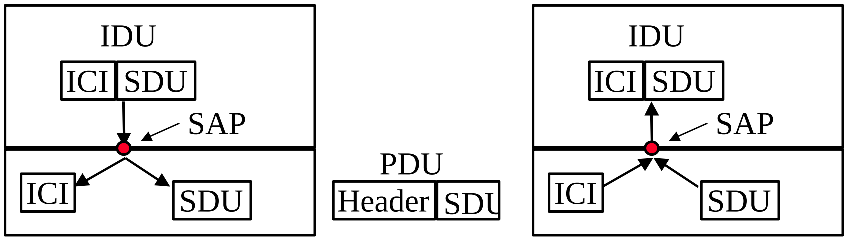
- Protocols@each layer perform a set of functions
- All alternatives for a row have the same interfaces
- Choice of protocols at each layer is independent of those of at other layers.
- May not be the most efficient implementation

ISO/OSI Reference Model

3	Application	File transfer, Email, Remote Login
	Presentation	ASCII Text, Sound
	Session	Establish/manage connection
2	Transport	End-to-end communication: TCP
	Network	Routing, Addressing: IP
1	Datalink	Two party communication: Ethernet
	Physical	How to transmit signal: Coding



OSI/ISO Lingo: Interfaces and Services



IDU

ICI SDU

SAP

ICI SDU

PDU

Header SDU

IDU

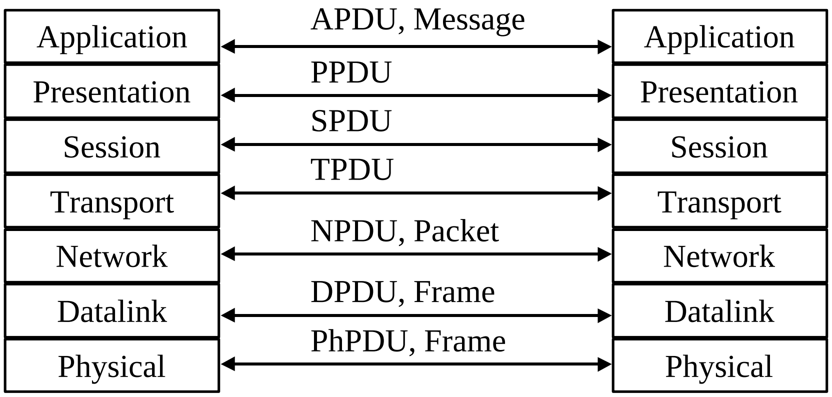
ICI SDU

SAP

ICI SDU

- ❑ IDU = Interface Data Unit = ICI + SDU
- ❑ ICI = Interface Control Information
- ❑ SDU = Service Data Unit
- ❑ PDU = Protocol Data Unit = Fragments of SDU + Header or Several SDUs + Header (blocking)
- ❑ SAP = Service Access Point

OSI/ISO Lingo: Protocol Data Unit (PDU)



Application | APDU, Message | Application

Presentation | PPDU | Presentation

Session | SPDU | Session

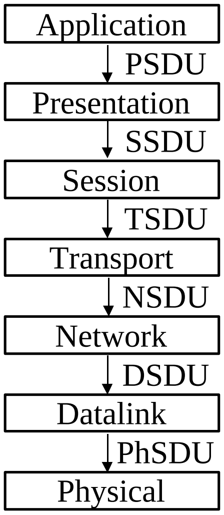
Transport | TPDU | Transport

Network | NPDU, Packet | Network

Datalink | DPDU, Frame | Datalink

Physical | PhPDU, Frame | Physical

OSI/ISO Lingo: Service Data Unit (SDU)



Application

PSDU

Presentation

SSDU

Session

TSDU

Transport

NSDU

Network

DSDU

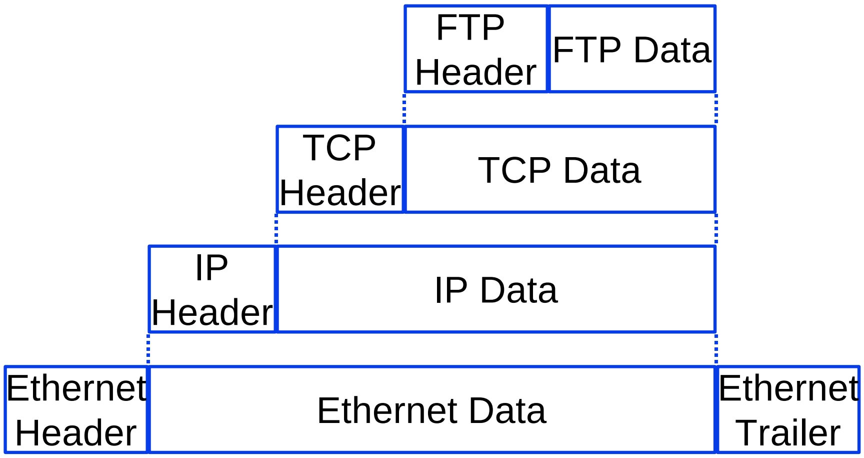
Datalink

PhSDU

Physical

Implementing layering: Encapsulation

- Nth layer control info is passed as N-1th layer data.



FTP Header | FTP Data

TCP Header | TCP Data

IP Header | IP Data

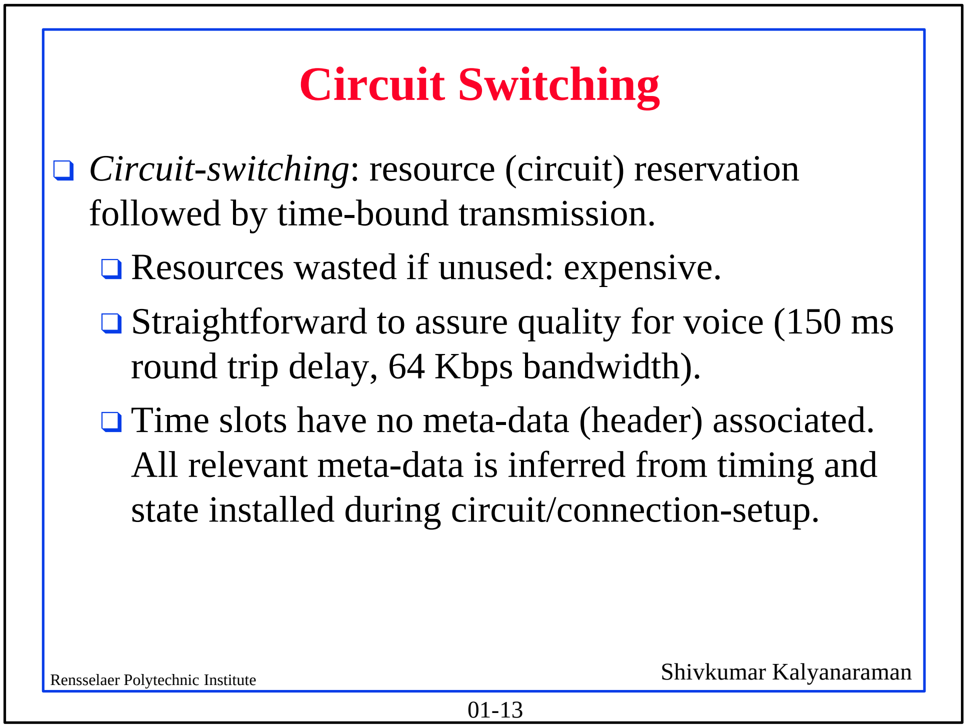
Ethernet Header | Ethernet Data | Ethernet Trailer

Application-layer framing

- *Application layer framing: a concept challenging traditional layering*
  - packet format at every layer flexible and application-defined
  - Eg: RTP (a transport protocol for multimedia)

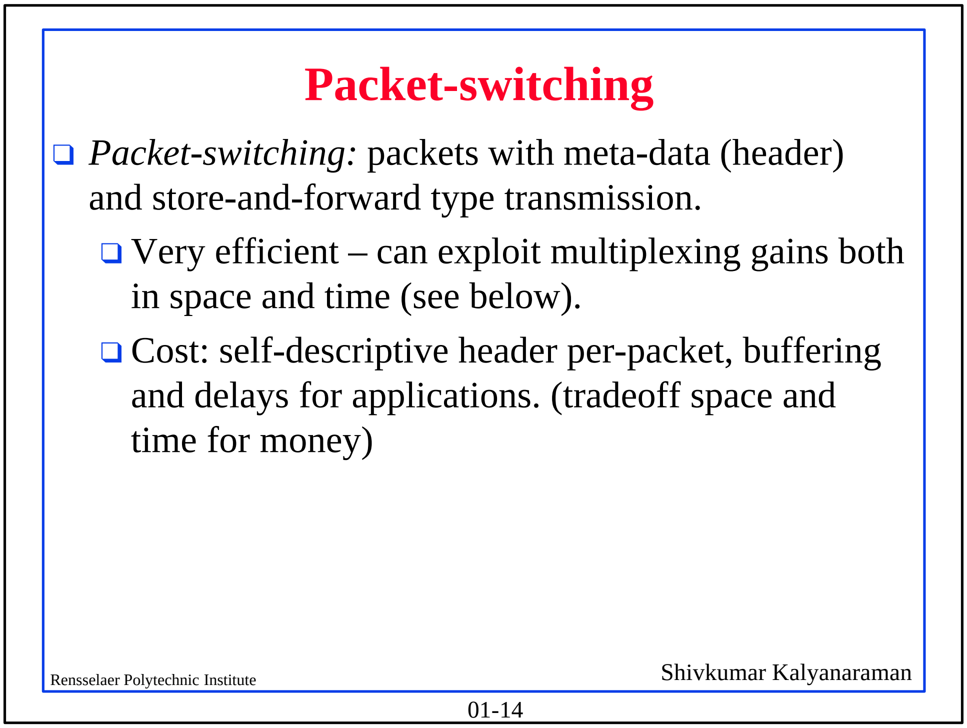
System Design Ideas

- *Resources:*
  - space
  - time
  - computation
  - money
  - labor
  - Design a system to ***tradeoff cheaper resources against expensive ones*** (for a gain)



Circuit Switching

- *Circuit-switching*: resource (circuit) reservation followed by time-bound transmission.
  - Resources wasted if unused: expensive.
  - Straightforward to assure quality for voice (150 ms round trip delay, 64 Kbps bandwidth).
  - Time slots have no meta-data (header) associated. All relevant meta-data is inferred from timing and state installed during circuit/connection-setup.



Packet-switching

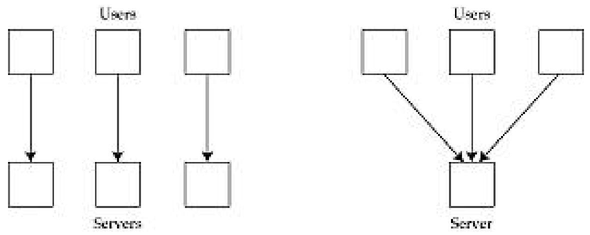
- *Packet-switching:* packets with meta-data (header) and store-and-forward type transmission.
  - Very efficient – can exploit multiplexing gains both in space and time (see below).
  - Cost: self-descriptive header per-packet, buffering and delays for applications. (tradeoff space and time for money)

Circuit, Virtual-ckt, Connection-Oriented, Connectionless

- ***Circuit***: Telephone system
  - Path setup and resources reserved before data is sent
  - Data need not have meta-info at all. Only timing.
- ***Virtual Circuit***: ATM networks
  - Multiple circuits on one wire.
- ***Connection-Oriented***: TCP
  - Have an association between end-points
- ***Connectionless:*** Also known as datagram. IP, postage service
  - Complete address on each packet
  - The address decides the next hop at each routing point

Multiplexing

- Multiplexing = sharing
  - Trades time and space for money
  - ***Cost***: waiting time (delay), buffer space, loss (if not enough buffer)
  - ***Gain***: Money ($$) => Overall system costs less
  - Eg: Time-Division Multiplexing (TDM), Frequency-Division Multiplexing (FDM)



Statistical Multiplexing

- ❑ Reduce resource requirements by *exploiting statistical knowledge* of the system. Specifically, choose service rate such that:
  - ❑ average rate <= service rate <= peak rate
  - ❑ *Multiplexing Gain* = peak rate/service rate.
  - ❑ Cost: buffering, delays for applications. Tradeoff space and time resources for money
  - ❑ *Useful only if peak rate differs significantly from average rate.*

Spatial and Temporal Multiplexing

- ❑ Spatial muxing: Decrease resource sizing expecting smaller set of sources to be active at any time instant.
  - ❑ Cost: call-blocking (time)
- ❑ Temporal muxing: even if many are active at any particular time instant, expect that the average over time will be much smaller.
  - ❑Cost: buffers and meta-data (headers) in packets (space).
- ❑ Note: We need packet switching to exploit both spatial and temporal gains.

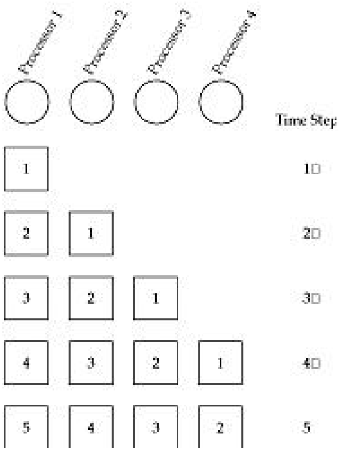
Virtualization

- Virtualization: If Quality of Service (QoS) is met, the multiplexed shared resource may seem like a *unshared virtual resource*.
- Multiplexing + indirection = virtualization, i.e., refer the virtual resource as if it were the physical resource itself.
  - Eg: virtual memory, virtual circuit, socket ports in BSD, telephone call.
  - Indirection requires binding and unbinding…
    - Similar to the use of pointers in the C language

Pipelining and Parallelism

- Goal: trading computation for (gain in) time.
- Degree of parallelism: response time x throughput
- Linear speedup: split up task into N independent subtasks, each requiring same amount of time.
  - Response time speedup of N. Throughput constant. Degree = N
- Pipelining: Can't independently split subtasks - the subtasks may be serially dependent.
  - We can get speedup in throughput, but NOT in response time by using pipelining

Pipelining example



Batching

- *Goal:* trading response time for (gain in) throughput
- Batching is good when:
  - overhead per task increases less than linearly w/ number of tasks
  - time to accumulate a batch is not too long.
  - Response time can be traded off
- Eg: Interrupt handling, Silly window avoidance in TCP
- TCP also has triggers to avoid batching for telnet packets -- when response time is important

Randomization

- Goal: Trade computation for (response) time
- Used in breaking ties without biases or high probability of repeat of tie.
  - Eg: Use of exponential backoff in broadcast multiple access (ethernet), avoidance of ACK or NAK implosion in reliable multicast, or in some routing algorithms.

Locality and Hierarchy

- *Locality*: Critical in exploiting smaller, faster resource to create an illusion of a larger, faster resource.
  - The larger, slower resource, is accessed when item is not found in the smaller resource.
- *Hierarchy*: for scalability.
  - Loose hierarchies more efficient than strict ones (eg: children can interconnect).
  - Eg: managing name space or address allocation and forwarding.

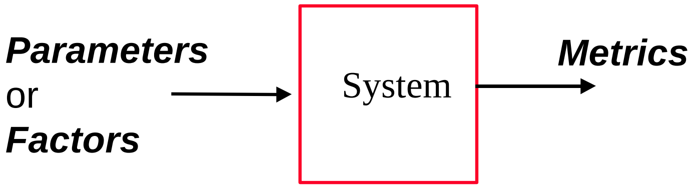
Miscellaneous ideas

  - Different types of hierarchy: topological, routing, traffic management, organizational.
- *Separating data and control:* Per-packet actions are part of critical data path -- fewer control actions => greater forwarding speed.
  - Greater separation of data and control => need to install more state in the network.
  - Eg: separate CCIS channel in telephony.
  - Eg: separate routing protocols in Internet.
- *Extensibility:* hooks for future growth. Eg: version field, reserved fields.

What is performance ?

- ***How fast*** does computer A run MY program ?
- Is machine A ***generally faster than*** machine B, and if so, ***how much faster*** ?
- Performance is one of the three factors ***driving*** architecture (interface design)
  - Others: <u>functionality</u> demanded, <u>technology</u> available

Metrics and Parameters



- *Parameters:* clock rate, poisson inter-arrivals, ftp workload etc
- *Metrics:* throughput, response time, queue length.
  - Metric choice should characterize the design tradeoffs (in space, time etc) adequately
  - Metrics are usually functions of many factors. Use of one factor alone may be misleading.

More on Metrics/Parameters

- User metrics:
  - How fast does MY program run => we need a measure of execution *time* ?
- System metrics:
  - How much is the system utilized ?
  - How much buffers do I need to provision ?
  - How many programs is it able to execute per second ?
  - => Need a measure of *throughput, queue length*
- Eg: Execution Time = Instrns/pgm *avg clock cycles/Instruction * time/clock cycle.
- T = I /P * CPI *Clock cycle time
- All three factors *combine* to affect the metric.

Workloads, Benchmarks

- ***Workload:*** a test case for the system
- ***Benchmark:*** A set of workloads which together is representative of "MY program". Should be reproduceable
  - Problem: combining metrics from each test case.
  - Pitfalls: ratio games(need to be careful w/ statistics)

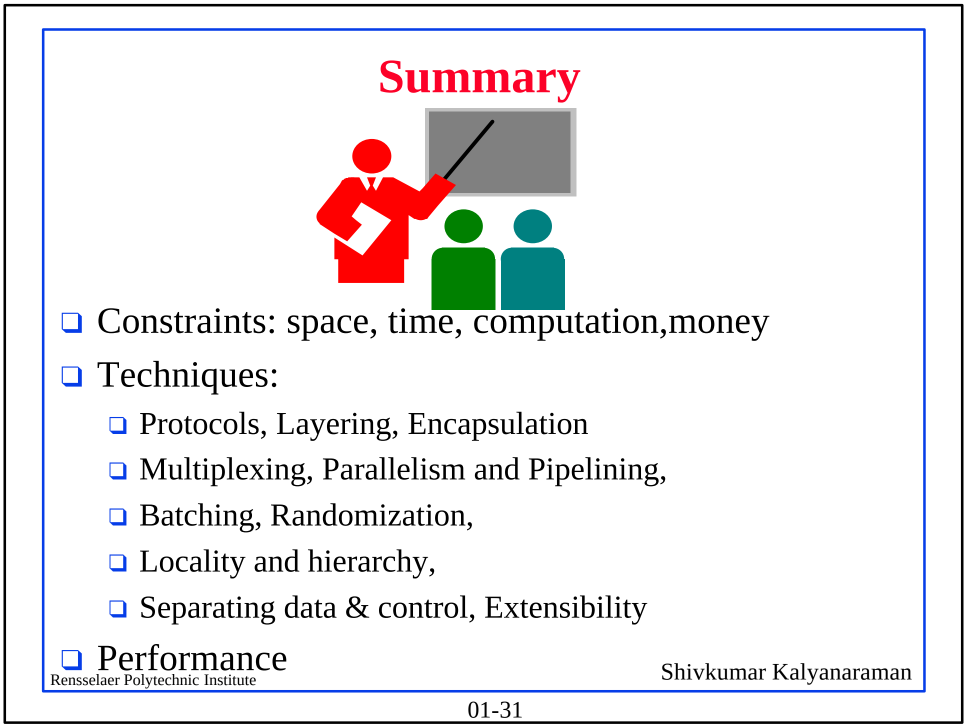
Machine	A	B
Test case		
1	1s	10s
2	100s	10s

Which is faster, A or B ?

Effect on Design: Amdahl's law

- Execution time after improvement =

  Execution time ***affected*** by improvement / speedup + ***Unaffected*** execution time
- ***Point:*** Speedup the common case !!



Summary

- ❑ Constraints: space, time, computation,money
- ❑ Techniques:
  - ❑ Protocols, Layering, Encapsulation
  - ❑ Multiplexing, Parallelism and Pipelining,
  - ❑ Batching, Randomization,
  - ❑ Locality and hierarchy,
  - ❑ Separating data & control, Extensibility
- ❑ Performance