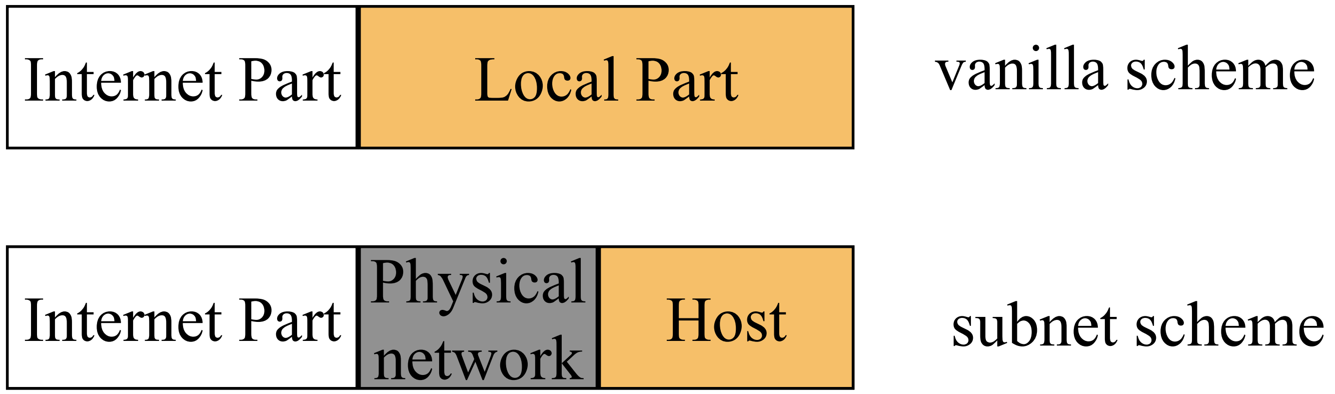
Announcements

- Project #5 is due next Wed
- Midterm #2 re-grade was returned

Subnet Addressing

- Single site which has many physical networks
  - Only local routers know about all the physical nets
  - Site chooses part of address that distinguishes between physical networks
- subnet mask: splits the IP address into two parts
- Common “Class B” netmask mask 255.255.255.0
  - use 3rd byte to represent physical net
  - use 4th byte to represent host



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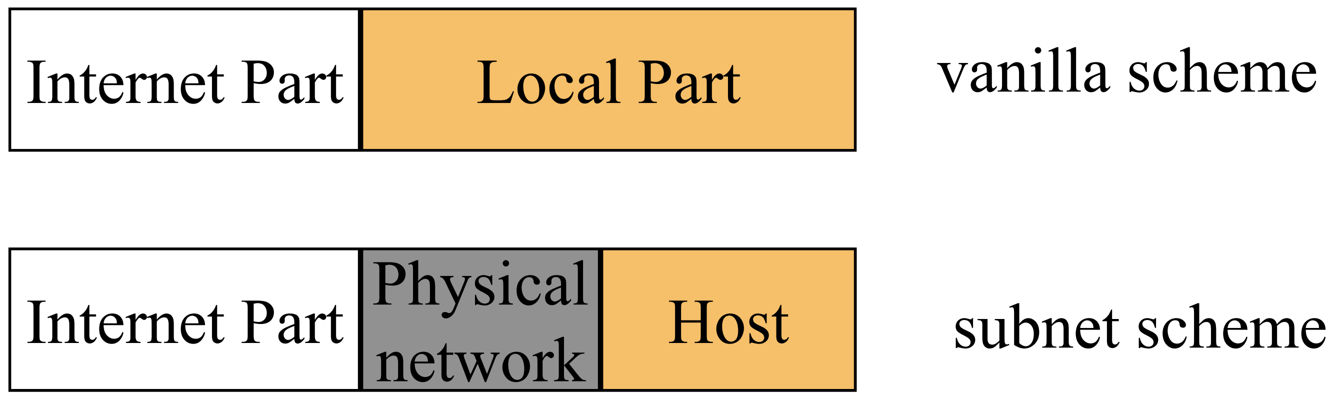
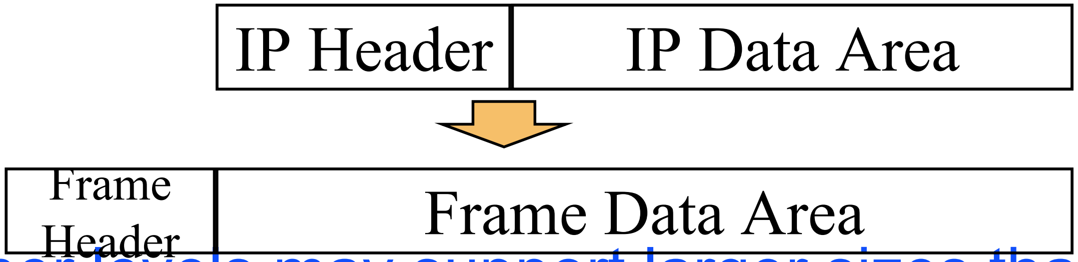


Encapsulation

How do we send higher layer packets over lower layers?

- Higher level info is opaque to lower layers
  - it's just data to be moved from one point to another



- Higher levels may support larger sizes than lower
  - could need to *fragment* a higher level packet
    - split into several lower level packets
    - need to re-assemble at the end
  - examples:
    - ATM cells are 48 bytes, but IP packets can be 64K
    - IP packets are 64K, but files are megabytes

Routing

- How does a packet find its destination?
  - problem is called routing
- Several options:
  - source routing
    - end points know how to get everywhere
    - each packet is given a list of hops before it is sent
  - hop-by-hop
    - each host knows for each destination how to get one more hop in the right direction
- Can route packets:
  - per session
    - each packet in a connection takes same path
  - per packet
    - packets may take different routes
    - possible to have out of order delivery

Routing IP Datagrams

- Direct Delivery:
  - a machine on a physical network can send a physical frame directly to a machine on another network
  - transmission of an IP datagram between two machines on a single physical network does not involve routers.
    - Sender encapsulates datagram into a physical frame, binds destination IP address to a physical hardware address and sends frame directly to destination
  - Sender knows that a machine is on a directly connected network
    - compare network portion of destination ID with own ID - if these match, the datagram can be sent directly
  - Direct deliver can be viewed as the final step in any datagram transmission

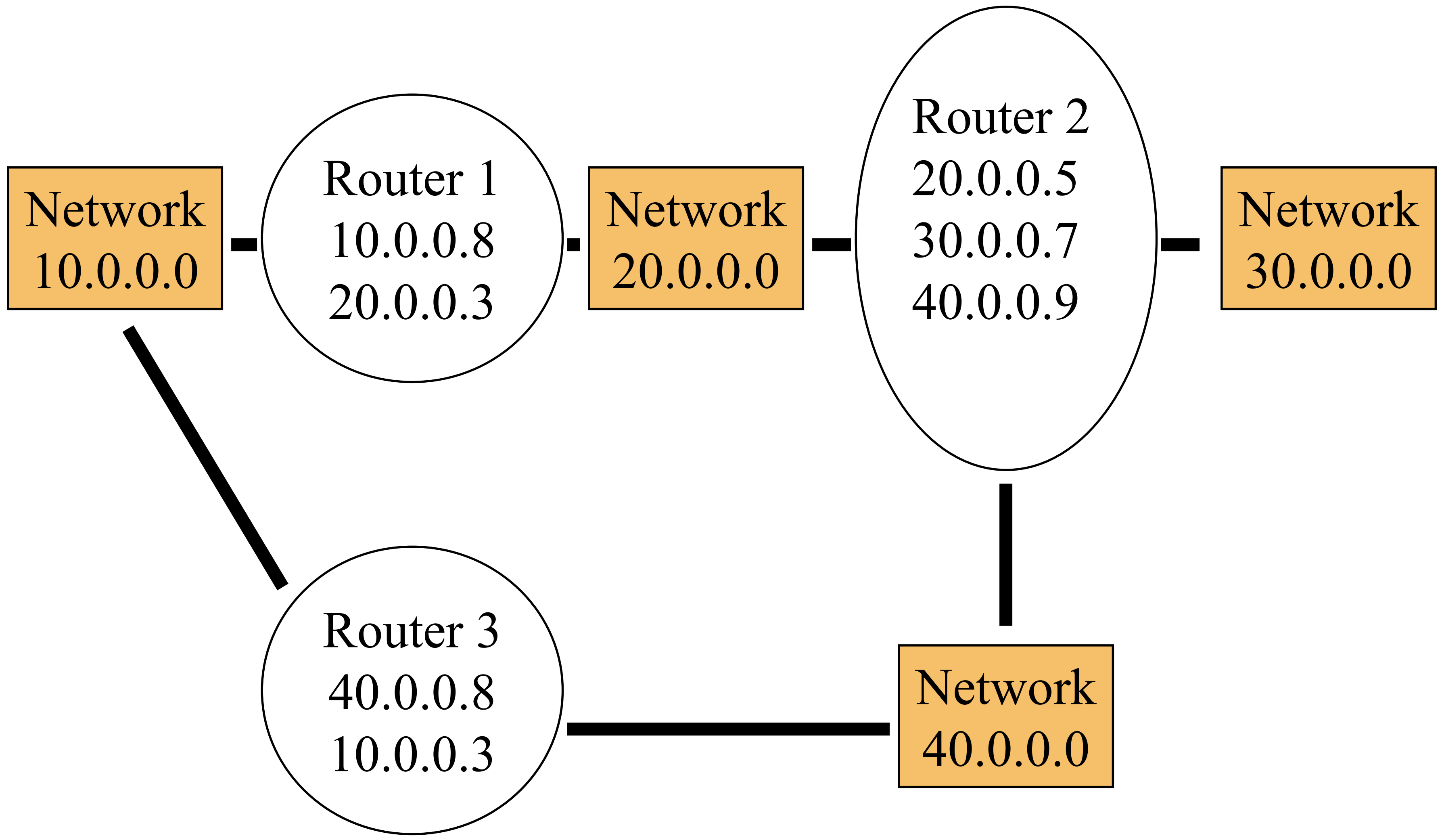
Routing Datagrams (cont.)

- Indirect Delivery
  - sender must identify a router to which a datagram can be sent
  - sending processor can reach a router on the sending processor's physical network (otherwise the network is isolated!)
  - when frame reaches router, router extracts encapsulated datagram and IP software selects the next router
    - datagram is placed in a frame and sent off to the next router

Table Driven Routing

- Routing tables on each machine store information about possible destinations and how to reach them
- Routing tables only need to contain network prefixes, not full IP addresses
  - No need to include information about specific hosts
- Each entry in a routing table points to a router that can be reached across a single network
- Hosts and routers decide
  - can packet be directly sent?
  - which router should be responsible for a packet (if there is more than one on physical net)

Routing


Network
10.0.0.0
Router 1
10.0.0.8
20.0.0.3
Network
20.0.0.0
Router 2
20.0.0.5
30.0.0.7
40.0.0.9
Network
30.0.0.0
Router 3
40.0.0.8
10.0.0.3
Network
40.0.0.0

IP Routing Algorithm (from Comer)

- RouteDatagram(Datagram, Routing Table)

- Extract destination IP address, D from datagram and compute network prefix N

```
if N matches any directly connected network address
else if the table contains a host-specific route for D
else if the table contains a default route for network N
else if the table contains a default route
else declare a routing error
```

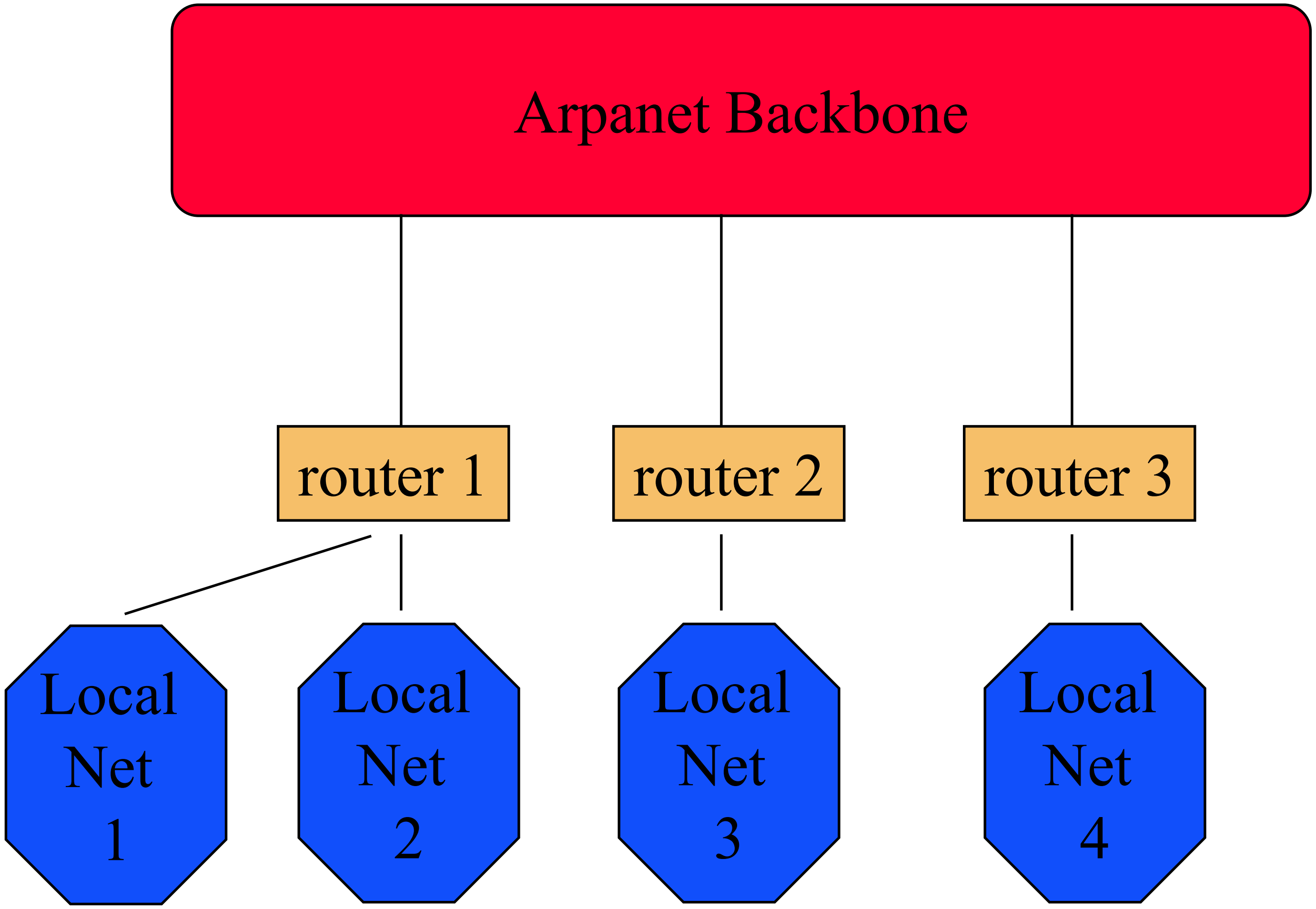
How are routing tables obtained?

- Routing with partial information
  - Hosts do not need complete knowledge of all possible destination addresses
  - Host sends non-local information to (a) router
- Routers can also route with partial information
  - consider a topology consisting of two completely connected subgraphs A and B
  - subgraphs A and B share a single link
  - If a router in A sees an address it does not recognize, it sends the packet to B and vice-versa

Early Internet Architecture

- Small central set of routers that kept complete information about all destinations
- Larger set of outlying routers with only local information
- Default route for outlying routers is to a central router
- Local administrators can make changes
  - Local changes need to be propagated locally as well as to the central routers

Internet Core Router System



Internet Core Routing System

- Core routers exchange routing information so each will have complete information about optimal routes to all destinations
- This did not scale:
  - maintaining consistency among core routers became increasingly difficult
  - further difficulties arise when there are several backbones (e.g. ARPAnet and NSFnet)
  - if the core architecture is partitioned so that all routers use default routes, may induce routing loops
    - if routing information is not consistent, it is possible for a packet to be repeatedly routed in a circle until the packet times out

Distributed Systems

- Provide:
  - access to remote resources
  - security
  - location independence
  - load balancing
- Basic Services:
  - remote login (telnet and rlogin protocols)
    - extends basic access provided by normal login
  - file transfer (ftp, rcp)
    - can support anonymous transfers
  - information services (http)
    - two way protocols (request/response)

Distributed Systems

- A unified view of local and remote access
- Typical Services
  - data migration
    - provide only the data required, not the whole file
    - manage multiple copies as versions of the same object
  - process migration
    - a process can move from one machine to another
    - reasons for migration:
      - load balancing
      - data affinity
      - hardware/software preference (better configuration)

Distributed OS Design Issues

- Should provide same model as a central system
  - easy to understand for users
- Needs to be scaleable
  - will it work with 100, 1,000, or 10,000 nodes?
- Failure Modes
  - avoid a single central failure point
  - can loss performance or functionality with failure
    - but loss should be proportional to size of failure
- Security
  - should provide same guarantees on data integrity as a local system