Network Programming
Computer Network Overview

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Spring 2026

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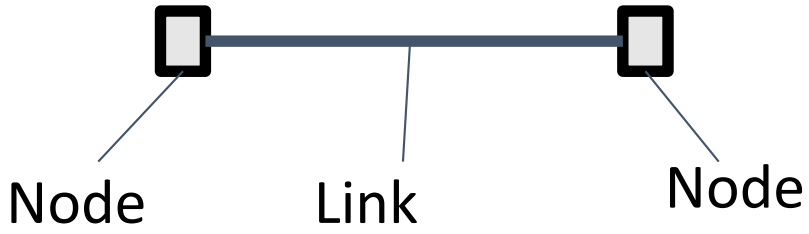
SCHOOL OF
DATA SCIENCE
數據科學學院

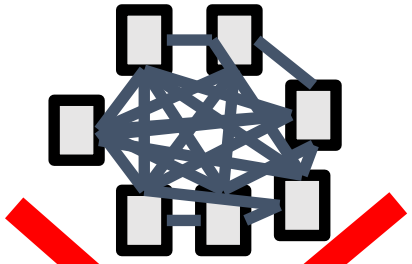
Basic building block – links



How to send data?

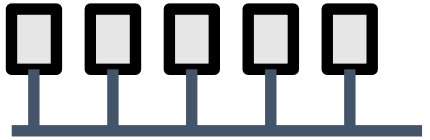
- When to talk – can either side talk at once?
- What to say – low-level format?

What if we want more nodes?



Wires for everybody!

Not scalable!

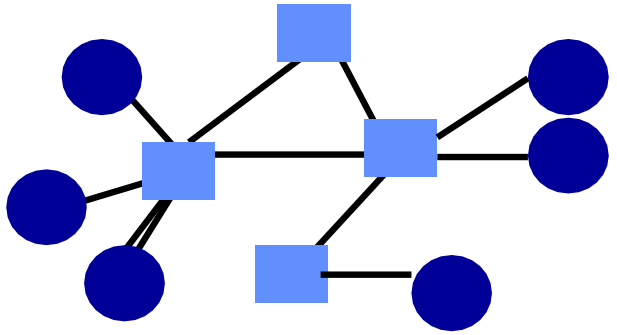


One wire

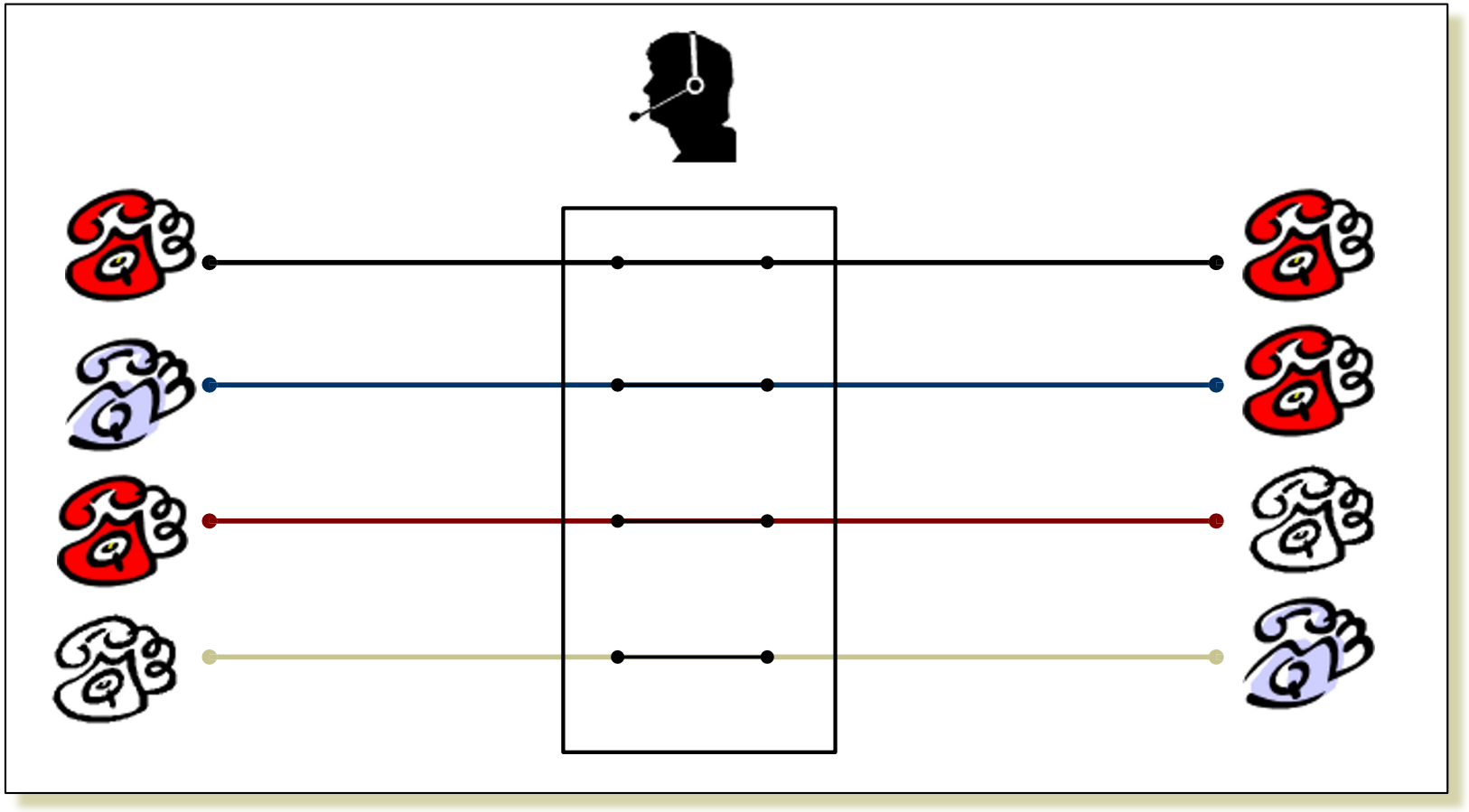
When to send?
Who should receive?

Multiplexing

- Need to share network resources
- How? Switched network
  - Party “A” gets resources sometimes
  - Party “B” gets them sometimes
- Interior nodes act as “Switches”
- What mechanisms to share resources?



In the Old Days…Circuit Switching



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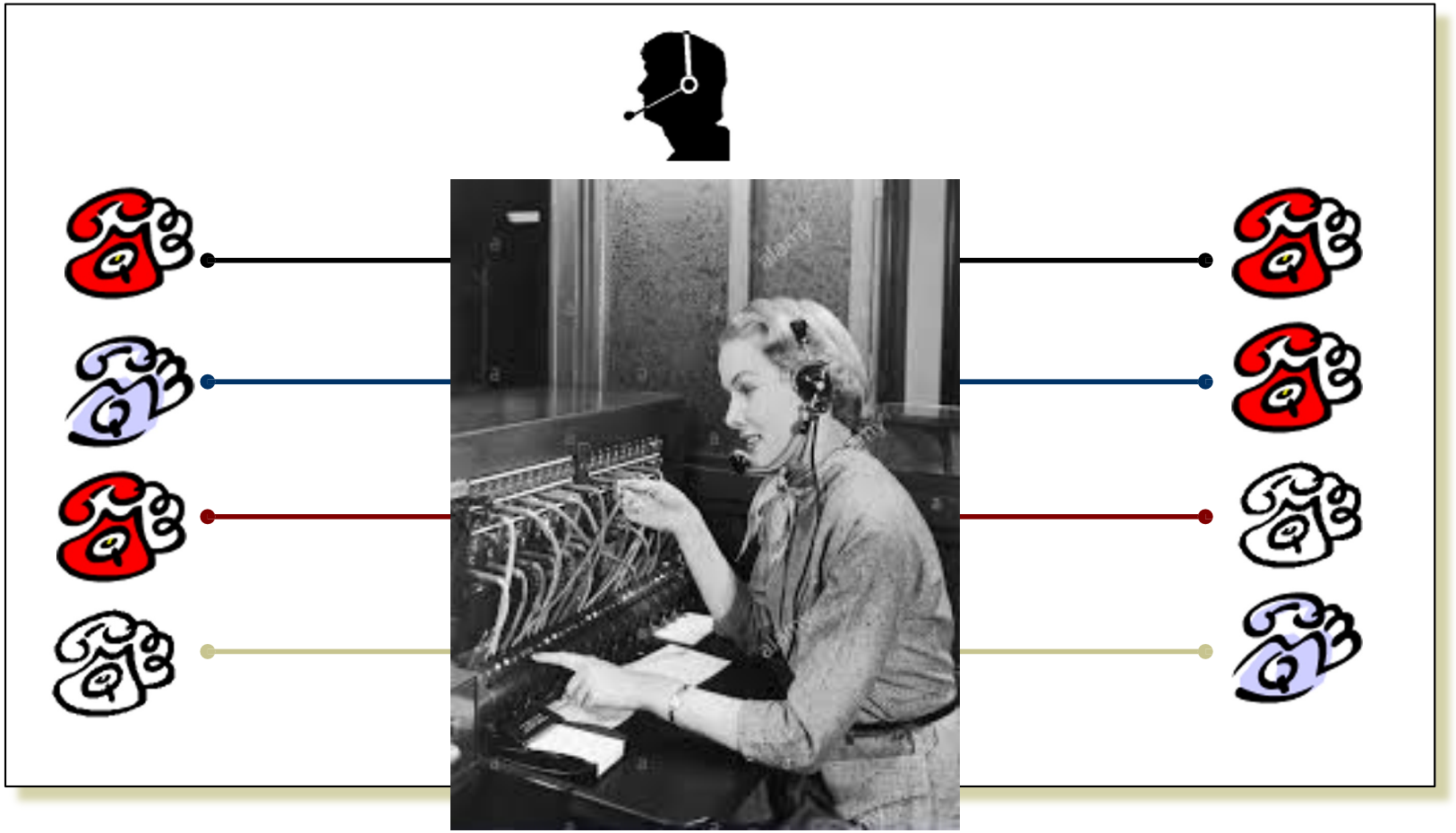
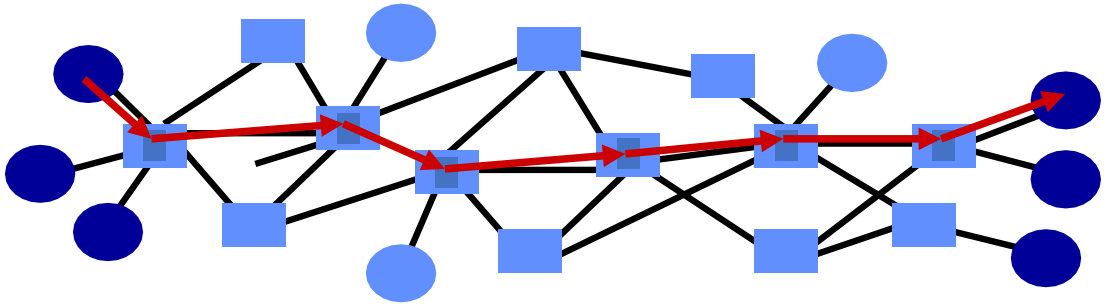
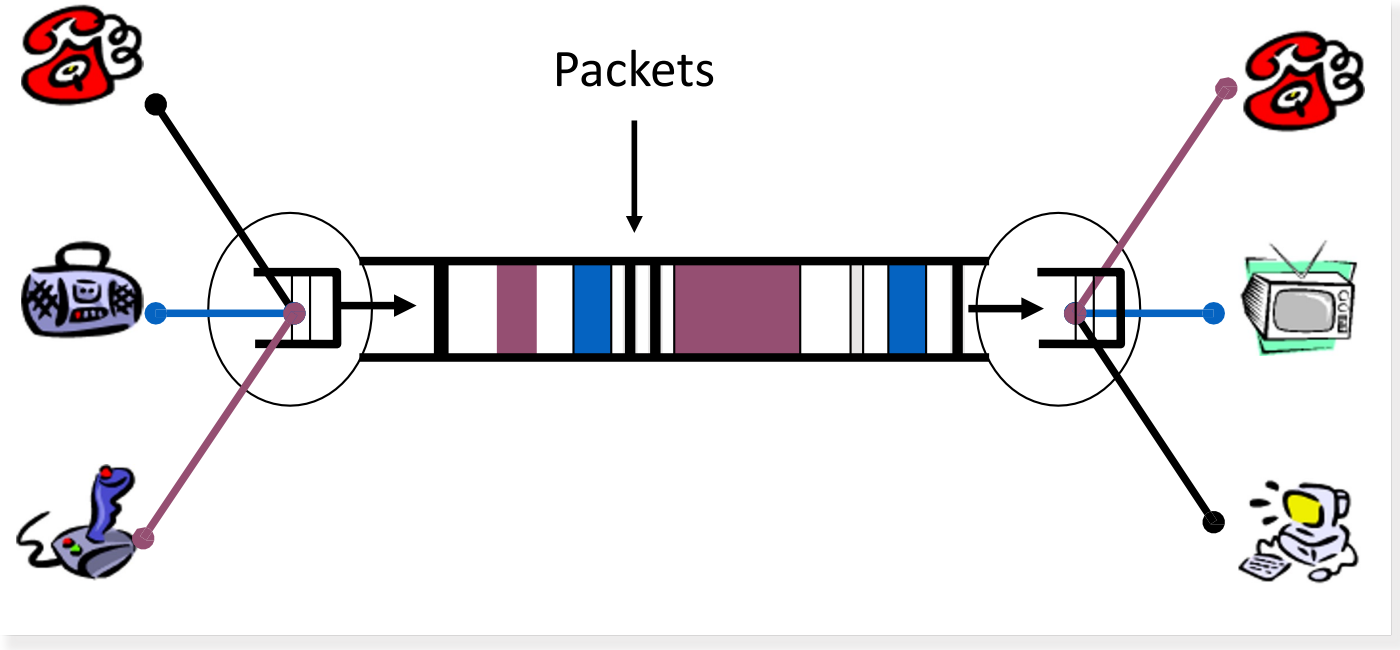


Packet switching

- Source sends information as self-contained packets
  - Have an address
  - Source may have to break up single message in multiple
- Each packet travels independently to the destination host
  - Switches use the address in the packet to determine how to forward it
  - Store and forward
- Analogy: a letter in surface mail



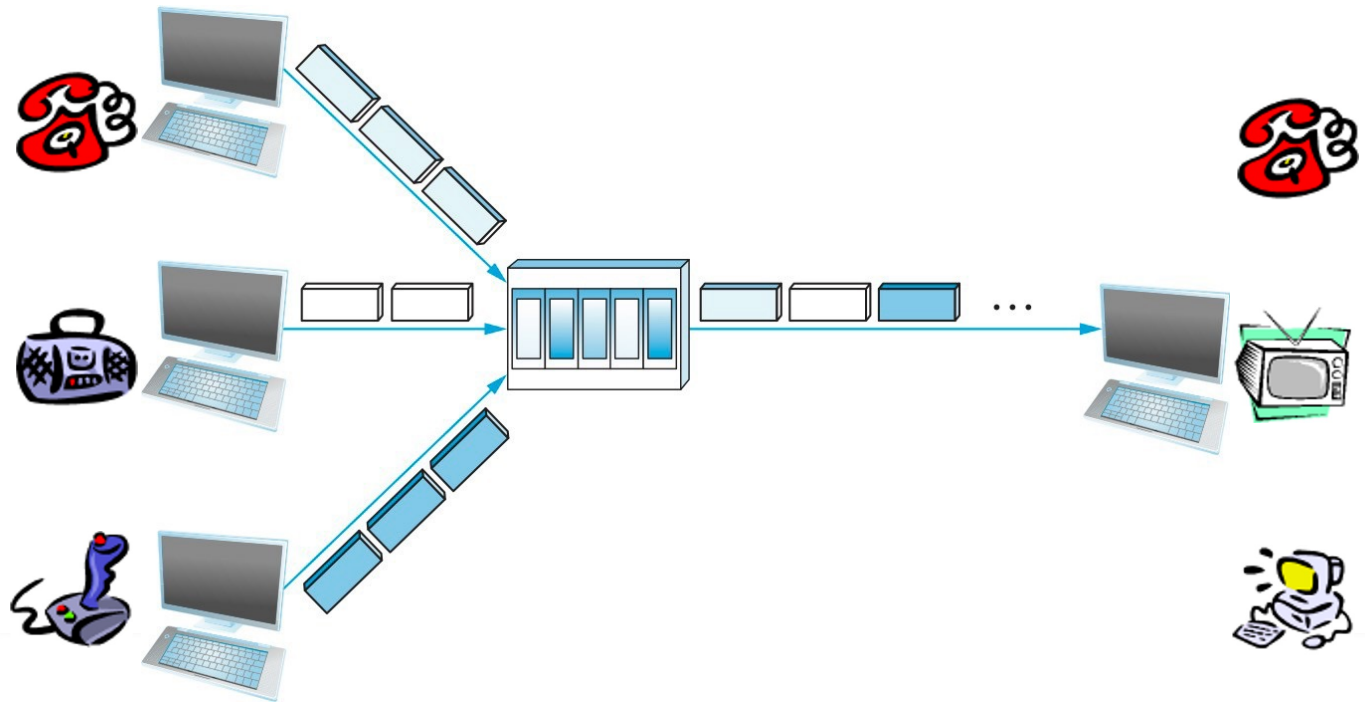
Packet switching – statistical multiplexing



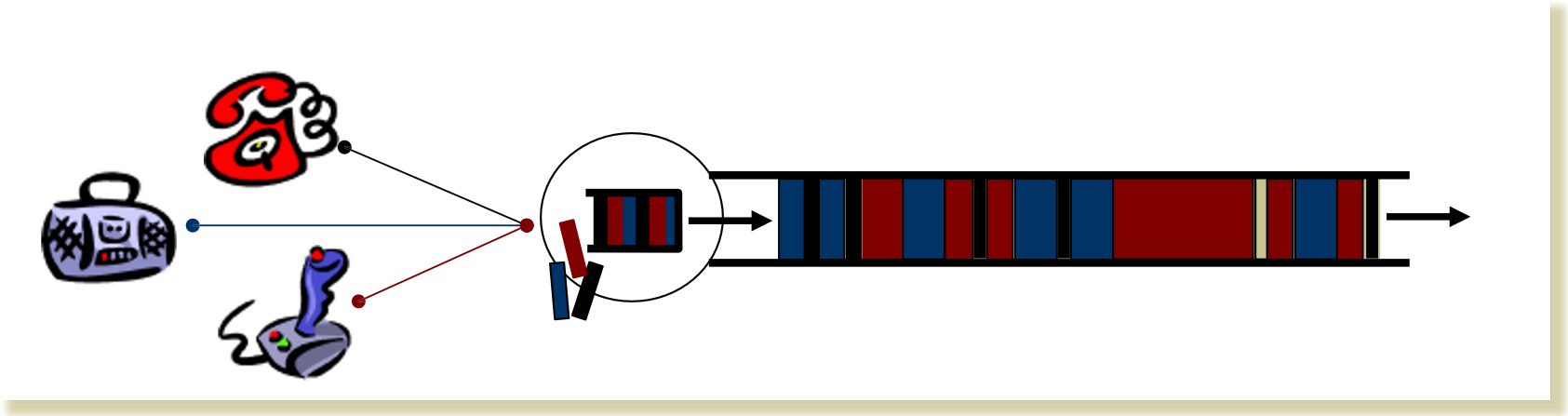
Switches arbitrate between inputs
Can send from any input that's ready

Efficiency!

Packet switching – statistical multiplexing



What if network is overloaded?



Solution: Buffering and Congestion Control

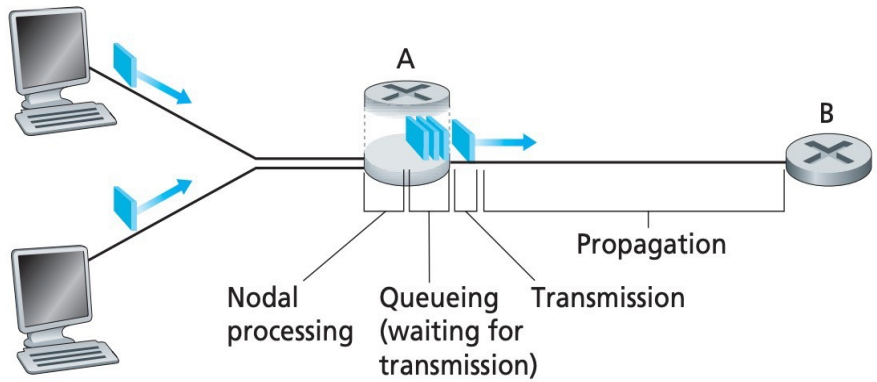
- Short bursts: buffer
- What if buffer overflows?
  - Packets dropped
  - Sender adjusts rate until load = resources → “congestion control”

Model of a communication channel

- **Latency:** how long does it take for the first bit to reach destination
- **Capacity:** how many bits/sec can we push through? (often termed “bandwidth”)
- **Jitter:** how much variation in latency?
- **Loss/Reliability:** can the channel drop packets?

Packet delay

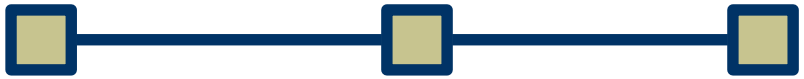
- Propagation delay on each link
  - Proportional to the length of the link
- Transmission delay on each link
  - Proportional to the packet size
- Processing delay on each router
  - Depends on the speed of the router
- Queuing delay on each router
  - Depends on the traffic load and queue size



Packet delay

xmit = transmission delay

Prop + xmit

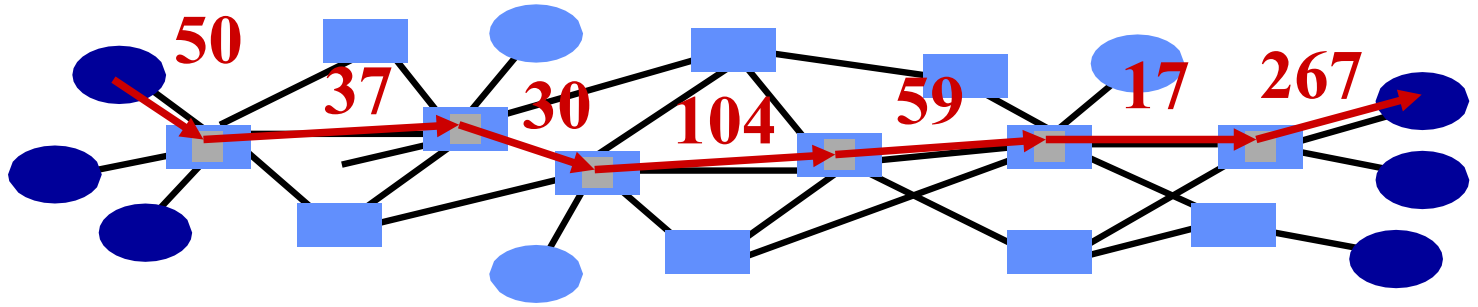


2*(Prop + xmit)

2*Prop + xmit

Sustained throughput

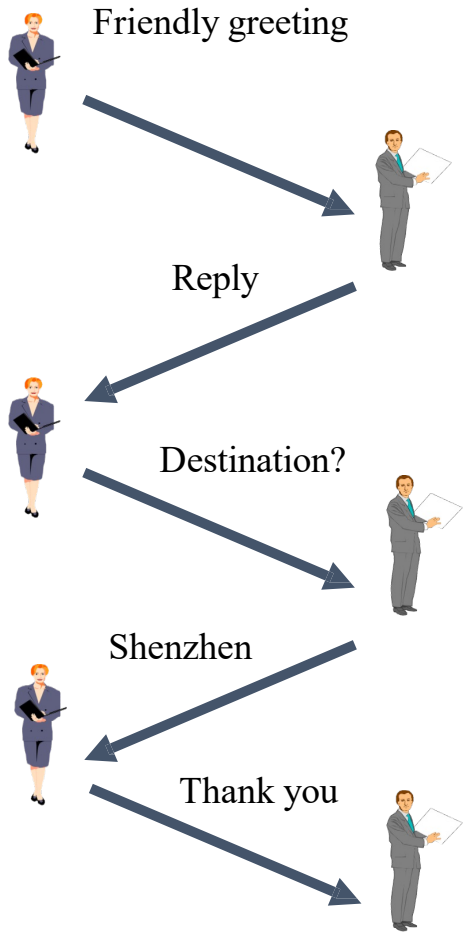
- When streaming packets, the network works like a pipeline
  - All links forward different packets in parallel
- Throughput is determined by the slowest stage
  - Called the bottleneck link
- Why some links are slow
  - Low link bandwidth
  - Many users sharing the link bandwidth



Can we know if the packet successfully arrives?
i.e., reliable transmission

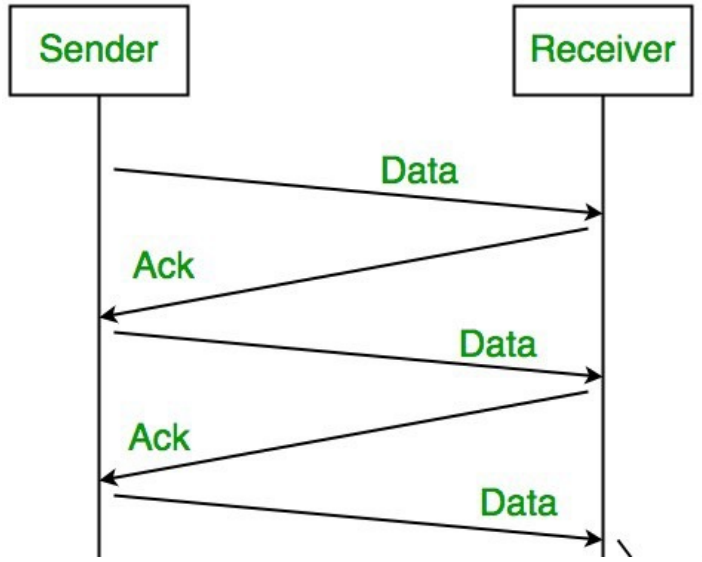
Network protocols

- Protocol
  - Agreement between parties on how communication should take place
- Stop & wait
  - Sender sends a single packet to receiver & waits for an acknowledgment
- Example
  - Polite conversation, buying airline ticket over phone



Network protocols

- A kind of reliable delivery
  - Acknowledgements (ACK) and timeouts
- Receipt of ACK
  - Sender knows the data was successfully delivered
- Timeouts
  - Retransmits original data if no ACK received after a reasonable timeout



Bandwidth calculation

Cross country latency of 1 bit

- Distance/speed = 5 * 10^6m / 2x10^8m/s = 25 * 10^-3 s = 25ms
- 50ms round-trip-time (RTT) for one bit

Link speed (capacity) 100Mbps

Packet size = 1250 bytes = 10 kbits

- Packet size on networks usually = 1500bytes across wide area or 9000bytes in local area

1 packet takes

- 10k/100M = .1 ms to transmit
- 25ms to reach there
- ACKs are small → so 0ms to transmit
- 25ms to get back

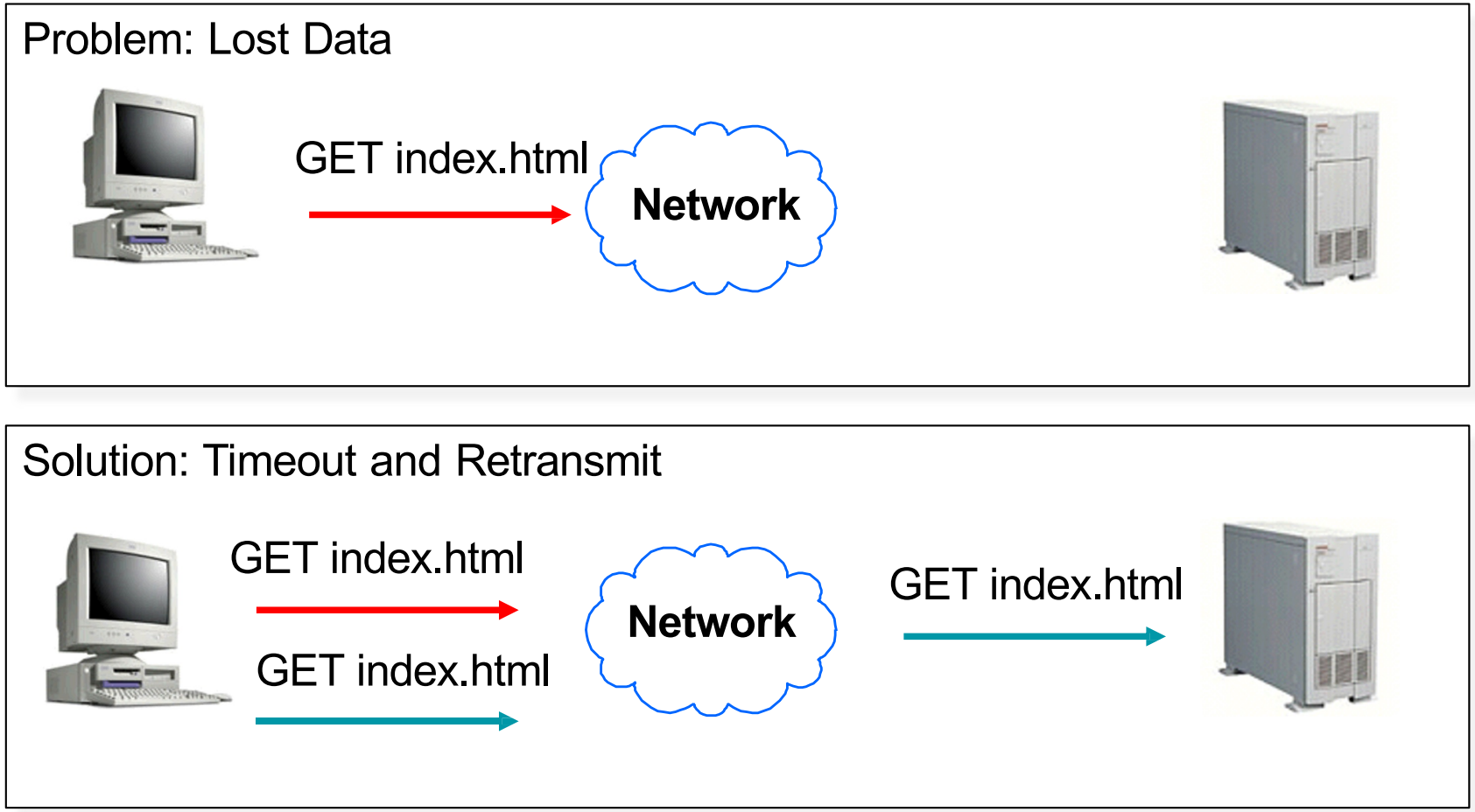
Effective bandwidth = 10kbits/50.1ms = 200kbits/sec ☹

How should we send packets?

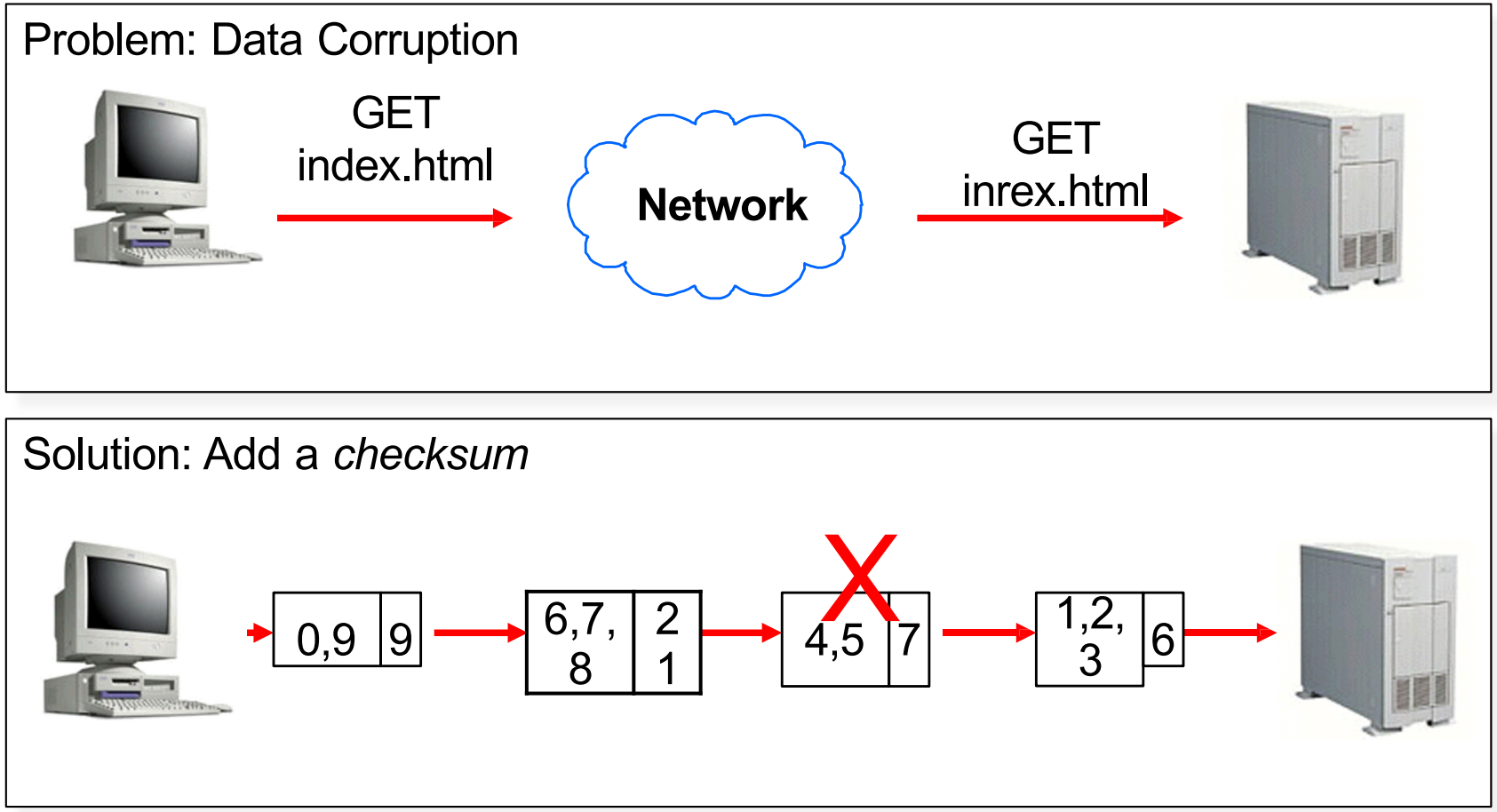
- What if we sent two packets before waiting for an ACK?
- What if we sent N packets?
- How many packets do we need to send before we use up the capacity of the link?

Answered in network protocols (next lectures)

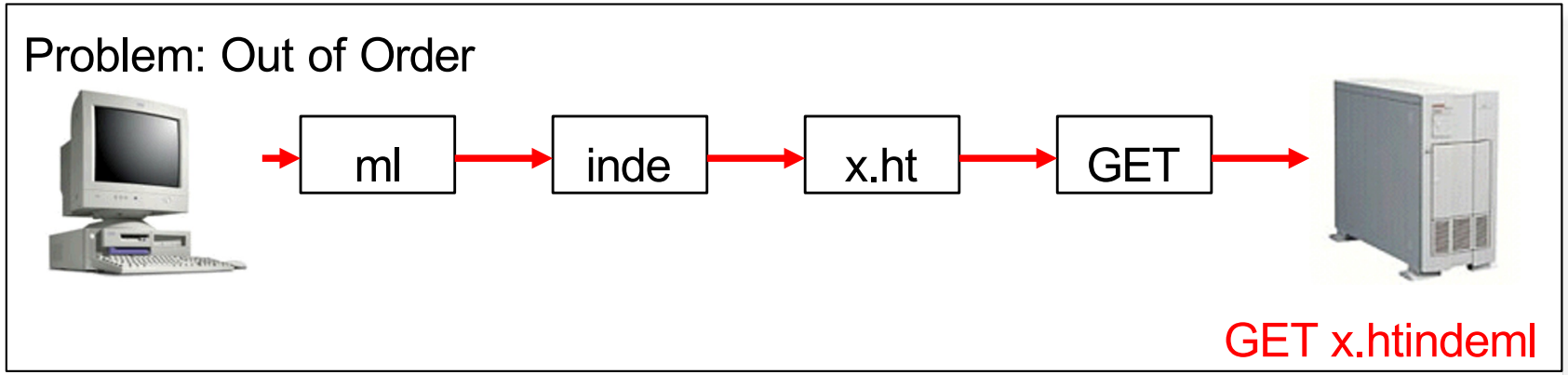
When data gets Lost

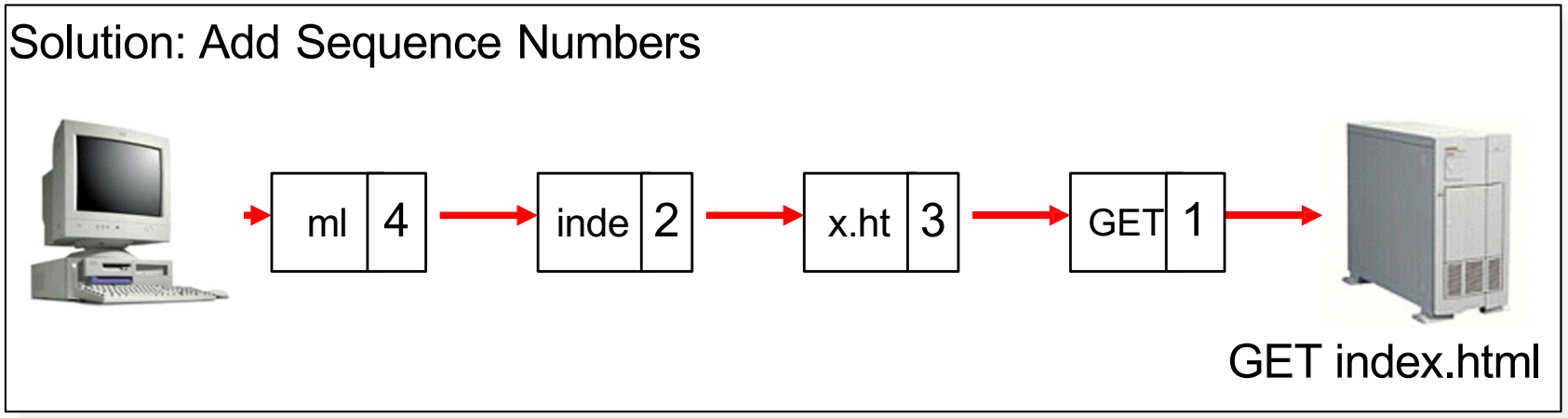


What if the data gets Corrupted?



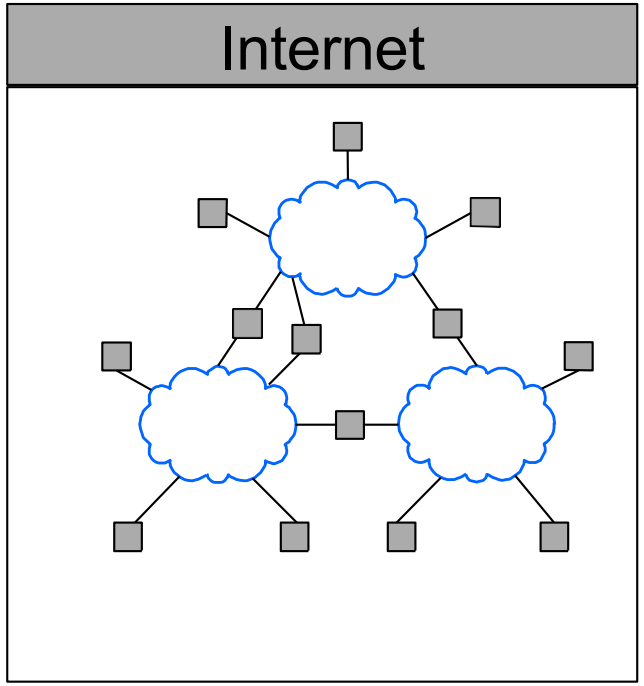
What if the data is Out of Order?





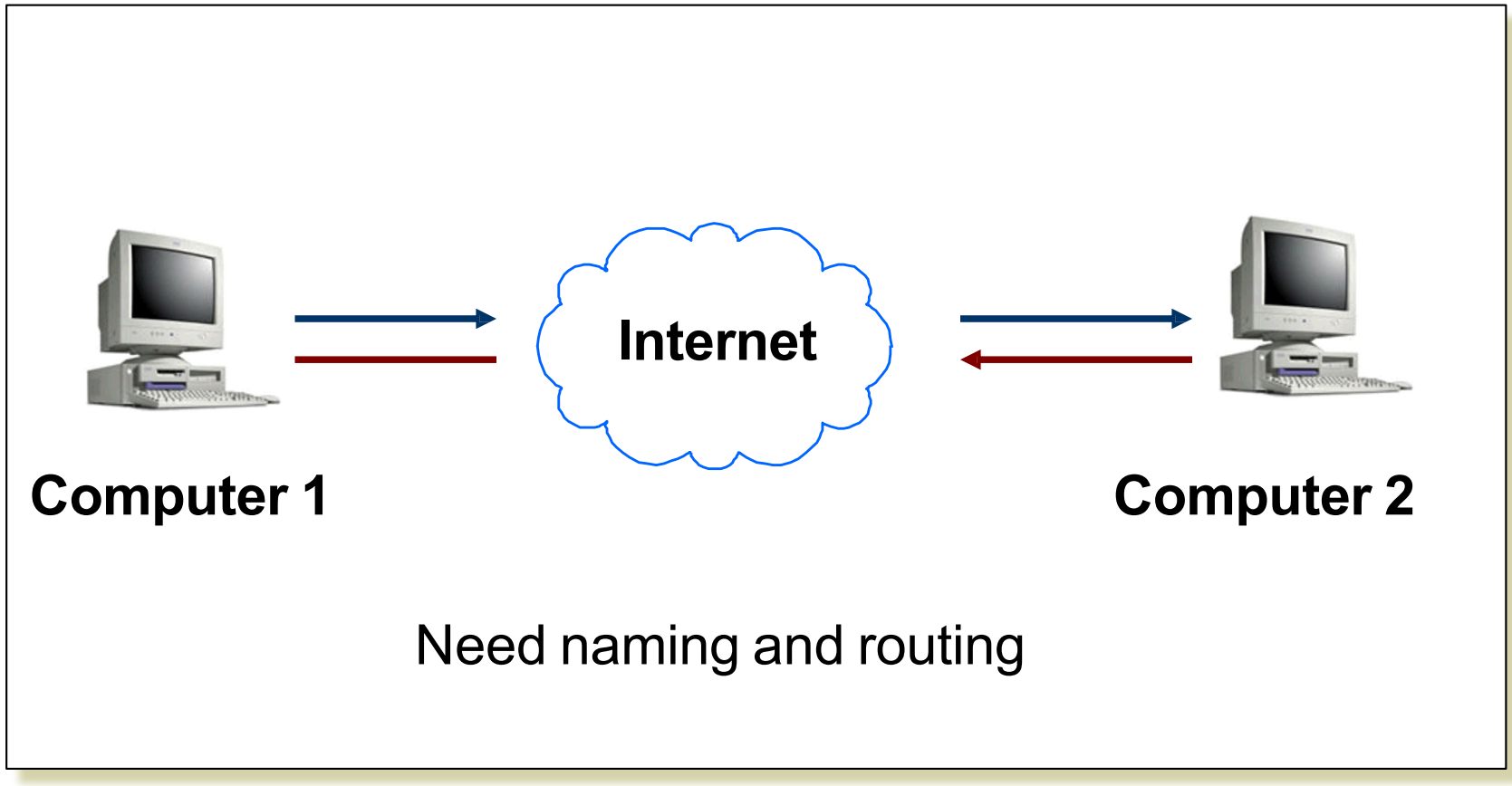
Internet

- An inter-net: a network of networks
  - Networks are connected using routers that support communication in a hierarchical fashion
  - Interconnected set of networks of the Internet Service Providers (ISPs)
  - > 40,000 different networks make up the Internet



Other functions in addition to reliability?

How to find nodes?



Naming

What's the IP address for www.google.com?

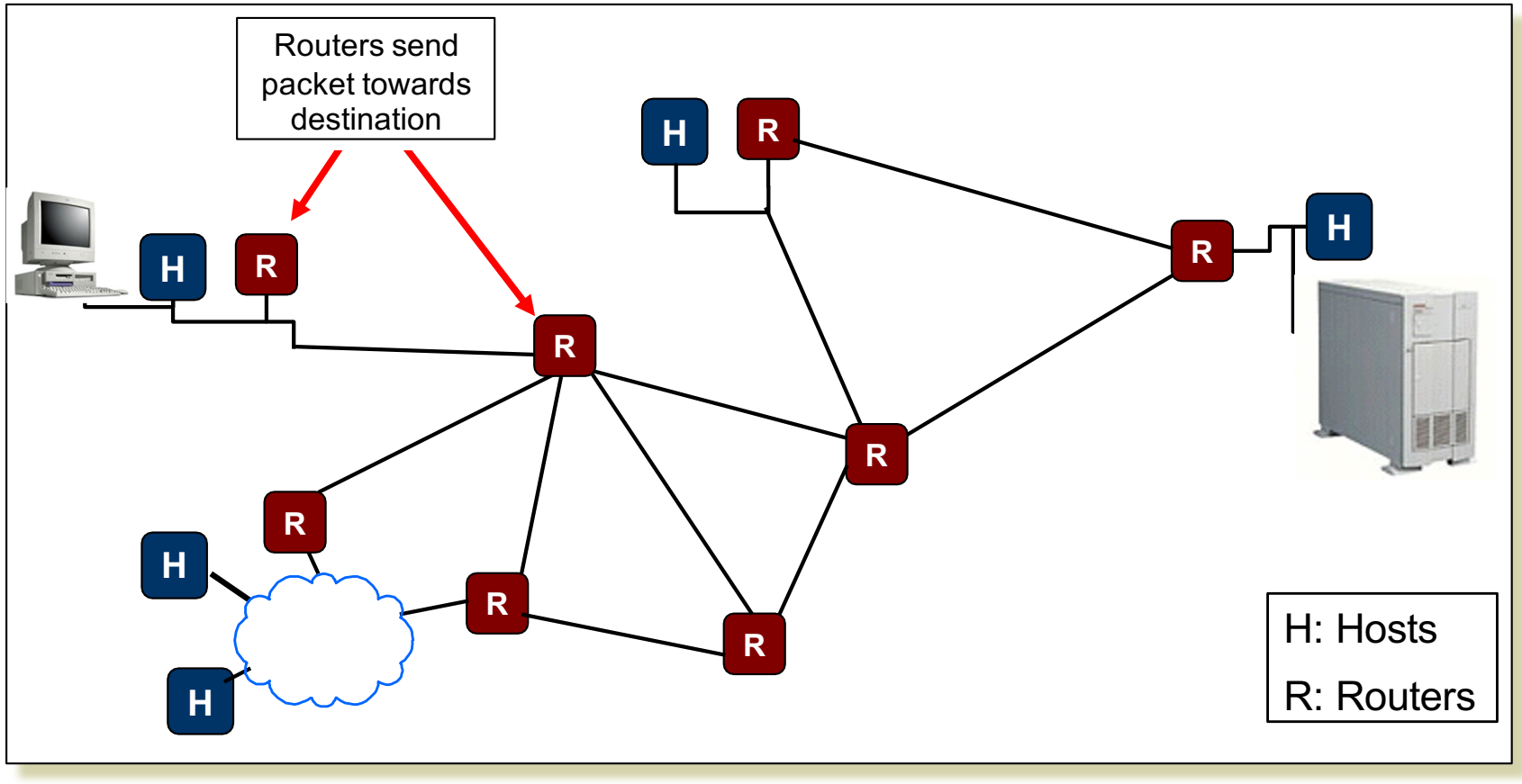
It is 142.256.46.238

Computer 1

Local DNS Server

Translates human readable names to logical endpoints

Routing


Routers send packet towards destination
H
R
H: Hosts
R: Routers

Networks with many functions

- Link
- Multiplexing
- Reliability
- Routing
- Addressing/naming (locating peers)

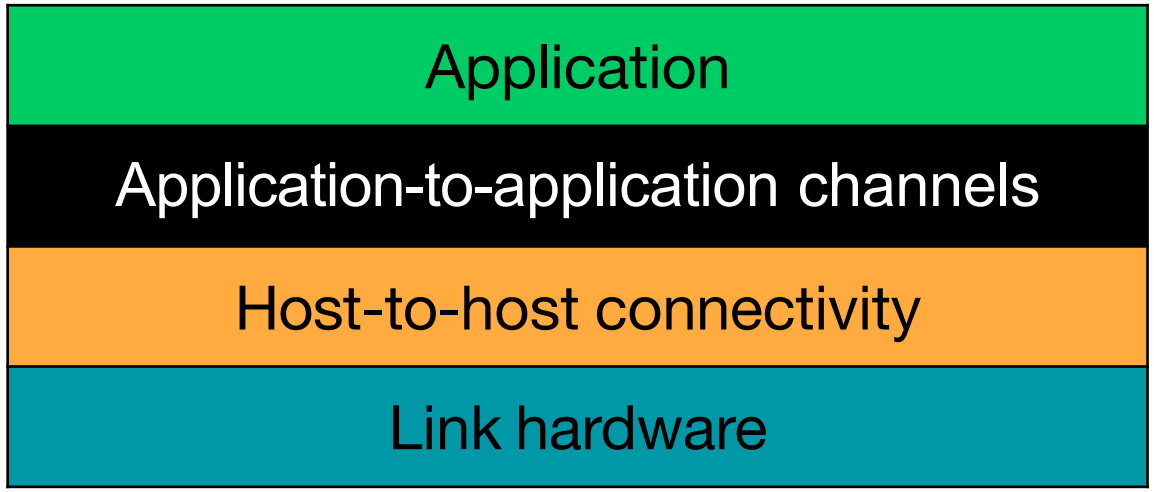
…

Where would you implement each function?

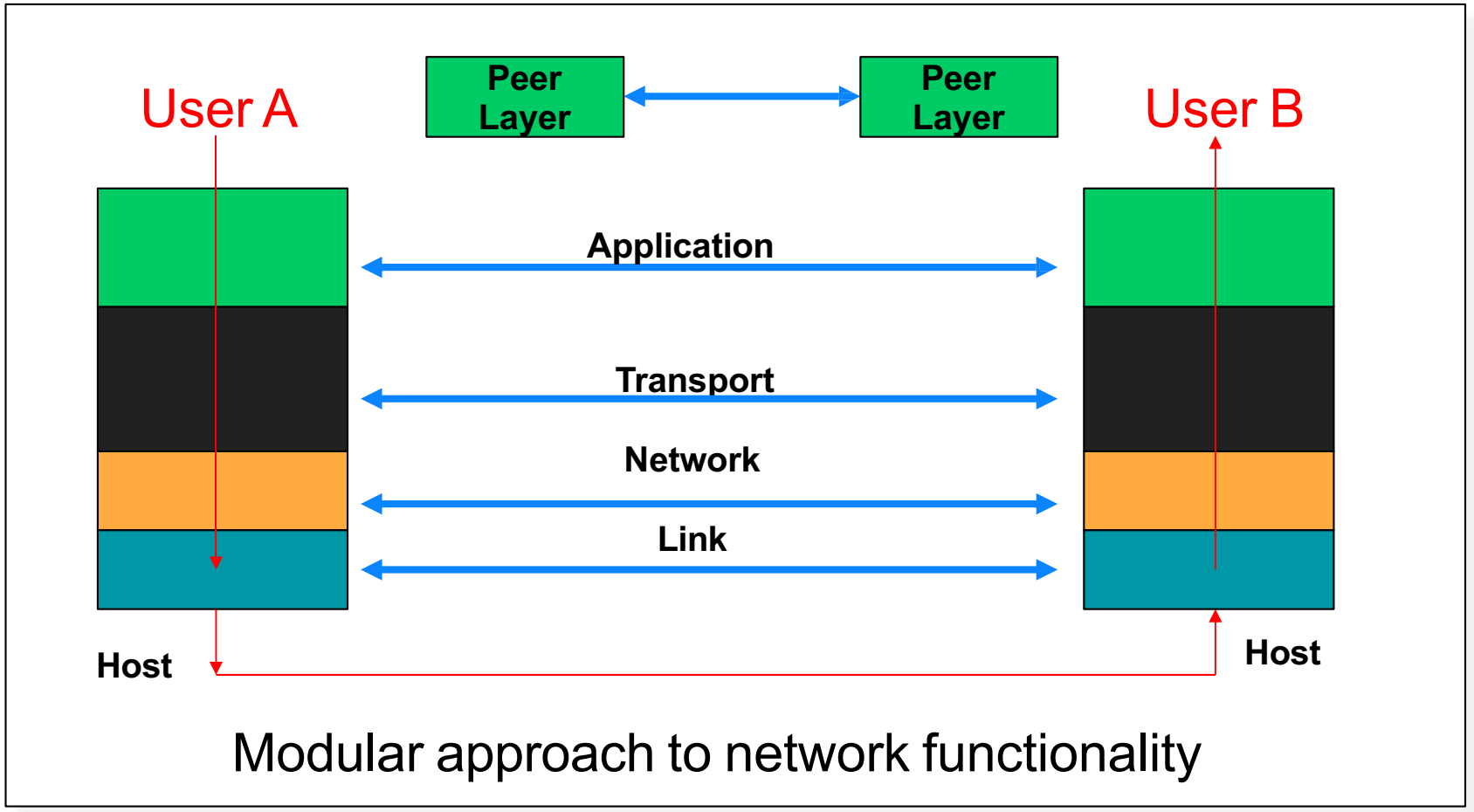
Layered design!

What is layering?

- Modular approach to network functionality



What is layering?

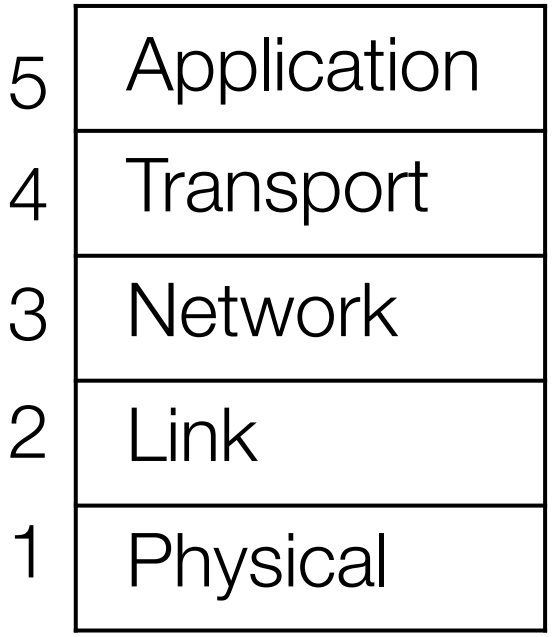


Modular approach to network functionality

Layering characteristics

- Each layer relies on services from layer below and exports services to layer above
- Interface defines interaction with peer on other hosts
- Protocols define:
  - Interface to higher layers (API)
  - Interface to peer (syntax & semantics)
    - Actions taken on receipt of a messages
    - Format and order of messages
    - Error handling, termination, etc.
- Hides implementation - layers can change without disturbing other layers (black box)

Reference Model



Programs that use network service

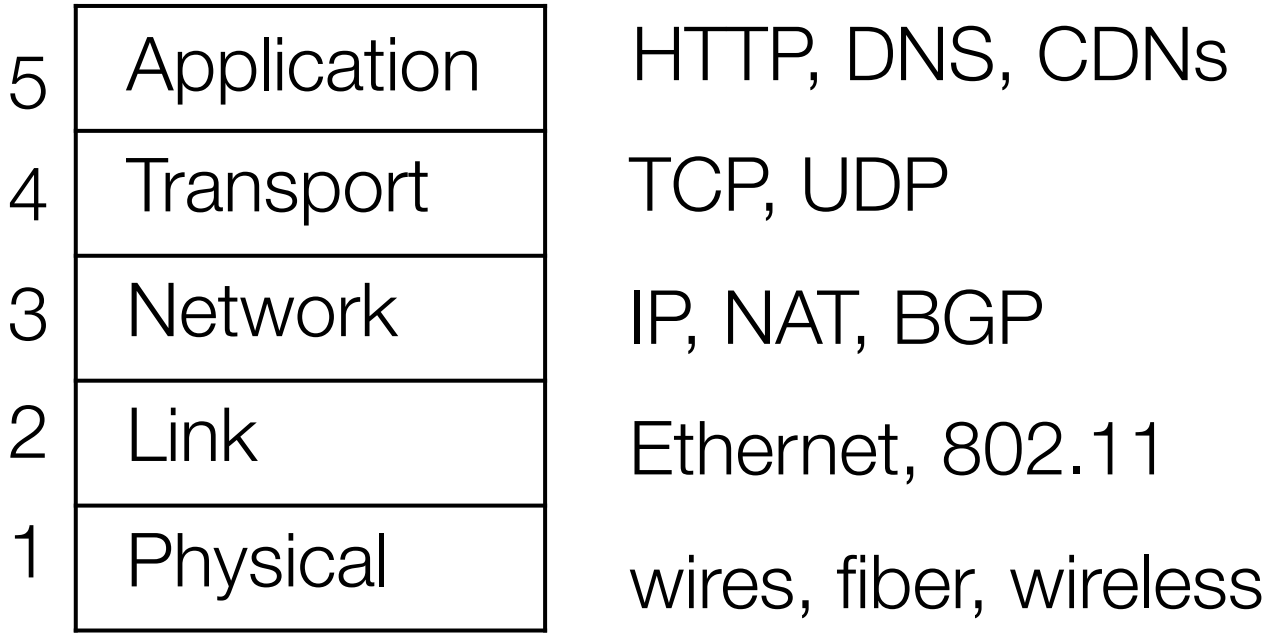
Provides end-to-end data delivery

Send packets over multiple networks

Send frames over one or more links

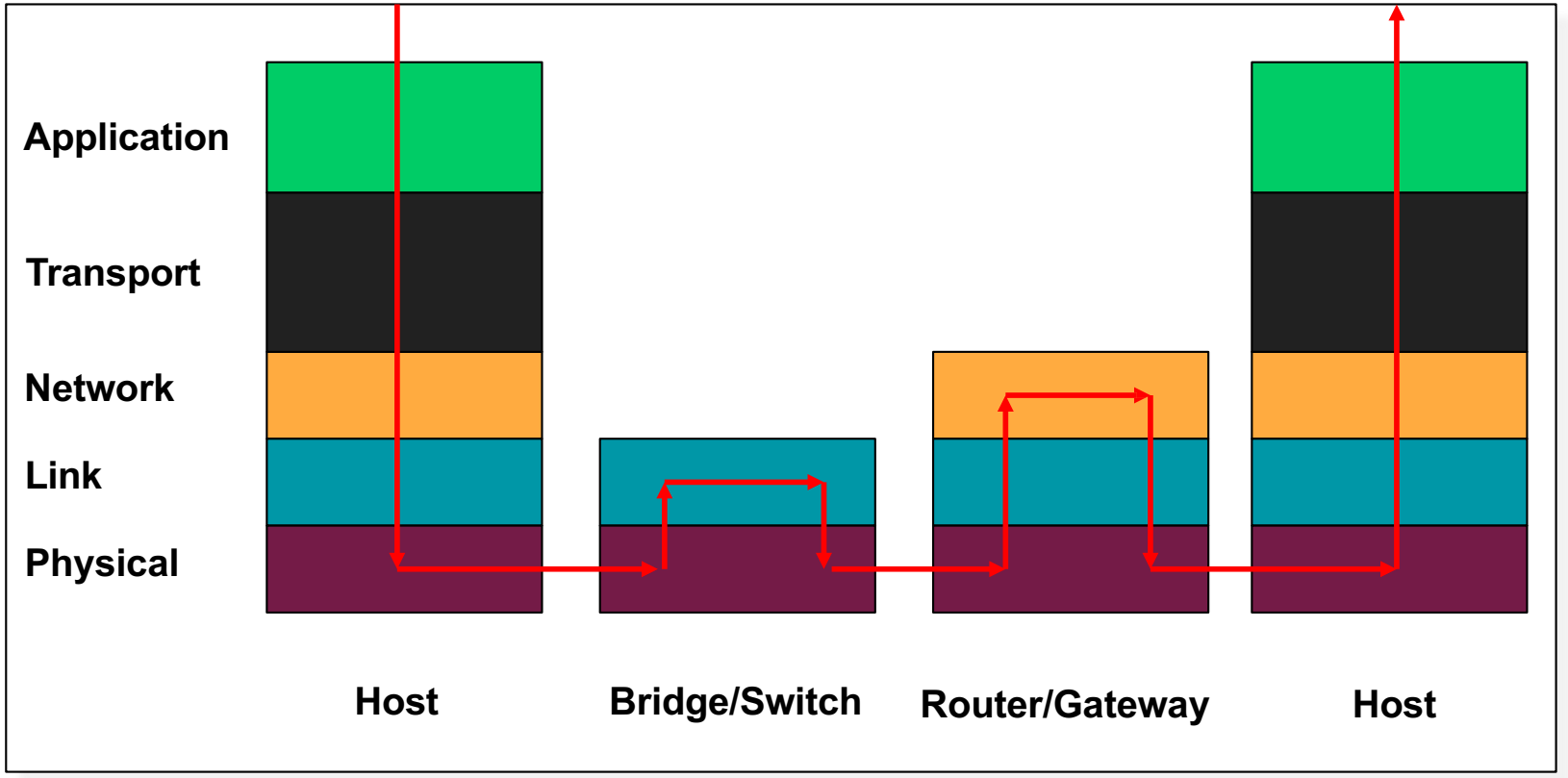
Send bits using signals

Reference Model

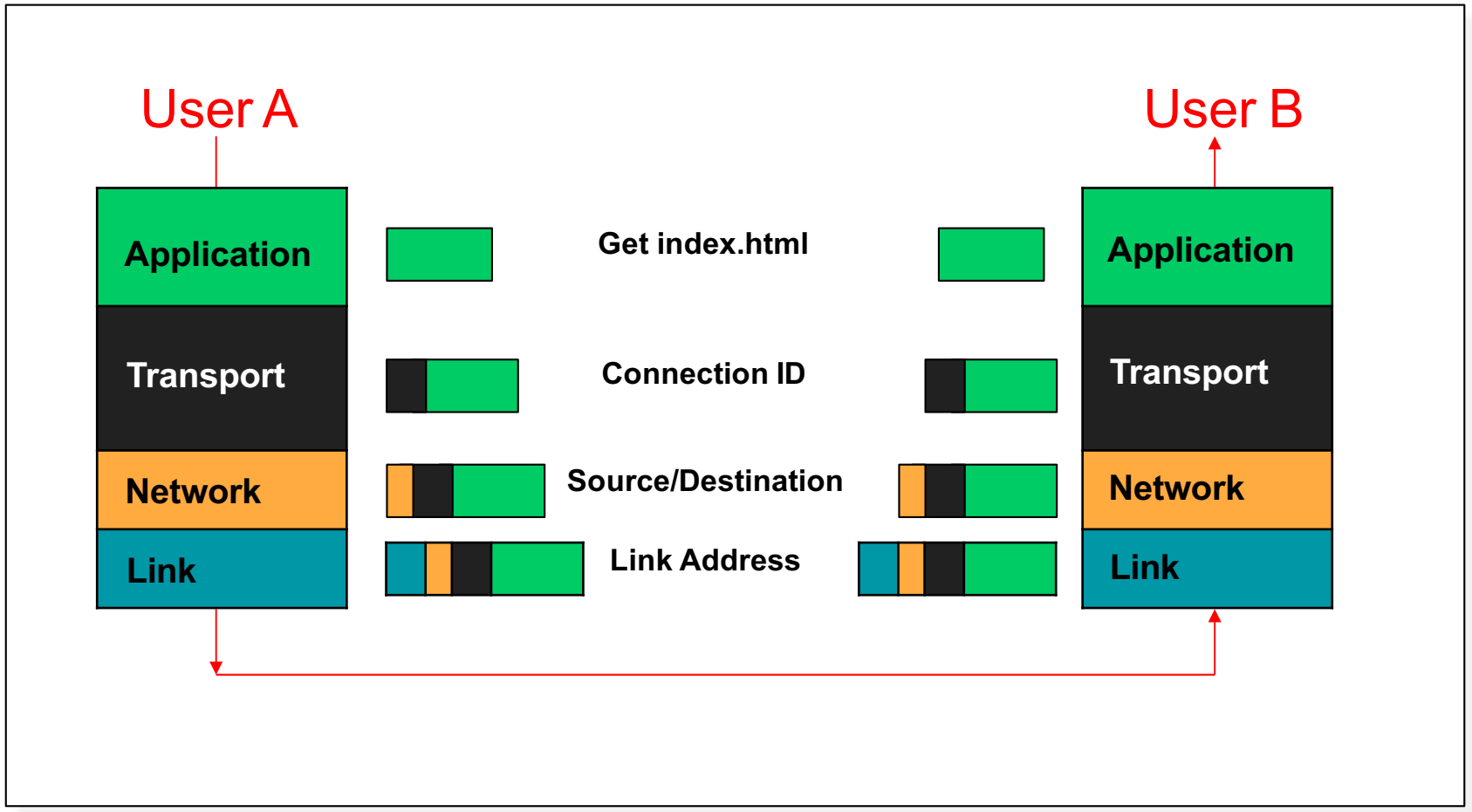


Internet protocol layering

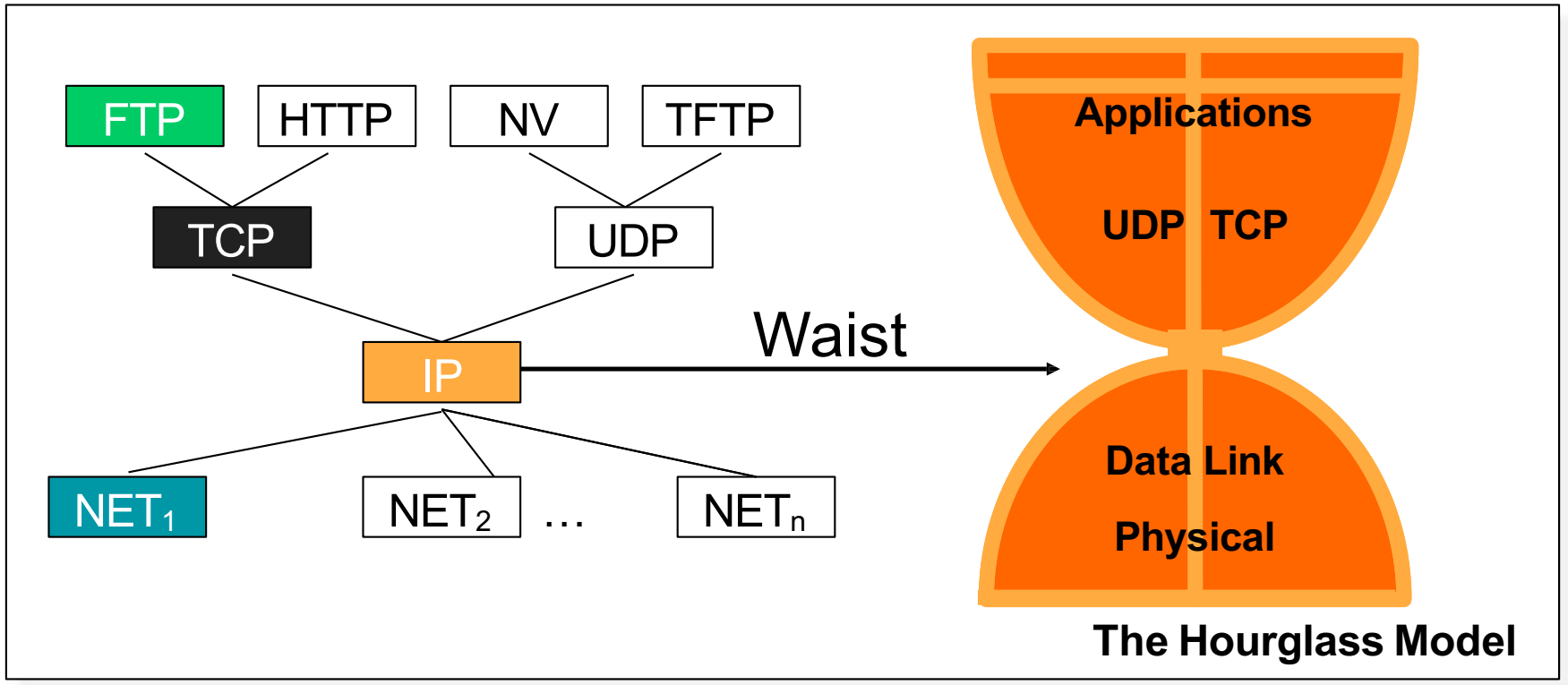
- Host-to-host communication over layers



Layer encapsulation



Internet protocol suite

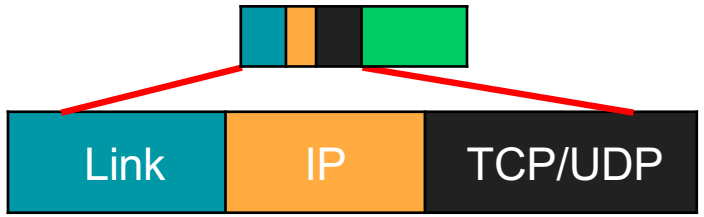


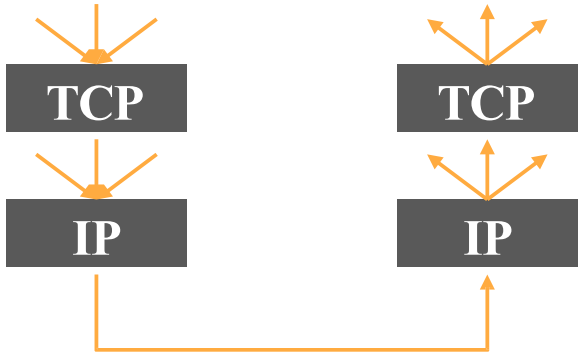
Interoperability: IP over anything, anything over IP

Any disadvantage of the “IP waist”?

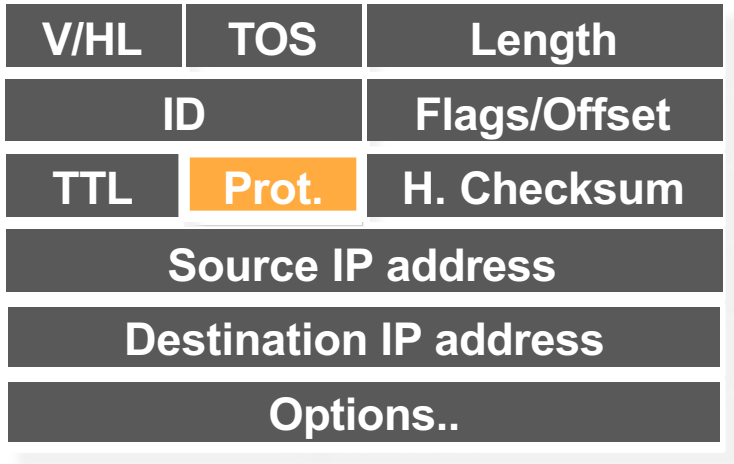
Multiplexing and demultiplexing

- There may be multiple implementations of each layer
  - How does the receiver know what version of a layer to use?
- Each header includes a demultiplexing field that is used to identify the next layer
  - Filled in by the sender
  - Used by the receiver





Example of IP header



What networks do?

- Make and break connections
- Find a path through the network
- Transfers information reliably
- Transfers arbitrary length information
- Send as fast as the network allows
- Shares bandwidth among users
- Secures information in transit
- …

Credit

- Some slides are adapted from course slides of 15-440 in CMU