

CS4450

Computer Networks: Architecture and Protocols

Lecture 3

- Packet Delays
- How the Internet works

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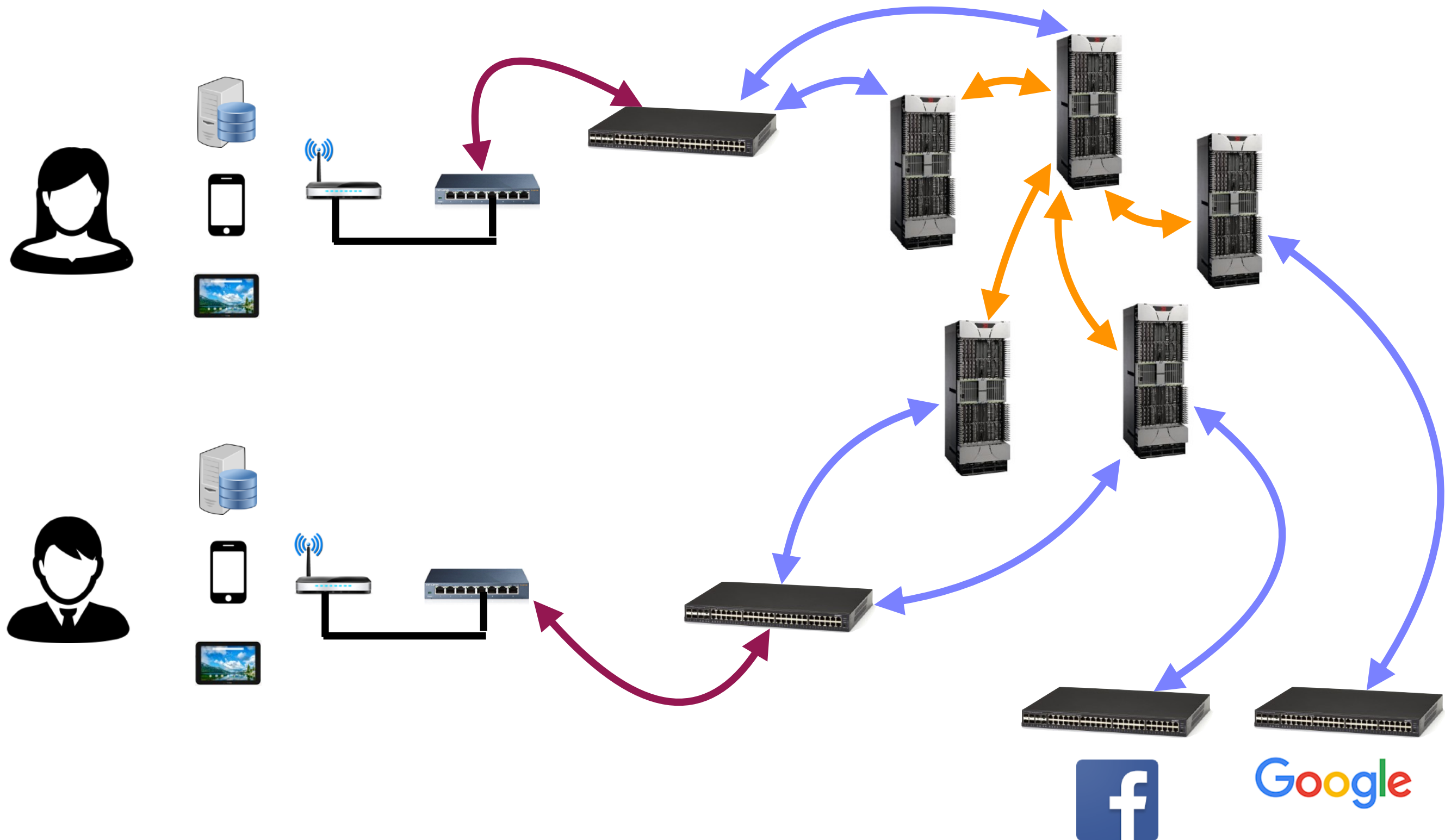
Context for and Goals of Today's Lecture

- Today's lecture is going to be one of the harder lectures
- If you understand everything
 - There is something wrong!
- **Goals:**
 - Wrap up discussion on transmission and propagation delays
 - How does the Internet work?
 - An end-to-end view

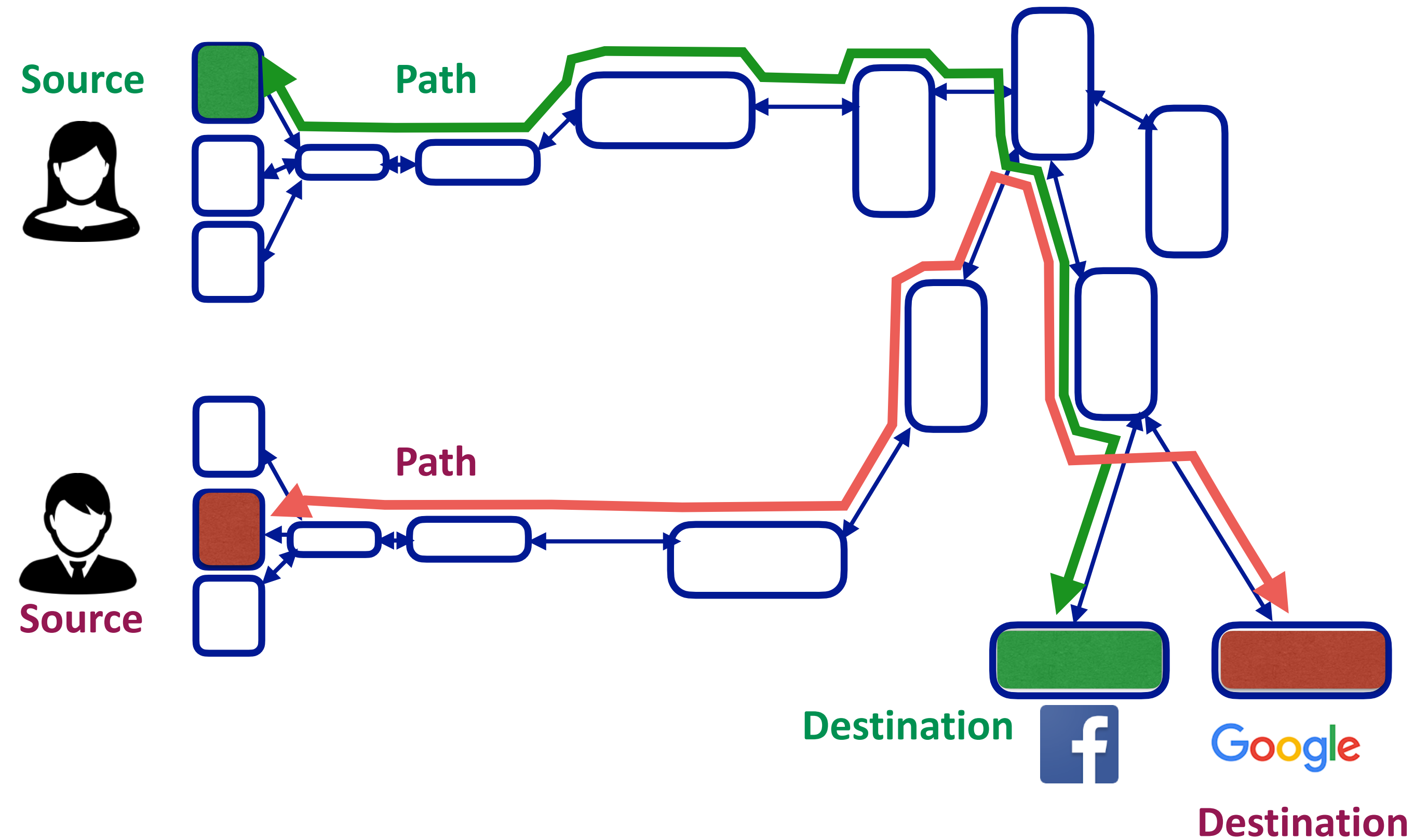
**But, as usual, lets start with:
what we have learnt so far**

Recap: What is a computer network?

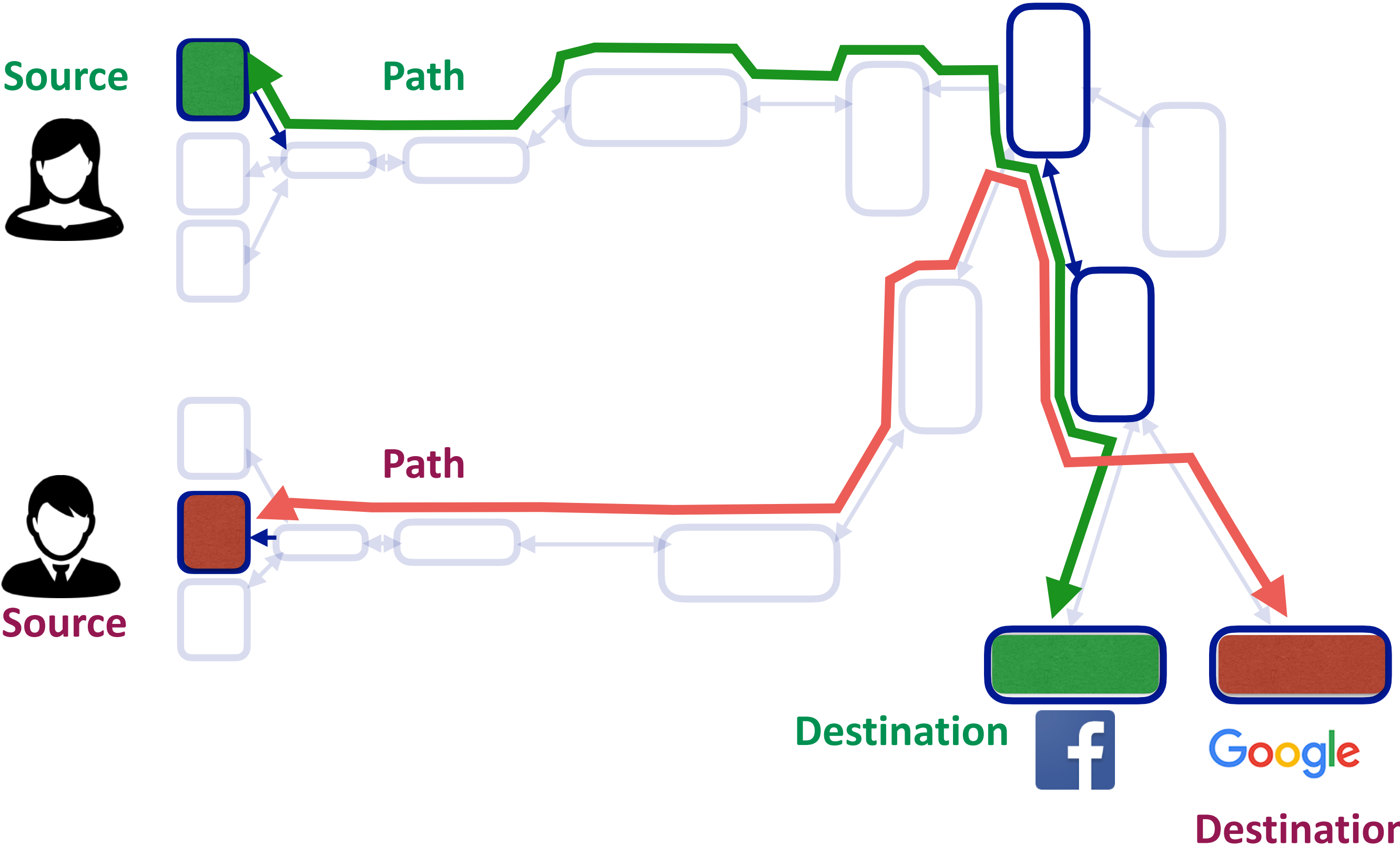
A set of network elements connected together, that implement a set of protocols for the purpose of sharing resources at the end hosts



Recap: network can be abstractly represented as a graph



Recap: Sharing the network



Recap: Performance metrics in computer networks!

- **Bandwidth:** Number of bits sent per second (bits per second, or bps)
 - Depends on hardware, network traffic conditions, ...
- **Delay:** Time for all bits to go from source to destination (seconds)
 - Depends on hardware, distance, traffic from other sources, ...
- **Many other performance metrics**
 - **Reliability, fairness, etc.**
 - We will come back to other metrics later ...

Recap: Two approaches to sharing networks

- **First: Reservations**
 - Reserve (peak) bandwidth needed in advance
- **One way to implement reservations: circuit switching**
 - Source sends a reservation request for peak demand to destination
 - Switches/routers establish a “circuit”
 - Source sends data
 - Source sends a “teardown circuit” message

Recap: Circuit switching (reservation-based sharing) summary

- **Goods:**

- Predictable performance
- Reliable delivery
- Simple forwarding mechanism

- **Not-so-goods**

- Handling failures
- Resource underutilization
- Blocked connections
- Connection set up overheads
- Per-connection state in switches (scalability problem)

Recap: Solution: Packet switching

- Break data into smaller pieces
 - **Packets!**
- Transmit the packets without any reservations
 - And, hope for the best

Recap: Packet switching summary

- **Goods:**

- With proper mechanisms in place
 - Easier to handle failures
- No resource underutilization
 - A source can send more if others don't use resources
- No blocked connection problem
- No per-connection state
- No set-up cost

- **Not-so-goods:**

- Unpredictable performance
- High latency
- Packet header overhead

Summary of network sharing

Statistical multiplexing

- **Statistical multiplexing:** combining demands to share resources efficiently
- Long history in computer science
 - Processes on an OS (vs every process has own core)
 - Cloud computing (vs every one has own datacenter)
- Based on the premise that:
 - **Peak of aggregate load is \ll aggregate of peak load**
- Therefore, it is better to share resources than to strictly partition them ...

Two approaches to sharing networks

Both embody statistical multiplexing

- Reservation: sharing at connection level
 - Resources shared between connections currently in system
 - **Reserve the peak demand**
- On-demand: sharing at packet level
 - Resources shared between packets currently in system
 - Resources given out on packet-by-packet basis
 - **No reservation** of resources

Understanding delay/latency

Packet Delay/Latency

- Consists of four components
 - **Transmission delay** (hardware properties)
 - **Propagation delay** (hardware properties, distance)
 - **Queueing delay** (traffic, switch internals)
 - Processing delay (switch internals, end hosts)
- First, consider transmission and propagation delays
- Queueing delay and processing delay later in the course

Transmission delay

- How long does it take to push **all the bits of a packet** into a link?
- **= Packet size / Link bandwidth**
- Example:
 - Packet size = 1500Byte
 - Bandwidth = 100Mbps
 - $1500 * 8 / 100 * 1024 * 1024$ seconds
- **Independent of the link length (distance that the packet traverses)**

Propagation delay

- How long does it take to move **one bit** from one end of a link to the other?
- = **Link length / Propagation speed of link**
 - Propagation speed \sim some fraction of speed of light
- Example:
 - Length = 30,000 meters
 - Delay = $30 \times 1000 / 3 \times 100,000,000$ second = 100us
- **Independent of packet size and bandwidth**

Group Exercise:

How long does it take for a *packet* on a link?

Constraints:

- Packet size = 1000 bits
- Bandwidth = 100 bits per second
- Length = 3 * speed of light

Solution to Group Exercise:

How long does it take for a *packet* on a link?

Questions?

Today's lecture: How does the Internet work?

1. Dive into **end-to-end**: from source to destination
2. First look into switches: routing, queueing, forwarding
3. First look into network stack: sockets, ports, “the stack”

How does the Internet work?

An end-to-end view

Four fundamental problems!

- **Naming, addressing:** Locating the destination
- **Routing:** Finding a path to the destination
- **Forwarding:** Sending data to the destination
- **Reliability:** Handling failures, packet drops, etc.

Four fundamental problems!

Naming, Routing, Forwarding, Reliability

- Each is motivated by a clear need
- The solutions are not always clean or deep
- **But if you keep in mind what the problem is**
 - You'll be able to understand the solutions
 - When the right time comes :-)

Will take the entire course to learn these:

Lets get an end-to-end picture!

Fundamental problem #1: Naming and Addressing

- **Network Address: where host is located**
 - Requires an address for the destination host
- **Host Name: which host it is**
 - why do we need a name?
- **Answer: When you move a host to new building**
 - Address changes
 - Name ***does not*** change
- **Same thing with your own name and address!**
- **Remember the analogy: human names, addresses, post office, letters**

Names versus addresses

- **Consider when you access a web page**
 - Insert URL into browser (eg, www.cornell.edu)
 - Packets sent to web site (reliably)
 - Packet reach application on destination host
- **How do you get to the website?**
 - URL is **user-level name** (eg, www.cornell.edu)
 - Network needs address (eg, where is www.cornell.edu)?
- **Must map names to addresses**
 - Just like we use an address book to map human names to addresses

Mapping Names to Addresses

- On the Internet, we only name hosts (sort of)
 - URLs are based on the name of the host containing the content (that is, www.cornell.edu names a host)
- Before you can send packets to www.cornell.edu, you must resolve names into the host's address
- Done by the **Domain Name System (DNS)**

The source knows the name;

Maps that name to an address using DNS!

Questions?

Fundamental problem #2

Routing packets through network elements (eg, routers) to destination

- Given **destination address (and name)**, how does each switch/router know where to send the packet so that the packet reaches its destination
- When a packet arrives at a router
 - a **routing table** determines which outgoing link the packet is sent on
 - Computed using **routing protocols**

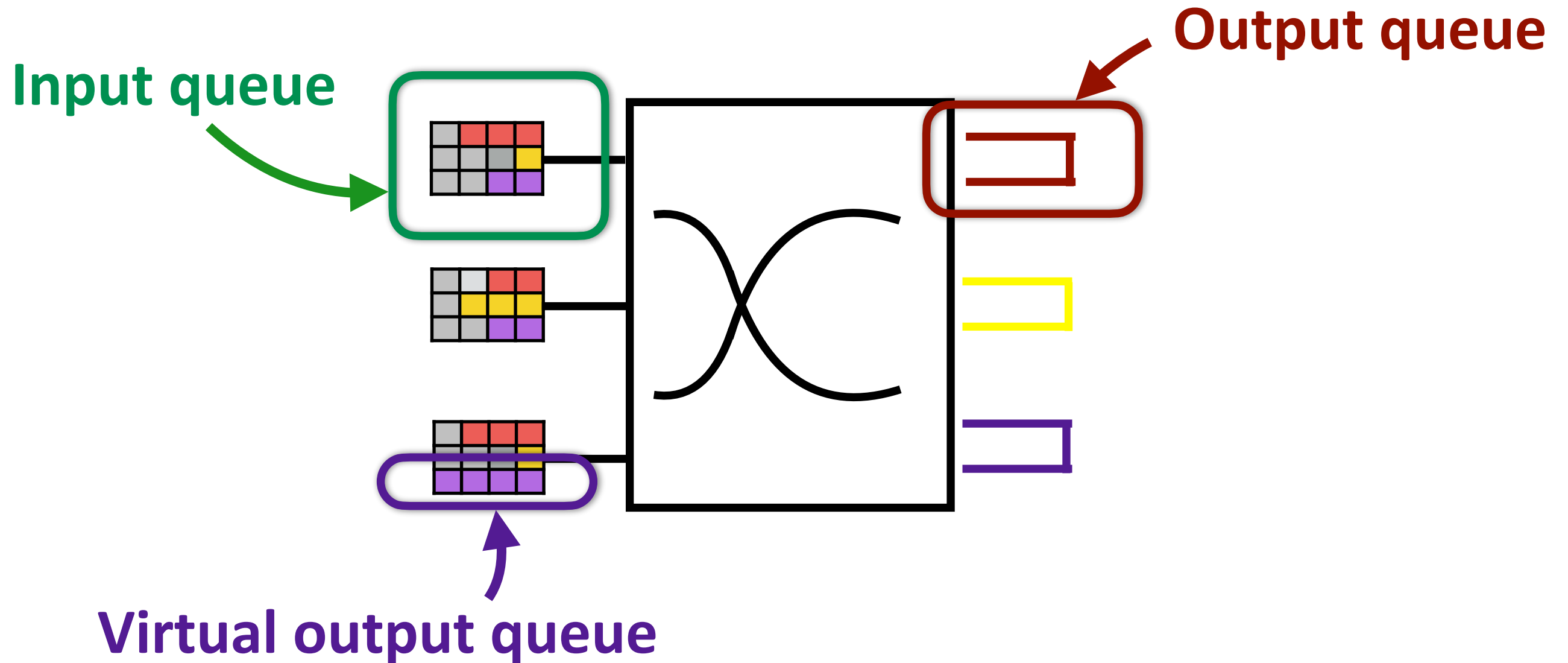
Routing protocols (conceptually)

- Distributed algorithm that runs between routers
 - Distributed means no single router has “full” view of the network
 - Exchange of messages to gather “enough” information ...
- ... about the network topology
- Compute paths through that topology
- Store forwarding information in each router
 - If packet is destined for X, send out using link l1
 - If packet is destined for Y, send out using link l2
 - Can packets going to different destinations sent out to same link?
- We call this a **routing table**

Questions?

Fundamental problem #3

Queueing and Forwarding of packets at switches/routers



Fundamental problem #3

Queueing and Forwarding of packets at switches/routers

- **Queueing:** When a packet arrives, store it in “input queues”
 - Each incoming queue divided into multiple virtual output queues
 - One virtual output queue per outgoing link
 - When a packet arrives:
 - Look up its destination’s address (how?)
 - Find the link on which the packet will be forwarded (how?)
 - Store the packet in corresponding virtual output queue
- **Forwarding:** When the outgoing link free
 - Pick a packet from the corresponding virtual output queue
 - forward the packet!

What must packets carry to enable forwarding?

- **Packets must describe where it should be sent**
 - Requires an address for the destination
- **Packets must describe where its coming from**
 - For handling failures, etc.
 - Requires an address for the source
- **Packets must carry data**
 - can be bits in a file, image, whatever



Switch Processing and Queueing delay

- **Processing delay**
 - Easy; each switch/router needs to decide where to put packet
 - Requires checking header, etc.
- **Queueing delay**
 - Harder; depends on “how many packets are in front of me”
 - Depends on network load
 - As load increases, queueing delay increases
- **In an extreme case, increase in network load**
 - results in packet drops
- We will return to this in much more depth later ...

Questions?

Fundamental problem #4

How do you deliver packets reliable?

- Packets can be dropped along the way
 - Buffers in router can overflow
 - Routers can crash while buffering packets
 - Links can garble packets
- How do you make sure packets arrive safely on an unreliable network?
 - Or, at least, know if they are delivered?
 - Want no false positives, and high change of success

Two questions about reliability

- **Who is responsible for this? (architecture)**
 - Network?
 - Host?
- **How is it implemented? (engineering)**
- We will consider both perspectives

Questions?

Finishing our story

- We now have the address of the web site
- And, a route/path to the destination
- And, mechanisms in place to forward the packets at each switch/router
- In a reliable manner
 - So, we can send packets from source to destination
 - Are we done?
- When a packet arrives at a host, what does the host do with it?
 - To which process (application) should the packet be sent?
- If the packet header only has the destination address, how does the host know where to deliver packet?
 - There may be multiple applications on that destination

And while we are finishing our story

- Who puts the source address, source port, destination address, destination port in the packet header?

The final piece in the game: End-host stack

Of Sockets and Ports

- When a process wants access to the network, it opens a socket, which is associated with a port
- **Socket:** an OS mechanism that connects processes to the network stack
- **Port:** number that identifies that particular socket
- The port number is used by the OS to direct incoming packets

Implications for Packet Header

- **Packet Header must include:**
 - Destination address (used by network)
 - Destination port (used by network stack)
 - And?
 - Source address (used by network)
 - Source port (used by network stack)
- When a packet arrives at the destination host, packet is delivered to the socket associated with the destination port
- More details later

Separation of concerns

- **Network:** Deliver packets from host to host (based on address)
- **Network stack (OS):** Deliver packets to appropriate socket (based on port)
- **Applications:**
 - Send and receive packets
 - Understand content of packet bodies

**Secret of the Internet's success is getting
these and other abstractions right**

The end-to-end story

- Application opens a **socket** that allows it to connect to the **network stack**
- Maps **name** of the web site to its **address** using **DNS**
- The network stack at the source embeds the address and **port** for both the source and the destination in **packet header**
- Each **router** constructs a **routing table** using a distributed algorithm
- Each router uses destination address in the packet header to look up the **outgoing link** in the routing table
 - And when the link is free, forwards the packet
- When a packet arrives the destination:
 - The network stack at the destination uses the port to forward the packet to the right application

Today's lecture

- The Internet is a huge, complicated system
- One can study the parts in isolation
 - Routing
 - Ports, sockets
 - Network stack
 - ...
- But the pieces all fit together in a particular way
- Today was quick overview of how pieces fit...
 - Don't worry if you didn't understand much of it
 - **You probably absorbed more than you realize**

