Networks

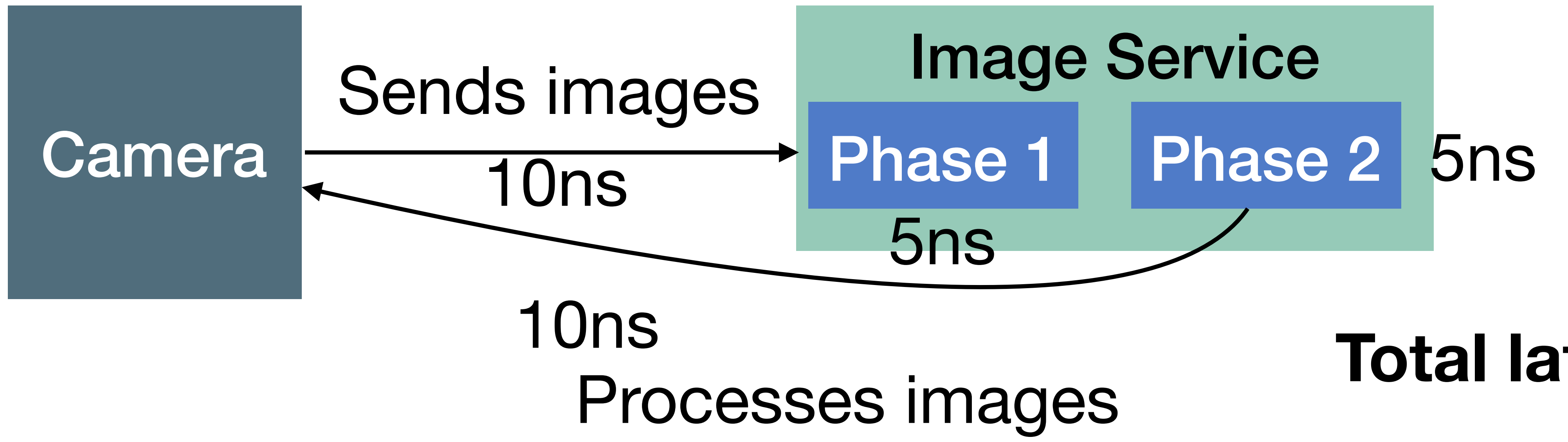
CS 475, Fall 2019

Concurrent & Distributed Systems

GEORGE MASON UNIVERSITY

Latency

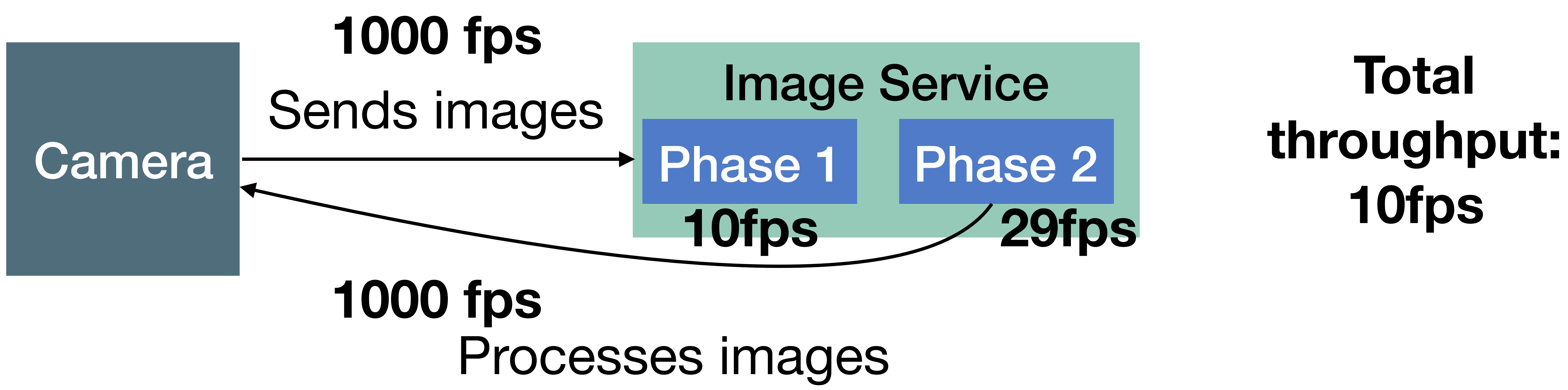
- In client/server model, latency is simply: time between client sending request and receiving response
- What contributes to latency?
  - Latency sending the message
  - Latency processing the message
  - Latency sending the response
- Adding pipelined components -> latency is cumulative



Total latency: 30ns

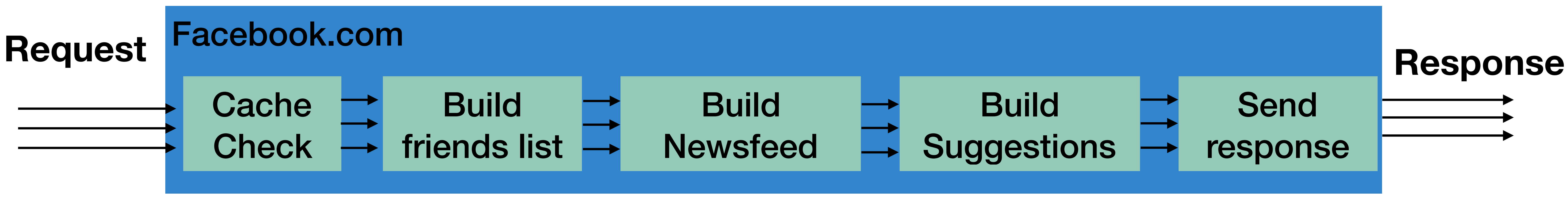
Throughput

- Measure of the rate of useful work done for a given workload
- Example:
  - Throughput is camera frames processed/second
- When adding multiple pipelined components -> throughput is the minimum value



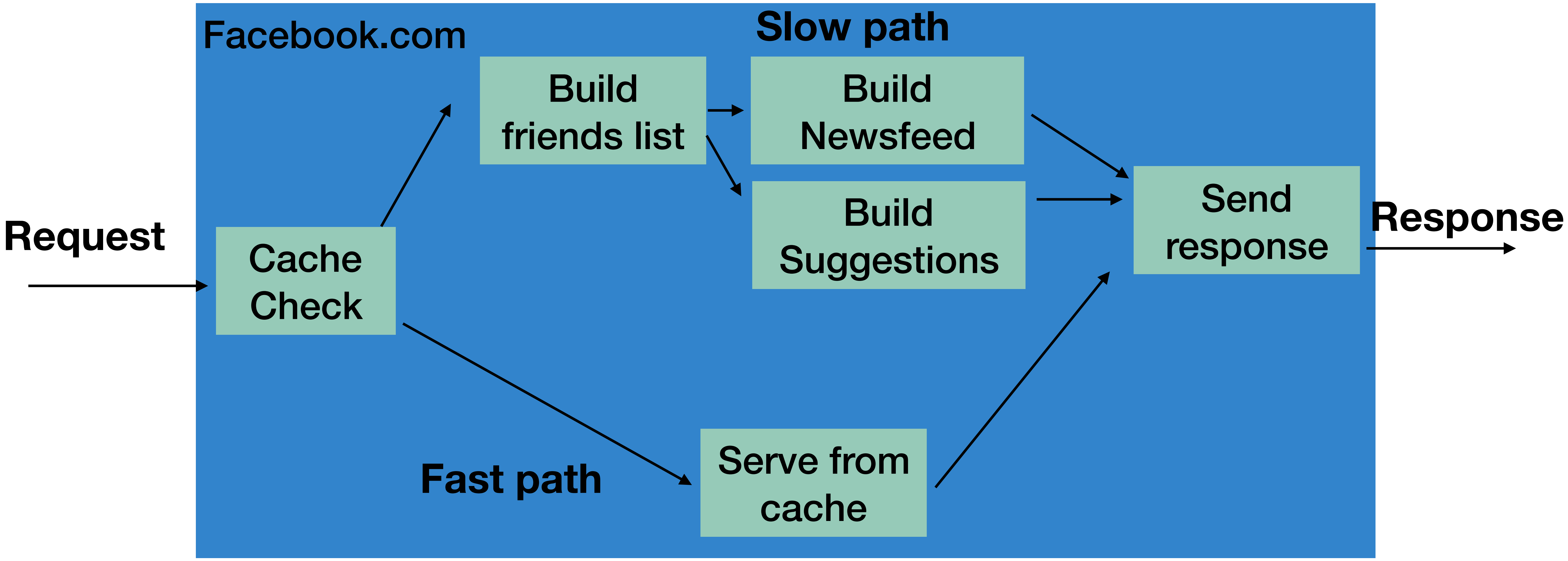
Improving Throughput

- Introduce concurrency into our pipeline
- Each stage runs in its own thread (or many threads, perhaps)
- If a stage completes its task, it can start processing the next request right away
  - E.g. our system will process multiple requests at the same time



Reducing Latency without lots of $$$

- Approach: use **concurrency**
- Limited by serial section



Thread Pools

- More sensible to keep a pool of long-lived threads
- Threads assigned short-lived tasks
  - Runs the task
  - Rejoins pool
  - Waits for next assignment

Thread Pool = Abstraction

- Insulate programmer from platform
  - Big machine, big pool
  - And vice-versa
- Portable code
  - Runs well on any platform
  - No need to mix algorithm/platform concerns

Multithreaded Fibonacci

```
class FibTask implements Callable<Integer> {
  static ExecutorService exec = 
Executors.newCachedThreadPool();
  int arg;
  public FibTask(int n) {
    arg = n;
  }
  public Integer call() {
    if (arg > 2) {
      Future<Integer> left  = exec.submit(new FibTask(arg-1));
      Future<Integer> right = exec.submit(new FibTask(arg-2));
      return left.get() + right.get();
    } else {
      return 1;
    }}}
```

Parallel calls

Multithreaded Fibonacci

```
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    } else {
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    }}}
```
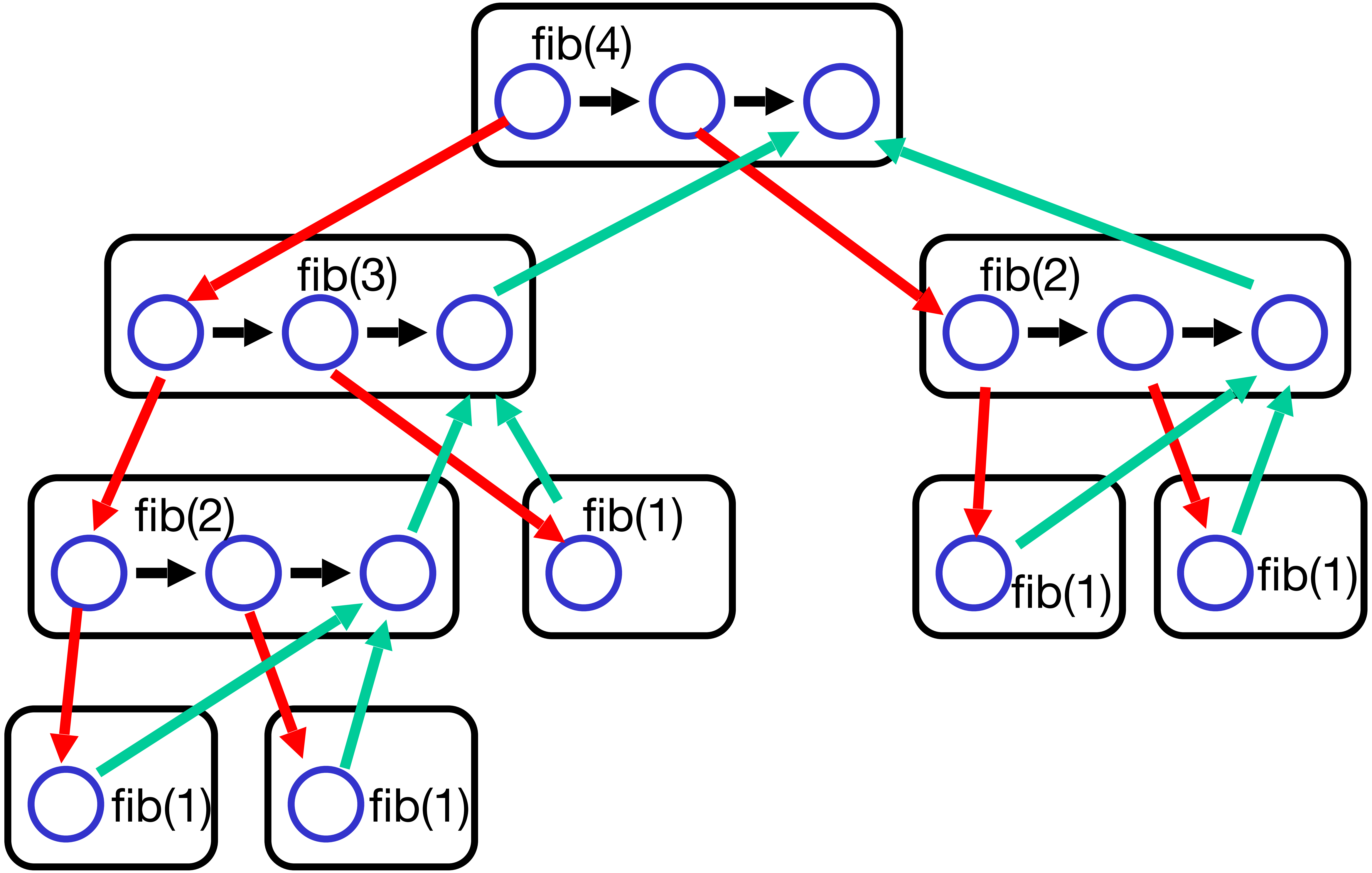

Pick up & combine results

Fib Work

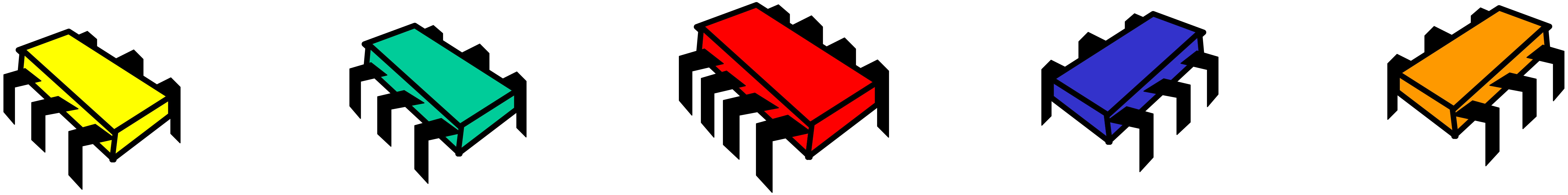


Today

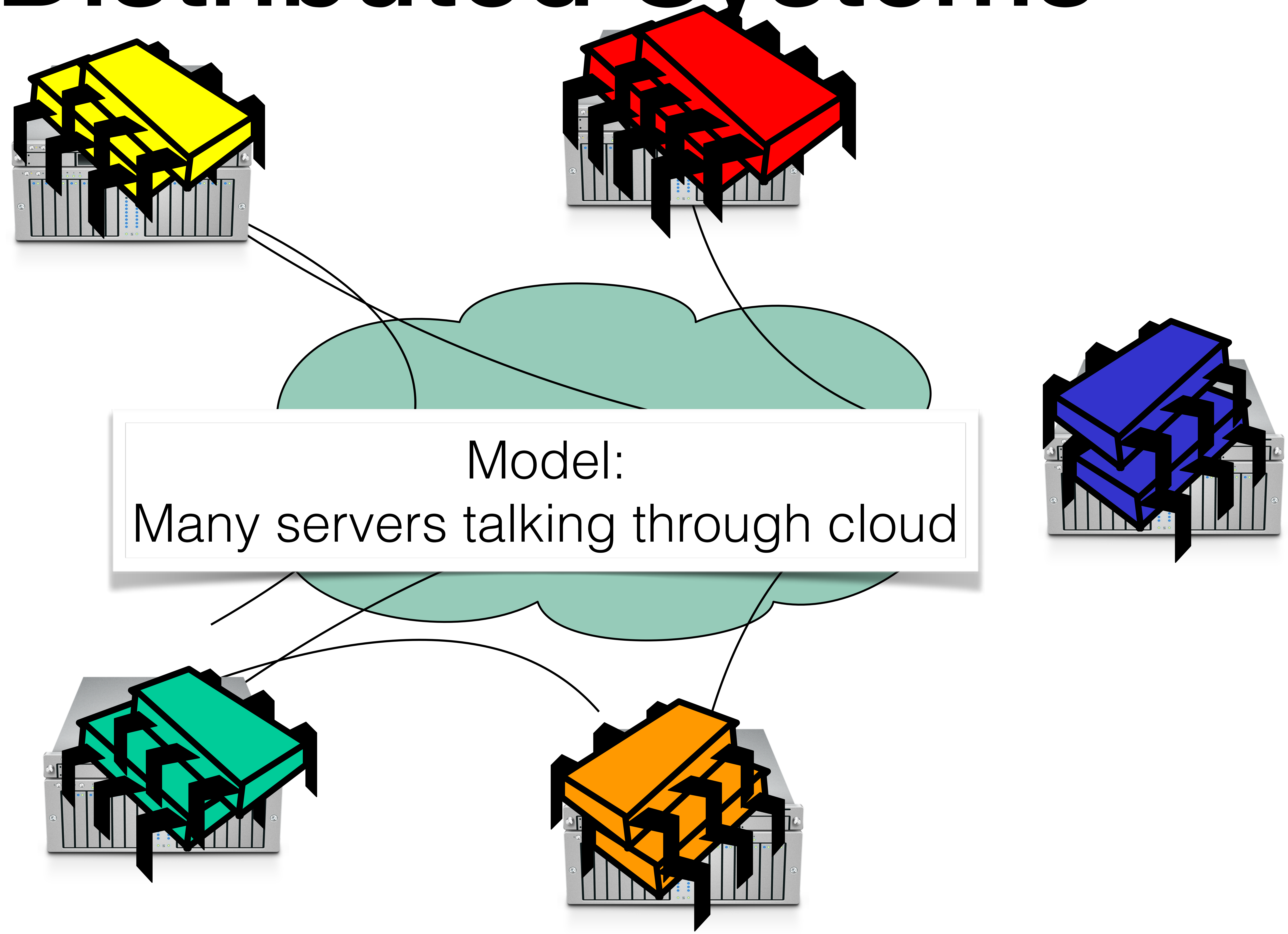
- HW2 discussion
- Gentle introduction to distributed computation
- Computer networks - what do they mean for us?
- We won’t return to the CompleteableFuture material we didn’t get to last class
- Reminders:
    - Midterm

More Abstractions

- Process + Thread -> one computer
- How can we abstract many computers working together?
- What does that even look like?

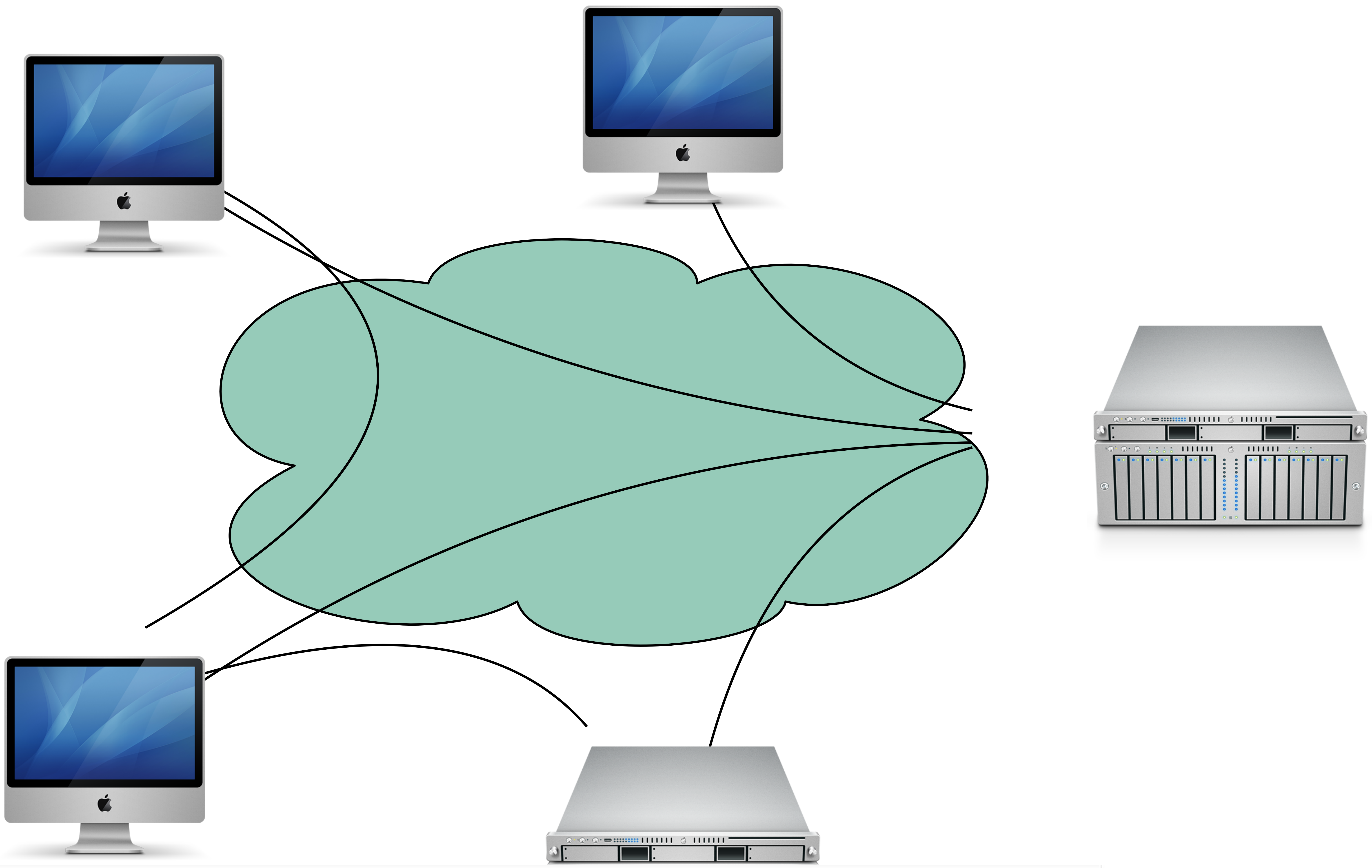


Distributed Systems



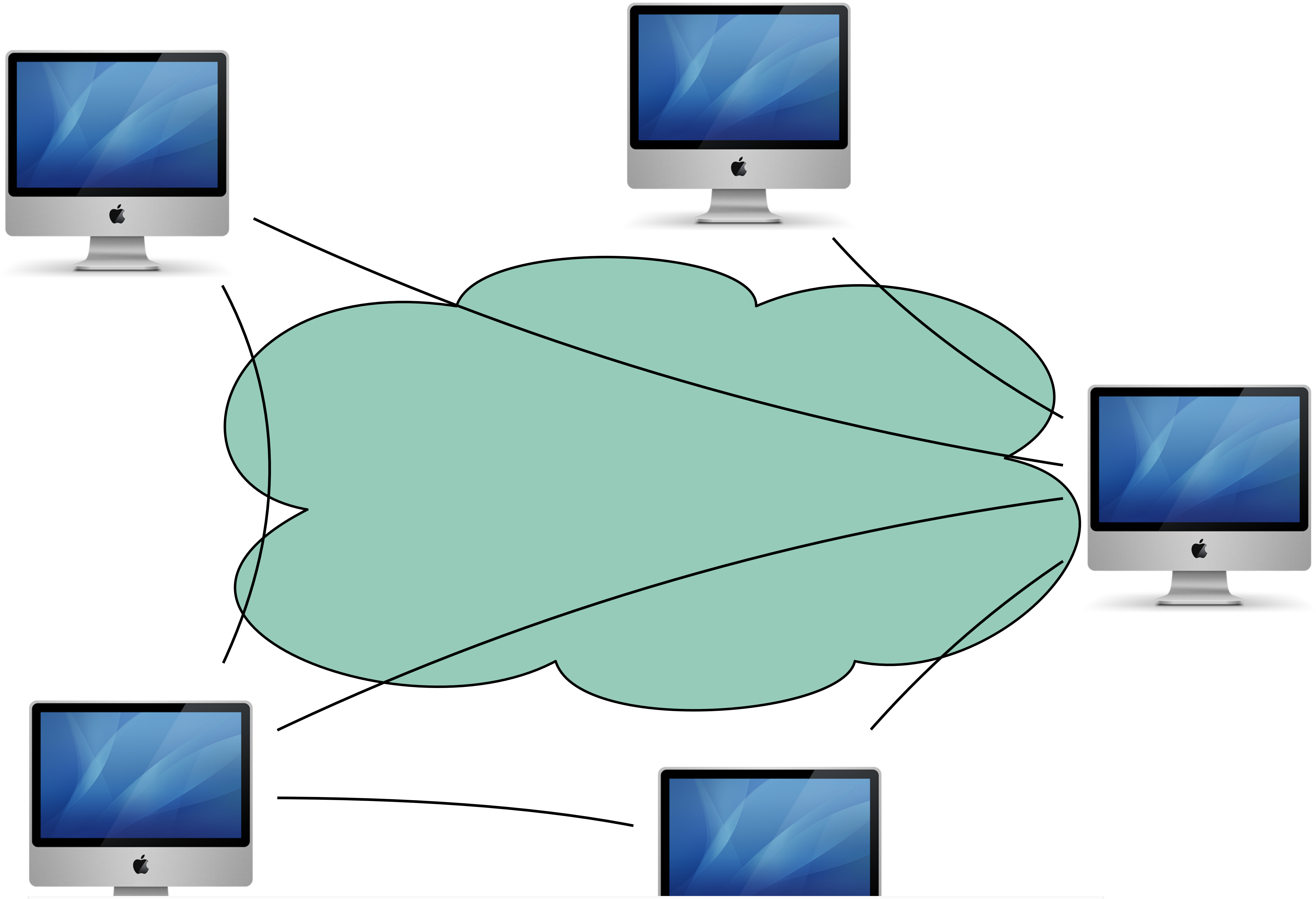
Model:
Many servers talking through cloud

Distributed Systems



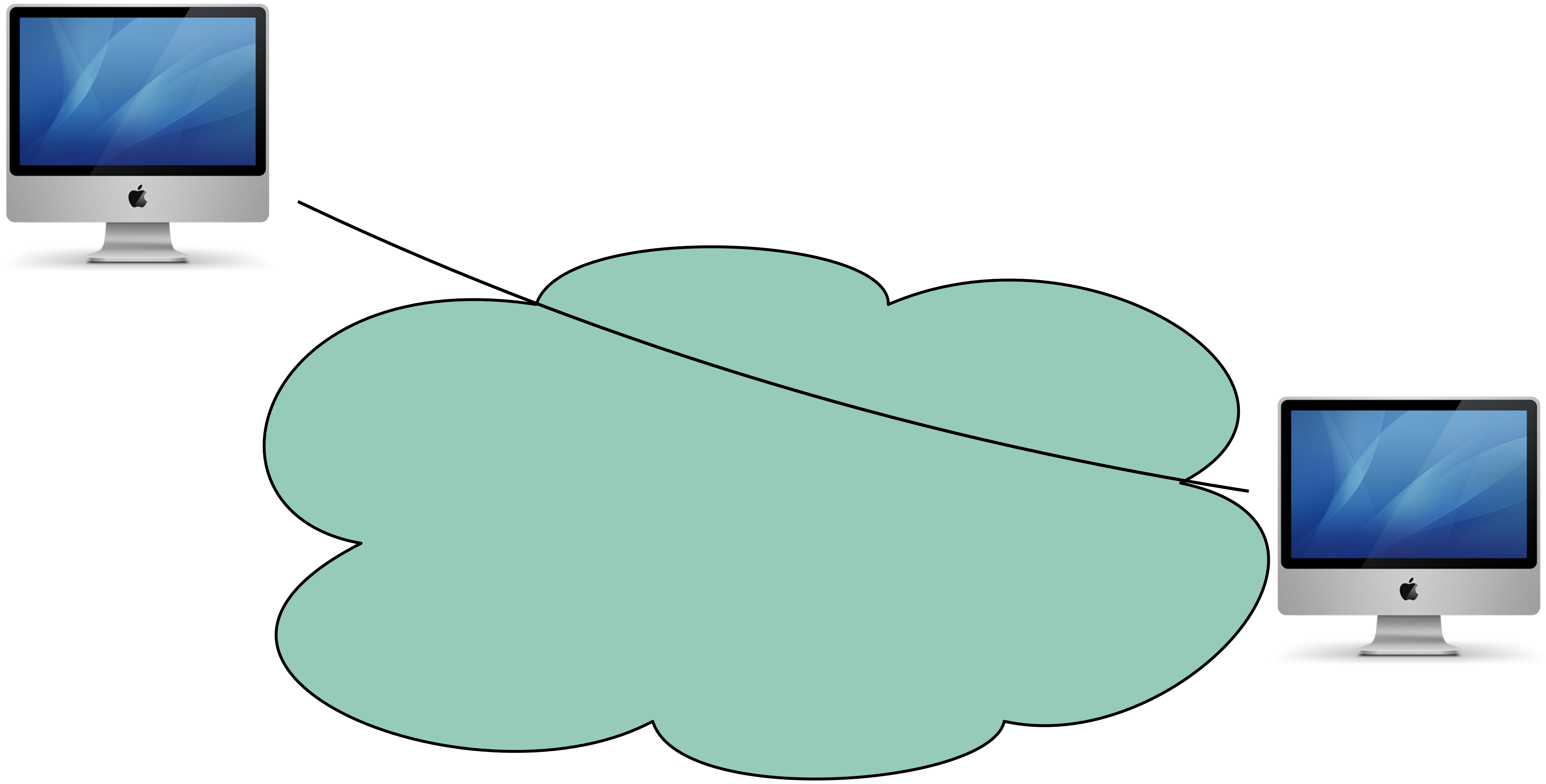
Model:
Servers and Clients talking through cloud

Distributed Systems



Model:
Many clients talking through cloud

Distributed Systems



Model:
Two clients talking through cloud

Why expand to distributed systems?

- Scalability
- Performance
- Latency
- Availability
- Fault Tolerance

Distributed Systems Goals

- **Scalability**
- Performance
- Latency
- Availability
- Fault Tolerance

“the ability of a system, network, or process, to handle a growing amount of work in a capable manner or its ability to be enlarged to accommodate that growth.”

Distributed Systems Goals

- Scalability
- **Performance**
- Latency
- Availability
- Fault Tolerance

"is characterized by the amount of useful work accomplished by a computer system compared to the time and resources used."

Distributed Systems Goals

- Scalability
- Performance
- **Latency**
- Availability
- Fault Tolerance

"The state of being latent; delay, a period between the initiation of something and the it becoming visible."

Distributed Systems Goals

- Scalability
- Performance
- Latency
- **Availability**
- Fault Tolerance

"the proportion of time a system is in a functioning condition. If a user cannot access the system, it is said to be unavailable."

Availability = uptime / (uptime + downtime).

Often measured in "nines"

Availability %	Downtime/year
90%	>1 month
99%	< 4 days
99.9%	< 9 hours
99.99%	<1 hour
99.999%	5 minutes
99.9999%	31 seconds

Distributed Systems Goals

- Scalability
- Performance
- Latency
- Availability
- **Fault Tolerance**

"ability of a system to behave in a well-defined manner once faults occur"

What kind of faults?

Disks fail

Networking fails

Power supplies fail

Security breached

Datacenter goes offline

Power goes out

More machines, more problems

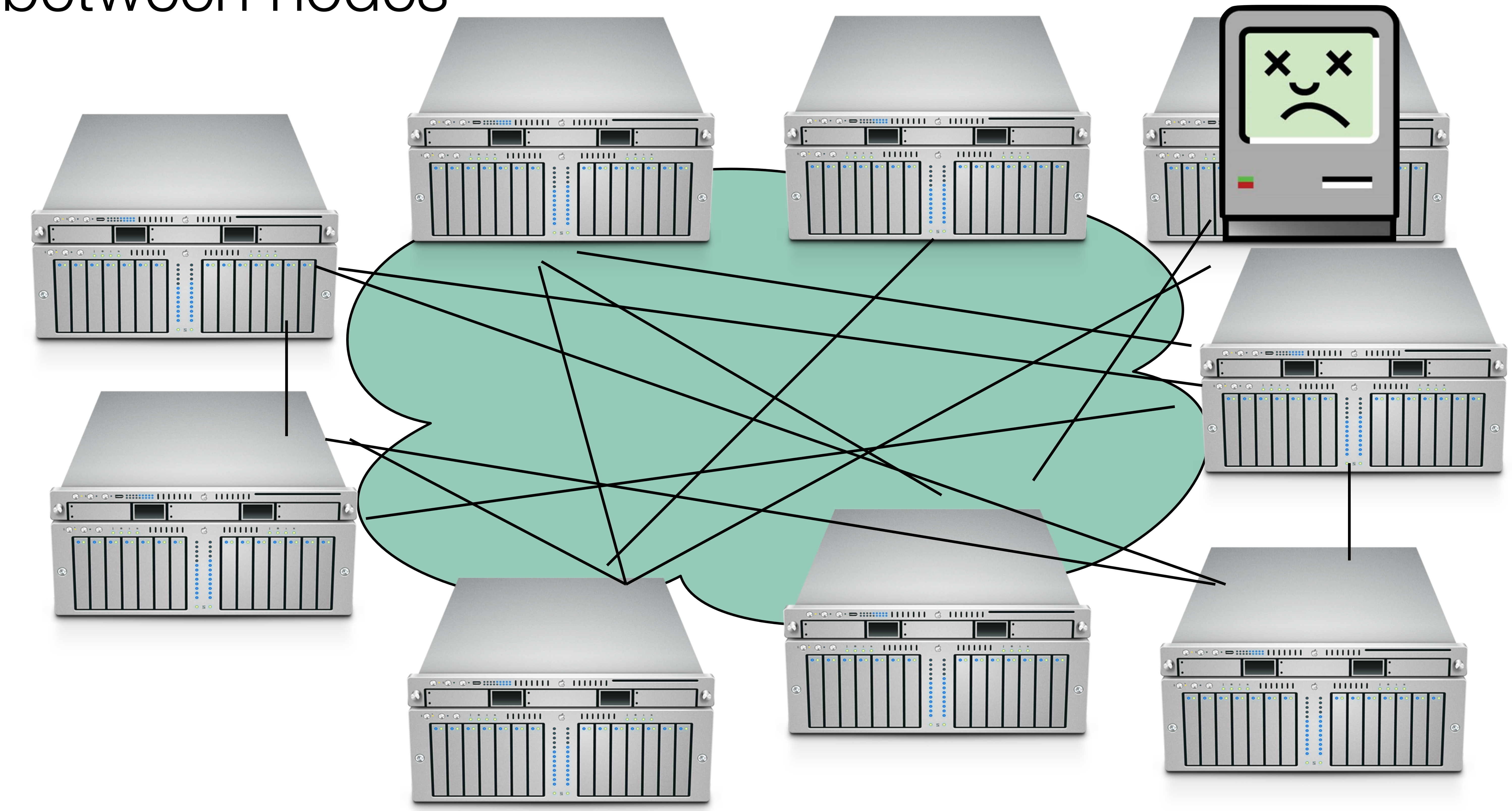
- Say there's a 1% chance of having some hardware failure occur to a machine (power supply burns out, hard disk crashes, etc)
- Now I have 10 machines
  - Probability(at least one fails) = 1 - Probability(no machine fails) = $1-(1-.01)^{10}$ = 10%
- 100 machines -> 63%
- 200 machines -> 87%
- So obviously just adding more machines doesn't solve fault tolerance

More machines, more problems

- PLUS, the network may be:
  - Unreliable
  - Insecure
  - Slow
  - Expensive
  - Limited

Constraints

- Number of nodes
- Distance between nodes



Networks as Abstractions

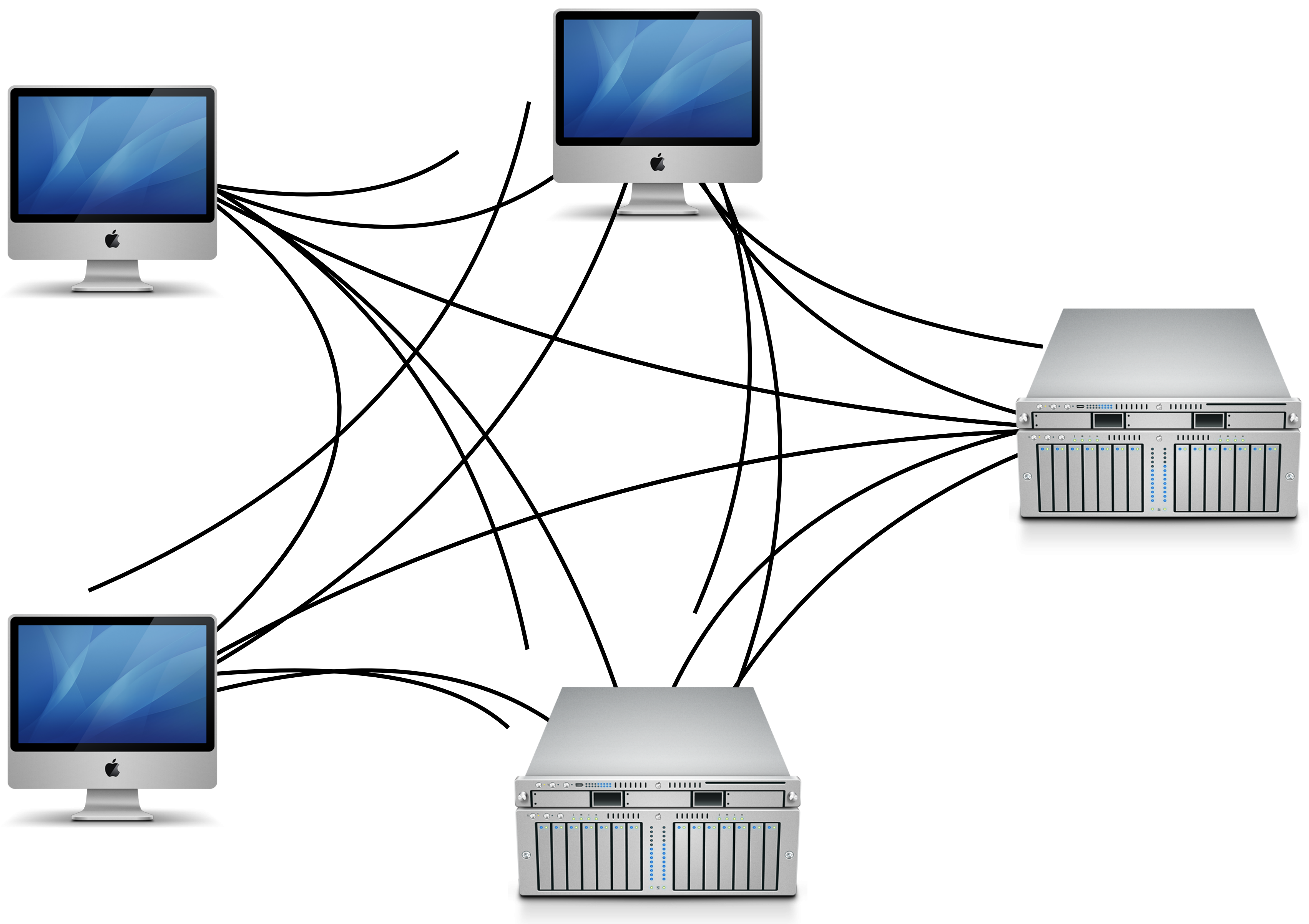
- A network consists of communication links
- Networks have several “interesting” properties we will look at
  - Latency
  - Failure modes
- What is the abstraction?

Networks as Abstractions

- Stuff goes in, stuff goes out?
- Not a perfect abstraction, because:
  - Speed of light (1 foot/nanosecond)
  - Communication links exist in uncontrolled/hostile environments
  - Communication links may be bandwidth limited (tough to reach even 100MB/sec)
- In contrast to a single computer, where:
  - Distances are measured in mm, not feet
  - Physical concerns can be addressed all at once
  - Bandwidth is plentiful (easily GB/sec)

Networks are Shared

- With processes, we considered how one CPU could be shared between multiple programs running at once
- With networks, communication links are probably shared even more widely



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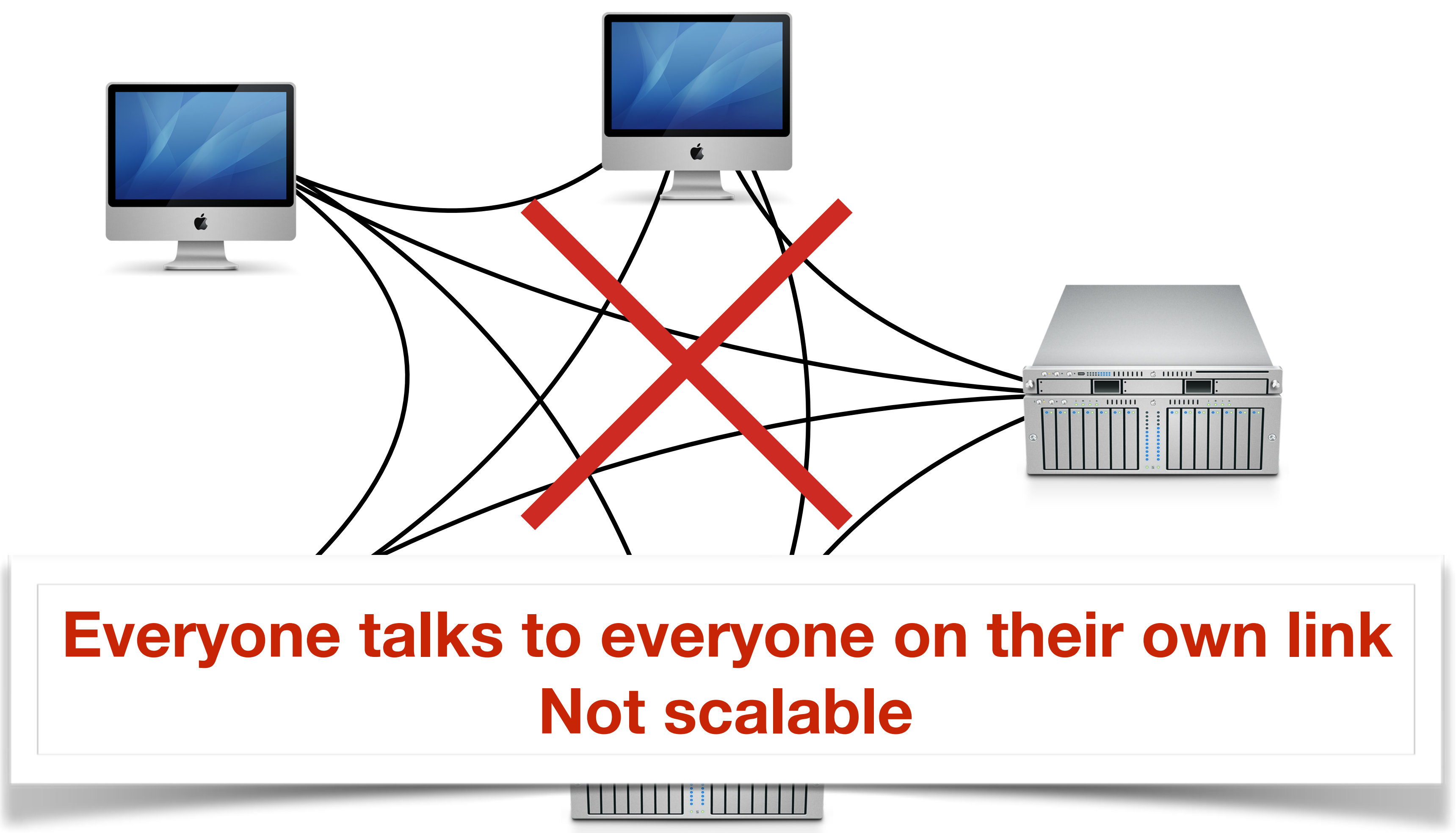
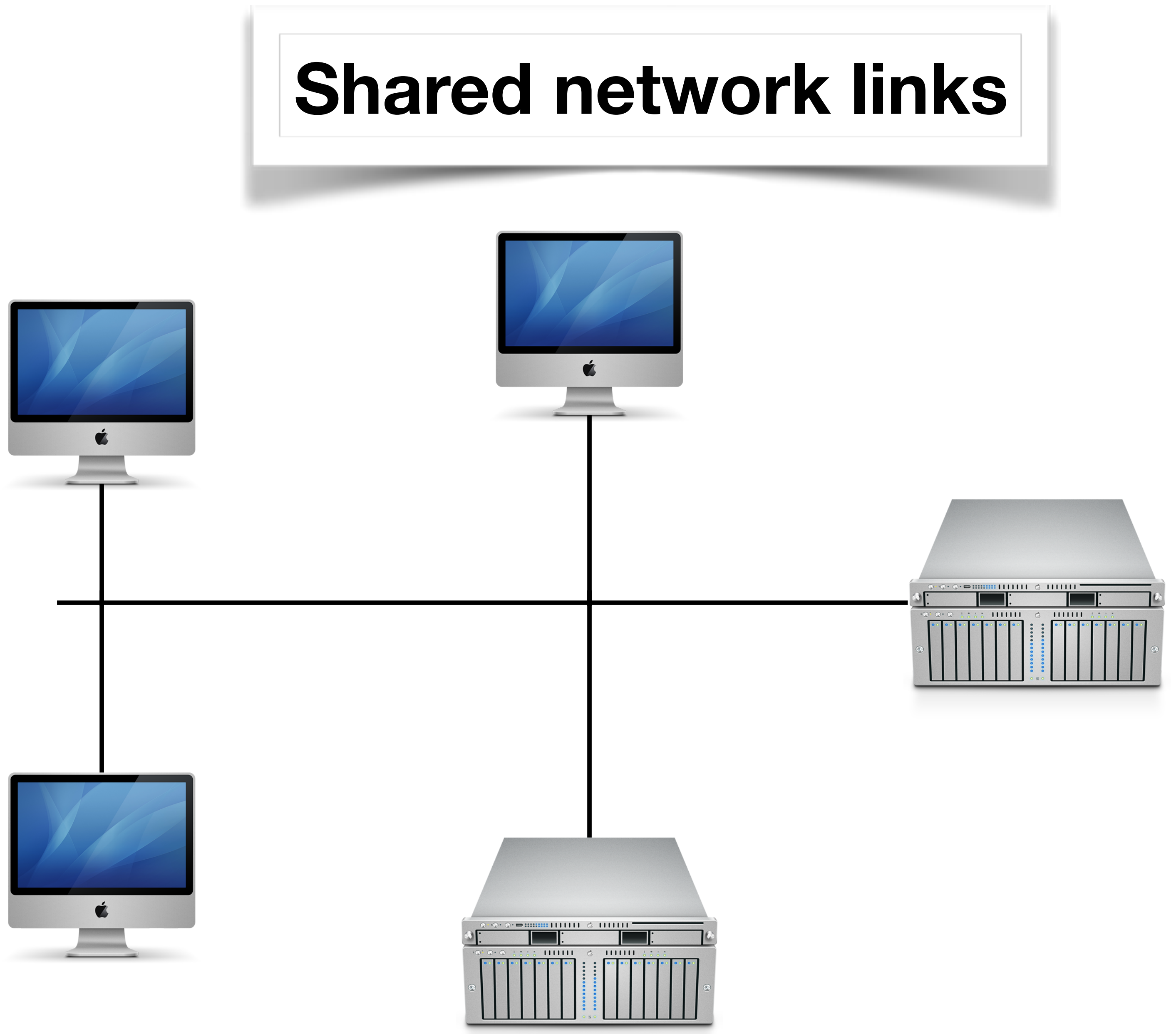
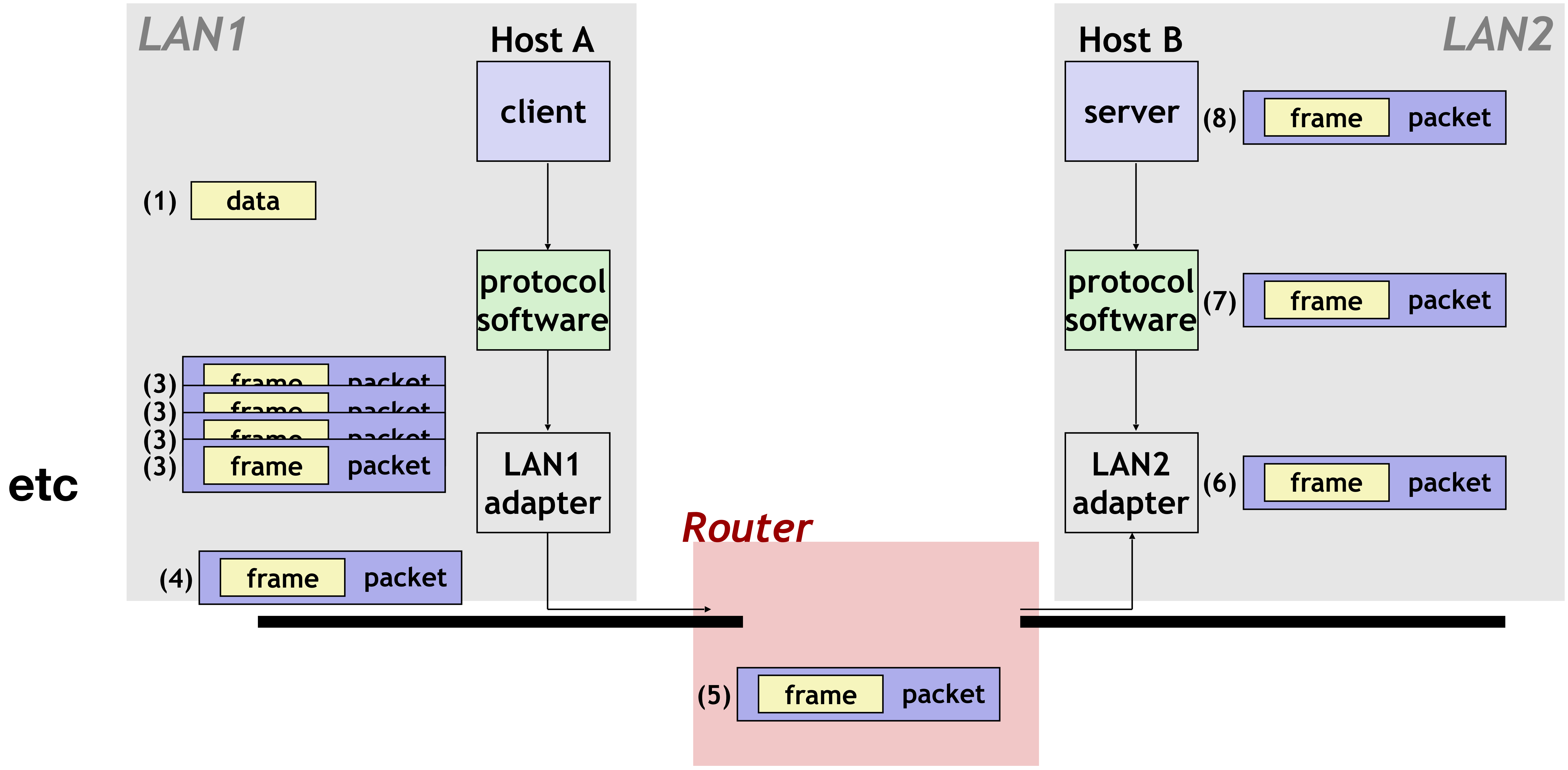




Network as Abstractions

- What do we send, what gets received?
- At the lowest level, we call what gets sent **frames**
- Each frame is limited in size
  - Ethernet: max 1522 **bytes**
- Frame is packed with source/destination info into a **packet**
- Network knows what to do with packets to get them to their destination

Networks as Abstractions



PH: Internet packet header
FH: LAN frame header

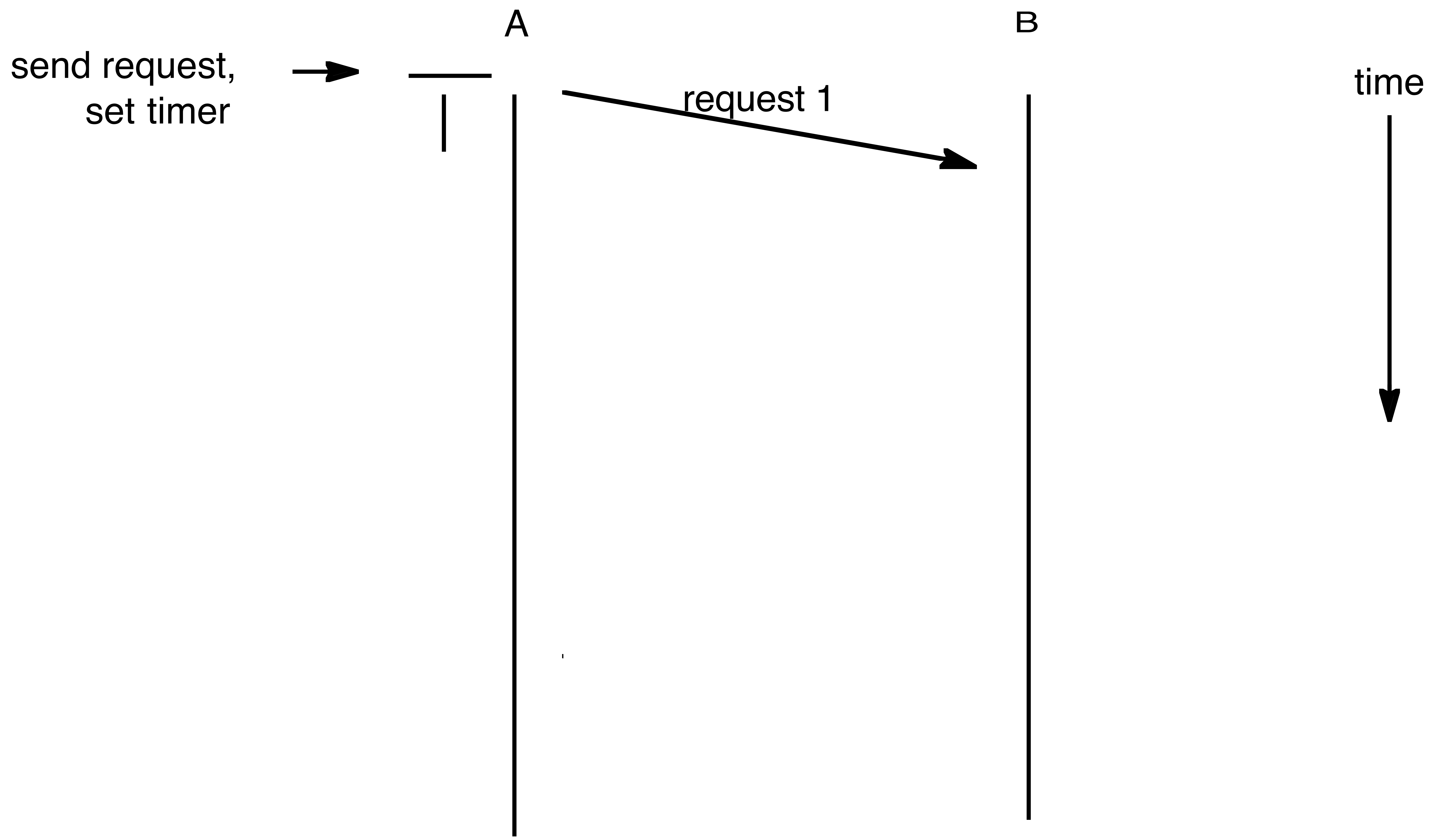
Packet Switching Delays

- As these packets flow through a network and are routed, we might see delays due to:
  - Propagation (traveling across the link, speed of light, etc)
  - Transmission delay (big packets take longer to transmit)
  - Processing delay (once switch sees packet, might be slow to process)
  - Queuing delay (link might be busy)

Packet Loss

- Some packets could be delayed, others might never reach their target, due to:
  - Buffers overflowing (e.g. on switch)
- Networks are usually considered **best-effort**
  - Aka third-class mail
  - We'll try to get your packet there, but if it doesn't, sorry.
- Solved by requiring recipient to send a confirmation message was received
  - If no confirmation received, assume didn't get sent
- What happens to duplicates?
  - Each message includes a unique ID, can be discarded if duplicate received

Resending Packets



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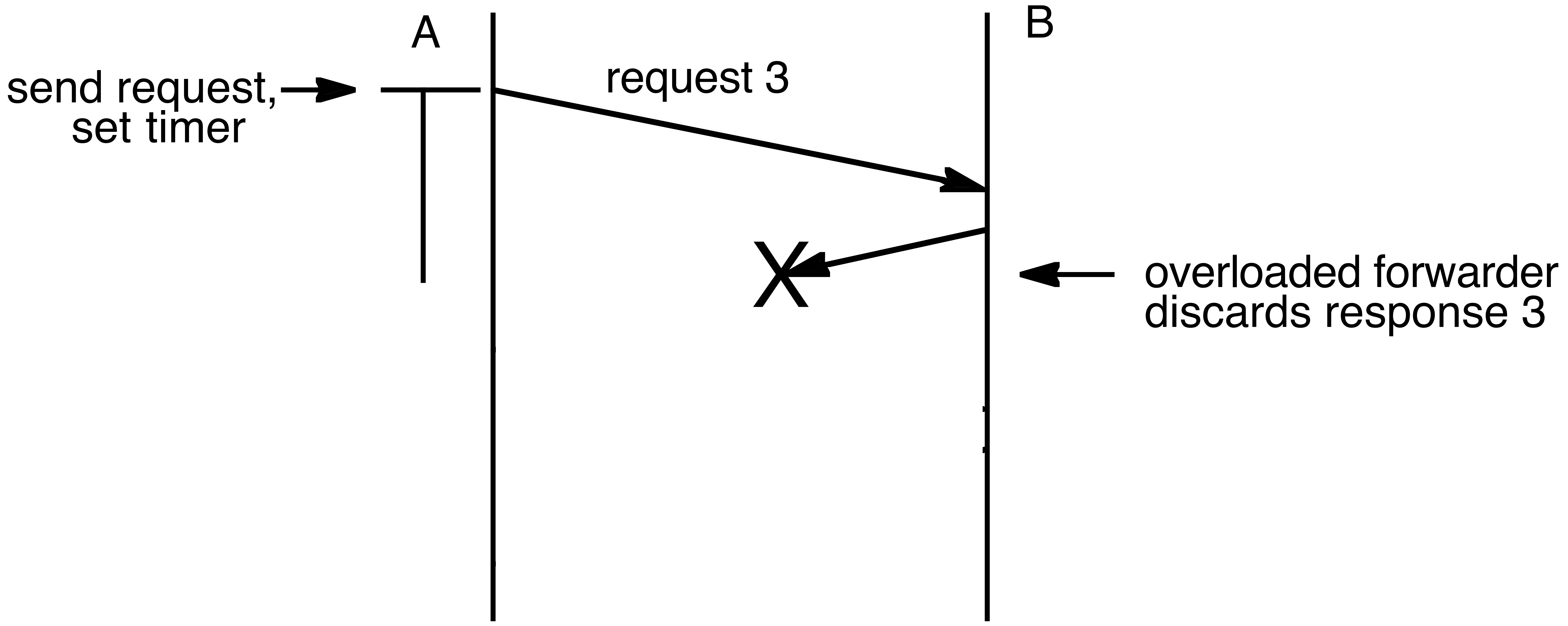
Resending Packets



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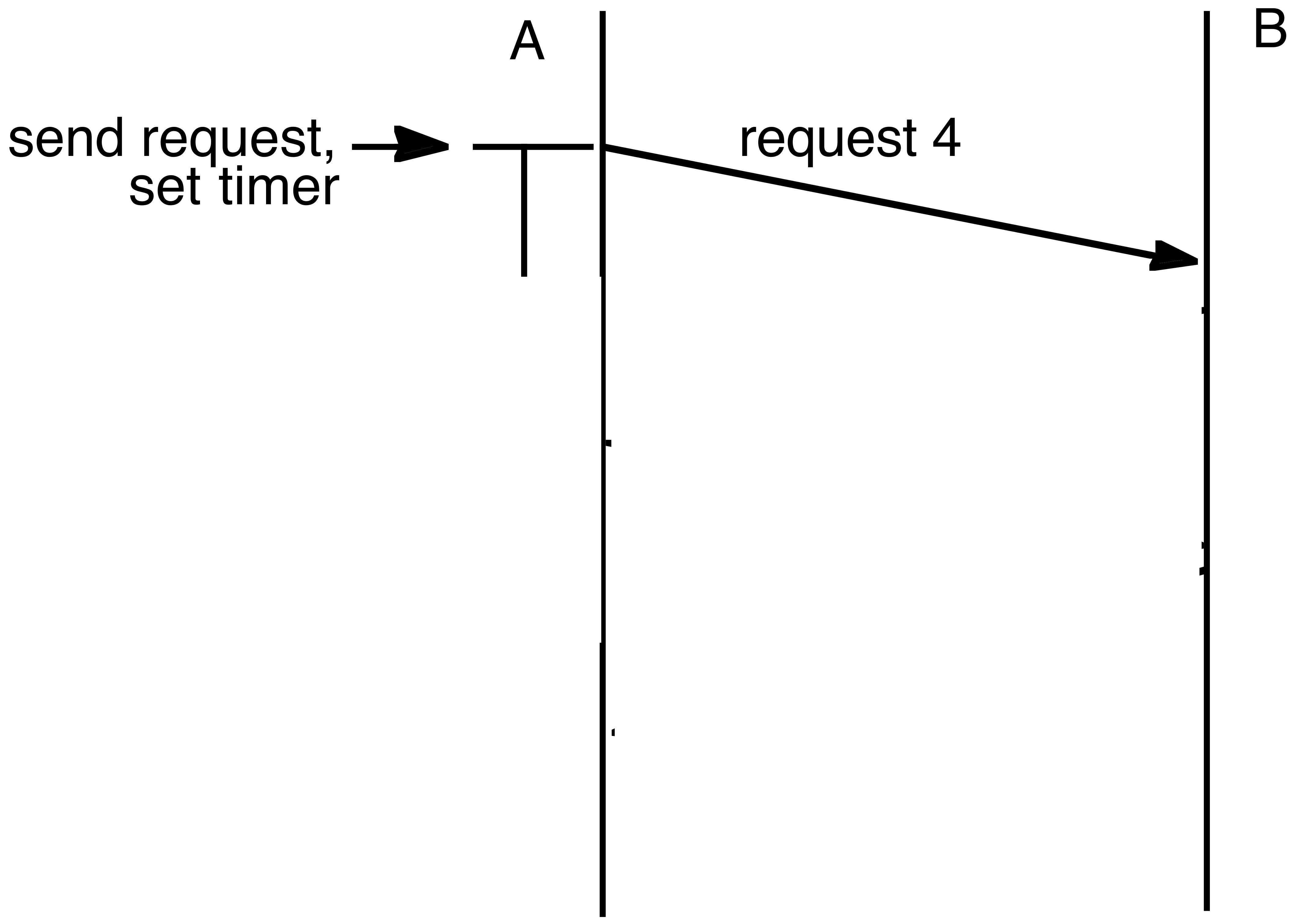
Resending Packets



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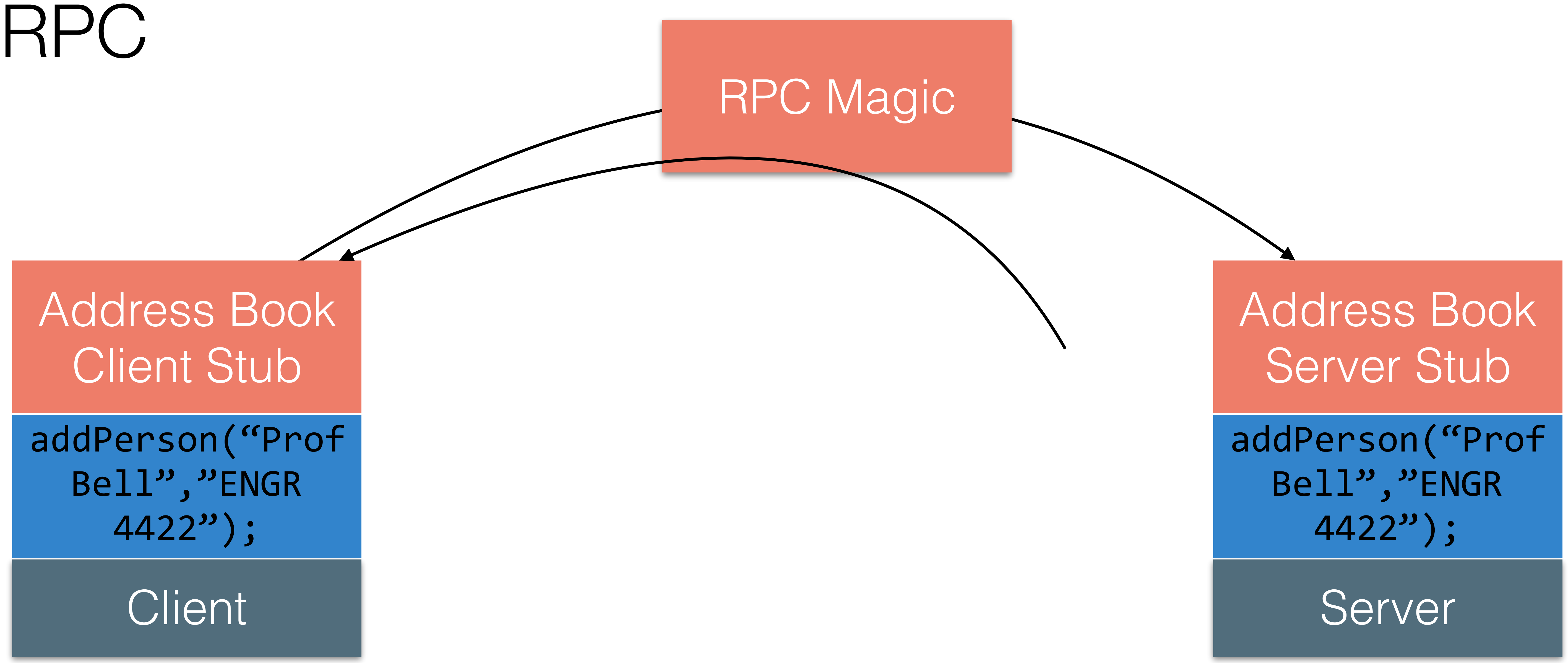
Resending Packets

- That ID is **really** important to put on the packets!
- Note: it works, but can result in **lots** of duplicate packets sent back and forth
- Also, note: no guarantee that packets are delivered in order!

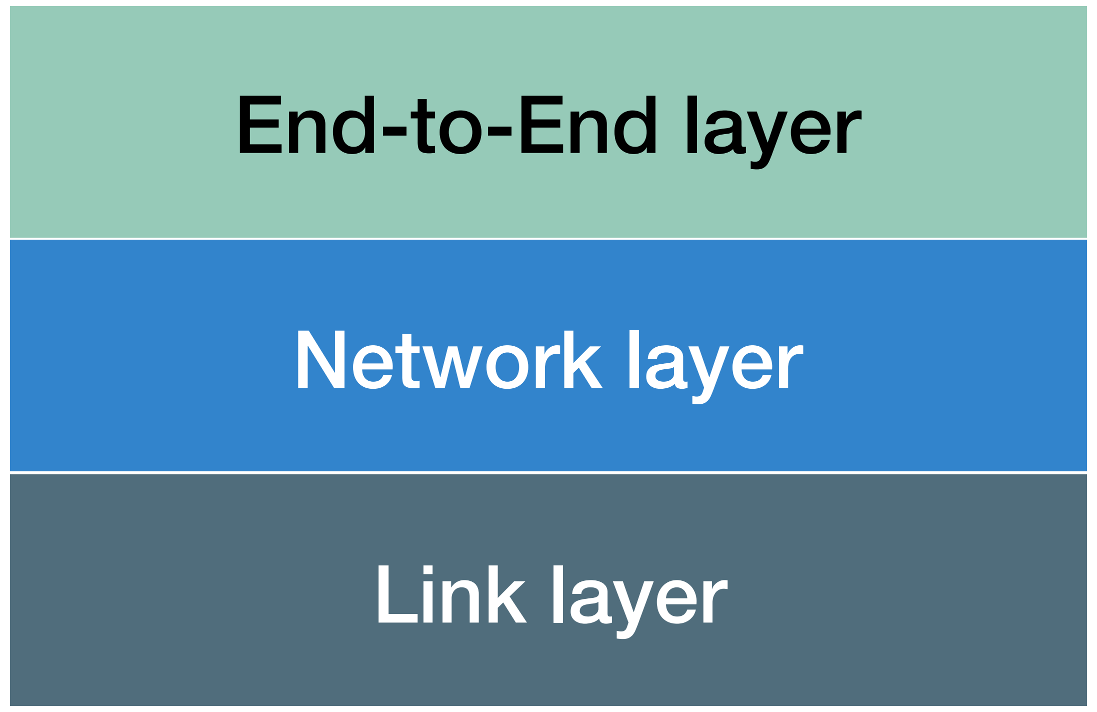
Networks as Abstractions

- Obviously, we don't think or care about packets
- We think and care about sending data!
- We want abstractions, like RPC (Remote Procedure Calls)
- Abstractions (try to) hide the complexity of what's below them
- Next class: all RPC



3 Layer Abstraction

- The typical network abstraction model has 7 layers
  - Take CS 455 if you want to know more about these
- We'll think about 3 abstraction layers, and really focus on the top one



Handles packet loss, etc. Translates from application-data to packets, implements a protocol

Figures out where to send packets

Physical links: care about how to deliver packets

Transport Protocols

- Anything in the end-to-end layer is likely built on top of some lower level protocol (**more** abstractions)
- TCP, or UDP
- Data integrity (checksumming) — **UDP** ✅ **TCP** ✅
- Ordering control — **UDP** ❎ **TCP** ✅
- Flow control
  (not worrying about congestion) — **UDP** ❎ **TCP** ✅

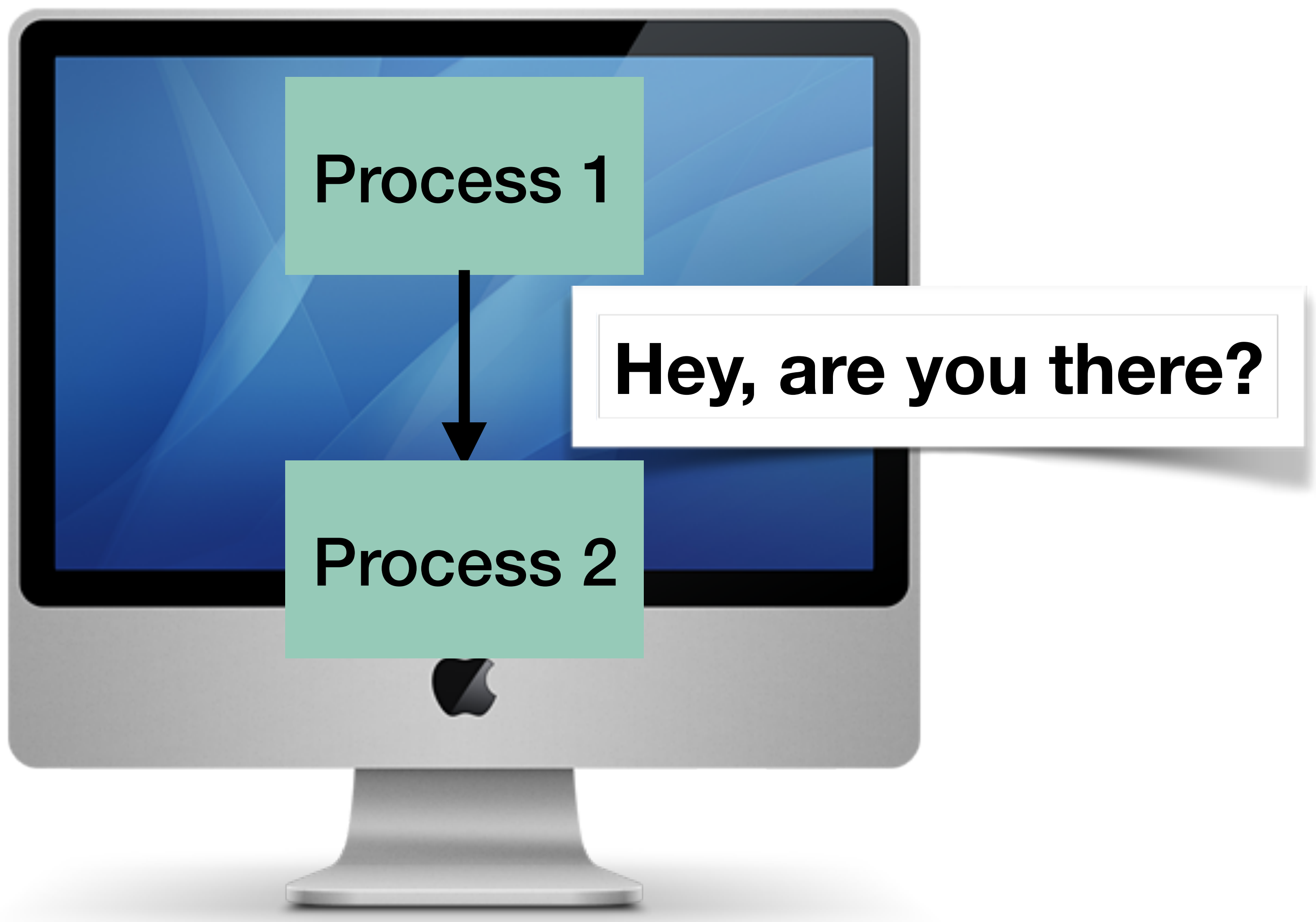
Reminder: Leaky Abstractions

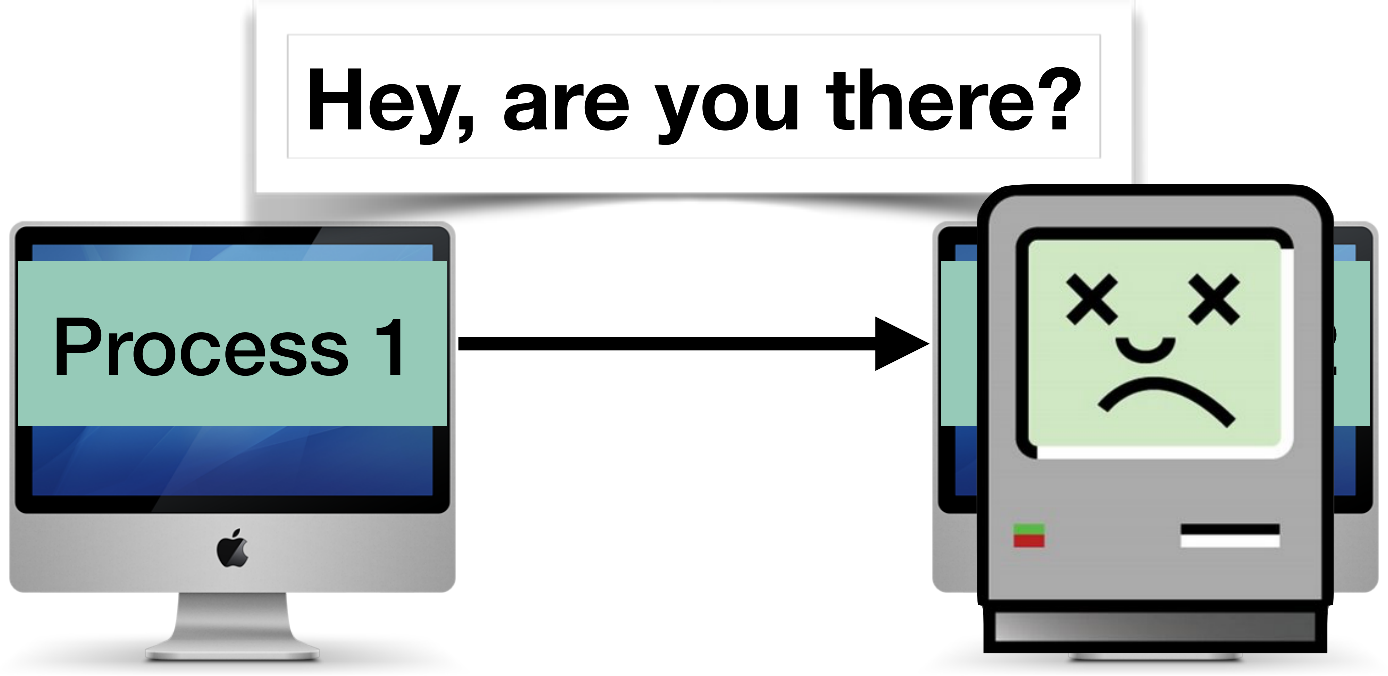
- From this lecture, you should have found out that networks:
  - Can vary in
    - Data rates
    - Propagation, transmission, queuing and processing delays
  - Traverse hostile environments and may corrupt data or stop working
  - Even best-effort networks have:
    - Variable delays, transmission rates, can discard packets, duplicate packets, have a maximum packet length, can reorder packets
- Even if using TCP, this can still show up!
  - Messages might still arrive late

Sockets as an Abstraction

- Simplest way to build our end-to-end layer is using a **socket**, which gives us an interface to TCP or UDP
- Socket looks **just** like reading/writing to a file (e.g. file descriptor in C, InputStream in Java)
- Sockets are identified by:
  - IP address - identifies the device on the network
  - Port number - identifies the application on the device

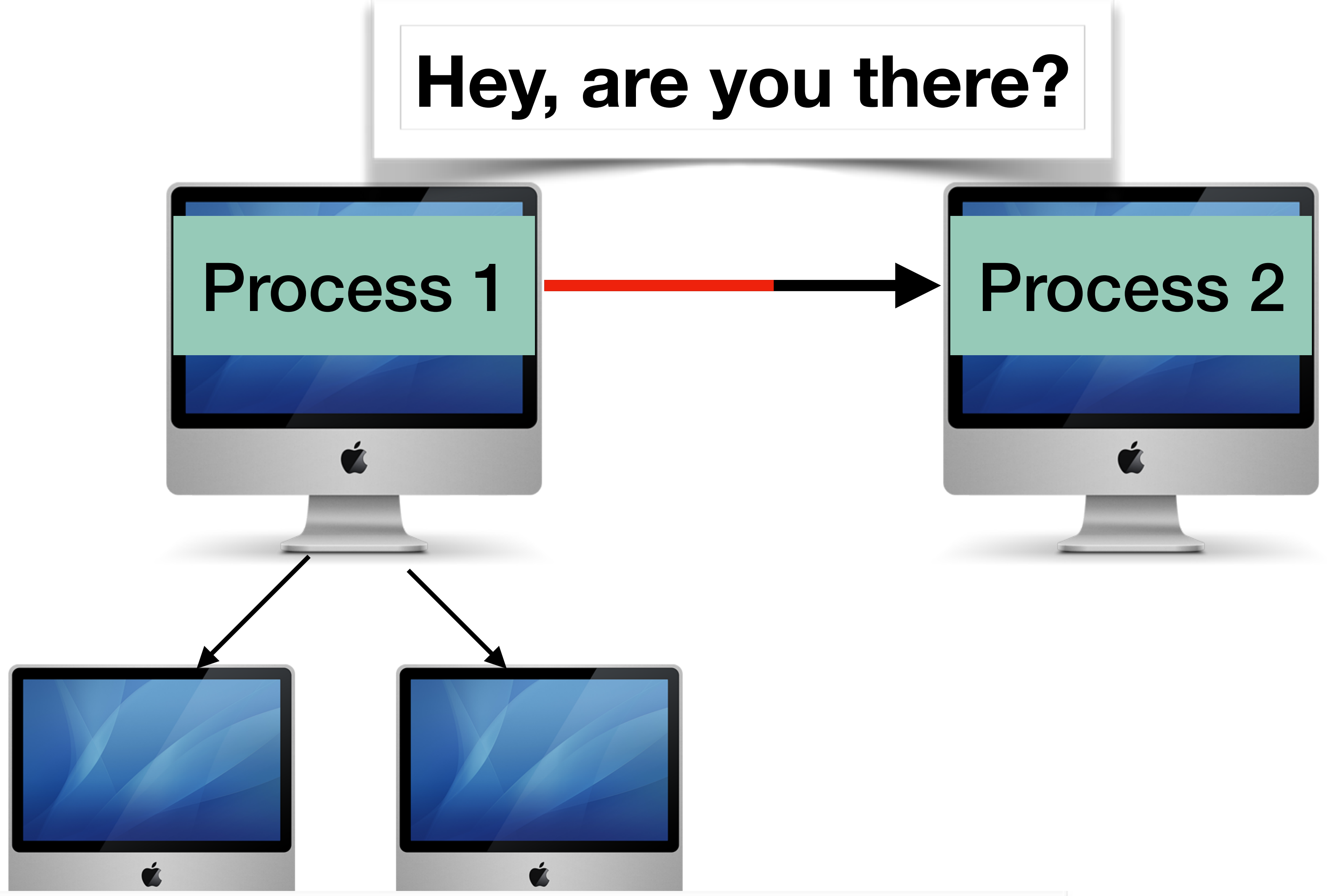
Preview for Next Class





Computer 2 fails

Spoiler alert: You can not tell the difference in a distributed system between a computer failing and network being arbitrarily slow!



…well, I can still talk to these guys so I guess internet is ok