Introduction to Concurrency

CS 475, Spring 2018
Concurrent & Distributed Systems

GEORGE MASON UNIVERSITY

Today

- Distributed & Concurrent Systems: high level overview and key concepts
- Relevant links:
  - Syllabus: http://www.jonbell.net/gmu-cs-475-spring-2018/

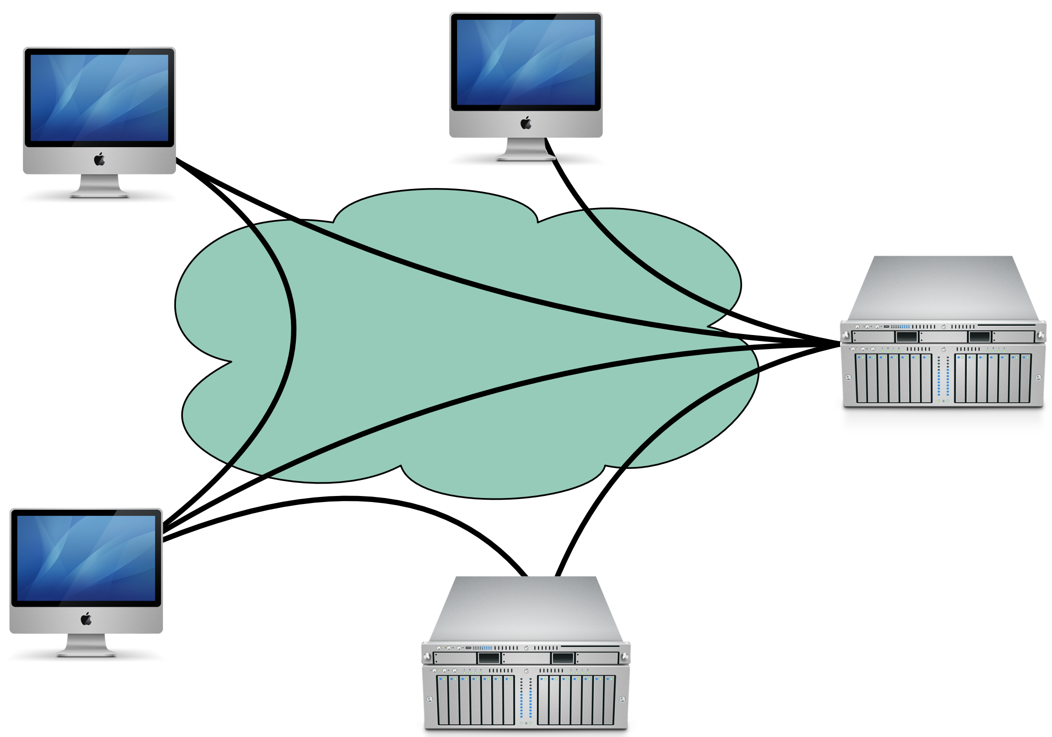
Course Topics

- This course will teach you **how** and **why** to build distributed systems
- Distributed System is “a collection of independent computers that appears to its users as a single coherent system”
- This course will give you theoretical knowledge of the tradeoffs that you’ll face when building distributed systems

Course Topics

How do I run multiple things at once on my computer?

Concurrency, first half of course



How do I run a big task across many computers?

Distributed Systems, second half of course

Layers

- From hardware
- To OS
- To programming languages
- To networks
- To libraries and middleware
- To developers

Grading

- 50% Homework
  - 5 assignments, ~2 weeks to do each, all done individually
  - Your code will be autograded; you can resubmit an unlimited number of times until the deadline and view your score
  - Also graded by hand for some non-functional issues
- 10% Quizes
  - Pass/fail (Pass if you are in class and submit a quiz, fail if you don't)
  - Use laptop or phone to complete the quiz in class
- 15% Midterm Exam, 20% Final Exam

Policies

- My promises to you:
- Quiz results will be available instananeously in class; we will discuss quiz in real time
- Homework will be graded within 3 days of submission
- Exams will be graded within a week

Policies

- Lateness on homework:
  - 10% penalty if submitted UP TO 24 hours after deadline
  - No assignments will be accepted more than 24 hours late
  - Out of fairness: **no exceptions**
- Attendance & Quizzes:
  - You can miss up to 3 with no penalty
  - Again, out of fairness: **no exceptions** beyond this

Honor Code

- Refresh yourself of the department honor code
- Homeworks are 100% individual
  - Discussing assignments at high level: ok, sharing code: not ok
  - If in doubt, ask the instructor
  - If you copy code, we WILL notice (see some of my recent research results in “code relatives”)
- Quizes must be completed by you, and while in class

Course Staff

- Prof Jonathan Bell (me)
  - Office hour: ENGR 4422 Mon & Weds 2:15-3:00 pm or by appointment
  - Areas of research: Software Engineering, Program Analysis, Software Systems

Two hobbies: cycling, ice cream

Course Staff

- GTA: Arda Gumusalan
    - Office Hours: TBA
- UTA: Thanh Luu
    - Office Hours: TBA
- Please, **no emails** to instructor or TAs about the class: use Piazza

Readings

- Bad news: no single book
- Good news: several free e-books are great references
  - Operating Systems: Three Easy Pieces (Arpaci-Dusseau and Arpaci-Dusseau) http://pages.cs.wisc.edu/~remzi/OSTEP/
  - Distributed Systems 3rd Edition (van Steen and Tanenbaum) https://www.distributed-systems.net/index.php/books/distributed-systems-3rd-edition-2017/
  - Principles of Computer Systems Design Part II (Saltzer and Kaashoek) https://ocw.mit.edu/resources/res-6-004-principles-of-computer-system-design-an-introduction-spring-2009/online-textbook/

Concurrency

- Goal: do multiple things, at once, coordinated, on one computer
  - Update UI
  - Fetch data
  - Respond to network requests
  - Improve responsiveness, scalability
- Recurring problems:
  - Coordination: what is shared, when, and how?

Abstractions

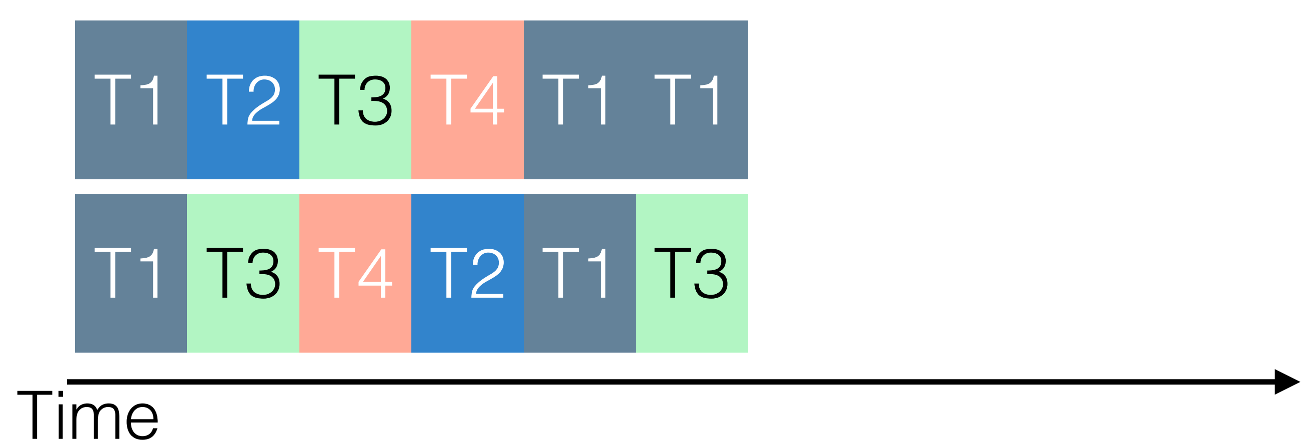
- Goal: take something complicated, make it “easy”
- Operating Systems
  - From CPUs and memory to processes and threads
- Distributed Systems
  - From collections of computers to coherent applications

Concurrency & Parallelism

4 different things: 

Concurrency:
(1 processor)

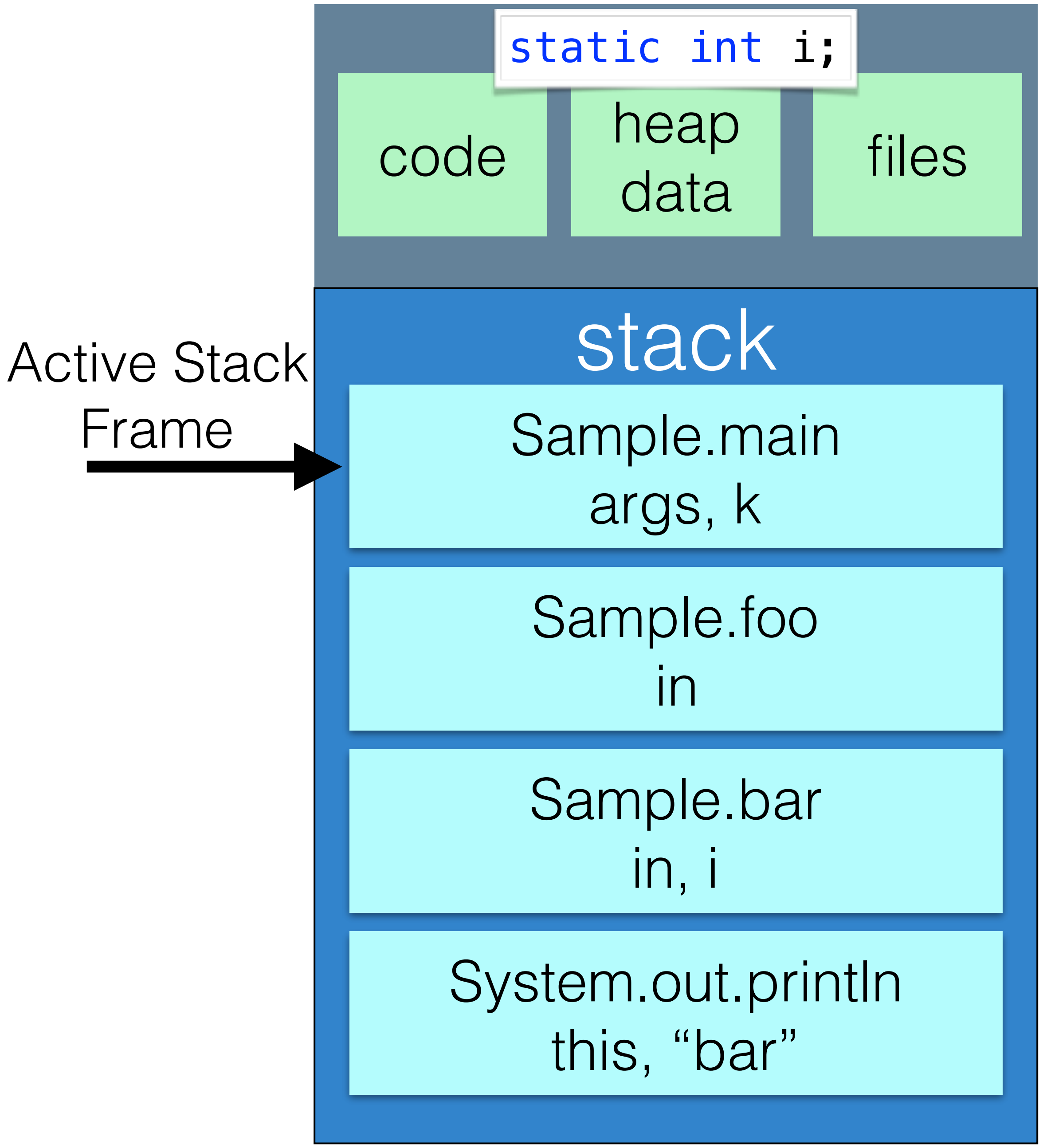
Parallelism:
(2 processors)



Processes

- Def: A process is an instance of a running program
- Process provides each program with two key abstractions
  - Logical control flow
    - Each program seems to have exclusive use of the CPU.
  - Private address space
    - Each program seems to have exclusive use of main memory.
- How are these illusions maintained?
  - Process executions interleaved (multitasking)
  - Address spaces managed by virtual memory system

Processes




```
public class Sample
{
    static int i;
    public static void main(String[] args)
    {
        int k = 10;
        foo(k);
    }
    public static void foo(int in)
    {
        bar(in);
    }
    public static void bar(int in)
    {
        i = in;
        System.out.println("bar");
    }
}
```

Threads

- Traditional processes created and managed by the OS kernel
- Process creation expensive - fork system call in UNIX
- Context switching expensive
- Cooperating processes - no need for memory protection (separate address spaces)

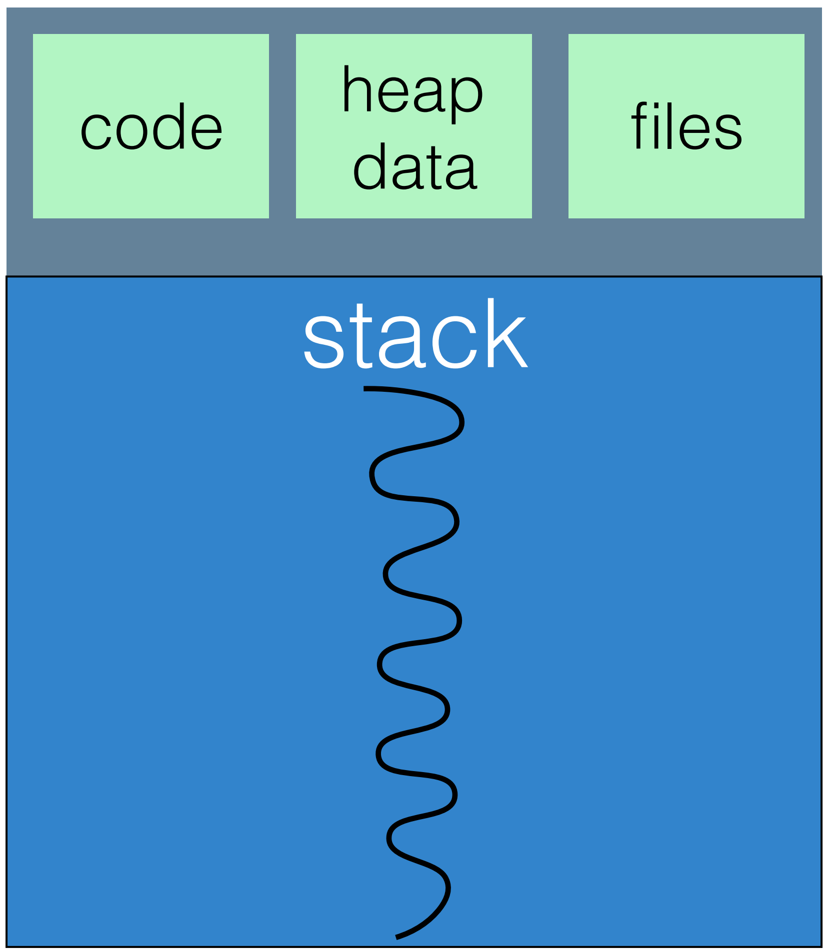
Coordination Problems

- Two threads call `increment()` at the same time
- What is the value of `i` afterwards?

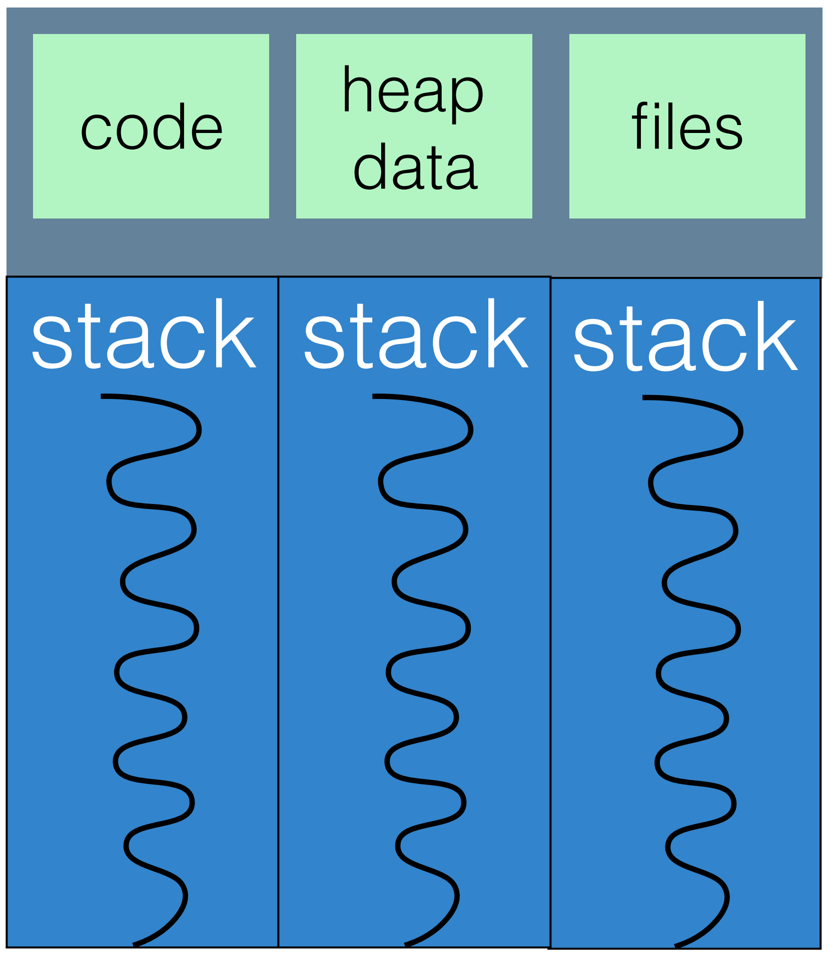
```
static int i = 0;
public static void increment()
{
    i = i + 1;
}
```

Spoiler alert: not guaranteed to be 2

Processes vs Threads



Single-Threaded Process



Multi-Threaded Process

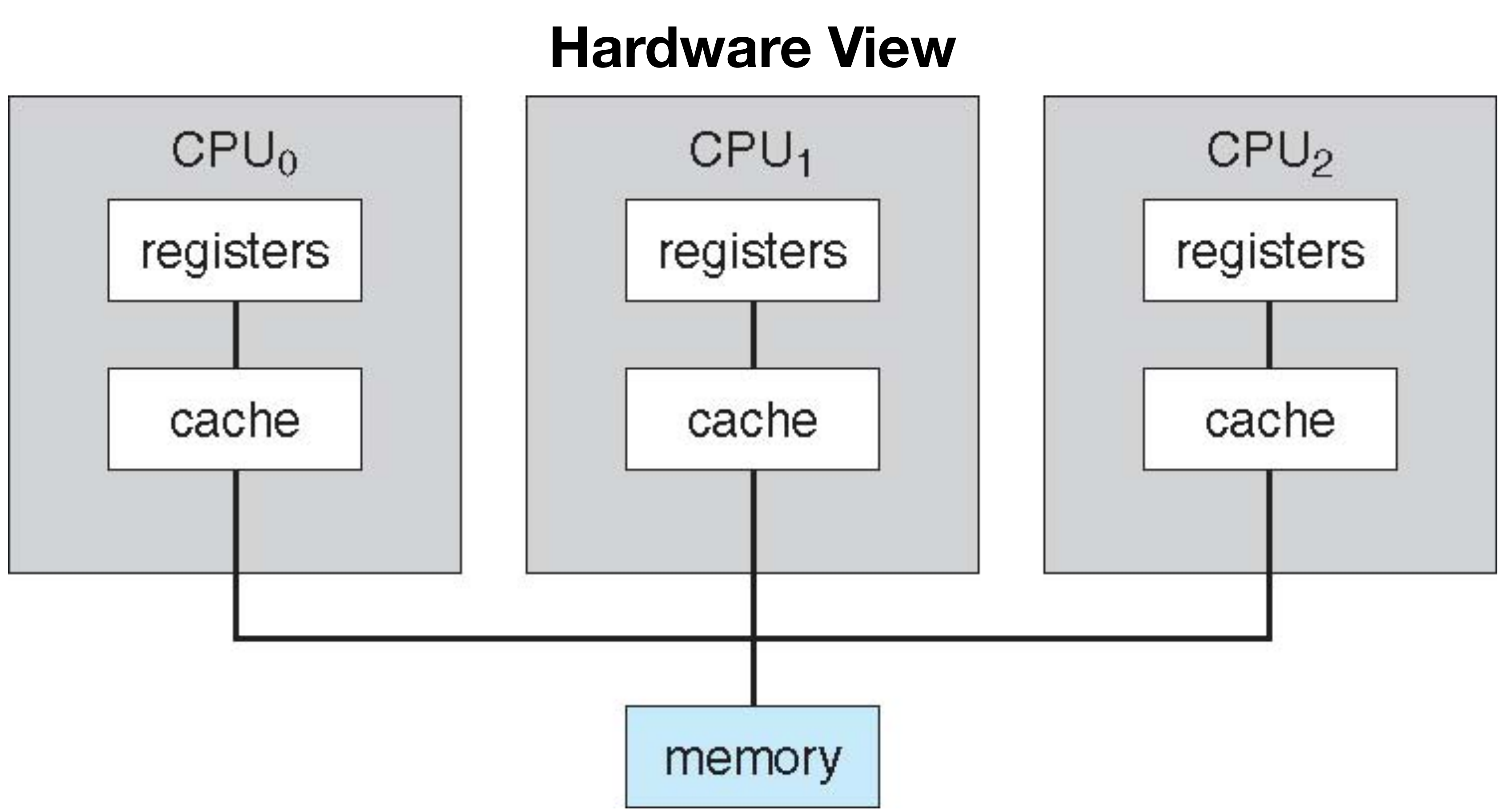
“All non-trivial abstractions, to some degree, are leaky.”

Joel Spolsky

https://www.joelonsoftware.com/2002/11/11/the-law-of-leaky-abstractions/

Leaky Abstractions

- Completely hiding the underlying complexity is never possible, usually not desirable
- Example: our first two abstractions (concurrency) - process and thread

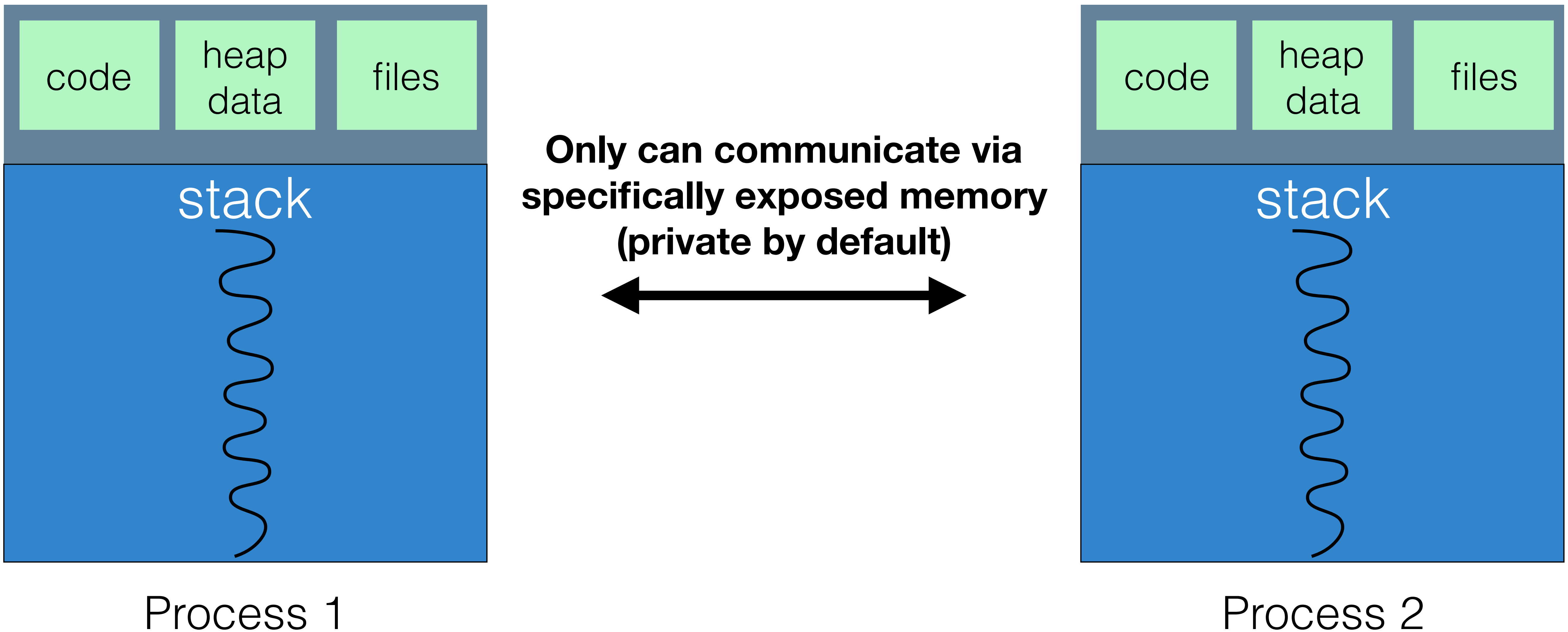


Processes vs Threads

- Context Switching
  - Processor context: The minimal collection of values stored in the registers of a processor used for the execution of a series of instructions (e.g., stack pointer, addressing registers, program counter).
  - When switching processes, **all** of that data needs to get flushed out (by the OS)
- Threads share the same address space: no need to do this switch

Processes vs Threads

- Although more expensive to switch, OS provides isolation between processes

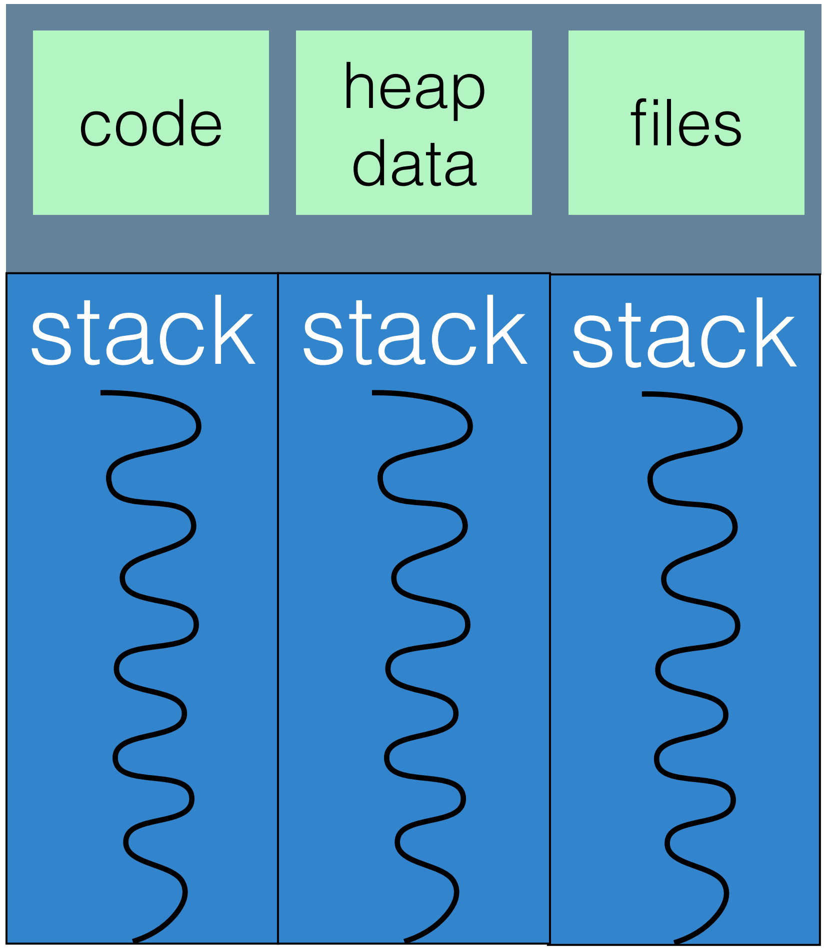


Only can communicate via specifically exposed memory (private by default)

Processes vs Threads

- Although more expensive to switch, processes OS provides isolation between processes

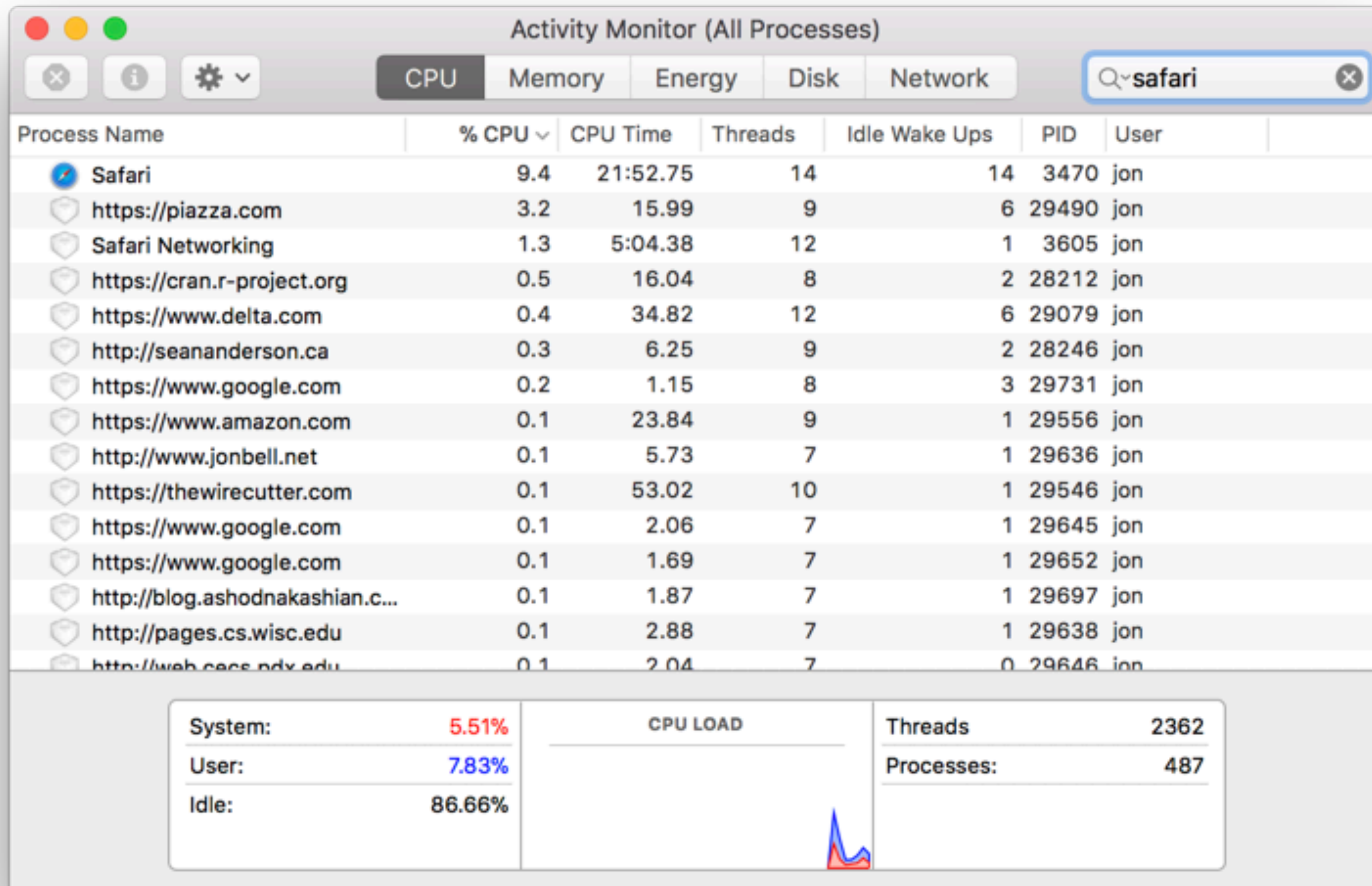
All heap data is shared between threads



Multi-Threaded Process

Processes vs Threads

- Example: browsers launching tabs in their own process

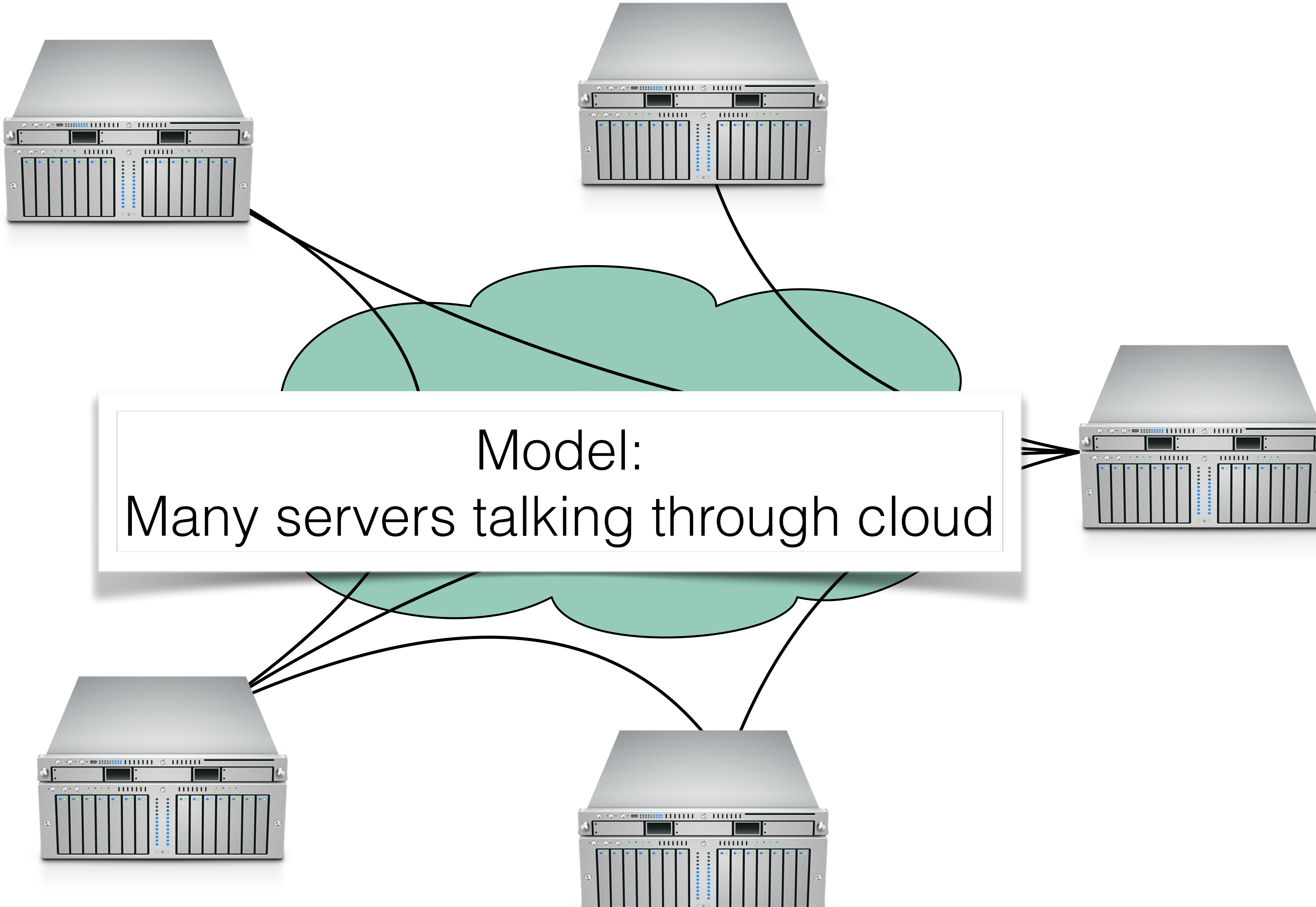


Process Name	% CPU	CPU Time	Threads	Idle Wake Ups	PID	User
Safari	9.4	21:52.75	14	14	3470	jon
https://piazza.com	3.2	15.99	9	6	29490	jon
Safari Networking	1.3	5:04.38	12	1	3605	jon
https://cran.r-project.org	0.5	16.04	8	2	28212	jon
https://www.delta.com	0.4	34.82	12	6	29079	jon
http://seananderson.ca	0.3	6.25	9	2	28246	jon
https://www.google.com	0.2	1.15	8	3	29731	jon
https://www.amazon.com	0.1	23.84	9	1	29556	jon
http://www.jonbell.net	0.1	5.73	7	1	29636	jon
https://thewirecutter.com	0.1	53.02	10	1	29546	jon
https://www.google.com	0.1	2.06	7	1	29645	jon
https://www.google.com	0.1	1.69	7	1	29652	jon
http://blog.ashodnakashian.c...	0.1	1.87	7	1	29697	jon
http://pages.cs.wisc.edu	0.1	2.88	7	1	29638	jon
http://web.cecs.pdx.edu	0.1	2.04	7	0	29646	jon

More Abstractions

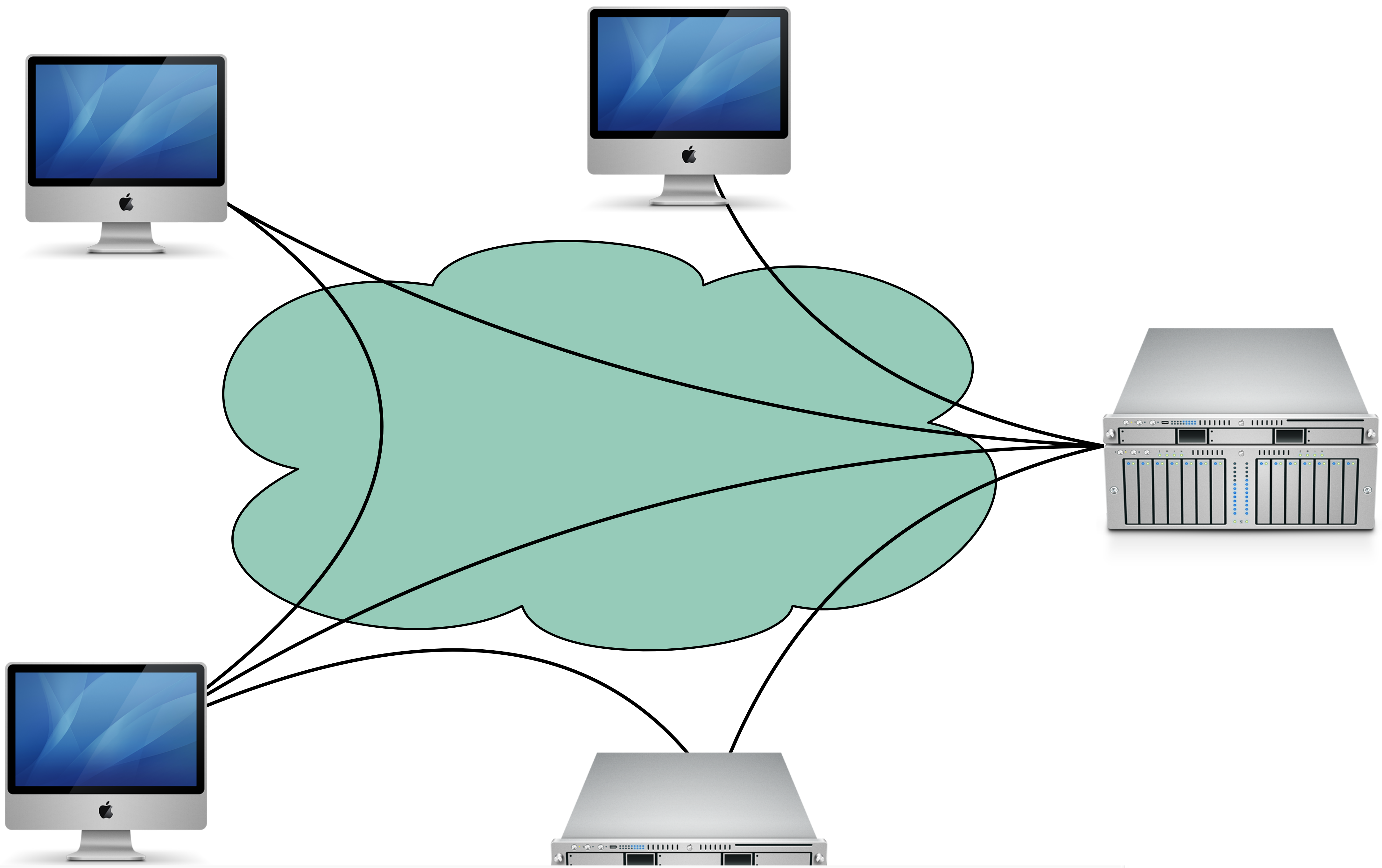
- Process + Thread -> one computer
- How can we abstract many computers working together?
- What does that even look like?

Distributed Systems



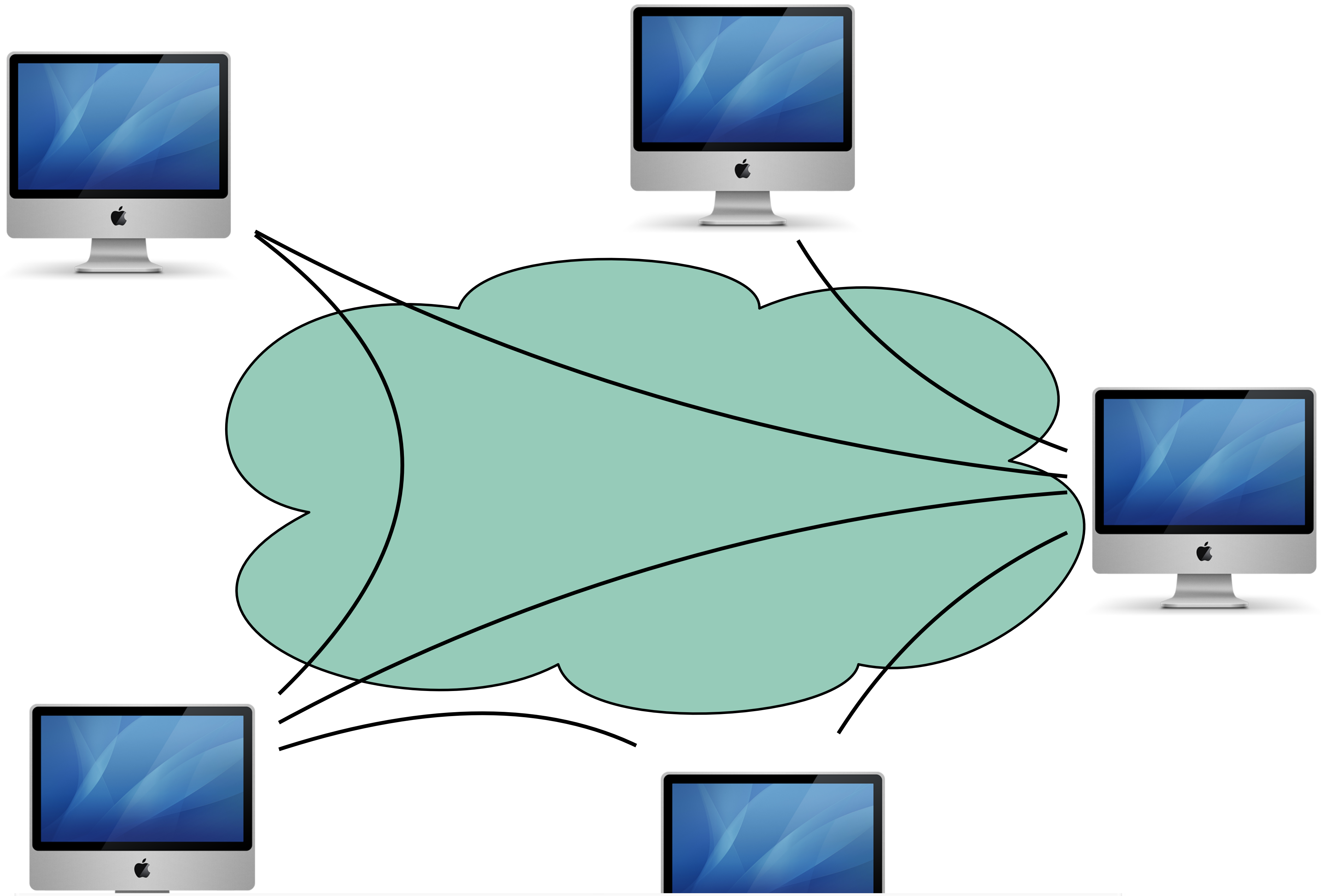
Model:
Many servers talking through cloud

Distributed Systems



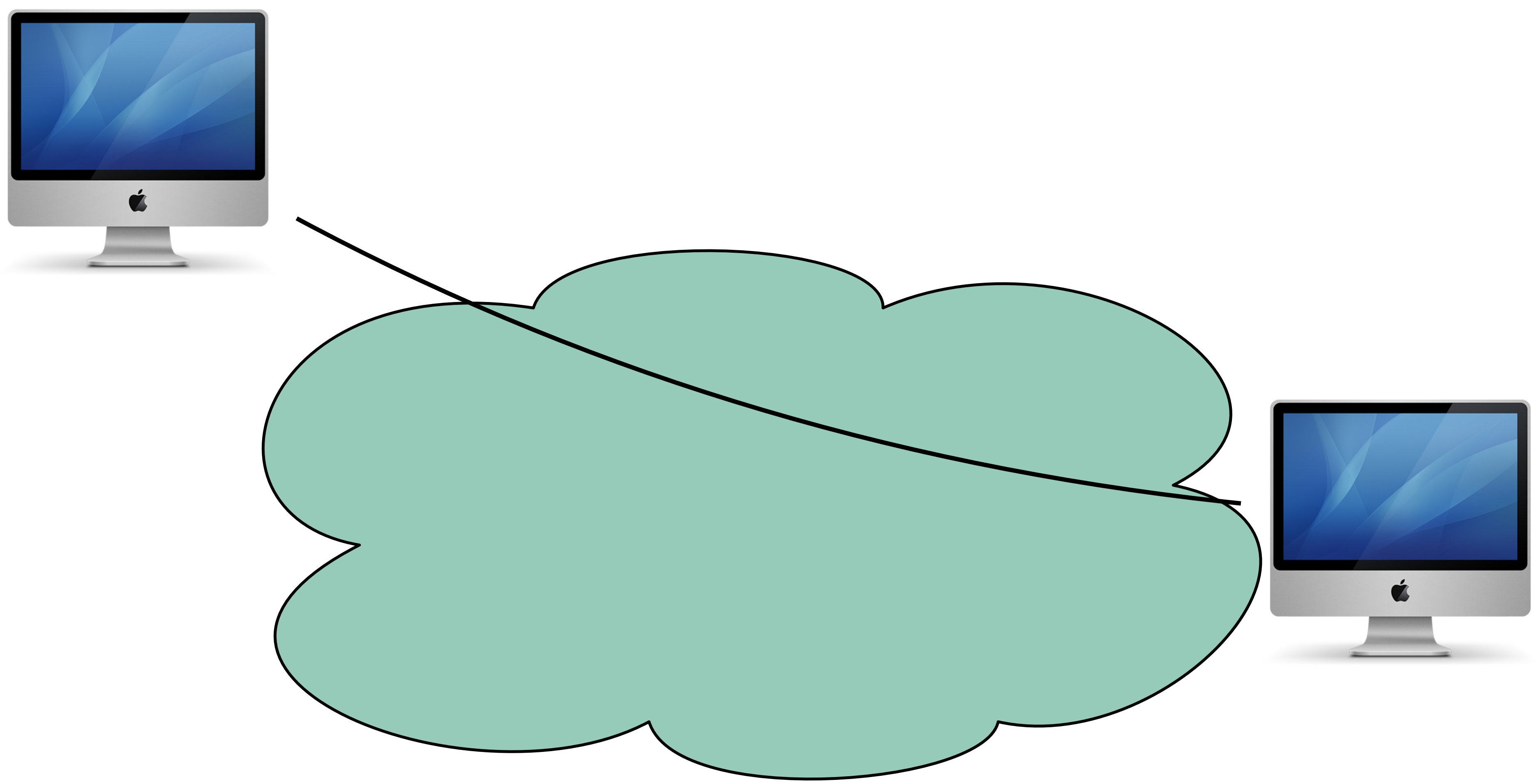
Model:
Servers and Clients talking through cloud

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 for Fun and Profit”, Takada

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 for Fun and Profit", Takada

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

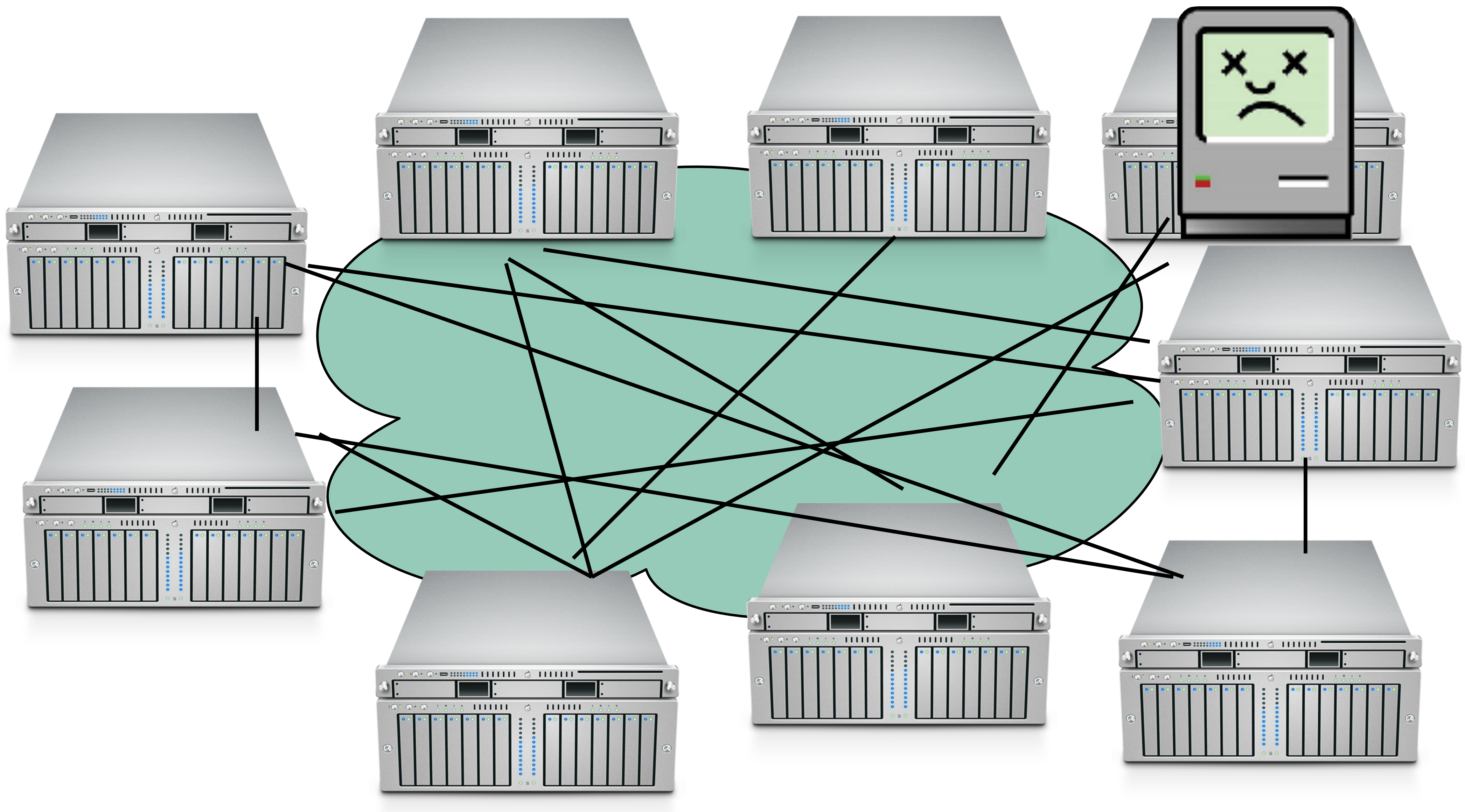
- Say there's a 1% chance of having some hardware failure occur to a machine (power supply burns out, hard disk crashes, etc)
- Now I have 10 machines
  - Probability(at least one fails) = 1 - Probability(no machine fails) = $1-(1-.01)^{10}$ = 10%
- 100 machines -> 63%
- 200 machines -> 87%
- So obviously 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



Constraints

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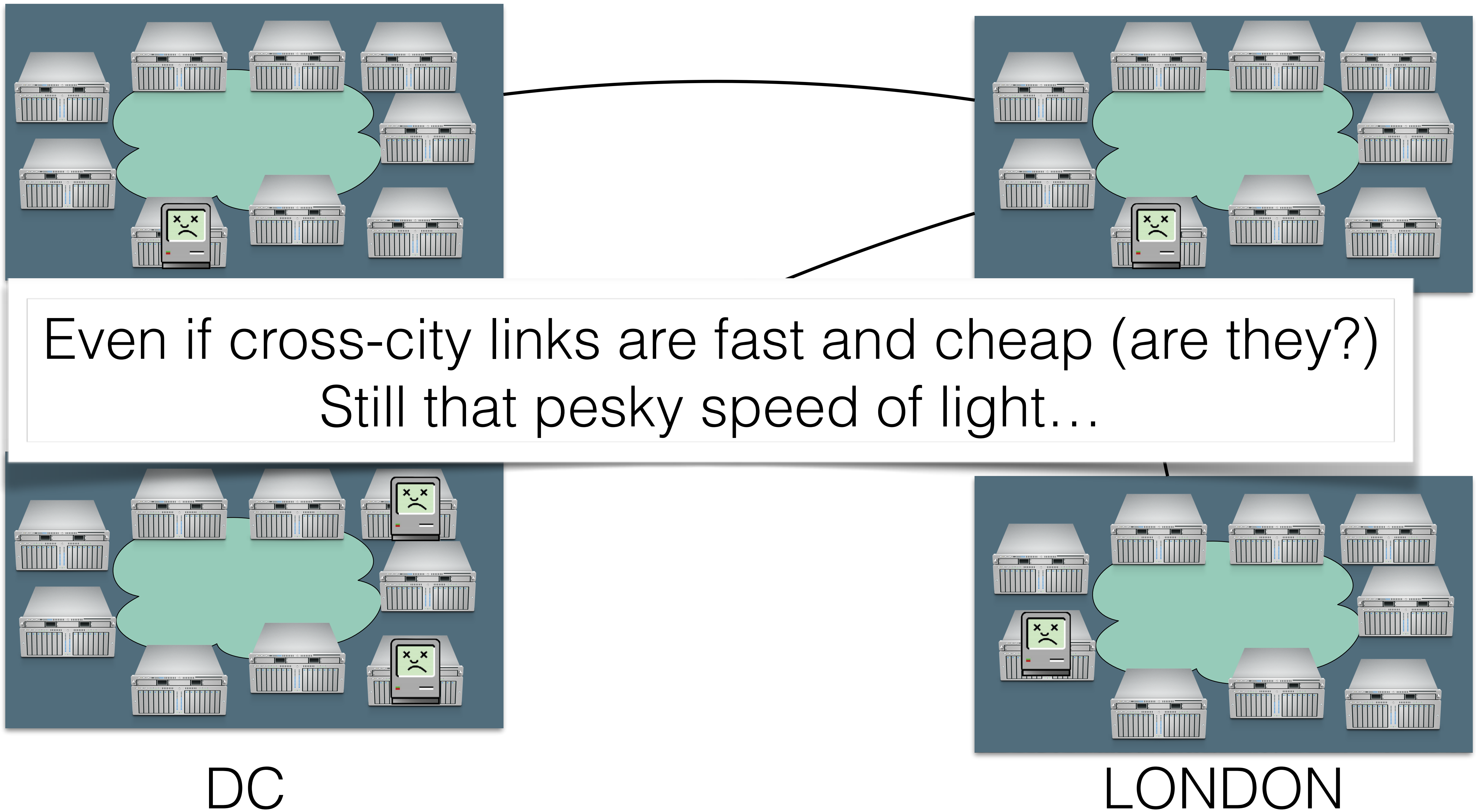
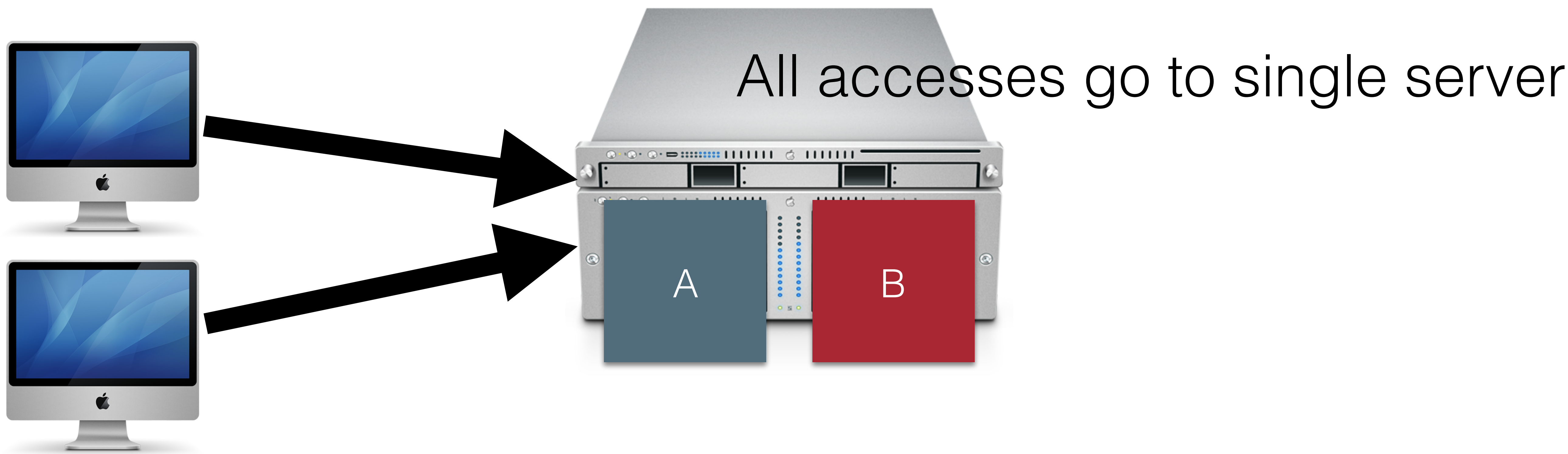


Even if cross-city links are fast and cheap (are they?)
Still that pesky speed of light…

Recurring Solution #1: Partitioning

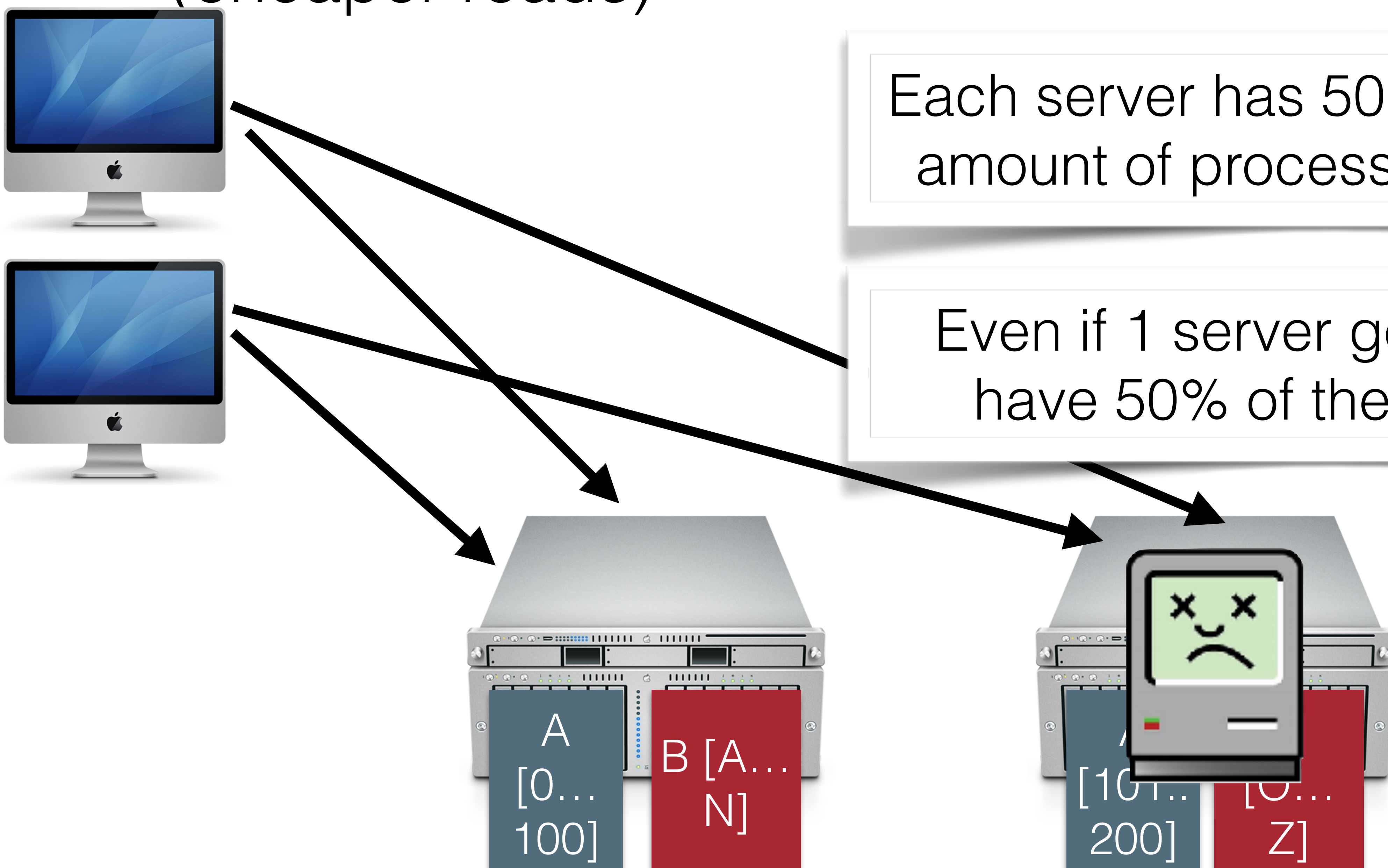


Recurring Solution #1: Partitioning

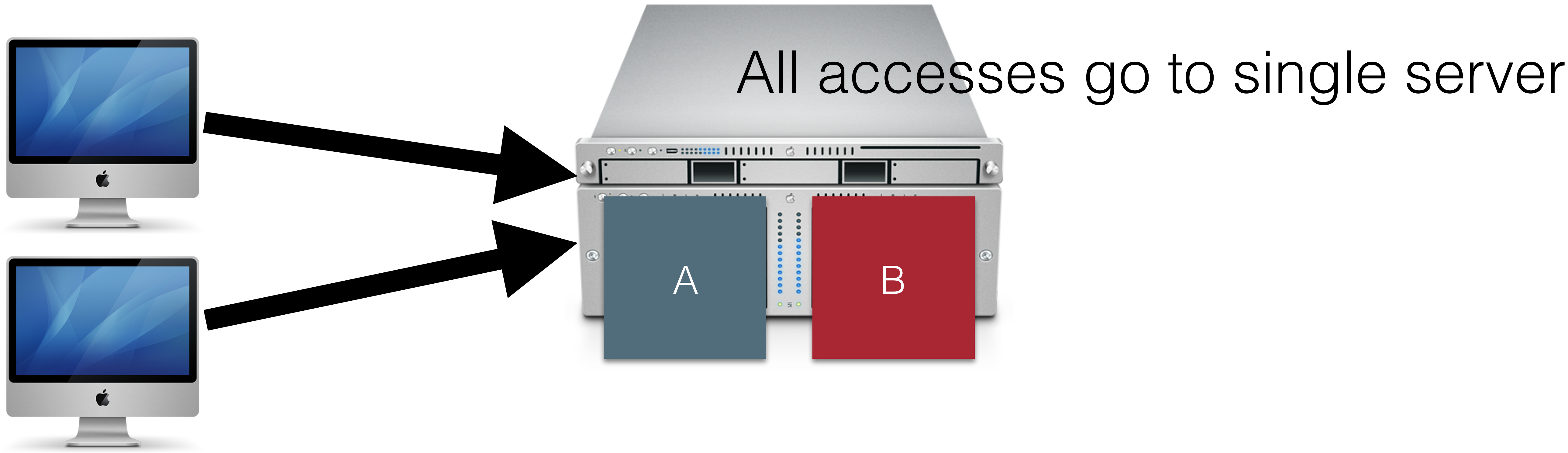
- Divide data up in some (hopefully logical) way
- Makes it easier to process data concurrently (cheaper reads)

Each server has 50% of data, limits amount of processing per server.

Even if 1 server goes down, still have 50% of the data online.

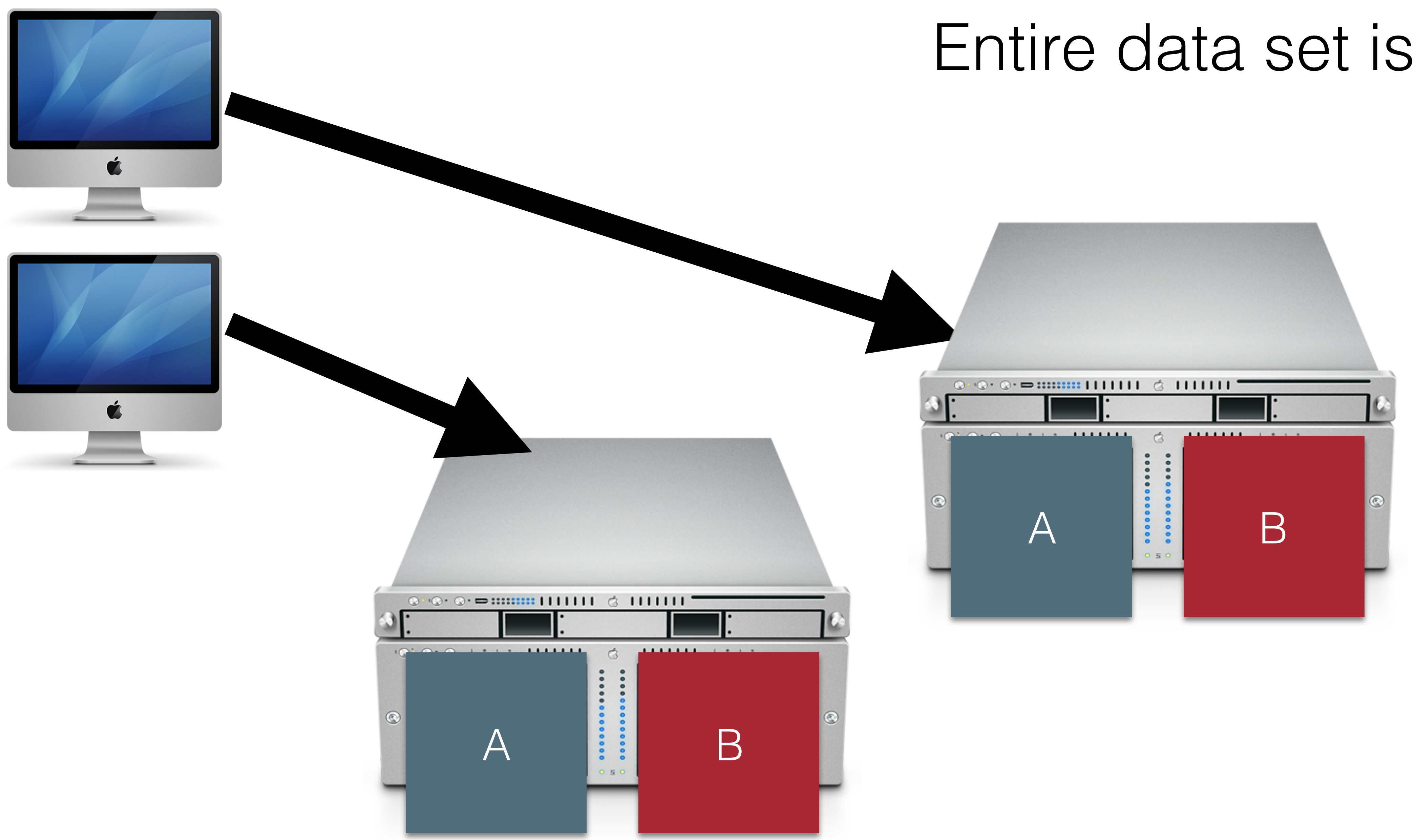


Recurring Solution #2: Replication



Recurring Solution #2: Replication

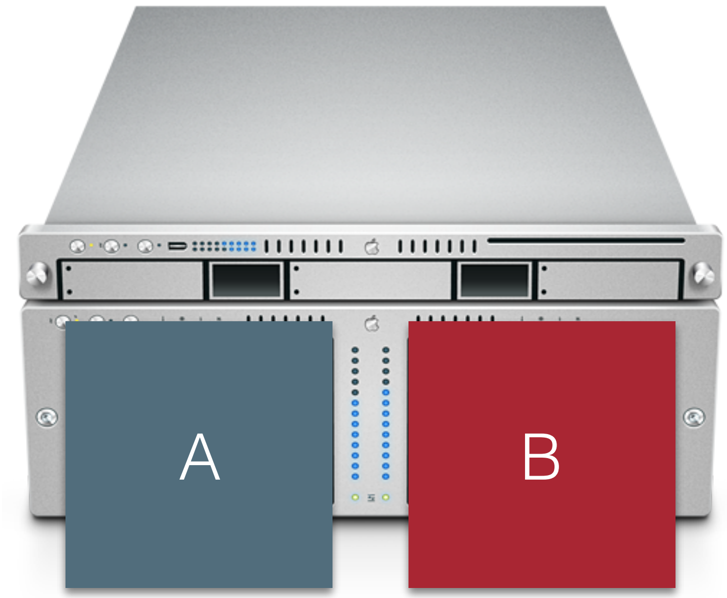
Entire data set is copied



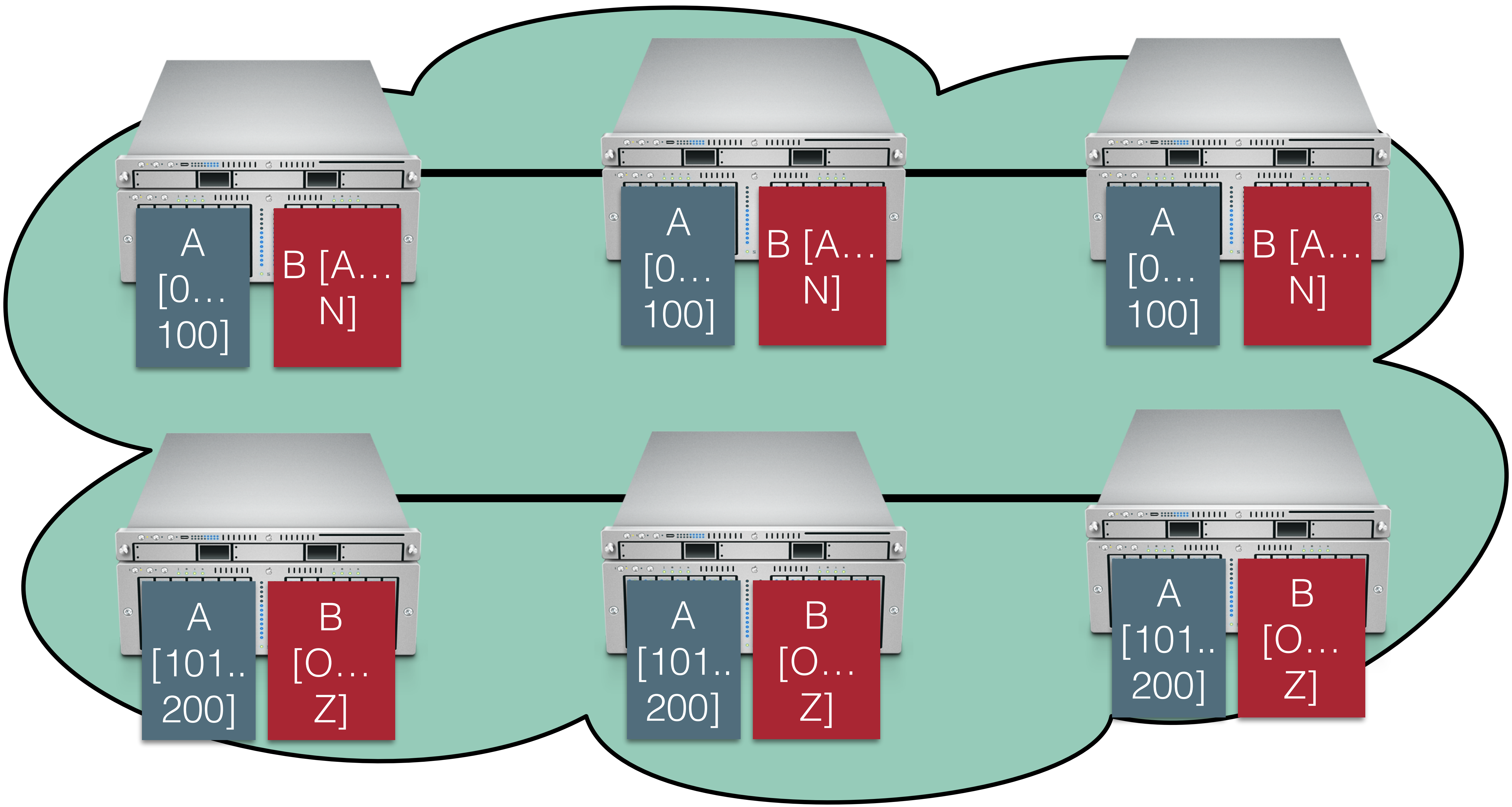
Recurring Solution #2: Replication

- Improves performance:
  - Client load can be evenly shared between servers
  - Reduces latency: can place copies of data nearer to clients
- Improves availability:
  - One replica fails, still can serve all requests from other replicas

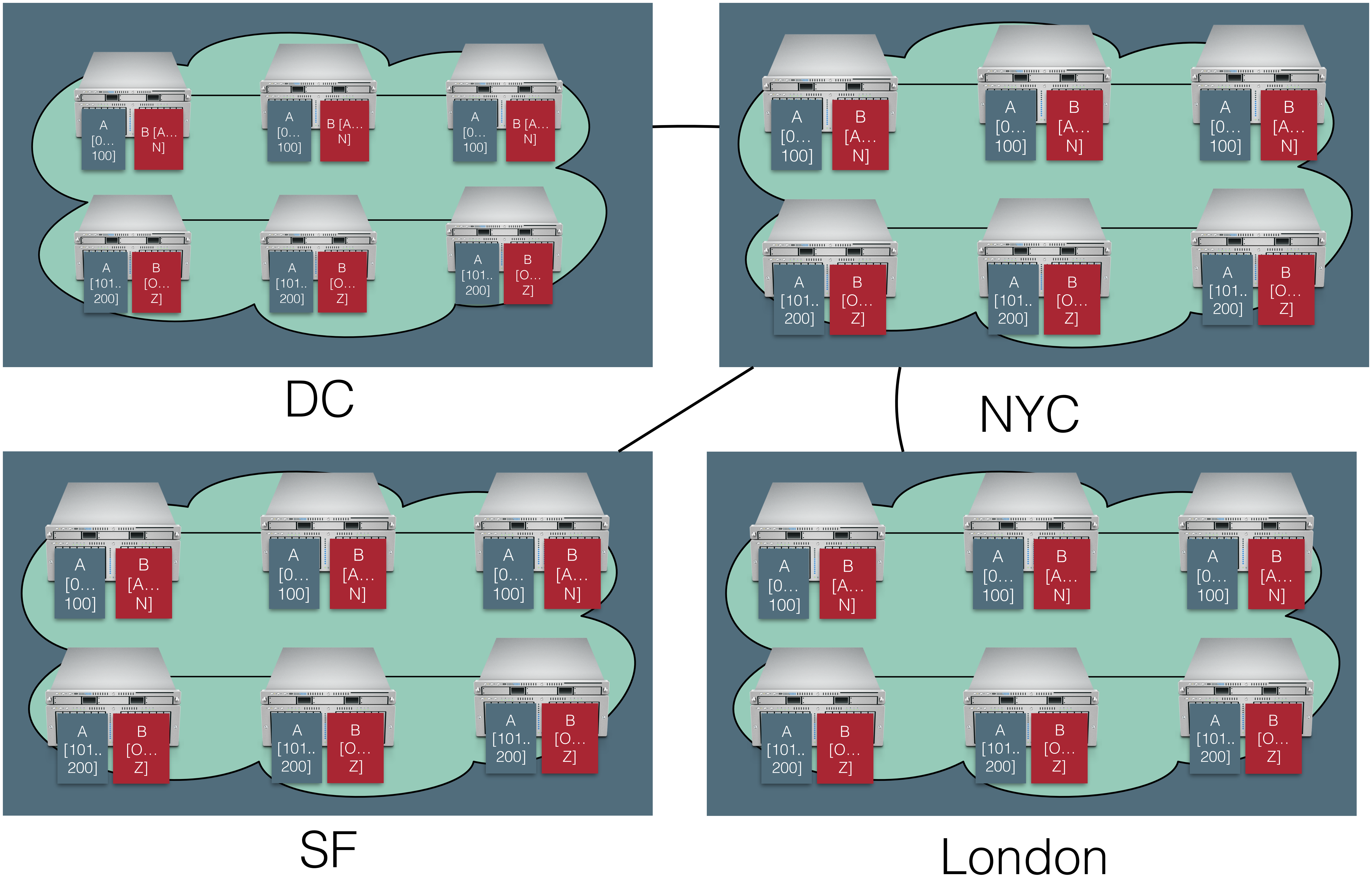
Partitioning + Replication



Partitioning + Replication

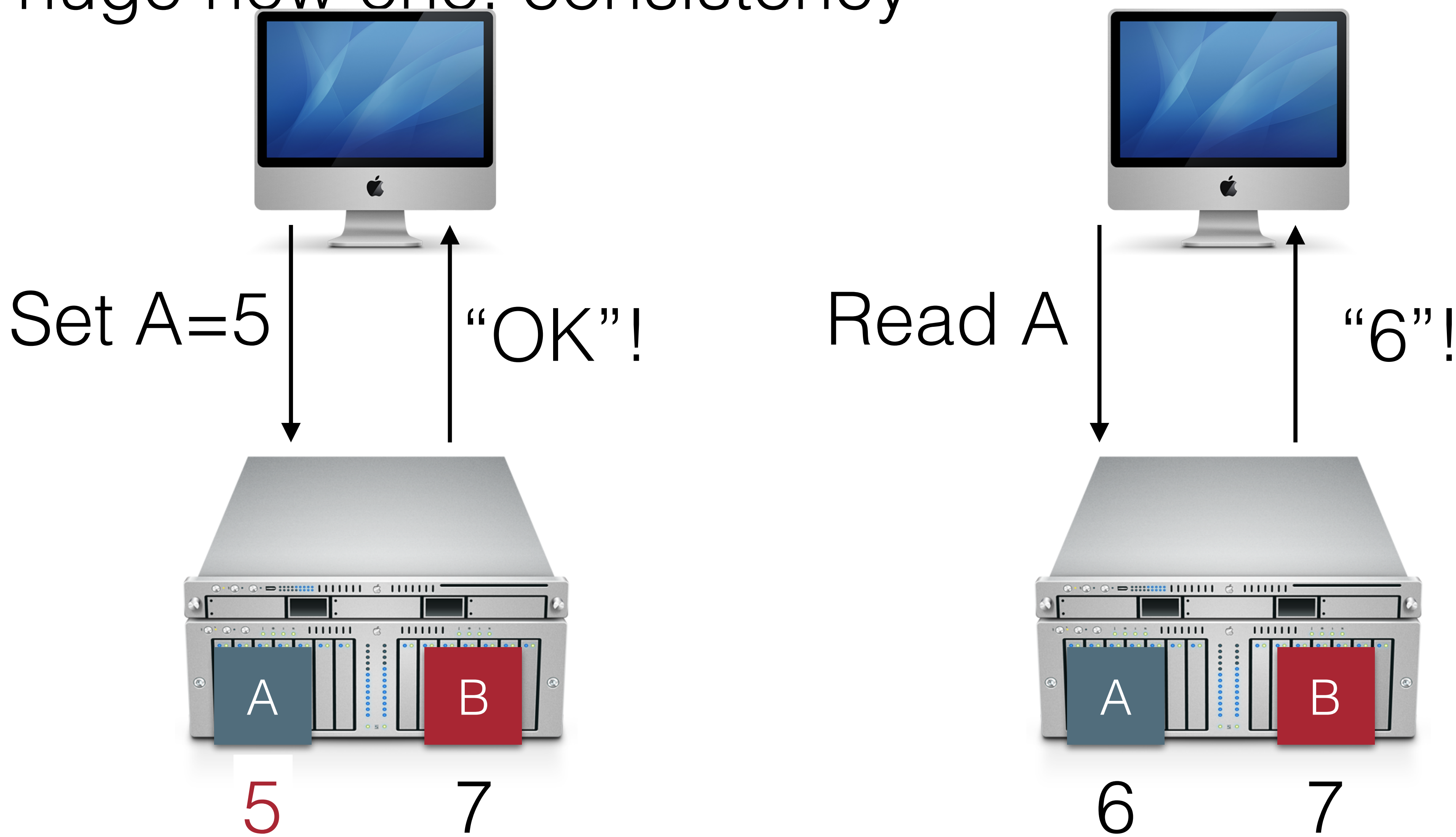


Partitioning + Replication



Recurring Problem: Replication

- Replication solves some problems, but creates a huge new one: consistency



OK, we obviously need to actually do something here to replicate the data… but what?

How much to hide?

- Completely hiding how distributed a system is may be too much:
  - Communication latencies can't be hidden (pesky speed of light!)
  - Completely hiding failures is **impossible** (we will prove this later in the semester)
    - Can never distinguish a slow computer from one that is crashed
- Hiding more adds performance costs

Exit-ticket activity

Go to socrative.com and select “Student Login” (works well on laptop, tablet or phone)

Class: CS475
ID is your @gmu.edu email