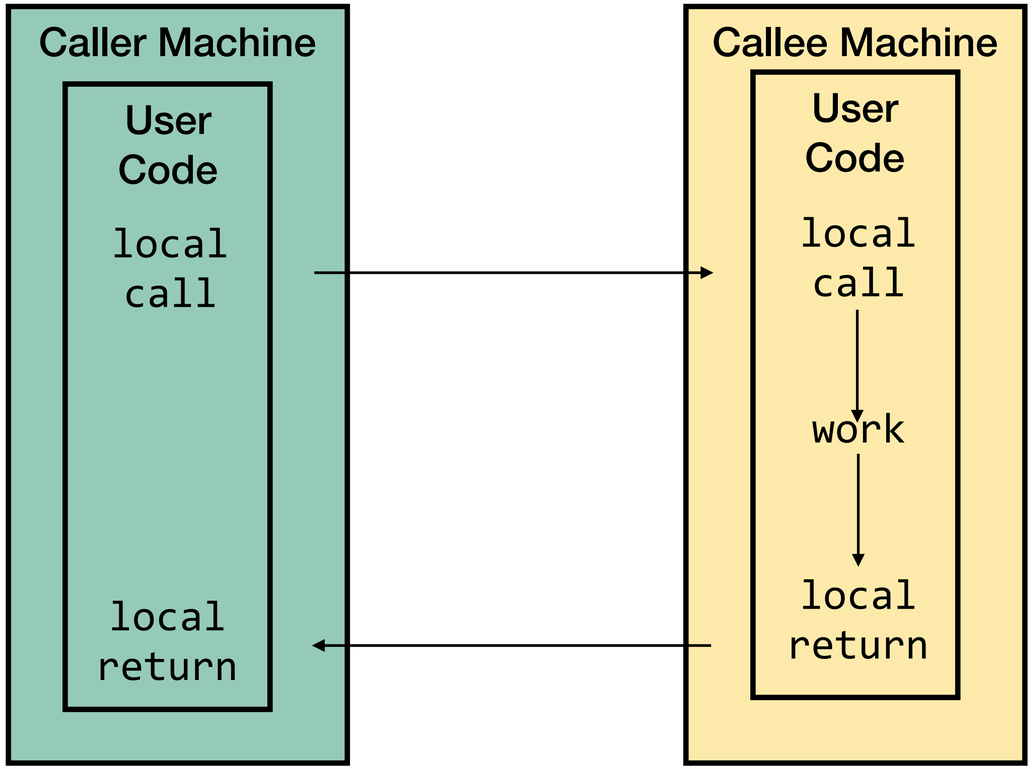
Distributed Architectures and Abstractions

CS 475, Fall 2019
Concurrent & Distributed Systems

GEORGE MASON UNIVERSITY

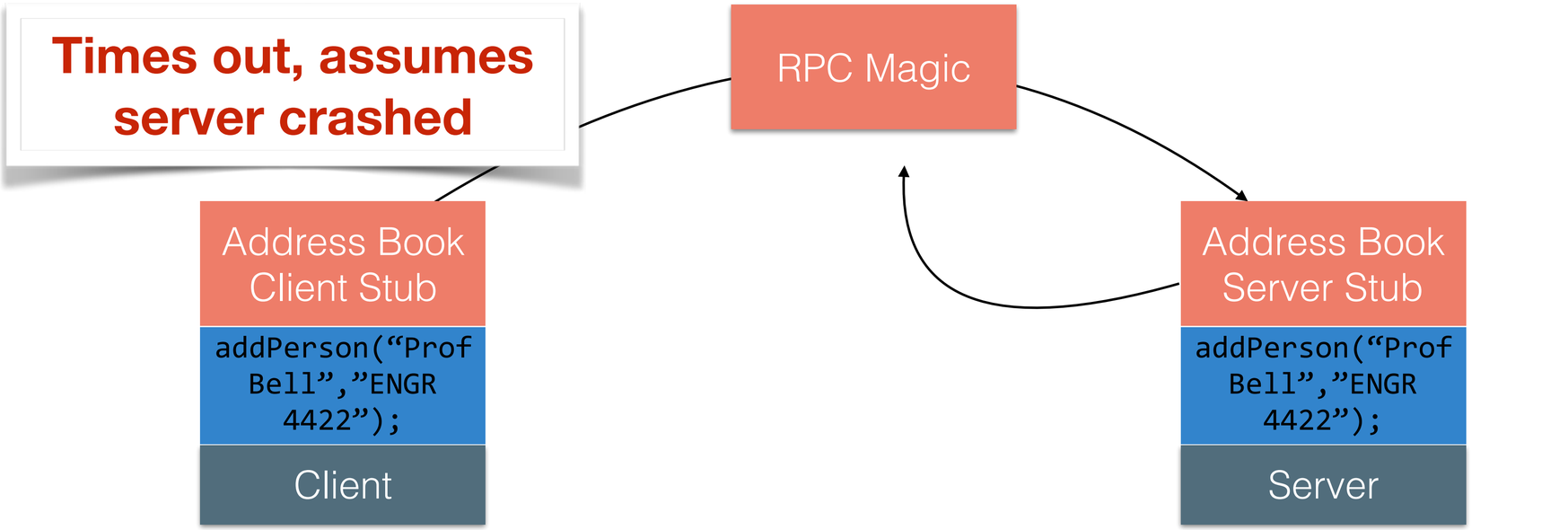
RPC: High Level Approach



Shared Fate

- Two methods/threads/processes running on the same computer generally have **shared fate**
- They will either both crash, or neither will crash

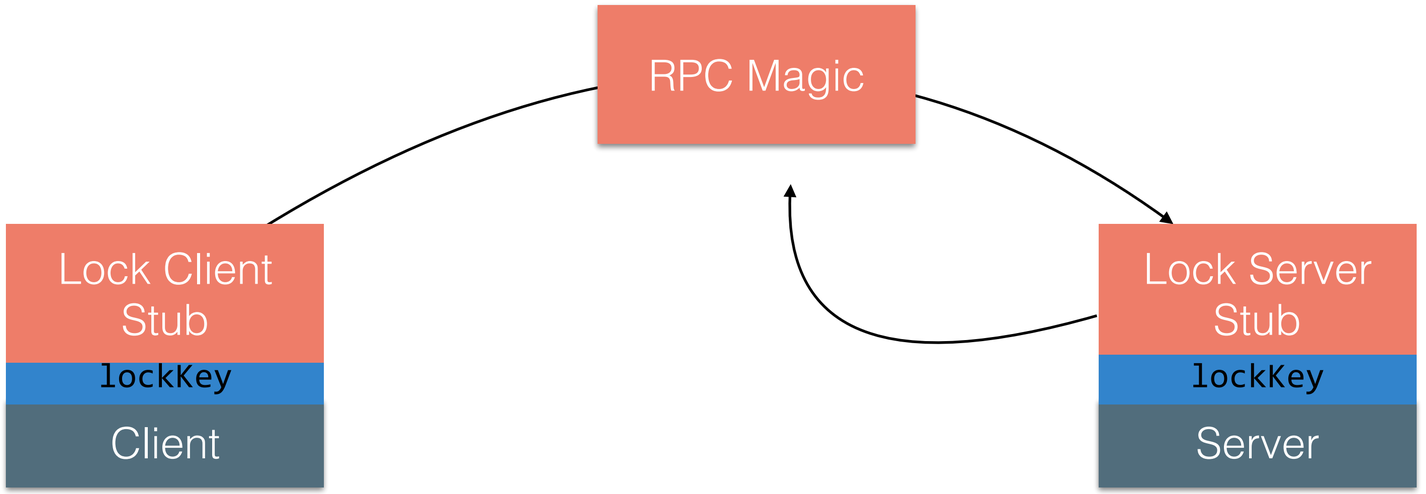
Split Brain in RPC



Split brain: Client thinks addPerson didn’t succeed, server did complete it though!

Split Brain in RPC

This gets even worse when you consider more complicated semantics



Who has the lock?

RPC Semantics

- No matter what we do, if we want RPC, we have networks, networks might have timeouts/failures
- How do we handle the potential for split brain?
  - If we don't hear a response, just freeze?
- What can the abstraction guarantee?
  - Leak some of this complexity through

Java RMI

- Synchronous (client method doesn't return until server completes)
- At most once delivery
- Hence, in the event of a communication failure, an exception is thrown on your client
- Implications:
  - Client code needs to be aware that failures might happen (and exception might be thrown)
  - Client code needs to have some plan to handle when a message fails to get through (application specific)

Java RMI

- Threading model:
  - What happens when there are multiple simultaneous RMI requests to the same server?
- RMI creates a *thread pool*, a set of threads ready to handle each request
  - Subsequent calls from the same client might or might not use the same thread
  - Subsequent calls from other clients might use the same thread as others
- Implications:
  - Can process multiple requests simultaneously
  - Need to be cognizant of thread safety

Java RMI

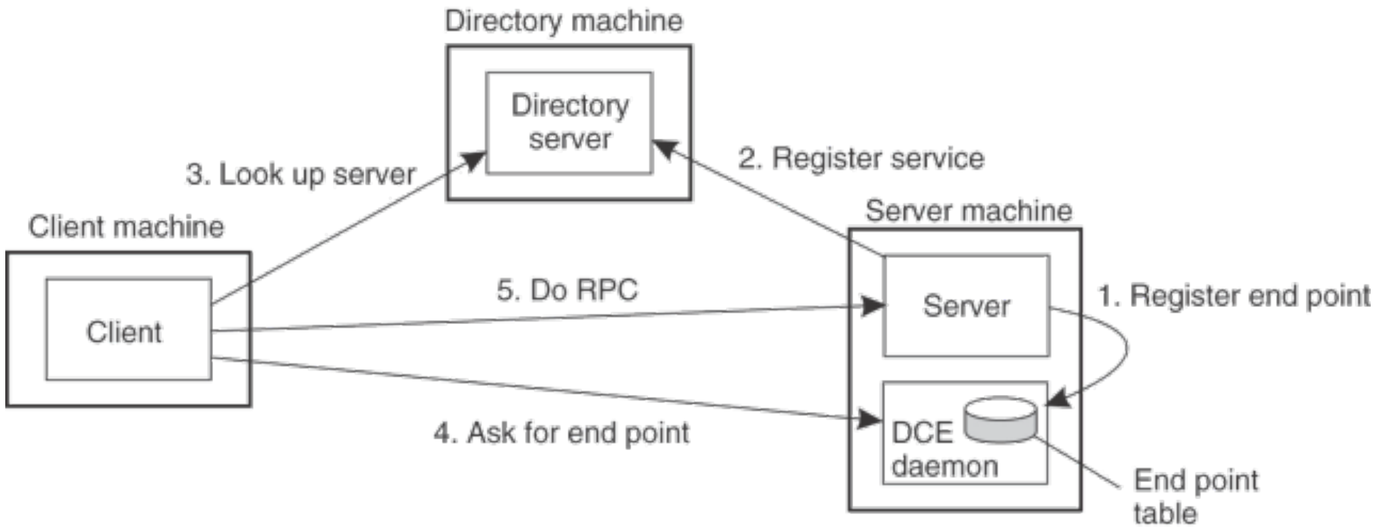
```
public interface AddressBook extends Remote {
   public LinkedList<Person> getAddressBook() throws RemoteException;

   public void addPerson(Person p) throws RemoteException;
}
```

```
AddressBook book = new AddressBookServer();
AddressBook stub = (AddressBook) UnicastRemoteObject.exportObject(book, 0);
Registry registry = LocateRegistry.createRegistry(port);
registry.rebind("AddressBook", stub);
```

```
Registry registry = LocateRegistry.getRegistry("localhost", 9000);
AddressBook addressBook = (AddressBook) registry.lookup("AddressBook");
```

Java RMI

- Registration of a server makes it possible for a client to locate the server and bind to it
- Server location is done in two steps:
  - Locate the server's machine.
  - Locate the server on that machine.



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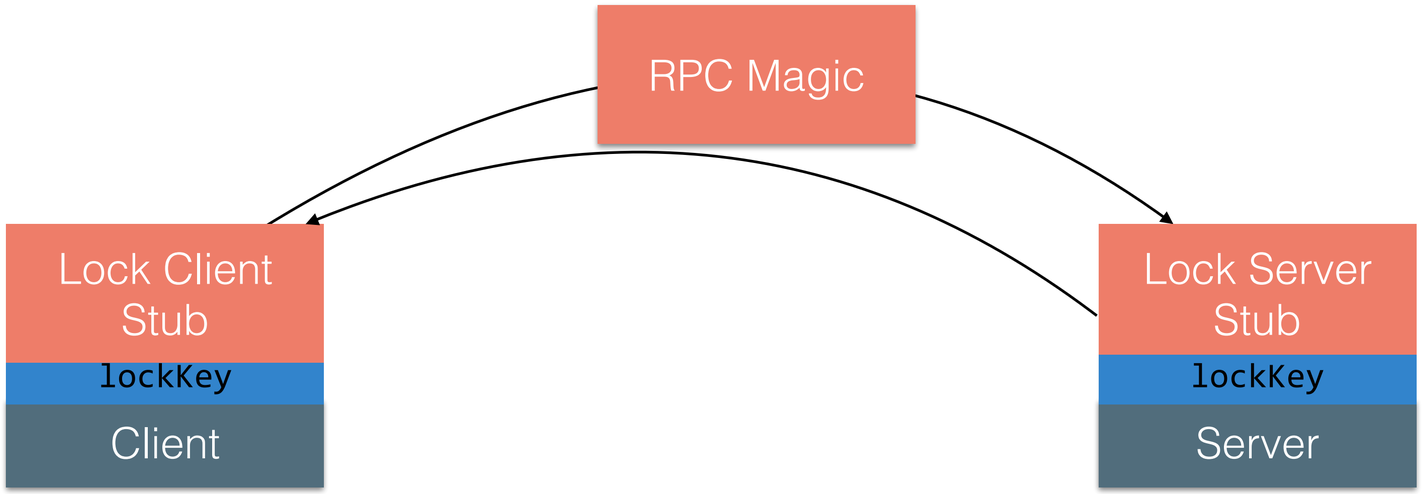
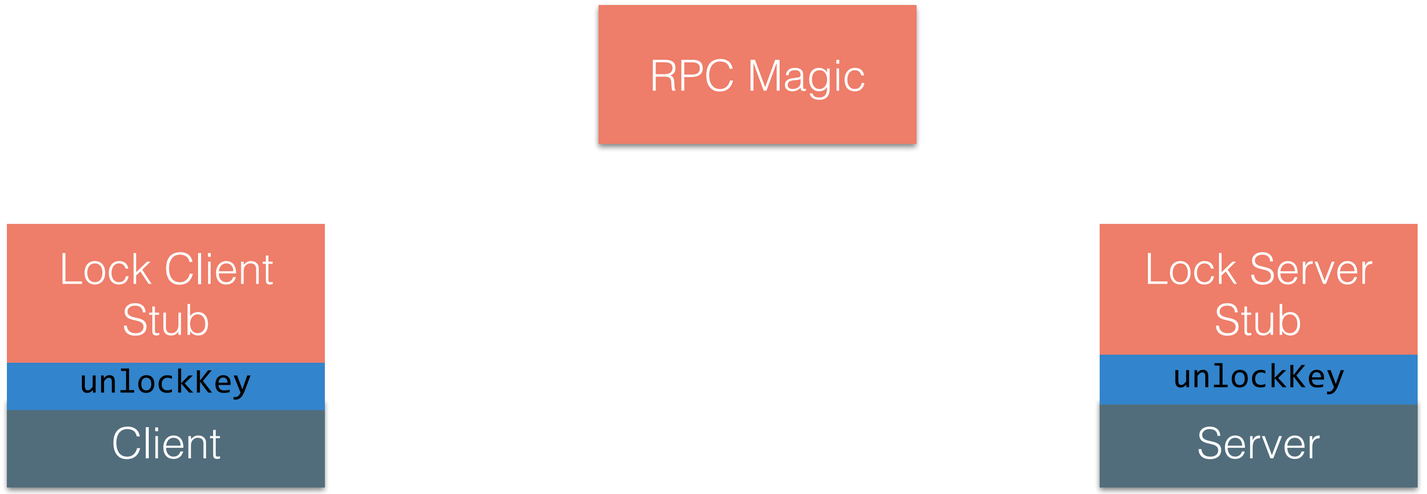


Who has the lock? How do we handle this?

Split Brain in RPC

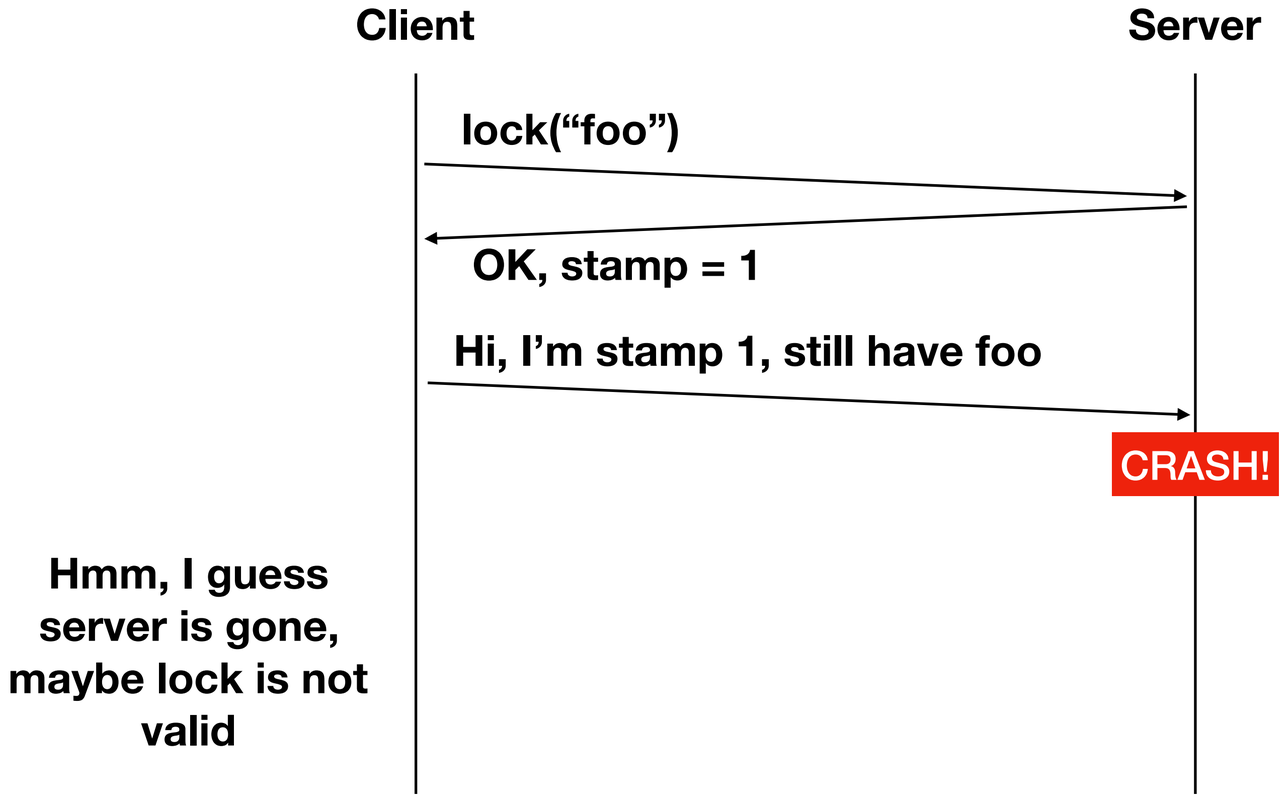
This gets even worse when you consider more complicated semantics



Who has the lock? How do we handle this?

Sidebar: Heartbeat Protocols

- Allow client/server to remain aware of each other's status
- For HW3: does client still have locks (client checking server, server checking client)



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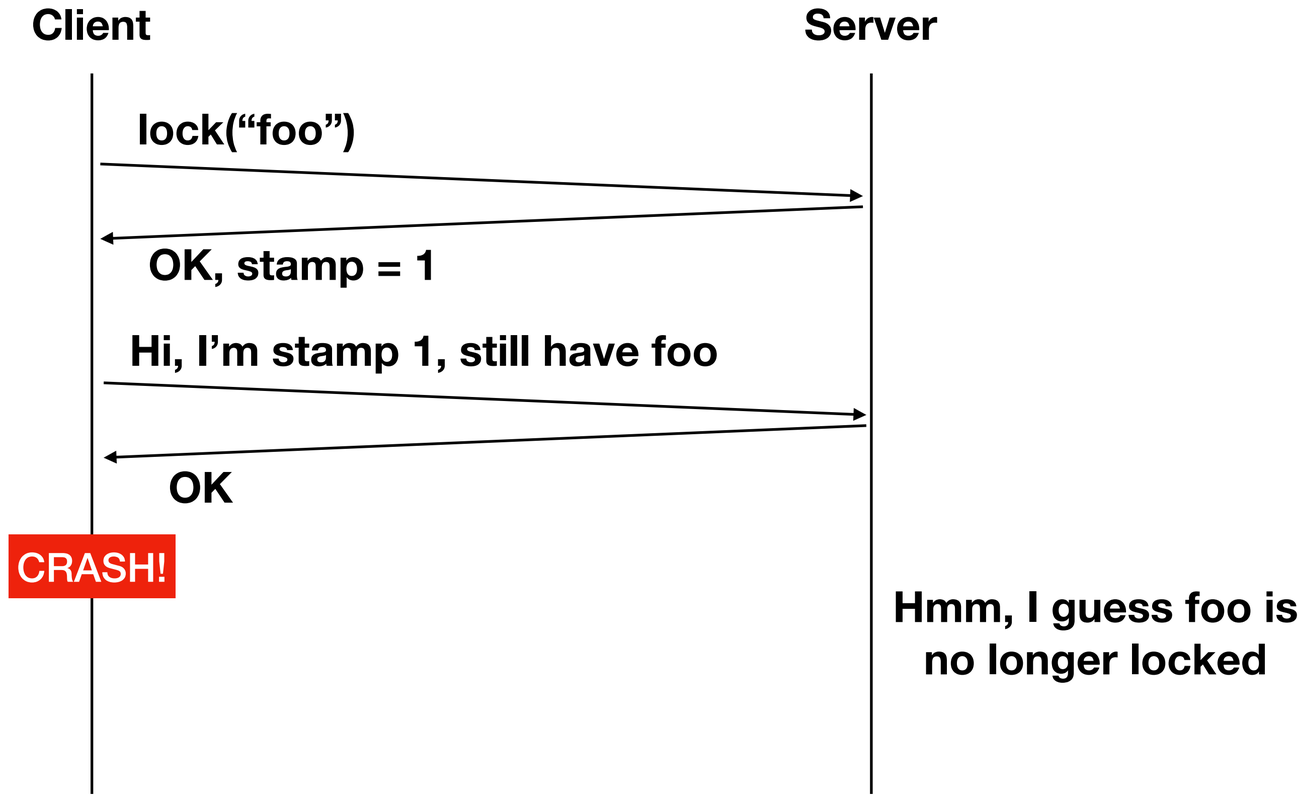


Sidebar: Heartbeat Protocols

- We call these time-limited locks **leases**
- What does a lease guarantee?
  - If no network failures
    - Locks that are relinquished when client crashes
  - If network failures/delays:
    - Nothing

RPC Summary

- Expose RPC properties to client, since you cannot hide them
  - Application writers have to decide how to deal with partial failures
  - Consider: E-commerce application vs. game

RPC on the Web

- How do we do RPC on the web?
- Challenges for scaling up (more clients) and out (heterogeneous clients)
  - Need to get beyond RMI (it's Java only)
  - How do we find API endpoints?
  - How do we format requests?
  - How do we encode data?

Today

- Distributed Systems Architectures: How do we build a big thing from lots of little things?
- Today: How to compose some big blocks
- Next few weeks: How to build each of those blocks
- Reminders:
  - HW3 Posted
  - Prof Bell out of town next week

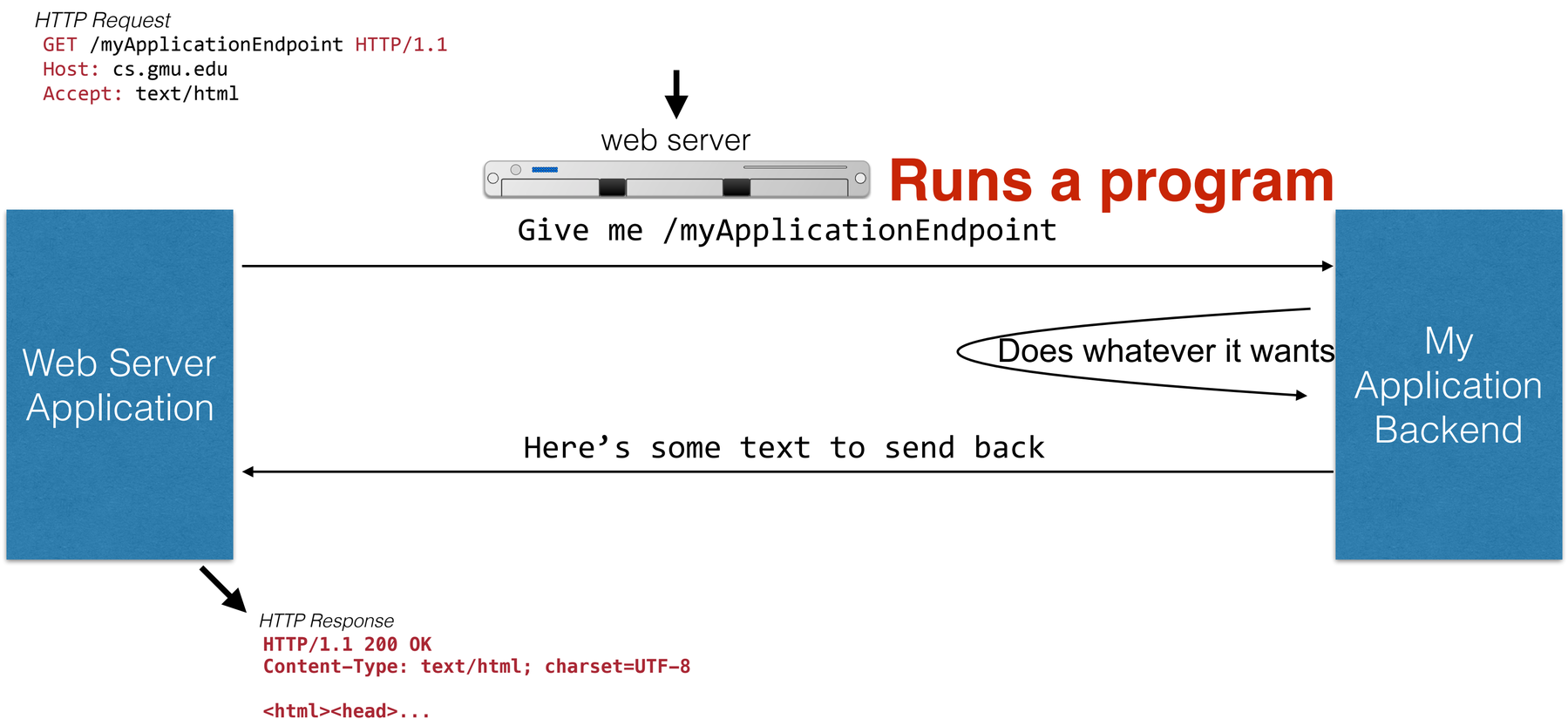
Distributed Systems Abstractions

- Goal: find some way of making our distributed system look like a single system
- Never achievable in practice
- BUT if we can come up with some model of how the world might behave, we can come up with some generic solutions that work pretty well
  - And hopefully we can understand how they can go wrong

Abstractions & Architectures

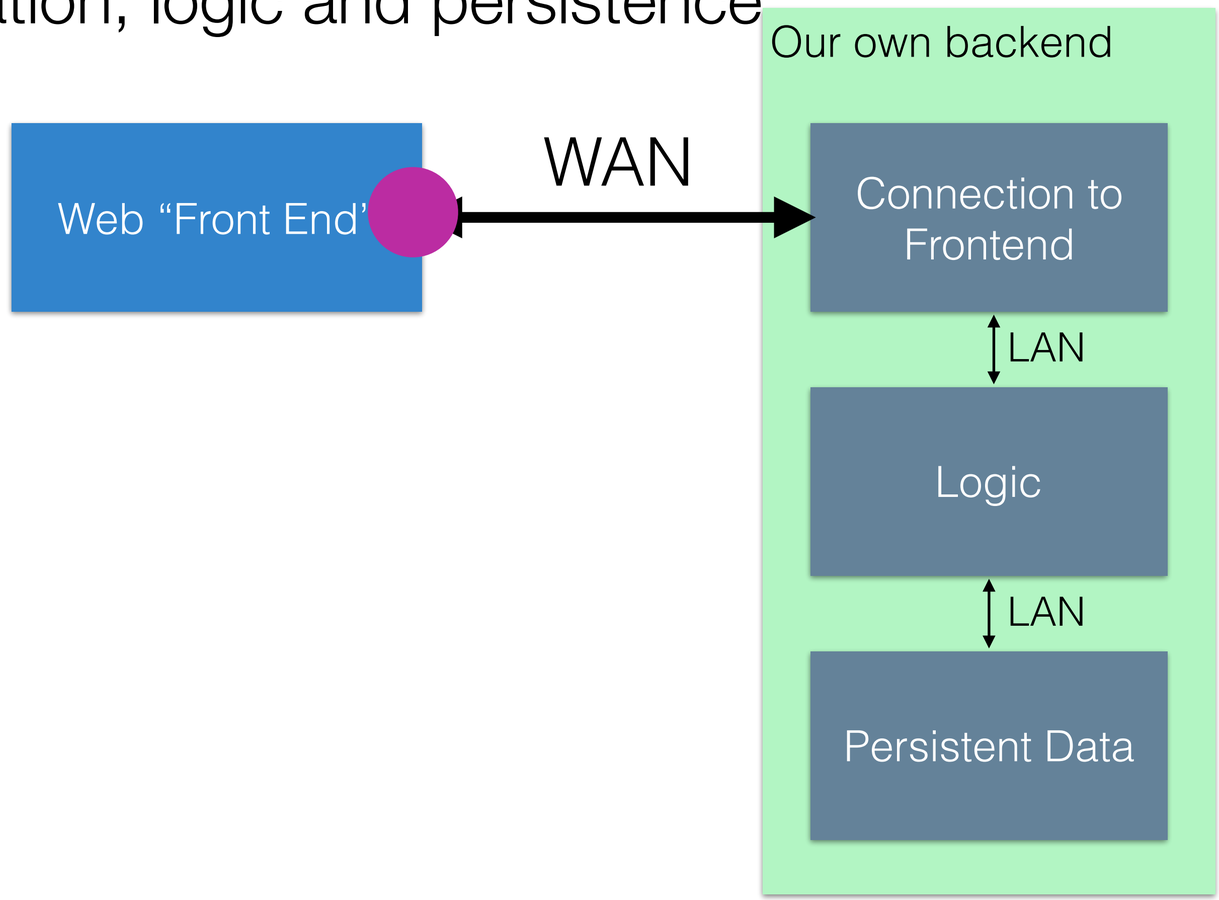
- We can design *architectures* that embody some systems model, providing some framework code to make it easier to get some task done
- Case study example: web architectures
- Assumptions:
  - “one” server, many clients
  - Synchronous communication
  - Client is unlikely to be partitioned from a subset of servers; likely some subset of servers are partitioned from other servers
  - Client is mostly stateless

The good old days of web apps



Backend Frameworks

- Then: **frameworks**
  - SailsJS, Ruby on Rails, PHP Symfony, Python Django, ASP.NET, EJB…
- MVC - separate presentation, logic and persistence

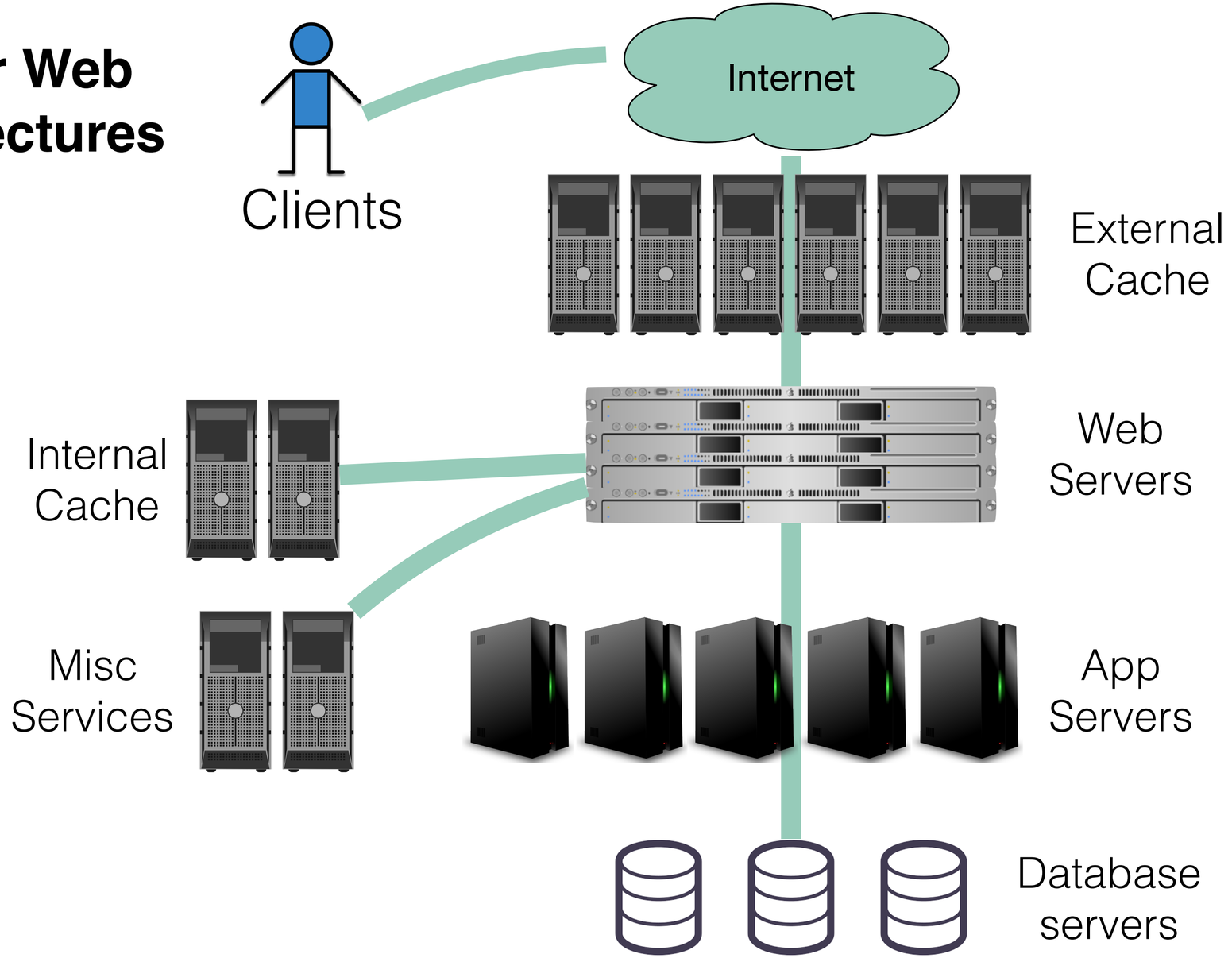


Scaling web architectures up

- What happens when we have to use this approach to run, say… Facebook?
- Tons of dynamic content that needs to be updated, petabytes of static content (like pictures), users physically located all over, lots of stuff to keep track of, where do we start?

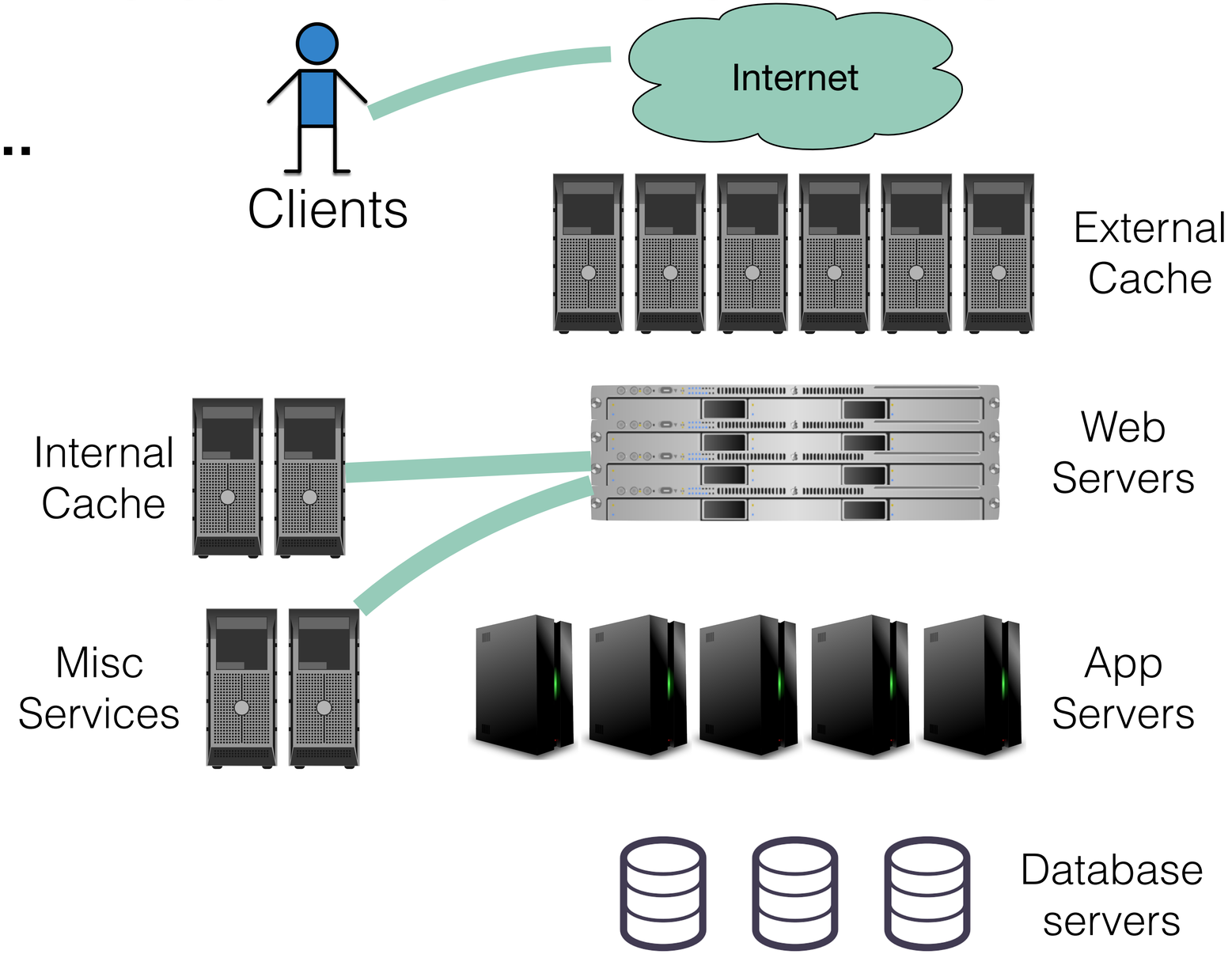
Real Architectures

N-Tier Web Architectures



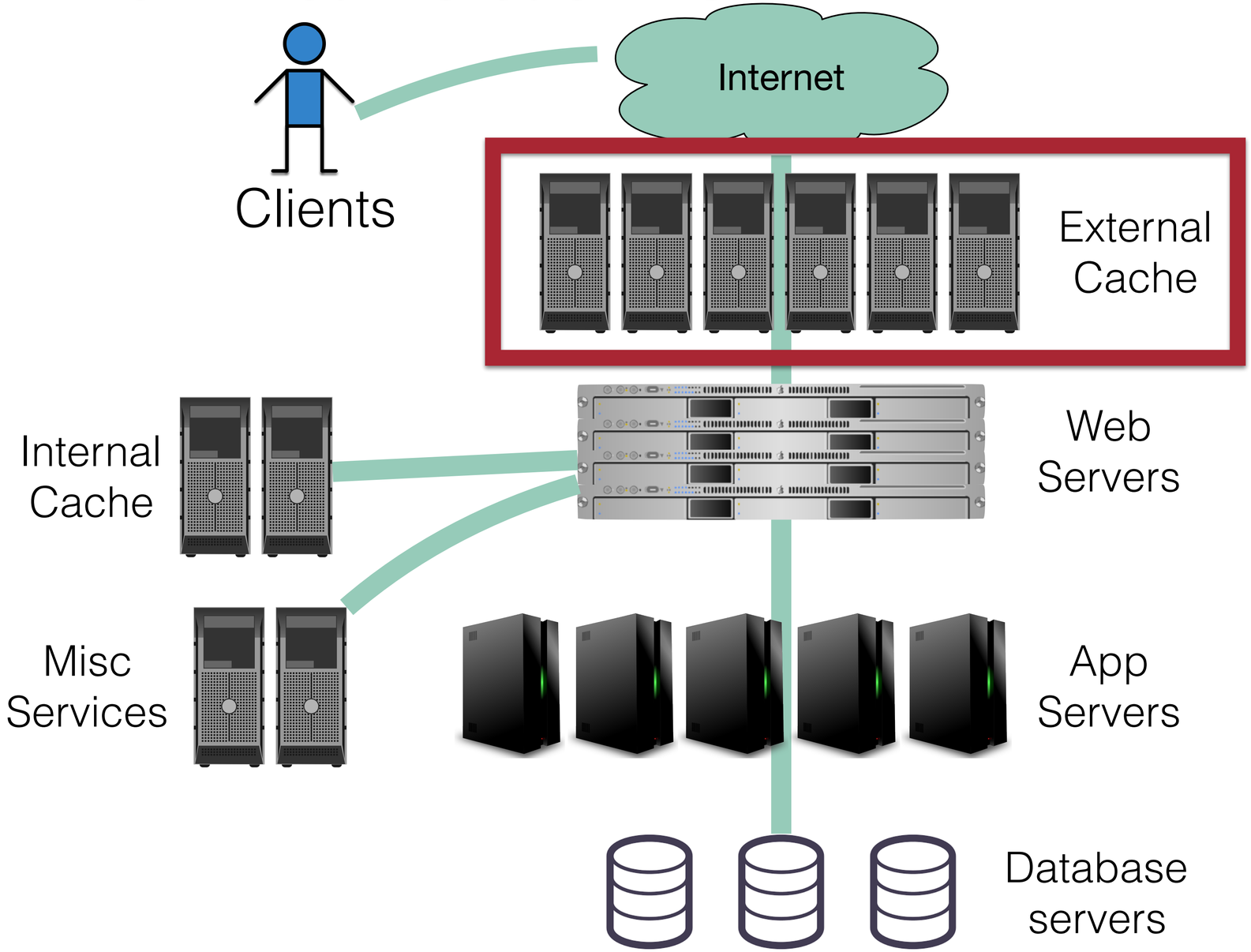
Real Architectures

- **For each layer…**
  - **What is it?**
  - **Why?**



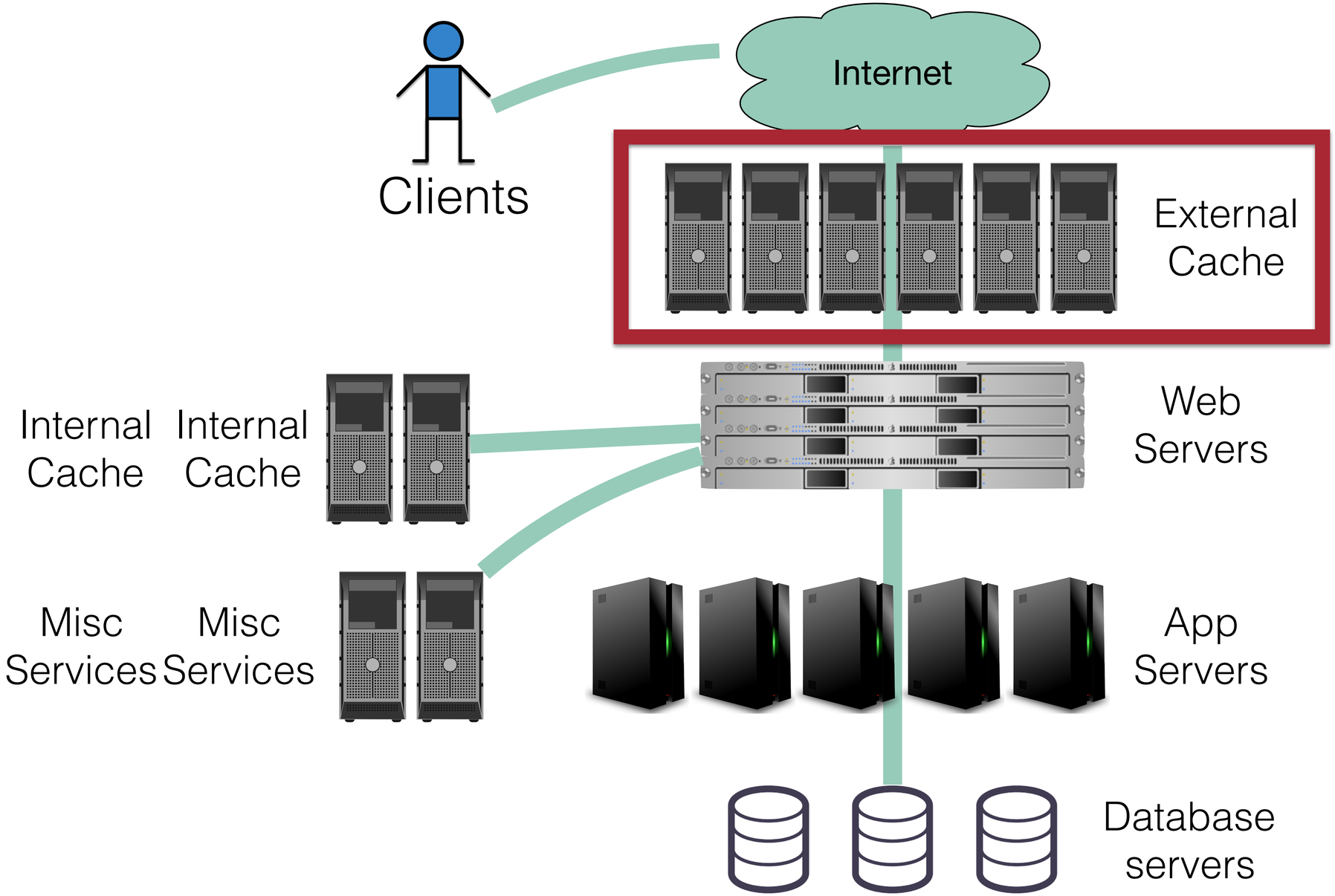
External cache

- What is it?
  - A proxy (e.g. squid, apache mod_proxy)
  - A content delivery network (CDN) e.g. Akamai, CloudFlare



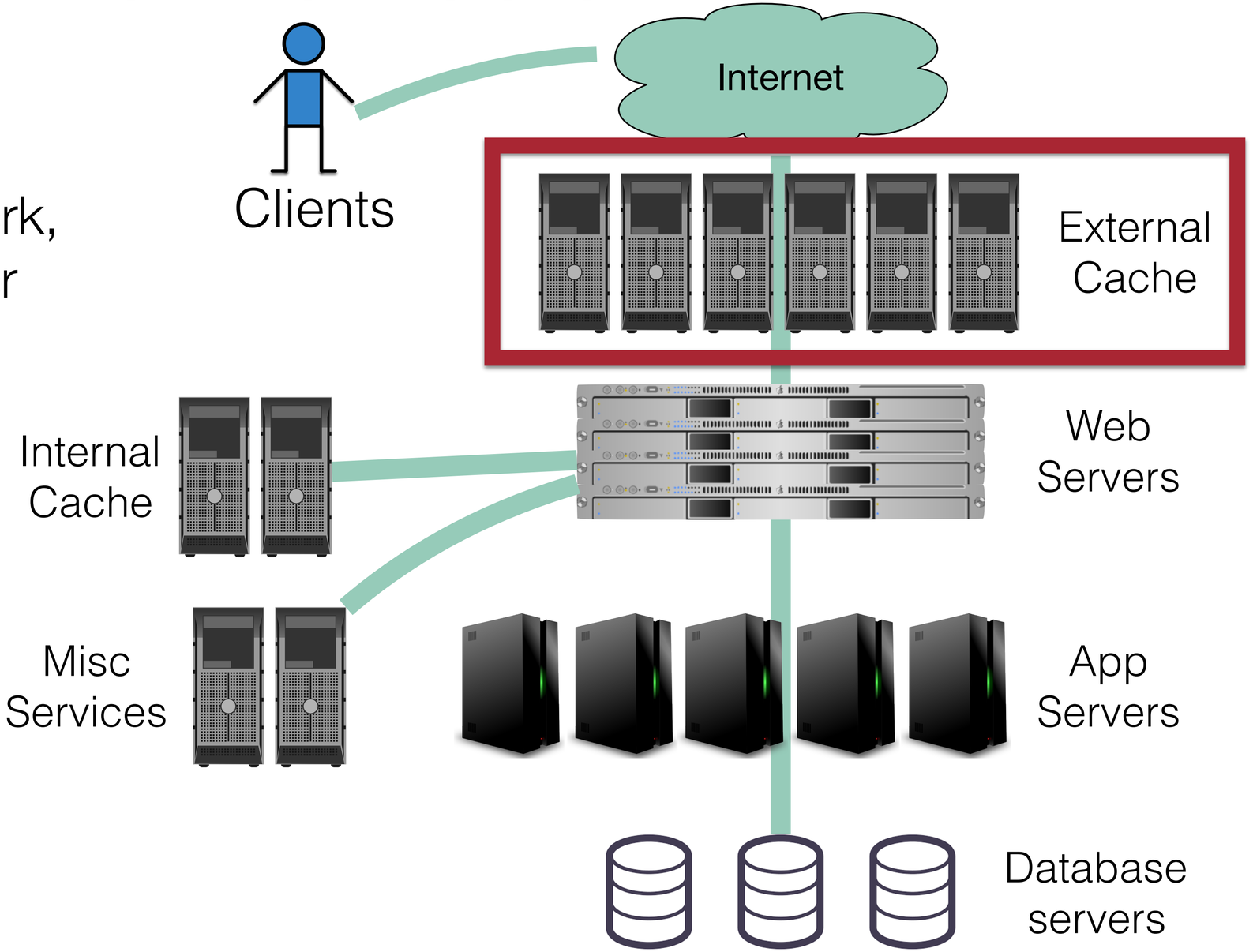
External cache

- What is it for?
  - Caches outbound data
    - Images, CSS, XML, HTML, pictures, videos, anything static (some stuff dynamic maybe)
  - DoS defense
  - Decrease latency - might be close to the user



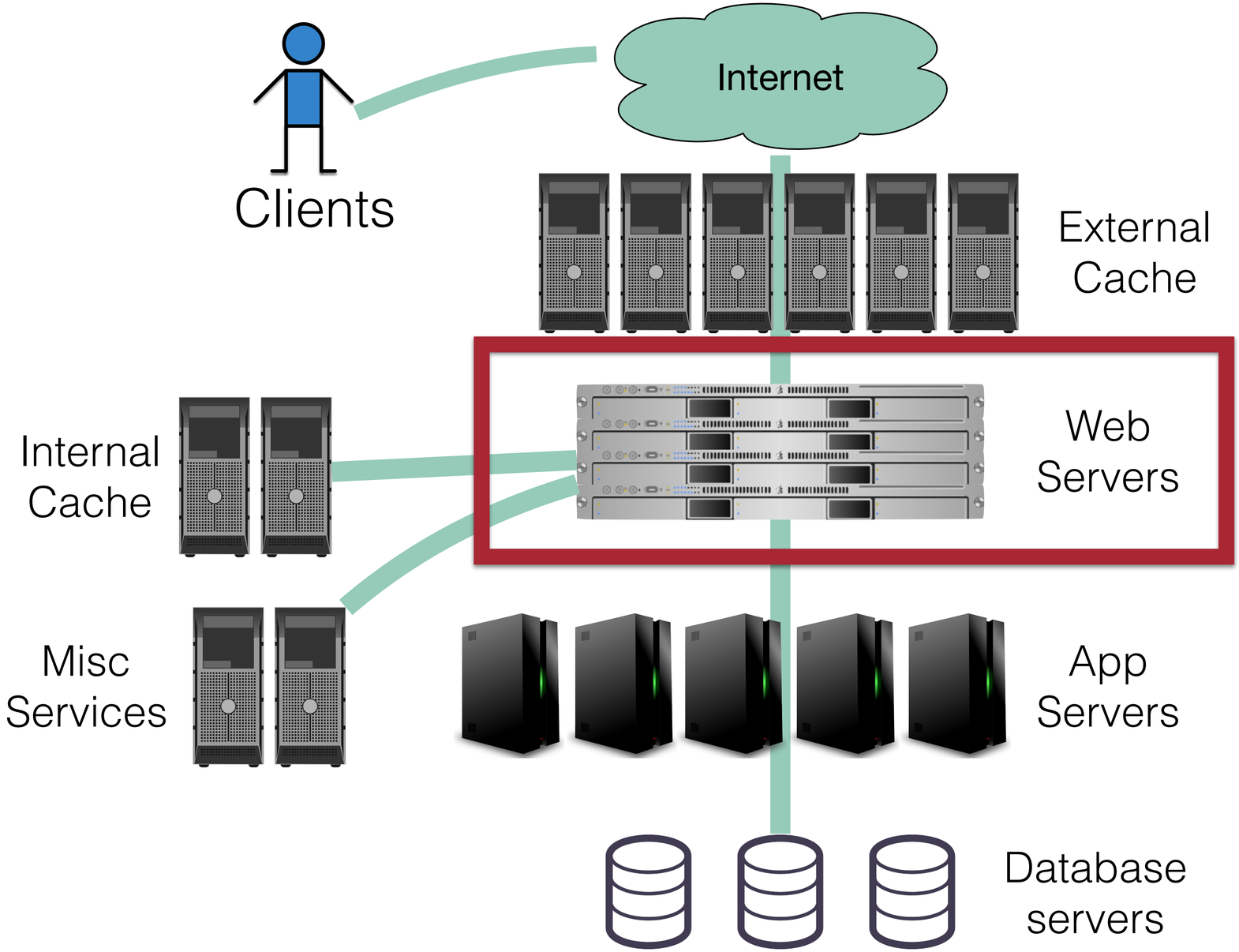
External cache

- What is it made of?
- Tons of RAM, fast network, physically located all over
- No need for much CPU



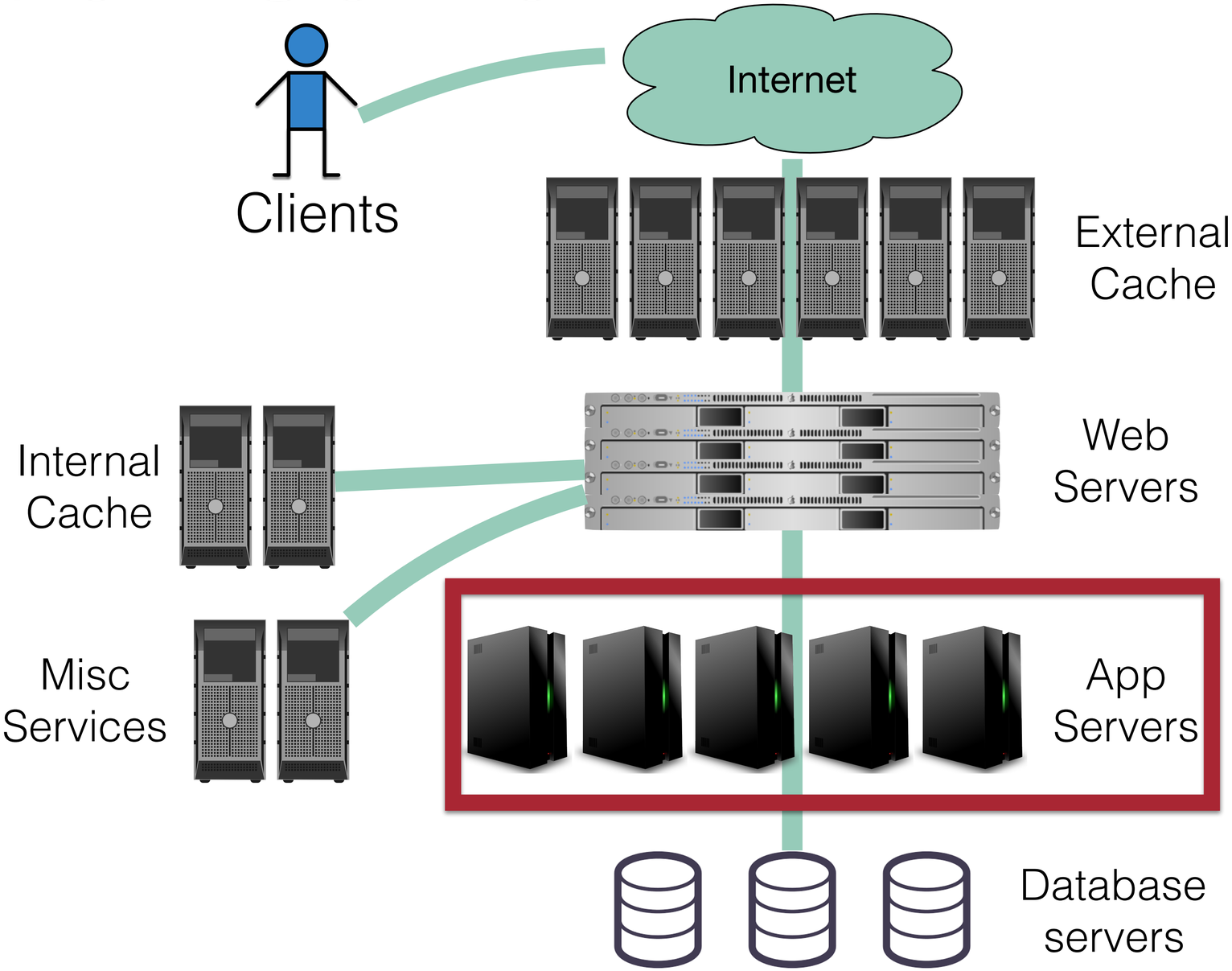
Front-end Tier

- Serves static content from disk, generates dynamic content by dispatching requests to app tier
- Speaks HTTP, HTTPS



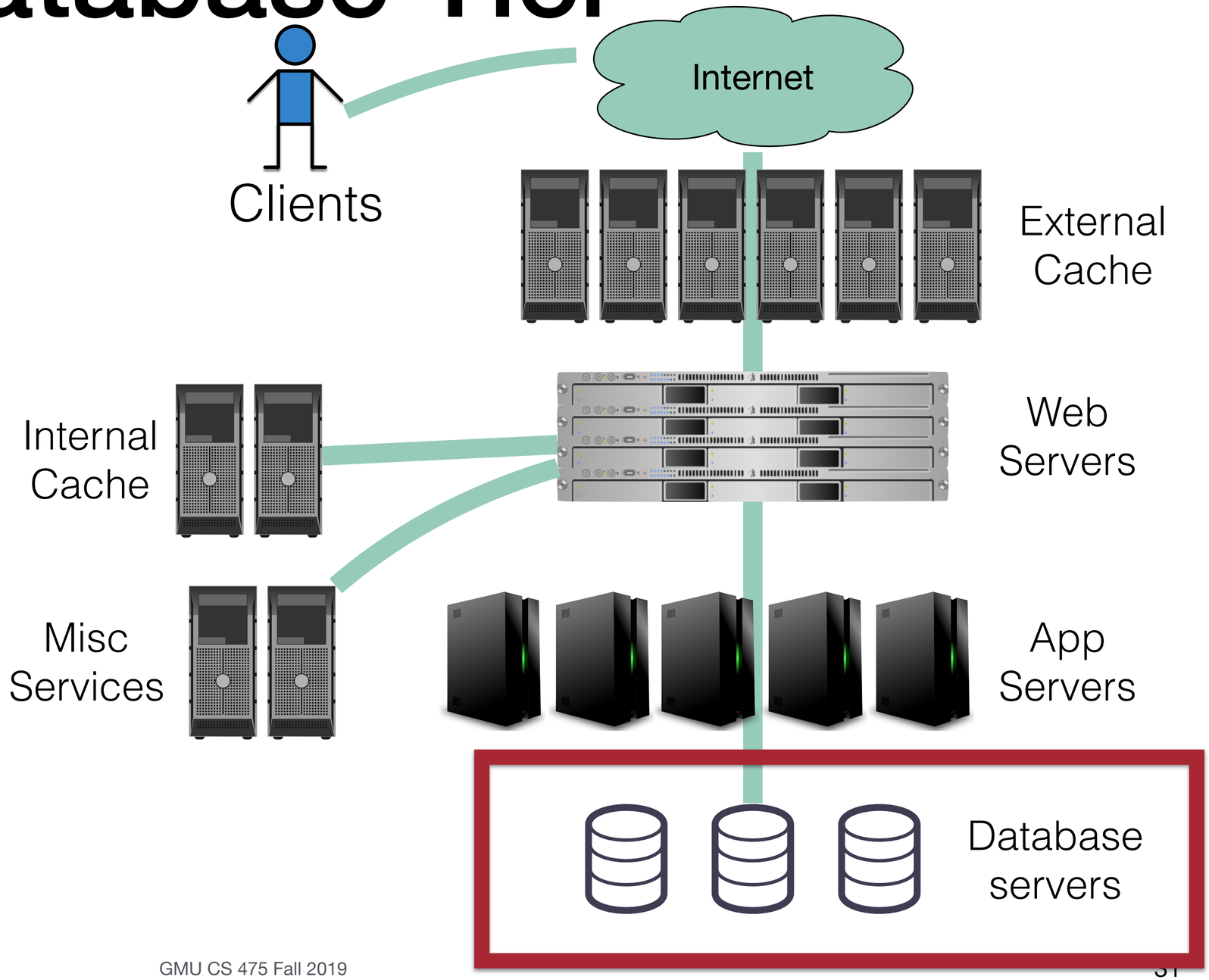
Application Server Tier

- Serves dynamic pages
- Provides internal services
  - E.g. search, shopping cart, account management
- Talks to web tier over..
  - RPC, REST, CORBA, RMI, SOAP, XMLRPC… whatever
- More CPU-bound than any other tier



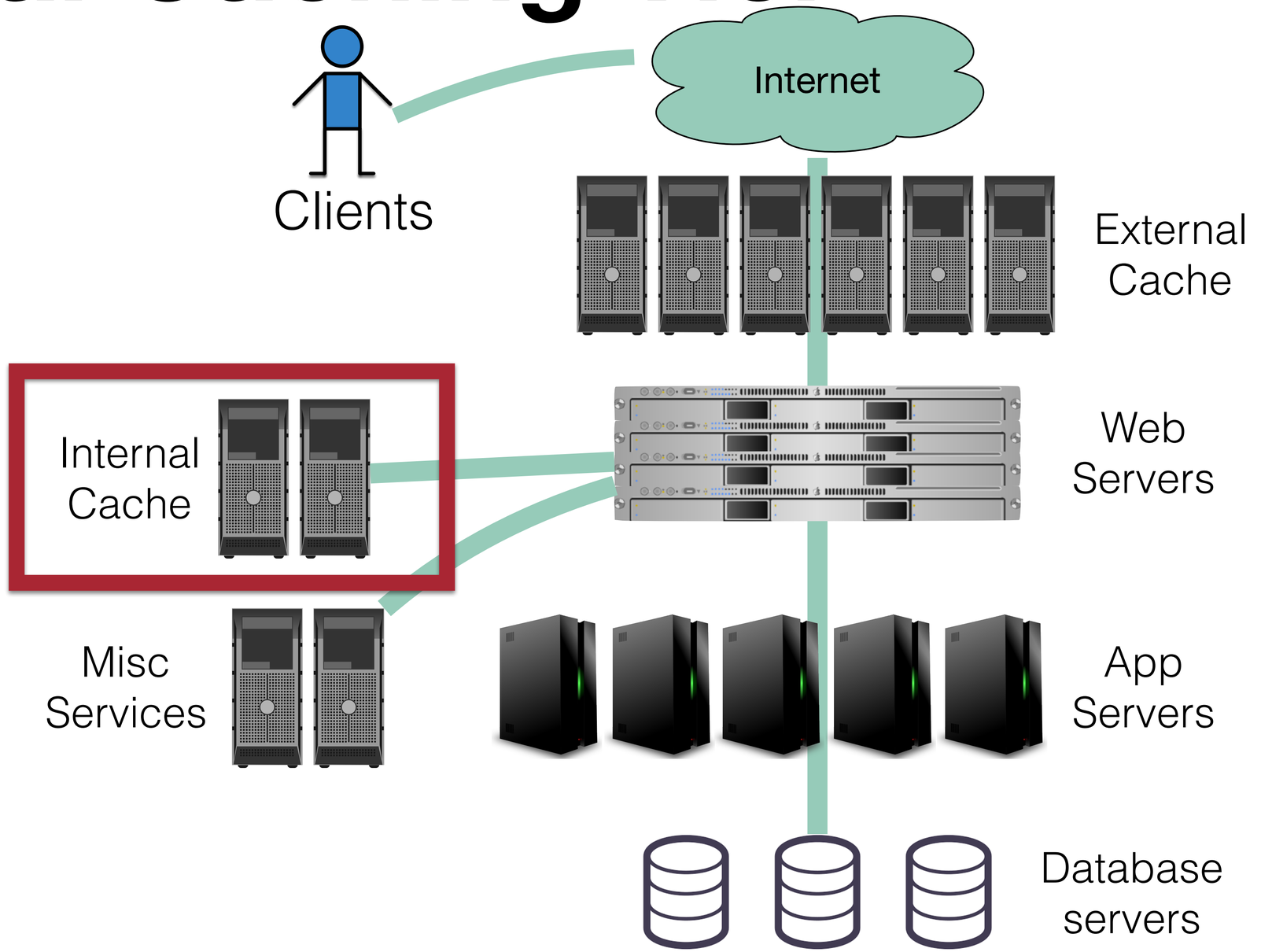
Database Tier

- Relational or non-relational DB
  - PostgreSQL, MySQL, Mongo, Cassandra, etc
- Most storage



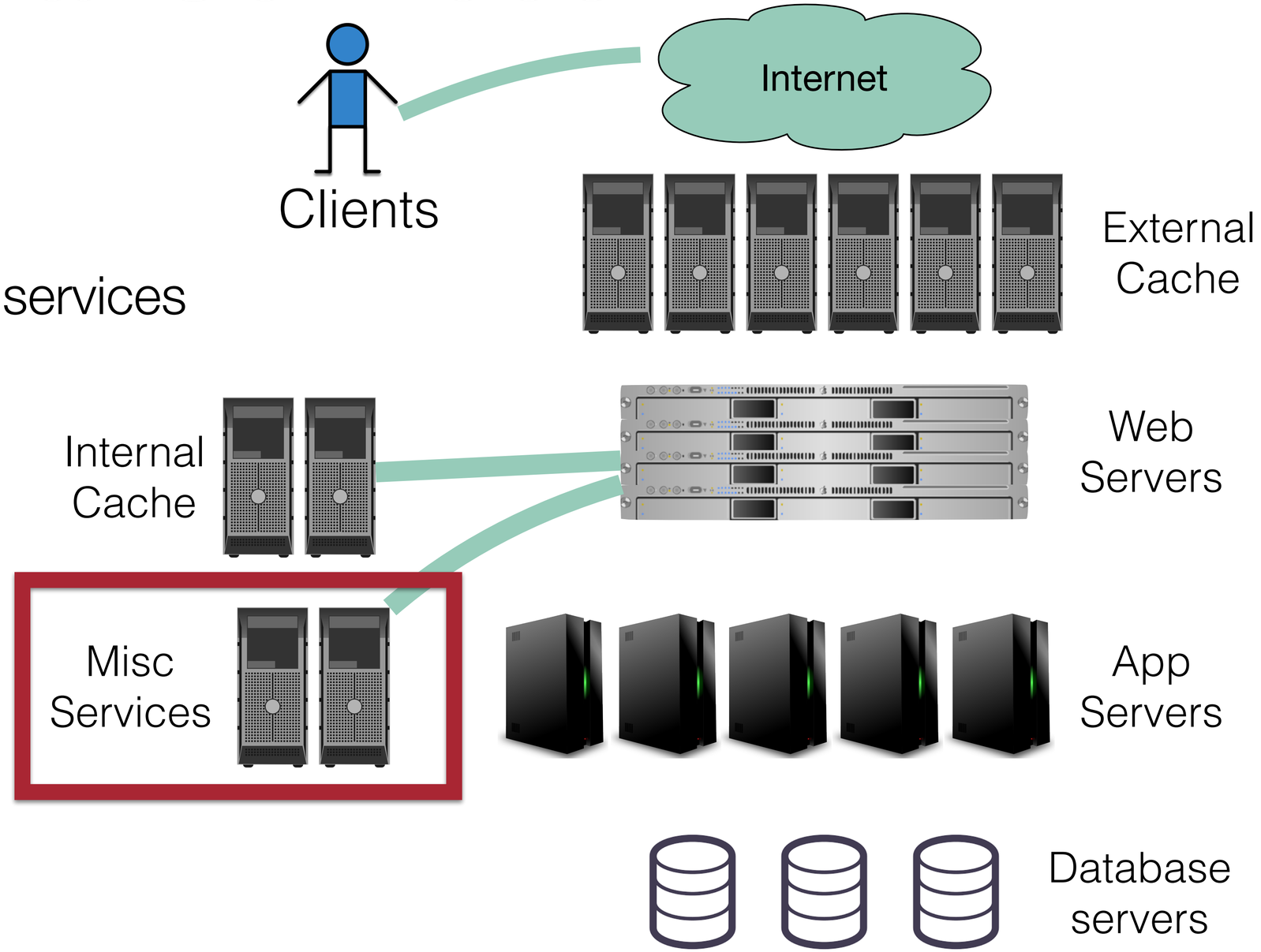
Internal Caching Tier

- Has tons of memory, right near the app servers to cache application-level (dynamic) objects



Internal Services Tier

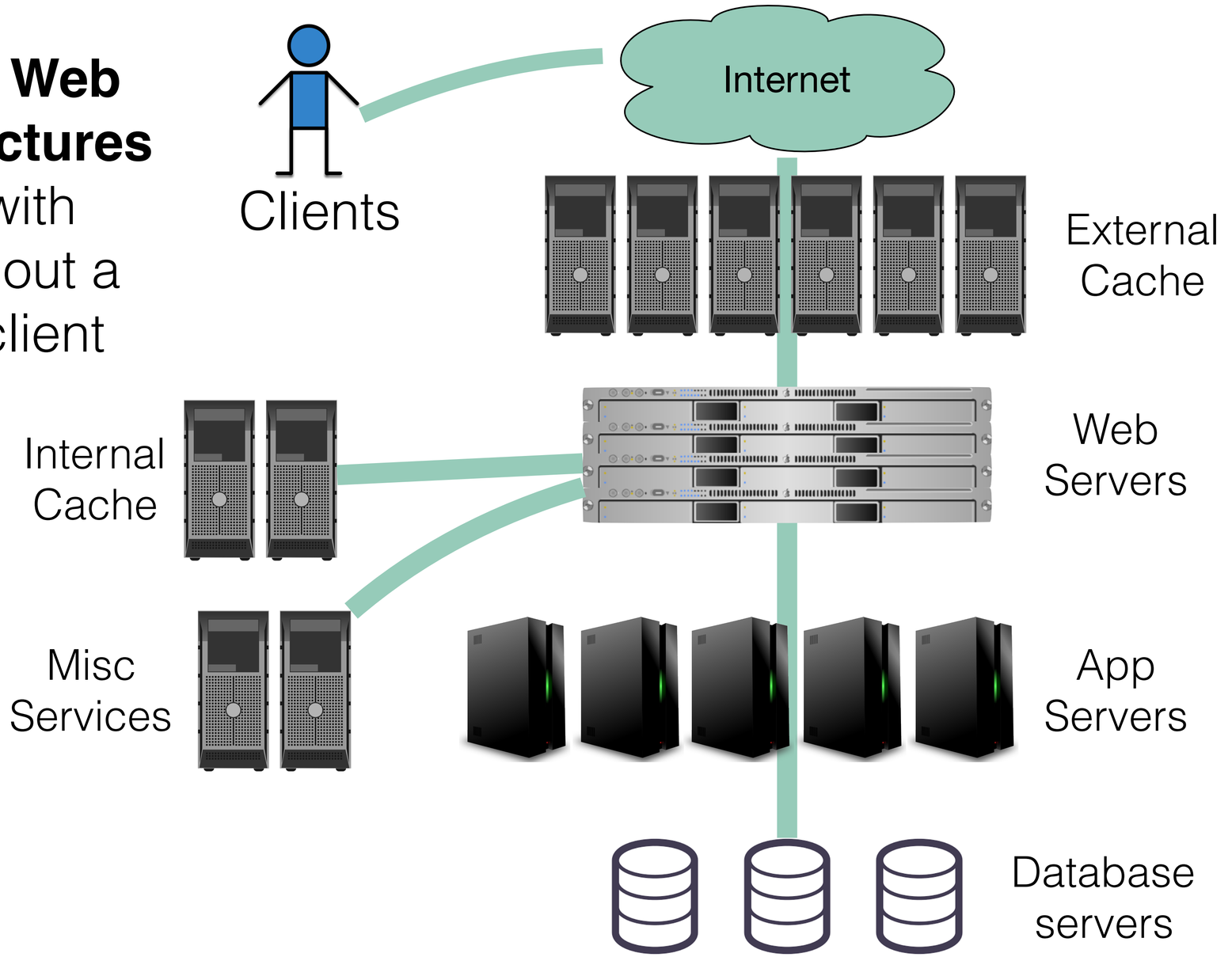
- Coordination services
  - E.g. time keeping
- Monitoring & maintenance services



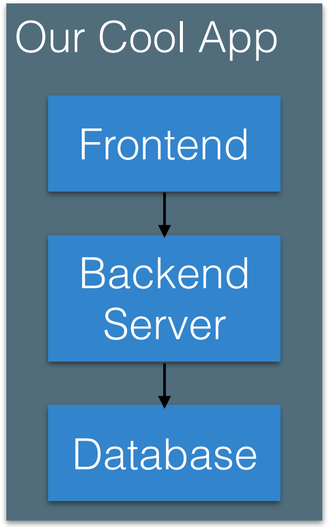
Real Architectures

N-Tier Web Architectures

Separate out responsibilities with abstractions: each tier cares about a different aspect of getting the client their response



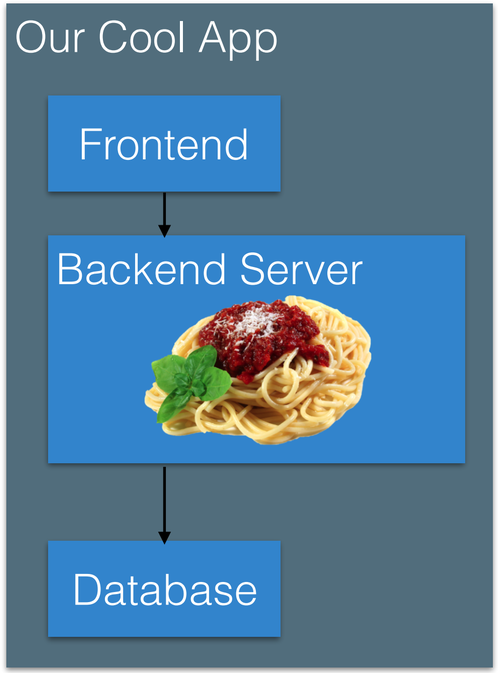
How do we build big apps?



Basic todo app

What happens when we want to add more functionality to our backend?

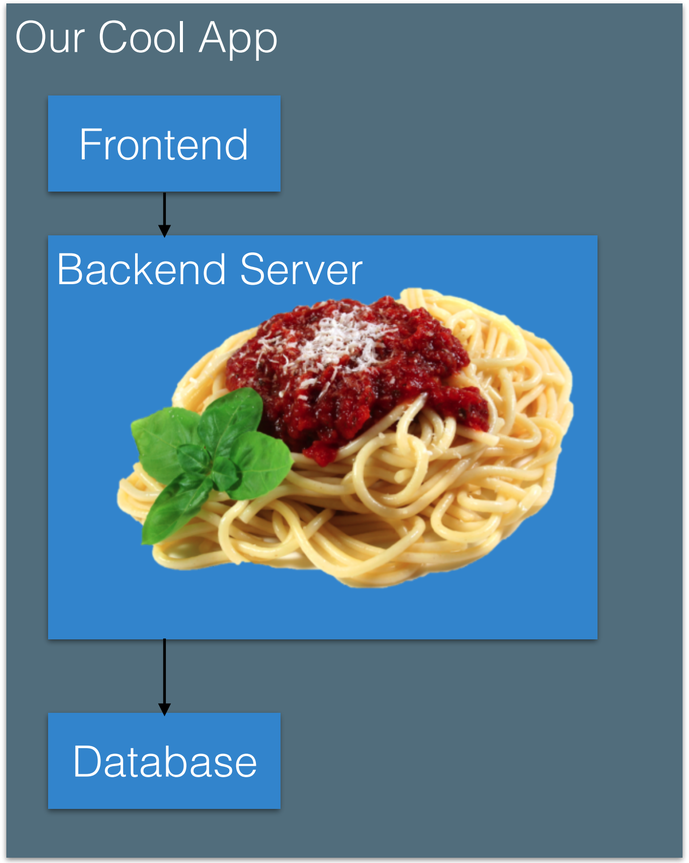
How do we build big apps?



Basic todo app with new feature to email todo reminders

What happens when we add more functionality?

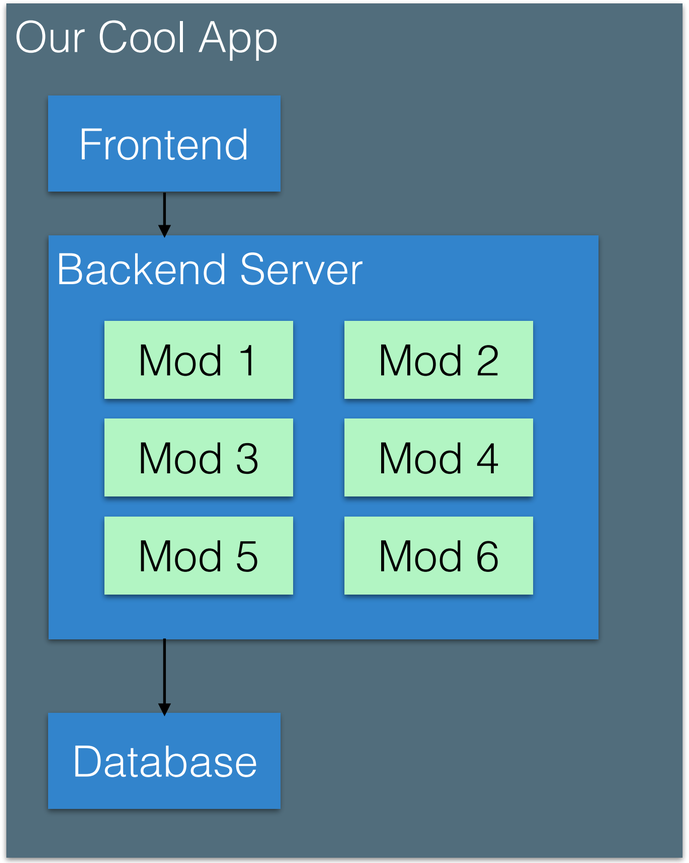
How do we build big apps?



Basic todo app with new feature to email todo reminders PLUS something to find events on Facebook and create Todos for them

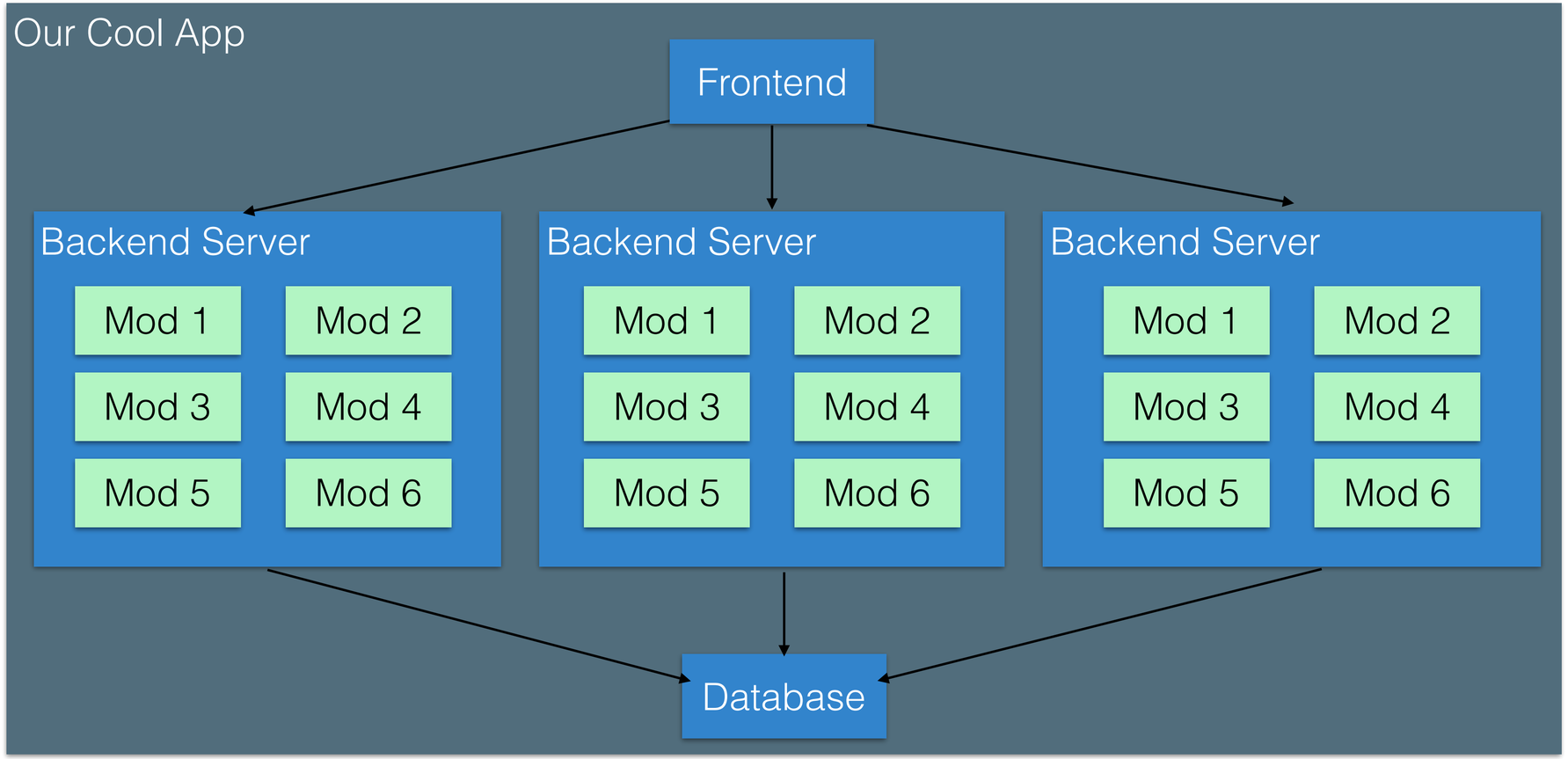
But we're smart, and learned about modules, so our backend isn't total spaghetti but rather…

How do we build big apps?



Sweet: Our backend is not an unorganized mess, but instead just modules. Now how do we scale it? Run multiple backends?

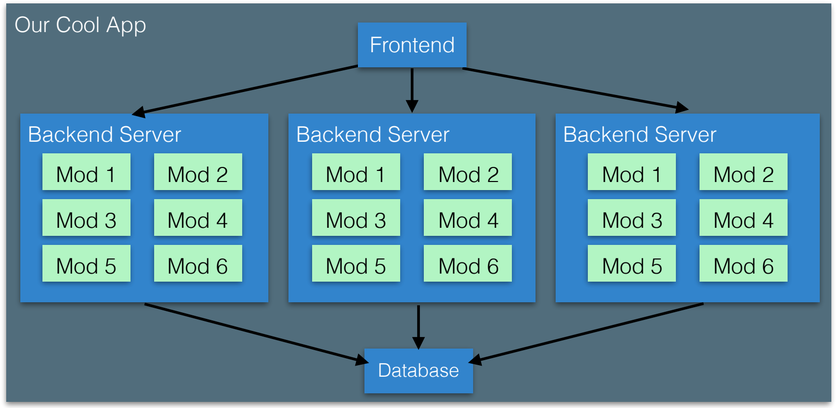
Now how do we scale it?



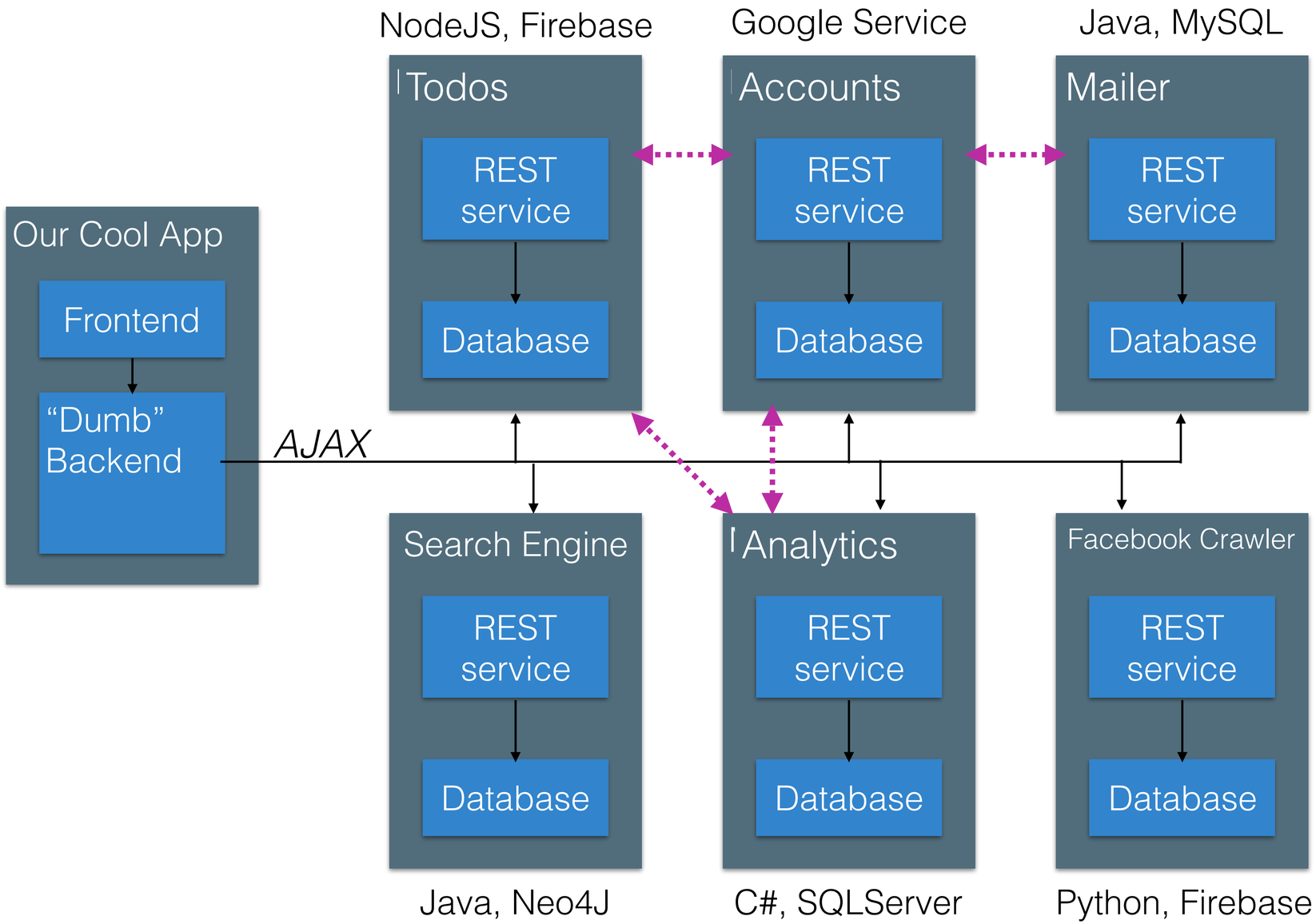
We run multiple copies of the backend, each with each of the modules

What's wrong with this picture?

- This is called the “monolithic” app
- If we need 100 servers…
- Each server will have to run EACH module
- What if we need more of some modules than others?
- How do we update individual modules?
- Do all modules need to use the same DB and language, runtime etc?

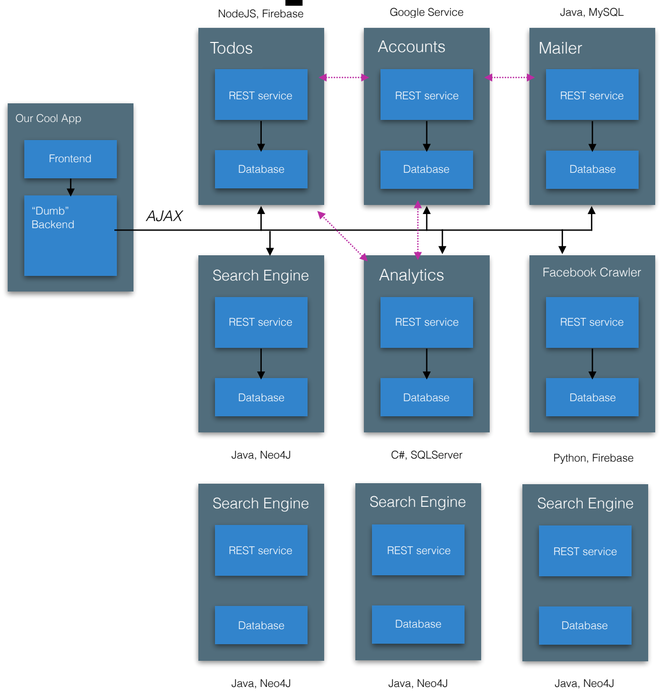


Microservices



What's good about this picture?

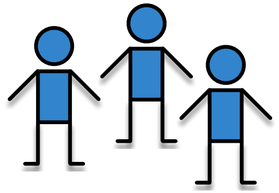
- Spaghetti is contained
- Components can be developed totally independently
  - Different languages, runtimes, OS, hardware, DB
- Components can be replaced easily
  - Could even change technology entirely (or use legacy service)
- Can scale individual components at different rates
  - Components may require different levels of resources



Requirements for successful microservices

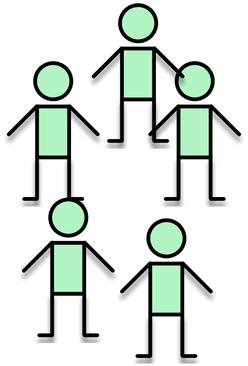
- 1 component = 1 service
- 1 business use case = 1 component
- Smart endpoints, dumb pipes
- Decentralized governance
- Decentralized data management
- Infrastructure automation
- Design for failure
- Evolutionary design

Organization around business capabilities



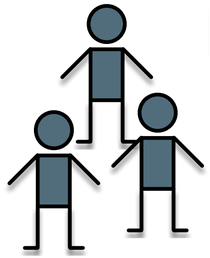
Frontend

Orders, shipping, catalog



Backend

Orders, shipping, catalog

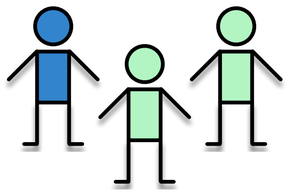


Database

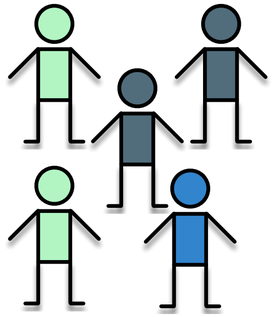
Orders, shipping, catalog

Classic teams:
1 team per “tier”

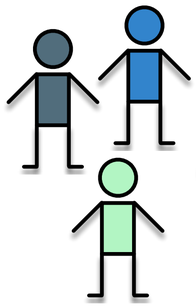
Organization around business capabilities



Orders



Shipping



Catalog

Example: Amazon

Teams can focus on one business task
And be responsible directly to users

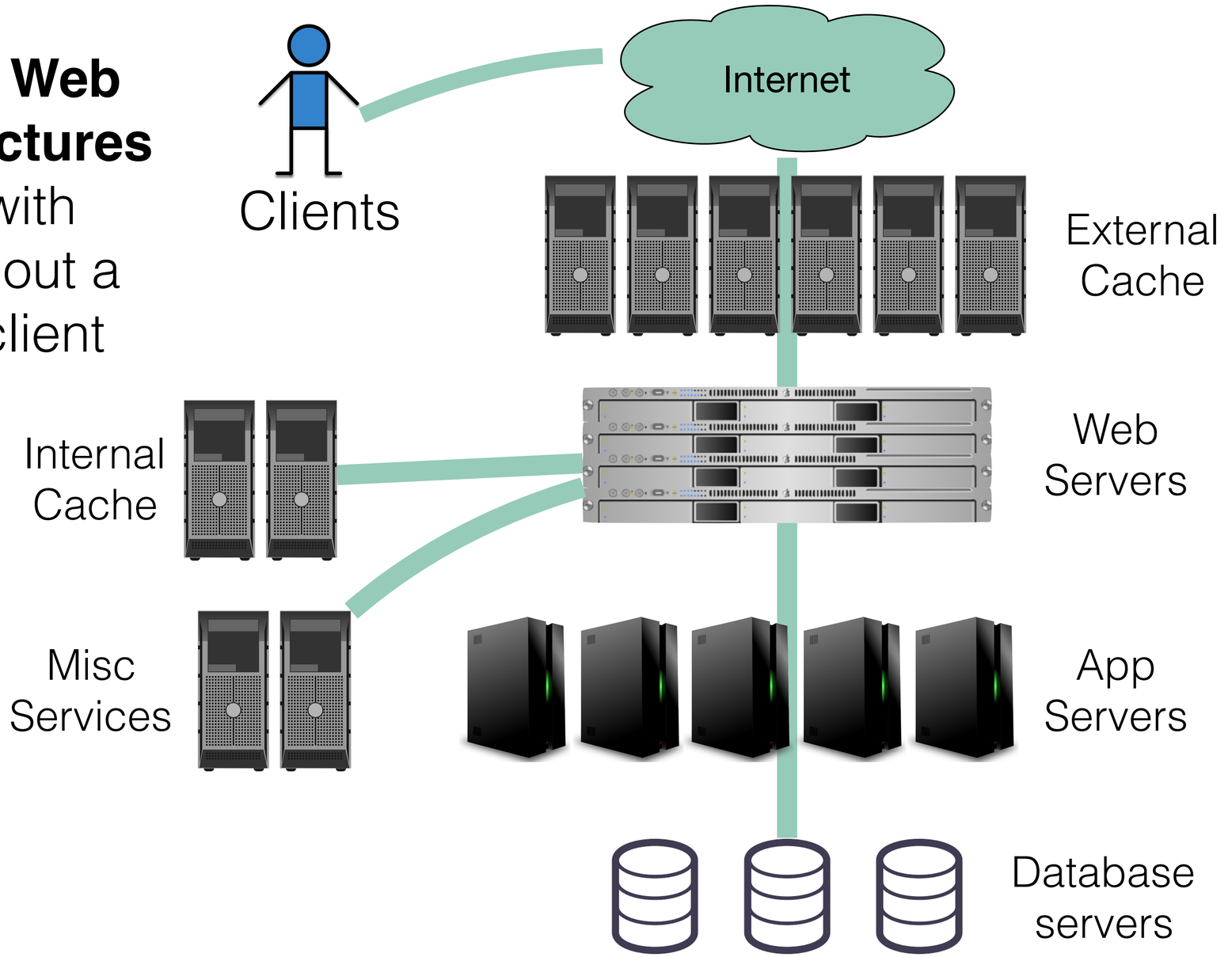
“Full Stack”

“2 pizza teams”

Real Architectures

N-Tier Web Architectures

Separate out responsibilities with abstractions: each tier cares about a different aspect of getting the client their response



Abstracting the tiers

- Take, for instance, this *internal cache*
- Can we build one really good internal cache, and use it for all of our problems?
- What is a reasonable model for the cache?
  - Partition: yes (get more RAM to use from other servers)
  - Replicate: NO (don’t care about crash-failures)
  - Consistency: Problem shouldn’t arise (aside from figuring out keys)

How much more can we abstract our system?

- At its most basic… what does a program in a distributed system look like?
  - It runs concurrently on multiple nodes
  - Those nodes are connected by some network (which surely isn't perfectly reliable)
  - There is no shared memory or clock
- So…
  - Knowledge can be localized to a node
  - Nodes can fail/recover independently
  - Messages can be delayed or lost
  - Clocks are not necessarily synchronized -> hard to identify global order

Back to reality

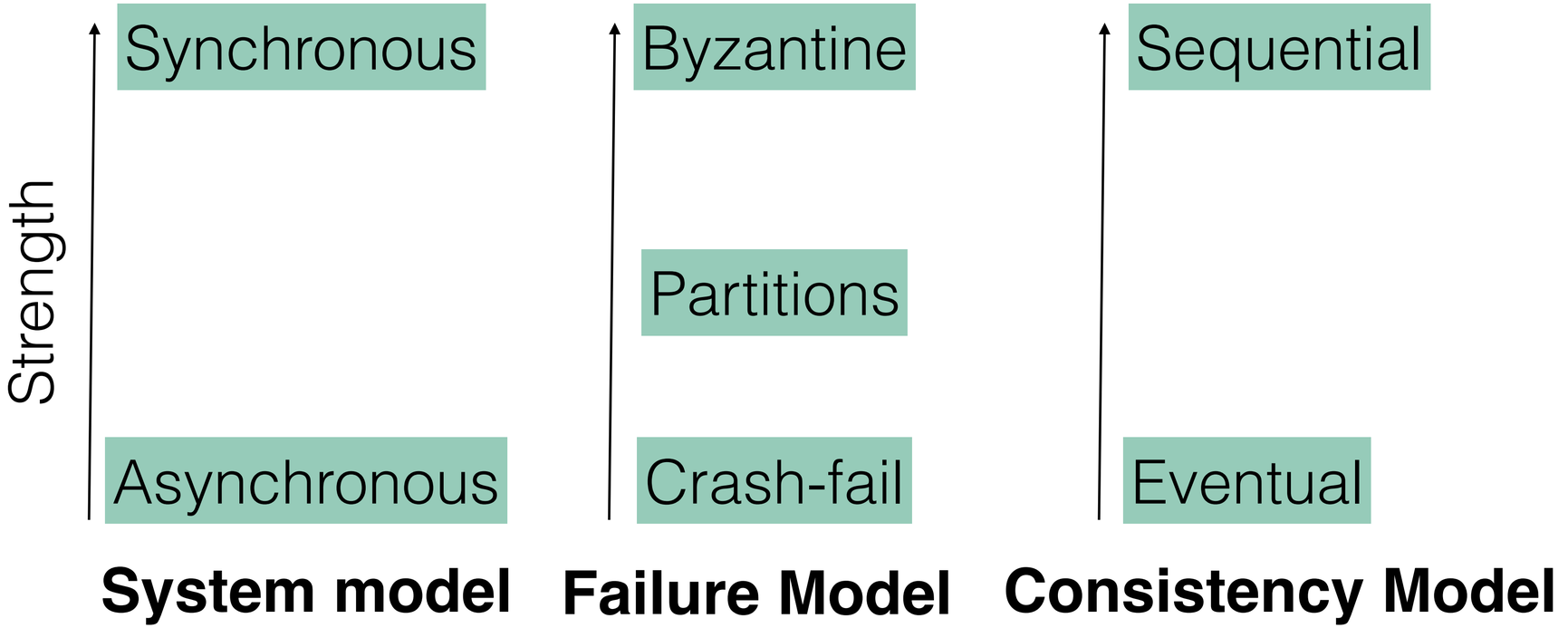
- That's a little TOO abstract - given that system, how can we define a good way to build one?
- In practice, we need to make assumptions about:
  - Node capabilities, and how they fail
  - Communication links, and how they fail
  - Properties of the overall system (e.g. assumptions about time and order)

Designing and Building Distributed Systems

To help design our algorithms and systems, we tend to leverage abstractions and models to make assumptions

Generally: Stronger assumptions -> worse performance

Weaker assumptions -> more complicated



Timing & Ordering Assumptions

- No matter what, there will be *some* latency between nodes processing the same thing
- What model do we assume though?
- Synchronous
  - Processes execute in lock-step
  - We (the designers) have a known upper bound on message transmission delay
  - Each process (somehow) maintains an accurate clock
- Asynchronous
  - Opposite - processes can run out of order, network arbitrarily delayed

Modeling network transmissions

- Assuming how long it can take a message to be delivered helps us figure out what a failure is
- Assume (for instance), messages are always delivered (and never lost) within 1 sec of being sent
- Now, if no response received after 2 sec, we know remote host failed
- Typically NOT reasonable assumptions

Back to synchronous models…

- So, it'll be possible to ensure that one event doesn't occur before another
- It won't be free
  - We need to keep these clocks in sync by sending messages back and forth!
- We now have a new way to fail…
  - If these clock messages start getting dropped

Asynchronous Systems

- The exact opposite
- Do not rely on *any* timing assumptions
- Processes execute at their own rates
- Messages can be delayed indefinitely
- No useful clocks

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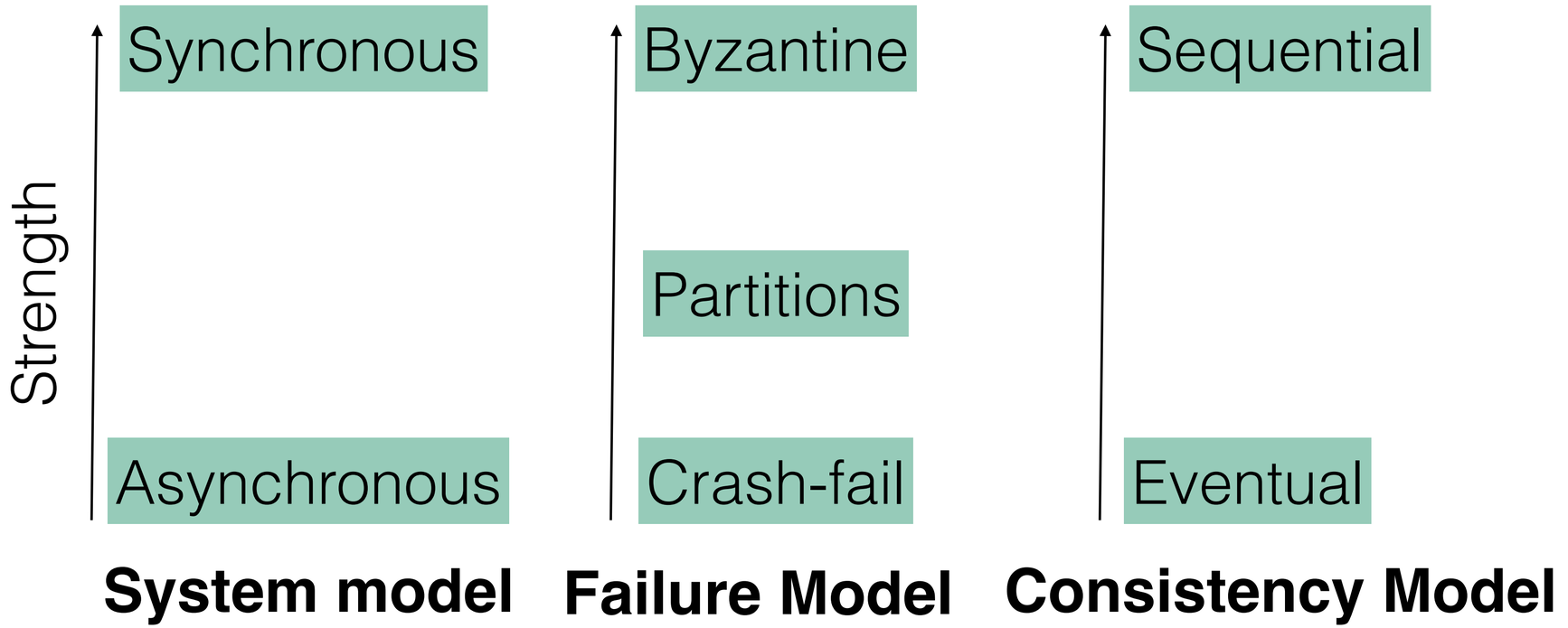
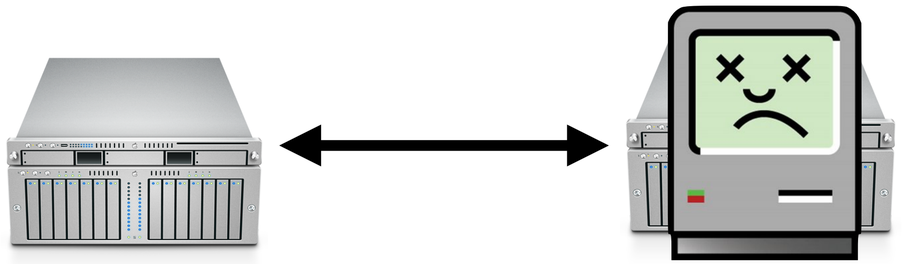


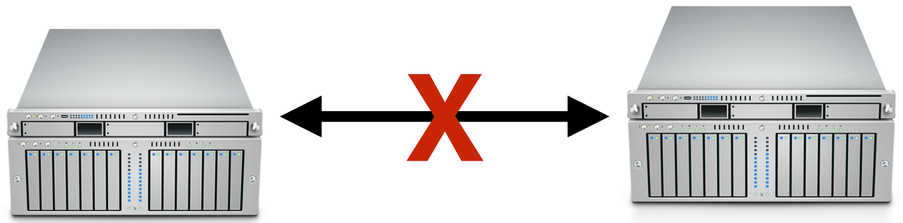
Nodes in our system

- Nodes…
  - Run programs
  - Store data in volatile memory (lost on crash) and stable storage (persists past some crashes)
  - Have some clock (may or may not be accurate)
- Key assumptions:
  - Nodes should typically behave *deterministically* given the same inputs/ messages/system state
  - Nodes are well-behaved, and fail by crashing (which they might be able to self-recover from)

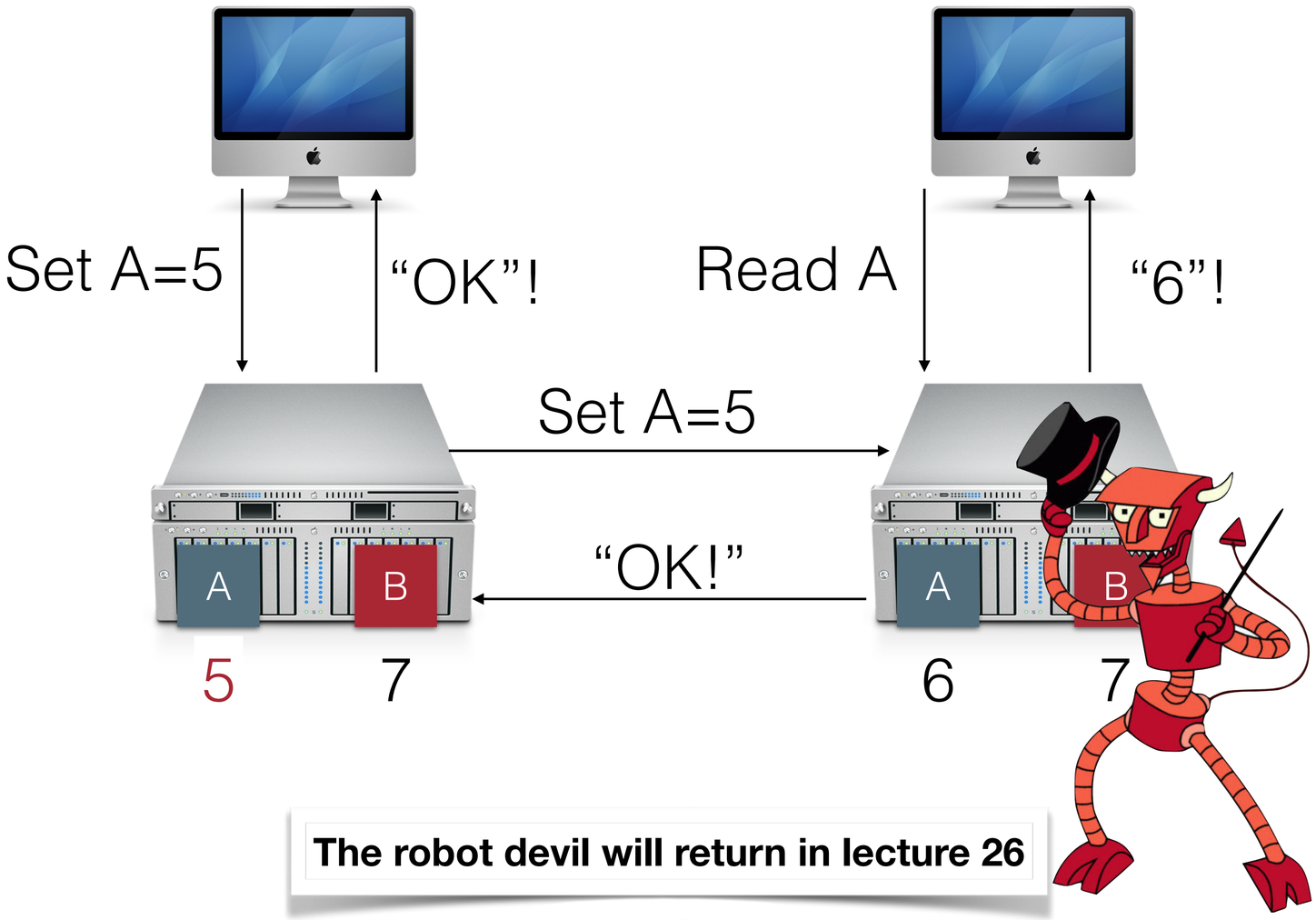


Communication Links in our System

- Does the network ensure ordering?
  - E.g. FIFO
- Is the network reliable?
  - E.g. will all messages eventually be delivered?
- Typically we make no other assumptions about the network
- Fail via *partition*



Byzantine Failures



The robot devil will return in lecture 26

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