CS 4530: Fundamentals of Software Engineering
Module 4: Web Applications

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Learning Goals for this Lesson

At the end of this lesson, you should be able to

- Explain the role of "client" and "server" in the context of web application programming
- Explain the role of REST versus WebSocket communication
- Describe the fundamental differences between the three layers of the controller, service, and repository layers in a C-S-R architecture
- Understand how the C-S-R architecture works in the context of a basic Express application
- Be able to answer an interview question about "business logic," "horizontal and vertical scaling," or "microservices"

So, software engineering must encompass:

	PEOPLE	PROCESSES	PROGRAMS
PLANNING			
ORGANIZING			
IMPLEMENTING			

We’re gonna be stuck over here for a bit.

Web Applications are Distributed Systems

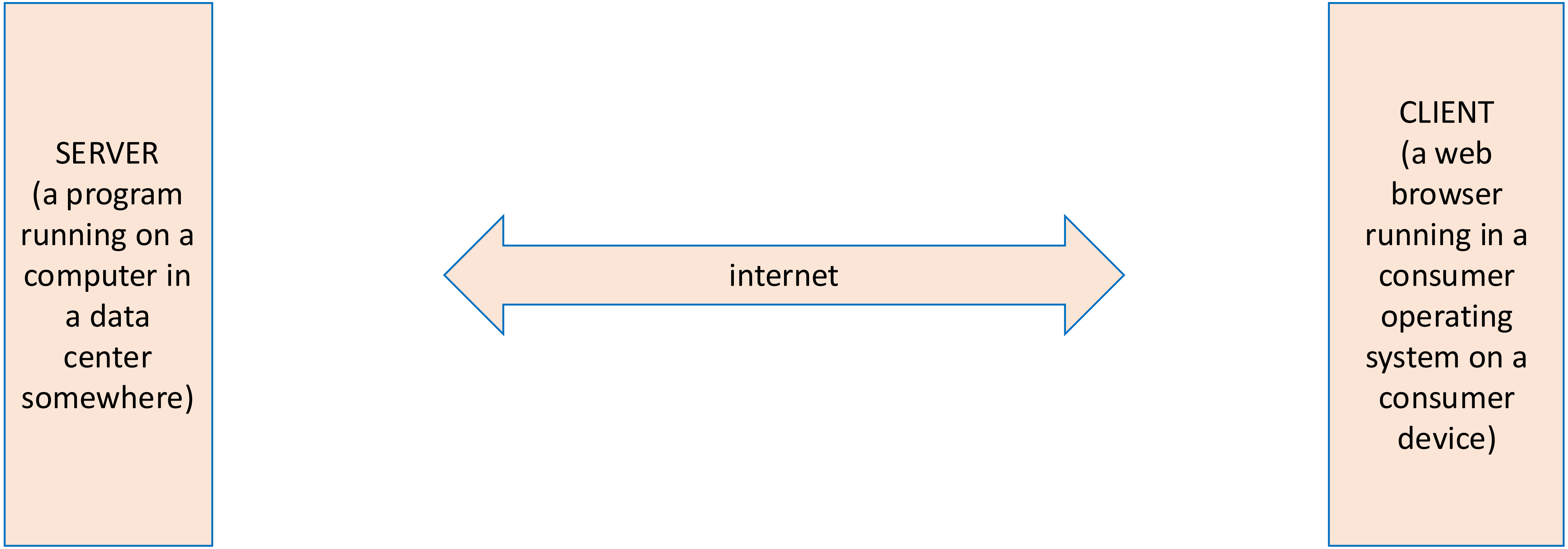
Distributed systems are hard!

- Web applications are designed to only be *kinda* difficult-to-build distributed systems
- Most of this lecture is bad advice if you're Google, Netflix, or Amazon

Web applications are distributed systems *because*

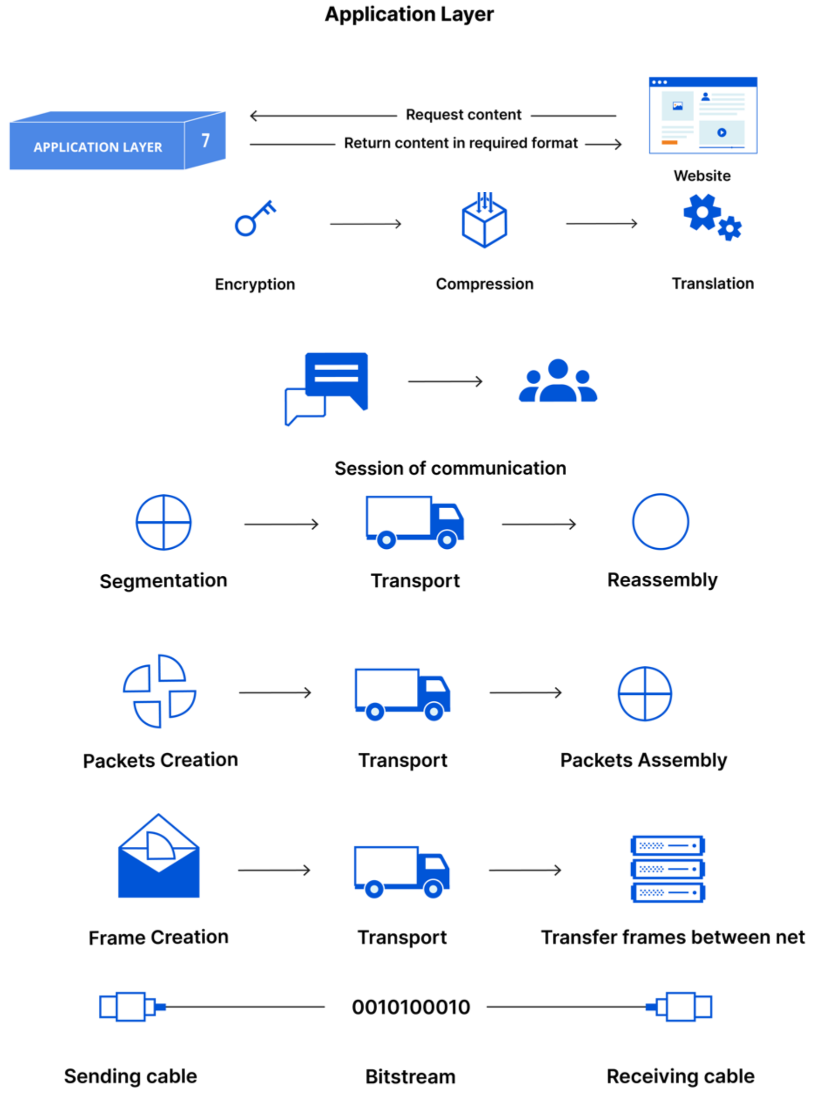
1. You don't live in the cloud
2. Scalability: Netflix needs at *least* two computers

An Insultingly Shallow Intro to Networking



Networking is a Big Stack Of Layered Abstractions

SERVER
(a program running on a computer in a data center somewhere)



CLIENT
(a web browser running in a consumer operating system on a consumer device)

https://www.cloudflare.com/learning/ddos/glossary/open-systems-interconnection-model-osi/

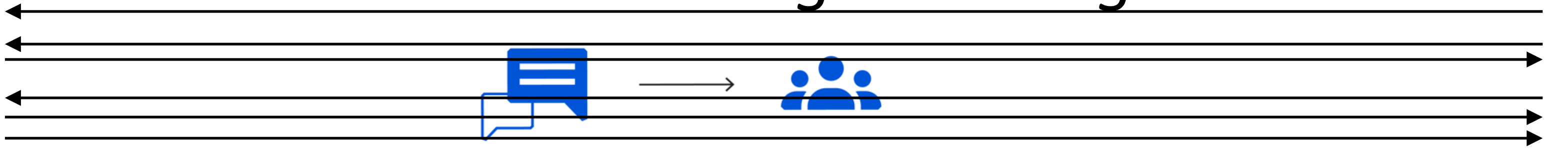
The Transport Networking Layer Provides Message Sending Abstraction

SERVER
(a program running on a computer in a data center somewhere)

Transport Layer

- TCP you may have heard of
- UDP you don’t need for this class
- QUIC is new

Abstraction: *sending a message*



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(a web browser running in a consumer operating system on a consumer device)

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The Application Layer Builds HTTP on Top of Transporting Messages

Remote procedure calls happen via HTTP requests

SERVER (a program running on a computer in a data center somewhere)

CLIENT (a web browser running in a consumer operating system on a consumer device)

GET `/`

ok here you go (status 200, payload `<!doctype html><html lang="en`...)

GET `/favicon.svg`

ok here you go (status 200, payload `<svg width="450" height="450" viewBox="`...)

POST `/api/user/login`, payload `{"username":"user1","password":"password"}`

ok here you go (status 200, payload `{"error":"Invalid username or password"}`)

The Application Layer Builds HTTP on Top of Transporting Messages

Remote procedure calls happen via HTTP requests

SERVER
(a program running on a computer in a data center somewhere)

CLIENT
browser running in a consumer operating
consumer device)

GET /

ok here you go (status 200, payload `<!doctype html><html lang=“en...`)

```
curl 'https://gamenite.onrender.com/'
```

GET `/favicon.svg`

ok here you go (status 200, payload `<svg width="450" height="450" viewBox="...`)

```
curl 'https://gamenite.onrender.com/favicon.svg'
```

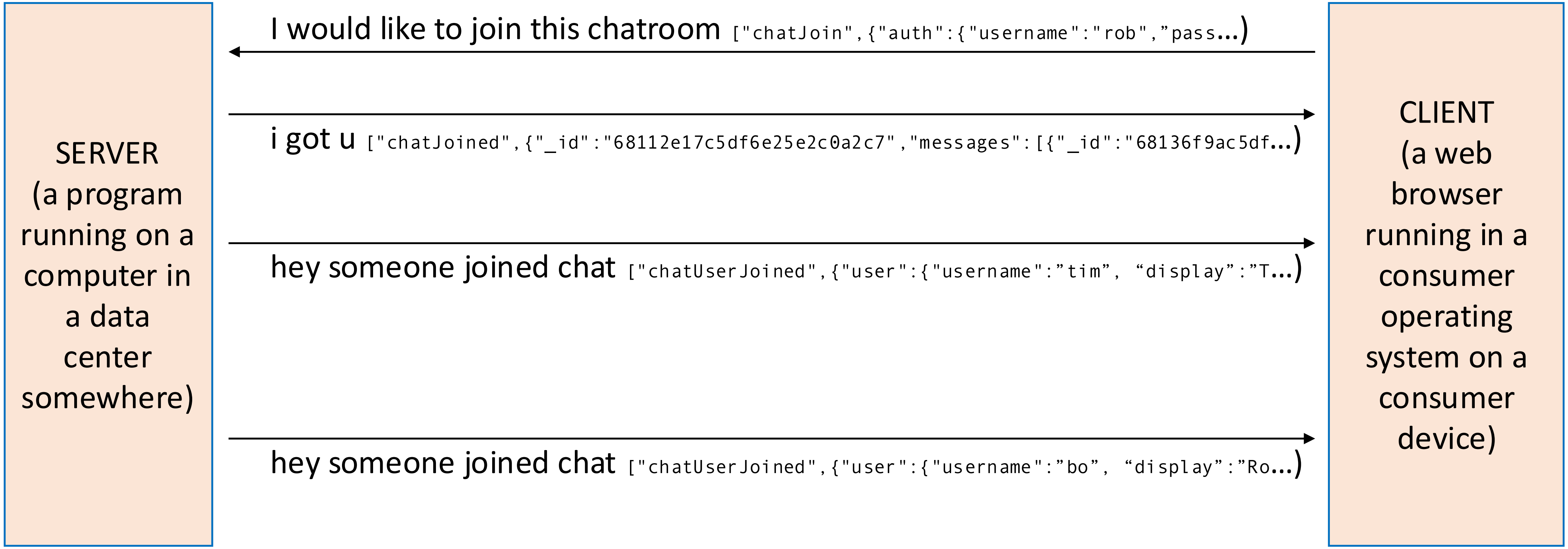
POST `/api/user/login`, payload `{"username":"user1","password":”password"}`

ok here you go (status 200, payload `{"error":"Invalid username or password"}`)

```
curl 'https://gamenite.onrender.com/api/user/login' \
  -H 'content-type: application/json' \
  --data '{"username":"user1","password":"password"}'
```

The Application Layer Builds WebSockets on Top of Transporting Messages

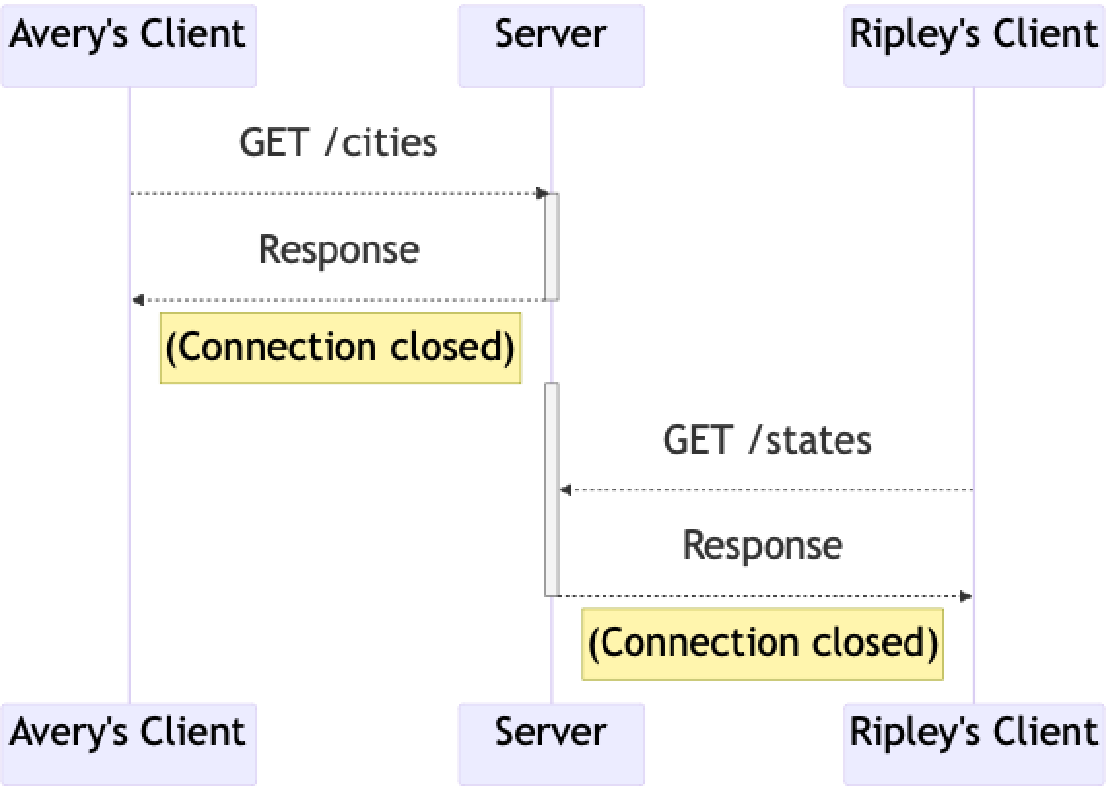
Message Passing happen via WebSockets



Application Layer Abstractions: RPC/REST API versus WebSockets

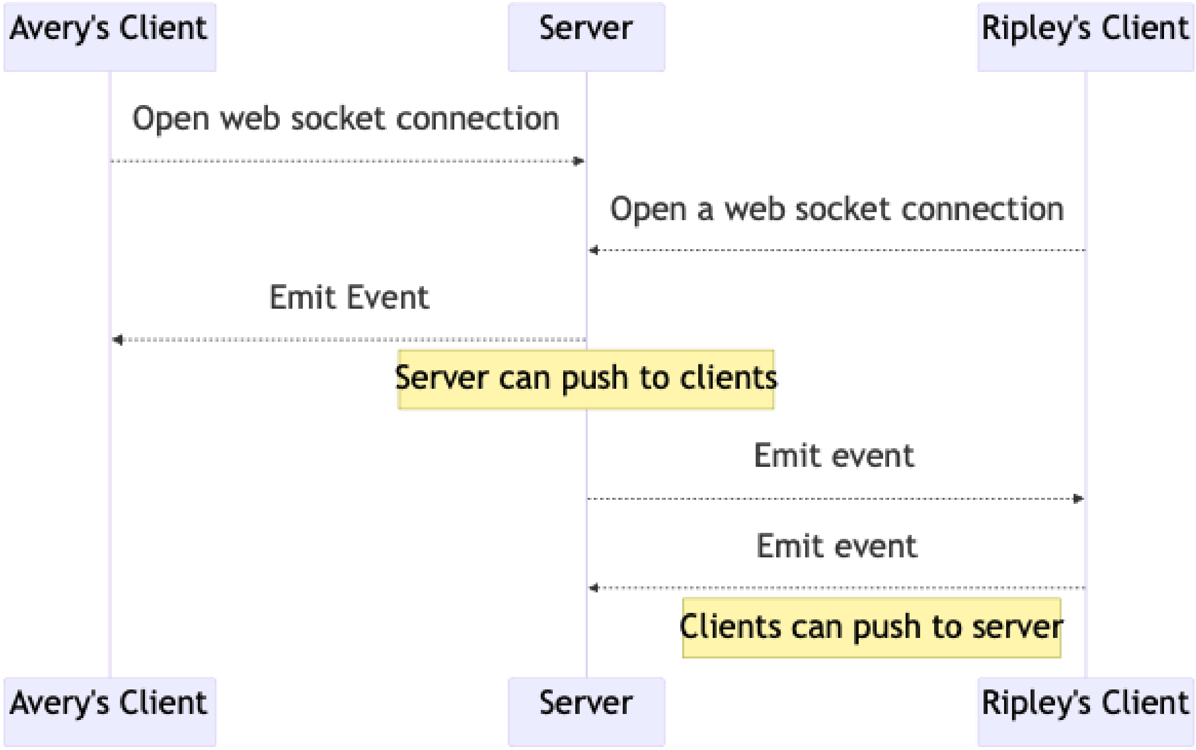
REST

(one-way, client initiates)



Web Sockets

(two-way after client opens socket)



RPC/REST in Express

How implementing RPC/REST looks for an Express server

SERVER
(a program running on a computer in a data center somewhere)

POST /api/user/login, payload `{"username":"user1","password":”password"}`

ok here you go (status 200, payload `{"error":"Invalid username or password"}`)

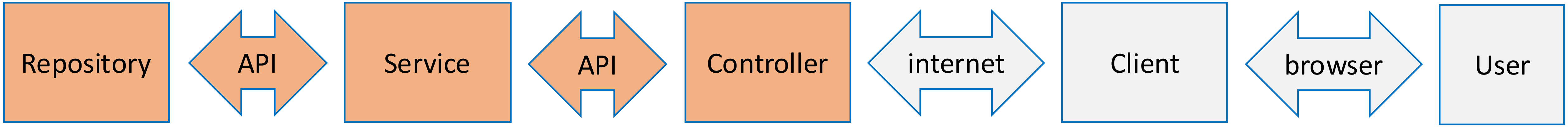
CLIENT

```
import express from 'express’;

let numLogins = 0;
const app = express();
app.use(express.json());
app.post('/api/user/login', (request, response) => {
  const { username, password } = request.body;
  if (username.toLowerCase() === 'user1' && password === 'sekret') {
    response.send({ success: true, numLogins: ++numLogins });
  } else {
    response.send({ error: 'Invalid username or password' });
  }
});
```

Preview: three parts of a web server

- The Controller-Service-Repository design separates the server into three parts
  - The **controller** knows how we communicate with client, doesn't know how we store data
  - The **service** doesn't know how we connect to the client or store data, but does as much of the interesting work ("business logic") as possible without knowing these things
  - The **repository** is the only part stores information long-term



The Controller: Knows about HTTP

```
// app.ts
import express from 'express';
import * as user from './controller.ts';
const app = express();
app.use(express.json());
app.post('/api/user/login', user.postLogin);

// controller.ts
import type { Request, Response } from 'express';
let numLogins = 0;


function postLogin(request: Request, response: Response) {
  const { username, password } = request.body;
  if (username.toLowerCase() === 'user1' && password === 'sekret') {
    response.send({ success: true, numLogins: ++numLogins });
  } else {
    response.send({ error: 'Invalid username or password' });
  }
};
```

The Controller (with Zod Validation)

```typescript
// controller.ts
import type { Request, Response } from 'express';
import { z } from 'zod';

let numLogins = 0;
const zLoginReq = z.object({ username: z.string(), password: z.string() });
export function postLogin(request: Request, response: Response) {
  const auth = zLoginReq.safeParse(request.body);
  if (!auth.success) {
    response.send({ error: 'Bad request' });
  } else if (auth.data.username.toLowerCase() === 'user1' && auth.data.password === 'secret') {
    numLogins += 1;
    response.send({ success: true, numLogins });
  } else {
    response.send({ error: 'Invalid username or password' });
  }
};
```

The Controller Relies on the Service Layer

```
// controller.ts
import type { Request, Response } from 'express';
import { z } from 'zod';
import { isAuthorized, incrementLogins } from './service.ts';

const zLoginReq = z.object({ username: z.string(), password: z.string() });
export function postLogin(request: Request, response: Response) {
 const auth = zLoginReq.safeParse(request.body);
  if (!auth.success) {
    response.send({ error: 'Bad request' });
  } else if (isAuthorized(auth.data.username, auth.username.password)) {
    const numLogins = incrementLogins();
    response.send({ success: true, numLogins });
  } else {
    response.send({ error: 'Invalid username or password' });
  }
};
```

The controller should validate inputs

The controller should decide what kind of response we give

The Service Layer Has Most of the Business Logic

```
// service.ts

export function isAuthorized(username: string, password: string) {
  return username.toLowerCase() === 'user1' && password === 'secret'
}

let numLogins = 0;
export function incrementLogins() {
  const oldNumLogins = numLogins;
  numLogins += 1;
  return oldNumLogins;
}
```

- What user needs *aren't* being met here (and in the IP1 starter code?)

(Change password? Save numLogins when rebooting?)

- How can we do better?

(Add a database)

The Repository Layer Provides Persistence

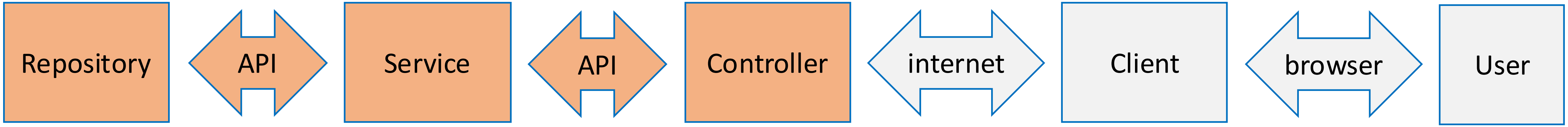
- Logins should be cumulative even if we restart the server
- Adding users and changing passwords shouldn’t necessarily require updating code
- Lots of ways to achieve this:
  - MongoDB
  - PostgreSQL
  - SQLite
  - A file on the hard drive

Foreshadowing

- Adding a persistent repository makes one big difference!
  - almost every action that reads or writes data is now *hundreds* of times slower, and involves reading to disk
  - this involves a relatively long delay, during which the CPU isn’t doing anything useful
- JavaScript handles this with *asynchronous programming*; that’s a topic we’ll return to in a few weeks.

Review: three parts of a web server

- The **repository** is the only part that stores information long-term
  - This is pretty much a synonym for “database”
- The **service** doesn’t know how we connect to the client
  - HTTP? REST? WebSockets? The service shouldn’t know!
  - Business logic lives here
- The **controller** doesn’t know how we store data
  - Controller knows if we’re or storing things in a database or in memory (like IP1)



Review: three parts of a web server

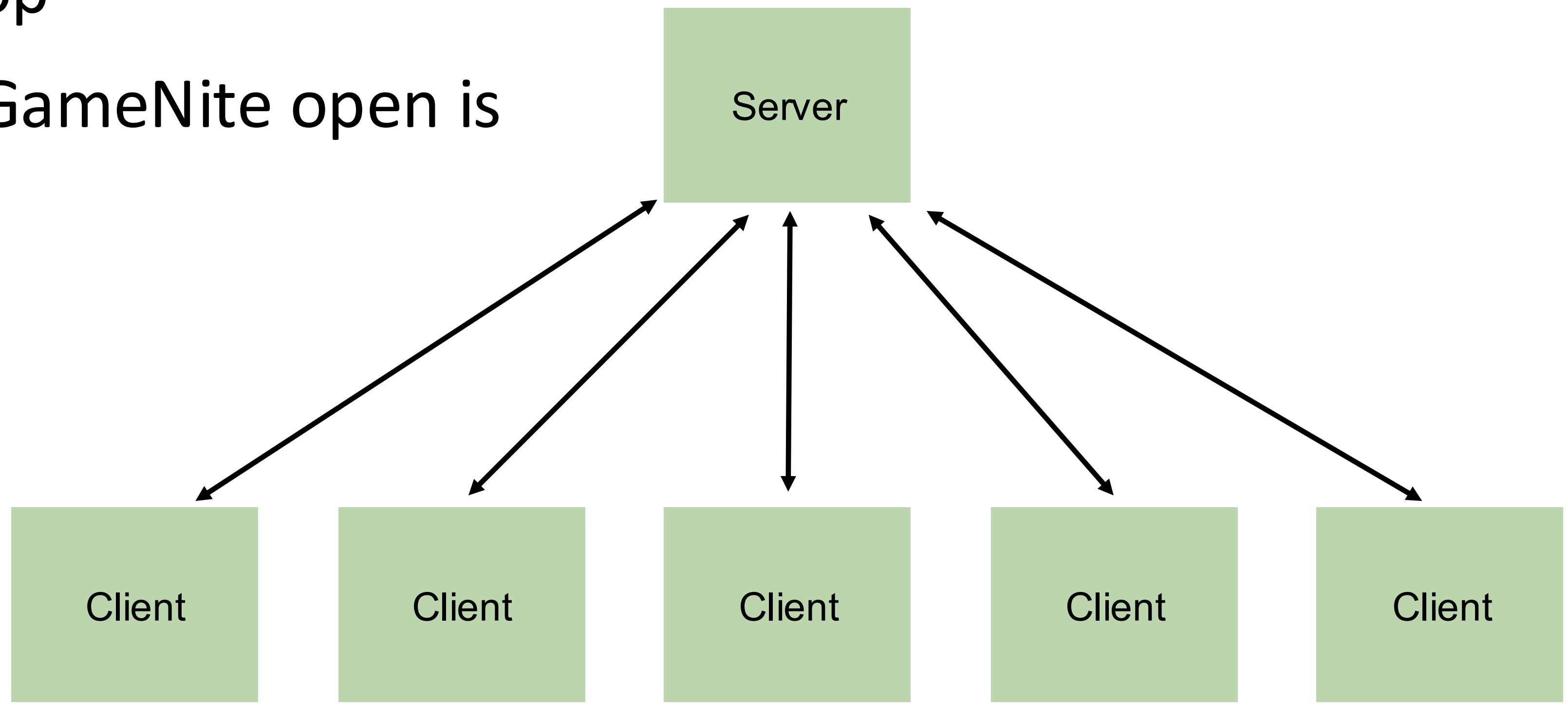
- Everything we saw from the transcript server is the **business logic** — a *boring-sounding* name that refers to most of the *interesting* stuff a web server does
  - "Is this HTTP request coming from a recognized user?" — not business logic
  - "Does this user have permission to access student records" — business logic!
  - "Do new grades go at the front or back of the list" — business logic!

Testing Controller-Service-Repository Servers

- We can test at both the service layer and the controller layer
  - What are the pros and cons of each?
- Sometimes we'll want to test the service layer and/or controller layer *without* the repository layer!
  - We'll come back to this.

Web Applications: One Server, Many Clients

- We've mostly ignored so far that one server is supposed to connect to many clients
- This isn't always apparent when everything's running on your laptop
- Each web page with GameNite open is a different client



Web Applications and Scalability

Distributed systems are hard!

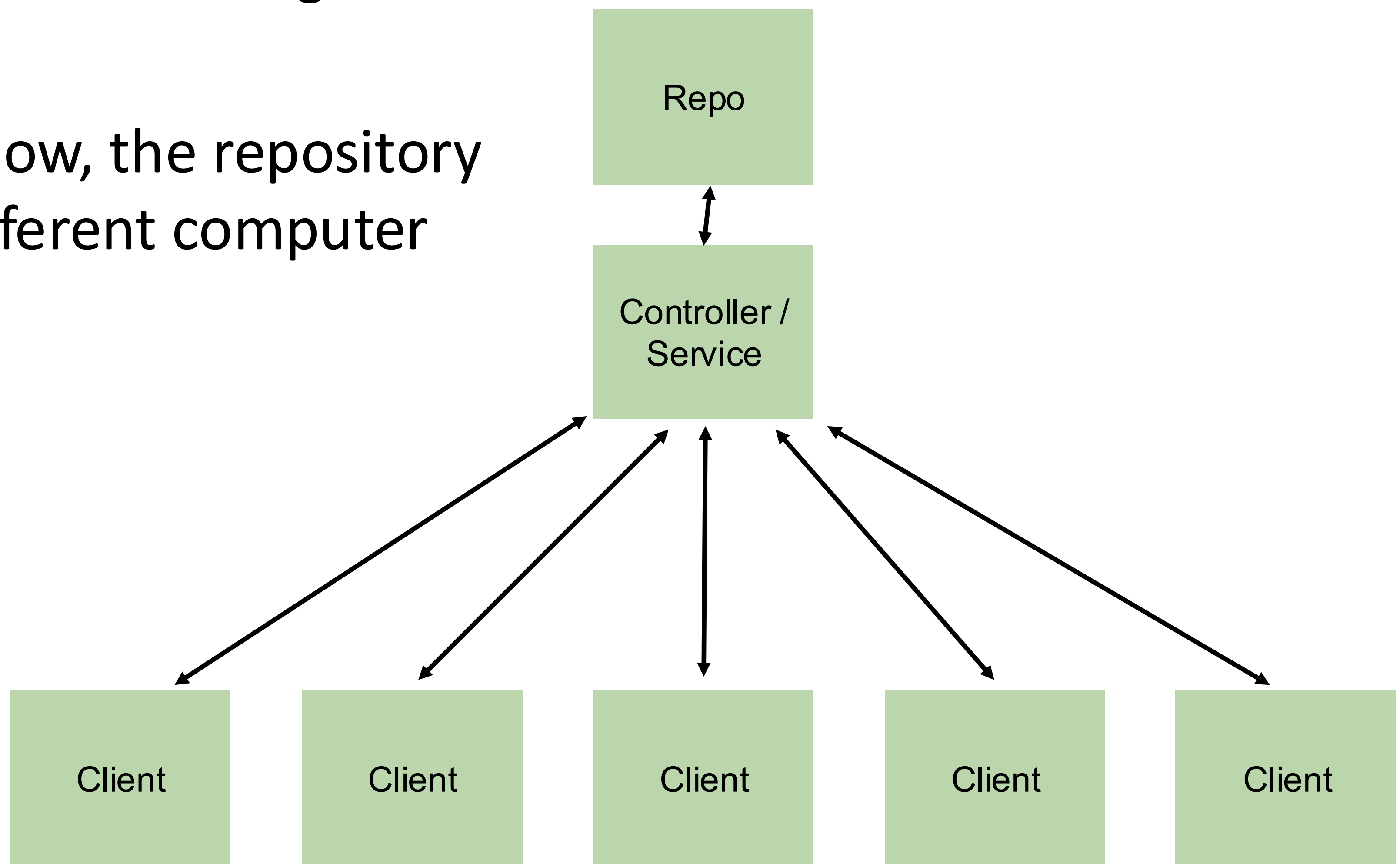
- Web applications are designed to only be *kinda* difficult-to-build distributed systems
- Most of this lecture is bad advice if you're Google, Netflix, or Amazon

Web applications are distributed systems *because*

1. You don't live in the cloud
2. **Scalability: Netflix needs at *least* two computers**

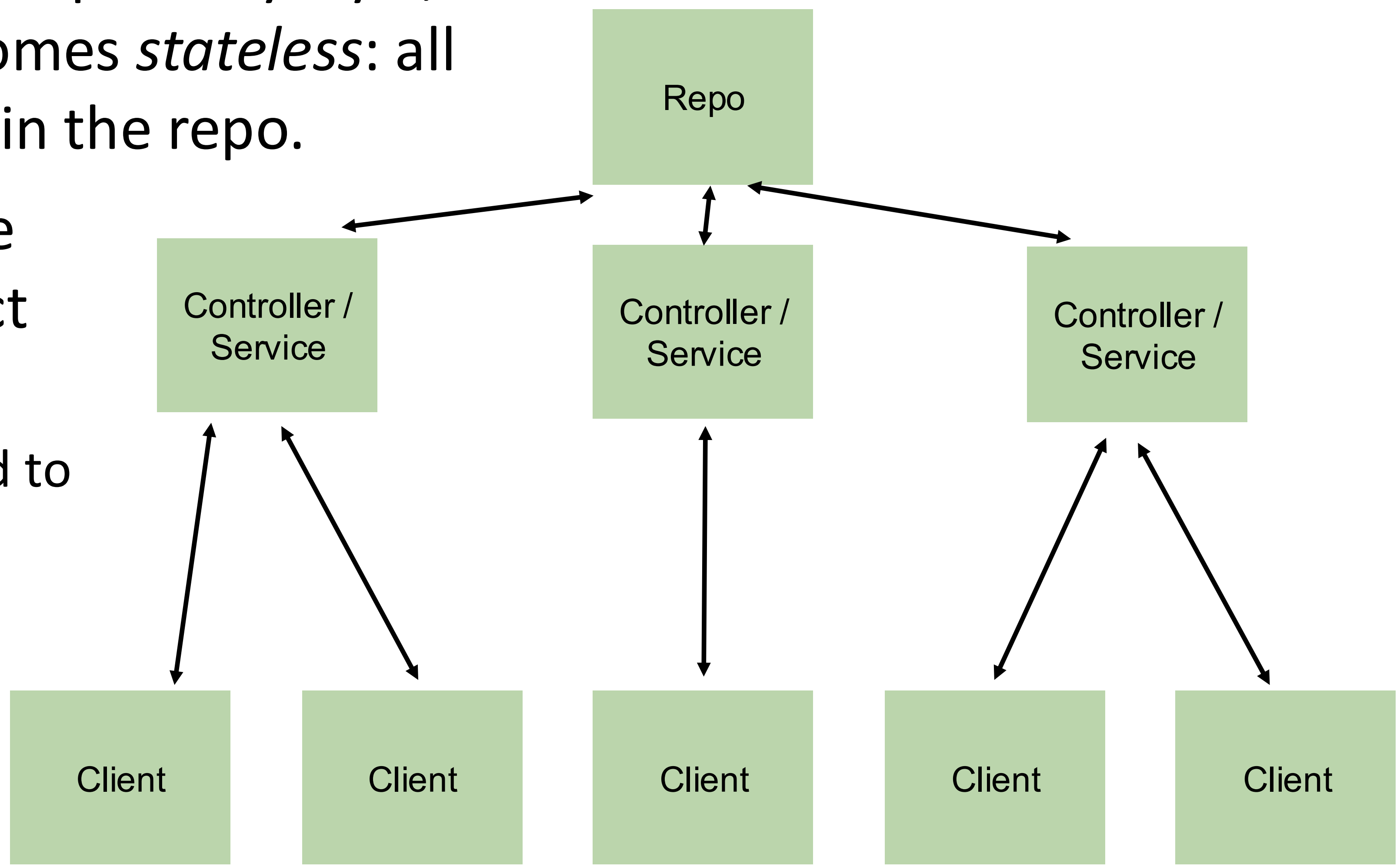
Scaling The C-S-R Architecture

- Web services often start on a single computer
- When that gets too slow, the repository is easy to put on a different computer



Horizontal Scaling

- By separating out the repository layer, the service layer becomes *stateless*: all the state it uses lives in the repo.
- Multiple copies of the controller can connect to multiple clients!
  - AWS will be delighted to help, only real limit is money

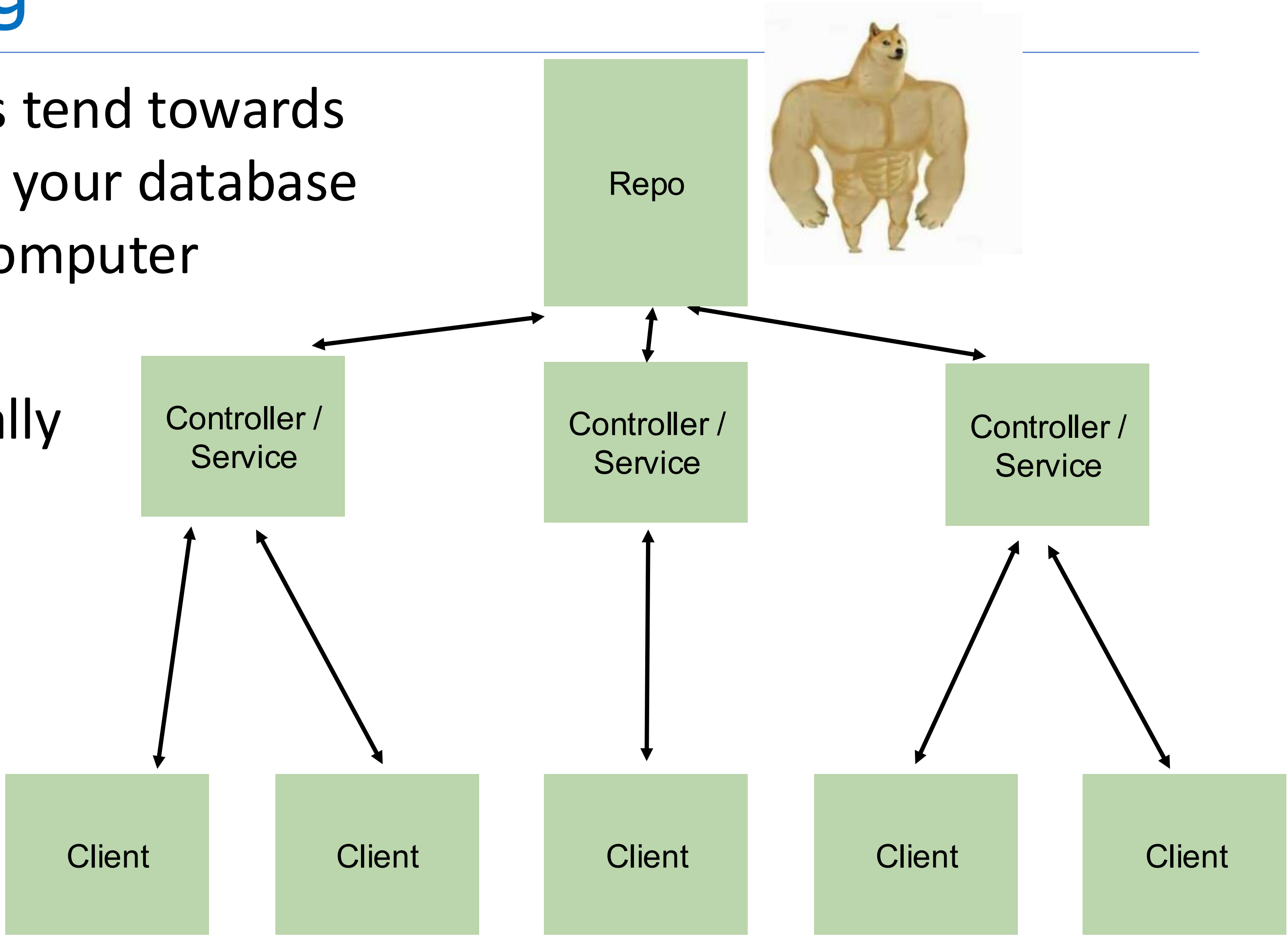


State and statelessness

- A web server or web service should be *stateless*
  - Every REST request should be indifferent to whether the node application has been *running* for several hours or five seconds
  - Also indifferent to whether other copies are communicating with different clients, as long as they're communicating with the same Repository
  - Our silly application, and the IP1 code, is *not* stateless (why?)
- If the web server is going to be stateless, and the web application has state, the server has to phone a friend (the Repository layer) to:
  - Access the filesystem
  - Query a database
- In C-S-R, the repository layer/database is the point of centralization
  - Centralization (& hierarchical centralization) is a cheat code for making distributed systems manageable

Vertical Scaling

- Centralized databases tend towards *vertical* scaling: move your database to a more powerful computer
- This has limits: the database will eventually become a bottleneck
- What to do?



Scaling Past the Database Bottleneck (1)

Maybe the problem is that you’re occasionally doing big, expensive analysis on your database, like analyzing your sales data

- Database *read-only-replicas* are an easy solution here — seconds to minutes behind reality (and can add reliability in case of failure!)

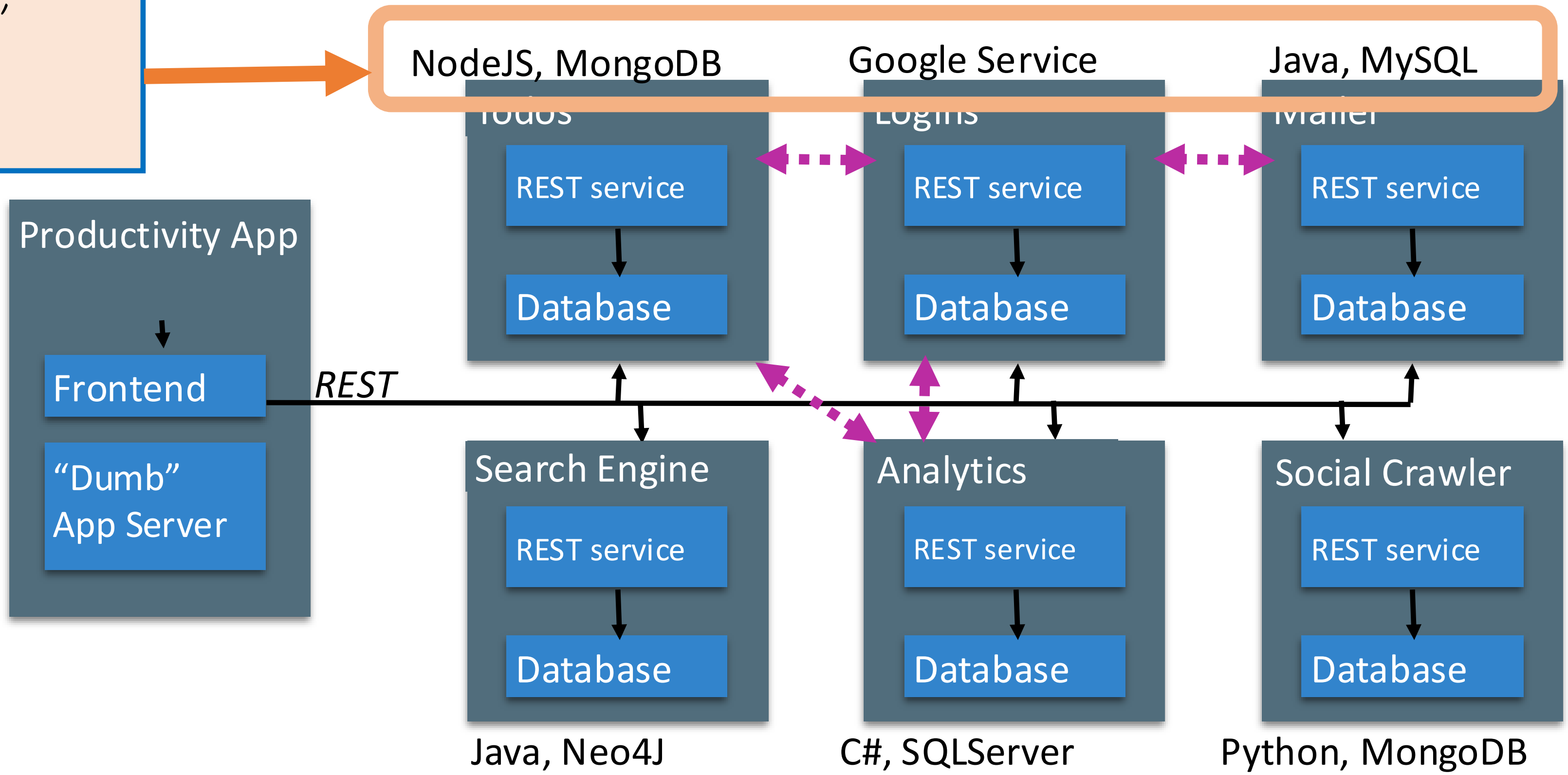
Scaling Past the Database Bottleneck (2)

Maybe you can identify parts of your data that are independent, and don't need to be synchronized or stored together

- Chat and game information in GameNite could live be in separate places
- Games could have their business logic running on different servers, written in different programming languages, and accessed (by the server the client is connected to) through their own REST API!
- This way lies microservices

Microservices

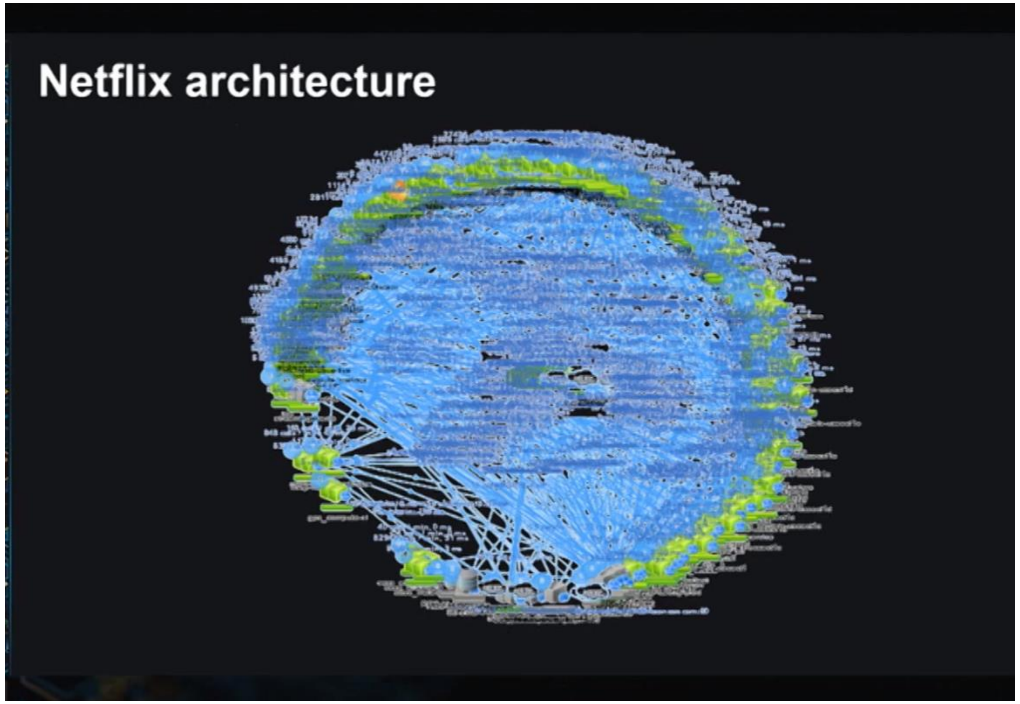
Different languages, different operating systems



Microservices

Netflix is the microservices darling

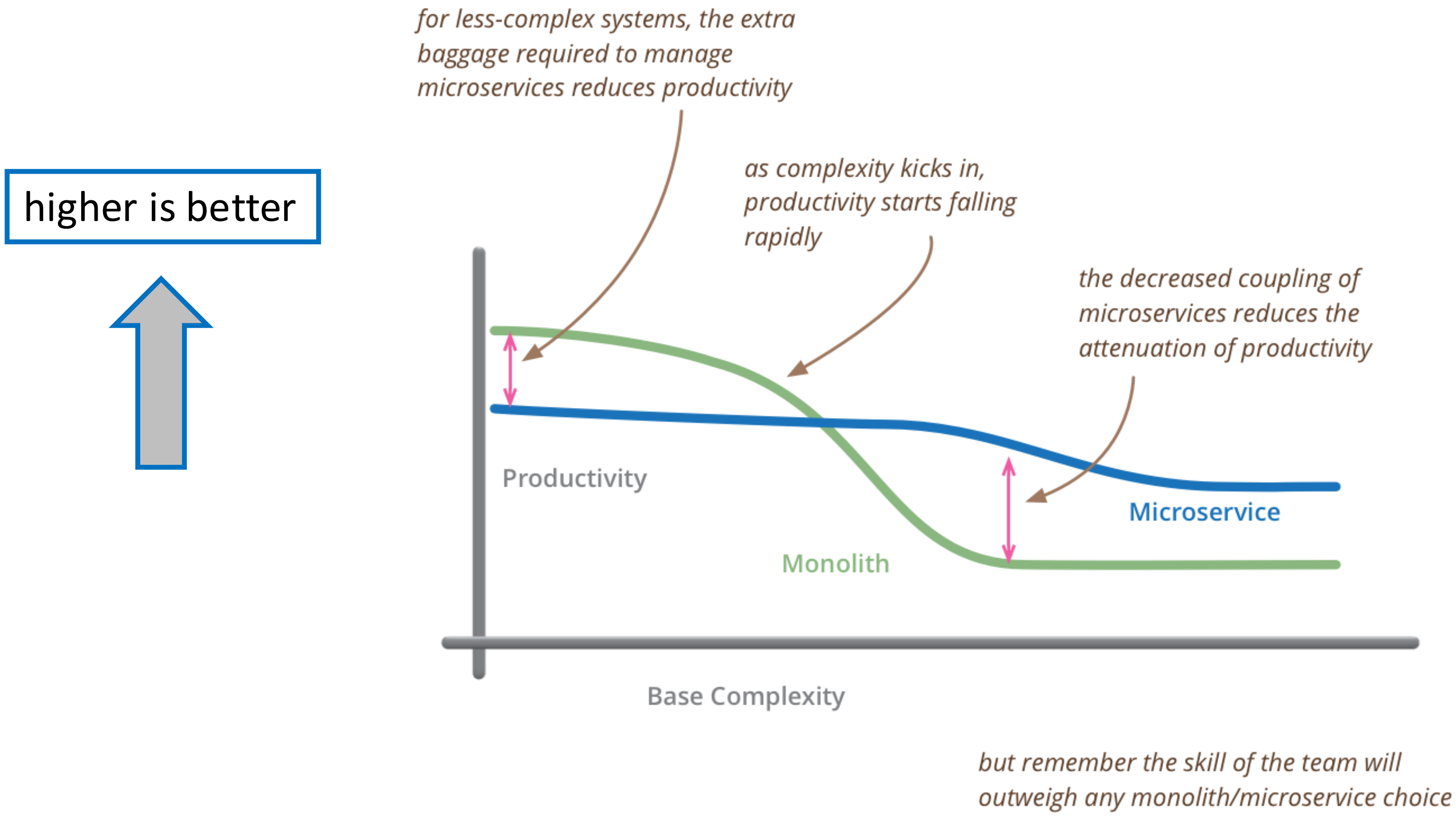
- 100s of microservices
- 1000s of daily production changes
- 10,000s of instances
- BUT:
- only 10s of operations engineers



https://medium.com/refraction-tech-everything/how-netflix-works-the-hugely-simplified-complex-stuff-that-happens-every-time-you-hit-play-3a40c9be254b

Microservices

The opposite of “microservices” is “monolith”



https://martinfowler.com/microservices/

GameNite is Monolithic

- GameNite is a monolithic application
- It’s not perfect: there’s probably a bit too much business logic in the controller layer (service layer doesn’t quite do enough)
- You’ll start IP2 with a more proper web app
  - MongoDB is the database used for repository layer, by way of a general-purpose adapter called Keyv
  - Changing the repository greatly changes the service layer
  - The controller doesn’t change much (the controller is mostly unaware of the repository later)

Review

At the end of this lesson, you should be able to

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