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

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Learning Goals for this Lesson

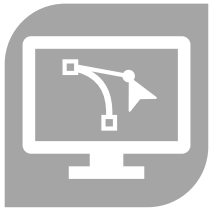
At the end of this lesson, you should be able to

- 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
- 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

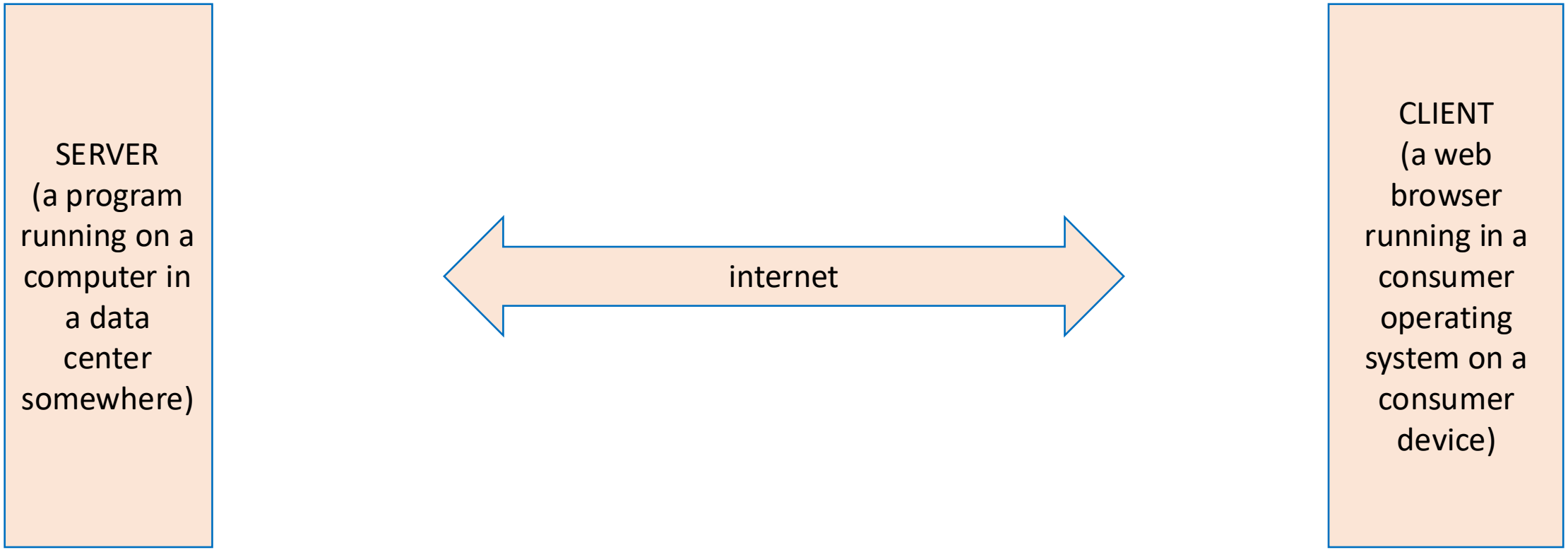
Distributed systems are hard!

- 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*

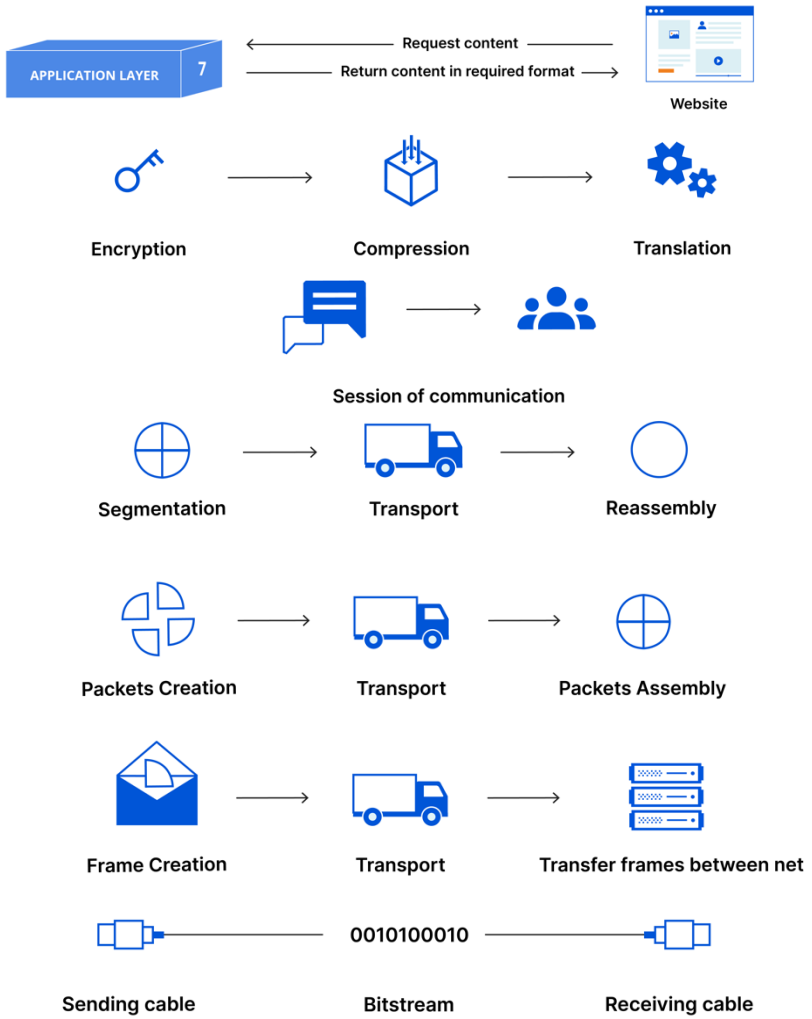
1. You don't live in the cloud
2. Scalability: Netflix needs at *least* two computers

An Insultingly Shallow Intro to Networking



An Insultingly Shallow Intro to Networking

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/

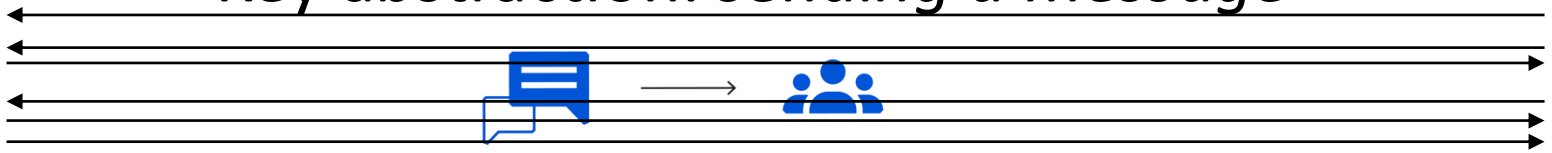
An Insultingly Shallow Intro to Networking

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

Key abstraction: *sending a message*



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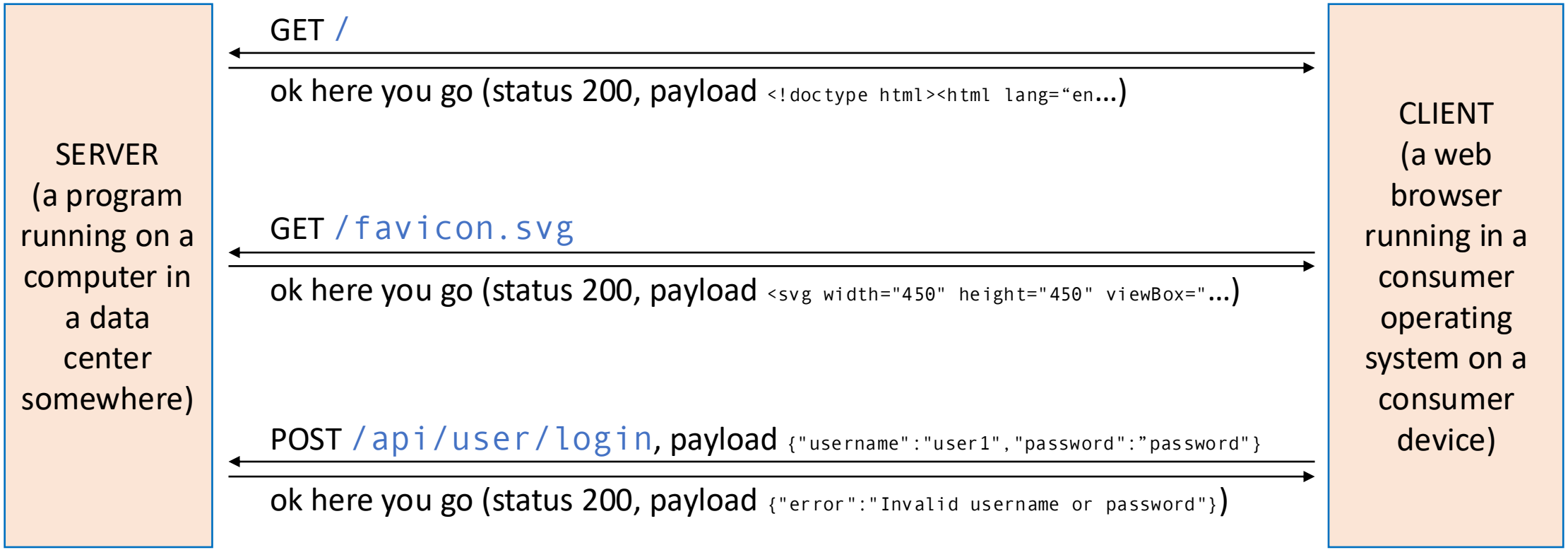
Application Layer Abstractions: RPC/REST

Remote procedure calls happen via HTTP requests (REST)



Application Layer Abstractions: RPC/REST in Express

How this 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"}`

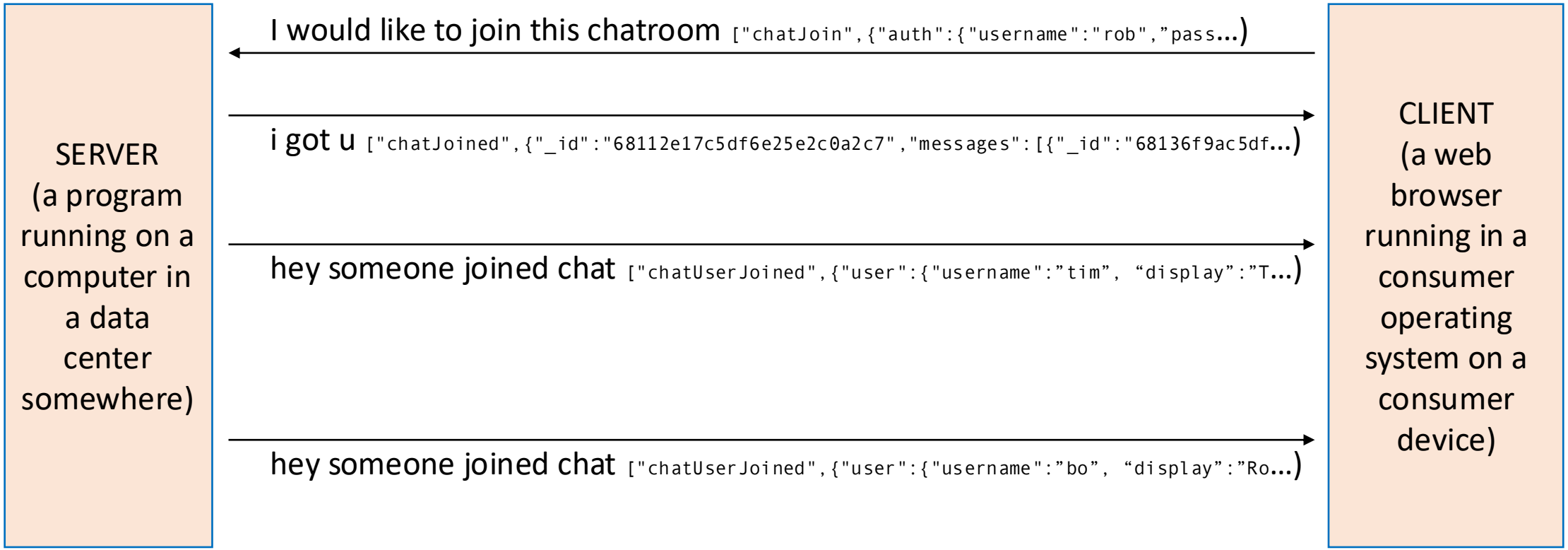
ok here you go (status 200, payload `{"error":"Invalid username or password"}`)

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' });
  }
});
```

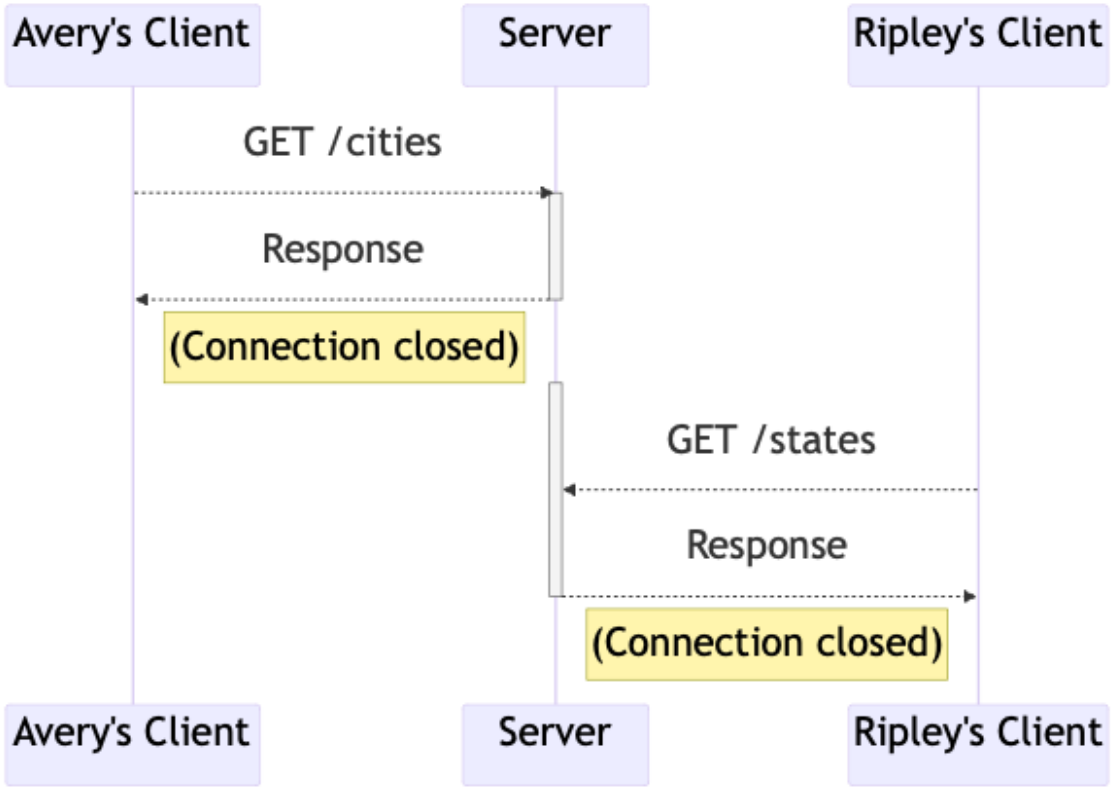
Application Layer Abstractions

Message Passing happen via WebSockets

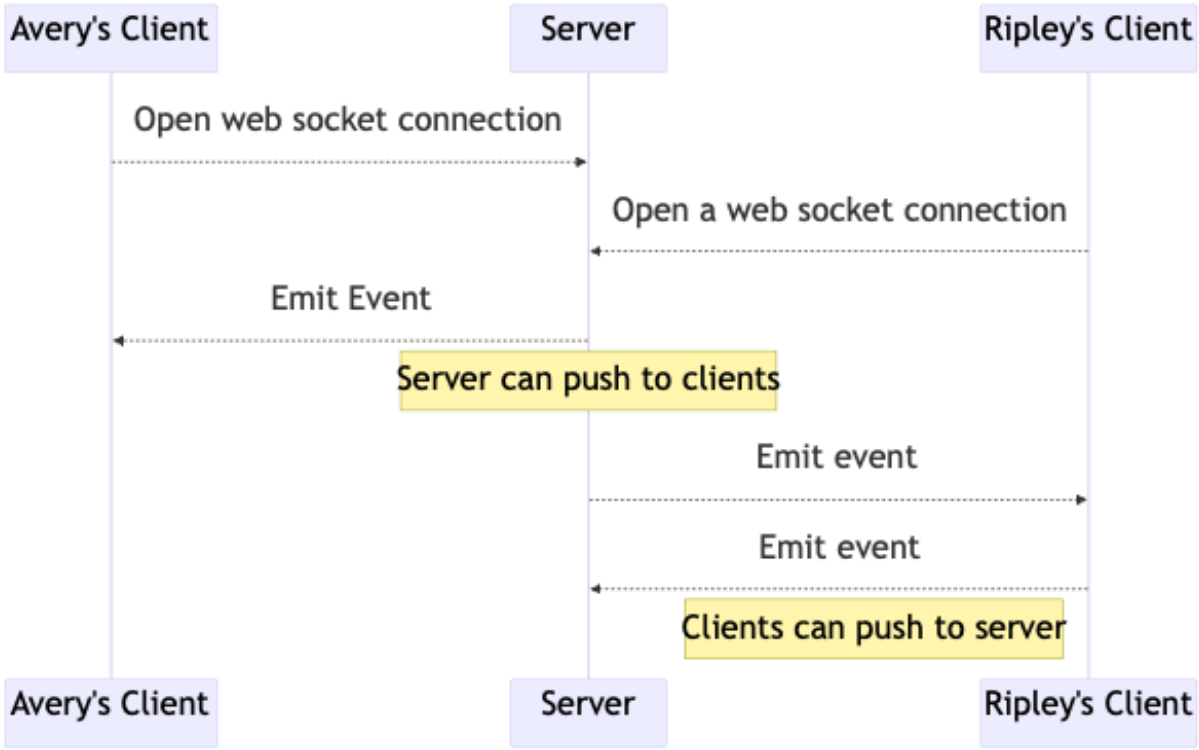


Application Layer Abstractions

REST



Web Sockets



Building Real Client-Server Applications

The Express servers we've seen in this class (including the IP1 code) aren't great

What user needs aren't they meeting? **(A user doesn't want their messages to disappear)**

How can we do better? **(Add a database)**

Building Real Client-Server Apps

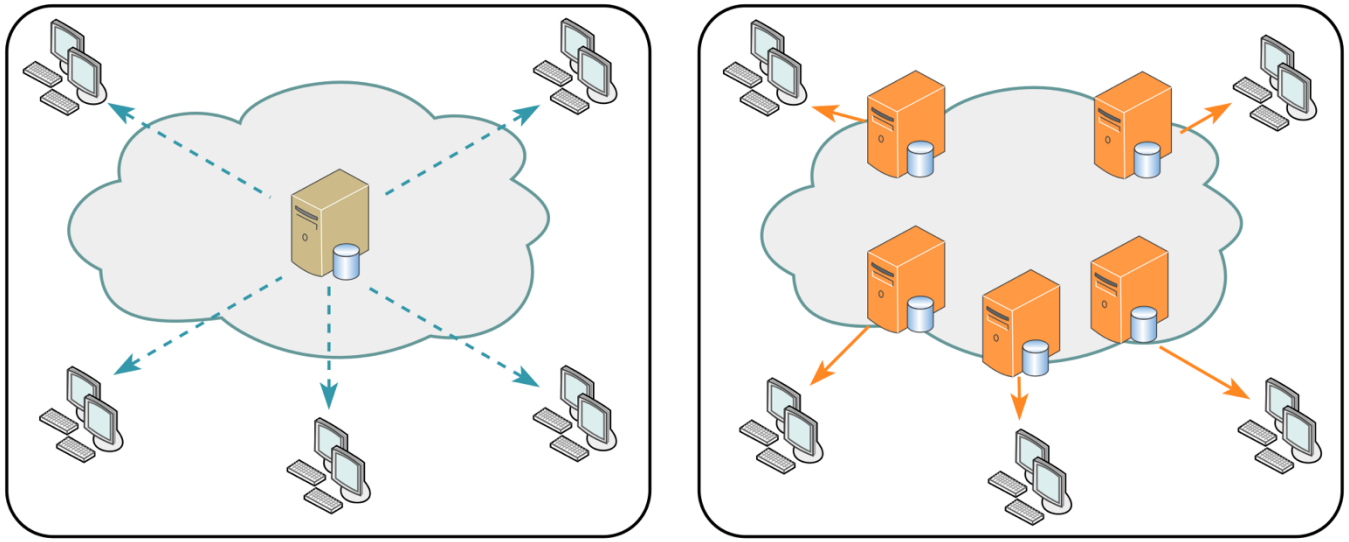
```
import express from 'express';
import { z } from 'zod';

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

numLogins resets whenever you stop running the program

there's one user and one password and it's hard-coded

State and statelessness

- Web applications have *state*: they're ultimately storing or modifying *something*
  - Otherwise, maybe don't have a server running Node at all?
  - Content Delivery Networks have put tons of work into solving that distributed systems problem.
  - Static sites are fast & cheap



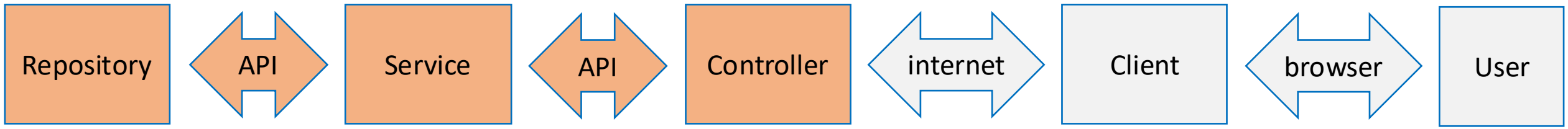
https://en.wikipedia.org/wiki/Content_delivery_network

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
  - 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 to:
  - Access the filesystem
  - Query a database
  - Initiate some other remote procedure call to another server
- Common case: a *database* is the point of centralization
  - Centralization (& hierarchical centralization) is a cheat code for making distributed systems managable

Three parts of a web server

- The **repository** is the only part that stores state
  - 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!
- The **controller** doesn’t know how we store data
  - Are we actually “stateless,” or storing things in memory like IP1?
  - MongoDB? PostgresQL? SQLite? A file on the hard drive?



CSR Architecture

```
import {
  StudentID,
  Student,
  Course,
  CourseGrade,
  Transcript,
} from './types.ts';
export interface StudentService {
  addStudent(studentName: string): Student;
  getTranscript(id: Student): Transcript;
  deleteStudent(id: Student): void;
  addGrade(id: Student, course: string, courseGrade: CourseGrade): void;
  getGrade(id: Student, course: string): CourseGrade;
  populateNames (studentName: string): Student[];
}
```

CSR Architecture: Service interface

- Everything we saw from the transcript server is the business logic — the most boring name possible for "the interesting stuff that a web server does that isn't just reading from a database"
  - "Is this person an authenticated user?" — usually 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

- 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 and Scalaibility

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Scaling & the database bottleneck

- Web services often start on a single computer
- Stateless web servers make it possible to *horizontally* scale your web service as you get more users: add more cheap stateless web servers!
  - AWS will be delighted to help, only real limit is money
- Centralized databases tend towards *vertical* scaling: move your database to a more powerful computer
  - This has limits

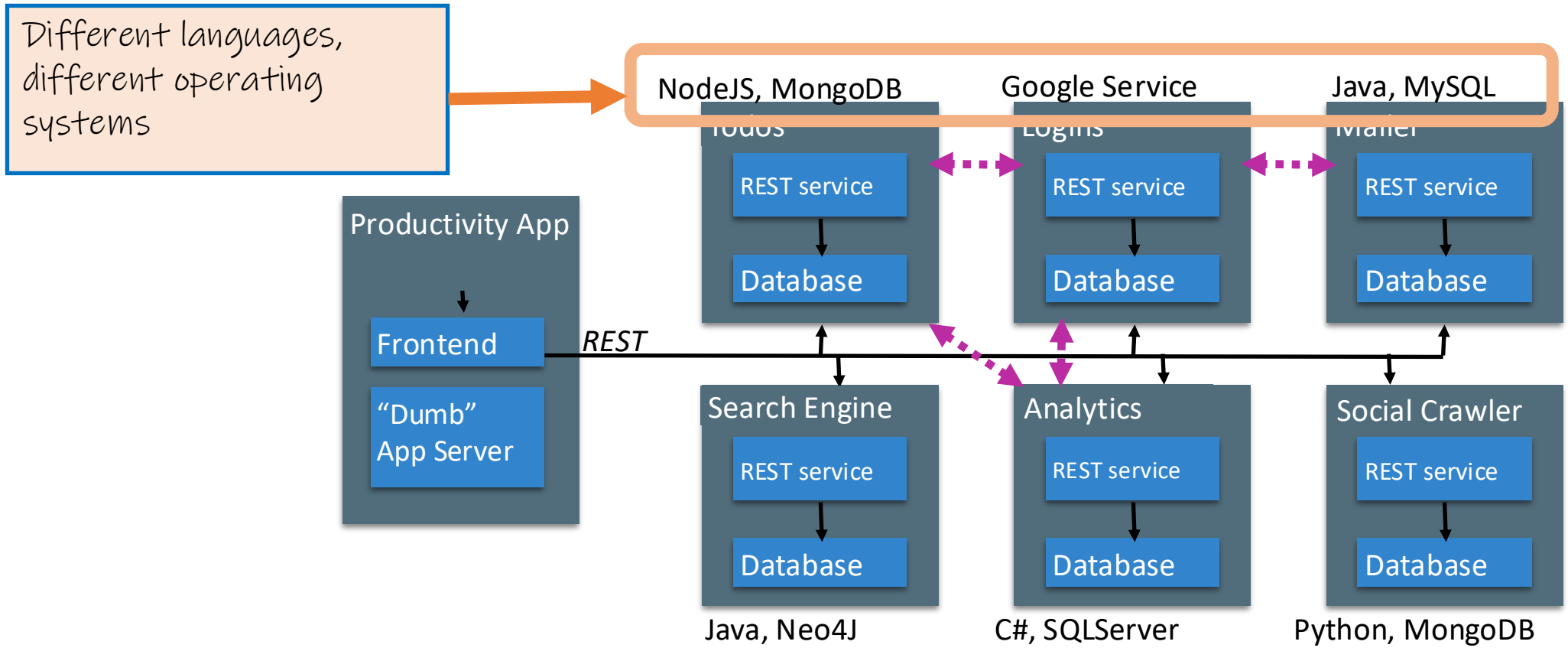
Scaling & the database bottleneck

- Most applications want to do expensive but periodic data analysis on the database
- Database *read-only-replicas* are an easy solution here — seconds to minutes behind reality (and can add reliability in case of failure!)

Scaling & the database bottleneck

- If you've got a bunch of data (or computation) that can handled separately and independently, you can put that somewhere else and have two independent databases
  - Chat and game information could 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

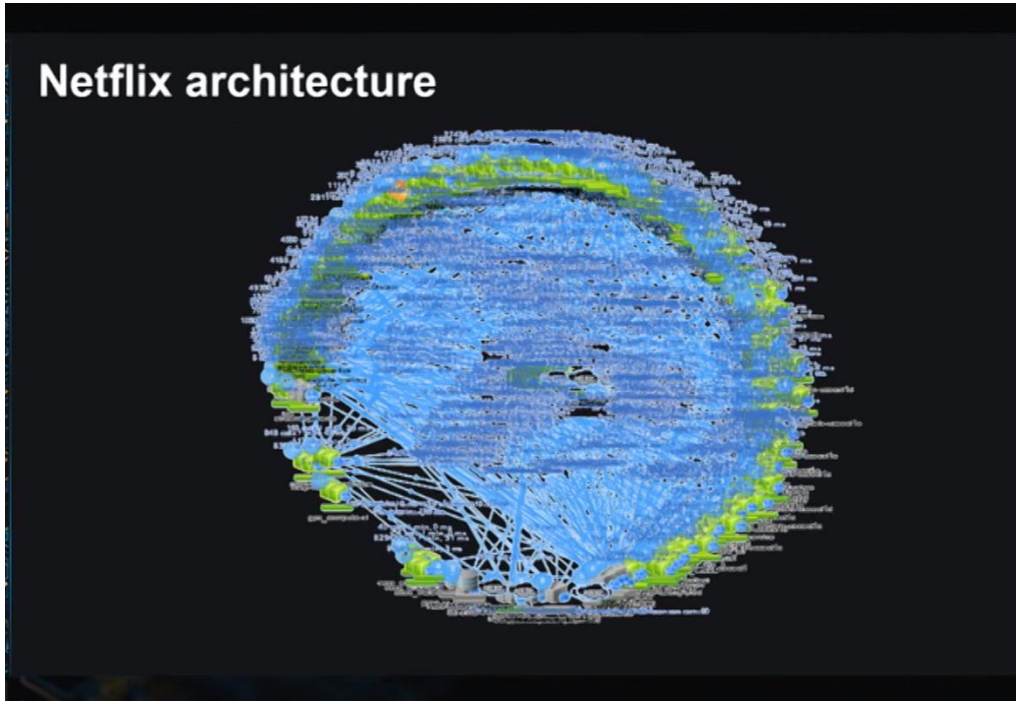
Microservices



Microservices

Netflix is the microservices darling

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

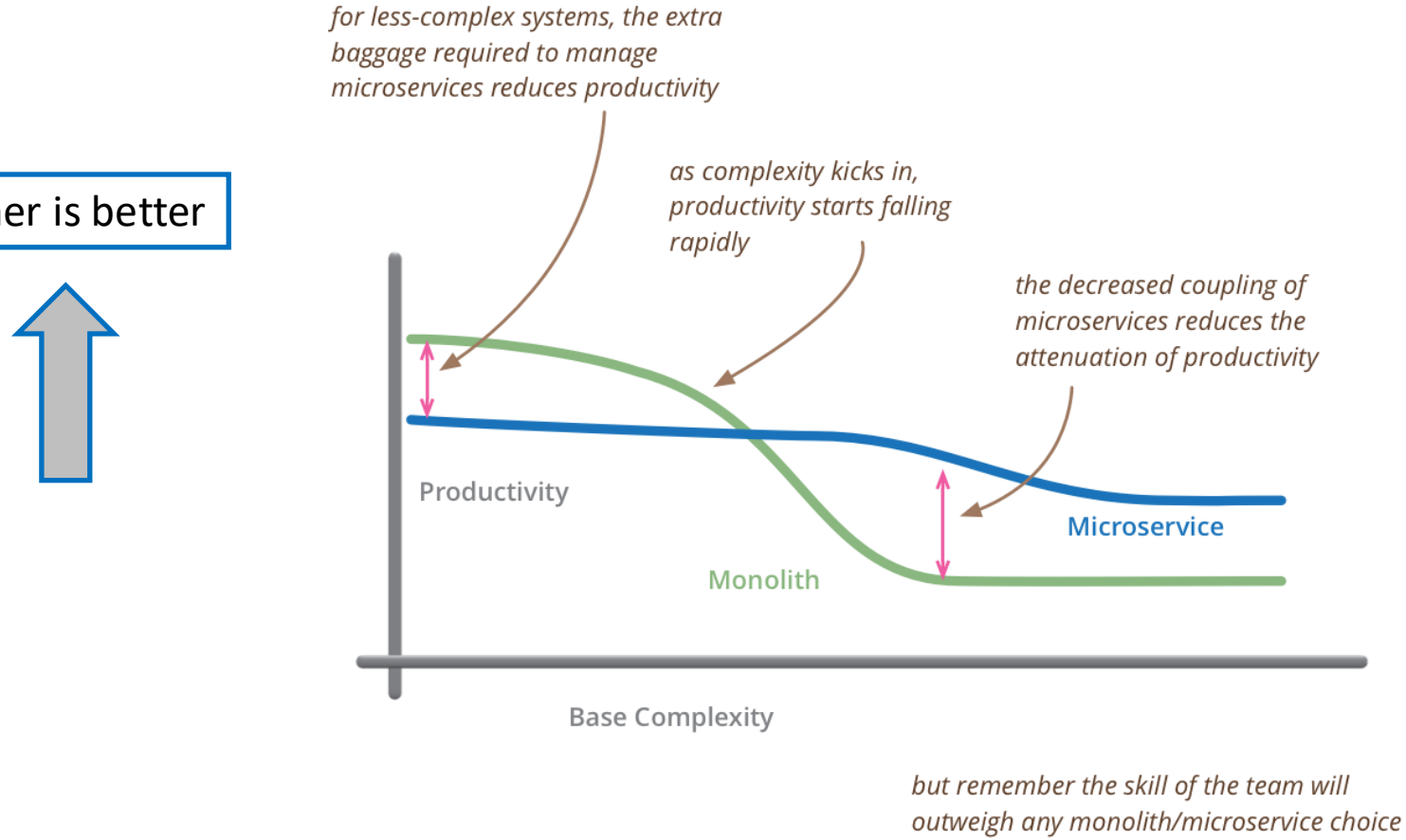


https://medium.com/refraction-tech-everything/how-netflix-works-the-hugely-simplified-complex-stuff-that-happens-every-time-you-hit-play-3a40c9be254b

Microservices

The opposite of “microservices” is “monolith”

higher is better



but remember the skill of the team will outweigh any monolith/microservice choice

https://martinfowler.com/microservices/

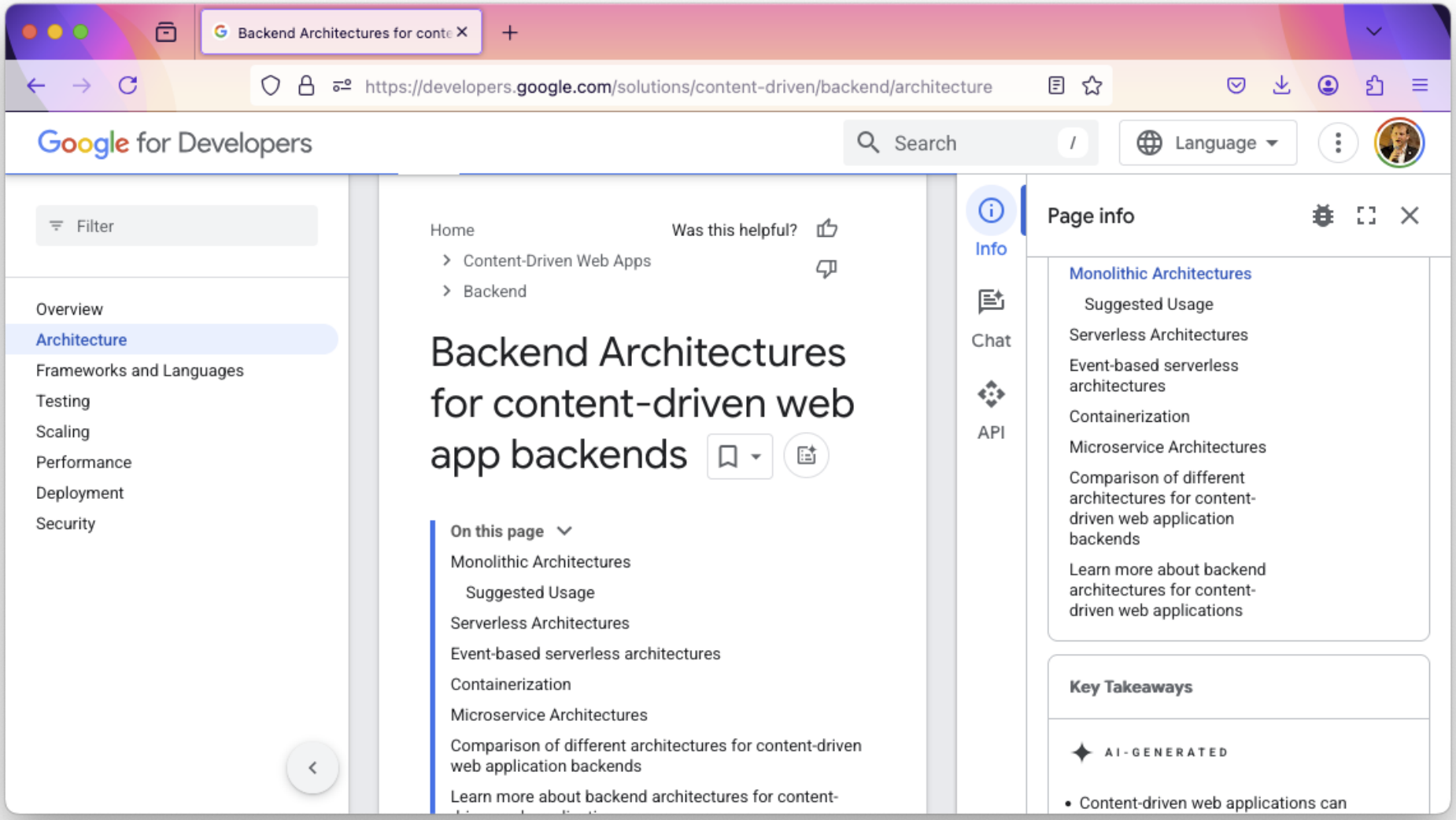
GameNite is Monolithic

- 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 proper repository
  - MongoDB is the database used for repository layer, using a library called KeyV
  - The controller doesn’t have to change (much) to support this

Foreshadowing

- Moving GameNite to a real repository requires one big change in the server!
  - 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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Comparison of different architectures for content-driven web application backends
Learn more about backend architectures for content-driven web applications
Key Takeaways
AI-GENERATED
Content-driven web applications can

Review

It’s the end of the lesson, so 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
- Be able to answer an interview question about “business logic,” “horizontal and vertical scaling,” or “microservices”