Cloud Infrastructure and Scalable Application Deployment

CS 40 | January 8, 2024

“If you’re at Stanford touting yourself an entrepreneurial genius with your app about antagonizing your classmates, you had better actually bring the bacon to your supposed technology. Because you have more than your founding team’s worth of classmates who hate your guts, but can actually program.”

– commenter “doctorpangloss” on Hacker News
August 28, 2023

Course Information

About Us: Teaching Team

Aditya Saligrama

Instructor || saligrama@stanford.edu
BSCS ‘24, MSCS ‘25 (Systems/Security)
SWE @ Verkada, Lacework, Uptycs, Akamai
Applied Cyber President

Cody Ho

Instructor || codyho@stanford.edu
Symsys ‘24, MSCS ‘25 (AI)
ML @ OpenAI, Tatsu Lab, Infosys
Applied Cyber Vice President

Ben Tripp

Teaching Assistant || btripp@stanford.edu
Symsys ‘25 (AI)
SWE @ Azure, CISA, DevOps & cloud consulting
Applied Cyber Projects Lead

About Us: Advisors

Mike Abbott

Advisor

EVP Software & Services @ GM
fmr VP Eng (Cloud Services) @ Apple, Twitter
Instructor CS153, CS349D

Christos Kozyrakis

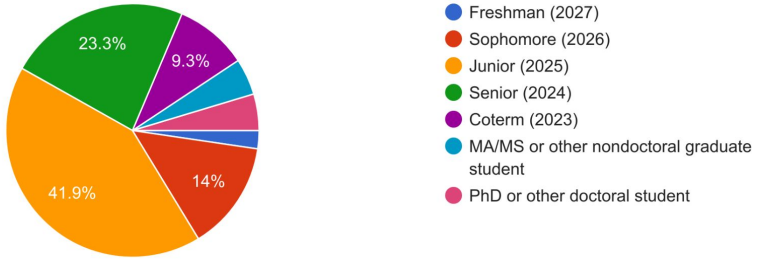
Faculty Sponsor

Professor EE/CS @ Stanford
Cloud computing research
Instructor EE180, CS349D

About You

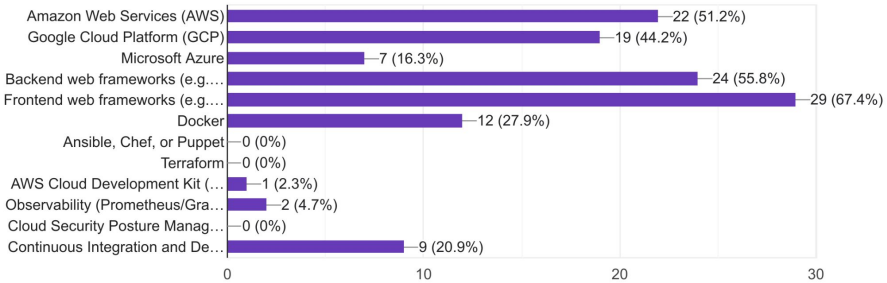
What class year / degree program are you?

43 responses



Which of the following technologies or frameworks have you used in the past? Again, none of these are required -- don't worry if you haven't used any of these before.

43 responses



Topics you're interested in:

- Kubernetes
- ML/AI applications
- Evaluating cost/performance across cloud environments
- Security, privacy, and observability

Prerequisites

- Programming maturity up to CS107

- Familiarity with the **command line, version control, and basic development tools** to the level of CS45/CS104. Tools include:
  - TUI editors: **`vim`**, **`emacs`**, or **`nano`**
  - **Git/GitHub**, including branching and pull requests
  - Language and OS package managers: e.g., **`pip, apt, homebrew`**

- Prior web development or networking experience helpful but not required
  - We'll run a web basics section on **Wednesday 1/10 at 8pm (Zoom/recorded)**

Please reach out if you have any questions about your readiness for CS40!

What you’ll learn

Why CS40

- Stanford CS courses teach foundational technical skills, but less on building projects from scratch **with robust and scalable architecture**
  - Course final projects usually involve building web or mobile apps or Jupyter Notebooks

- Before CS40: “I built an app with a frontend and a backend”
- After CS40: **“My app can handle lots of users at minimal cost”**

- These skills are **broadly applicable to all technical careers** (academic, industrial, entrepreneurial) and even to hobby projects!

Why Cloud

- Before ~2004, deploying web apps required buying **physical servers** or renting **datacenter** server capacity
  - Inflexible (what if you suddenly need more capacity?), and not very redundant
  - Needs a lot of **manual infrastructure management**: installing required software, keeping base software up to date, updating the application itself

- Today: pay-as-you-go for cloud resources
  - **Automatically adjust required capacity** in a very fine-grained way → cost reduction
  - Letting cloud providers **manage most of your resources** has security benefits, plus reduces engineering mindshare
  - Easy redundancy and availability close to customers → performance improvements

Course Goals

You'll learn about:

1. What **resources** are made available by cloud providers that help in deploying applications

2. Architecting a cloud deployment by selecting resources for **optimal scaling** (performance) and **cost efficiency**

3. Systematically deploying cloud resources using **Infrastructure as Code** (IaC)

4. Ensuring your deployment remains **secure, observable, and continuously updated**

Building Blocks of Cloud Infrastructure

Types of Cloud Product Offerings

Infrastructure as a Service (IaaS)
(CS40 focus)

Lowest level of abstraction
is directly above hardware
(e.g., networks, storage, servers)

Platform as a Service (PaaS)

Abstraction: all hosting
infrastructure managed for you
Just bring the code!

TechWorld WithMilan
simplifying complex topics

Cloud Product Mapping

Google Cloud Platform

	aws	Azure	Google Cloud Platform
AI & ML	Augmented AI, Comprehend, Elastic Inference, Forecast, Fraud Detector, Kendra, Neuron, Lex, Lookout for Metrics, PyTorch, Personalize, Polly, TensorFlow, Rekognition, SageMaker, Transcribe, Translate	Bot Service, Cognitive Search, Computer Vision, Conversational Language Understanding, Face API, Speech Service, Language Service, Personaliser, Translator, Azure Machine Learning, Form Recognizer	AutoML, DialogFlow, Natural Language AI, Speech-to-Text, Text-to-Speech, Natural Language AI, Vertex AI, Video AI, Vision AI
Application – Mgmt	Amplify, API Gateway, App Mesh, App Runner, AppSync, Elastic Beanstalk, Serverless Application Repository	API Apps, API Management, Azure Maps, Visual Studio App Centre, App Service, Cloud Services, Service Febric, Web Apps	App Engine, Cloud APIs, Apigee
Application – Mobile	Mobile Hub, Publisher Services	Mobile Apps, Xamarin with Azure	App Engine, Firebase
Automation	OpsWorks	Automation	
Compliance	Artifact, Audit Manager, Compliance Center	Microsoft Compliance Manager, Trust Center	Assured Workloads, Compliance Reports Manager
Compute – Container	App2Container, Elastic Container Registry (ECR), Elastic Container Service (ECS), Elastic Kubernetes Service (EKS), Fargate	Azure Kubernetes Service (AKS), Container Instances, Container Registry, Container Apps	Artifact Registry, Cloud Run, Kubernetes Engine, Migrate for Anthos and GKE
Compute – FaaS	Lambda	Azure Functions	Cloud Functions
ompute – Server	Auto Scaling, Batch, Elastic Compute Cloud (EC2), Lightsail, VMware Cloud on AWS	AutoScale, Batch, Virtual Machines, Azure VMware Solution	Compute Engine, VMware Engine
Cost	Application Cost Profiler, Billing, Budgets, Cost Anomaly Detection, Cost Categories, Cost Explorer, Pricing Calculator	Advisor, Cost Management and Billing, Pricing Calculator, TCO Calculator	Cost Management, Recommender, Pricing Calculator

What services do cloud providers offer?

Cloud Concepts in CS40

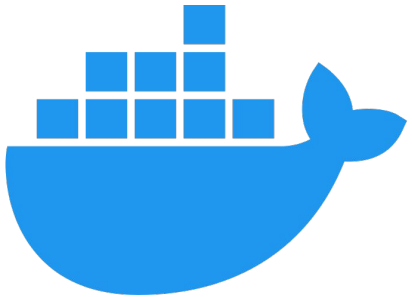
- Building blocks
  - Compute (EC2, ECS)
  - Network (VPC, ACM)
  - Storage (S3, databases)

- Structuring cloud deployments
  - Infrastructure-as-Code (CDK)
  - Continuous Integration and Continuous Deployment (GitHub Actions)
  - Auditing, Security, and Observability (CloudWatch, CloudTrail, Datadog)

- Applications of cloud computing
  - Serverless compute (Lambda)
  - AI/ML pipelines (GPUs on EC2, Sagemaker)

Containers

- **Definition**: a *container* is a portable software package containing all resources needed to run it, providing:
    - **Isolation**: processes of container A don't interfere with those of container B
    - **Replicability**: same process from same container image should execute the same on any host machine/OS/configuration



- A container behaves like its own isolated machine, but **shares its kernel with the host machine**
    - Cannot run directly on hardware: **needs to run on a real OS**
    - Manage the OS yourself, or cloud providers can abstract the OS layer for you, e.g. *AWS Elastic Container Service, Google Cloud Run*

Demo: Containers

Virtual Machines

- **Definition**: a *virtual machine* is a computer system created using software on one physical computer in order to emulate the functionality of another separate physical computer.
  - Virtual machines cannot interfere with the host or other virtual machines
  - Run their own kernel
  - Managed by a *hypervisor*

- Primary service offered by cloud providers:
  - AWS Elastic Compute Cloud (EC2)
  - Google Compute Engine
  - Azure VMs

Demo: Virtual Machines

Storage

- Object storage
  - Store arbitrary blobs: great for media, but also process inputs/outputs, logs, etc.
  - e.g. AWS S3, GCP Cloud Storage Buckets, Azure Blob Storage

- Block storage
  - Only get the base storage device, with no file abstraction
  - e.g. AWS EBS, GCP Persistent Disk, Azure Disk Storage

- Databases
  - Traditional SQL DBs, plus newer NoSQL DBs (e.g. document, KV, graph models)
  - AWS RDS/Aurora, AWS Neptune, GCP Database, Azure SQL Database, Azure Cosmos
  - Vector DBs, ChromaDB, Pinecone (PaaS)

Network

- **Virtual Private Cloud** (VPC): a logically isolated virtual network with controls for resource placement, connectivity, and security

- A VPC is located in one geographical region, but can span multiple availability zones (datacenters) in that region for redundancy and scalability

- We'll talk more about cloud networking in the next couple of lectures

Course Logistics

Course Structure

- Lectures: Mon, Wed 4:30pm-5:50pm, 530-127
  - Lecture attendance optional but encouraged; **must attend guest speakers' lectures**
  - Recordings are best-effort and only available in extenuating circumstances

- Four Assignments: hands-on, deployments to AWS

- Final project
  - More details to come

Grading

60%: Assignments (15% each)

40%: Final project

Guest Speaker Attendance is Mandatory

Don’t stress about this! Assignments are intended to be straightforward, and we’ll release autograders so you can check your assignment score as you work

Assignments (60%)

- Four assignments (15% each)
  - A1: Hello World, AWS account setup, CLI refresh, EC2/Nginx static webpage deployment (1/23)
  - A2: Intro to Infrastructure-as-Code; deploy a complex webapp to AWS (2/13)
  - A3: Lambdas, Observability, and AI/ML pipelines (2/27)
  - A4: Continuous Integration & Continuous Deployment (3/7)
- Mostly in Python, but significant shell usage + configuration files (JSON, YAML)
- Can work in pairs for assignments 2-4
- **Credits provided for all students after add/drop deadline**, look out for communication on Ed on how to access

Final Project (40%)

- Open-ended (with suggested ideas you're free to use)
  - Deploy an application of your choosing to AWS!
- Due **3/17**, can be completed in pairs
- More details to come

Participation

Required attendance at the following guest lectures:

- Benjamin Bercovitz (Co-Founder of Verkada), **Wed 1/24**
- Corey Quinn (Chief Cloud Economist, Duckbill Group), **Wed 3/6**
- Mark Russinovich (CTO of Microsoft Azure), **TBD**
- Bill Jia (Google Cloud, fmr VP of Engineering @ Meta), **TBD**

Every unexcused absence will drop you a letter grade. Absences must be excused before lecture or have extenuating circumstances.

A few quick policy notes

- You MUST follow the letter and spirit of the Honor Code
  - Please reach out if you have any questions about our Honor Code policy

- You can use ChatGPT and other LLM's for reference, preferably as a last resort
  - Don't ask for entire assignment solutions
  - We use modern (2024) best practice constructs which may not be in LLM training data
  - **Detail LLM usage in your assignment writeups**

- If you find bugs in course infrastructure, please tell us!
  - At our discretion, we might give you some extra credit
  - But you still need to complete the assignments as specified

Course Resources

- Course website: https://cs40.stanford.edu
- Ed discussion: https://edstem.org/us/courses/50007/discussion/
  - This is where all course communication will be handled
- Gradescope: **4GYR7J**
- GitHub:
  - Public resources: https://github.com/infracourse
  - Assignments 2-4 will be on a GitHub classroom within https://github.com/cs40-24win
- Office hours:
  - **Aditya**: Mon, Wed 10:00am-11:00am
  - **Cody**: Wed, Fri 12:00pm-1:00pm
  - **Ben**: Tue, Thu 1:00pm-2:00pm
  - Starting next Tuesday 1/16