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Infrastructure as Code

Software Engineering

2025/2026

Outline

- Deployment History
  - Pre-cloud Era
  - Cloud Era
  - DevOps Recap
- Infrastructure as Code (IaC)
  - What is IaC?
  - IaC Tools
- Terraform 101
- Scalability & Availability

Deployment History

CAPEX vs OPEX

Capital Expenditure

- Upfront investment in physical infrastructure
- Large initial cost
- Fixed assets
- Long-term expenses
- Ownership of infrastructure

Operational Expenditure

- Pay-as-you-go model
- No depreciation
- Operational expenses
- Flexible scaling costs
- No ownership required

Pets vs Cattle servers

Pets

- **Individually named and cared for:** Each server has a unique name (like "*db-server-prod-01*" or "*WebServerJohn*")
- **Lovingly maintained:** You diagnose and manually fix each problem
- **Irreplaceable:** Server failure causes crisis and significant downtime
- **Manually configured:** Hand-crafted with custom settings and accumulated tweaks
- **Long-lived:** Run for years, becoming difficult to replicate
- **You know when they're sick:** Problems trigger immediate all-hands response

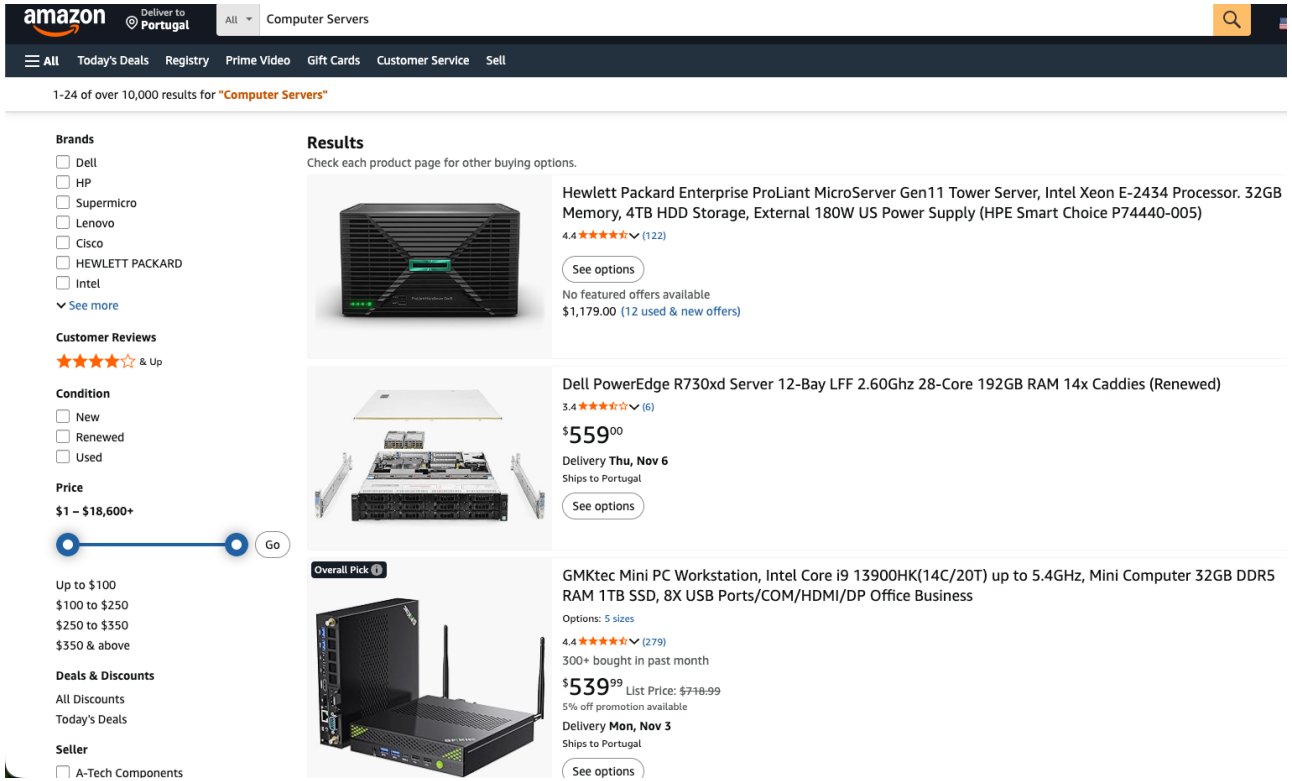
Pets vs Cattle servers

➢ Cattle

- **Numbered, not named:** Servers are "*web-server-001*", "*web-server-002”*
- **Disposable:** Terminate and replace rather than fix problems
- **Automatically provisioned:** Created from templates/code in minutes
- **Ephemeral:** Expected to be short-lived for easy updates
- **Scalable:** Add or remove servers automatically as needed
- **Self-healing:** System auto-replaces failures without human intervention

Pre-Cloud Era

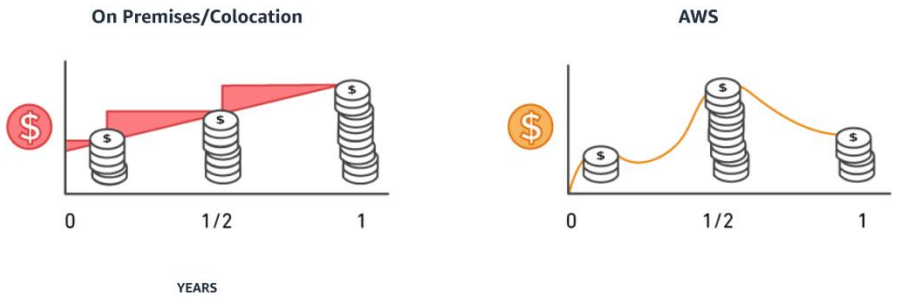
- **On-Premise Model**
  - **Capex**
  - **Pet Servers**
  - Buy Physical Servers
  - High Initial Cost
  - Difficult to Scale
  - Manual Configuration

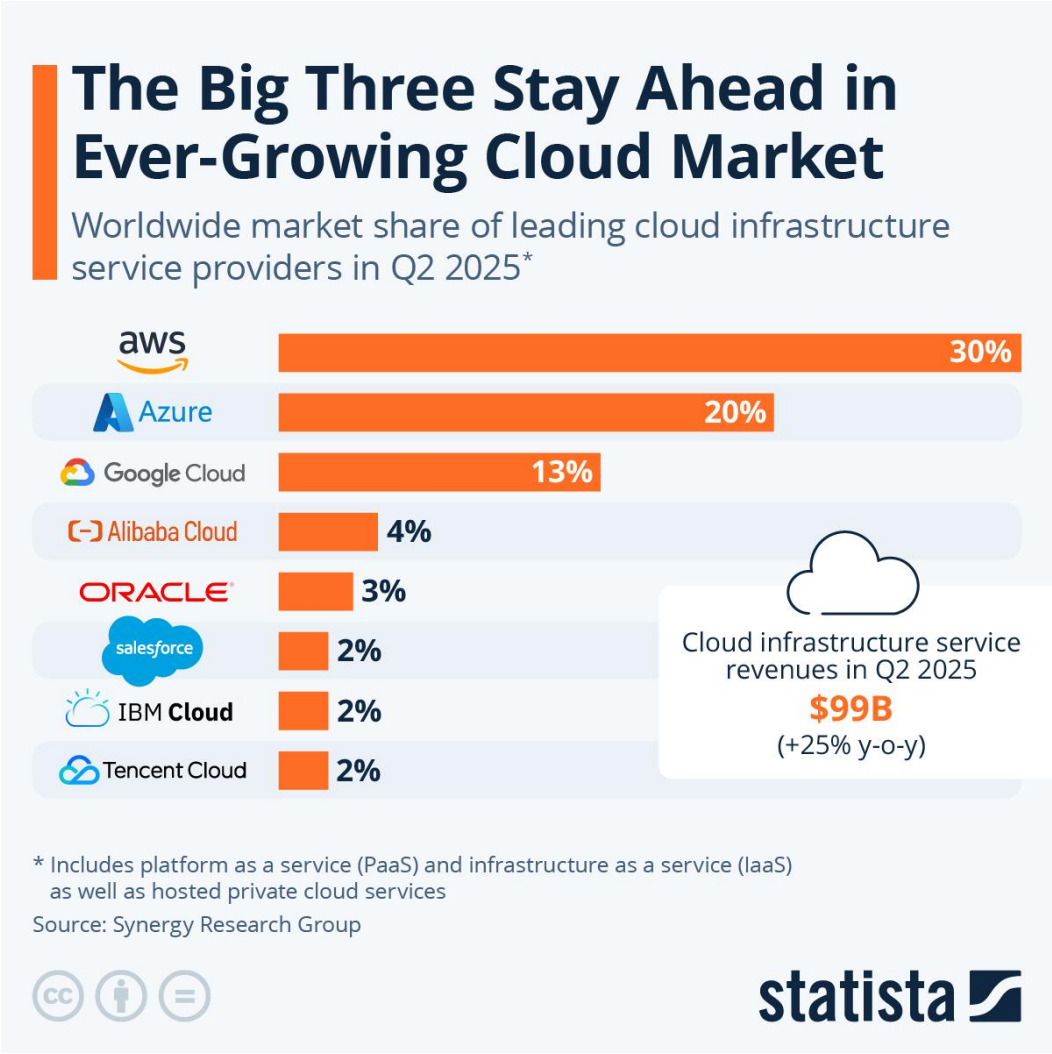


Cloud Era

➢ Cloud Model

- **Opex**
- **Cattle Servers**
- Pay-per-usage
- Provisioning on-the-fly
- Scalability on-demand
- Easier for startups





Cloud Era

- **Cloud Model**
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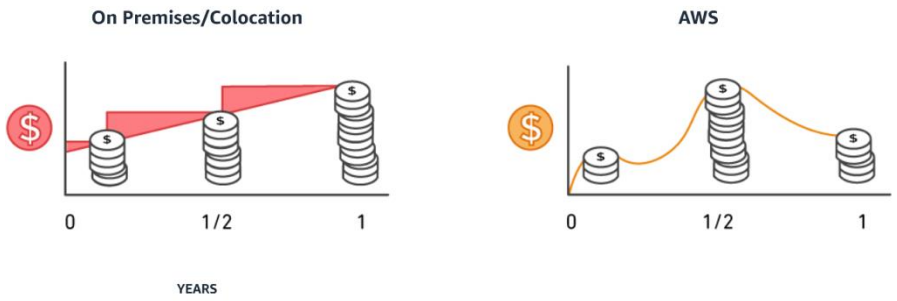

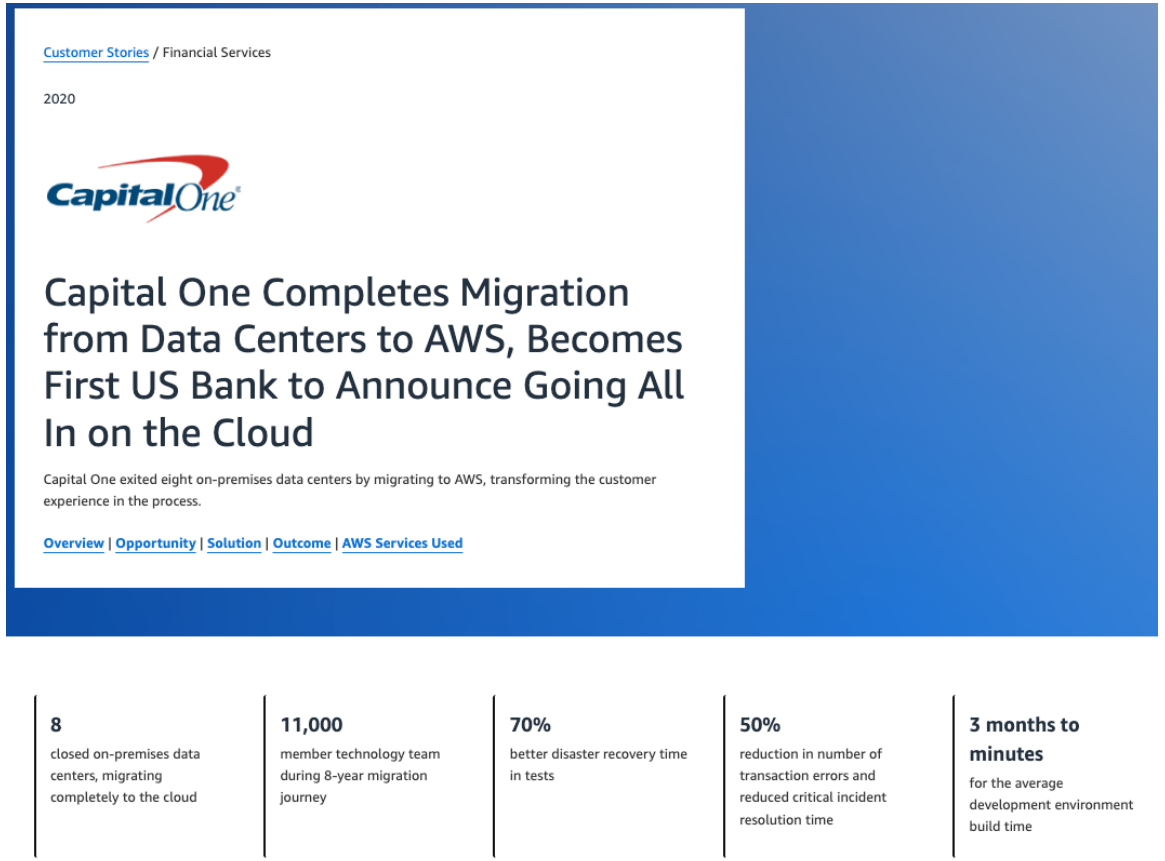

Not All Days Are Sunny Days

Computing > Internet

LIVE Is AWS down? Service seems to be back as Amazon disputes outage and users disagree

AWS is disputing the outage, but users disagree

News By Jason England, Dave LeClair last updated 1 hour ago

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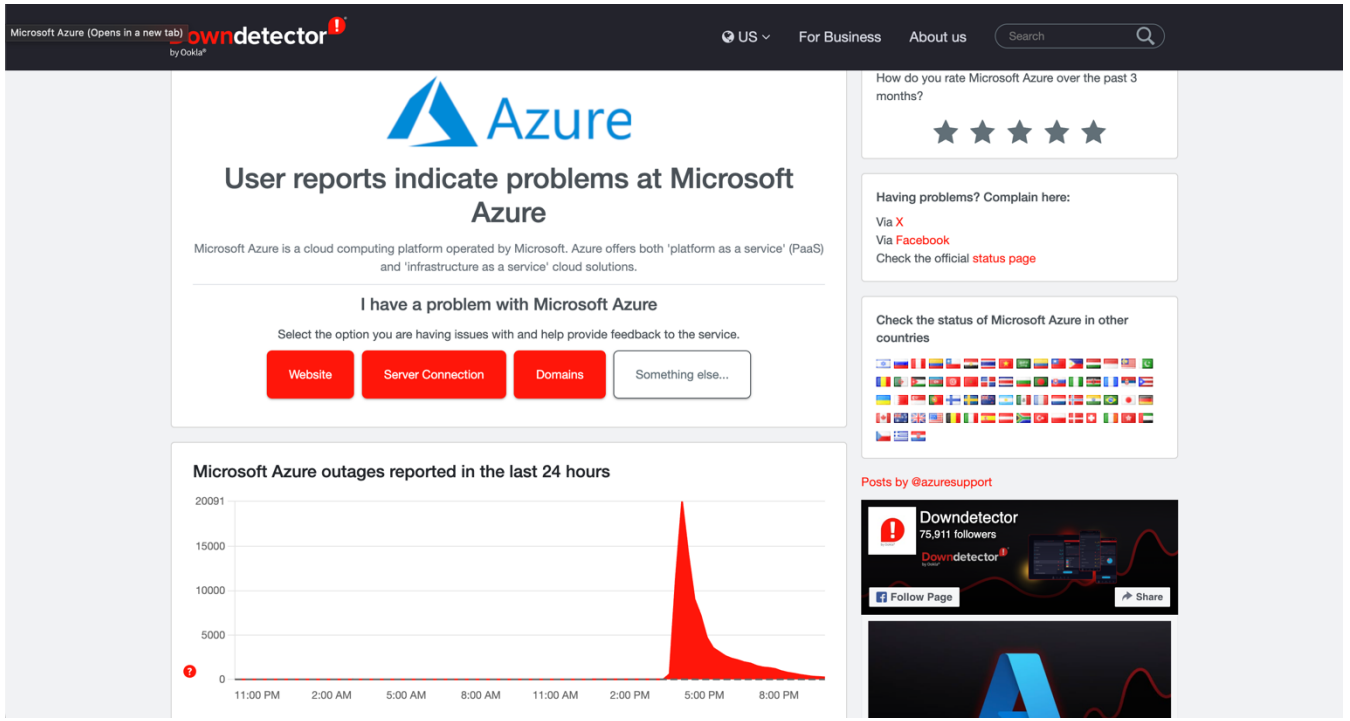
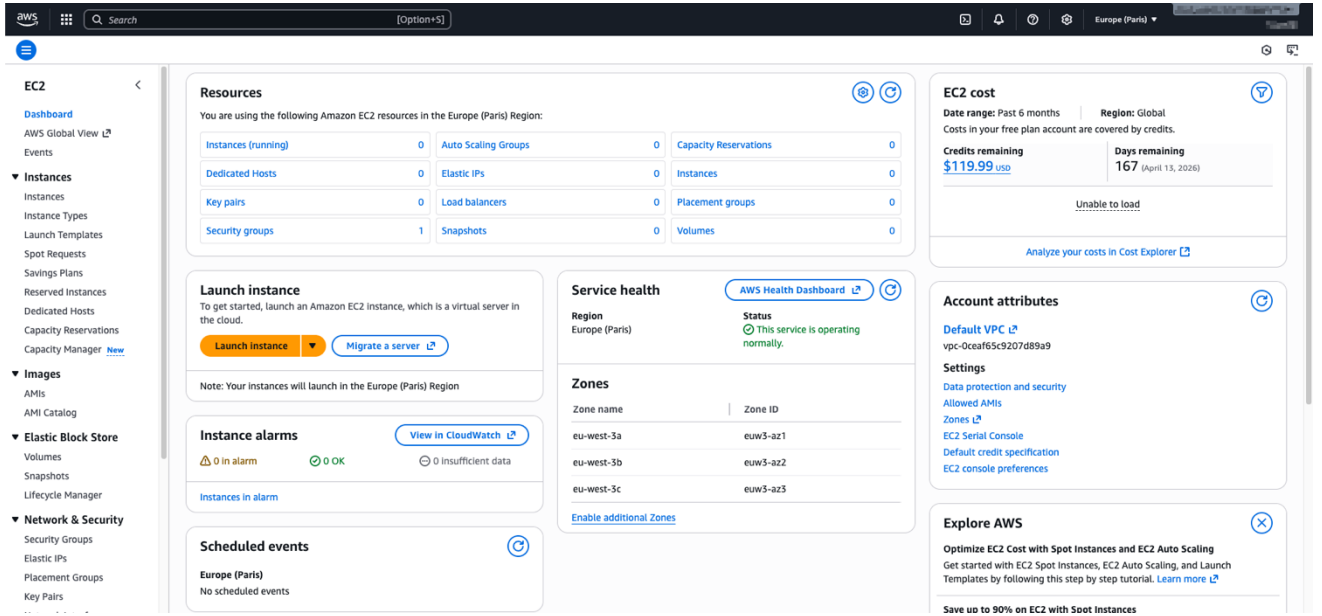


Configuration Problem

Manual Configuration

- Even when using cloud solutions, it is needed **manual configuration**.
- **Snowflake servers**, that diverge over time and become hard to replicate
- No **versioning control** making impossible to rollback



Configuration Problem

➢ Manual Configuration

- Even when using cloud solutions, it is needed **manual configuration**.
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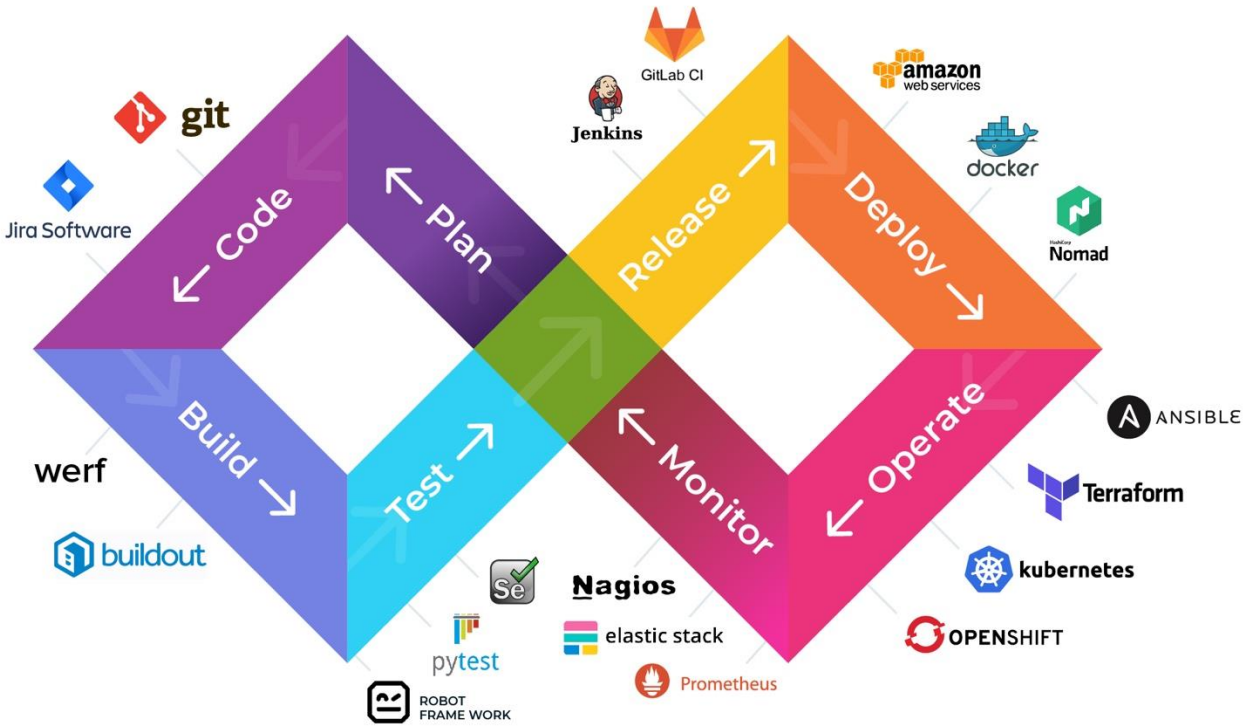
Solution: **Infrastructure as Code**

DevOps Recap

Movement

- Culture, automation, measurement and sharing (CAMS)
- Join the Developer Team with the Operator Team
- Combat the "*It works on my machine syndrome!*"
- Enhance Software delivery



DevOps Recap

➢ Operate Tools

- Running and maintaining applications in production environments
- Ensuring system reliability, performance, and availability
- Managing infrastructure and responding to incidents

DevOps Recap

Table P-1. DORA metrics performance from the 2024 State of DevOps Report

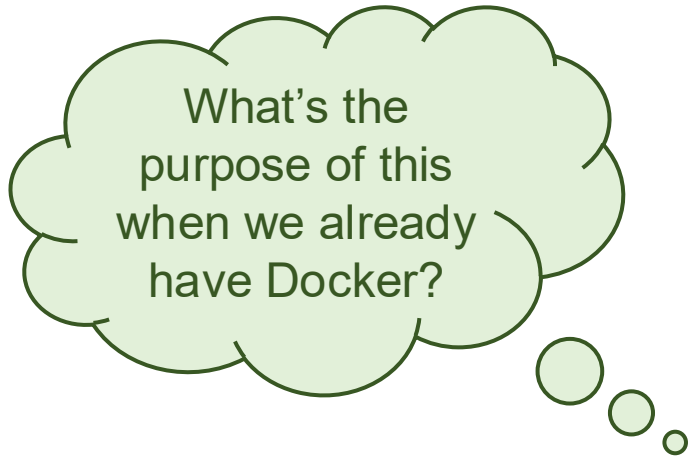
Metric	Description	Elite vs. low performers
Deployment frequency	How often you deploy to production	182× more often
Lead time	How long it takes a change to go from committed to deployed	127× faster
Change failure rate	How often deployments cause failures that need immediate remediation	8× lower
Recovery time	How long it takes to recover from a failed deployment	2,293× faster

Infrastructure as Code

IaC

Overview

- Infrastructure as Code (IaC) is the idea of writing and executing code to define, deploy, update and destroy your infrastructure
  - Infrastructure defined as text files
  - Version Control (Git)
  - Declarative
  - Idempotent
  - Automatic and Reproducible



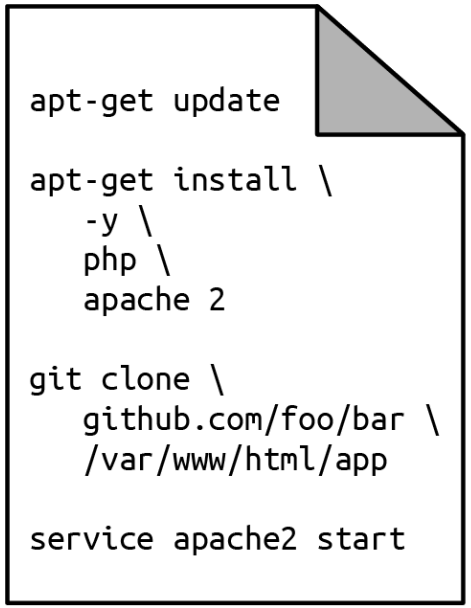
IaC Tools: Docker

- Docker is about running your app:
  - It creates containers: self-contained environments that hold your app and its dependencies.
  - It ensures the same environment on any host.
  - It's great for build → ship → run consistency.

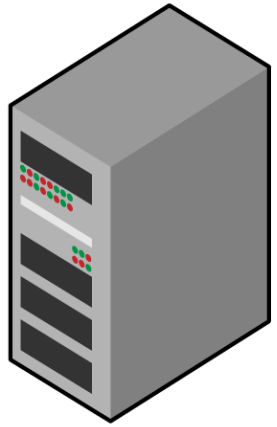
- Example:
  - You can run a web app in a Docker container with its specific version of Python, Nginx, and libraries, without caring about the host OS.

IaC Tools: Ad-hoc scripts

- **The most straightforward way**
  - Writing a simple script in your favorite scripting language (Bash, Python) to define each step to execute
  - The main advantage is you can use your preferred language
  - The main disadvantage is you can use your preferred language, provoking inconsistency
  - More ad-hoc scripts generally means more spaghetti code to maintain.

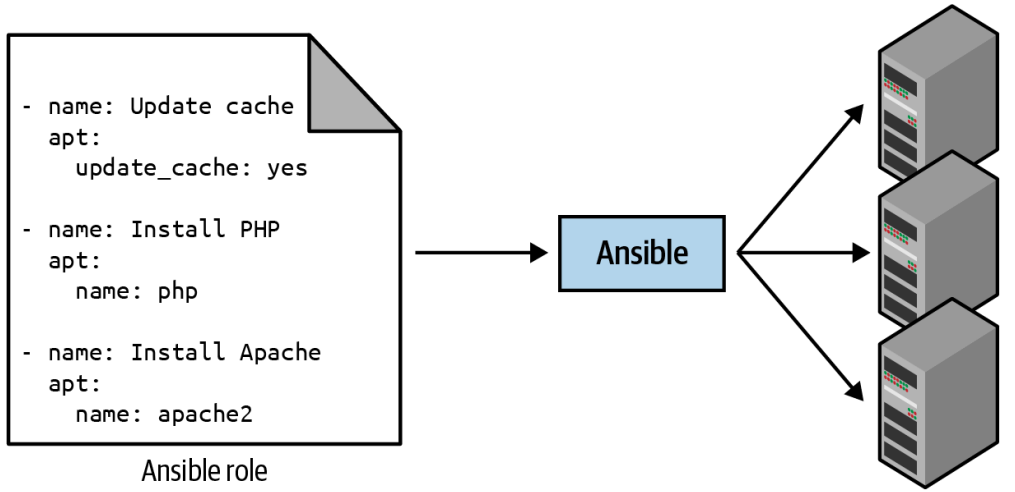


Ad hoc script



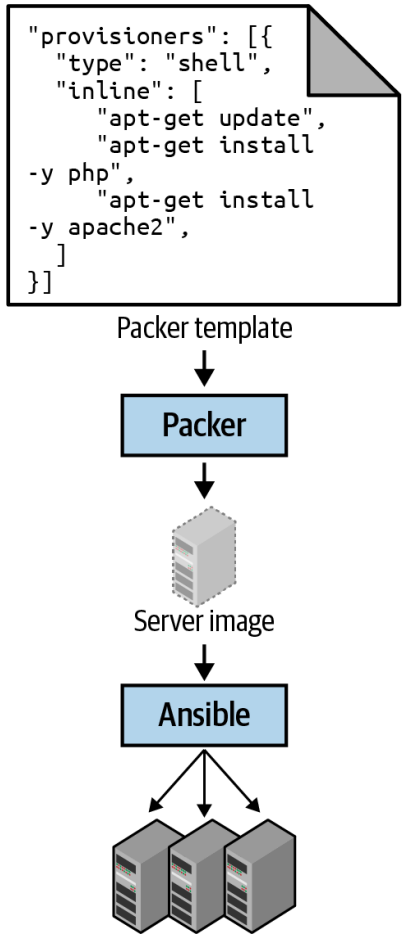
IaC Tools: Configuration management tools

- **The most common tools: Chef, Puppet, Ansible**
  - Designed to install and manage software on existing servers
  - Enforces consistent coding conventions including documentation, file layout, and secrets management
  - The main advantage is **idempotence** - code that works correctly no matter how many times you run it
  - Built for distribution - designed to manage large numbers of remote servers in parallel
  - The main disadvantage is still requires managing the servers themselves



IaC Tools: Server Templating Tools

- **The most common tools: Docker, Packer, Vagrant**
  - Create an image that captures a fully self-contained snapshot of the OS, software, and files
  - Two main types: Virtual Machines (VMware, VirtualBox) and Containers (Docker, rkt)
  - The main advantage enables immutable infrastructure - servers never change after deployment
  - The main disadvantage requires orchestration tools to manage the images at scale



IaC Tools: Orchestration Tools

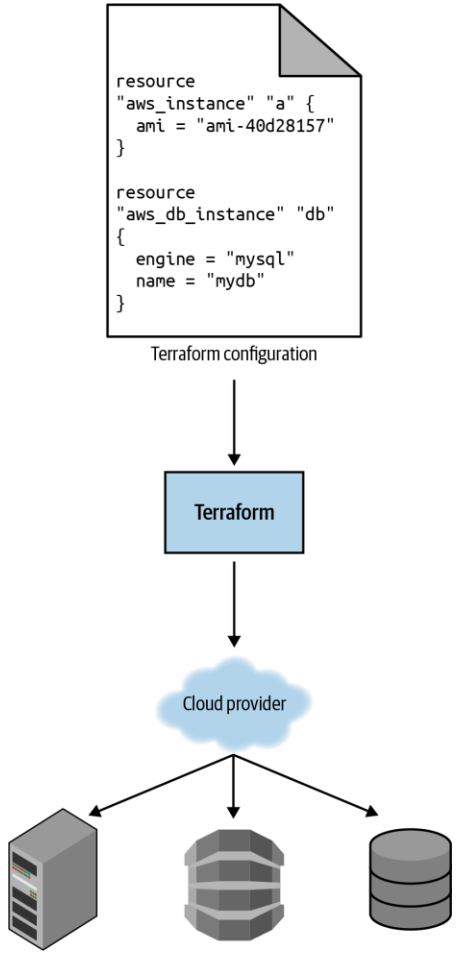
- **The most common tools: Kubernetes, Docker Swarm**
  - Manage deployment of VMs and containers making efficient use of hardware
  - Handle rolling updates, blue-green deployments, and canary deployments
  - Provide auto-healing by monitoring health and replacing unhealthy instances
  - Enable auto-scaling in response to load
  - Distribute traffic through load balancing
  - Facilitate service discovery so containers can communicate

deployment.yaml — YAML

```yaml
apiVersion: apps/v1

# Use a Deployment to deploy multiple replicas of your Docker
# container(s) and to declaratively roll out updates to them
kind: Deployment

# Metadata about this Deployment, including its name
metadata:
  name: example-app

# The specification that configures this Deployment
spec:
  # This tells the Deployment how to find your container(s)
  selector:
    matchLabels:
      app: example-app

  # This tells the Deployment to run three replicas of your
  # Docker container(s)
  replicas: 3

  # Specifies how to update the Deployment. Here, we
  # configure a rolling update.
  strategy:
    rollingUpdate:
      maxSurge: 3
      maxUnavailable: 0
    type: RollingUpdate

  # This is the template for what container(s) to deploy
  template:
    # The metadata for these container(s), including labels
    metadata:
      labels:
        app: example-app

    # The specification for your container(s)
    spec:
      containers:
        # Run Apache listening on port 80
        - name: example-app
          image: httpd:2.4.39
          ports:
            - containerPort: 80
```

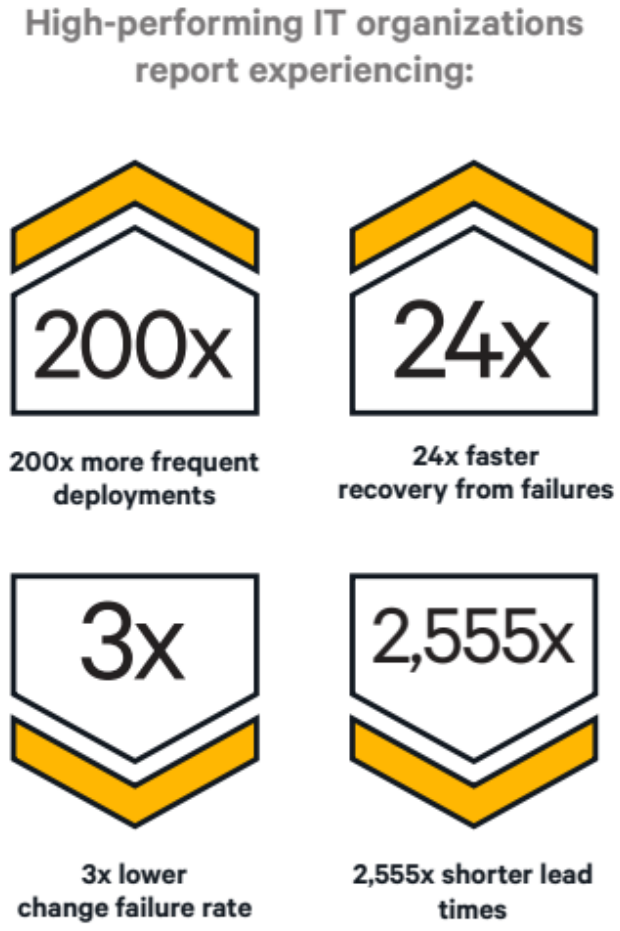
IaC Tools: Provisioning Tools

- **The most common tools: Terraform, OpenTofu, Pulumi**
  - Responsible for creating the servers and infrastructure themselves
  - Create not only servers but databases, load balancers, networks, firewall rules, SSL certificates
  - Define infrastructure resources declaratively as code
  - Work across multiple cloud providers
  - Often used in combination with other IaC tools (config management, templating, orchestration)



Benefits of IaC

- Entire deployment process automated, developers can deploy without bottlenecks
- Automated deployments are faster and more consistent than manual processes
- Infrastructure state is in source files everyone can read, not locked in one person's head



State of DevOps Report 2016

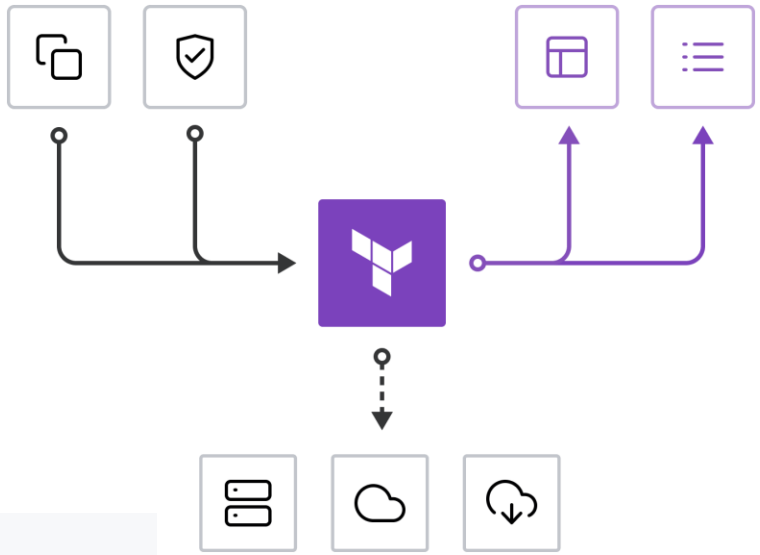
Benefits of IaC

- Complete infrastructure history captured in commit logs for debugging and rollbacks
- Every change can go through code review, automated tests, and static analysis
- Package infrastructure into reusable modules instead of building from scratch each time
- Eliminates repetitive manual work, letting computers handle automation and developers focus on coding

State of DevOps Report 2016

Terraform 101

Terraform

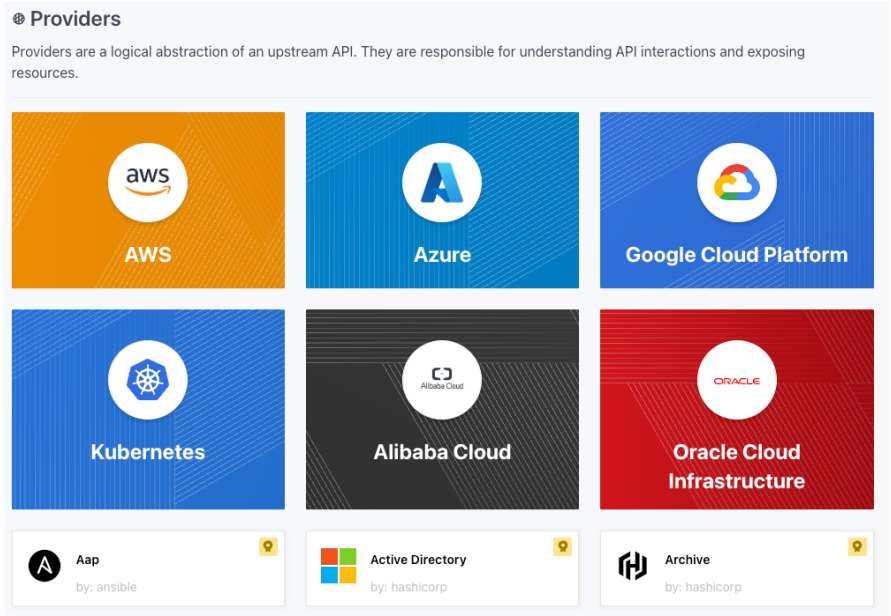


What is Terraform?

- "*Terraform is a tool for building, changing, and versioning infrastructure safely and efficiently.*"

Main Features

- Open Source
- Declarative
- Cloud-agnostic
- Multiple Provider Support
- State Management
- Planned Execution



Terraform: Declarative Infrastrucure

- **HCL (HashiCorp Configuration Language)**
  - Describe the desired state, Terraform handles the "how"
  - Resources are the building blocks of infrastructure
  - Terraform determines the order of operations automatically

main.tf HCL

```
resource "aws_instance" "web_server" {
  ami           = "ami-0fb653ca2d3203ac1"
  instance_type = "t2.micro"

  tags = {
    Name = "MyWebServer"
  }
}
```

Terraform: State Management

- **Terraform tracks infrastructure state**
  - State file stores current infrastructure configuration
  - Enables Terraform to detect what needs to be changed
  - Can be stored locally or remotely (S3, Terraform Cloud)
  - Allows collaboration across teams

backend.tf — HCL

```hcl
terraform {
  backend "s3" {
    bucket = "my-terraform-state"
    key    = "prod/terraform.tfstate"
    region = "us-east-1"
  }
}
```

Terraform: Variables

- **Make configurations reusable and flexible**
  - Variables allow parameterization of configurations
  - Support different types: string, number, list, map, object
  - Can have default values and validation rules
  - Values can be provided via CLI, files, or environment variables

variables.tf — HCL

```hcl
variable "instance_type" {
  description = "EC2 instance type"
  type        = string
  default     = "t2.micro"
}
```

main.tf — HCL

```hcl
resource "aws_instance" "app" {
  ami           = "ami-0fb653ca2d3203ac1"
  instance_type = var.instance_type
}
```

Terraform: Output

- **Expose information from your infrastructure**
  - Outputs display values after terraform apply
  - Can be used by other Terraform configurations
  - Useful for passing data between modules
  - Help document important infrastructure details

outputs.tf — HCL

```hcl
output "instance_ip" {
  description = "Public IP of the instance"
  value       = aws_instance.web.public_ip
}

output "instance_id" {
  description = "ID of the EC2 instance"
  value       = aws_instance.web.id
}
```

Terraform: Resource Dependencies

- **Automatic and explicit dependency management**
  - Terraform automatically detects dependencies
  - Can explicitly define dependencies when needed
  - Creates resources in correct order
  - Handles parallel resource creation when possible

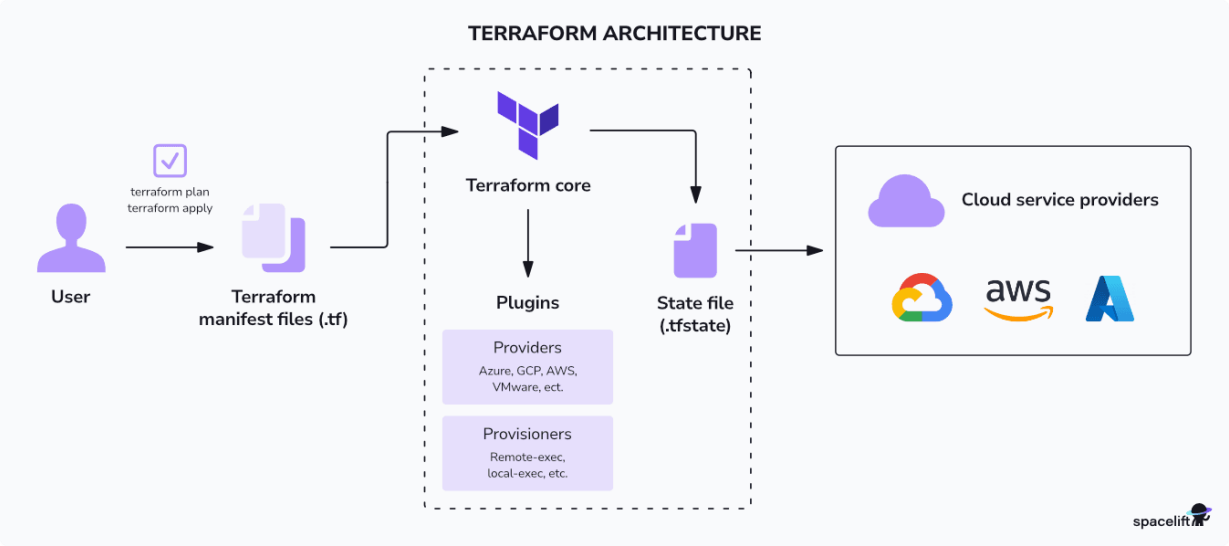
main.tf HCL

```hcl
resource "aws_security_group" "web_sg" {
  name = "web-security-group"

  ingress {
    from_port   = 80
    to_port     = 80
    protocol    = "tcp"
    cidr_blocks = ["0.0.0.0/0"]
  }
}

resource "aws_instance" "web" {
  ami             = "ami-0fb653ca2d3203ac1"
  instance_type   = "t2.micro"
  security_groups = [aws_security_group.web_sg.name]

  depends_on = [aws_security_group.web_sg]
}
```

Terraform: Workflow

➢ Three Steps when using Terraform

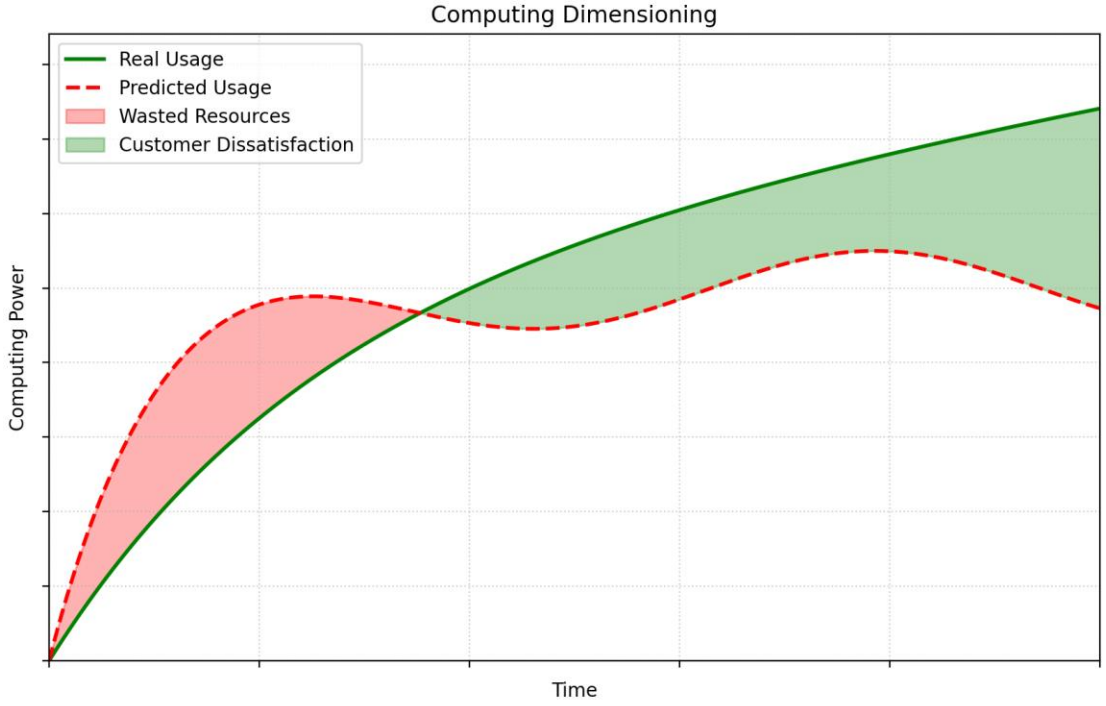
- **Write** - Author infrastructure as code.
- **Plan** - Preview changes before applying.
- **Apply** - Provision reproducible infrastructure.



Scalability & Availability

Overview

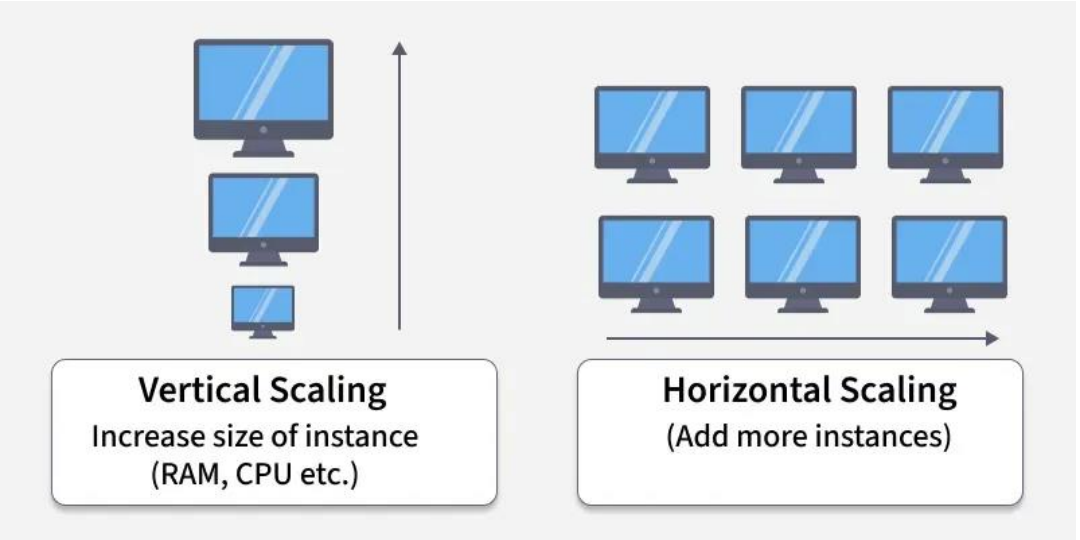
- **Modern applications need to handle growth and stay online**
  - Cloud infrastructure provides flexible and scalable options
  - Users expect systems to be always available and responsive
  - Traffic patterns can be unpredictable and change significantly
  - Systems must handle both normal operations and unexpected failures



Scalability

Scalability is the ability of a system to handle increasing workload

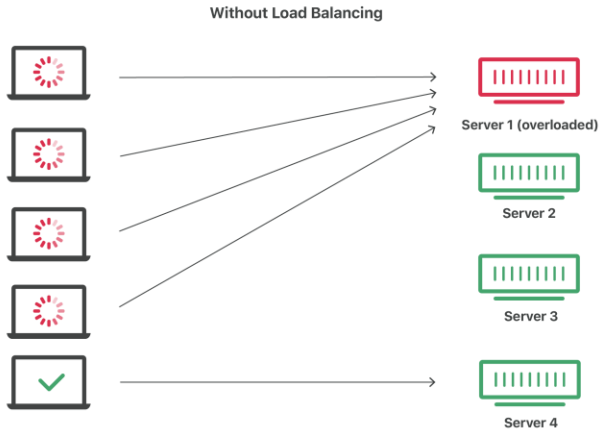
- Vertical scaling: adding more CPU, RAM, or storage to existing servers
- Horizontal scaling: adding more servers to distribute the load
- Auto-scaling adjusts resources based on demand
- Scalability = (Maximum Load / Initial Load) or (Performance at Scale / Baseline Performance)

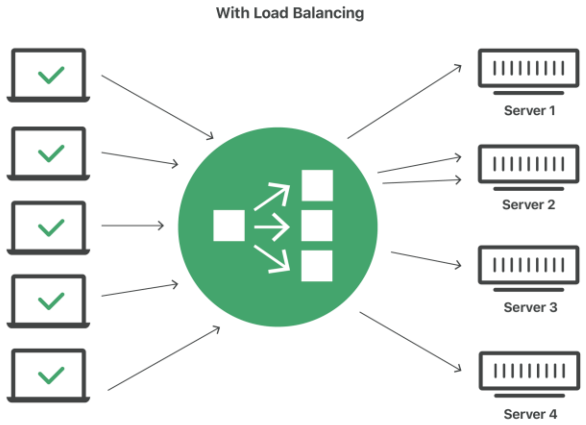


Load Balancing

Load balancers distribute incoming traffic across multiple servers. This prevents any single server from being overwhelmed and improves overall performance.

- Distributes requests evenly across available servers
- Health checks detect and remove failing servers from rotation
- Load per server = Total Load / Number of Active Servers
- Supports different methods: round-robin, least connections, IP hash





Availability

Availability measures how often your system is up and running.

- 99.9% availability = 8.76 hours downtime per year
- 99.99% availability = 52 minutes downtime per year
- Availability (%) = (Uptime / (Uptime + Downtime)) × 100
- Redundancy removes single points of failure

Practice Guide

Practical Guide

- In this lab:
  - Learn from this tutorial (Use Terraform with Docker provider):
    - https://developer.hashicorp.com/terraform/tutorials/docker-get-started

- In your project:
  - You should change your deployment from docker compose into terraform scripts, **only your frontend, backend and database.**
  - They should be integrated in your CI-CD pipeline
  - You need to make sure that there are **two replicas** of your frontend and backend
  - If one of the services fail the application must be fault tolerant
    - TIP: You can use nginx as load balancer to achieve High Availability

Bibliography