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1ST EDITION

The Self-Taught Cloud Computing Engineer

A comprehensive professional study guide to AWS, Azure, and GCP

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Part 1: Learning about the Amazon Cloud

This first part kicks off the cloud journey by introducing the Amazon cloud. In this part, we will digest the concept of cloud computing and examine the AWS cloud services, including compute, storage, networking, database, big data, machine learning, and security, aiming for a comprehensive understanding of the Amazon cloud and obtaining hands-on skills in the AWS cloud.

This part comprises the following chapters:

- *Chapter 1, Amazon EC2 and Compute Services*
- *Chapter 2, Amazon Cloud Storage Services*
- *Chapter 3, Amazon Cloud Networking Services*
- *Chapter 4, Amazon Cloud Database Services*
- *Chapter 5, Amazon Cloud Big Data Services*
- *Chapter 6, Amazon Cloud Machine Learning Services*
- *Chapter 7, Amazon Cloud Security Services*

1
Amazon EC2 and Compute Services

Amazon Web Services (**AWS**) is a cloud computing platform offered by Amazon. It provides a wide range of cloud-based services, including compute, storage, networks, databases, data analytics, **machine learning** (**ML**), and other functionality that can be used to build scalable and flexible applications. We will start our Amazon cloud learning journey from the AWS compute services—specifically, **Elastic Compute Cloud** (**EC2**), which was one of the most basic and earliest cloud services in the world.

In this chapter, we will cover the following topics:

- **The history of computing**: How the first computer evolved from physical to virtual and led to cloud compute
- **Amazon Global Cloud Infrastructure**: Where all the AWS global cloud services are based
- **Building our first EC2 instances in the Amazon cloud**: Provision EC2 instances in the AWS cloud, step by step
- **Elastic Load Balancers** (**ELBs**) and **Auto Scaling Groups** (**ASGs**): The framework providing EC2 services elastically
- **AWS compute – from EC2 to containers to serverless**: Extend from EC2 to other AWS compute services, including **Elastic Container Service** (**ECS**), **Elastic Kubernetes Service** (**EKS**), and Lambda

By following the discussions in this chapter, you will be able to grasp the basic concepts of cloud computing, AWS EC2, and compute services, and gain hands-on skills in provisioning EC2 and compute services. Practice questions are provided to assess your knowledge level, and further reading links are included at the end of the chapter.

The history of computing

In this section, we will briefly review the computing history of human beings, from the first computer to Amazon EC2, and understand what has happened in the past 70+ years and what led us to the cloud computing era.

The computer

The invention of the computer is one of the biggest milestones in human history. On December 10, 1945, **Electronic Numerical Integrator and Computer** (**ENIAC**) was first put to work for practical purposes at the University of Pennsylvania. It weighed about 30 tons, occupied about 1,800 sq ft, and consumed about 150 kW of electricity.

From 1945 to now, in over 75 years, we human beings have made huge progress in upgrading the computer. From ENIAC to desktop and data center servers, laptops, and iPhones, *Figure 1.1* shows the computer evolution landmarks:

Figure 1.1 – Computer evolution landmarks

Let's take some time to examine a computer—say, a desktop PC. If we remove the cover, we will find that it has the following main *hardware* parts—as shown in *Figure 1.2*:

- **Central processing unit** (**CPU**)
- **Random access memory** (**RAM**)
- **Hard disk** (**HD**)
- **Network interface card** (**NIC**)

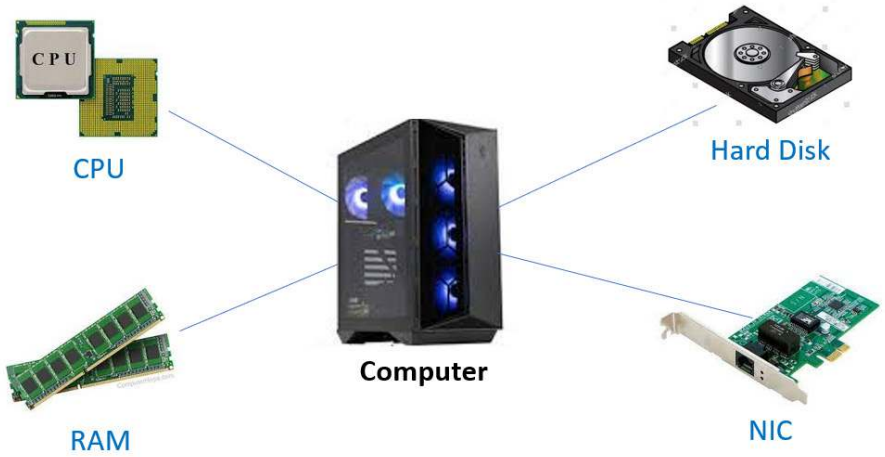


Figure 1.2 – Computer hardware components

These hardware parts work together to make the computer function, along with the *software* including the **operating system** (such as Windows, Linux, macOS, and so on), which manages the hardware, and the **application programs** (such as Microsoft Office, web servers, games, and so on) that run on top of the operating system. In a nutshell, hardware and software specifications decide how much power a computer can serve for different business use cases.

The data center

Apparently, one computer does not serve us well. Computers need to be able to communicate with each other to fulfill network communications, resource sharing, and so on. The work at Stanford University in the 1980s led to the birth of Cisco Systems, Inc., an internet company that played a great part in connecting computers together and forming the intranet and the internet. Connecting many computers together, *data centers* emerged as a central location for computing resources—CPU, RAM, storage, and networking.

Data centers provide resources for businesses' information technology needs: computing, storing, networking, and other services. However, the concept of data center ownership lacks flexibility and agility and entails huge investment and maintenance costs. Often, building a new data center takes a long time and a big amount of money, and maintaining existing data centers—such as tech refresh projects—is very costly. In certain circumstances, it is not even possible to possess the computing resources to complete certain projects. For example, the Human Genome Project was estimated to consume up to 10,000 trillion CPU hours and 40 exabytes (1 exabyte = 10^{18} bytes) of disk storage, and it is impossible to acquire resources at this scale without leveraging cloud computing.

The virtual machine

The peace of physical computers was broken in 1998 when VMware was founded and the concept of a **virtual machine** (**VM**) was brought to Earth. A VM is a software-based computer composed of virtualized components of a physical computer—CPU, RAM, HD, network, operating system, and application programs.

VMware's hypervisor virtualizes hardware to run multiple VMs on bare-metal hardware, and these VMs can run various operating systems of Windows, Linux, or others. With virtualization, a VM is represented by a bunch of files. It can be exported to a binary image that can be deployed on any physical hardware at different locations. A running VM can be *moved* from one host to another, *LIVE*—so-called" v-Motion". The virtualization technologies virtualized physical hardware and caused a revolution in computer history, and also made cloud computing feasible.

The idea of cloud computing

The limitation of data centers and virtualization technology made people explore more flexible and inexpensive ways of using computing resources. The idea of cloud computing started from the concept of "*rental*"—use as needed and pay as you go. It is the on-demand, self-provisioning of computing resources (hardware, software, and so on) that allows you to pay only for what you use. The key concept of cloud computing is *disposable computing resources*. In the traditional information technology and data center concept, a computer (or any other compute resource) is treated as a *pet*. When a pet dies, people are very sad, and they need to get a new replacement right away. If an investment bank's trading server goes down at night, it is the end of the world—everyone is woken up to recover the server. However, in the new cloud computing concept, a computer is treated as cattle in a herd. For example, the website of an investment bank, `zhebank.com`, is supported by a *herd* of 88 servers—`www001` to `www88`. When one server goes down, it's taken out of the serving line, shot, and replaced with another new one with the same configuration and functionalities, automatically!

With cloud computing, enterprises are leveraging the **cloud service provider** (**CSP**)'s *unlimited* computing resources that are featured as global, elastic and scalable, highly reliable and available, cost-effective, and secure. The main CSPs, such as Amazon, Microsoft, and Google, have global data centers that are connected by backbone networks. Because of cloud computing's pay-as-you-go characteristics, it makes sense for cost savings. Because of its strong monitoring and logging features, cloud computing offers the most secure hosting environment. Instead of building physical hardware data centers with big investments over a long time, virtual software-based data centers can be built within several hours, immutable and repeatedly, in the global cloud environment. Infrastructure is represented as code that can be managed with version control, which we can call **Infrastructure as Code** (**IaC**). More details can be found at `https://docs.aws.amazon.com/whitepapers/latest/introduction-devops-aws/infrastructure-as-code.html`.

EC2 was first introduced in 2006 as a web service that allowed customers to rent virtual computers for computing tasks. Since then, it has become one of the most popular cloud computing platforms available, offering a wide range of services and features that make it an attractive option for enterprise

customers. Amazon categorizes the VMs with different EC2 instance types based on hardware (CPU, RAM, HD, and network) and software (operating system and applications) configurations. For different business use cases, cloud consumers can choose EC2 instances with a variety of instance types, operating system choices, network options, storage options, and more. In 2013, Amazon introduced the **Reserved Instance** feature, which gave customers the opportunity to purchase instances at discounted rates in exchange for committing to longer usage terms. In 2017, Amazon released EC2 Fleet, which allows customers to manage multiple instance types and instance sizes across multiple **Availability Zones** (**AZs**) with a single request.

The computer evolution path

From ENIAC to EC2, a computer has evolved from a huge, physical unit to a disposable resource that is flexible and on-demand, portable, and replaceable, and a data center has evolved from being expensive and protracted to a piece of code that can be executed globally at any time on demand, within hours.

In the next sections of this chapter, we will look at the Amazon Global Cloud Infrastructure and then provision our EC2 instances in the cloud.

Amazon Global Cloud infrastructure

The **Amazon Global Cloud Infrastructure** is a suite of cloud computing services offered by AWS, including compute, storage, databases, analytics, networking, mobile, developer tools, management tools, security, identity compliance, and so on. These services are hosted globally, allowing customers to store data and access resources in locations that best meet their business needs. It delivers highly secure, low-cost, and reliable services that can be used by almost any application in any industry around the world.

Amazon has built physical data centers around the world, in graphical areas called AWS Regions, which are connected by Amazon's backbone network infrastructure. Each Region provides full redundancy and connectivity among its data centers. An AWS Region typically consists of two or more AZs, which is a fully isolated partition of the AWS infrastructure. An AZ has one or more data centers connected with each other and is identified by a name that combines a letter identifier with the region's name. For example, `us-east-1d` is the *d AZ* in the `us-east-1` region. Each AZ is designed for fault isolation and is connected to other AZs using high-speed private networking. When provisioning cloud resources such as EC2, you choose the region and AZs where the EC2 instance will be sitting. In the next section, we will demonstrate the EC2 instance provisioning process.

Building our first EC2 instances in the Amazon cloud

In this section, we will use the AWS cloud console and CloudShell command line to provision EC2 instances running in the Amazon cloud—Linux and Windows VMs, step by step. Note that the user interface may change, but the procedures are similar.

Before we can launch an EC2 instance, we need to create an AWS account first. Amazon offers a *free tier* account for new cloud learners to provision some basic cloud resources, but you will need a credit card to sign up for an AWS account. Since your credit card is involved, there are three things to keep in mind with your AWS 12-digit account, as follows:

- Enable **multi-factor authentication** (**MFA**) to protect your account
- You can log in to the console with your email address, but be aware that this is the root user, which has the superpower to provision any resources globally
- Clean up all/any cloud resources you have provisioned after completing the labs

Having signed up for an AWS account, you are ready to move to the next phase—launching EC2 instances using the cloud console or CloudShell.

Launching EC2 instances in the AWS cloud console

Logging in to the AWS console at `console.aws.amazon.com`, you can search for EC2 services and launch an EC2 instance by taking the following nine steps:

1. **Select the software of the EC2 instance**: Think of it just like selecting software (OS and other applications) when purchasing a physical desktop or laptop PC.

   In AWS, the software image for an EC2 instance is called an **Amazon Machine Image** (**AMI**), which is a template that is used to launch an EC2 instance. Amazon provides AMIs in Windows, Linux, and other operating systems, customized with some other software pre-installed:

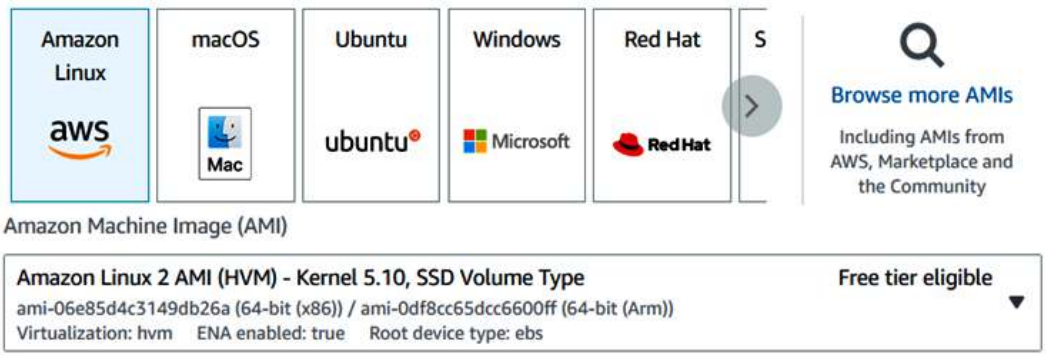


Figure 1.3 – Selecting an AMI

   As shown in *Figure 1.3*, we have chosen the Amazon Linux 2 AMI, which is a customized Linux OS tuned for optimal performance on AWS and easy integration with AWS services, and it is free-tier eligible.

In many enterprises, AMI images are standardized to be used as **seeds** to deploy EC2 instances—we call them **golden images**. A production AMI includes all the packages, patches, and applications that are needed to deploy EC2 instances in production and will be managed with secure version-control management systems.

2. **Select the hardware configuration of the EC2 instance**: This is just like selecting hardware—the number of CPUs, RAM, and HD sizes when purchasing a physical desktop or laptop PC. In AWS, the hardware selection is to choose the right EC2 instance type—Amazon has categorized the EC2 hardware configurations into various instance types, such as **General Purpose**, **Compute Optimized**, **Memory Optimized**, and so on, based on business use cases. Some AWS EC2 instance types are shown in *Figure 1.4*:

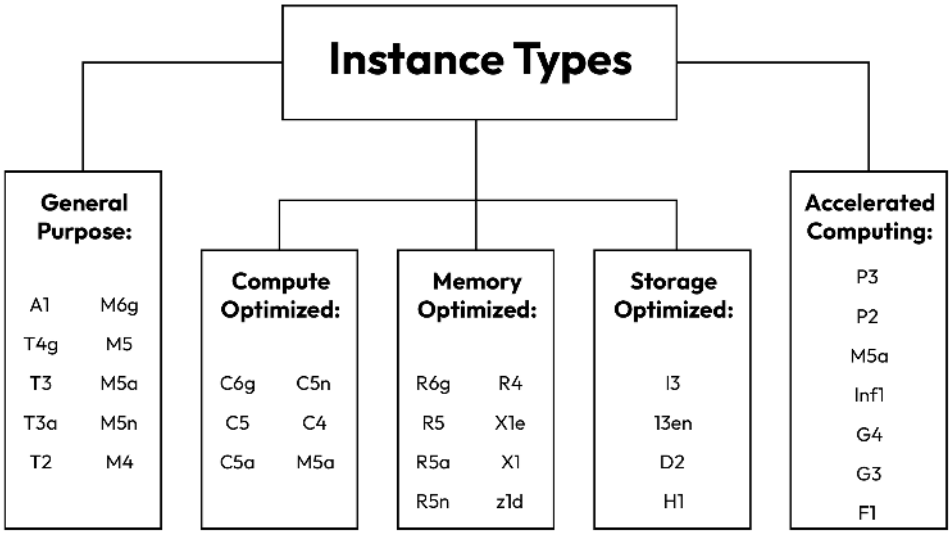


Figure 1.4 – EC2 instance types

Each instance type is specified by a category, family series, generation number, and configuration size. For example, the `p2.8xlarge` instance type can be used for an Accelerated Computing use case, where `p` is the instance family series, `2` is the instance generation, and `8xlarge` indicates its size is 8 times the `p2.large` instance type.

We will choose `t2.micro`, which is inexpensive and free-tier eligible, for our EC2 instances.

3. **Specify the EC2 instance's network settings**: This is like subscribing to an **Internet Service Provider** (**ISP**) for our home PC to connect to a network and the internet. In the AWS cloud, the basic network unit is called a **Virtual Private Cloud** (**VPC**), and Amazon has provided a default VPC and subnets in each region. At this time, we will take the default setting—our first EC2 instance will be placed into the default VPC/subnet and be assigned a public IP address to make it internet-accessible.

4. **Optionally attach an AWS Identity and Access Management (IAM) role to the EC2 instance**: This is something very different from traditional concepts but is very useful for software/applications running on the EC2 instance to interact with other AWS services.

   With IAM, you can specify who can access which resources with what permissions. An IAM role can be created and assigned with permissions to access other AWS resources, such as reading an **Amazon Simple Storage Service** (**Amazon S3**) bucket. By attaching the IAM role to an EC2 instance, all applications running on the EC2 instance will have the same permissions as that role. For example, we can create an IAM role, assign it read/write access to an S3 bucket, and attach the role to an EC2 instance, then all the applications running on the EC2 instance will have read/write access to the S3 bucket. *Figure 1.5* shows the concept of attaching an IAM role to an EC2 instance:

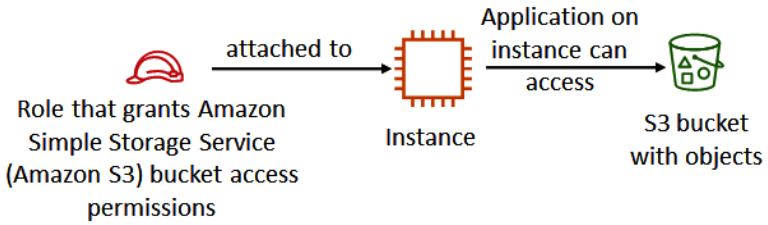


Figure 1.5 – Attaching an IAM role to an EC2 instance

5. **Optionally specify a user data script to the EC2 instance**: User data scripts can be used to customize the runtime environment of the EC2 instance—it executes the first time the instance starts. I have had experience using the EC2 user data script—at a time when the Linux system admin left my company and no one in the company was able to access a Linux instance sitting in the AWS cloud. While there exist many ways to rescue this situation, one interesting solution we used was to generate a new key pair (public key and private key), stop the instance, and leverage the instance's user data script to append the new public key to the `EC2-user` user's **Secure Shell** (**SSH**) profile, during the instance starting process. With the new public key added to the EC2 instance, the `ec2-user` user can SSH into the instance with the new private key.
6. **Optionally attach additional storage volumes to the EC2 instance**: This can be thought of as buying and adding additional disk drives to our PC at home. For each volume, we need to specify the size of the disk (in GB) and the volume type (hardware types), and whether encryption should be used for the volume.
7. **Optionally assign a tag to the EC2 instance**: A tag is a label that we can assign to an AWS resource, and it consists of a key and an optional value. With tags, we attach metadata to cloud resources such as an EC2 instance. There are many potential benefits of tagging in managing cloud resources, such as filtering, automation, cost allocation and chargeback, and access control.

8. **Setting a Security Group (SG) for the EC2 instance**: Just like configuring firewalls on our home routers to manage access to our home PCs, an SG is a set of firewall rules that control traffic to and from our EC2 instance. With an SG, we can create rules that specify the source (for example, an IP address or another SG), the port number, and the protocol, such as HTTP/HTTPS, SSH (port `22`), or **Internet Control Message Protocol** (**ICMP**). For example, if we use the EC2 instance to host a web server, then the SG will need an SG rule to open ports for `http` (`80`) and `https` (`443`). Note that SGs exist outside of the instance's guest OS—traffic to the instance can be controlled by both SGs and guest OS firewall settings.
9. **Specify an existing key pair or create a new key pair for the EC2 instance**: A key pair consists of a public key that AWS stores on the instance and a private key file that you download and store on your local computer for remote access. When you try to connect to the instance, the keys from both ends are matched to authenticate the remote user/connections. For Windows instances, we need to decrypt the key pair to obtain the administrator password for logging in to the EC2 instance remotely. For Linux instances, we utilize the private key and use SSH to securely connect to the cloud instance. Note that the only chance to download an EC2 key pair is during the instance creation time. If you've lost the key pair, you cannot recover it. The only workaround is to create an AMI of the existing instance, and then launch a new instance with the AMI and a new key pair. Also, note that there are two formats for an EC2 key pair when you save it to the local computer: the `.pem` format is used on Linux-based terminals including Mac, and the `.ppk` format is used for Windows.

Following the preceding nine steps, we have provisioned our first EC2 instance—a Linux VM in the AWS cloud. Following the same procedure, let us launch a Windows VM. The only difference is that in *step 1*, we choose the Microsoft Windows operating system— specifically, **Microsoft Windows Server 2022 Base**—as shown in *Figure 1.6*, which is also free-tier eligible:

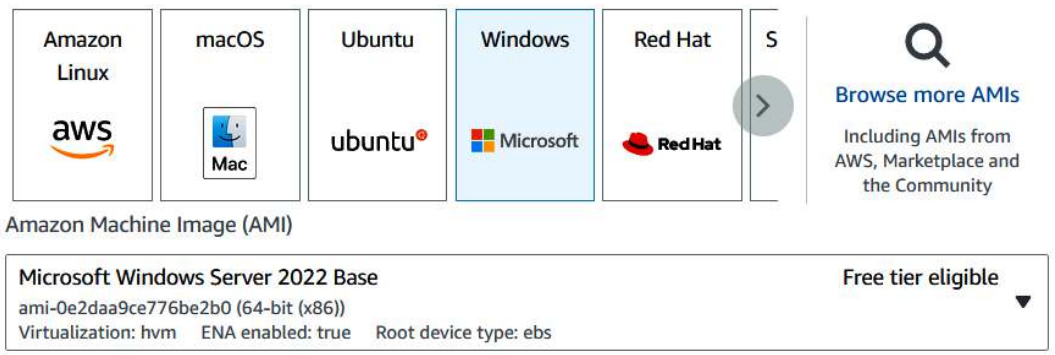


Figure 1.6 – Selecting Microsoft Windows as the operating system

So far, we have created two EC2 instances in our AWS cloud—one Linux VM and one Windows VM—via the AWS Management console.

Launching EC2 instances using CloudShell

We can also launch EC2 instances using the command line in CloudShell, which is a browser-based, pre-authenticated shell that you can launch directly from the AWS Management Console. Next are detailed steps to create an EC2 Windows instance in the `us-west-2` Region:

1. **From the AWS console, launch CloudShell** by clicking the CloudShell sign, as shown in *Figure 1.7*:

Figure 1.7 – Launching CloudShell from the AWS console

2. **Find the AWS AMI image ID** in the `us-west-2` region, with the following CloudShell command – the results are shown in *Figure 1.8*:

```
[cloudshell-user]$ aws ec2 describe-images --region us-west-2
```

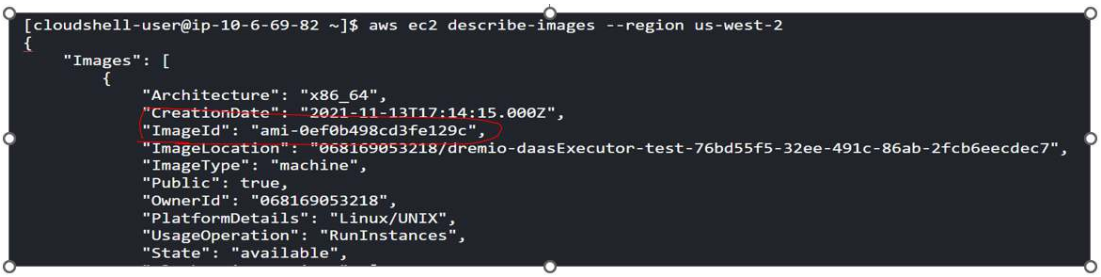


Figure 1.8 – Finding the Linux AMI image ID

3. **Find the SG name** we created in the previous section, as shown in *Figure 1.9*:

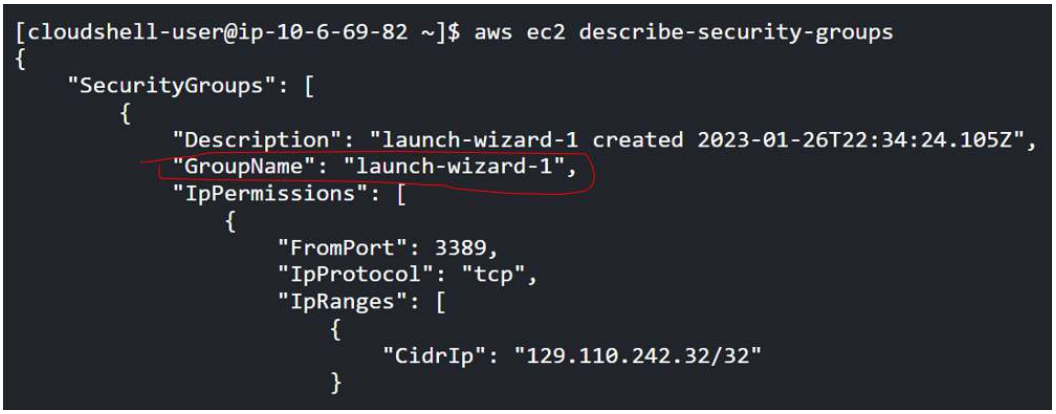


Figure 1.9 – Finding the SG name

4. **Find the key pair** we created in the previous section, as shown in *Figure 1.10*:

Figure 1.10 – Finding the key pair name

5. **Create an EC2 instance** in the `us-west-2` region, using the `aws ec2 run-instances` command, with the following configurations we obtained from the previous steps. A screenshot is shown in *Figure 1.11*. The instance ID is called out from the output

   AMI:

   `ami-0ef0b498cd3fe129c`

   SG:

   `launch-wizard-1`

   Key pair:

`mywestkp`

Instance type:

`t2.micro`

```
aws ec2 run-instances --image-id ami-0ef0b498cd3fe129c --count 1
--instance-type t2.micro --key-name mywestkp --security-groups
launch-wizard-1 --region us-west-2
```

Figure 1.11 – Launching an EC2 instance

6. **Examine the details of the instance** from its `InstanceId` value. As shown in *Figure 1.12*, the instance has a public IP address of `35.93.143.38`:

Figure 1.12 – Finding the EC2 instance's public IP address

So far, we have created another EC2 instance using CloudShell with command lines. Note that CloudShell allows us to provision any cloud resources using lines of code, and we will provide more examples in the rest of the book.

Logging in to the EC2 instances

After the instances are created, how do we access them?

SSH is a cryptographic network protocol for operating network services securely over an unsecured network. We can use SSH to access the Linux EC2 instance. **PuTTY** is a free and open source terminal emulator, serial console, and network file transfer application. We will download PuTTY and use it to connect to the Linux VM in the AWS cloud, as shown in *Figure 1.13*:

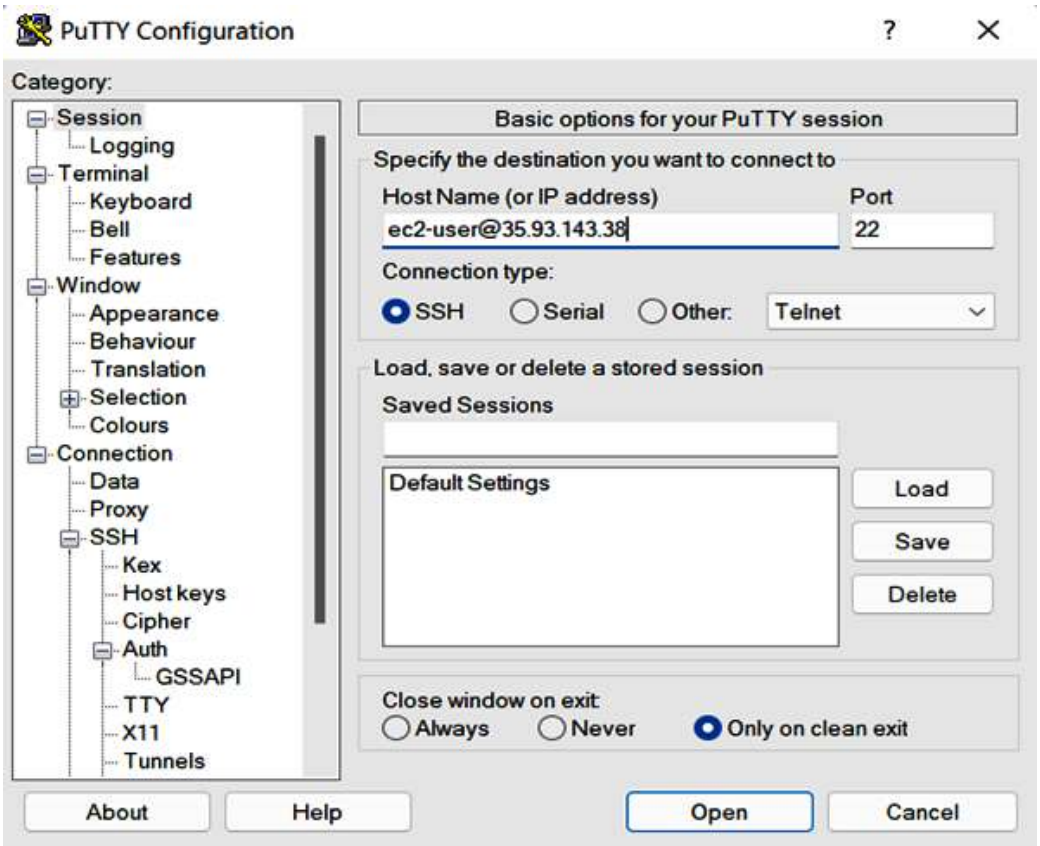


Figure 1.13 – Using PuTTY to connect to the Linux instance

As shown in *Figure 1.13*, we entered `ec2-user@35.93.143.38` in the **Host Name (or IP address)** field. `ec2-user` is a default user created in the guest Linux OS, and `35.93.143.38` is the public IP of the EC2 instance. Note we need to open the SSH port (`22`) in the EC2 instance's SG to allow traffic from our remote machine, as discussed in *step 8* of the *Launching EC2 instances in the AWS cloud console* section earlier in the chapter.

We also need to provide the key pair in the **PuTTY Configuration** window by going to **Connection | SSH | Auth**, as shown in *Figure 1.14*:

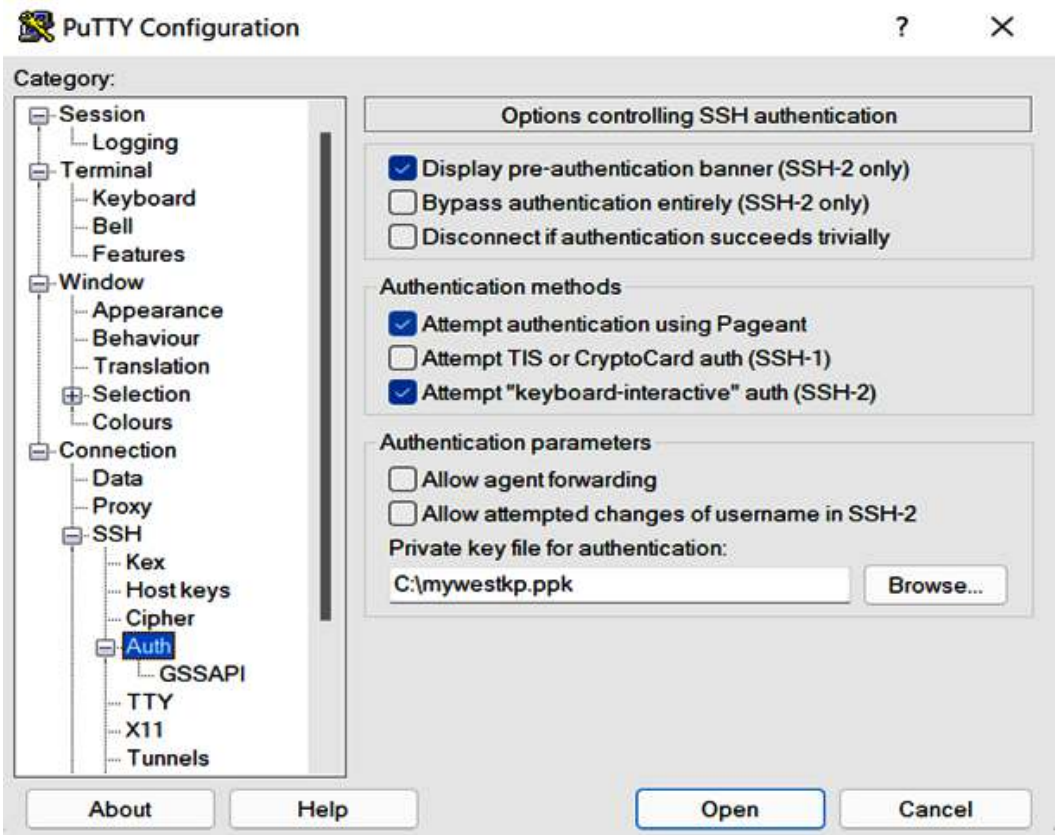


Figure 1.14 – Entering the key pair in PuTTY

Click **Open**, and you will be able to SSH into the Linux instance now. As shown in *Figure 1.15*, we have SSH-ed into the cloud EC2 instance:

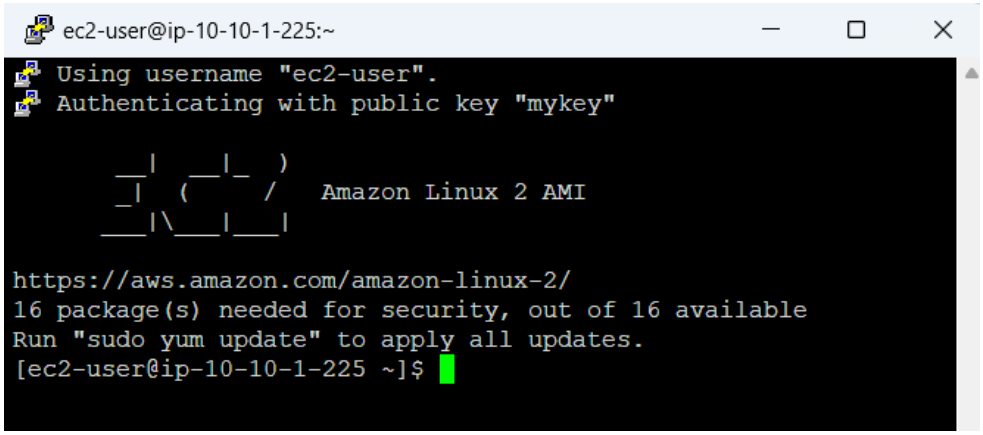


Figure 1.15 – SSH-ing into ec2-1 from the internet

Since we are using a Windows terminal to connect to the remote Linux instance, the key pair format is `.ppk`. If you are using a Mac or another Linux-based terminal, you will need to use the `.pem` format. These two formats can be converted using the open source software PuTTYgen, which is part of the PuTTY family.

With a Linux-based terminal including Mac, use the following command to connect to the cloud Linux EC2 instance:

```
ssh -i keypair.pem ec2-user@35.93.143.38
```

`keypair.pem` is the key pair file in `.pem` format. Make sure it's set to the right permission using the `chomd 400 keypair.pem` Linux command. `ec2-user@35.93.143.38` is `user@EC2`'s public IP address. The default user may change to `ubuntu` if the EC2 instance is an Ubuntu Linux distribution.

For the Windows EC2 instance, just as we access another PC at our home using **Remote Desktop Protocol** (**RDP**), a proprietary protocol developed by Microsoft that provides a user with a graphical interface to connect to another computer over a network connection, we use RDP to log in to the Windows EC2 instance in the AWS cloud. By default, RDP client software is installed on our desktop or laptop, and the Windows EC2 instance has RDP server software running, so it becomes very handy to connect our desktop/laptop to the Windows VM in the cloud. One extra step is that we need to decrypt the administrator's password from the key pair we downloaded during the instance launching process, by going to the AWS console's **EC2 dashboard** and clicking **Instance** | **Connect** | **RDP Client**.

ELB and ASG

We previously briefed the "cattle in a herd" analogy in cloud computing. In this section, we will explain the actual implementation using ELBs and ASGs and use an example to illustrate the mechanism.

An ELB automatically distributes the incoming traffic (workload) across multiple targets, such as EC2 instances, in one or more AZs, so as to balance the workload for high performance and **high availability** (**HA**). An ELB monitors the health of its registered targets and distributes traffic only to the healthy targets.

Behind an ELB, there is usually an ASG that manages the fleet of ELB targets—EC2 instances, in our case. ASG monitors the workload of the instances and uses auto-scaling policies to scale—when the workload reaches a certain up-threshold, such as CPU utilization of 80%, ASG will launch new EC2s and add them into the fleet to offload the traffic until the utilization drops below the up-threshold. When the workload reaches a certain down-threshold, such as CPU utilization of 30%, ASG will shut down EC2s from the fleet until the utilization rises above the threshold. ASG also utilizes a health-check to monitor the instances and replace unhealthy ones as needed. During the auto-scaling process, ASG makes sure that the running EC2 instances are loaded within the thresholds and are laid out across as many AZs in a region.

Let us illustrate ELB and ASG with an example. `www.zbestbuy.com` is an international online e-commerce retailer. During normal business hours, it needs a certain number of web servers to work together to meet online shopping traffic. To meet the global traffic requirements, three web servers are built in different AWS regions—North Virginia (`us-east-1`), London (`eu-west-2`), and Singapore (`ap-southeast-1`). Depending on the customer browser location, Amazon Route 53 (an AWS DNS service) will route the traffic to the nearest web server: when customers in Europe browse the retailer website, the traffic will be routed to the `eu-west-2` web server, which is really an ELB (or **Application Load Balancer** (**ALB**)), and distributed to the EC2 instances behind the ELB, as shown in *Figure 1.16*.

When Black Friday comes, the traffic increases and hits the ELB, which passes the traffic to the EC2 instance fleet. The heavy traffic will raise the EC2 instances' CPU utilization to reach the up-threshold of 80%. Based on the auto-scaling policy, an alarm will be kicked off and the ASG will automatically scale, launching more EC2 instances to join the EC2 fleet. With more EC2s joining in, the CPU utilization will be dropped. Depending on the Black Friday traffic fluctuation, the ASG will always keep up to make sure enough EC2s are working on the workload with normal CPU utilization. When Black Friday sales end, the traffic decreases and thus causes the instances' CPU utilization to drop. When it reaches the down-threshold of 30%, the ASG will start shutting down EC2s based on the auto-scaling policy:

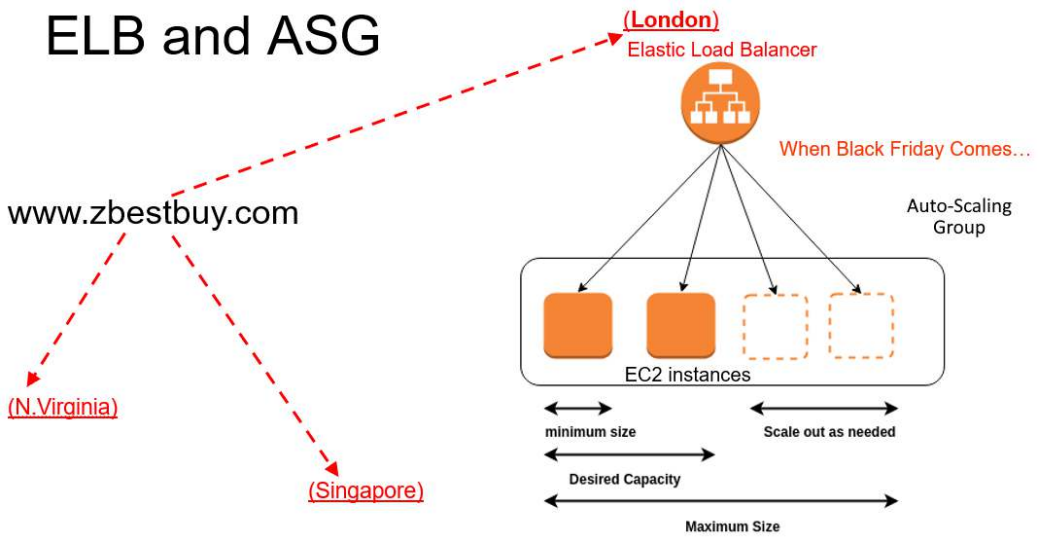


Figure 1.16 – ELB and ASG

As we can see from the preceding example, ELB and ASG work together to scale elastically. Please refer to `https://docs.aws.amazon.com/autoscaling/ec2/userguide/autoscaling-load-balancer.html` for more details.

AWS compute – from EC2 to containers to serverless

So far in this chapter, we have dived into the AWS EC2 service and discussed AWS ELB and ASG. Now, let's spend some time expanding to the other AWS compute services: ECS, EKS, and Lambda (serverless service).

We have discussed the virtualization technology led by VMware at the beginning of the 21st century. While transforming from physical machines to VMs is a great milestone, there still exist constraints from the application point of view: every time we need to deploy an application, we need to run a VM first. The application is also tied up with the OS platform and lacks flexibility and portability. To solve such problems, the concept of **Docker** and **containers** came into the world. A Docker engine virtualizes an OS to multiple apps/containers. A Docker image is a lightweight, standalone, executable package of software that includes everything needed to run an application: code, runtime, system tools, system libraries, and settings. A container is a runtime of the Docker image, and the application runs quickly and reliably from one computing environment to another. Multiple containers can run on the same VM and share the OS kernel with other containers, each running as isolated processes in user space. To further achieve fast and robust deployments and low lead times, the concept of **serverless** computing emerged. With serverless computing, workloads run on servers behind the scenes. From a developer or user's point of view, what they need to do is just submit the code and get the running results back—there is no hassle of building and managing any infrastructure platforms at all, while

resources can continuously scale and be dynamically allocated as needed, yet you never pay for idle time as it is pay per usage.

From VM to container to serverless, Amazon provides EC2, ECS/EKS, and Lambda services correspondingly.

Amazon ECS is a fully managed container orchestration service that helps you easily deploy, manage, and scale containerized applications using Docker or Kubernetes. Amazon ECS provides a highly available and scalable platform for running container-based applications. Enterprises use ECS to grow and manage enterprise application portfolios, scale web applications, perform batch processing, and run services to deliver better services to users.

Amazon EKS, on the other hand, is a fully managed service that makes it easy to deploy, manage, and scale Kubernetes in the AWS cloud. Amazon EKS leverages the global cloud's performance, scale, reliability, and availability, and integrates it with other AWS services such as networking, storage, and security services.

Amazon Lambda was introduced in November 2014. It is an event-driven, serverless computing service that runs code in response to events and automatically manages the computing resources required by that code. Amazon Lambda provides HA with automatic scaling, cost optimization, and security. It supports multiple programming languages, environment variables, and tight integration with other AWS services.

For more details about the aforementioned AWS services and their implementations, please refer to the *Further reading* section at the end of the chapter.

Summary

Congratulations! We have completed the first chapter of our AWS self-learning journey: cloud compute services. In this chapter, we have thoroughly discussed Amazon EC2 instances and provisioned EC2 instances step by step, using the AWS cloud console and CloudShell command lines. We then extended from EC2 (VM) to the container and serverless concepts and briefly discussed Amazon's ECS, EKS, and Lambda services.

In the next chapter, we will discuss Amazon *storage* services, including block storage and network storage that can be added and shared by EC2 instances, and the Simple Storage Service.

At the end of each chapter, we provide practice questions and answers. These questions are designed to help you understand the cloud concepts discussed in the chapter. Please spend time on each question before checking the answer.

Practice questions

1. Which of the following is not a valid source option when configuring SG rules for an EC2 instance?

    A. Tag name for another EC2 instance

    B. IP address for another EC2 instance

    C. IP address ranges for a network

    D. SG name used by another EC2 instance

2. An AWS cloud engineer signed up for a new AWS account, then logged in to the account and created a Linux EC2 instance in the default VPC/subnet. They were able to SSH to the EC2 instance. From the EC2 instance, They:

    A. can access `www.google.com`

    B. cannot access `www.google.com`

    C. can access `www.google.com` only after they configure SG rules

    D. can access `www.google.com` only after they configure **Network Access Control List** (**NACL**) rules

3. Alice launched an EC2 Linux instance in the AWS cloud, and then successfully SSH-ed to the instance from her laptop at home with the default `ec2-user` username. Which keys are used during this process?

    A. `ec2-user`'s public key, which is stored on the EC2 instance, and the private key on the laptop

    B. The `root` user's public key on the EC2 instance

    C. `ec2-user`'s public key, which is stored on the laptop

    D. `ec2-user`'s private key, which is stored on the cloud EC2 instance

    E. `ec2-user`'s symmetric key, which is stored on both the laptop and EC2 instance

4. `www.zbestbuy.com` is configured with ELB and ASG. At peak time, it needs 10 AWS EC2 instances. How do you make sure the website will never be down and can scale as needed?

    A. Set ASG's `minimum instances = 2, maximum instances = 10`

    B. Set ASG's `minimum instances = 1, maximum instances = 10`

    C. Set ASG's `minimum instances = 0, maximum instances = 10`

    D. Set ASG's `minimum instances = 2, maximum instances = 2`

5. A middle school has an education application system using ASG to automatically scale resources as needed. The students report that every morning at 8:30 A.M., the system becomes very slow for about 15 minutes. Initial checking shows that a large percentage of the classes start at 8:30 A.M., and it does not have enough time to scale out to meet the demand. How can we resolve this problem?

A. Schedule the ASGs accordingly to scale out the necessary resources at 8:15 A.M. every morning

B. Use Reserved Instances to ensure the system has reserved the capacity for scale-up events

C. Change the ASG to scale based on network utilization

D. Permanently keep the running instances that are needed at 8:30 A.M. to guarantee available resources

6. AWS engineer Alice is launching an EC2 instance to host a web server. How should Alice configure the EC2 instance's SG?

A. Open ports `80` and `443` inbound to `0.0.0.0/0`

B. Open ports `80` and `443` outbound to `0.0.0.0/0`

C. Open ports `80` and `443` inbound to `10.10.10.0/24`

D. Open ports `80` and `443` outbound to `my IP`

7. An AWS cloud engineer signed up for a new AWS account, then logged in to the account and created an EC2-1 Windows instance and an EC2-2 Linux instance in one subnet (172.31.48.0/20) in the default VPC, using an SG that has `SSH` and `RDP` open to `172.31.0.0/16` only. They were able to RDP to the EC2-1 instance. From the EC2-1 instance, they:

A. can SSH to EC2-2

B. can ping EC2-2

C. cannot ping EC2-1

D. cannot SSH to EC2-2

8. `www.zbestbuy.com` has a need for 10,000 EC2 instances in the next 3 years. What should they use to get these computing resources?

A. Reserved Instances

B. Spot Instances

C. On-demand instances

D. Dedicated-host instances

9. AWS engineer Alice needs to log in to an EC2-100 Linux instance that no one can access since the AWS engineer who was managing it left the company. What does Alice need to do?

    A. Generate a key pair, and add the public key to EC2-100 using `user-data`

    B. Generate a key pair, and add the public key to EC2-100 using `meta-data`

    C. Generate a key pair, and copy the public key to EC2-100 using **Secure Copy Protocol** (**SCP**)

    D. Remove the old private key from EC2-100

10. An AWS architect launched an EC2 instance using the `t2.large` type, installed databases and web applications on the instance, then found that the instance was too small, so they want to move to an `M4.xlarge` instance type. What do they need to do?

Answers to the practice questions

1. A
2. A
3. A
4. A
5. A
6. A
7. A
8. A
9. A

10. One way is to stop the instance in the AWS console and start it with the `M4.xlarge` instance type.

Further reading

For further insights into what you've learned in this chapter, refer to the following links:

- `https://aws.amazon.com/ec2/`
- `https://aws.amazon.com/ecs/`
- `https://aws.amazon.com/eks/`
- `https://aws.amazon.com/lambda/`

- https://docs.aws.amazon.com/autoscaling/ec2/userguide/autoscaling-load-balancer.html
- https://docs.aws.amazon.com/ec2/
- https://aws.amazon.com/blogs/compute/

2

Amazon Cloud Storage Services

We explored Amazon EC2 and compute services in the previous chapter and provisioned EC2 instances in the Amazon cloud, including Windows and Linux instances. In this chapter, we will discuss Amazon cloud storage, including the block cloud storage that can be attached to an EC2 instance, the network filesystem cloud storage that can be shared by many EC2 instances, and the object cloud storage storing objects in the cloud. We will cover the following topics in this chapter:

- **Amazon Elastic Block Store** (**EBS**): Provides block-level storage volumes to EC2 instances. We will show how to create and attach storage volumes to EC2 instances and use them as primary storage.
- **Amazon Elastic File System** (**EFS**): Provides scalable and fully managed filesystem storage to be shared by EC2 instances and on-premises resources.
- **Amazon Simple Storage Service** (**S3**): Provides object storage that can store and retrieve any amount of data from anywhere on the web.
- **Amazon Snowball** and **Snowmobile**: Physical data transfer services for transferring large amounts of data into or out of the AWS cloud.
- **Accessing S3 from EC2 instances**: By leveraging an EC2 IAM role, EC2 instances can easily access S3 and take advantage of S3's scalable, durable, and highly available storage services for your applications running on EC2.

Following the discussions in this chapter and integrating the EC2 knowledge and skills learned from the last chapter, you will be able to dive deep and understand why we need to and how to create block storage, network filesystem storage, and simple storage in the cloud, how you can transfer storage from your on-premises data centers to the cloud, and how to access the cloud storage from an EC2 instance.

Understanding EBS

When we run out of storage on our home PC, we usually buy a new disk drive, shut down the computer, install the disk drive, reboot the computer to recognize the new disk drive, and then log into the computer guest OS to format the new disk drive and start using it.

This type of disk storage is called *block storage*, which is a technology that controls storage on the computer, using a block as the storing unit. It takes the data to be stored, divides it into blocks of equal sizes, and stores the data blocks on the underlying physical storage. With block storage, a block is the unit for data storing and retrieving, and only changes to the blocks are written to the disk. For example, when you change a sentence in a Microsoft Word doc and save the doc, only the blocks that store the sentence were updated to the physical disk drive, in contrast to *object storage*, which uses an object (such as a fingerprint file) as a storing unit - any *partial* changes to the object will update the *whole* object. Object storage stores the whole object as a unit, which has metadata for object retrieval.

Block storage is usually formatted by the computer's guest OS to form a filesystem. If the disk drive is locally attached to the computer and formatted, it will be a local filesystem. A local filesystem can be shared with another computer through a network, and it is called a *network filesystem* from the remote computer's point of view. When you write to a file on a network filesystem, the changed portion is updated to the source disk drive via the network. The filesystem has a directory/folder hierarchy and stores files with blocks. Block storage uses disk drive blocks directly for reading and writing. The concepts of object storage, filesystem, and block storage are illustrated in *Figure 2.1*:

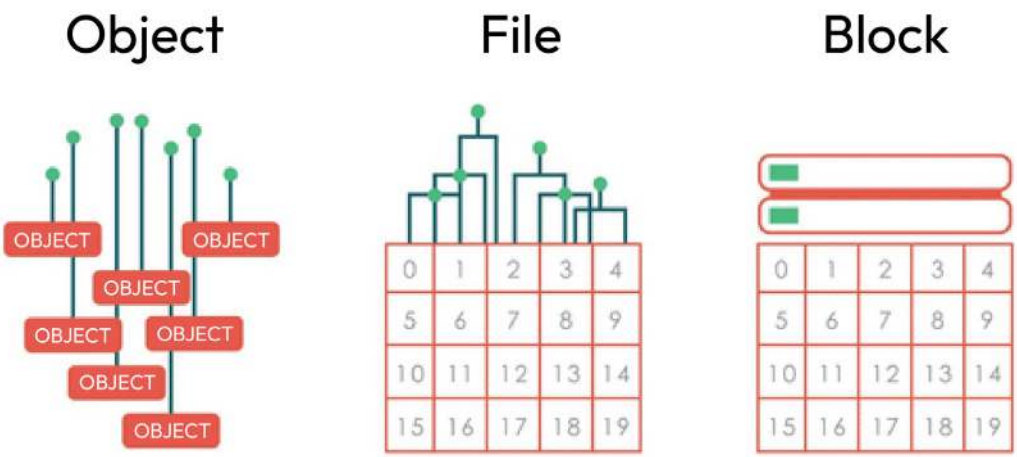


Figure 2.1 – Object storage, filesystem, and block storage

How do we add disk storage to an EC2 instance in Amazon cloud? Instead of buying a new disk drive for our home computer, we create a virtual disk drive in the AWS cloud, called an **EBS** volume. Instead of shutting down a computer and physically installing a disk drive to it, we attach the EBS volume to an EC2 instance on the fly (without shutting down the instance), and then format the disk from the guest OS. Much simpler than our earlier example of adding a physical disk to a PC, we create a virtual disk drive in the AWS cloud, called an **EBS** volume, and attach it to an EC2 instance on the fly.

With only a couple of clicks, we add disk storage to the instance and format it to use. Here are the detailed steps:

1. **Log into the Linux instance and check its existing disk storage:**

   Log into the Linux instance we launched earlier, and run the following OS commands:

   ```
   sudo su     (become the superuser in the Linux system)
   fdisk -l     (list the disks visible in the Linux system)
   ```

   As shown in *Figure 2.2*, the preceding command lists all the disks and one 8 GB disk drive, which is the root disk for the guest OS:

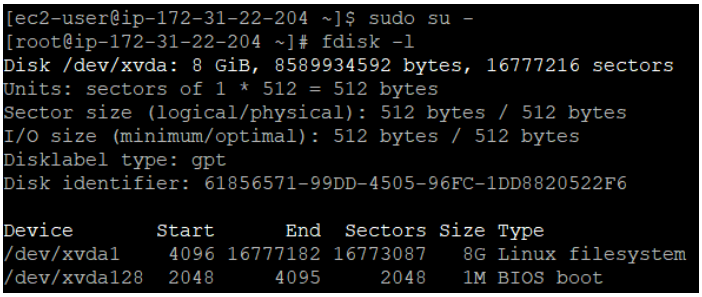


Figure 2.2 – Check the Linux instance disk storage

2. **Create an Amazon EBS volume:**

   Go to **AWS console | EC2 instance dashboard | Elastic Block Store | Volumes**, and we can see the root EBS volume of the instance, as shown in *Figure 2.3*. Click on **Create Volume**:

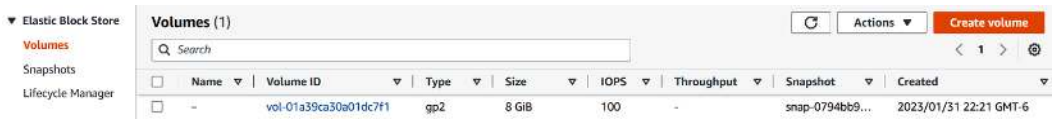


Figure 2.3 – The EBS volume for the EC2 instance

   In the new window shown in *Figure 2.4*, fill in the details such as volume size, type, and AZ, then click **Create volume**. Based on performance and price, Amazon EBS provides three different volume types: **Solid State Drive** (**SSD**) volumes, **Hard Disk Drive** (**HDD**) volumes, and previous-generation volumes. More details are available from `https://docs.aws.amazon.com/AWSEC2/latest/UserGuide/ebs-volume-types.html`.

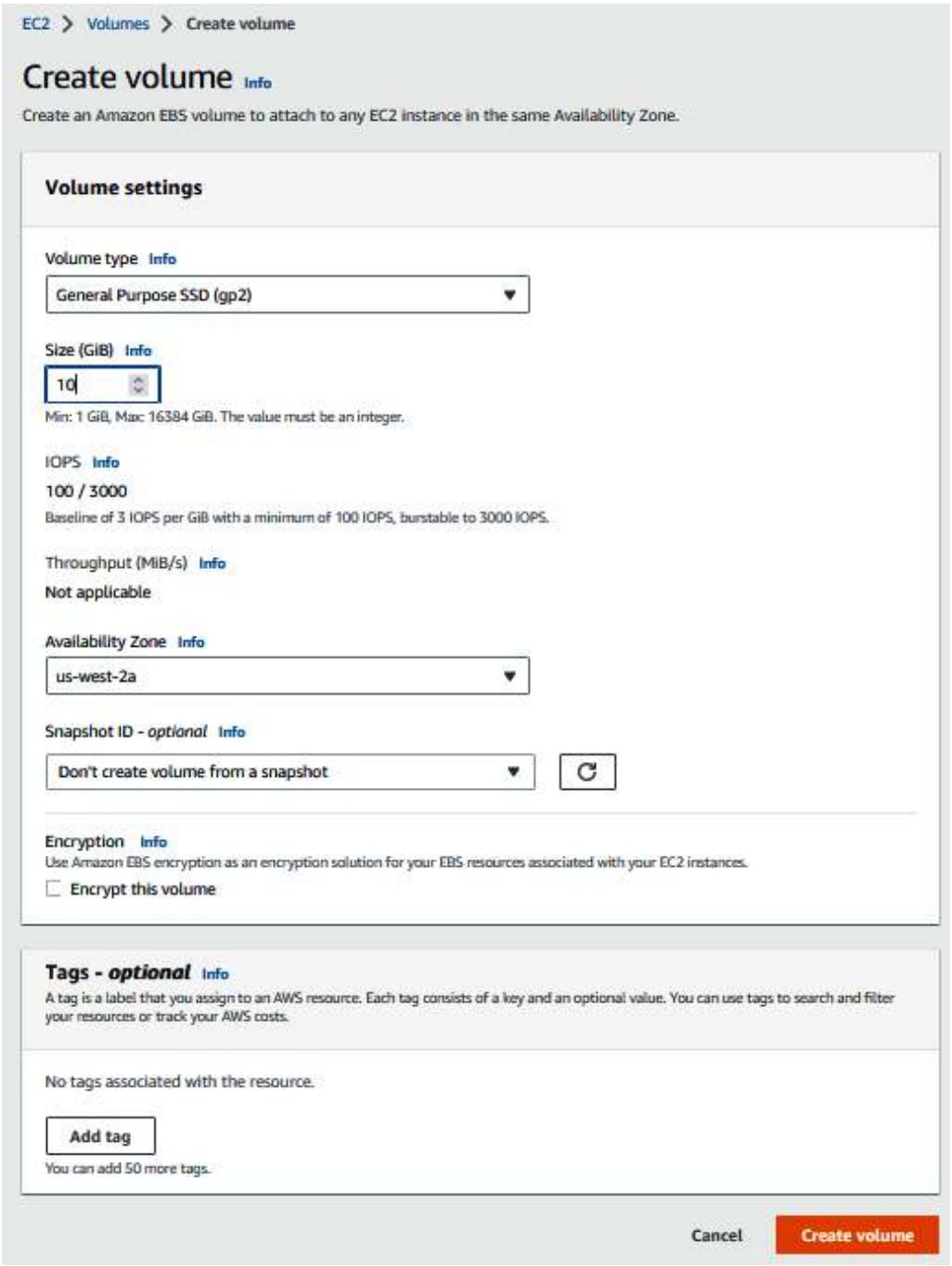


Figure 2.4 – Create an EBS volume

3. **Attach the new EBS volume to the Linux EC2 instance:**

   Now, we will see two EBS volumes. Choose the newly created volume and select **Attach volume** from the drop-down **Actions** menu, as shown in *Figure 2.5*:

Figure 2.5 – Attach the EBS volume

Select the EC2 instance we created earlier in the pop-up window. Click **Attach Volume**, as shown in *Figure 2.6*:

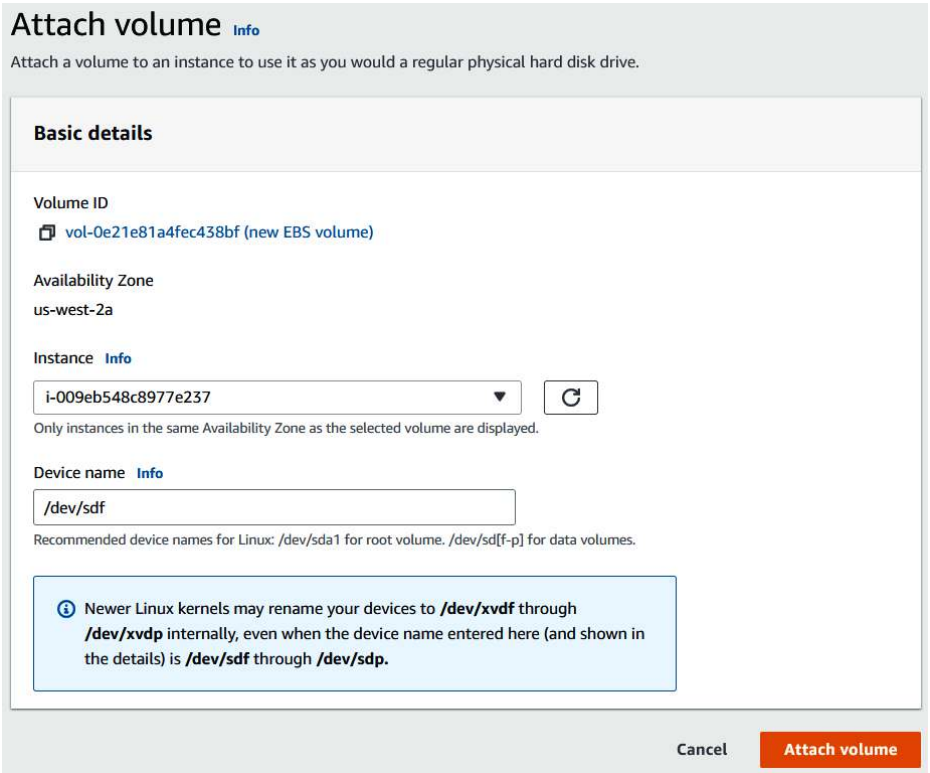


Figure 2.6 – Attach the EBS volume to the EC2 instance

4. **Go back to the Linux Guest OS, format the new disk, and use the storage:**

   Afterward, the EBS volume is attached to the instance. On the Linux Guest OS, run `fdisk -l` again. We now see two disk drives, including the new 10 GB disk drive. Run the Linux command `mkfs` to create a new filesystem from the newly added disk, make a new directory/ebs and `use mount` to mount the filesystem to `/ebs1`, as shown in *Figure 2.7*. We are now using the new disk storage:

```
[root@ip-172-31-22-204 ~]# fdisk -l
Disk /dev/xvda: 8 GiB, 8589934592 bytes, 16777216 sectors
Units: sectors of 1 * 512 = 512 bytes
Sector size (logical/physical): 512 bytes / 512 bytes
I/O size (minimum/optimal): 512 bytes / 512 bytes
Disklabel type: gpt
Disk identifier: 61856571-99DD-4505-96FC-1DD8820522F6

Device       Start      End  Sectors Size Type
/dev/xvda1    4096 16777182 16773087   8G Linux filesystem
/dev/xvda128  2048     4095     2048   1M BIOS boot

Partition table entries are not in disk order.


Disk /dev/xvdf: 10 GiB, 10737418240 bytes, 20971520 sectors
Units: sectors of 1 * 512 = 512 bytes
Sector size (logical/physical): 512 bytes / 512 bytes
I/O size (minimum/optimal): 512 bytes / 512 bytes
[root@ip-172-31-22-204 ~]# mkfs /dev/xvdf
mke2fs 1.42.9 (28-Dec-2013)
Filesystem label=
OS type: Linux
Block size=4096 (log=2)
Fragment size=4096 (log=2)
Stride=0 blocks, Stripe width=0 blocks
655360 inodes, 2621440 blocks
131072 blocks (5.00%) reserved for the super user
First data block=0
Maximum filesystem blocks=2684354560
80 block groups
32768 blocks per group, 32768 fragments per group
8192 inodes per group
Superblock backups stored on blocks:
        32768, 98304, 163840, 229376, 294912, 819200, 884736, 1605632

Allocating group tables: done
Writing inode tables: done
Writing superblocks and filesystem accounting information: done

[root@ip-172-31-22-204 ~]# mkdir /ebs1
[root@ip-172-31-22-204 ~]# mount /dev/xvdf /ebs1
[root@ip-172-31-22-204 ~]# cd /ebs1; touch x
[root@ip-172-31-22-204 ebs1]# ls
lost+found  x
```

Figure 2.7 – List disks and format the new disk

5. **Increase the EBS storage as needed**

   After an EBS volume is attached to the Linux instance and made a useable filesystem by the guest OS, we can increase the EBS volume size and extend the filesystem at any time, with two steps:

   - Increase the size of the EBS volume in the AWS console
   - Extend the filesystem on the Linux Guest OS

More details are available at `https://docs.aws.amazon.com/AWSEC2/latest/UserGuide/modify-ebs-volume-on-instance.html`.

In the preceding example, we created an Amazon EBS volume and attached it to the Linux instance, then formatted the disk to a filesystem, and used it from the instance guest OS. The filesystem is expandable at any time as needed. For EC2 instances with Windows guest OS, you will use the `format` command to format the new disk and label it with a drive letter such as `D`, `E`, and so on. More details are available from `https://www.bu.edu/comtech/students/technical-guides/hardware/how-to-format-hard-drives/`.

In the next section, we will discuss Amazon EFS and demonstrate how to create and use it for multiple EC2 instances as a network filesystem.

Understanding EFS

An Amazon EBS volume can be created and attached to an EC2 instance, but usually, it is not meant for many instances to share. Amazon EFS provides simple, scalable, elastic file system storage that can be shared among many EC2 instances on the AWS Cloud and servers on-premises. With only a couple of clicks, we can create and share Amazon EFS to EC2 instances easily. Here are the detailed steps:

1. **Create an Amazon EFS filesystem**

   Log into the AWS console, go to the EFS service, and create a filesystem, as shown in *Figure 2.8*:

Figure 2.8 – Create the Amazon EFS filesystem (1)

I. Click "Create file system":

In the pop-up window, provide a name for the EFS filesystem and choose a storage class: a `One Zone` EFS filesystem stores data at the AZ level, and a `standard` filesystem stores data redundantly across multiple AZs in the same region. Note that there is no need to specify the size of the EFS filesystem since it scales elastically depending on the EC2 instances' demands on the shared filesystem. Click **Create**, as shown in *Figure 2.9*. The EFS filesystem is now created:

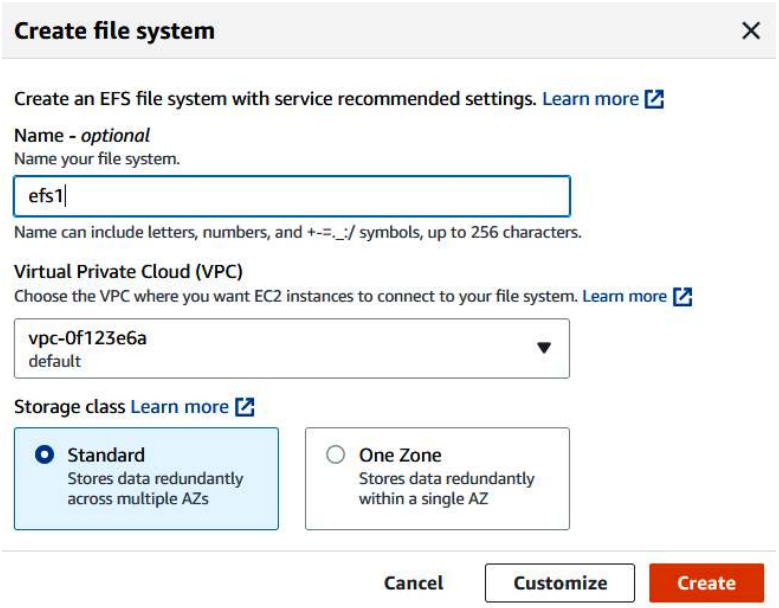


Figure 2.9 – Create the Amazon EFS filesystem (2)

2. **Attach the created EFS filesystem to a Linux instance:**

   Review the EFS filesystem and click the **Attach** tab, as shown in *Figure 2.10*:

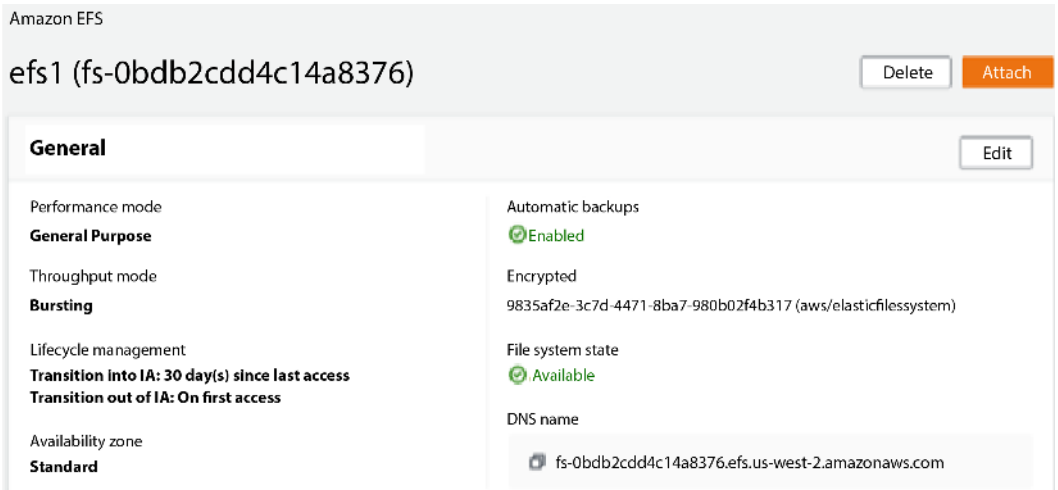


Figure 2.10 – Review the Amazon EFS filesystem

Then click the **Using the NFS client tab**, then copy the Linux `sudo mount` command, as shown in *Figure 2.11*:

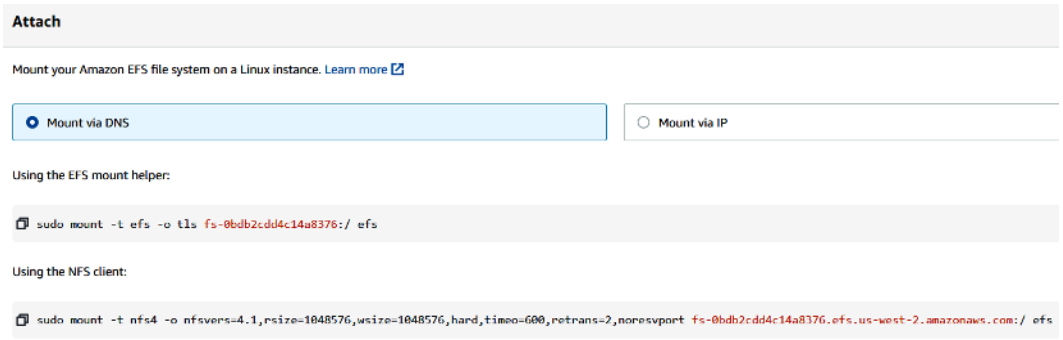


Figure 2.11 – Copy the mount command

Go to the Linux guest OS, use mkdir to create a new directory, and mount the EFS filesystem to the directory using the `sudo mount` command copied earlier. As you can see from *Figure 2.12a*, the new filesystem is now ready for reading and writing:

```
[root@ip-172-31-26-122 /]# mkdir /efs1
[root@ip-172-31-26-122 /]# sudo mount -t nfs4 -o nfsvers=4.1,rsize=1048576,wsize=1048576,hard,timeo=600,
retrans=2,noresvport fs-0bdb2cdd4c14a8376.efs.us-west-2.amazonaws.com:/ /efs1
[root@ip-172-31-26-122 /]# cd /efs1; cp /etc/hosts .
[root@ip-172-31-26-122 efs1]# ls
hosts
[root@ip-172-31-26-122 efs1]# touch x
[root@ip-172-31-26-122 efs1]# ls
hosts  x
```

Figure 2.12a – Mount the EFS file system to a Linux Instance

3. **Verify the EFS filesystem is shared from another Linux instance:**

   Log into another Linux instance in the same region, use `mkdir` to create a directory, and **mount** *the same EFS filesystem* to the local directory. You will find that the filesystem is shared among the two EC2 instances with read and write, as shown in *Figure 2.12*:

```
[root@ip-172-31-31-184 ~]# sudo mount -t nfs4 -o nfsvers=4.1,rsize=1048576,wsize
=1048576,hard,timeo=600,retrans=2,noresvport fs-0bdb2cdd4c14a8376.efs.us-west-2.
amazonaws.com:/ /efs2
[root@ip-172-31-31-184 ~]# ls /efs2
hosts  x
[root@ip-172-31-31-184 ~]#
```

Figure 2.12b – Verify the shared EFS filesystem on another Linux instance

With a few clicks, we have created an EFS filesystem and shared it among two EC2 Linux instances in the same region. In the next section, we will investigate the AWS object storage: S3.

Understanding S3

As we have discussed, Amazon EBS is block storage that can be attached to an EC2 instance. Amazon EFS is an elastic filesystem storage that can be shared among EC2 instances. Now, we will examine Amazon's object storage: S3.

S3 is object-based storage and is a public end point accessible globally via the web and other means. In S3, objects or files are stored in a bucket (*folder*). S3 is a universal namespace storage, which means the names must be unique globally. While there is unlimited storage for S3 customers, each object or file is limited to 0 TB to 5 TB in size.

Amazon S3 offers a range of object-level storage classes that are designed for different use cases:

- `S3 Standard`, with 4x9 (99.99%) availability and durability.
- `S3 Standard-Infrequent` (Standard-IA), with 3x9 (99.9%) availability and 11x9 durability.
- `S3 Reduced` Redundancy Storage with 3x9 availability and 4x9 durability.
- `S3 Intelligent-Tiering`, which places the objects to the right tier based on access activities.
- `Glacier` is for archive only, with 11 x 9 data durability. You can choose from different archive storage classes optimized for different access patterns and storage durations.

Amazon S3 offers versioning to manage different versions of an object in the same bucket, so we can easily recover an object from both unintended user actions and application failures.

Amazon S3 offers life cycle management that manages the automatic movement of objects between different S3 storage classes. With life cycle management, you can configure a set of rules that automatically transition objects from one storage class to another storage class at a specified condition, to minimize storage costs or optimize performance as needed. S3 life cycle management offers an easy way to manage object storage rate and cost for long-term storage and to configure actions and configurations for expiration, including the permanent deletion of objects.

Figure 2.13 shows an example of life cycle management: the current version of S3 objects will sit in Standard S3 class for 30 days, then transition to Standard-IA for 100 days, then move to AWS Glacier, and will be permanently deleted after 455 days:

Figure 2.13 – S3 lifecycle management example

AWS S3 storage provides a simple and easy-to-use storage service that integrates well with the other AWS services. But how to transfer a big amount of data from on-prem to the AWS cloud? We will answer this question in the next section.

Understanding Snowball and Snowmobile

To help customers transfer a huge amount of data (close to petabytes) to the cloud, Amazon offers data transportation services including AWS Snowcone, AWS Snowball, and AWS Snowmobile.

AWS Snowcone is a small, rugged, but secure and versatile device that can help organizations to extend their AWS infrastructure to the edge and enable them to do fast data transfers. With Snowcone, you can collect, process, and transfer data to AWS, either offline by shipping the device or online with AWS DataSync.

AWS Snowball is an appliance-based data transfer service that uses secure, portable storage devices that are delivered to your doorstep, for you to load your data and then send it back to AWS after the data transfer is complete. The data is encrypted during the transferring process, leveraging Amazon S3 for secure storage and Amazon **Key Management Service (KMS)** for encrypting the data on the device. An AWS Snowball appliance provides up to 80 TB of usable HDD storage.

AWS Snowmobile is a truck-based data transfer service that uses a secure truck with 100 **Petabytes** (**PB**) storage capacity, to be dispatched to your site, and connected to your network to perform high-speed data transfer. The truck will be driven back to AWS to transfer the data to your cloud accounts. During the whole process, data is encrypted at rest and in transit. AWS Snowmobile also provides users with analytics and reporting capabilities during the data transfer process.

Accessing S3 from EC2 instances

Now that we have launched an EC2 instance in *Chapter 1* and created S3 buckets in *Chapter 2*, naturally, we will ask the question: do my EC2 instances have access to my S3 buckets?

To answer this question, we need to look at it from two perspectives:

- S3 is a public endpoint, so the EC2 instance needs to have a public IP address.

  However, that's not enough – when you log into the EC2 instance, and run the command (as shown in the following figure):

  ```
  aws s3 ls
  ```

  You will find that there are no S3 buckets listed:

```
[ec2-user@ip-172-31-28-114 ~]$ aws s3 ls
Unable to locate credentials. You can configure credentials by running "aws configure".
```

Figure 2.14 – No S3 bucket is found from EC2

- To have an EC2 instance access S3 buckets, we need to assign an IAM role to the EC2 instance. Recall that we briefly covered this in the EC2 section in *Chapter 1*:

  An IAM role can be assigned with permissions to access other AWS resources, such as reading an Amazon Simple Storage Service (S3) bucket. By attaching the IAM role to an EC2 instance, all the applications running on the EC2 instance will have the permissions of that role.

Here, *the applications running on the EC2 instance* include a terminal/shell running on the EC2 instance. Let us implement this step by step, starting from an EC2 role creation:

1. Log into the AWS console, go to the IAM services, and click **Create role** as shown in *Figure 2.15*:

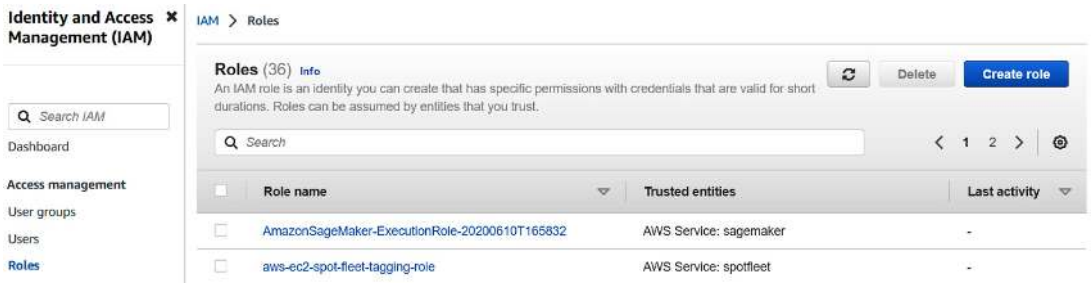


Figure 2.15 – Create an IAM role

2. In the pop-up window, choose **AWS service** under **Trusted entity type**, and **EC2** as the use case, then click **Next**, as shown in the following figure:

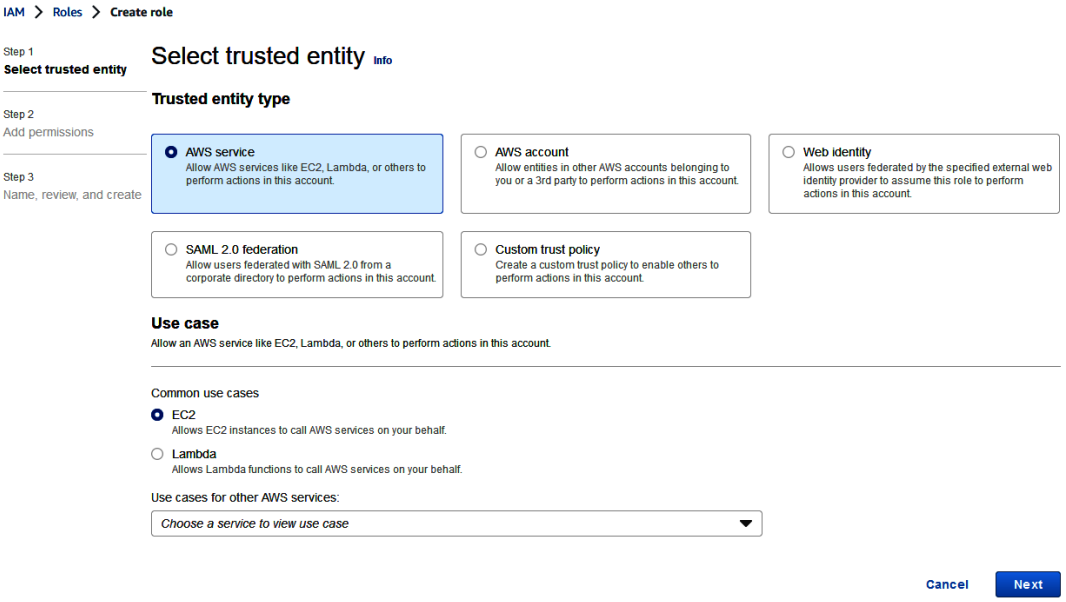


Figure 2.16 – Selecting a trusted entity type

3. In the **Add permissions** tab, type **AmazonS3** as the filter and then choose **AmazonS3FullAccess**, and click **Next**, as shown in *Figure 2.17*:

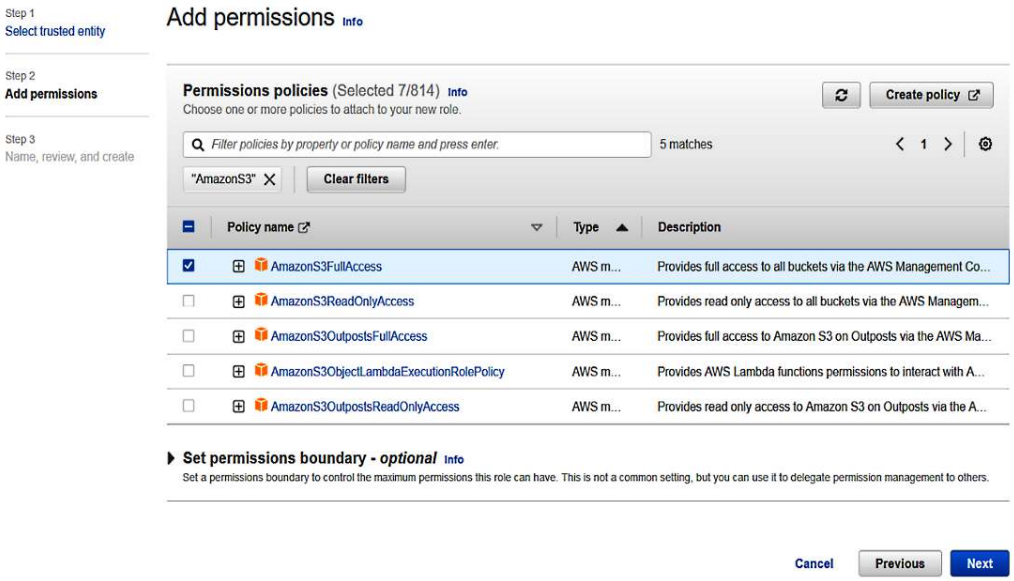


Figure 2.17 – Add permission to the role

4. Review the role name and click **Create role**, as shown in *Figure 2.18*:

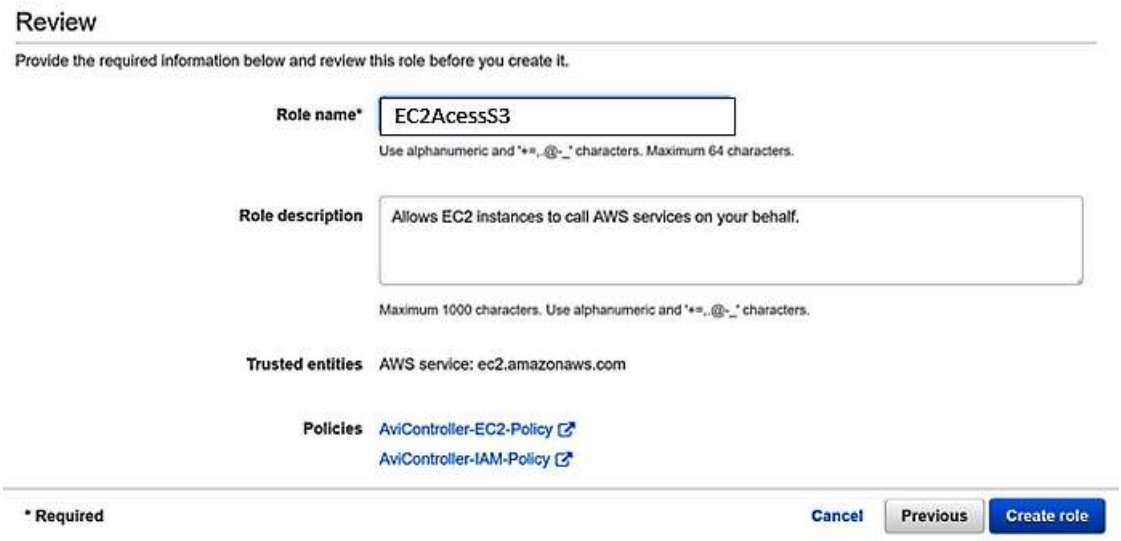


Figure 2.18 – Review and create role

5. After the IAM EC2 role is created, we need to attach it to the EC2 instance named **test**. Navigate to the EC2 dashboard and select our instance, then go to **Actions** -> **Security** -> **Modify IAM role**, as shown in *Figure 2.19*:

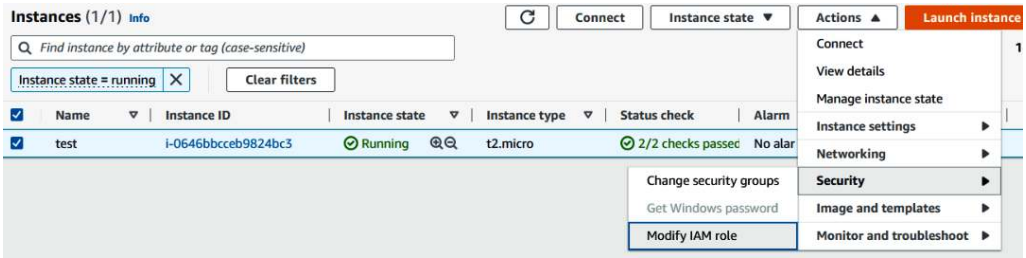


Figure 2.19 – Modify the IAM role to the instance

6. In the new window, choose the role we created earlier, and then click **Update IAM role**, as shown in *Figure 2.20*:

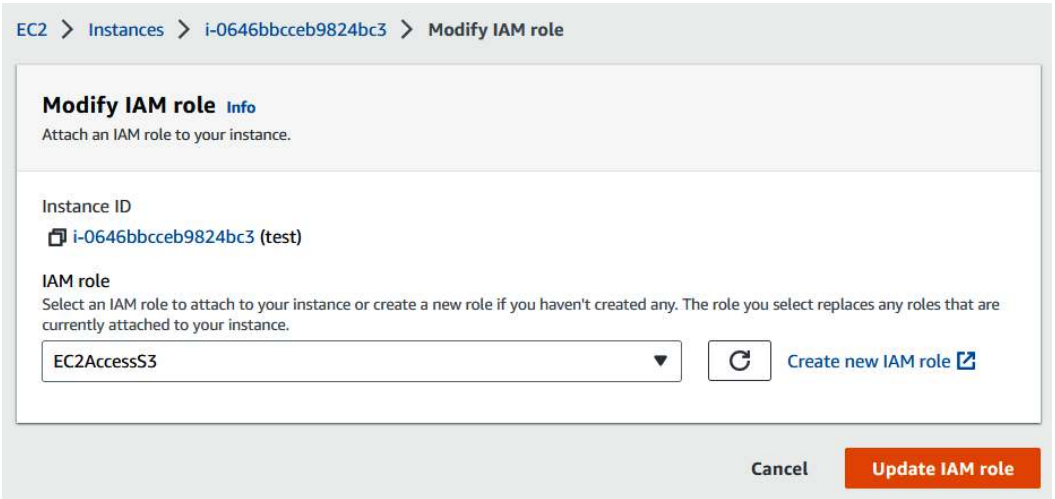


Figure 2.20 – Update the IAM role to the instance

7. Now, go back to the EC2 instance and run the following command:

```
aws s3 ls
```

Now, the S3 buckets for the AWS account will be listed, as shown in *Figure 2.21*:

```
[ec2-user@ip-172-31-28-114 ~]$ aws s3 ls
2021-04-17 20:21:43 asr-x-dll-gpt-3
```

Figure 2.21 – List the S3 bucket on the EC2 instance

By attaching the EC2 role to the EC2 instance, all the applications running on the instance will be able to assume the EC2 role's permissions. However, there is one question remaining: what if the EC2 instance does not have a public IP address? Can it still access the S3 buckets? The answer is yes, and we will explore and implement it in *Chapter 3*, *AWS Networking Services*.

Summary

Congratulations! We have completed *Chapter 2* of our AWS self-learn journey: *Amazon Cloud Storage Services*. In this chapter, we introduced the Amazon EBS and EFS concepts, provisioned block storage and network filesystems for EC2 instances step by step, and then discussed the Amazon S3 services and Amazon data transfer services: Snowcone, Snowball, and Snowmobile.

As you can see, AWS provides these storage solutions to meet different business needs. Amazon EBS provides block storage volumes for EC2 instances, and some use cases include running a database that needs high-performance block storage, hosting a website that requires persistent storage, or an application that requires low-latency access to data. Amazon EFS provides a shared filesystem that can be accessed from multiple EC2 instances simultaneously. Some use cases for EFS include running web applications that require shared file storage, or a big data application that requires shared storage. Amazon S3 provides object storage that is highly scalable and durable. Some use cases for S3 include storing and sharing files, images and videos, hosting a static website with static assets, and archiving data for long-term retention.

So far, we have covered the compute services and storage services from the Amazon cloud. In the next chapter, we will discuss the AWS network services. As we stated earlier, a single computer without networking is useless. It is the networks that make all the computers and services communicate and integrate to achieve business goals.

Practice questions

Questions 1-4 are based on *Figure 2.22*. You need to design an AWS storage system to move the on-prem storage to the cloud:

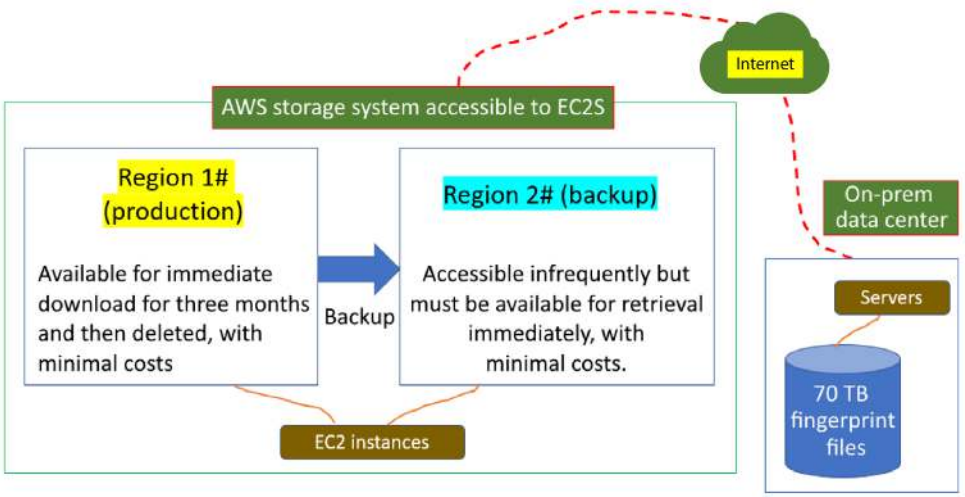


Figure 2.22 – An AWS system storage

1. How will you choose production storage in Region 1#?

   A. EBS
   B. S3
   C. Glacier
   D. EFS

2. How will you design cloud storage in Region 2#?

   A. Amazon Glacier with expedited retrievals
   B. Amazon S3 Standard-Infrequent Access
   C. Amazon EFS
   D. Amazon S3 Standard

3. What's the best way to transfer files from on-prem to Region 1#?

   A. Amazon transfer with multi-part uploading
   B. AWS Snowball
   C. AWS Snowmobile
   D. AWS Transfer using direct-connect networks

4. What's the best way to back up from Region 1# to Region 2#?

   A. Amazon S3 Cross-Region Replication
   B. AWS Snowball or Snowmobile
   C. Copy the video records from the cloud to a third-party data center
   D. Migration using direct-connect networks between regions

5. For Amazon S3, what is the largest object that can be uploaded in a single `PUT`?

   A. 5 gigabytes
   B. 5 terabytes
   C. 500 megabytes
   D. 5 telebytes

6. Which of the following statements is true?

   A. EBS volumes are ephemeral.
   B. EBS volumes can be attached to an EC2 instance in another AZ.
   C. EBS volumes can be attached to an EC2 instance in another Region.
   D. EBS volumes can be attached to certain EC2 instances simultaneously.

7. Company XYZ requires you to preserve, restore, and retrieve immediately every version of every file that you have stored in the AWS cloud. Which service should you use?

   A. S3 One Zone-IA
   B. S3 Standard with versioning enabled
   C. S3 Glacier
   D. S3 Reduced Storage with versioning enabled

8. An AWS engineer created an EC2 instance with a public IP address and an S3 bucket in the same Region. What do they need to do to have the instance read from and write into the S3 bucket?
9. An AWS engineer created an EC2 instance with no public IP address and an S3 bucket in the same Region. What do they need to do to enable the instance to read from and write into the S3 bucket?
10. After mounting an Amazon EFS to the EC2 instance, do you need to format mkfs to it?

Answers to the practice questions

1. B.
2. A.
3. B.
4. A.
5. A.
6. D.
7. B.
8. Create an EC2 role that has read and write access to the S3 bucket, and assign the role to the EC2 instance.
9. Create a VPC endpoint for S3. Create an EC2 role that has read and write access to the S3 bucket, and assign the role to the EC2 instance.
10. No.

Further reading

For further insights into what you've learned in this chapter, refer to the following links:

- `https://aws.amazon.com/ebs/`
- `https://aws.amazon.com/efs/`
- `https://aws.amazon.com/s3/`
- `https://docs.aws.amazon.com/ebs/index.html`
- `https://docs.aws.amazon.com/efs/index.html`
- `https://docs.aws.amazon.com/s3/index.html`

3

Amazon Networking Services

In the previous chapters, we learned about Amazon compute and storage services, focusing on EC2, EBS, EFS, and S3. We provisioned EC2 instances and the cloud storage that can be used by EC2 and other services. In this chapter, we will discuss Amazon cloud networking, where all the cloud resources are connected and communicate with each other.

We will cover the following topics in this chapter:

- Computer network basics – the fundamental network concepts, such as IP address, network address, and CIDR notation.
- Amazon **Virtual Private Cloud** (**VPC**) – the Amazon cloud network where EC2 and other services communicate with each other. We will provision VPCs, subnets, and EC2 instances in the VPC/subnets and explore EC2 instance communications within the VPC and to the internet.
- AWS network security – this becomes a priority once our VPC and EC2 instances are exposed to the internet. We will show how to build and configure network firewalls for cloud resource protection.
- AWS Direct Connect – the information highway connecting your private on-premises data centers to the AWS public cloud to form a hybrid cloud.
- The Amazon cloud **Domain Name System** (**DNS**) – Route 53 is a reliable and scalable DNS service that provides essential functionality for hosting and managing your domains and resources in the AWS cloud.
- The Amazon **Content Delivery Network** (**CDN**) – CloudFront is an AWS CDN service that delivers content, such as web pages, videos, and images, to users with low latency and high speeds.

Cloud networking is one of the most important AWS services. By learning about the basic cloud networking concepts and practicing the fundamental skills in this chapter, you will build a solid and strong foundation for constructing your AWS cloud framework. We will start the chapter by reviewing computer network basics.

Reviewing computer network basics

In *Chapter 1*, we learned that a computer network is a collection of interconnected devices, such as computers, servers, printers, and other devices, that are linked together to share resources and communicate with each other. A subnet, or subnetwork, is a smaller network that is created by partitioning a larger network into smaller segments, typically used to improve network performance, security, and management. Each subnet is identified by a unique network address, and devices within the same subnet share the same network address prefix. Each device has a unique address in the network/subnet. For a computer to talk to another one in a computer network, it must have an address for communication, which we call an **IP address**.

IP address

An **IP address**, or an **Internet Protocol** address, is a numerical address assigned to a device in a computer network for communication with the other devices that are also assigned IP addresses. An IP address serves as an identifier for the device on the network and allows it to send and receive data. There are two versions of IP addresses in use today: IPv4 and IPv6. IPv4 addresses consist of four decimal numbers separated by dots, while IPv6 addresses use a hexadecimal format with eight sets of four characters separated by colons. We will mainly use IPv4 in our book. *Figure 3.1* shows a fictitious website, `www.zeebestbuy.com`, and its IP address

Figure 3.1 – An IP address

As we can see, an IPv4 address can be represented by four decimal numbers, `172.217.9.36`, or by 4 bytes (32 bits) of binary numbers, `10101100.11011001.00001001.00100100`. Since an IP address has 4 bytes or 32 bits, the total number of addresses in this IP space is 2^{32}. We cannot put this number of computers in one network, so we need to develop a way to separate the network into subnets, which requires something called **Classless Inter-Domain Routing** (**CIDR**).

CIDR

CIDR is a method used to allocate IP addresses in networks and specify network addresses. In the CIDR notation, a network address is represented by an IP address followed by a slash (/) and a number indicating the number of bits in the network address. For example, the CIDR notation `172.217.9.0/24` represents a network address – the first 24 bits (`10101100.11011001.00001001`) represent the network portion and are *fixed*, and the remaining 8 bits represent the host portion and are *varied* (from `00000000` to `11111111`). For the subnet `172.217.9.0/24`, since 24 bits out of 32 are fixed and 8 bits are variable, there are 2^8=`256` IP addresses in the subnet:

`172.217.9.0` to `172.217.9.255`. *Figure 3.2* shows CIDR notations for some subnets, from `/32` to `/24`, and the available IP addresses for the subnets:

Subnet Mask Hierarchy

Subnet Mask	CIDR	Binary Notation	Available Addresses Per Subnet
255.255.255.255	/32	11111111.11111111.11111111.11111111	1
255.255.255.254	/31	11111111.11111111.11111111.11111110	2
255.255.255.252	/30	11111111.11111111.11111111.11111100	4
255.255.255.248	/29	11111111.11111111.11111111.11111000	8
255.255.255.240	/28	11111111.11111111.11111111.11110000	16
255.255.255.224	/27	11111111.11111111.11111111.11100000	32
255.255.255.192	/26	11111111.11111111.11111111.11000000	64
255.255.255.128	/25	11111111.11111111.11111111.10000000	128
255.255.255.0	/24	11111111.11111111.11111111.00000000	256
255.255.254.0	/23	11111111.11111111.11111110.00000000	512
255.255.252.0	/22	11111111.11111111.11111100.00000000	1024
255.255.248.0	/21	11111111.11111111.11111000.00000000	2048
255.255.240.0	/20	11111111.11111111.11110000.00000000	4096
255.255.224.0	/19	11111111.11111111.11100000.00000000	8192
255.255.192.0	/18	11111111.11111111.11000000.00000000	16384
255.255.128.0	/17	11111111.11111111.10000000.00000000	32768
255.255.0.0	/16	11111111.11111111.00000000.00000000	65536
255.254.0.0	/15	11111111.11111110.00000000.00000000	131072
255.252.0.0	/14	11111111.11111100.00000000.00000000	262144
255.248.0.0	/13	11111111.11111000.00000000.00000000	524288
255.240.0.0	/12	11111111.11110000.00000000.00000000	1048576
255.224.0.0	/11	11111111.11100000.00000000.00000000	2097152
255.192.0.0	/10	11111111.11000000.00000000.00000000	4194304
255.128.0.0	/9	11111111.10000000.00000000.00000000	8388608
255.0.0.0	/8	11111111.00000000.00000000.00000000	16777216

Figure 3.2 – CIDR notation

With IP address and network address notations, we can construct any networks and connect them with routing devices. And that's how we build the internet, which will be discussed next.

The internet

The internet is a global network of interconnected computer networks that allows the exchange of information and communication among users around the world. It is composed of millions of devices, including computers and networking hardware devices, and software applications, protocols, and standards that enable these devices to communicate and share data with each other.

At a high level, the internet is made up of physical infrastructure, such as computers, routers, and switches. A router is a network device that connects multiple networks and routes data packets between them. Routers use a route table to determine the best path for data packets to take between networks, and they can be used to filter and direct traffic based on various criteria, such as port numbers, IP addresses, and protocols. Each subnet must be associated with one and only one route table. A switch

is a network device that connects multiple devices within a network. Switches use MAC addresses to direct traffic to the correct device and can be used to segment networks and improve performance by limiting the amount of traffic that flows through each segment.

On the internet, routers, switches, and computers work together, under network routing protocols such as **Transmission Control Protocol** (**TCP**) and IP. Just like computers have evolved from physical machines to virtual machines, networks have evolved from hardware-based physical networks to software-based virtual networks. In the next section, we will discuss Amazon VPC, which is a virtual network in the cloud.

Understanding Amazon Virtual Private Cloud

A VPC is a network in the Amazon cloud. With Amazon VPC, you can assign custom IP address ranges, create subnets, and configure route tables, network gateways, and security settings. You can launch instances in a specified subnet of a VPC. By default, you can create five VPCs per AWS account per region, and you can increase this default quota by contacting Amazon cloud support. AWS VPC provides several benefits over traditional data center-based network designs, including the following:

- **High availability**: Amazon VPC is software based. Within a VPC, the routers are virtual and provide high availability. VPCs are regional in AWS and thus a VPC can span multiple AZs, with each subnet mapping to an AZ.
- **Flexibility**: Amazon VPC provides the flexibility to design and build your network topology to meet your specific business and technical requirements. With Amazon VPC, you select the IP address range for VPCs and subnets, configure route tables, and associate them with subnets.
- **Isolation**: Amazon VPC provides isolation of cloud resources, allowing you to create separate virtual networks for different applications or workloads, for example, separate a production VPC from a development VPC. A VPC is logically isolated from other VPCs in the same AWS account.
- **Time and cost effectiveness**: Amazon VPCs are created and used at no cost. Since they are virtual, you can provision VPCs and subnets on the fly and reduce the cost of your network infrastructure.
- **Security**: In the Amazon cloud, you can define **Network Access Control Lists** (**NACLs**) to control traffic in and out of subnets.
- **Connectivity to on-premises**: You can configure Amazon VPC to connect the virtual network to an on-premises data center using a VPN or AWS Direct Connect. This allows enterprises to extend their existing IT infrastructure to the cloud and access AWS services securely.

Next, we will provision our VPC networks in the Amazon cloud. We will use the AWS cloud console to show how to create a VPC and subnet. We will use CloudShell to create an AWS cloud, including a VPC, subnets, and instances, and then configure the VPC/subnet/EC2 instances for internet access. Let's start with the first part of building our AWS cloud framework.

Part one – creating a VPC with subnets

In the first part, we will use the AWS console to create a VPC and a subnet under the VPC, to demonstrate how to use the AWS console in creating networks in the cloud.

Creating a VPC and a subnet using the AWS cloud console

Log in to the AWS console, search for VPC services, and select **Create VPC**, then fill in the VPC settings. Enter `my vpc1` for the name. For simplicity, we will select **No IPV6 CIDR block** and choose a CIDR of `10.10.0.0/16` for our VPC. Click **Create VPC**, as shown in *Figure 3.3*:

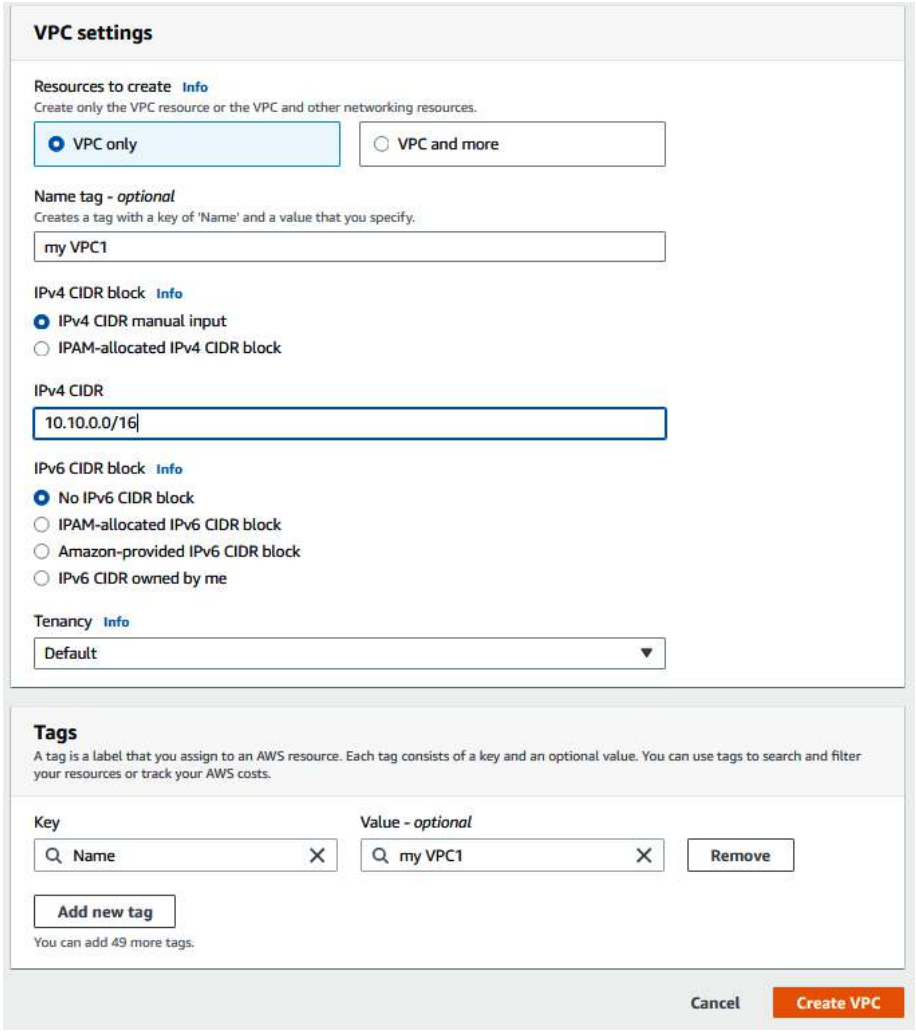


Figure 3.3 – VPC settings

After the VPC is created, go back to the VPC dashboard and then to **Subnets**, then click **Create subnet**. Fill in the subnet settings; choose **my VPC1** as the VPC, enter `public-subnet` as the name, set its CIDR to `10.10.1.0/24`, and click **Create subnet**, as shown in *Figure 3.4*:

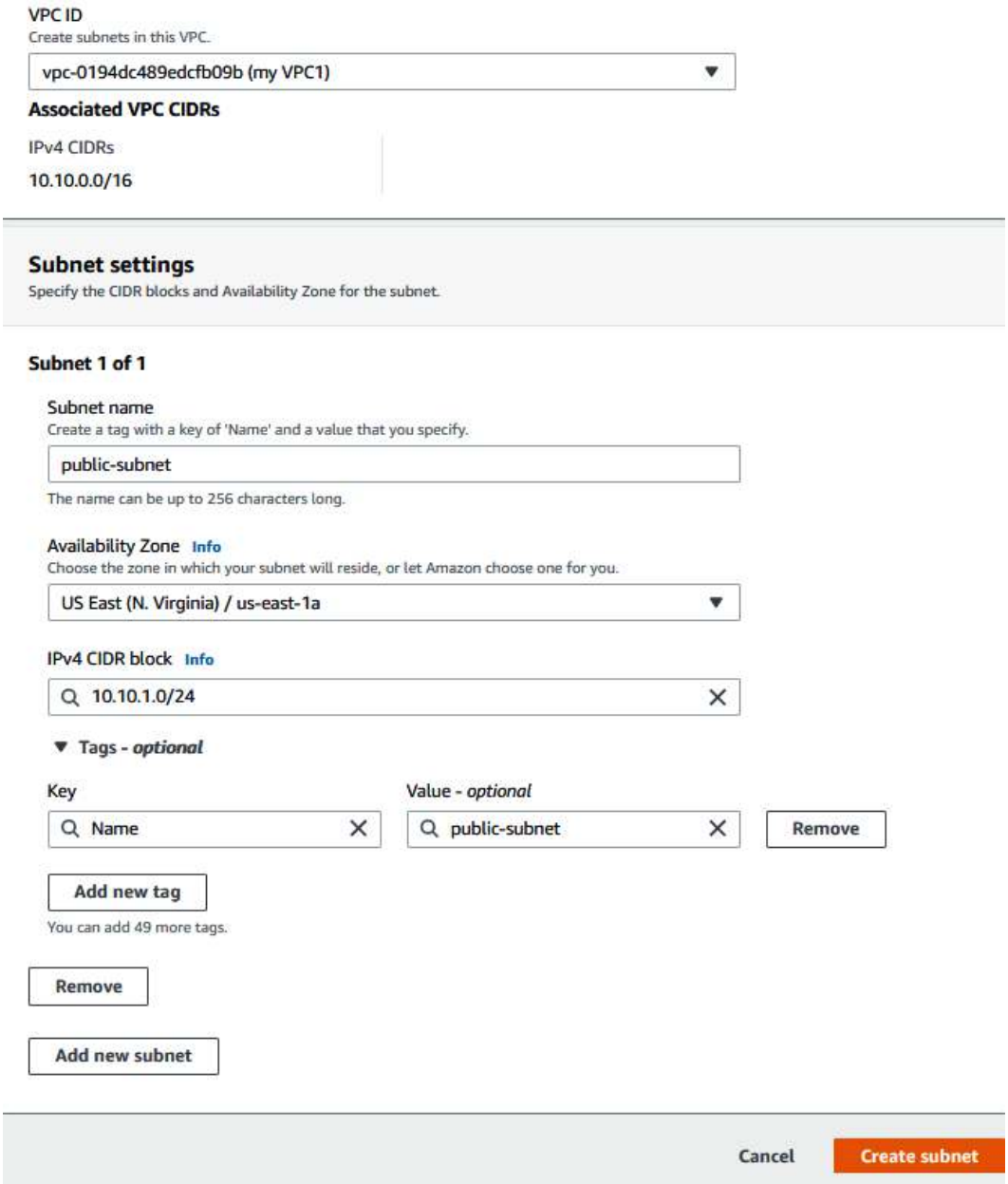


Figure 3.4 – Subnet settings

Note

As we discussed earlier, a VPC with an IPv4 CIDR block of `10.10.0.0/16` has 65,536 total IP addresses and can be divided into subnets. For each subnet, there are some addresses reserved for Amazon. For example, the subnet `10.10.1.0/24` has a total of 256 total IP addresses, but the following 5 IP addresses are reserved, thus leaving 251 IP addresses available to create EC2 instances in the subnet:

`10.0.1.0`

Network address

`10.0.1.1`

Internal communication

`10.0.1.2`

DNS resolution

`10.0.1.3`

Future use

`10.0.1.255`

Network broadcast address

Creating an AWS cloud network using CloudShell

As we discussed earlier, we can also use AWS CloudShell to create and manage any cloud resources with the **Command Line Interface** (**CLI**). In this section, we will use CloudShell to recreate a VPC named **VPC1** and two subnets named **public-subnet** and **private-subnet** under VPC1, in the US-west-2 region, and launch two instances – one Linux instance in **public-subnet** with a public IP address and another Linux instance in **private-subnet** without a public IP address:

1. **Create VPC1**:

```
aws ec2 create-vpc --cidr-block
10.10.0.0/16 --tag-specifications
ResourceType=vpc,Tags='[{Key=Name,Value="VPC1"}]'
```

```
[cloudshell-user@ip-10-2-126-119 ~]$ aws ec2 create-vpc \
>     --cidr-block 10.10.0.0/16 \
>     --tag-specifications ResourceType=vpc,Tags='[{Key=Name,Value="VPC1"}]'
{
    "Vpc": {
        "CidrBlock": "10.10.0.0/16",
        "DhcpOptionsId": "dopt-f8579e9d",
        "State": "pending",
        "VpcId": "vpc-0e6043d6091faa7cd",
        "OwnerId": "317332158300",
        "InstanceTenancy": "default",
        "Ipv6CidrBlockAssociationSet": [],
        "CidrBlockAssociationSet": [
            {
                "AssociationId": "vpc-cidr-assoc-04116e8e5e98b256f",
                "CidrBlock": "10.10.0.0/16",
                "CidrBlockState": {
                    "State": "associated"
                }
            }
        ],
        "IsDefault": false,
        "Tags": [
            {
                "Key": "Name",
                "Value": "VPC1"
            }
        ]
    }
}
```

Figure 3.5 – Create VPC1

2. **Create public-subnet and private-subnet in VPC1**, as shown in *Figure 3.6*:

```
aws ec2 create-subnet --vpc-id vpc-0e6043d6091faa7cd \
--cidr-block 10.10.1.0/24 --tag-specifications ResourceType=subn
et,Tags='[{Key=Name,Value="public-subnet"}]'
aws ec2 create-subnet --vpc-id vpc-0e6043d6091faa7cd --cidr-
block 10.10.2.0/24 --tag-specifications ResourceType=subnet,Tags
='[{Key=Name,Value="private-subnet"}]'
```

```
[cloudshell-user@ip-10-2-126-119 ~]$ aws ec2 create-subnet \
>     --vpc-id vpc-0e6043d6091faa7cd \
>     --cidr-block 10.10.2.0/24 \
>     --tag-specifications ResourceType=subnet,Tags='[{Key=Name,Value="private-subnet"}]'
{
    "Subnet": {
        "AvailabilityZone": "us-west-2a",
        "AvailabilityZoneId": "usw2-az1",
        "AvailableIpAddressCount": 251,
        "CidrBlock": "10.10.2.0/24",
        "DefaultForAz": false,
        "MapPublicIpOnLaunch": false,
        "State": "available",
        "SubnetId": "subnet-0328a7940791d9fc0",
        "VpcId": "vpc-0e6043d6091faa7cd",
        "OwnerId": "317332158300",
        "AssignIpv6AddressOnCreation": false,
        "Ipv6CidrBlockAssociationSet": [],
        "Tags": [
            {
                "Key": "Name",
                "Value": "private-subnet"
            }
        ],
        "SubnetArn": "arn:aws:ec2:us-west-2:317332158300:subnet/subnet-0328a7940791d9fc0",
        "EnableDns64": false,
        "Ipv6Native": false,
        "PrivateDnsNameOptionsOnLaunch": {
            "HostnameType": "ip-name",
            "EnableResourceNameDnsARecord": false,
            "EnableResourceNameDnsAAAARecord": false
        }
    }
}
```

Figure 3.6 – Create subnets

3. **Create two EC2 instances**, one in each subnet. EC2-1 is in the public subnet and is assigned a public IP address, while EC2-2 is in the private subnet and does not have a public IP address. The commands are as follows and a screenshot is provided in *Figure 3.7*:

```
aws ec2 run-instances --image-id ami-0ef0b498cd3fe129c --count
1 --instance-type t2.micro --subnet-id subnet-0871b6aaa7092c075
--key-name mywestkp --region us-west-2  --associate-public-ip-
address
aws ec2 run-instances --image-id ami-0ef0b498cd3fe129c –count 1
--instance-type t2.micro --subnet-id subnet 0328a7940791d9fc0
--key-name mywestkp --region us-west-2 --no-associate-public-ip-
address
```

```
[cloudshell-user@ip-10-6-43-95 ~]$ aws ec2 run-instances --image-id ami-0ef0b498cd3fe129c --count 1 \
> --instance-type t2.micro --subnet-id subnet-0328a7940791d9fc0 \
> --key-name mywestkp --region us-west-2  --no-associate-public-ip-address
{
    "Groups": [],
    "Instances": [
        {
            "AmiLaunchIndex": 0,
            "ImageId": "ami-0ef0b498cd3fe129c",
            "InstanceId": "i-0288c5d94570afe62",
            "InstanceType": "t2.micro",
            "KeyName": "mywestkp",
            "LaunchTime": "2023-02-14T01:56:33+00:00",
            "Monitoring": {
                "State": "disabled"
            },
            "Placement": {
                "AvailabilityZone": "us-west-2a",
                "GroupName": "",
                "Tenancy": "default"
            },
            "PrivateDnsName": "ip-10-10-2-11.us-west-2.compute.internal",
            "PrivateIpAddress": "10.10.2.11",
```

Figure 3.7 – Create instances

Figure 3.8 shows a network diagram of the VPC we have built so far, including VPC1, its two subnets, and the two instances – EC2-1 in the public subnet and EC2-2 in the private subnet:

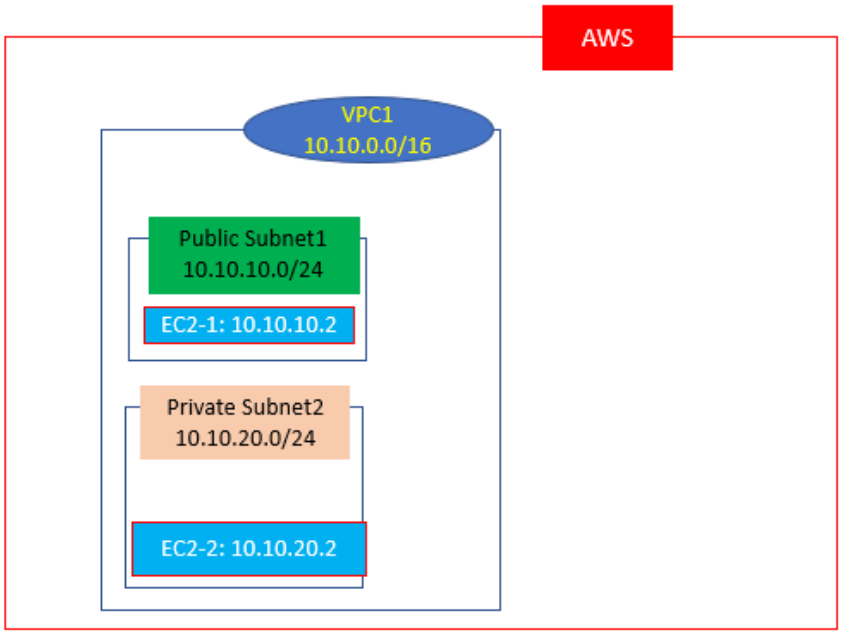


Figure 3.8 – VPC network

Now that we have provisioned VPCs/subnets/EC2 instances, it's time to discuss how to access them from the internet.

Accessing the EC2 instances from the internet

While VPCs are isolated networks in the cloud, there are needs to access an EC2 from the internet and for the EC2 instances to access the internet, such as to patch the guest OS. For the EC2-1 instance in public subnet1 in VPC1 to communicate with the internet, we need to open a route from the public subnet to the internet, with three steps:

1. **Create IGW1 and attach it to VPC1**

   To open a route from our VPC to the internet, we need to create an **Internet Gateway** (**IGW**) and attach it to VPC1.

   From the AWS console, go to the VPC dashboard and find the **Internet Gateway** section. Click **Create internet gateway**, and in the new window, provide a name tag for the IGW. We will call it `IGW1`, as shown in *Figure 3.9*:

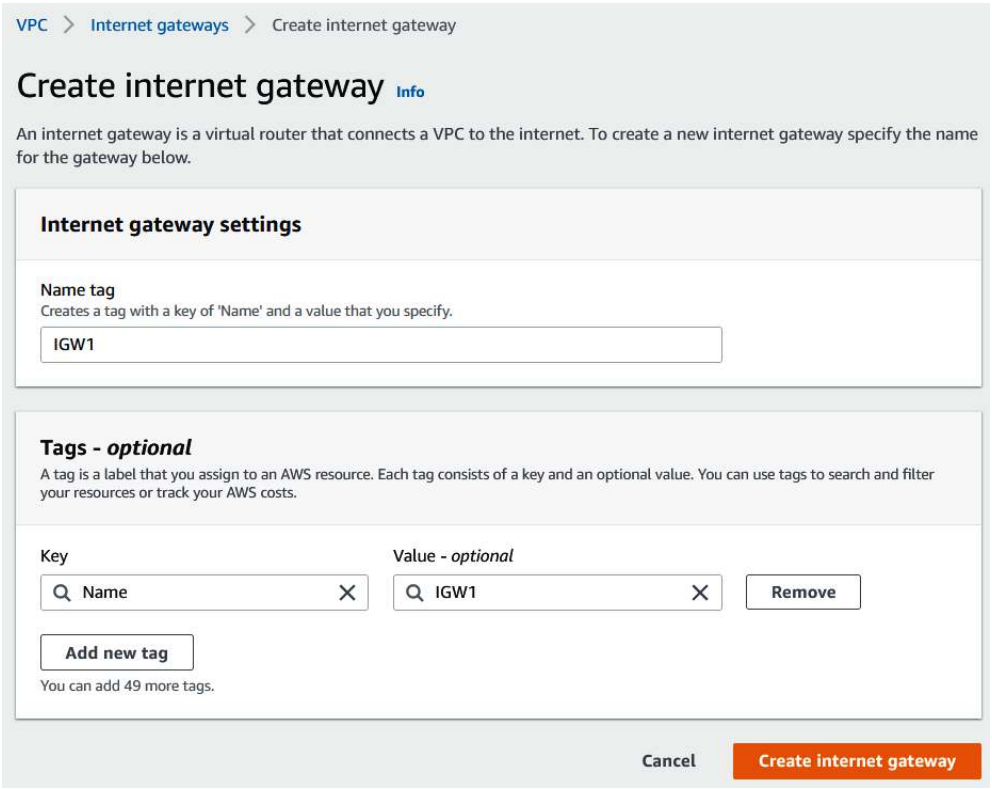


Figure 3.9 – Create IGW1

Attach IGW1 to VPC1, as shown in *Figure 3.10*.

Figure 3.10 – Attach IGW1 to VPC1

2. **Add an internet route to public subnet1**

Now we need to modify the route table for VPC1's public subnet1 and add a route to the internet – via an IGW. Note that when we created VPC1 and its two subnets earlier, there was an *invisible* VPC router created to route the traffic within VPC1; all subnets with a VPC are routable. We will now check out the route table for VPC1, as shown in *Figure 3.11*:

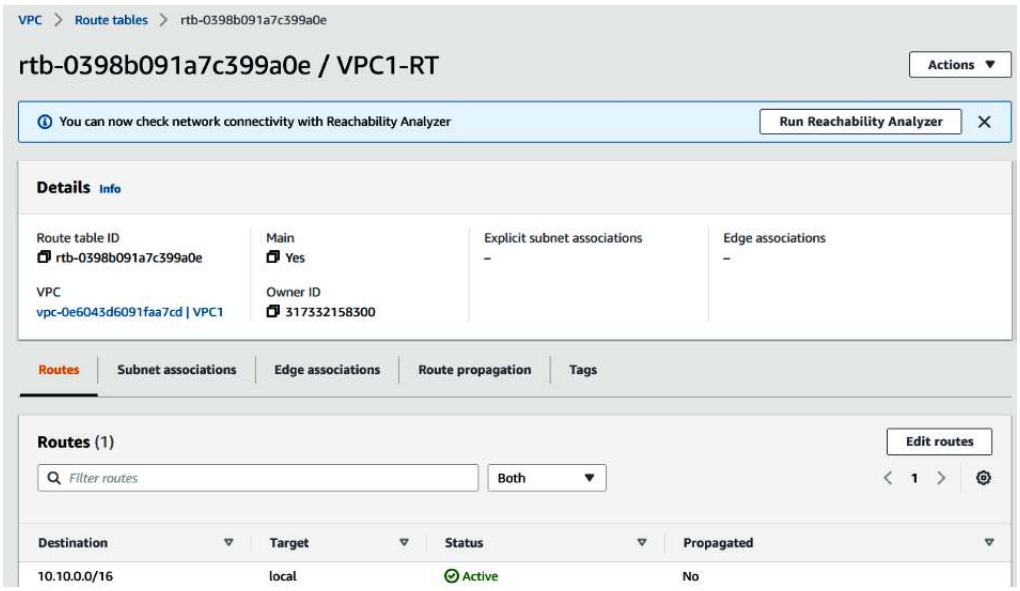


Figure 3.11 – Route table for VPC1

Click **Edit routes** and add a new route with a destination of `0.0.0.0/0` (meaning anywhere) and a target of IGW1, which is the IGW we created and attached to VPC1 earlier. Click **Save changes**, as shown in *Figure 3.12*:

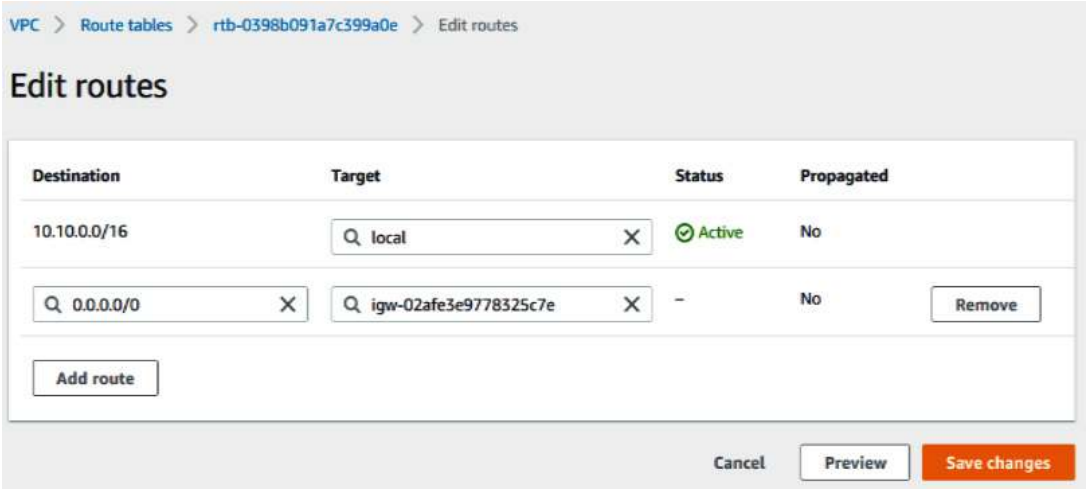


Figure 3.12 – Add internet route to route table

Go back to the route table and then to **Subnet association | Edit subnet associations** and associate the route table with the public subset we created earlier, as shown in *Figure 3.13*:

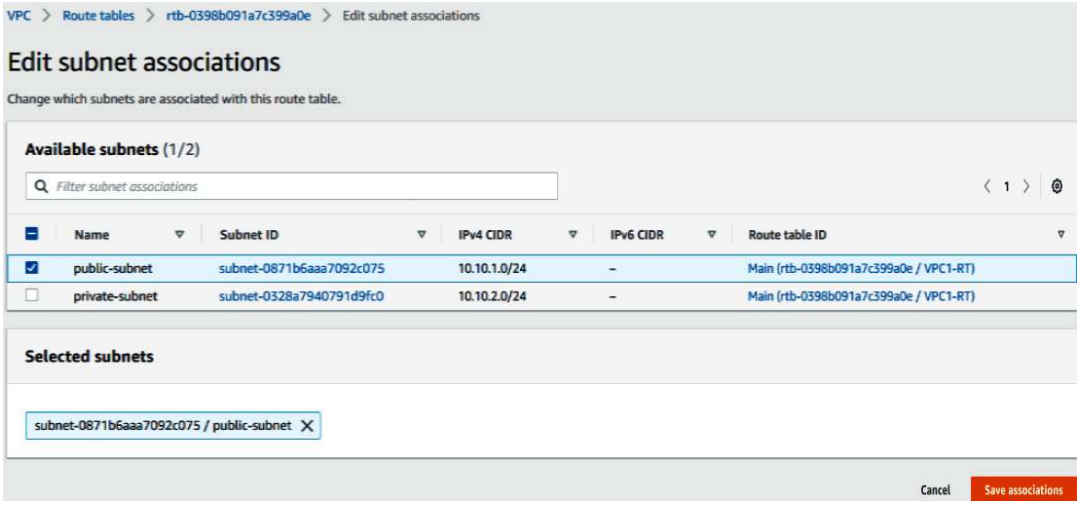


Figure 3.13 – Associate route table to subnet

Click **Save associations**. Now, we have built a route from VPC1 to the internet, so all internet traffic will go to IGW1 as the next hop.

3. **SSH to the EC2 instance in the public subnet**

In *Chapter 1*, we have introduced PuTTY to SSH into the Linux EC2 instances in the cloud. Now, we SSH through the internet into the EC2-1 instance, as shown in *Figure 3.14*:

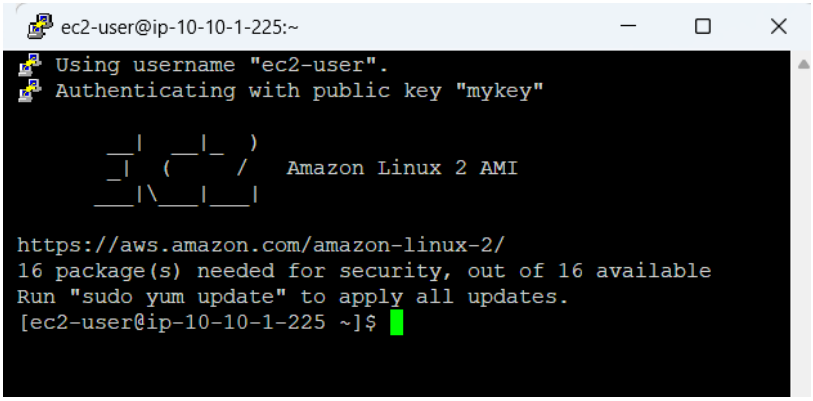


Figure 3.14 – SSH to EC2-1 from the internet

We have set up the route between the EC2-1 instance and the internet. *Figure 3.15* shows the AWS network we have built so far:

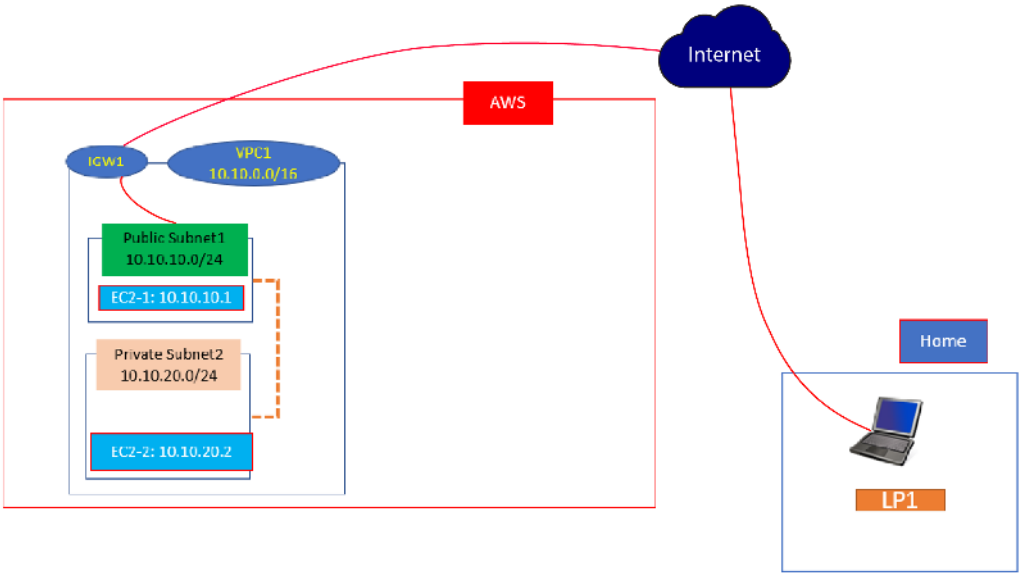


Figure 3.15 – AWS cloud with internet access

Now, let's add more VPC/subnet/EC2 instances to the cloud.

Part two – Provisioning more cloud resources and connecting them together

In this part, we will add more VPCs, subnets, and EC2 instances into the cloud and connect them together by peering the VPCs.

Provisioning more cloud resources

With the same procedure, let us create VPC2, subnet8 in VPC2, and an EC2 instance in subnet8. The network architecture is shown in *Figure 3.16*. Note EC2-2 and EC2-8 do not have public IPs assigned:

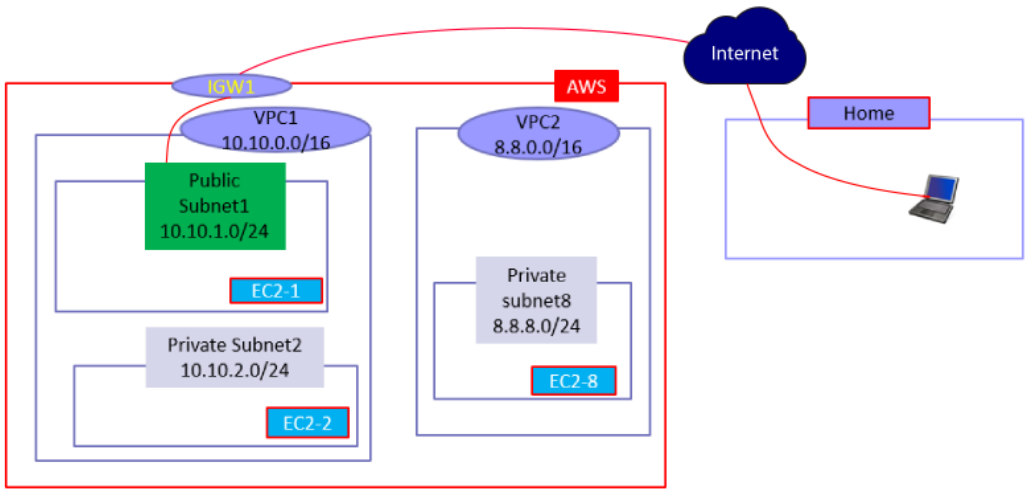


Figure 3.16 – VPC network architecture

As we addressed earlier, all EC2 instances in the same VPC can communicate with each other. From EC2-1, we can ping EC2-2 after we have configured EC2-2's SG to allow ICMP (ping) from EC2-1. However, we cannot ping EC2-8 from EC2-1, since there are no routes between them. Let's resolve this issue by *peering* VPC1 and VPC2 together.

Peering the VPCs

In the Amazon cloud, we can peer two VPCs in the same AWS account, no matter which region they sit in, and we can also peer two VPCs in different AWS accounts, provided they agree on peering with each other. The following figure provides an example of peering two VPCs in the same account. From the AWS console, go to the VPC dashboard and then click **Peering connections | Create peering connection**. Fill in the peering name, a local VPC to peer with (VPC1), and another VPC to peer with (in my account and this region, it is VPC2). Then, click **Create peering connection**, as shown in *Figure 3.17*:

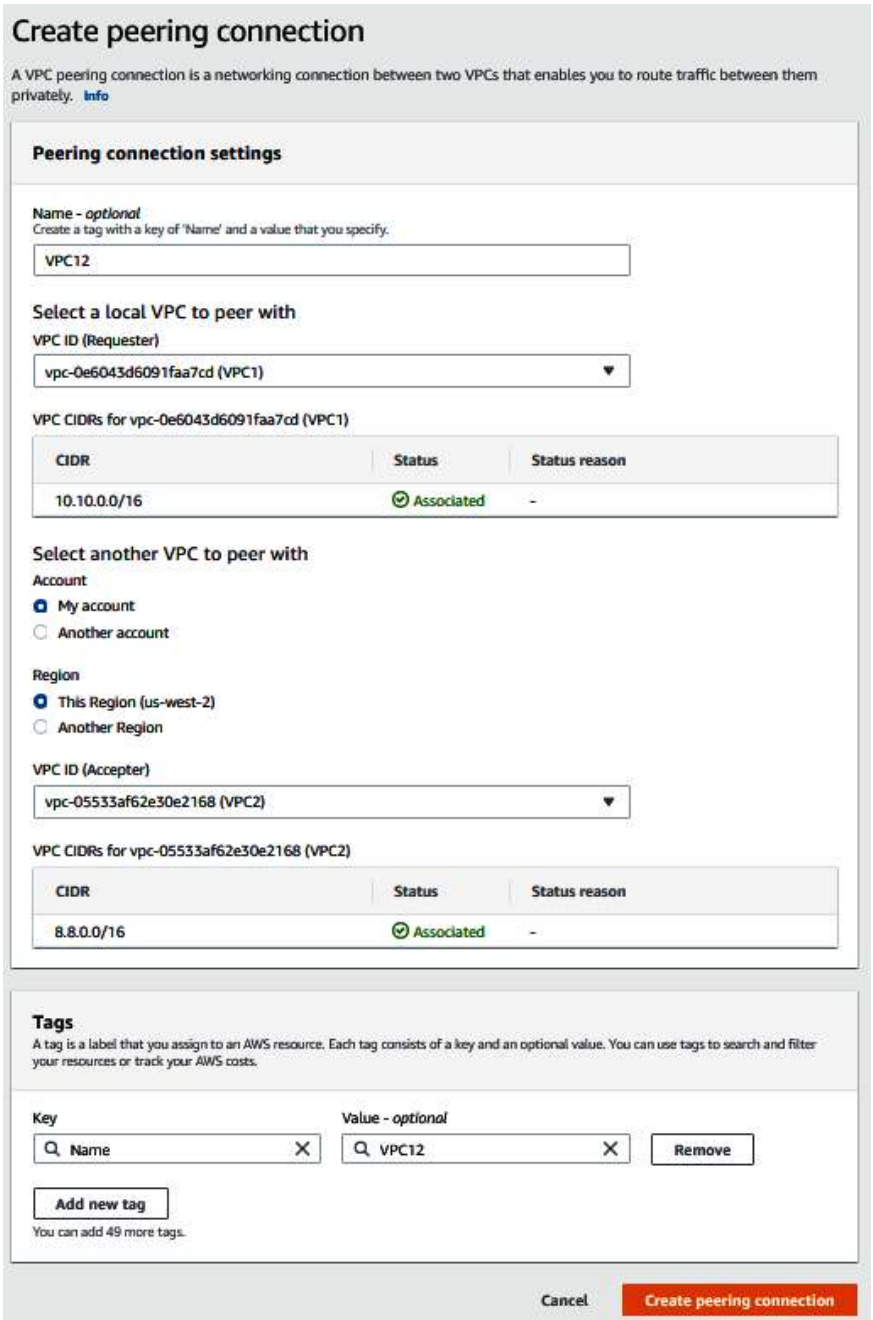


Figure 3.17 – VPC peering

The connection is now in the *pending status*. Click it and accept the peering request, then it will be in the active state. The bridge is now built, but we still need to configure the routes between VPC1 and VPC2 – that is, configure route tables on both VPCs.

Go to the VPC dashboard and then to **Route tables,** select the VPC1 route able, **Edit routes**, then add a route from VPC1 to VPC2 (8.8.0.0/16) with the target of the peering connection (VPC12). Click **Save changes**. This is shown in *Figure 3.18*:

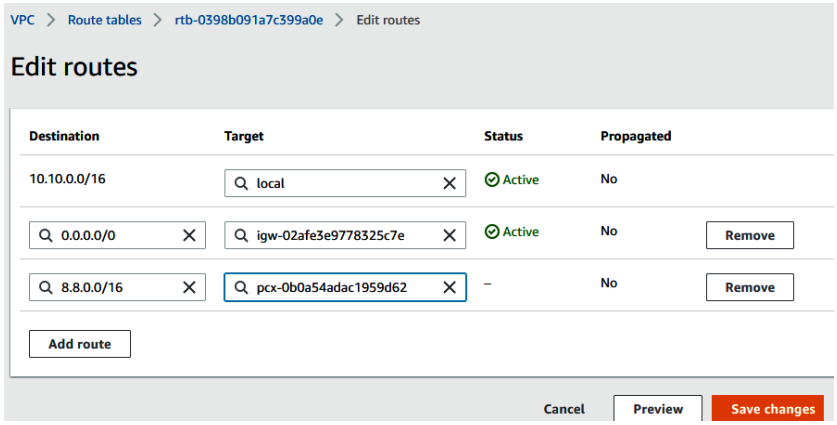


Figure 3.18 – Edit routes for the VPC1 route table

Repeat the preceding steps for the VPC2 route table – add a route from VPC2 to VPC1 (`10.10.0.0/16`) with the **peering connection** (VPC12) as the target. Then, associate it to the subnet (`8.8.8.0/24`).

There is one more thing to do. Go to the EC2 dashboard and then to **EC2-8 | Security | Security Group | Edit inbound rules**, and add a rule to EC-8's security group to allow ping from VPC1. Then, click **Save rules**, as shown in *Figure 3.19*:

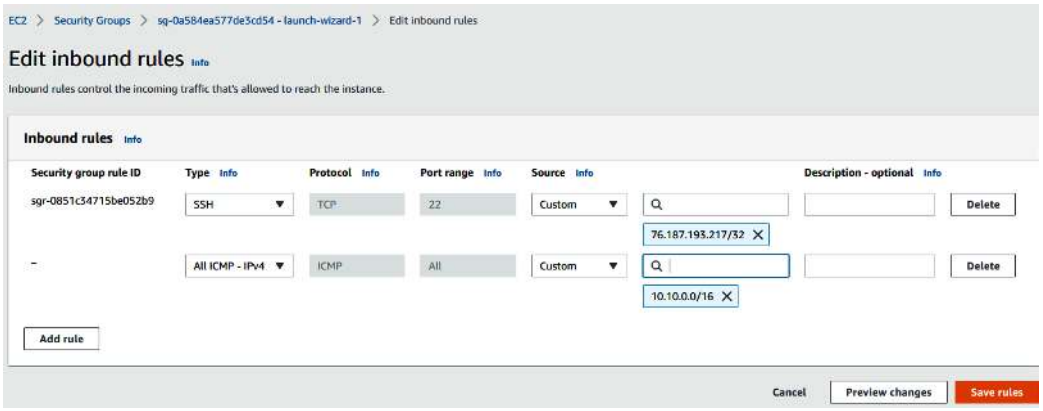


Figure 3.19 – Edit SG inbound rules for EC2-8

Now, let's verify that EC2-1 and EC2-8 can communicate with each other. Go back to EC2-1's guest OS terminal and try to ping EC2-8 (the IP address is `8.8.8.43`). We can see it is working, as in *Figure 3.20*:

```
[ec2-user@ip-10-10-1-225 ~]$ ping  8.8.8.43
PING 8.8.8.43 (8.8.8.43) 56(84) bytes of data.
64 bytes from 8.8.8.43: icmp_seq=1 ttl=255 time=0.955 ms
64 bytes from 8.8.8.43: icmp_seq=2 ttl=255 time=0.553 ms
64 bytes from 8.8.8.43: icmp_seq=3 ttl=255 time=0.495 ms
^C
--- 8.8.8.43 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2023ms
rtt min/avg/max/mdev = 0.495/0.667/0.955/0.206 ms
```

Figure 3.20 – Ping EC2-8 from EC2-1

Figure 3.21 shows the AWS VPC network we have built so far:

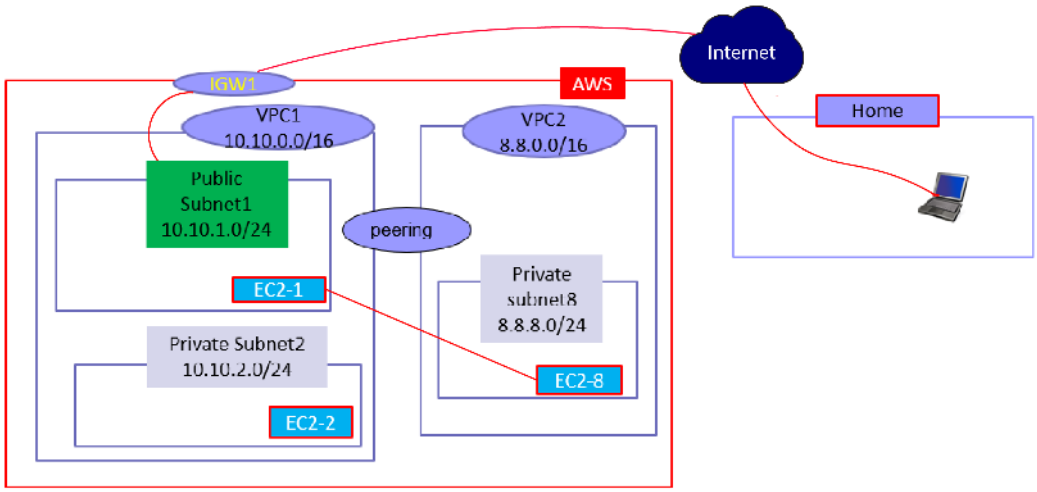


Figure 3.21 – VPC network with peering

Now, we have opened communication channels between EC2-1 in the public subnet and the internet via IGW1. But what about the EC2-2 and EC2-8 instances that are in the private subnets of VPC1 and VPC2? In the next section, we will discuss a way for EC2-2 and EC2-8, the two instances that do not have public IP addresses, to access the internet.

Creating a Network Address Translation (NAT) gateway

A NAT gateway allows EC2 instances in a VPC to go outbound to resources on the internet, but does not allow inbound traffic to the EC2 instance from the internet. Different from the IGW way in which we assign public IP addresses to EC2, here we use NAT to map EC2's private IP addresses to the NAT's public address for outbound requests and map the public IP address back to the EC2 private IP addresses for inbound responses. Take the following steps:

1. **Create a public NAT gateway**. Go to the VPC dashboard and then to **NAT gateways** | **Create NAT gateway**. Fill in the name (`NAT1`) and subnet (public subnet) and click **Allocate Elastic IP** to get an **Elastic IP** (**EIP**) for `NAT1`, then click **Create NAT gateway**, as shown in *Figure 3.22*.

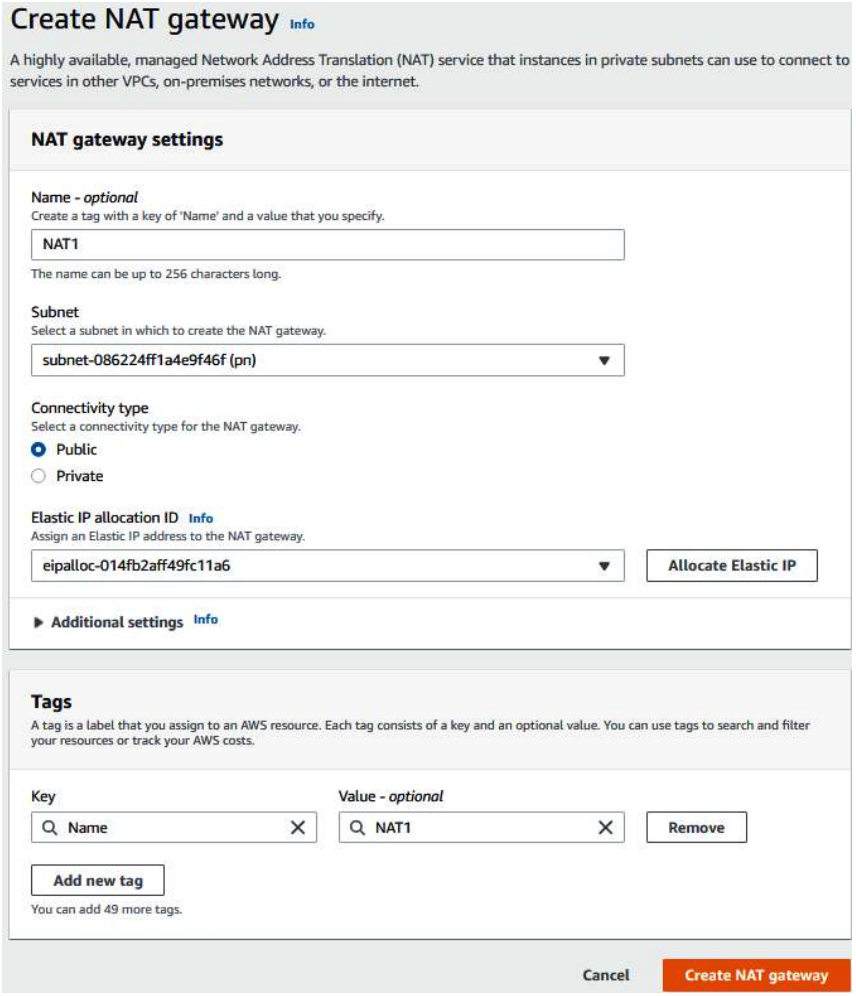


Figure 3.22 – Create NAT gateway

2. **Set up the private subnet route table:**

   After the NAT gateway is created, navigate to the VPC dashboard and then **route tables** and create a new route table called `VPC1PriRT` under VPC1. Add a route under **Destination** (`0.0.0.0/0`) using `NAT1` we created earlier as the target, then click **Save changes**, as shown in *Figure 3.23*. Then, associate the route table to the private subnet.

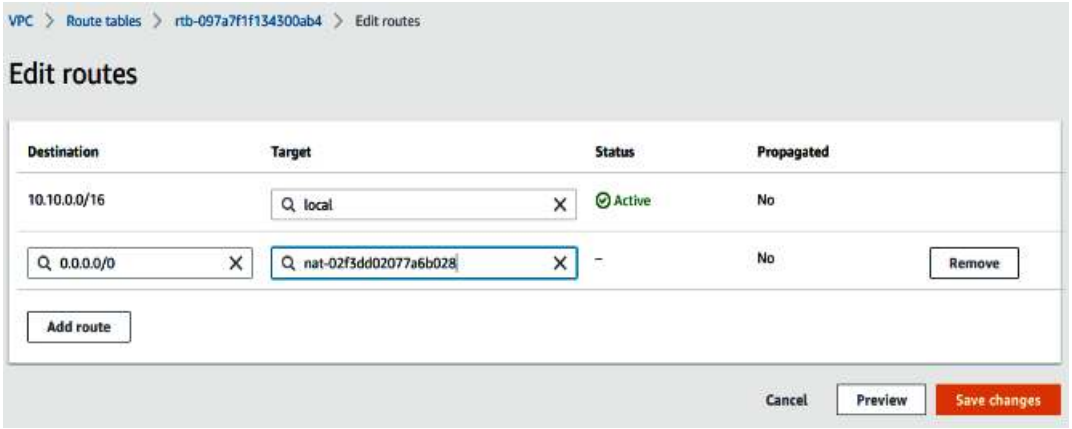


Figure 3.23 – Edit routes for the private subnet route table

3. **Validate internet access from EC2-2**

Now, SSH to EC2-1 (via the IGW), then SSH from EC2-1 to EC2-2 (make sure the SG for EC2-2 allows SSH traffic from EC2-1, and the private key is copied to EC2-1) and execute the `curl www.google.com` command. As shown in *Figure 3.24*, it works (the curl messages are partially shown)!

```
[ec2-user@ip-10-10-1-229 ~]$ ls -l
total 4
-r-------- 1 ec2-user ec2-user 1675 Feb 15 16:10 mykey.pem
[ec2-user@ip-10-10-1-229 ~]$ ssh 10.10.2.249 -i mykey.pem
The authenticity of host '10.10.2.249 (10.10.2.249)' can't be established.
ECDSA key fingerprint is SHA256:AYodQL9fBbvln6XRQLbHSjkNtbsFGevS7CqHSmr2vrk.
ECDSA key fingerprint is MD5:77:e0:ec:a4:40:61:95:68:c3:94:ba:62:98:23:35:7f.
Are you sure you want to continue connecting (yes/no)? yes
Warning: Permanently added '10.10.2.249' (ECDSA) to the list of known hosts.

       __|  __|_  )
       _|  (     /   Amazon Linux 2 AMI
      ___|\___|___|

https://aws.amazon.com/amazon-linux-2/
[ec2-user@ip-10-10-2-249 ~]$ curl www.google.com
<!doctype html><html itemscope="" itemtype="http://schema.org/WebPage" lang="en"
><head><meta content="Search the world's information, including webpages, images
, videos and more. Google has many special features to help you find exactly wha
```

Figure 3.24 – Access www.google.com from EC2-2

Now, we have implemented the AWS cloud architecture shown in *Figure 3.25*, and successfully connected EC2-1 to the internet via IGW1 and EC2-2 via NAT1-IGW1:

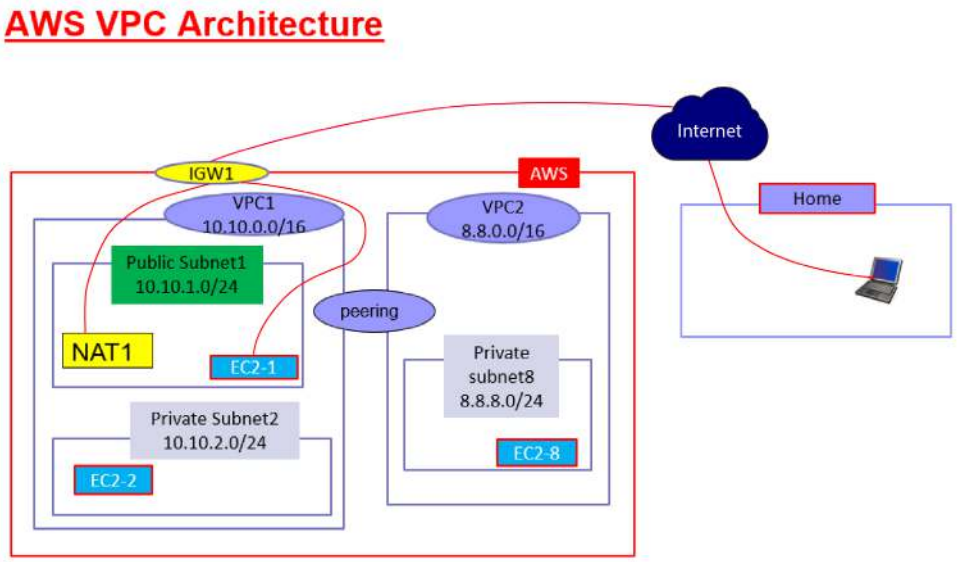


Figure 3.25 – AWS VPC architecture

As a practice lab, configure subnet8 to allow EC2-8 outbound access to the internet (but not inbound from the internet).

Part three – hardening AWS network security

Since we opened VPC1 to the internet, security has become a very important factor. Here, we will discuss the configurations in VPC to harden the security of the VPC and the cloud resources sitting in it. We will discuss two topics: VPC firewalls and VPC endpoints.

VPC firewalls

From *Chapter 1*, we know that a key pair and security groups are used to protect EC2 instances. Here, we will review **SGs**, which are virtual firewalls for EC2 instances and have the following features:

- Act as a virtual firewall that controls the inbound and outbound traffic for one or more EC2 instances
- Can be used to allow or deny traffic based on IP address, port number, and protocol (such as TCP or UDP)
- Can be associated with one or more EC2 instances or with a specific network interface of an instance

- Support the principle of least privilege, which means that only necessary traffic is allowed to reduce the attack surface and improve security
- Are stateful, which means that any traffic that is allowed to come into the EC2 instances will be allowed to go out; any traffic that is allowed to go out will be allowed to come in

Let me use an example to explain the term *stateful*. As shown in *Figure 3.26*, you have a PC at home with the IP address `54.24.12.19` that needs to SSH to an EC2 instance in the Amazon cloud with the address `10.10.1.1`. Since the SG has an inbound rule open for SSH at port `22` from `54.24.12.19`, the packet (source IP: `54.24.12.19`, source port: `2000`, destination IP: `10.10.1.1`, and destination port: `22`) is allowed to go into the EC2 server. When the packet is received by the EC2 instance, it will compile a return packet (source IP: `10.10.1.1`, source port: `22`, destination IP: `54.24.12.19`, and destination port: `2000`). The SG is stateful, meaning that the return packet will be allowed to go out, and there is no need to add any outbound rules for the packet:

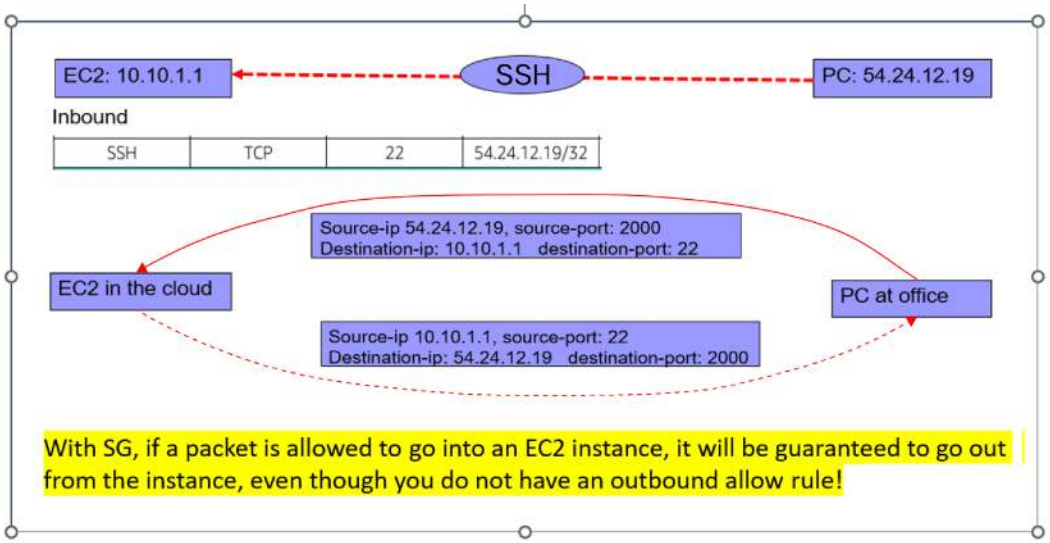


Figure 3.26 – SG is stateful (1)

Figure 3.27 shows another SG example for outbound traffic. You have an EC2 instance in the Amazon cloud with the IP address `10.10.1.1` and need to access a web server running on an office PC with the address `54.24.12.19`. Since the SG has an outbound rule open for port `80` from `10.10.1.1`, the packet (source IP: `10.10.1.1`, source port: `1234`, destination IP: `54.24.12.19`, and destination port: `80`) will be allowed to go out to the PC server. When the packet is received by the web server, it will compile a return packet (source IP: `54.24.12.19`, source port: `80`, destination IP: `10.10.1.1`, and destination port: `1234`). The SG is stateful, meaning that the return packet will be allowed to come in, and there is no need to add any inbound rules for the packet:

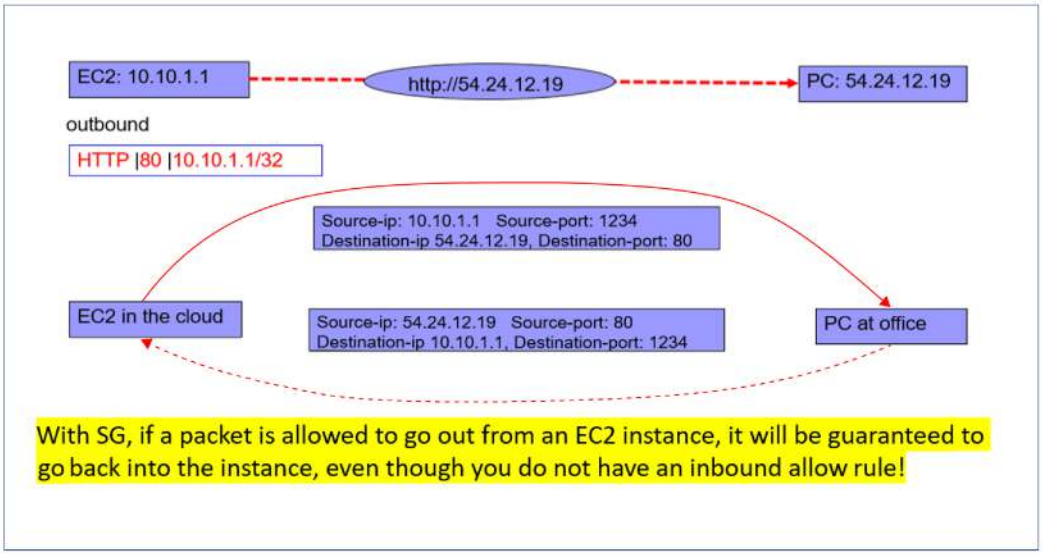


Figure 3.27 – SG is stateful (2)

An NACL is another type of firewall at the subnet level, and it has the following features:

- It is used to allow or deny traffic based on the IP address, port number, and protocol
- It is evaluated before SGs and applies to all instances in a subnet, whereas security groups are associated with individual instances
- It supports numbered rules that are evaluated in order, with the lowest number taking precedence
- It is stateless, which means that any traffic that is allowed to go into the EC2 instances is not guaranteed to be allowed to go out, and we need an NACL rule to explicitly specify the outbound permission

Let us use an example to explain the term *stateless*. As shown in *Figure 3.28*, you have a PC at home with the IP address `54.24.12.19` and need to SSH to an EC2 instance in the Amazon cloud with the address `10.10.1.1`. Since the NACL has an inbound rule to allow for SSH traffic at port `22` from `54.24.12.19`, the packet (source IP: `54.24.12.19`, source port: `2000`, destination IP: `10.10.1.1`, and destination port: `22`) is allowed to go into VPC1. When the packet is received by the EC2 instance, it will compile a return packet (source IP: `10.10.1.1`, source port: `22`, destination IP: `54.24.12.19`, and destination port: `2000`). Because NACLs are stateless, the return packet may not be allowed to go out, and you will need to add an outbound rule for the packet:

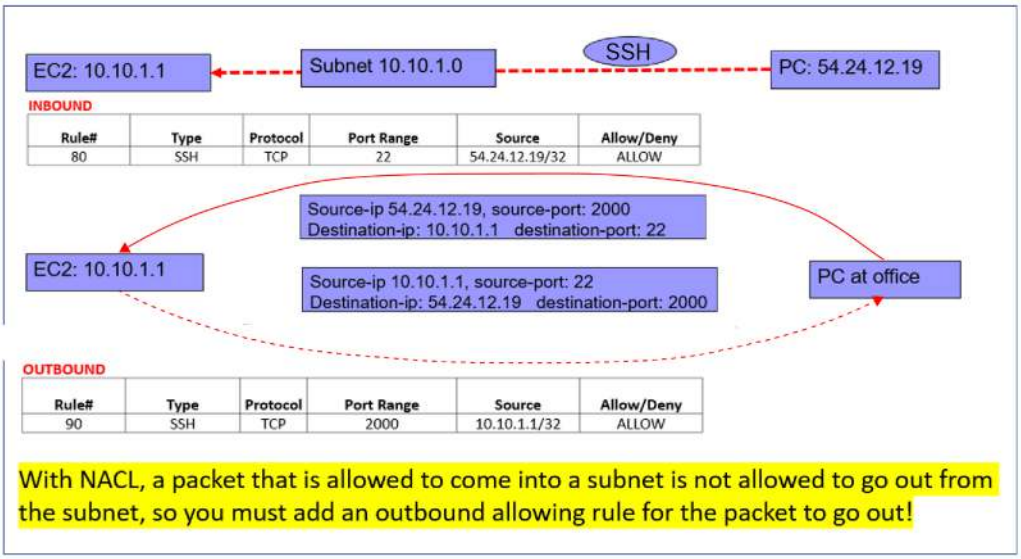


Figure 3.28 – NACL is stateless (1)

Figure 3.29 shows another example of outbound traffic. You have an EC2 instance in the Amazon cloud with the IP address `10.10.1.1` and need to access a web server running on a PC with the address `54.24.12.19`. Since the NACL has an outbound rule to allow traffic to go out from port `80` from `10.10.1.1`, the packet (source IP: `10.10.1.1`, source port: `1234`, destination IP: `54.24.12.19`, and destination port: `80`) will be allowed to go out to the PC server. When the packet is received by the web server running on the PC, it will compile a return packet (source IP: `54.24.12.19`, source port: `80`, destination IP: `10.10.1.1`, and destination port: `1234`). The NACL is stateless, meaning that the return packet may not be allowed to come in, unless there is an explicit inbound rule added to allow the packet to come back in:

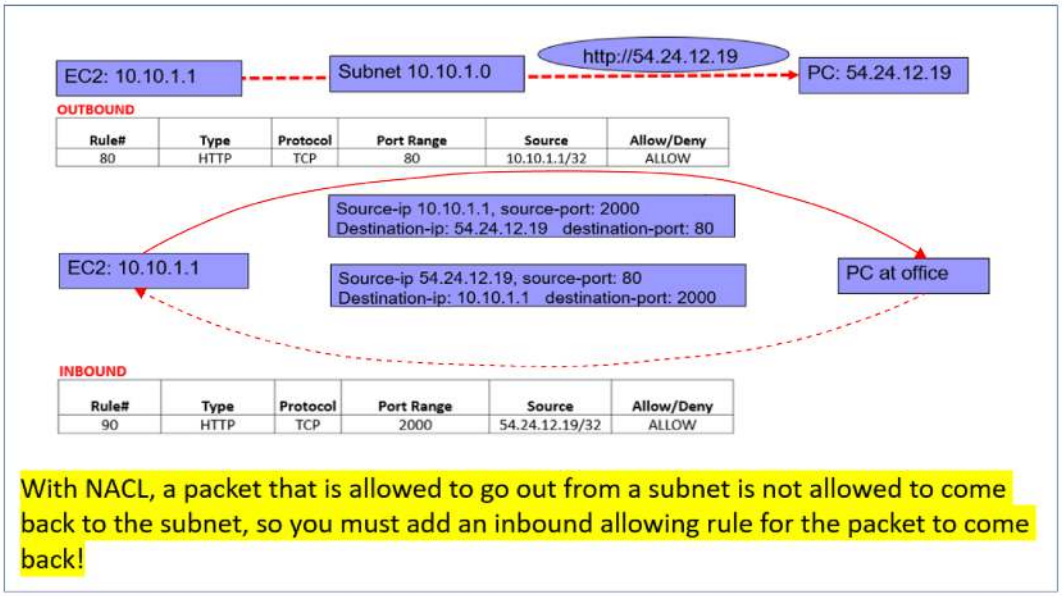


Figure 3.29 – NACL is stateless (2)

As we have learned from the preceding discussions, SGs and NACLs provide protection to the cloud resources inside a VPC, such as EC2 instances. But what about EC2 instances in a VPC to access an S3 bucket? We will introduce VPC endpoints for S3 next.

VPC endpoints

In the previous sections, we learned that an IGW provides inbound and outbound communication with internet resources, and NAT only provides outbound internet access for private cloud resources. Any EC2 instances that have internet access can access public endpoints such as S3 buckets after being assigned an EC2 role that has permission to access the buckets. However, due to security reasons, some companies do not allow internet trespassing to access AWS public endpoints from VPC resources. To that end, VPC endpoints were introduced.

A VPC endpoint for S3 is a way to access S3 resources privately within an Amazon VPC without using a public IGW, a VPN connection, or NAT devices. Using the network diagram shown in *Figure 3.30*, we will create a VPC endpoint for S3 and provide S3 bucket access for an EC2-2 instance that has no public IP addresses:

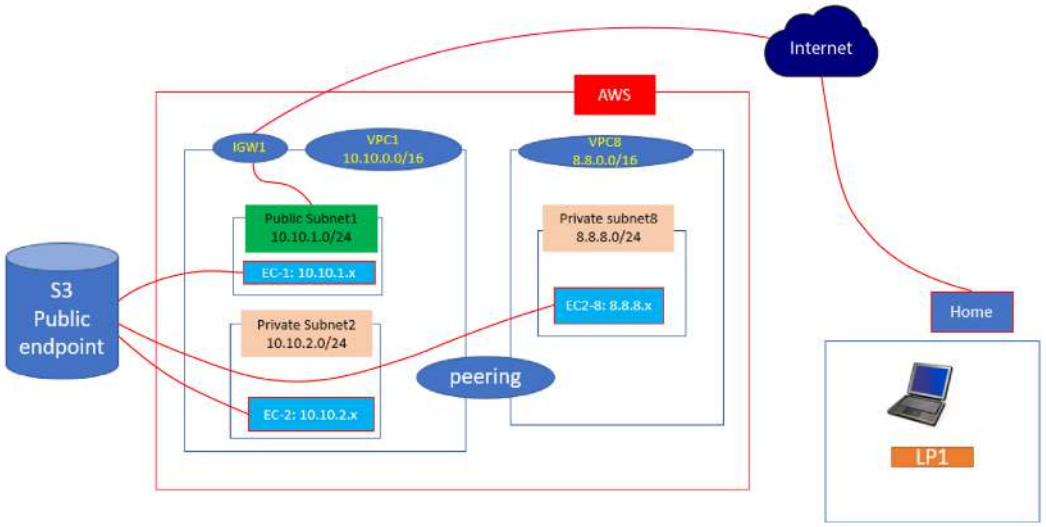


Figure 3.30 – VPC network diagram

Here are the detailed steps:

First, we need to create an EC2 role that has access to the S3 bucket and assign the role to our EC2 instance. We discussed and did this in the previous chapter, and now we create the endpoint:

1. Create a VPC endpoint for S3 in the us-east1 region:

    I. Log in to the AWS Management Console and navigate to the Amazon VPC console. Click on **Endpoints** in the left-hand menu. Click the **Create Endpoint** button.

    II. Fill in the endpoint settings in the new pop-up window, as shown in *Figure 3.31*:

    `vpc-s3-endpoint` is the name

    Select **AWS services** as the service category

    Select **com.amazonaws.us-east-1.s3** as the service name

    Select **VPC1** to create the endpoint

    Select the **VPC1-Pri** route table to associate with the endpoint

    Enable policies for resource-based policies to control access to the bucket

    III. Click **Create endpoint** to create the VPC endpoint.

2. Now you can verify S3 access from EC2-2, which does not have internet access.

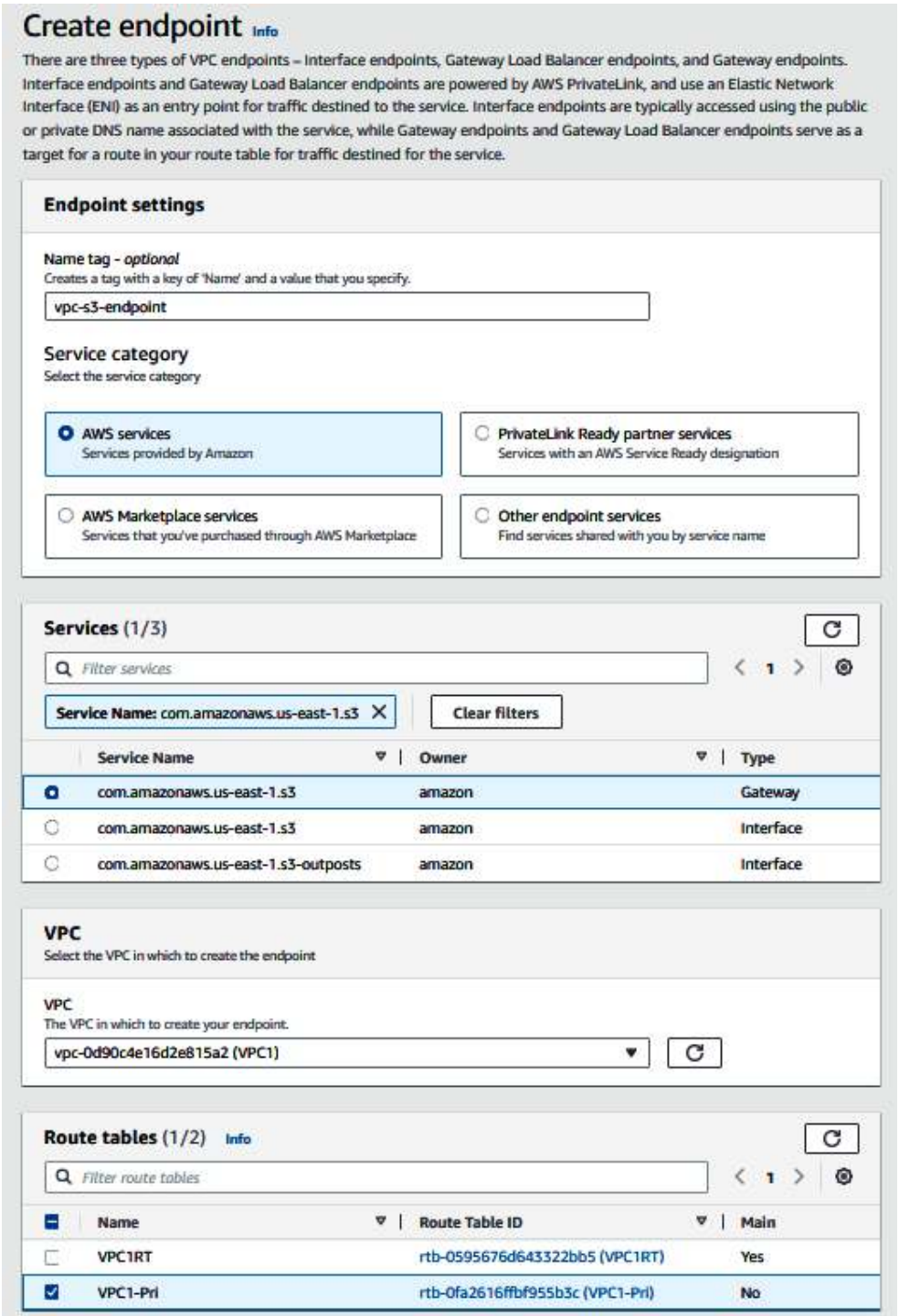


Figure 3.31 – VPC endpoint settings

So far, we have provisioned VPCs, subnets, and EC2 instances in the AWS cloud, and discussed their security hardening. What about the network connections between the public cloud and the on-premises data centers? Let's look at that in the next section.

Understanding Amazon Direct Connect

Amazon Direct Connect is a network service that provides a dedicated and private connection between your on-premises data center environment and the virtual data centers in the cloud. This connection is a private, high-speed, low-latency connection that is not accessible over the public internet. With Amazon Direct Connect, the connection between your on-premises environment and the AWS cloud will have guaranteed bandwidth and performance.

To set up AWS Direct Connect, you'll need to follow these steps:

1. **Review the prerequisites**: Before you begin, make sure you have an AWS account and access to the AWS Management Console, a Direct Connect location, and a device that can connect to the Direct Connect location.
2. **Request a connection**: Log in to the AWS Management Console and go to the Direct Connect console. Choose a Direct Connect location and request a new connection. Provide details such as your connection name, port speed, and virtual private gateway.
3. **Choose a Partner**: Choose a Direct Connect Partner who can provide a network connection between your on-premises environment and the Direct Connect location.
4. **Configure the connection**: Once the connection has been approved by the Direct Connect Partner, you'll receive a **Letter of Authorization and Connecting Facility Assignment** (**LOA-CFA**) document. You'll need to provide this document to the colocation facility where your equipment will be located. You'll also need to configure your routers to connect to the Direct Connect location.
5. **Test the connection**: After the connection is set up, test it to make sure it's working properly. You can do this by creating a test VPC and connecting to it from your on-premises environment.
6. **Start using Direct Connect**: Once you're confident that the connection is working as expected, you can start using Direct Connect to connect to your AWS resources.

More details are available at `https://docs.aws.amazon.com/directconnect/latest/UserGuide/getting_started.html`.

To secure the traffic over Amazon Direct Connect, you can set up a VPN over an Amazon direct connection, extend your private network into AWS, and securely access resources running in the cloud. To set up a VPN over Amazon Direct Connect, you will need to configure a virtual private gateway in your AWS VPC and a customer gateway in your on-premises environment and configure a VPN connection between the two gateways. More details are available at `https://aws.amazon.com/premiumsupport/knowledge-center/create-vpn-direct-connect/`.

As a basic network service, DNS plays a critical role in networking and the internet. When we extend our network from on-premises to the cloud, how does DNS work in the cloud? We will examine this in the next section.

Understanding Amazon DNS – Route 53

Amazon Route 53 is a scalable and highly available DNS web service provided by AWS. Some details about AWS Route 53 are as follows:

- It provides translation from human-readable names (such as `example.com`) into IP addresses that computers use to connect to network resources
- It can also be used to route traffic to AWS resources, such as EC2 instances, S3 buckets, and load balancers
- It offers features such as latency-based routing, geo DNS, health checks, and DNS failover, which help improve the performance, availability, and reliability of applications
- It integrates with other AWS services, such as CloudWatch and CloudTrail, to provide additional monitoring and logging capabilities

Amazon Route 53 supports the following routing policies:

- **Simple routing**: Uses one Route 53 server
- **Weighted round-robin routing**: Assign weights to Route 53 server rotations
- **Latency routing**: Route traffic based on latencies
- **Geolocation routing**: Route traffic based on the location of users
- **Geoproximity routing**: Route traffic based on the location of resources
- **Failover routing**: Route traffic to the failover site when the primary site is not reachable
- **Multivalue answer routing**: Distributes DNS responses across multiple IP addresses – up to eight healthy records can be selected at random

More details on Amazon Route 53 can be found at `https://aws.amazon.com/route53/`.

In the next section, we will cover the AWS CDN, which provides efficient delivery of cloud content, such as photos and PDF files.

Understanding the Amazon CDN

The Amazon CDN is called Amazon **CloudFront** (**CF**). It is a global delivery service that leverages edge locations to securely deliver content with low latency and high speed. CF is integrated with AWS cloud services, and has the following features:

- It is a global network of edge locations that cache and deliver content (such as web pages, videos, and software downloads) to end users with low latency and high data transfer speeds.
- It can be used to distribute both static and dynamic content from AWS and non-AWS origin servers, such as EC2 instances, S3 buckets, and on-premises servers.
- It offers features such as content compression, SSL/TLS encryption, and custom domain names, which help improve the security, reliability, and performance of applications.
- It has a pay-as-you-go pricing model, with no upfront costs or minimum fees. The cost is based on the amount of data transferred, the number of requests made, and the edge locations used.

More details about Amazon CF can be found at `https://aws.amazon.com/cloudfront/`.

Summary

In this chapter, we discussed the Amazon cloud network – VPC, Direct Connect, Route 53, and the CDN, CF. We focused on building a small AWS cloud, by provisioning VPCs, subnets, EC2 instances, and peering VPCs, and setting up internet access for the EC2 instances. We discussed AWS VPC network security and compared the differences between SGs and NACLs. At the end of the chapter, we briefly looked at AWS Direct Connect, providing a connection between on-premises and the Amazon cloud, Amazon Route 53, and Amazon CF concepts and features. In the next chapter, we will discuss database concepts and introduce Amazon cloud database services.

Practice questions

1. What is the main function of an **Internet Gateway** (**IGW**) in AWS VPC?

    A. To provide **Network Address Translation** (**NAT**) for instances in the VPC

    B. To allow instances in the VPC to communicate with other resources outside the VPC

    C. To restrict access to the VPC to only authorized users or resources

    D. To provide load-balancing capabilities for instances in the VPC

2. Which of the following is not a valid use case for a NAT gateway in Amazon VPC?

    A. Allowing instances in a private subnet to access the internet

    B. Enabling communication between two VPCs in different regions

    C. Enabling communication between a VPC and an on-premises network

D. Enabling communication between a VPC and a third-party service that requires a whitelisted IP address

3. Which of the following statements is true about AWS security groups?

A. Security groups are stateless, meaning that inbound and outbound rules must be specified separately

B. Security groups are attached to individual instances, not to a VPC

C. Security groups can be used to restrict inbound and outbound traffic based on IP addresses or port numbers

D. Security groups can be used to allow traffic from a specific IP address range requiring a VPN connection

4. Which of the following is a key difference between an AWS SG and NACL?

A. Security groups can only be applied at the subnet level, while NACLs can be applied at the instance level

B. Security groups are stateful, meaning that they automatically allow return traffic for allowed inbound traffic, while NACLs are stateless

C. Security groups can only allow traffic based on IP addresses, while NACLs can allow or deny traffic based on IP addresses, port numbers, or protocols

D. Security groups can be used to create complex security policies that can filter traffic at multiple layers, while NACLs are simpler and more restrictive in nature

5. Which statement about AWS Direct Connect is true?

A. It is a service that allows you to securely connect your on-premises network to AWS over the public internet

B. It is a service that allows you to create a private, dedicated network connection between your on-premises infrastructure and AWS

C. It is a service that enables you to register domain names and route traffic to AWS resources

D. It is a service that provides managed DNS hosting and traffic management capabilities for your domain names

6. Which of the following is not a valid reason to use AWS Direct Connect?

A. To reduce bandwidth costs for accessing AWS services

B. To improve the reliability and performance of your network connections to AWS

C. To improve the security of your network connections to AWS

D. To access AWS services from a location where internet access is not available

7. What is AWS Route 53?

    A. A service that enables you to register domain names and route traffic to AWS resources

    B. A service that provides managed DNS hosting and traffic management capabilities for your domain names

    C. A service that enables you to establish a private, dedicated network connection between your on-premises infrastructure and AWS

    D. A service that allows you to securely connect your on-premises network to AWS over the public internet

8. Which of the following is a valid use case for Route 53 traffic routing policies?

    A. Distributing traffic evenly across multiple EC2 instances in a single Availability Zone

    B. Directing traffic to the nearest AWS region based on the location of the user

    C. Balancing traffic across multiple AWS accounts using weighted routing

    D. Limiting the amount of traffic that can be sent to a specific AWS resource

9. What is AWS CloudFront?

    A. A service that allows you to run containers on AWS using Docker

    B. A service that enables you to manage and store large amounts of data in the cloud

    C. A **Content Delivery Network** (**CDN**) that speeds up the delivery of your static and dynamic web content

    D. A service that provides serverless computing capabilities for running code in response to events

10. Which of the following is a valid use case for AWS CloudFront?

    A. Storing and managing large volumes of data for analysis using AWS analytics services

    B. Running containers on AWS using Kubernetes

    C. Hosting a website that requires complex server-side processing and database access

    D. Accelerating the delivery of content to users worldwide, especially those in remote or high-latency locations

Answers to the practice questions

1. B
2. B
3. C
4. B
5. B

6. D
7. B
8. B
9. C
10. D

Further reading

For further insights into what you've learned in this chapter, refer to the following links:

- https://aws.amazon.com/vpc
- https://docs.aws.amazon.com/vpc/index.html
- https://aws.amazon.com/vpc/faqs/
- https://aws.amazon.com/getting-started/hands-on/getting-started-create-vpc/
- https://docs.aws.amazon.com/directconnect/index.html
- https://aws.amazon.com/directconnect/faqs/
- https://aws.amazon.com/getting-started/hands-on/getting-started-dc/
- https://docs.aws.amazon.com/cloudfront/index.html
- https://aws.amazon.com/cloudfront/faqs/
- https://aws.amazon.com/getting-started/hands-on/get-started-with-cloudfront/
- https://docs.aws.amazon.com/Route53/index.html
- https://aws.amazon.com/route53/faqs/
- https://aws.amazon.com/getting-started/hands-on/get-started-route-53/

4

Amazon Database Services

Amazon database services provide a scalable, flexible, and high-performance solution for a wide range of applications and workloads. These services are fully managed, meaning that AWS handles the underlying infrastructure and administration tasks such as managing high availability and scalability. This allows users to focus on their data and applications. They also integrate with other AWS services, allowing for seamless integration with other parts of an AWS application stack.

In this chapter, we will cover the following Amazon database services:

Amazon cloud relational databases: Fully managed AWS relational databases that can be used for transactional applications, reporting and analytics, and content management, including **Amazon Relational Database Service** (**RDS**) for traditional databases such as MySQL, MariaDB, PostgreSQL, Oracle, SQL Server, and **Amazon Aurora** for a high-performing, MySQL and PostgreSQL-compatible database.

Amazon cloud NoSQL databases: Fully managed AWS NoSQL databases that can handle large volumes of unstructured data with high scalability and availability, including **Amazon DynamoDB**, a key-value and document database, and **Amazon DocumentDB**, a MongoDB-compatible document database.

Amazon cloud in-memory caching: Fully managed AWS in-memory data caching services that can be used to improve application performance by caching frequently accessed data, including **Amazon ElastiCache** for **Redis** and **Memcached**.

Amazon Cloud Data Warehousing: Fully managed data warehousing services that can be used to store and analyze large volumes of structured and unstructured data, including **Redshift** for large-scale data warehousing, and **Amazon EMR** (**Elastic MapReduce**) for processing large datasets using Apache Hadoop, Spark, and other big data tools. We will focus on Redshift in this chapter and discuss the others in the next chapter.

By following these topics in this chapter, you will understand the basic concepts and gain hands-on skills with Amazon cloud database services. If you are familiar with database basics and **structured query language** (**SQL**), a programming language for storing and processing information in a relational database, you can skip the first section. The examples shown in this chapter are also available in the GitHub repository for this book: `https://github.com/PacktPublishing/Self-Taught-Cloud-computing-Engineer`.

Database basics

A **database** is an organized collection of data that is stored and managed on a computer. It allows for efficient storage, retrieval, and management of data, which can be used for a wide range of applications, such as websites, mobile apps, financial systems, and more. A database consists of one or more tables that contain related data. Each table contains rows and columns, where the columns represent the attributes or fields of the data, and the rows represent the individual instances or records of the data. There are many different types of databases:

- **Relational databases**: These are the most common type of database, where structured data is organized in a tabular format with rows and columns. Data is organized into tables, and relationships between tables are established through keys.
- **NoSQL databases**: These databases are designed to handle unstructured or semi-structured data that cannot be easily organized into tables. Instead, they use document-based, key-value, or graph-based approaches to store and organize data.
- **Object-oriented databases**: These databases store data as objects rather than in a tabular format. They are designed to work with object-oriented programming languages, such as Java, C++, and so on.
- **Data warehouses**: These databases are used to store large amounts of data from different sources, such as transactional systems, social media, and other data sources. They are designed to support complex data analysis and reporting

Overall, databases are an essential tool for managing and organizing data and are used in many different industries and applications. They provide a scalable, efficient, and secure way to store and manage data, which can be accessed by multiple users and applications at the same time. We will discuss each of them in the upcoming sections.

Relational databases

A relational database stores and organizes data in tables or relations, with each table representing a specific entity or concept. The tables are made up of columns and rows, where each column represents a particular attribute or characteristic of the entity, and each row represents a specific instance or record of the entity. We use a schema to define the structure of a database, including the tables and relationships between them.

A schema is a map of how data is stored and organized in the database. It has tables and keys including a **primary key** and a **foreign key**. A primary key is a column or group of columns in a table that uniquely identifies each row in that table: no two rows have the same value in the primary key column(s). Primary keys are important for maintaining the integrity and consistency of the data in the database, as they ensure that each record can be uniquely identified and retrieved. A foreign key is a column in one table that refers to the primary key of another table. It establishes a link or relationship between the two tables, enabling data to be retrieved from multiple tables at the same time. Foreign keys are

essential for maintaining referential integrity in a database, which means that data in one table must always correspond to data in another table.

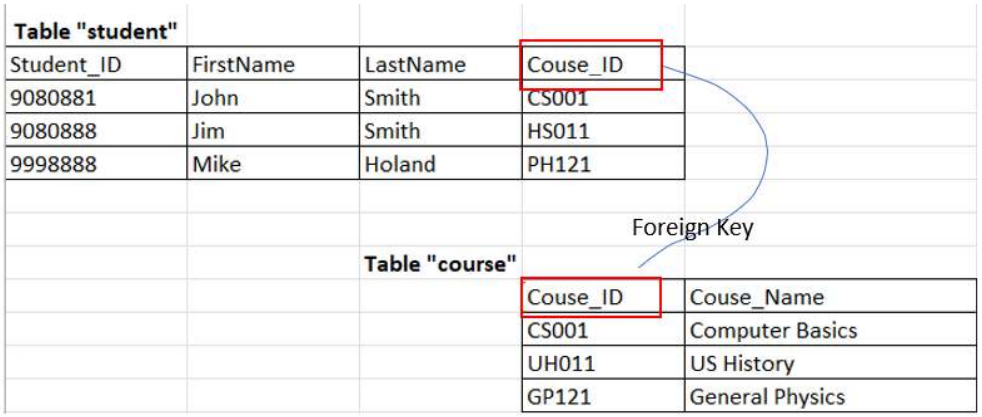


Figure 4.1 – Database schema

Figure 4.1 shows a small database consisting of two tables: a `student` table and a `course` table. The primary key for the `course` table is `Course_ID` ,which is also a foreign key in the `student` table. This relationship defines the database schema and allows you to retrieve information about both students and the courses they take using a single query.

Relational databases use **Structured Query Language** (**SQL**) to create, manipulate, and retrieve data. SQL allows users to write complex queries that can extract specific data from one or more tables, based on various conditions or criteria. The ability to query data in this way makes relational databases a powerful tool for data management and analysis. The following examples create a database called `school`, and create a table called `students` in the database, with `StudentID` as the primary key:

```
Create database school;
Create table school.students (
    StudentID int primary key,
    LastName varchar(100),
    FirstName varchar(100),
    City varchar(100)  );
```

Relational databases have **Atomicity, Consistency, Isolation, and Durability** (**ACID**) to ensure data reliability and transactional integrity in database transactions. More details are available at `https://aws.amazon.com/relational-database/`.

NoSQL databases

NoSQL databases were designed to handle unstructured or semi-structured data and to support highly scalable and distributed systems. Different from relational databases , which rely on structural data models, NoSQL databases use a more flexible, non-relational data model such as key-value pairs, documents, graphs, and other formats. There are several different types of NoSQL databases, including document-oriented databases, key-value stores, graph databases, and column-family stores. Each type has its unique strengths and weaknesses and is best suited for different types of applications and data models.

NoSQL databases are more flexible since there is no schema among the tables. The following example shows a `Student` table that has entries with the key-value format:

```
Student =
{ "Student class number" : 101,
"Student details": [


{"Student name" : "John Smith", "Born City" : "Houston", "Course_
taking" : "CS201"},


{"Student name" : "Jim Smith", "Born City" : "Plano", "Age" : 20},


{"Student name" : "Neil Armstrong", "Age" : 18, "Course_taking" :
"CS202"}


{"Student name" : "Neil Smith", "Age" : 21, "Born City" : "Chicago"}

],}
```

NoSQL databases are not a replacement for traditional relational databases. Rather, they are complementary technology that can be used in conjunction with them to address specific data management needs.

In-memory cache databases

An **in-memory cache database**, also known as an **in-memory data grid**, is a type of database that stores data entirely in RAM for very fast data access and retrieval. In-memory cache databases are often used to accelerate the performance of high-traffic, latency-sensitive applications.

Here are some examples of in-memory cache databases:

- **Redis**: In addition to being a popular NoSQL database, Redis can also be used as an in-memory cache database. It supports a wide range of data structures and can be used for caching, messaging, and more.

- **Memcached**: A high-performance, distributed in-memory cache database that is widely used for caching web applications. It can be used to store key-value pairs and can be accessed from multiple servers in a cluster.

In-memory cache databases are often used in conjunction with other databases, such as a traditional disk-based relational database, to provide a fast and efficient caching layer for frequently accessed data.

Data warehouses

The goal of a **data warehouse** is to provide a comprehensive, unified view of an organization's data so that it can be used for decision-making, reporting, and other analytical purposes. They are also optimized for fast querying and reporting and often use specialized tools and technologies, such as **online analytical processing** (**OLAP**) and data mining, to extract insights and intelligence from data.

Data warehouses are typically used by large organizations that need to analyze and report on large amounts of data from multiple sources. They are commonly used in industries such as finance, retail, healthcare, and telecommunications, where there is a need to analyze data from many different sources and perform complex analyses and reporting. *Figure 4.2* shows examples of data warehouse functions:

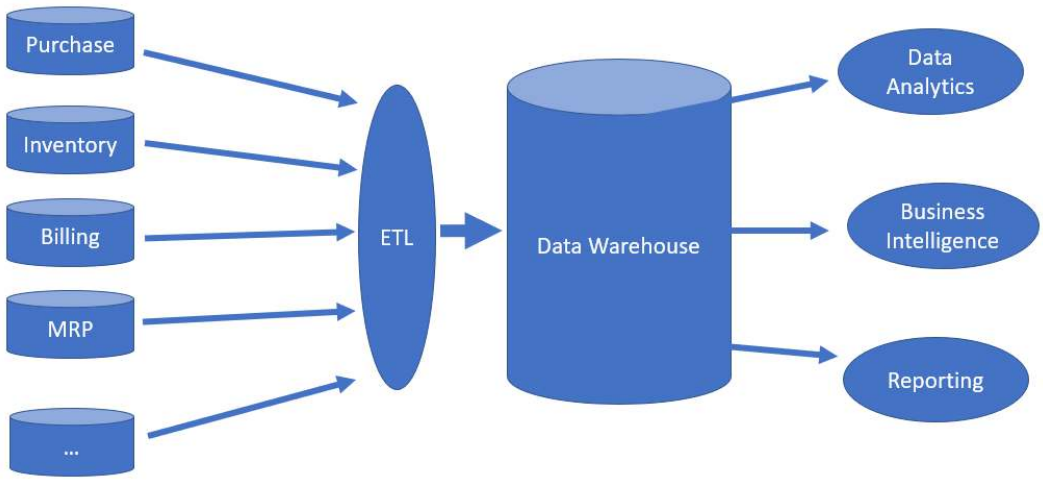


Figure 4.2 – Data warehouse functions

By **Extracting, Transforming, and Loading** (**ETL**) from various sources, data is ingested into the data warehouse, which is a large, centralized data repository, in a structured format that is optimized to conduct data analytics and business intelligence, and generate reporting. After we have briefed the different types of AWS cloud database services, we will now closely examine each of these services.

Amazon RDS

RDS is a fully managed relational database service provided by Amazon in the cloud. With RDS, AWS provides a few popular relational database management systems as a service, including MySQL, PostgreSQL, Oracle, SQL Server, and MariaDB.

Amazon RDS is a managed service. There are different ways to create a database, such as MySQL, in the cloud. One is provisioning an EC2 instance and installing a **database management system** (**DBMS**) on the instance, and then creating databases, tables, and so on. This is an unmanaged approach since you will have to take care of all the administrative tasks such as database scaling, high availability, disaster recovery, and so on. Another is using cloud-managed services to provision a database where AWS will handle the mundane and time-consuming tasks such as hardware provisioning, software installation, backup and recovery, patching, scaling, and so on. Managed services allow users to focus on their applications and data without worrying about the underlying infrastructure.

RDS is a managed service. It provides high availability and fault tolerance by replicating the database to multiple **AZs** and providing automatic failover in the event of a primary database failure. It also supports automated backups and point-in-time restores, ensuring data durability and recoverability. RDS allows users to scale databases vertically as needed with minimal downtime.

As an AWS cloud service, RDS integrates with other AWS services, such as Amazon CloudWatch, which provides monitoring, alarms, and AWS IAM, which allows users to control who can access their databases and what they can do with them.

Recall that an EC2 instance in the public subnet can send or receive traffic directly to and from the internet, whereas an instance in the private subnet can only access the internet via a NAT gateway in the public subnet. This holds true for the database instances in different subnets. A typical multi-tier design is to expose the web tier to the internet while hiding the app tier and database tier in the private subnets. *Figure 4.3* shows an architecture of multi-tiers including web, application, and RDS databases:

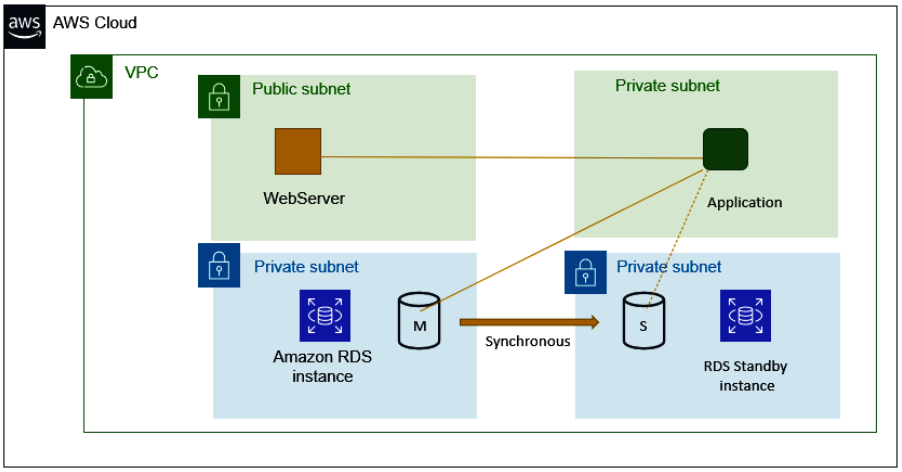


Figure 4.3 – Multi-tier architecture with a multi-AZ RDS

The web server instance is sitting in the public subnet, the application instance sits in the private subnet, and the RDS instance is configured as multi-AZ with a master server in one subnet and the slave server in another so that the slave can take charge when the master is down. We will now implement the RDS portion of the architecture and connect it from an EC2 instance, step by step (for simplicity, we use Zonal RDS):

1. **From the AWS Console | RDS | Create Database**: Fill in the details and click **Create Database**. *Figure 4.4* shows a summary of the database:

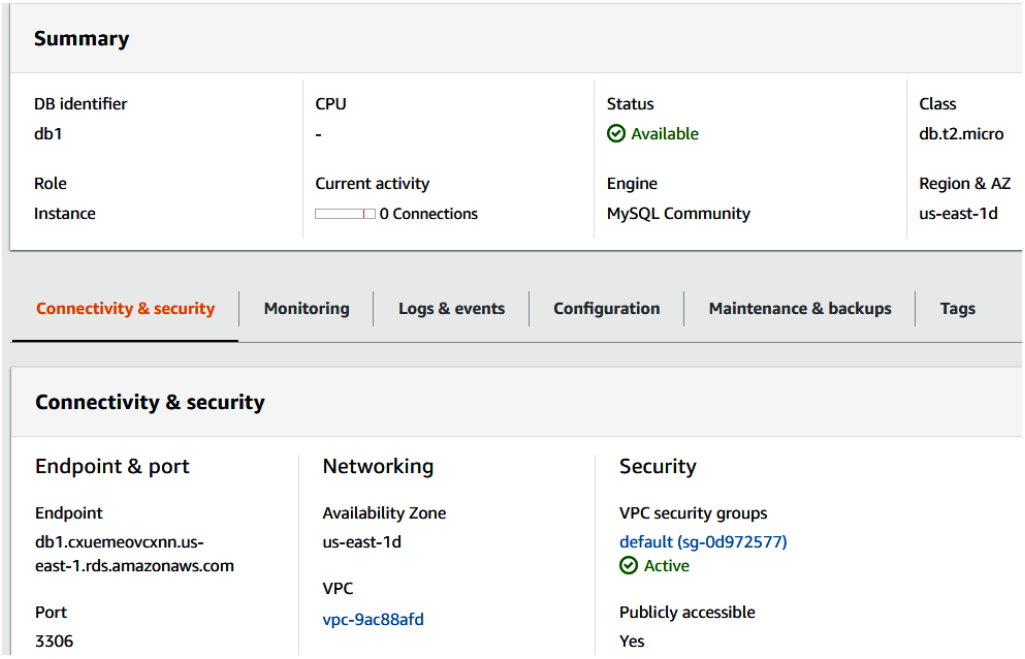


Figure 4.4 – RDS database

2. **Connect from an EC2 instance**: Using `Putty` to connect to a Linux instance, install `mysql client pkg` and connect to the RDS endpoint:

```
sudo yum install mysql
mysql --user admin --password --host db1.cxuemeovcxnn.us-east-1.
rds.amazonaws.com
```

3. Once connected to the RDS instance, we will create a database and a table, insert entries into the table, and run some SQL queries, as shown in *Figure 4.5*:

```
ec2-user@ip-172-31-73-129:~
[ec2-user@ip-172-31-73-129 ~]$ mysql --user admin --password --host db1.cxuemeov
cxnn.us-east-1.rds.amazonaws.com
Enter password:
Welcome to the MariaDB monitor.  Commands end with ; or \g.
Your MySQL connection id is 15
Server version: 8.0.28 Source distribution

Copyright (c) 2000, 2018, Oracle, MariaDB Corporation Ab and others.

Type 'help;' or '\h' for help. Type '\c' to clear the current input statement.

MySQL [(none)]> Create database test;
Query OK, 1 row affected (0.00 sec)

MySQL [(none)]> Create table test.students (StudentID int, LastName varchar(100), FirstName varchar(100), City varchar(100));
Query OK, 0 rows affected (0.03 sec)

MySQL [(none)]> INSERT INTO test.students values (101, "Smith", "John", "Houston");
INSERT INTO test.students values (102, "Smith", "Jim", "Plano");
INSERT INTO test.students values (201, "Armstrong", "Neil", "Dallas");
INSERT INTO test.students values (202, "Smith", "Neil", "Dallas");Query OK, 1 row affected (0.00 sec)

MySQL [(none)]> INSERT INTO test.students values (102, "Smith", "Jim", "Plano");
Query OK, 1 row affected (0.00 sec)

MySQL [(none)]> INSERT INTO test.students values (201, "Armstrong", "Neil", "Dallas");
Query OK, 1 row affected (0.00 sec)

MySQL [(none)]> INSERT INTO test.students values (202, "Smith", "Neil", "Dallas");
Query OK, 1 row affected (0.01 sec)

MySQL [(none)]>
MySQL [(none)]> Select * from test.students;
+-----------+-----------+-----------+---------+
| StudentID | LastName  | FirstName | City    |
+-----------+-----------+-----------+---------+
|       101 | Smith     | John      | Houston |
|       102 | Smith     | Jim       | Plano   |
|       201 | Armstrong | Neil      | Dallas  |
|       202 | Smith     | Neil      | Dallas  |
+-----------+-----------+-----------+---------+
4 rows in set (0.00 sec)

MySQL [(none)]> quit
Bye
[ec2-user@ip-172-31-73-129 ~]$
```

Figure 4.5 – Connect and operate the RDS database

AWS RDS provides an option that enables users to create one or more read-only copies of their database instance within the same AWS region or across different AWS regions, called `read- replicas`. By copying the data from the primary/source database instance to the replica instance, you can offload read traffic from the primary instance to the replica. Because a read replica is read-only, any write operations must still be performed on the primary instance. The read replica can be used to improve the performance of read-intensive workloads or to create a DR solution. In the case of DR, if the primary instance fails, the read replica can be promoted to the primary instance, reducing downtime.

AWS RDS read replicas can be created for various database engines, including MySQL, PostgreSQL, Oracle, and SQL Server. The replica instances can be resized, backed up, and deleted independently of the primary instance. Additionally, users can configure the replication settings, including the replication frequency and the source and destination databases.

In addition to cloud RDS, Amazon offers another powerful cloud relational database service, Amazon Aurora, which is highly available globally, highly scalable, durable, and performs great. Amazon Aurora has many features:

- It uses a distributed architecture that enables its scaling horizontally across multiple nodes, while maintaining low latency and high throughput
- It can automatically replicate data across multiple AZs for high availability and durability
- It supports both across-region read replicas and global databases
- It offers point-in-time recovery, allowing the database to restore to a specific point in time
- It's compatible with MySQL and PostgreSQL – existing applications and tools that use MySQL/PostgreSQL can be migrated to Aurora easily
- It offers advanced security features such as encryption at rest and in transit

Overall, AWS RDS and Aurora are powerful and flexible cloud relational database services that are highly available, scalable, and cost-effective. They are great choices for organizations of all sizes, from start-ups to enterprises that need to manage their relational databases in the cloud. While RDS suits small or medium-sized databases with relatively low cost, Aurora is a global petabyte-scale database for mission-critical applications and is thus more expensive than RDS. More details about AWS relational databases can be found at `https://aws.amazon.com/rds/pricing/` and `https://aws.amazon.com/rds/aurora/pricing/`.

In the next section, we will examine the NoSQL databases in the AWS cloud.

Amazon cloud NoSQL databases

DynamoDB is a fully managed NoSQL database service provided by Amazon in the cloud. It is a key-value and document database that can handle structured, semi-structured, and unstructured data, making it a versatile solution for a wide range of applications. It is also designed to be highly available, with automatic multi-AZ replication for built-in redundancy and durability.

DynamoDB can scale seamlessly with no downtime or disruption, allowing users to scale their databases up or down as needed, with pay-as-you-go pricing based on the amount of data stored and the number of requests made.

DynamoDB is designed for high performance with sub-millisecond latency for read and write operations, making it an ideal choice for real-time, low-latency applications. It is also highly secure, with support for encryption at rest and in transit, as well as fine-grained access control through AWS IAM. We will create a DynamoDB through AWS Cloudshell:

```
aws dynamodb create-table \
--table-name Music \
--attributedefinitions \
AttributeName=Artist, AttributeType=S \
```

```
AttributeName=SongTitle, AttributeType=S \
--key-schema \
AttributeName=Artist,KeyType=HASH \
AttributeName=SongTitle, KeyType=RANGE \
--provisionedthroughput \
ReadCapacityUnits=5,WriteCapacityUnits=5 \
--table-class STANDARD
```

As shown in *Figure 4.6*, the DynamoDB table `Music` is created:

```
[cloudshell-user@ip-10-2-48-206 ~]$ aws dynamodb create-table \
>     --table-name Music \
>     --attribute-definitions \
>         AttributeName=Artist,AttributeType=S \
>         AttributeName=SongTitle,AttributeType=S \
>     --key-schema \
>         AttributeName=Artist,KeyType=HASH \
>         AttributeName=SongTitle,KeyType=RANGE \
>     --provisioned-throughput \
>         ReadCapacityUnits=5,WriteCapacityUnits=5 \
>     --table-class STANDARD
{
    "TableDescription": {
        "AttributeDefinitions": [
            {
                "AttributeName": "Artist",
                "AttributeType": "S"
            },
            {
                "AttributeName": "SongTitle",
                "AttributeType": "S"
            }
        ],
        "TableName": "Music",
        "KeySchema": [
            {
                "AttributeName": "Artist",
                "KeyType": "HASH"
            },
            {
                "AttributeName": "SongTitle",
                "KeyType": "RANGE"

            }
        ],
        "TableStatus": "CREATING",
        "CreationDateTime": "2023-02-21T20:36:32.696000+00:00",
        "ProvisionedThroughput": {
            "NumberOfDecreasesToday": 0,
            "ReadCapacityUnits": 5,
            "WriteCapacityUnits": 5
        },
        "TableSizeBytes": 0,
        "ItemCount": 0,
        "TableArn": "arn:aws:dynamodb:us-east-1:317332158300:table/Music",
        "TableId": "ded6c371-078f-420d-bf03-e604c1459deb",
        "TableClassSummary": {
            "TableClass": "STANDARD"
        }
    }
}
[cloudshell-user@ip-10-2-48-206 ~]$
```

Figure 4.6 – Create a DynamoDB database

In the preceding DynamoDB table creation command, there are some concepts we need to understand:

- **Key schema**: A DynamoDB table has two types of keys:

  The **hash key**, also known as the **partition key**, is a required attribute that uniquely identifies items in a table. The hash key is used to partition the table's items across multiple physical storage partitions for scalability and performance. For example, for the `Music` table, we choose the `Artist` attribute as the hash key to ensure that all items for a given artist are stored in the same partition, which allows for fast access to that artist's data.

  The **range key**, also known as the **sort key**, is an optional attribute that is used in combination with the hash key to uniquely identify items in a table. The range key is used to further sort and organize items within a particular hash key partition. For example, for the `Music` table, we choose the `SongTitle` attribute as the range key to ensure that all items for a given artist are sorted by song titles within their partition.

  The combination of a hash key and a range key is called a **composite primary key**. This allows for efficient querying of items in a table based on both the hash key and range key values.

- **Provisioned throughput**: This is a setting that determines the amount of read and write capacity that is provisioned for a table or an index. Provisioned throughput is specified as two separate values: the **read capacity unit** (**RCU**) and the **write capacity unit** (**WCU**). One RCU represents the capacity to read up to 4 KB of data per second, while one WCU represents the capacity to write up to 1 KB of data per second.

  Provisioned throughput is important because it determines the rate at which your application can read and write data to the table or index. If your application exceeds the provisioned throughput capacity, then DynamoDB may start returning throttling errors. On the other hand, if you provision more capacity than you need, you will be paying more for unused capacity. In the DynamoDB instance created earlier, we have set an RCU of 5 and a WCU of 5, now let's add some items to the table and run some queries against it:

1. **Add items to the DynamoDB table**:

```
aws dynamodb put-item --table-name Music --item \
'{"Artist": {"S": "Broadway"}, "SongTitle": {"S": "Call Me"},
"AlbumTitle": {"S": "Somewhat Famous"}}'


aws dynamodb put-item --table-name Music --item \
'{"Artist": {"S": "Broadway"}, "SongTitle": {"S": "Howdy"},
"AlbumTitle": {"S": "Famous"}, "Awards": {"N": "2"}}'


aws dynamodb put-item --table-name Music --item \
'{"Artist": {"S": "Acme Band"}, "SongTitle": {"S": "Happy"},
"AlbumTitle": {"S": "About Life"}, "Awards": {"N": "10"}}'
```

```
aws dynamodb put-item --table-name Music --item \
'{"Artist": {"S": "Acme Band"}, "SongTitle": {"S": "Rocks"},
"Awards": {"N": "8"}}'
```

2. **Query the table in the AWS console**:

   Going to **AWS Console** | **DynamoDB** | **Tables**, we can see the table shown in *Figure 4.7*:

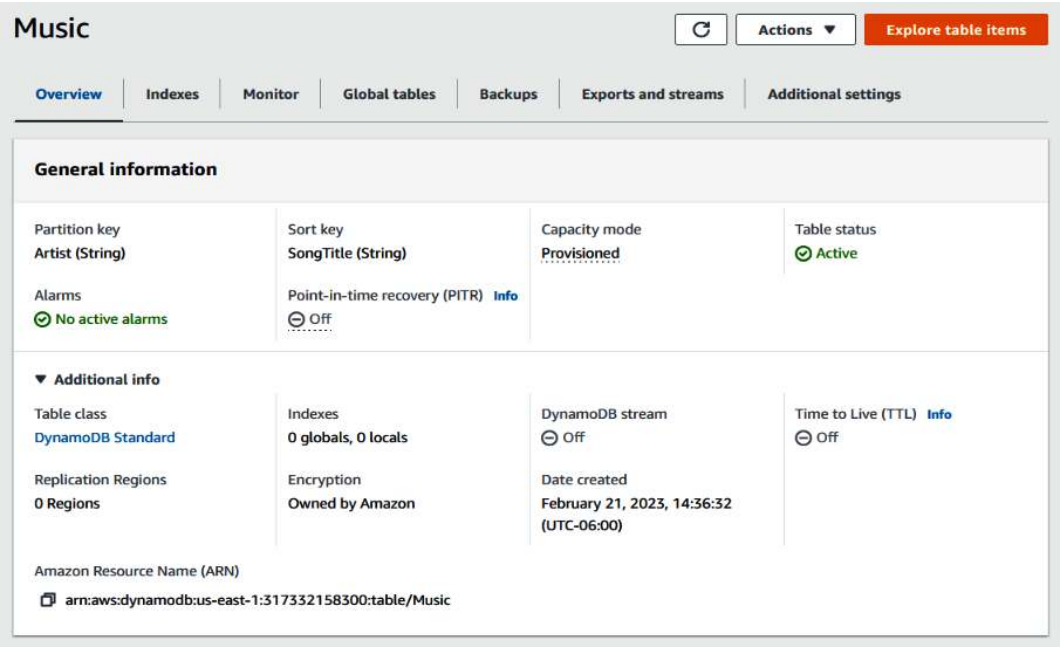


Figure 4.7 – DynamoDB "Music" table

Click **Explore table items**, and you can scan the table or run a query against the table. *Figure 4.8* shows the result of scanning the table:

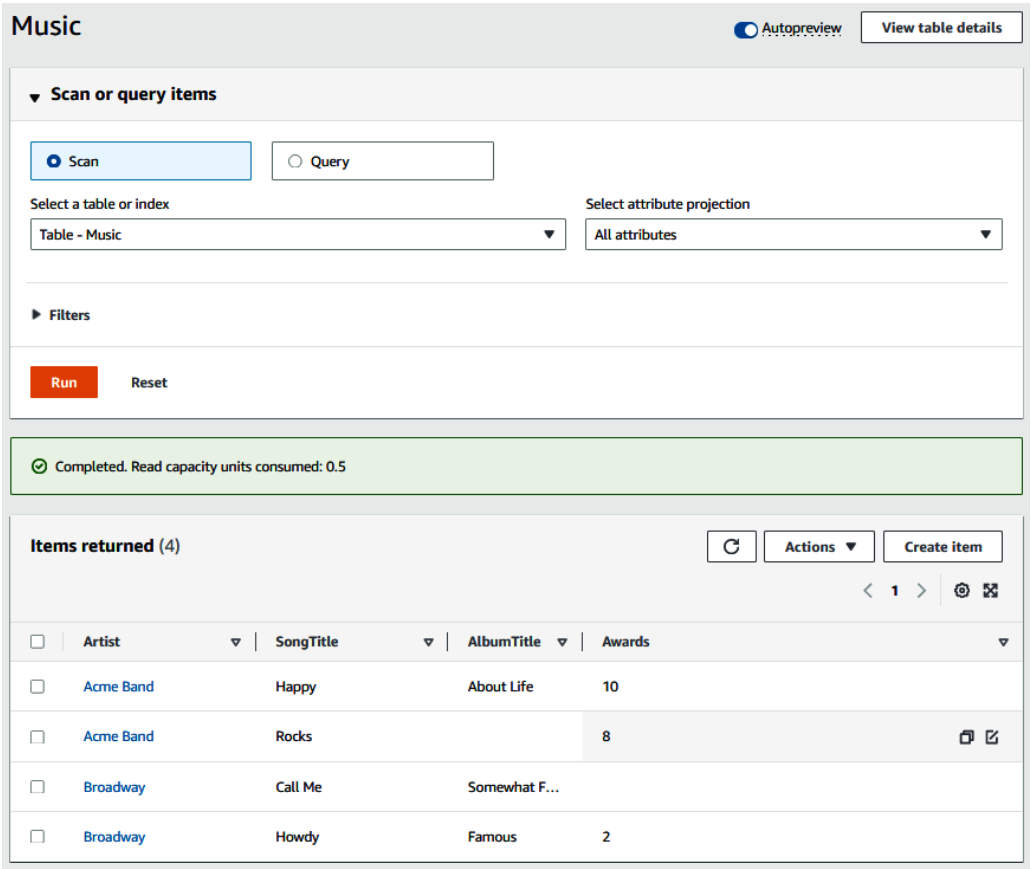


Figure 4.8 – Scan the "Music" table

Figure 4.9 shows the result of running a query by listing all the items for **Artist | Broadway**:

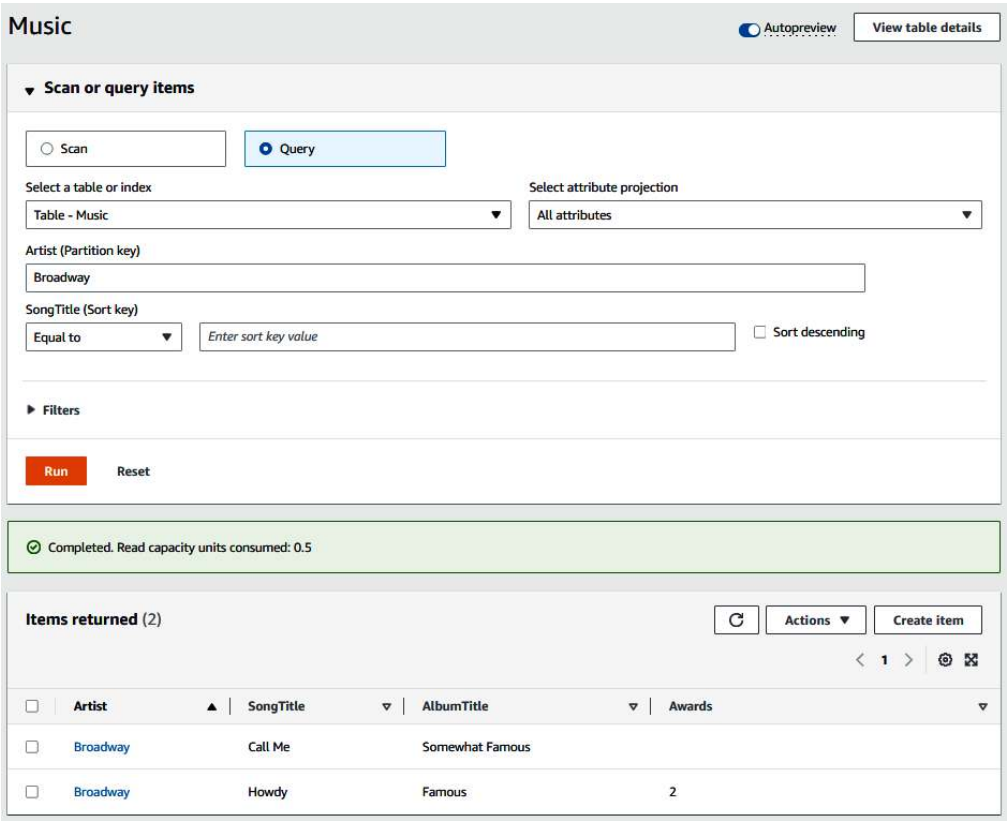


Figure 4.9 – Query the "Music" table

As we can see from *Figure 4.9*, DynamoDB provides a range of features for managing and querying data, including built-in support for indexing, filtering, and sorting, as well as a powerful query language called AWS Query and Scan. It also integrates with other AWS services, such as AWS Lambda and Amazon CloudWatch, for seamless integration with other parts of an AWS application stack. Overall, DynamoDB provides a scalable, flexible, and high-performance NoSQL database solution for a wide range of applications, from mobile and web applications to large-scale enterprise systems.

We have discussed Amazon RDS and DynamoDB. One of the issues with databases is performance, specifically when a table in the database is accessed by many users or applications and poses delays in responding to queries against it. One solution is caching the table into memory. This will lead us to the next section about Amazon ElastiCache.

Amazon ElastiCache

ElastiCache is a fully managed, in-memory data caching service provided by Amazon in the cloud. ElastiCache supports two popular in-memory data stores, Redis and Memcached, which can be used as caching layers for a wide range of applications, including web applications, mobile applications, and gaming applications.

ElastiCache provides automatic scaling and availability, with the ability to scale up or down based on the needs of the application. It also integrates with other AWS services, such as Amazon EC2, AWS Lambda, and Amazon RDS, for seamless integration with other parts of an AWS application stack. ElastiCache provides a range of features for managing and monitoring the caching environment, including automatic failover and automated backups.

ElastiCache also supports a range of use cases, including read-heavy workloads, session management, caching database queries, and real-time analytics. It also supports a range of data structures, including strings, hashes, sets, and lists, and provides a powerful query language for searching and manipulating data.

We will now create an ElastiCache instance and connect it to a client application:

1. **Create an EC2 instance with an SG**: This is to allow default SSH from the computer where you will access the ElastiCache cluster. Use the `VPC/subnet` for the EC2 instance, which we will name `EC2-1`, with an SG of allowing `SSH from my computer` so we can access the EC2 instance from our home computer. Save the key pair and the instance's public IP address. In our case, they are `kp.pem` and `3.238.218.212`.

   Create an SG named **RedisSG** to allow `SSH` from the previous SG.

2. **Go to the Amazon ElastiCache service**: Click **Get started**, then click **Create cluster**. Choose **Create Redis cluster**. Choose **RedisSG** as the security group, and select **minimum configuration**. *Figure 4.10* shows the details after the cluster has been created:

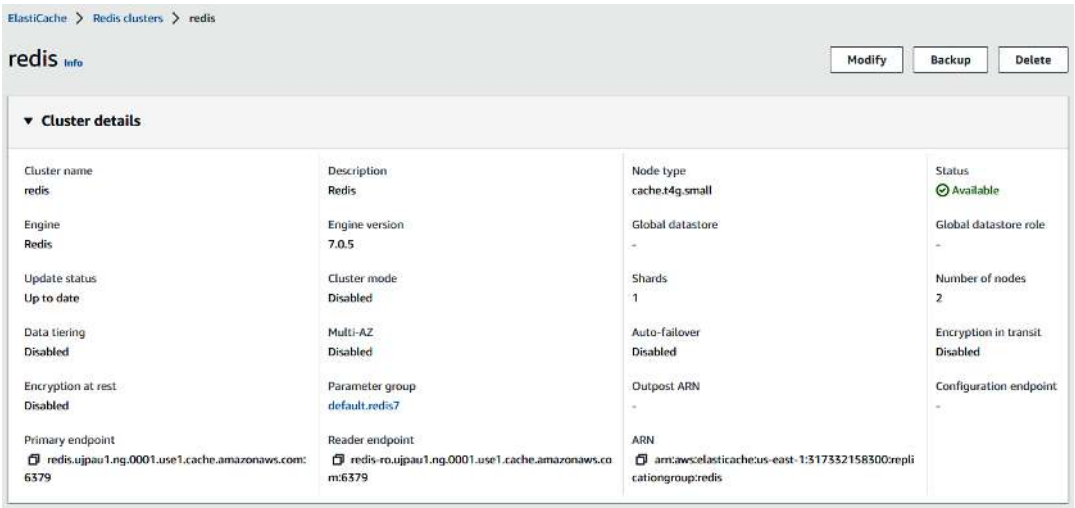


Figure 4.10 – Redis cluster details

3. **Access the Redis cluster from RedisInsight**: Just like the `PUTTY` tool we used to access Linux EC2 instances in the cloud, RedisInsight is a tool to access the Redis cluster remotely. After launching RedisInsight, click **Add Database**, then fill in the information for the cluster. Fill in **Host** using the primary endpoint copied from the Redis cluster details, leaving the default Redis port of `6379`. Since we will use the EC2 instance as the SSH tunnel, check **Use SSH Tunnel** and enter the instance's public IP address for **Host**, leaving the SSH port `22`. Check **Private Key** and copy the key from the `kp.pem` file as shown in *Figure 4.11*:

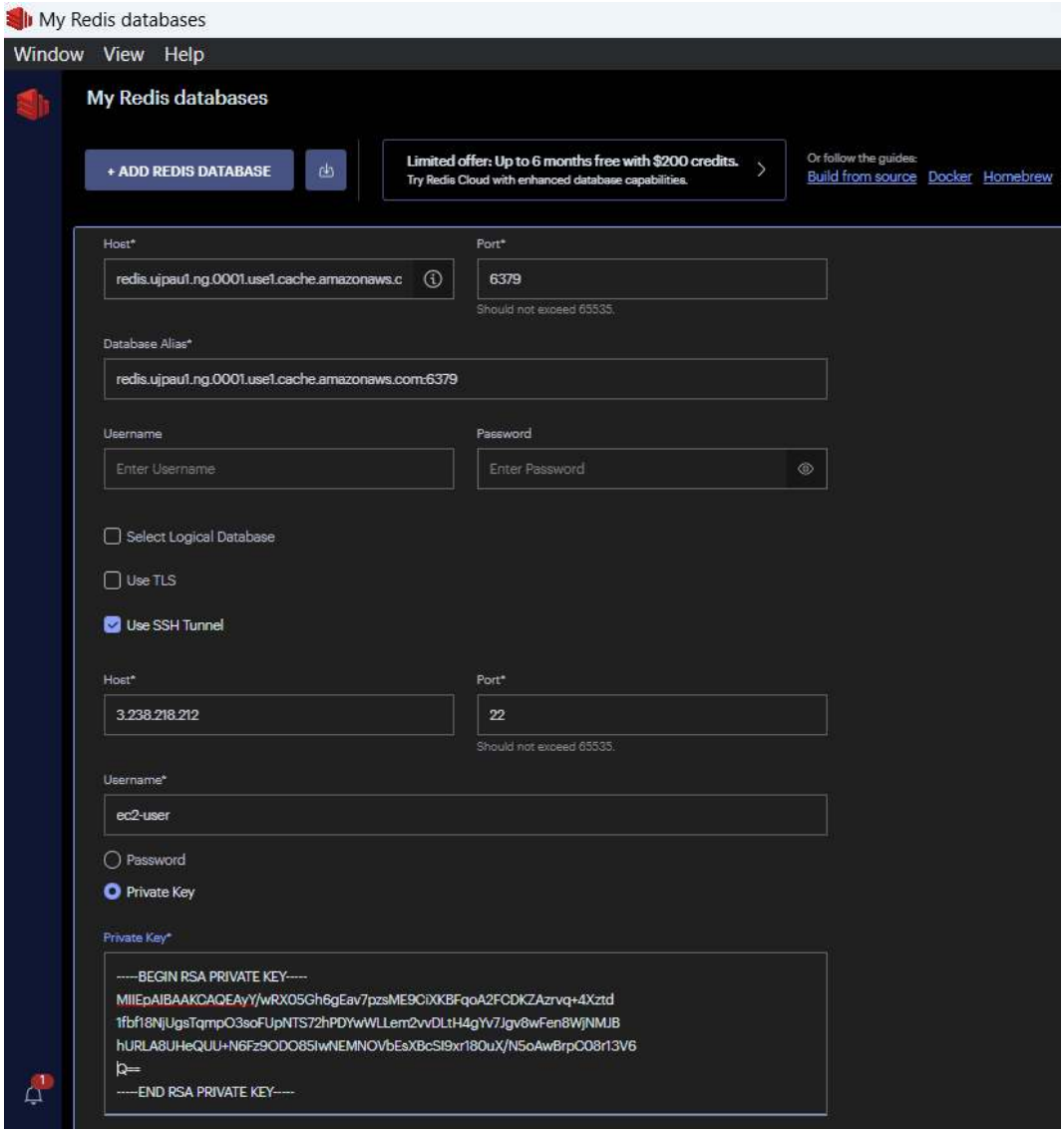


Figure 4.11 – Connecting to the Redis cluster

Once the Redis database is added, we can use **Browser**, **Workbench,** and the **Analysis** tools from the left side. More details are available at `https://redis.io/docs/ui/insight/`.

Amazon ElastiCache provides a highly scalable, fully managed in-memory data caching service that can improve application performance and reduce the need for expensive database queries. It is a popular choice for organizations of all sizes, from start-ups to enterprises that need to manage their caching environment in the cloud.

So far, we have learned about the Amazon cloud databases that support OLTP, including RDS, DynamoDB, and ElastiCache. There is another type of database that supports OLAP, which we refer to as data warehouses. Let's examine an AWS data warehouse: Redshift.

Amazon cloud data warehouse service

Amazon Redshift is a cloud-based data warehousing service that is designed to provide fast querying and analysis of large datasets. Redshift is a fully managed service where AWS handles the infrastructure and administration tasks, such as hardware provisioning, software installation, and backup and recovery, to allow users to focus on their data and analysis without worrying about the underlying infrastructure.

Redshift is based on a columnar storage format, which provides efficient storage and fast querying of large datasets. It can scale up or down as needed, with pay-as-you-go pricing based on the amount of data stored and the number of queries made. It also integrates with other AWS services, such as Amazon S3, Amazon EMR, and Amazon Kinesis, for seamless integration with other parts of an AWS application stack. Redshift supports standard SQL and BI tools such as Tableau, MicroStrategy, and Looker, allowing users to perform complex analytics and reporting on their data. It also provides a range of features for managing and optimizing queries, including query monitoring, query profiling, and automatic query optimization. Redshift is highly secure, with support for encryption at rest and in transit, as well as fine-grained access control through AWS IAM. It is also designed for high availability, with automatic replication of data to multi-AZs and automatic failover in the event of a node failure.

We will now create a Redshift instance and connect it to a client application:

1. **Create a security group**: This allows Redshift traffic from the computer where you will access the data warehouse, as shown in *Figure 4.12*:

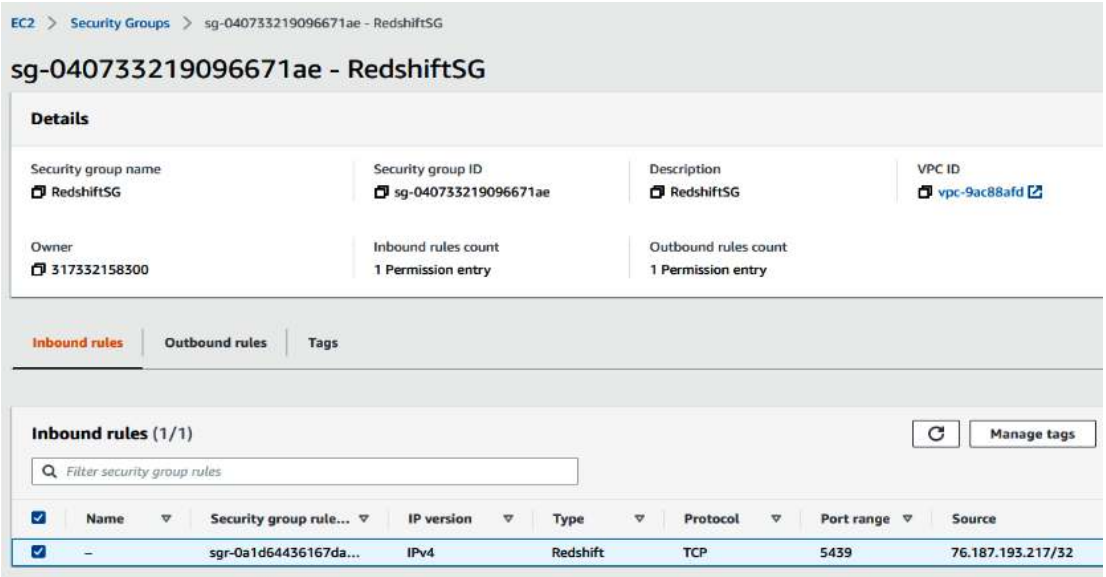


Figure 4.12 – SG for Redshift access

2. Create a subnet group that is designated for the Redshift clusters running in the VPC environment. Create an IAM role that has permissions to copy, unload, and query data with Amazon Redshift, and to run SELECT statements for related services, such as Amazon S3, Amazon CloudWatch logs, and so on.
3. Navigate through **AWS Console | Amazon Redshift | Create Cluster**: Fill in the cluster configurations, including name, SG, subnet group, and role and choose the minimum requirements in monitoring, backup, and so on. Make sure the cluster is publicly available. When the cluster is created, copy its endpoint:

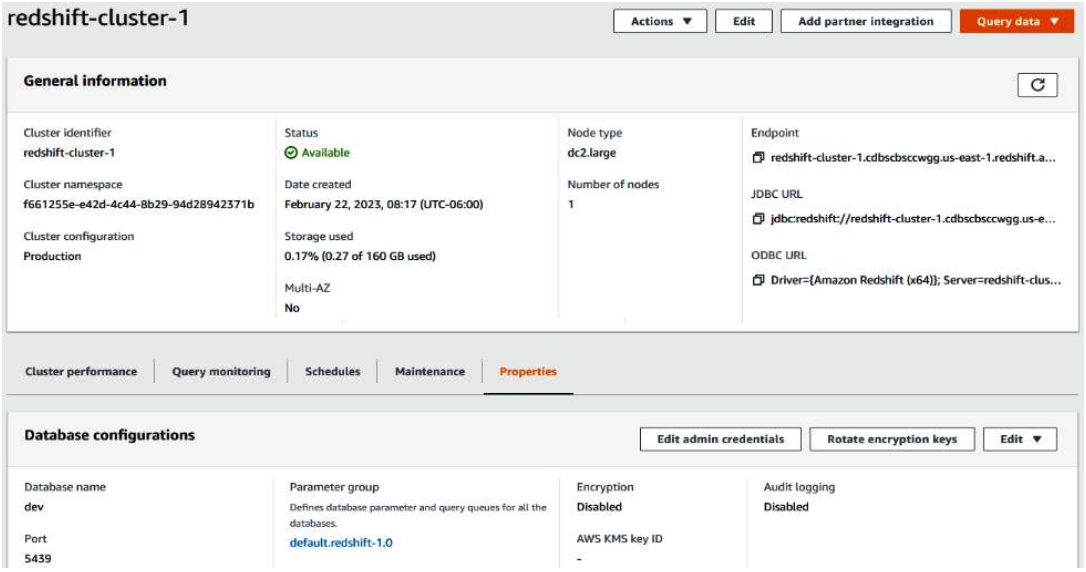


Figure 4.13 – Redshift cluster

4. **Access the Redshift database from DBeaver**: Just like the `PUTTY` tool we used to access Linux EC2 instances in the cloud, **Dbeaver** is a tool to access cloud databases remotely.

   Open **DBeaver | Database | New Database Connection**. In the new pop-up window, choose **Redshift** as the database type, and fill in the endpoint copied from the AWS Redshift dashboard, the **Database** name, **Username**, and **Password**, as shown in *Figure 4.14*:

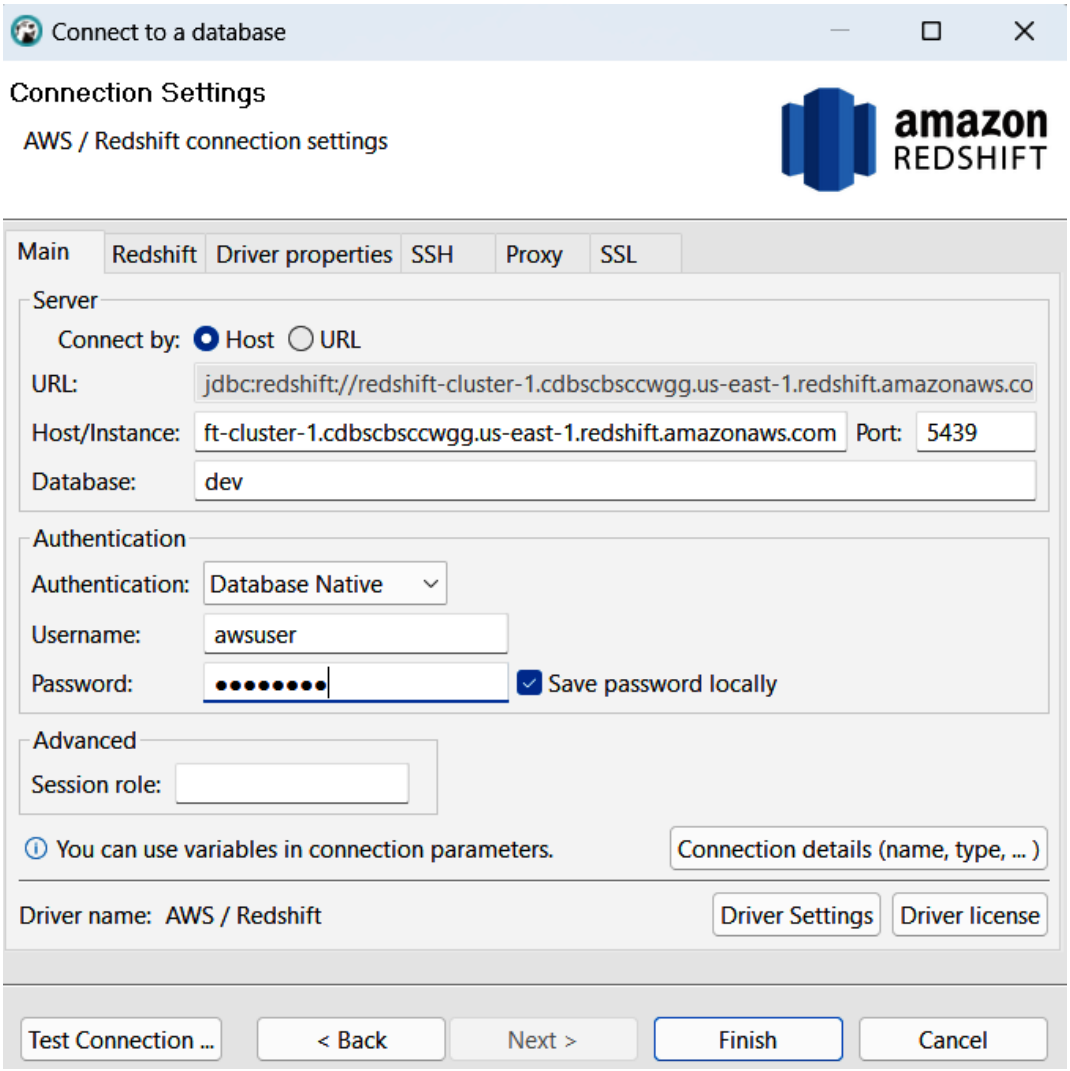


Figure 4.14 – Connect to Redshift cluster

Figure 4.15 shows the connection to the Redshift cluster. You can see the database schemas and use SQL Editor to compile and run queries again in the data warehouse:

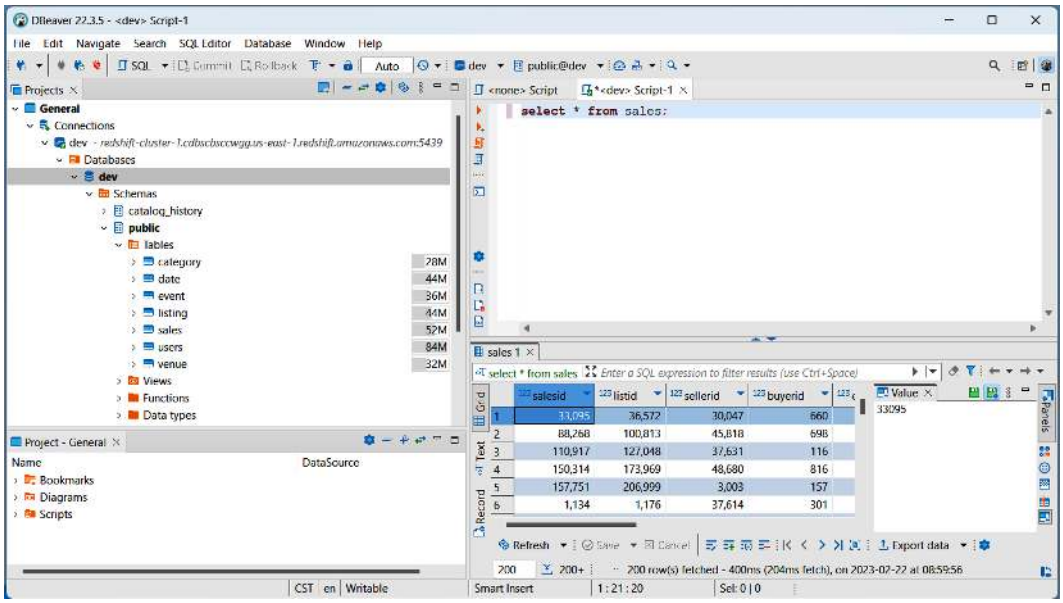


Figure 4.15 – Connection to Redshift cluster

Redshift provides a scalable, flexible, and high-performance data warehousing solution for a wide range of applications, from small data marts to large-scale enterprise data warehouses. More details are available at `https://docs.aws.amazon.com/redshift/`.

Summary

In this chapter, we discussed Amazon cloud databases including RDS, Aurora, DynamoDB, ElastiCache, and Redshift. We provisioned simple database instances and showed how to connect them and use the services. With all the different data schemas, business use cases, and application requirements such as size, scale, performance, and cost, selecting the right database is a critical step. More details are included at `https://aws.amazon.com/startups/start-building/how-to-choose-a-database/`.

In the next chapter, we will further explore Amazon's big data services.

Practice questions

Questions 1-10 are based on *Figure 4.16*:

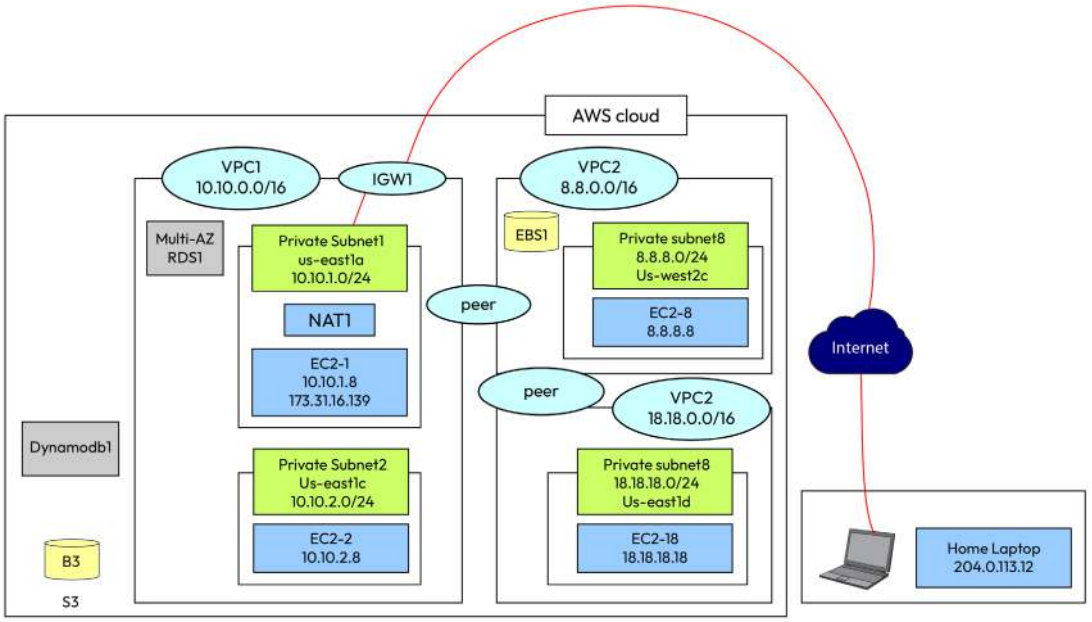


Figure 4.16 – Cloud architect diagram

1. RDS1 is created in VPC1. How would you configure it to be accessible from your home laptop?

   A. Configure SG for RDS1 and NACL for subnet1/subnet2.

   B. Configure SG for RDS1.

   C. Configure NACL for VPC1.

   D. Configure SG for VPC1.

2. Which of the following is not true?

   A. EC2-18 can access RDS1 via VPC peering.

   B. EC2-2 can access RDS1 within VPC1.

   C. EC2-8 can access RDS1 via VPC peering.

   D. EC2-1 can access RDS1 within VPC1.

3. An engineer is developing a web server W1 on EC2-18. W1 needs to access Dynamodb1. What is your recommendation?

   A. Create an EC2 role R1 for Dynamodb1 access, assign R1 to EC2-18, and create an endpoint for Dynamodb1 in VPC3.

   B. Create an EC2 role R1 for Dynamodb1 access, and assign R1 to EC2-18.

   C. Create an endpoint for Dynamodb1 in VPC3.

   D. Create an EC2 role R1 for Dynamodb1 access, assign R1 to EC2-18, create an endpoint for Dynamodb1 in VPC1, and create peering between VPC1 and VPC3.

4. RDS1 was created without encryption, but now encryption is required for compliance reasons. What is your recommendation?

   A. Back up RDS1 and enable encryption on the fly.

   B. Export RDS1. Create a new RDS2 with encryption and import from the RDS1 export.

   C. Snapshot RDS1. Create a new RDS2 and restore it from the RDS1 snapshot.

   D. Snapshot RDS1. Create an encrypted copy of the snapshot. Create a new RDS2 from the encrypted snapshot.

5. RDS1 is not configured with auto-scaling, and it ran out of storage space in the last hour. What is your recommendation?

   A. Add more space to RDS1 using the `ModifyDBInstance` option. Then, enable storage auto-scaling thereafter.

   B. Create a new RDS2 with more storage space. Import it from the latest backup.

   C. Enable storage auto-scaling for RDS1 immediately.

   D. Configure a new read replica of RDS1 with more storage space.

6. The master database for RDS1 is in `Subnet1`. Where shall the slave database be placed for RDS1?

   A. Subnet2

   B. Subnet8

   C. Subnet1

   D. VPC2

7. RDS1 has performance issues with table1, which is updated by many users. What's your recommendation?

   A. Use Elastic Cache.

   B. Use Read Replica for RDS1.

C. Create RDS2.

D. Separate table1 into multiple tables.

8. EC2-8 needs to access Dynamodb1 without trespassing the internet. What needs to be done?

A. Create a DynamoDB endpoint in VPC1 and access Dynamodb through VPC-peering.

B. Create a DynamoDB endpoint in VPC2 directly.

C. Create a DynamoDB endpoint in subnet2.

D. Create a DynamoDB endpoint in subnet8.

9. EC2-2 needs to add a new EBS volume. Where shall the new volume be created?

A. US-EAST1a

B. US-EAST1b

C. US-EAST1d

D. US-WEST1c

10. EC2-2 has a web application that needs to generate new reports from RDS1. Without impacting the database, what's your suggestion?

A. Create a read replica and allow the application to access the replica.

B. Upgrade RDS1 to Aurora.

C. Copy RDS1 to RDS2. Provide EC2-2 access to RDS2.

D. Load RDS1 to ElastiCache, and allow the application to access the cache.

Answers to the practice questions

1. A
2. A
3. A
4. D
5. A
6. A
7. A
8. A
9. D
10. A

Further reading

For further insights into what you've learned in this chapter, refer to the following links:

- `https://aws.amazon.com/products/databases/`
- `https://docs.aws.amazon.com/AmazonRDS/latest/UserGuide/Welcome.html`
- `https://docs.aws.amazon.com/amazondynamodb/latest/developerguide/Introduction.html`
- `https://docs.aws.amazon.com/AmazonRDS/latest/AuroraUserGuide/CHAP_GettingStartedAurora.html`
- `https://docs.aws.amazon.com/elasticache/`

5
Amazon Data Analytics Services

Amazon provides analytics tools and services for many forms of data. Continuing from the **Amazon Web Services** (**AWS**) database discussions in the previous chapter, we will focus on the AWS big data analytics services in this chapter.

What is big data? In a nutshell, **big data** refers to big and complex datasets that are difficult to process using traditional data analytics tools. Big data is typically characterized by its volume, velocity, and variety:

- **Volume**: Big data refers to datasets that are too large to be processed using traditional database management systems. The size of big data can range from terabytes to petabytes, and it is often generated in real time.
- **Velocity**: Big data is often generated at a high velocity, meaning that it is created and collected rapidly. This requires real-time or near-real-time processing and analysis to turn the data into meaningful insights.
- **Variety**: Big data comes in many different forms, including structured data, semi-structured data, and unstructured data. It can also include audio and video files, images, and sensor data.

Big data can be collected from a wide range of sources, including social media, online transactions, mobile devices, and sensors. It can provide valuable business insights and opportunities. However, it requires advanced tools and techniques to manage and process, including cloud-based storage, computing and other modern tools. AWS offers a range of data analytics services that can be used to manage big data. In this chapter, we will cover the following AWS big data analytics services:

- AWS Glue and data crawlers
- Amazon Athena
- The AWS Kinesis service family

- Amazon QuickSight
- Amazon **Elastic MapReduce** (**EMR**)

During our discussions in this chapter, we will use sample code to process big data. The examples shown in this chapter are also available in the GitHub repository for this book: `https://github.com/PacktPublishing/Self-Taught-Cloud-computing-Engineer`.

Let us start with the AWS big data pipeline and understand the data life cycle in the cloud, including the ingestion, storing, processing, and visualization steps.

Understanding the AWS big data pipeline

With the rise of big data and the increasing availability of data analytics tools and technologies, data analytics has become an essential component of modern business operations. Cloud-based technologies and services have been widely used to analyze and derive insights from big data, and provide the following benefits:

- **Scalability**: Cloud-based data analytics systems can scale up or down based on the input volume of data and traffic, allowing businesses to handle large-scale datasets without having to invest in expensive hardware and infrastructure
- **Cost-effectiveness**: Cloud-based data analytics systems are typically pay-as-you-go, allowing businesses to only pay for the resources they need and avoid extra investment in expensive hardware and infrastructure
- **Flexibility**: Cloud-based data analytics provides a flexible and agile environment for processing and analyzing data, allowing businesses to select the best from different techniques and algorithms
- **Accessibility**: Cloud-based data analytics can be accessed from anywhere with an internet connection, providing a globally accessible and collaborative environment for analyzing data
- **Security**: Cloud-based data analytics provides strong security features, such as encryption, access controls, and compliance with **General Data Protection Regulation** (**GDPR**) and other requirements

AWS provides a suite of data analytics services to manage big data life cycles:

- **Data ingestion**: In *Chapter 1*, we learned about Amazon Snowball and Snowmobile, which transfer large amounts of data from on-premises to the AWS cloud. In this chapter, we will discuss the following data ingestion services:
  - **AWS Glue**: A fully managed ETL service that can automate the process of discovering and cataloging metadata about data sources, generate ETL code to transform and load data, and schedule and run ETL jobs. As part of the AWS Glue service, an **AWS crawler** detects the schema and structure of data and enables users to automatically discover, categorize, and organize their data in various data stores.

  - **Amazon Kinesis**: A fully managed service that enables real-time streaming data ingestion at scale. With Kinesis, organizations can easily collect, process, and analyze data from various sources, such as website clickstreams, IoT devices, and social media feeds.

- **Data storage**: In previous chapters, we introduced Amazon cloud storage services such as EBS, EFS, S3, and Glacier. We also discussed Amazon database services such as RDS, DynamoDB, ElastiCache, and Redshift.
- **Data processing**: We will cover the following AWS data processing services:
  - **Amazon EMR**: A managed Hadoop framework that allows you to process large amounts of data using distributed computing. It can also be used to run other distributed data processing frameworks, such as Apache Spark and Apache Hive.
  - **Amazon Athena**: A flexible, serverless, interactive service to analyze structured, semi-structured, or structured data stored in Amazon S3, using SQL or Python.
- **Data visualizing**: We will focus on **Amazon QuickSight**, a **business intelligence** (**BI**) service that allows users to create interactive visualizations, dashboards, and reports using a web-based interface. QuickSight supports a wide range of data sources, including AWS data services such as Amazon S3, Amazon Redshift, Amazon Athena, and Amazon RDS.

From data ingestion, storing, and processing to visualization, these Amazon cloud tools provide efficient big data management services. Let's start by looking at an Amazon data ingestion service – Amazon Glue and data crawlers.

AWS Glue

As we explained earlier, AWS Glue is an ETL process used to extract data from various sources, transform it into a consistent format and structure, and then load it into a target data repository, such as an S3 bucket or a data warehouse. In an ETL process such as the one used in AWS Glue, the data is typically transformed before it is loaded into the target database. AWS Glue has the following features:

- Automatically generate schemas from semi-structured data by using crawlers, which run on your data sources, derive a schema from them, and populate the Data Catalog. Crawlers can run on many data stores, including Amazon S3, Amazon Redshift, most relational databases, and DynamoDB. By using the metadata in the Data Catalog, you can also automatically generate scripts with AWS Glue extensions as the starting point of your AWS Glue jobs.
- Catalog data and get a unified view with the AWS Glue Data Catalog, which stores metadata including schema information about data sources and targets of your ETL jobs. When ingesting multiple data sources, the Data Catalog provides a centralized location to store and manage metadata about the various data assets across different AWS services.

- Use AWS Glue Studio to author ETL jobs that bring data in from different sources and load it into a target. AWS Glue Studio provides an easy-to-use graphical interface to author ETL jobs. With AWS Glue Studio, you can pull data from Amazon S3 or other sources, configure a transformation that joins or transforms source data, specify a target location for the transformed data, view the schema or a sample of the dataset, and run, monitor, and manage the ETL jobs.
- Perform serverless ETL processing in the AWS Glue Spark runtime engine, which is a serverless compute engine for running ETL jobs. Designed to be highly scalable to process large volumes of data quickly and efficiently, the AWS Glue runtime engine supports both Apache Spark-based jobs, which are heavy-duty and so for large datasets, and Python shell-based jobs, which are lightweight and so for smaller datasets or simple transformations.
- Orchestrate complex ETL tasks with interdependencies by using workflows.

After AWS Glue detects the data from the sources and generates metadata in the target, we can use AWS Athena to query and analyze. Let's look at the Athena service.

Amazon Athena

Amazon Athena is a serverless, interactive, query-managed service that allows users to analyze data stored in Amazon S3 by using standard SQL queries. With Athena, users can easily query data in S3 without the need to set up or manage any infrastructure. Athena is designed to work with a wide variety of data formats, including CSV, JSON, ORC, Parquet, and Avro. It also supports complex data types, such as arrays and maps, making it easy to query nested data structures. Athena has the following features:

- **Serverless architecture**: Athena is a serverless service, which means users don't need to form or manage any infrastructure. AWS takes care of all the underlying infrastructure management, including scaling, monitoring, and maintenance.
- **Standard SQL support**: Athena supports standard SQL, which makes it easy for users to get started and query data using their existing SQL skills.
- **Integration with AWS S3**: Athena integrates seamlessly with Amazon S3, making it easy to analyze data stored in S3 without the need to move the data.
- **Compatibility with popular BI tools**: Athena is compatible with a variety of popular BI tools, including Tableau, Amazon QuickSight, and Microsoft Power BI.
- **Cost-effective**: The service is cost-effective since users only pay for the queries they run.

Now, let's get our hands dirty and provision an AWS Glue service to ingest data from a CSV spreadsheet, and then use the Amazon Athena service to analyze the data with SQL queries:

1. Use S3 to set up **the source and target for the Glue service**, as in the following screenshot:

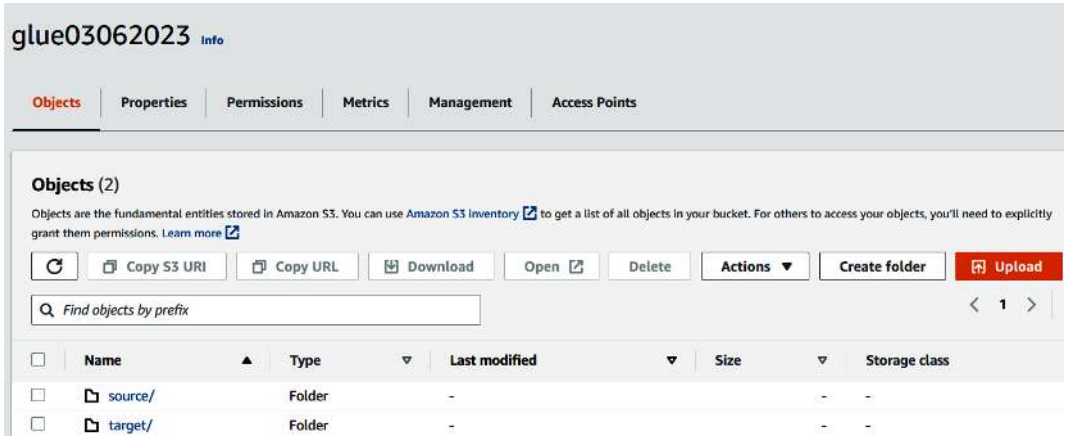


Figure 5.1 – Glue data ingestion source and target store

As shown in *Figure 5.1*, we have created an S3 bucket named **Glue03062023** and two folders underneath – **source**, which has the source data file uploaded from a client, and **target**, which will be the output destination of the AWS Glue crawler job.

2. Use IAM to create a **role for Glue:**

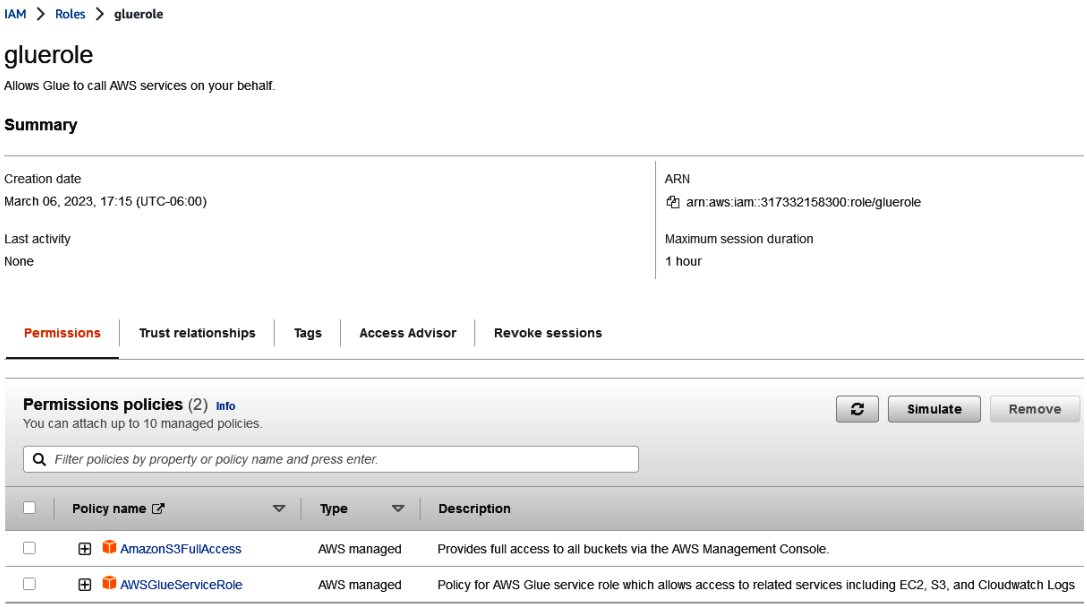


Figure 5.2 – IAM gluerole role in AWS Glue

As shown in *Figure 5.2*, we have created an AWS service role named **gluerole**, which is assigned the **AmazonS3FullAccess** and **AWSGlueServiceRole** permissions.

3. **Create a Glue database:**

   Log in to the AWS Management Console, then in the search box next to **Services**, search for and choose **AWS Glue** to open the AWS Glue console.

   In the navigation pane, under **Databases**, add a database named `salesdb`, as shown in *Figure 5.3*:

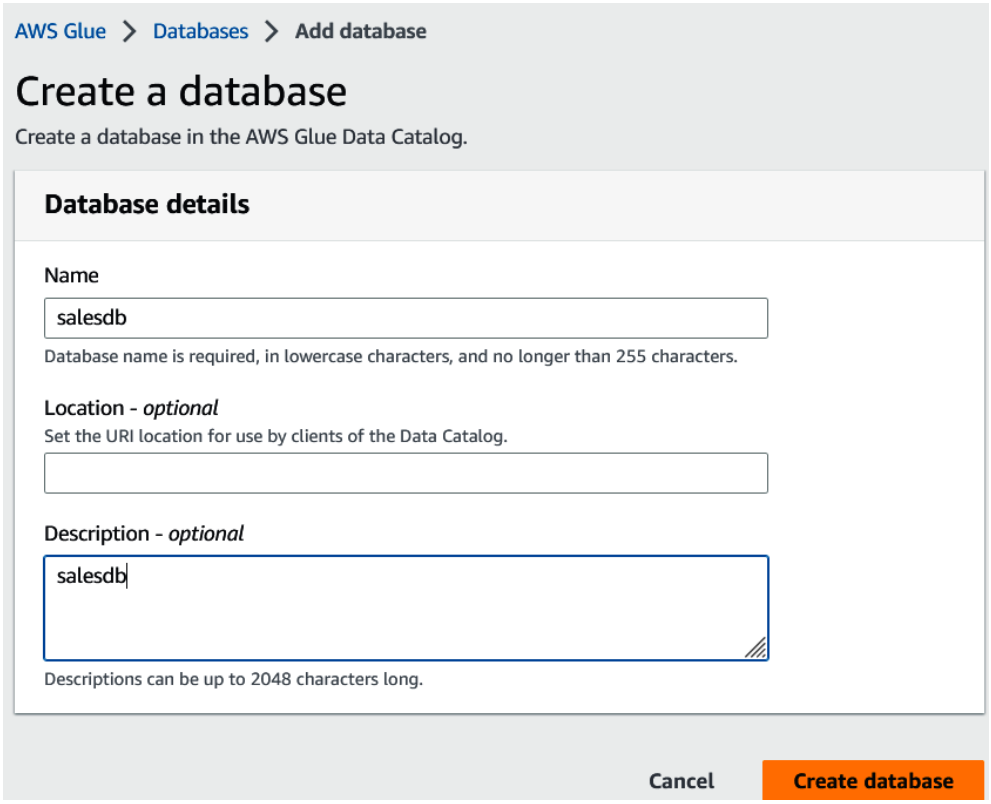


Figure 5.3 – Create an AWS Glue database called salesdb

4. **Configure and create the AWS Glue crawler:**

Under the created database, select **Tables**. Then, click **Add tables using crawler**.

For **Name**, enter `sales`. Click **Next** at the bottom of the page. Select **Add a data source** and configure the following, as shown in *Figure 5.4*:

- **Data sources**: Choose **S3**
- **Location of S3 data**: Choose **in the same account**, and enter the source S3 bucket: `s3://glue03062023/source/`
- **Existing IAM role**: Choose **gluerole**, which we created earlier

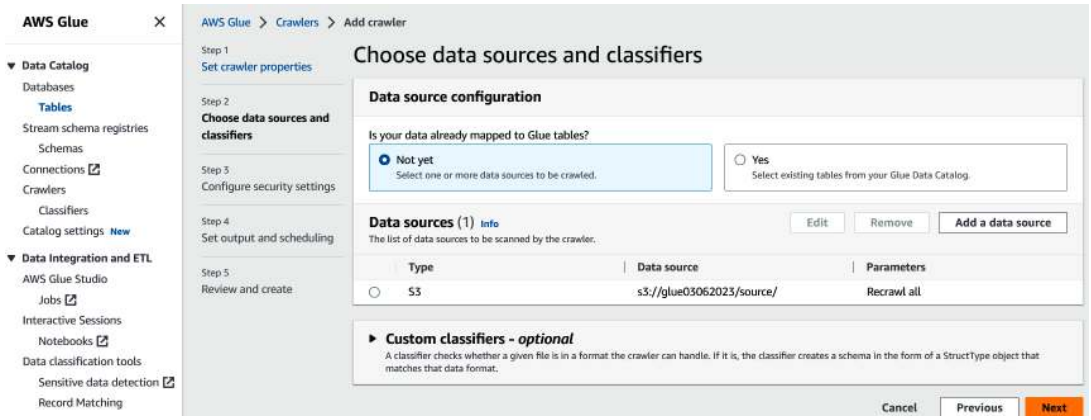


Figure 5.4 – Choose data sources for the Glue crawler

Click **Next**. In the **Output configuration** section, select **Add database**. For **Name**, enter `salesdb`. In the **Crawler schedule** section, for **Frequency**, keep the default **On demand**, as shown in *Figure 5.5*:

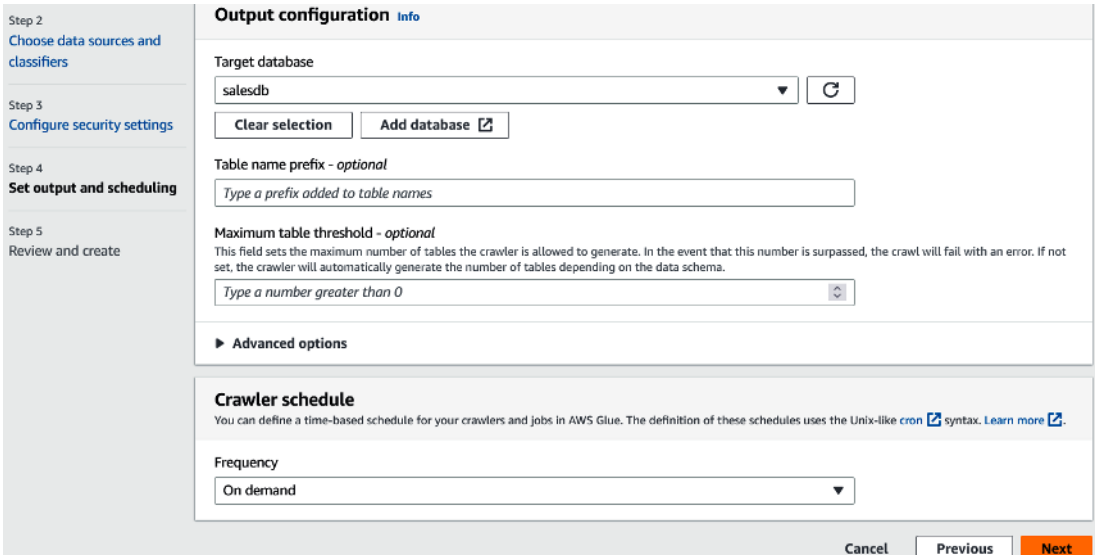


Figure 5.5 – Crawler output configuration

Click **Next** to go to the **Review and create crawler** page, as shown in *Figure 5.6*. Click **Create crawler**:

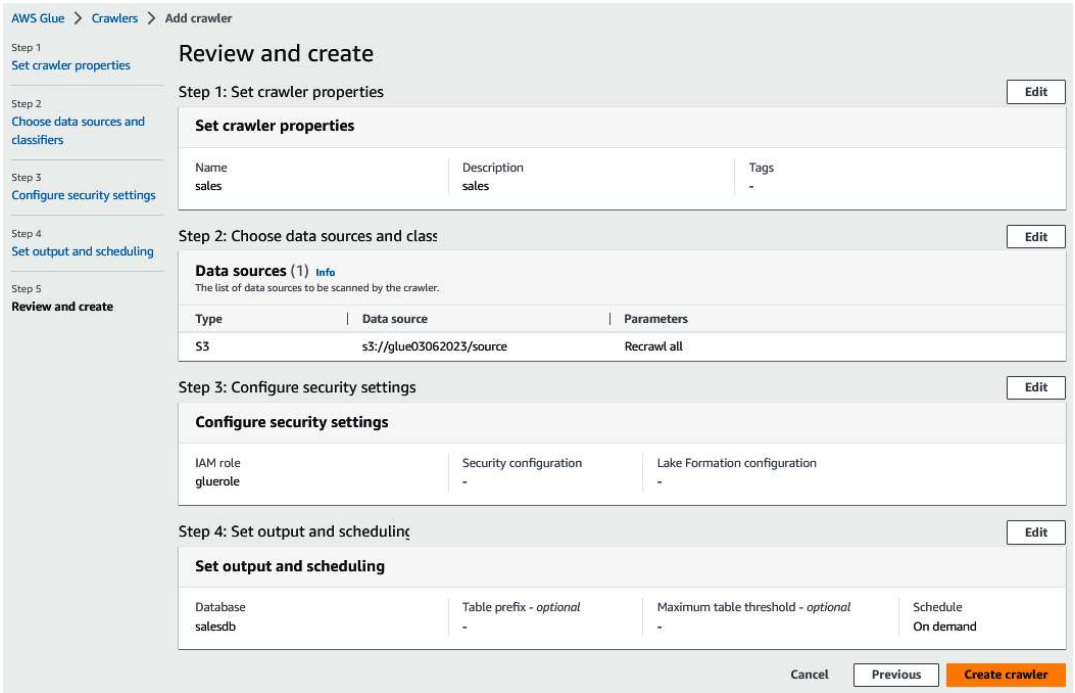


Figure 5.6 – Review and create crawler

5. **Run the crawler:**

After the crawler is created, select it and click **Run**.

The crawler state changes to **Running**, then to **Completed**, as shown in *Figure 5.7*:

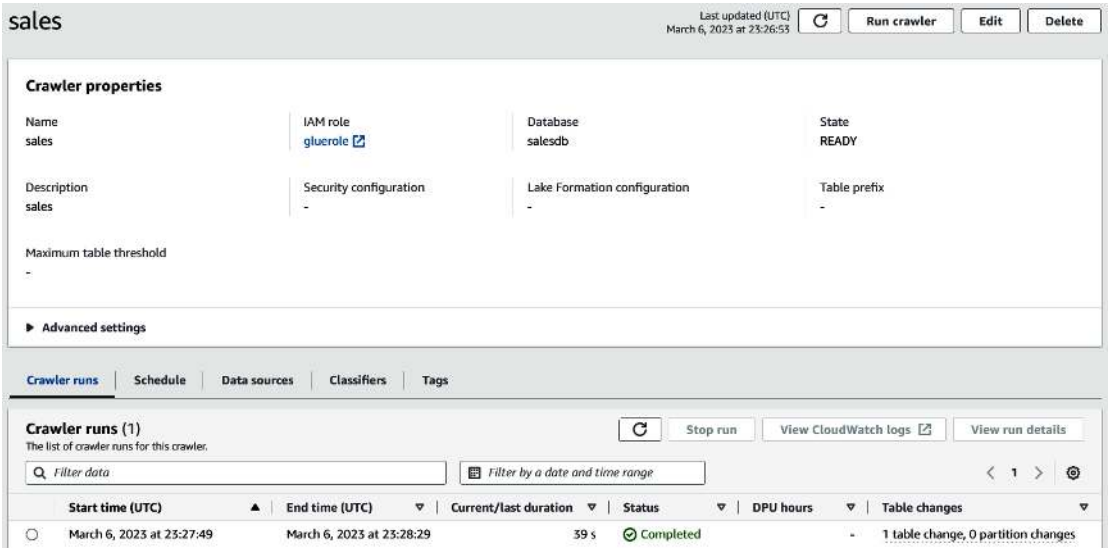


Figure 5.7 – Crawler job was run and completed

6. **Review the metadata that AWS Glue created:**

   In the navigation pane, select **Databases**. Choose the link for the **salesdb** database. In the **Tables** section, click the **sales** link.

   Review the metadata that the crawler has captured, as shown in *Figure 5.8*. The schema lists the columns that the crawler discovered from the source dataset.

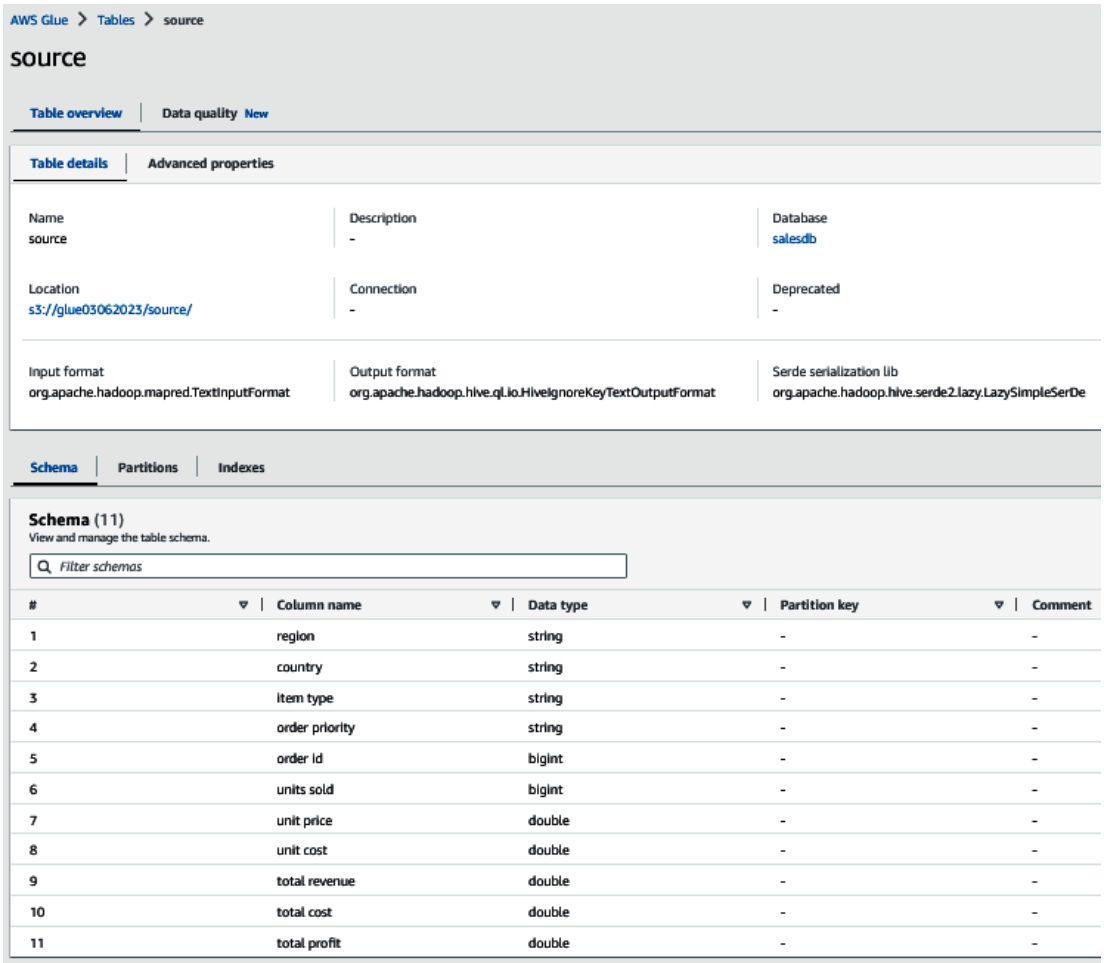
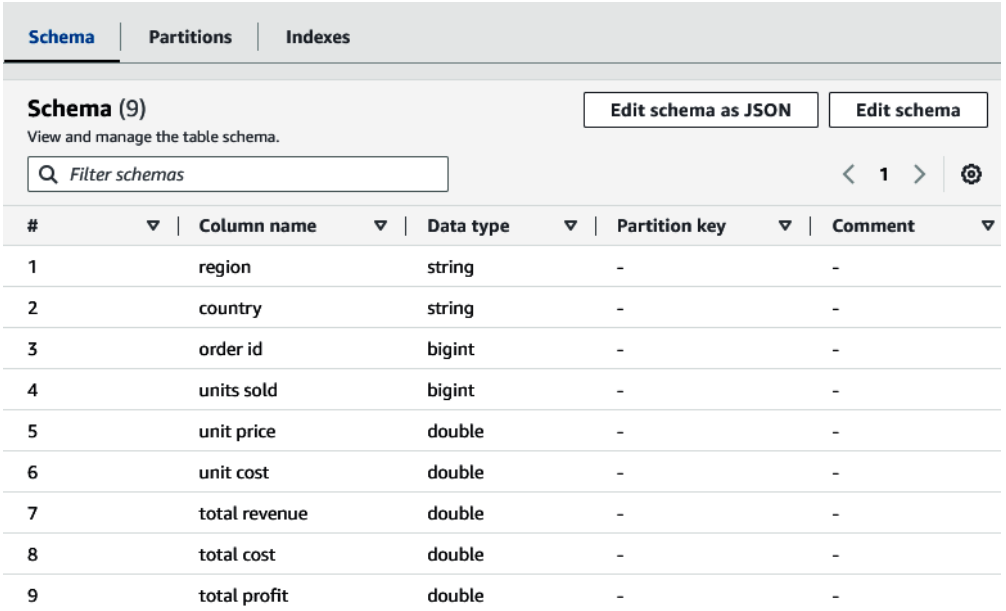


Figure 5.8 – Metadata crawler created

7. **Edit the data schema:**

From the **Actions** menu in the upper-right corner of the page, choose **Edit schema**. Change the schema as needed and click **Update schema**. *Figure 5.9* shows the updated schema:



#	Column name	Data type	Partition key	Comment
1	region	string	-	-
2	country	string	-	-
3	order id	bigint	-	-
4	units sold	bigint	-	-
5	unit price	double	-	-
6	unit cost	double	-	-
7	total revenue	double	-	-
8	total cost	double	-	-
9	total profit	double	-	-

Figure 5.9 – Updated schema

8. **Configure an S3 bucket to store Athena query results**:

In the Glue navigation pane, under **Databases**, choose **Tables**. Choose the link for the sales table.

Select **Actions** | **View data**. When the popup appears to warn you that you will be taken to the Athena console, click **Proceed**.

The Athena console opens. Before you run a query in Athena, you need to specify an S3 bucket to hold the query results.

Click on the **Settings** tab. Choose **Manage**.

To the right of **Location of query result**, click on **Browse S3**. Choose the bucket name **s3://glue03062023/target**. Select **Choose**. Fill in the **Expected bucket owner** section and then click **Save**, as shown in *Figure 5.10*:

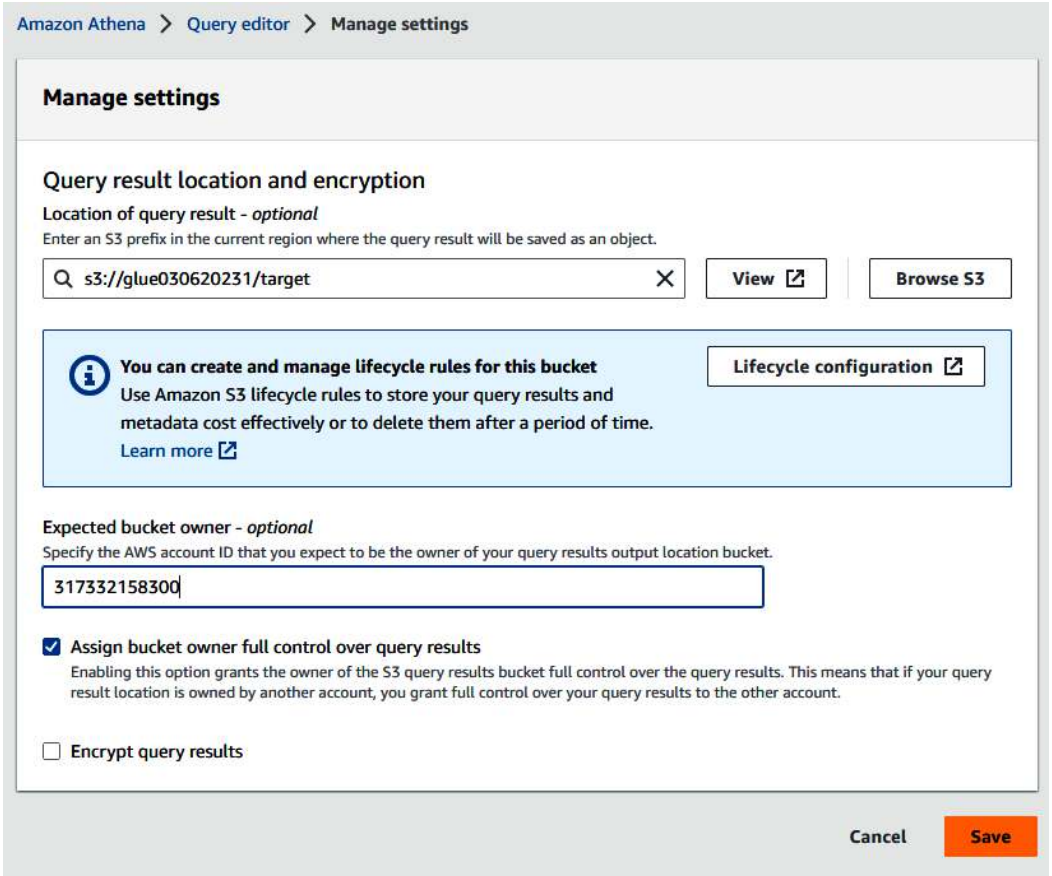


Figure 5.10 – Athena query result settings

9. **Preview a table in Athena**:

Return to the Athena query editor.

Click on the **Editor** tab. In the **Data** panel on the left, notice that the data source is **AwsDataCatalog**. For **Database**, choose **salesdb**.

In the **Tables** section, click the ellipsis (three-dot) icon for the **sales** table, and then select **Preview Table**. The first 10 records from the **sales** table will display.

10. **Create a table for the Europe region**:

In the Athena query editor, copy and paste the following query into a `query` tab:

```
CREATE table salesdb.region
WITH (
```

```
  format='PARQUET', external_location='s3://glue030620231/
target/'
) AS SELECT * FROM source
where region = 'Europe';
```

Click **Run**. The query and result are shown in *Figure 5.11*:

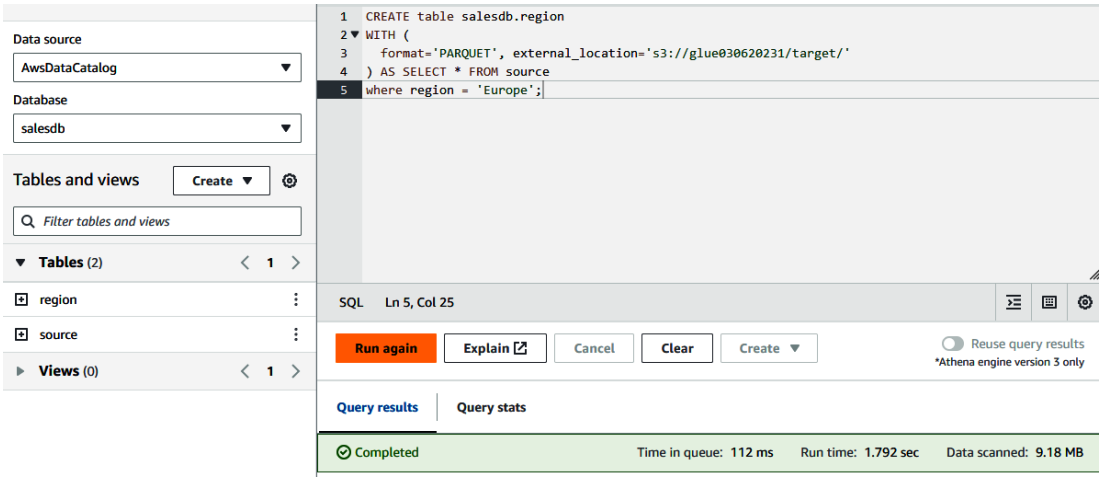


Figure 5.11 – Athena query and result

To preview the results, in the **Tables** section, to the right of the **region** table, click the ellipsis icon, and then select **Preview Table**.

Now that you have isolated the data that you are interested in, you can write queries for further analysis.

Through the preceding process, you learned how to use Athena to query tables in a database that an AWS Glue crawler created. You built a table called `salesdb.region` from the original dataset and store output to the target S3 bucket.

As we can see, AWS Glue created a crawler to ingest the original dataset from the S3 target folder into a database and infer the appropriate schema, which can be edited. Then, using Athena, we can develop queries and better understand the data. This integration reduces the time that it takes to derive insights from the raw data and apply these insights to make better decisions. With AWS Glue, we can batch-ingest data from various data sources.

In the next section, we will switch gears and discuss streaming data ingestion with Amazon Kinesis.

The Amazon Kinesis family

The **Amazon Kinesis** family is a set of fully managed services provided by AWS for streaming data processing and analysis. The family consists of the following main services:

- **Amazon Kinesis Data Streams**: This is a service for collecting and processing large amounts of data in real time from various sources, such as websites, mobile apps, IoT devices, and social media. Data is stored in shards and processed with custom applications. You can use Kinesis Data Streams to process data with Amazon Lambda and other custom applications. Kinesis Data Streams also offers the ability to store data in Amazon S3, enabling you to perform additional analysis on data stored in Amazon S3.
- **Amazon Kinesis Data Firehose**: This is a fully managed service that enables you to capture, transform, and load streaming data into various destinations. Firehose provides a simple and scalable way to capture and transform streaming data from various sources, such as IoT devices, clickstreams, social media feeds, and server logs. Kinesis Data Firehose supports a variety of destination options, including Amazon S3 for cost-effective and durable storage of raw data, Amazon Redshift for data warehousing and analytics, and Amazon Elasticsearch for full-text search and analysis. Kinesis Data Firehose also supports third-party destinations such as Splunk, Datadog, and New Relic.
- **Amazon Kinesis Data Analytics**: This is a fully managed service provided by AWS that enables you to perform real-time data analysis on streaming data using SQL queries. Kinesis Data Analytics provides a simple and scalable way to perform real-time data analysis on streaming data from various sources, such as Amazon Kinesis Data Streams, Amazon Kinesis Data Firehose, and Amazon S3. You can use Kinesis Data Analytics to query data from these sources, apply real-time transformations, and then output the results to a variety of destinations, such as Amazon S3, Amazon Kinesis Data Streams, and Amazon Elasticsearch.

The AWS Kinesis family provides powerful big data processing capacities, such as real-time analytics, machine learning, and security monitoring. *Figure 5.12* shows two paths for data streaming ingestion. In the top path, streaming data from various sources is ingested into **Kinesis Data Streams**, passed to **Kinesis Data Firehose**, and stored in **Amazon S3** for future use. In the second path, after data is ingested into **Kinesis Data Streams**, it is fed to **Kinesis Data Analytics** for real-time analytics:

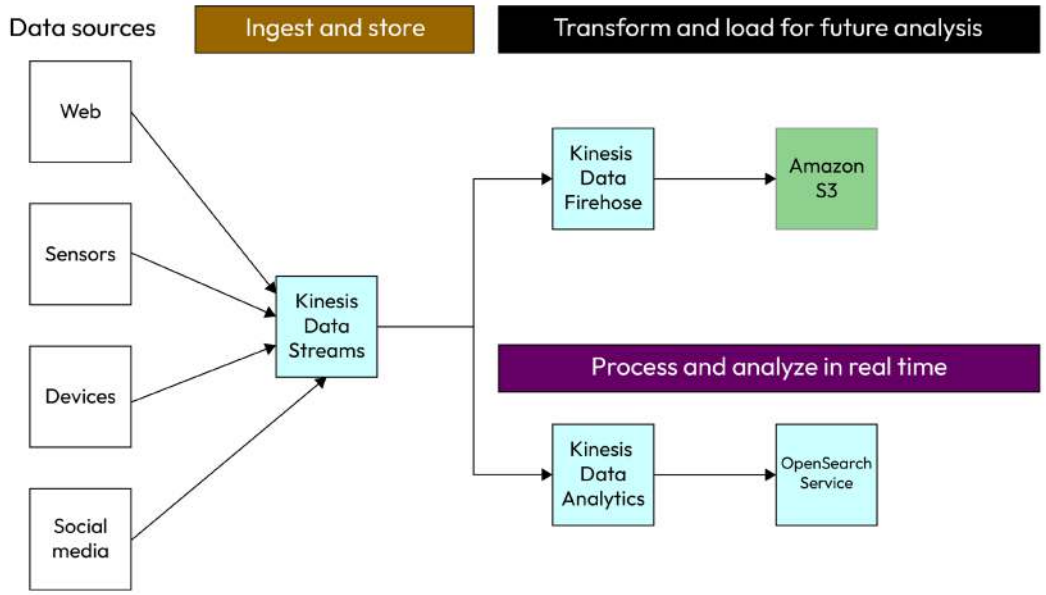


Figure 5.12 – Amazon Kinesis family

As shown in *Figure 5.13*, Kinesis Data Firehose can ingest streaming data and store it in an Amazon cloud storage service such as S3, Redshift, or OpenSearch:

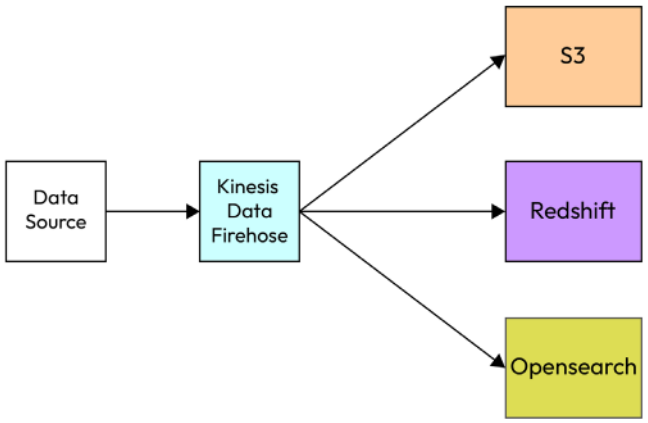


Figure 5.13 – Amazon Kinesis DataFirehose

After introducing the concepts, now let us show how to set Kinesis Firehose up to ingest data and store outputs to Amazon S3 buckets:

1. **Create a target for Kinesis Firehose:**

   Create a target S3 bucket for Firehose to store raw data, as shown in *Figure 5.14*:

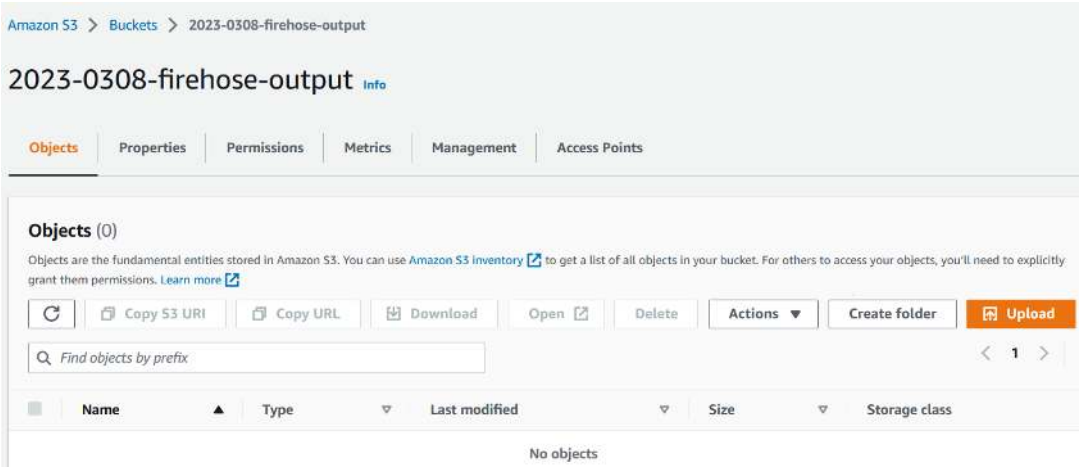


Figure 5.14 – Create a target S3 bucket

2. **Create a Kinesis delivery stream:**

Log in to the AWS console and navigate to **Kinesis**. Click **Create delivery stream**, then fill in the details as shown in *Figure 5.15*.

> **Note**
>
> We have used **Direct PUT** as the source – it means Kinesis Data Firehose will ingest data directly into the source. Also, note that we have used 2 MiB or 120 seconds as the buffer size, whichever comes first, and we have used all the default settings.

Click **Create delivery stream**:

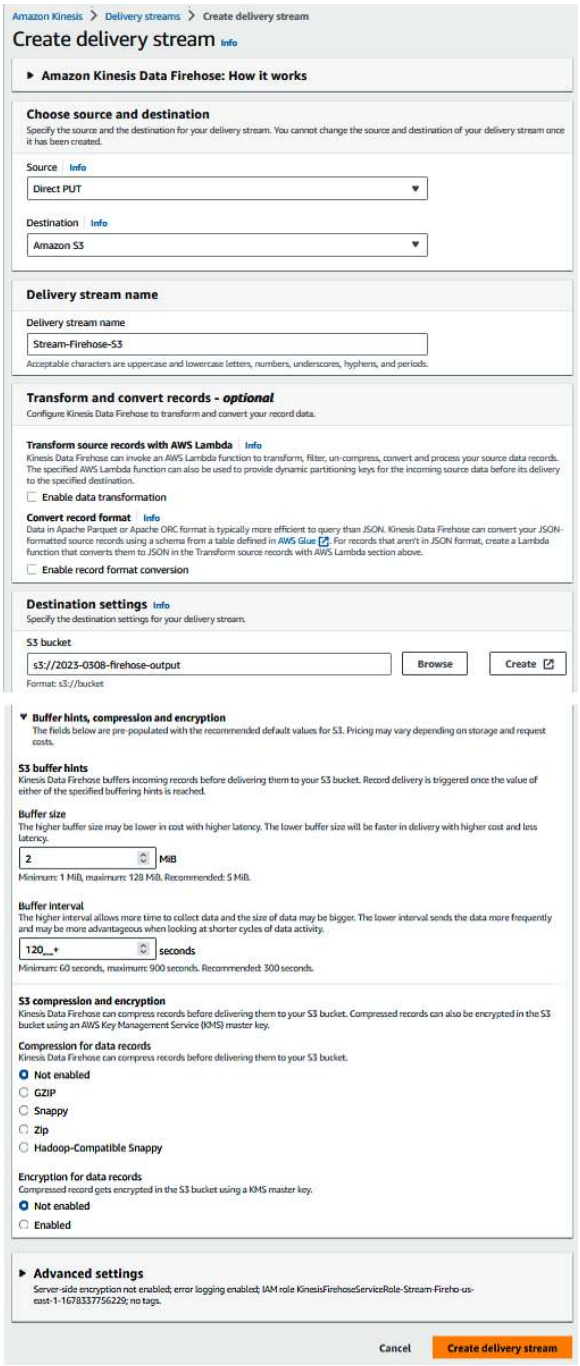


Figure 5.15 – Firehose delivery stream details

3. **Test with demo data:**

When the delivery stream shows as **Active**, click its name, **Stream-Firehose-S3**, and then click **Test with demo data**, as shown in *Figure 5.16*. This test runs a script and puts demo data in your Kinesis Data Firehose delivery stream. Click **Start sending demo data** and wait for several minutes, then click **Stop sending demo data**:

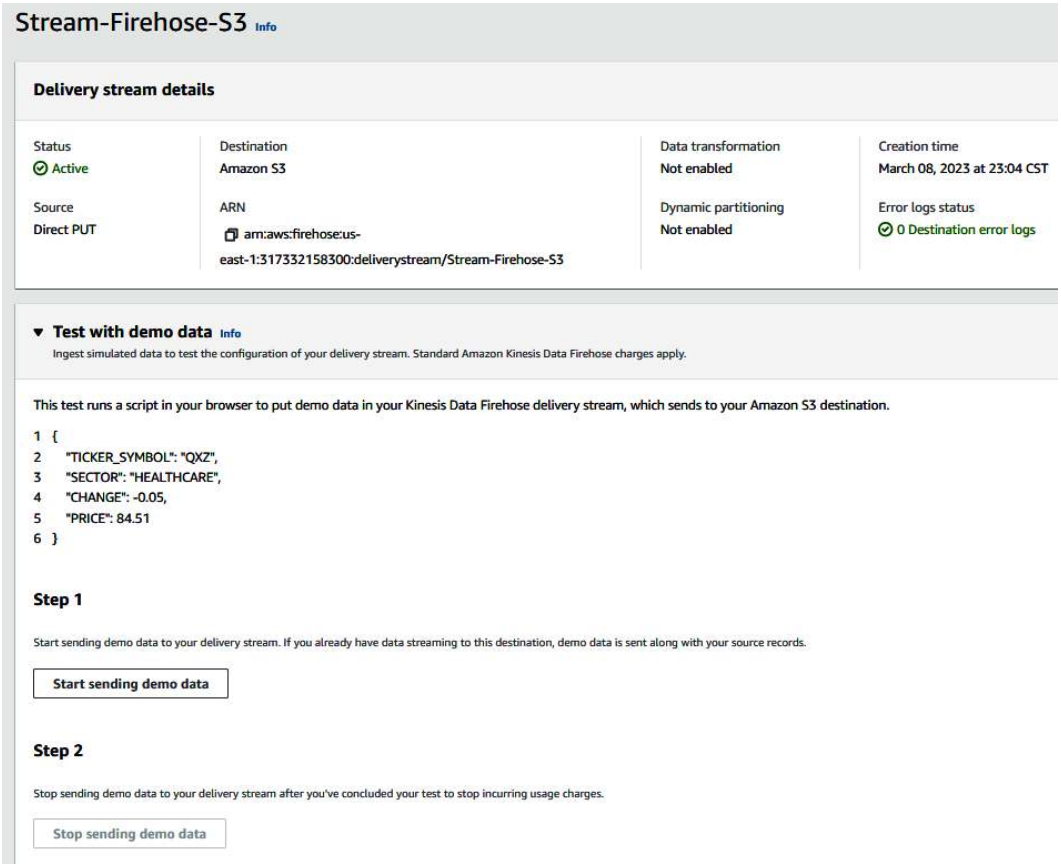


Figure 5.16 – Test with demo data

4. **Examine the target output:**

Now, check the S3 target folder. You will see output files are generated in the target S3 bucket folder. As shown in *Figure 5.17*, there are four files generated in the target:

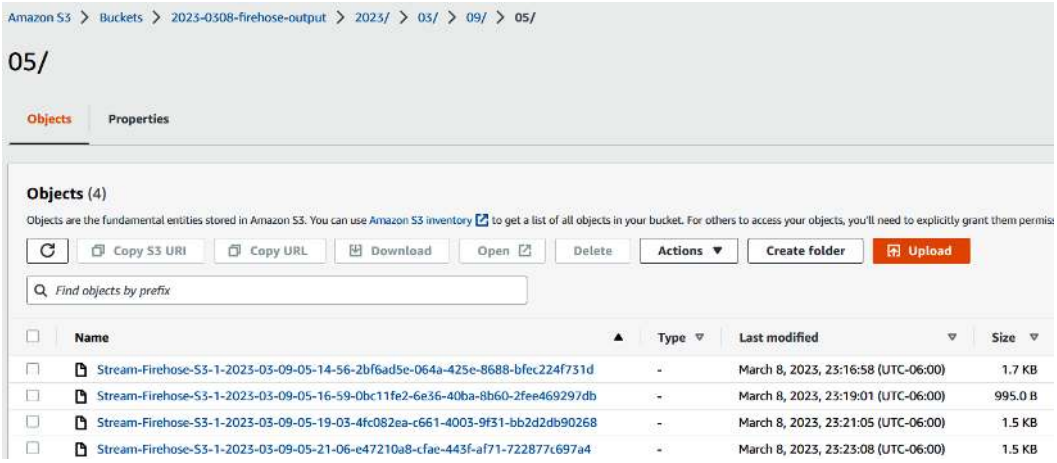


Figure 5.17 – Target output files

With the preceding steps, we have used Kinesis Firehose to directly ingest the demo data and output it into the target S3 folder. In the next section, we will introduce Amazon QuickSight and use it to visualize these output files.

Amazon QuickSight

Amazon QuickSight is a cloud-based BI and data visualization service. It enables users to easily create interactive dashboards, perform ad hoc data analysis, and share insights with others in their organization. Some of the key features of Amazon QuickSight include the following:

- **Data connectivity**: Amazon QuickSight can connect to a wide range of data sources, including AWS services such as Amazon S3, Amazon Redshift, and Amazon RDS, as well as other popular data sources, such as Salesforce, MySQL, and Microsoft Excel.
- **Data preparation**: Amazon QuickSight provides a simple, intuitive interface for preparing data for analysis, including features such as data cleaning, filtering, and aggregation.
- **Data visualization**: Amazon QuickSight offers a variety of visualization options, including charts, tables, and maps, allowing users to easily create interactive dashboards and reports.
- **Team collaboration**: Amazon QuickSight allows users to share dashboards and reports with others in their organization and provides access controls to ensure that data is shared only with authorized users.
- **Integration with other AWS services**: As a virtualization tool, QuickSight integrates seamlessly with the other Amazon data analytics services.
- **Leveraging Super-fast, Parallel, In-memory Calculation Engine (SPICE)**: This is an in-memory data caching service for faster querying and visualization of data.

Amazon QuickSight can be used in Business Intelligence to create dashboards and reports for BI purposes, allowing users to easily analyze and visualize data and gain insights into business performance. It can be used in sales and marketing to analyze sales and marketing data, such as customer demographics, purchase history, and campaign performance, allowing users to optimize their sales and marketing strategies. It can be used in finance and accounting to analyze financial data, such as revenue, expenses, and cash flow, allowing users to monitor financial performance and identify areas for improvement.

Amazon QuickSight is a powerful tool for data visualization and analysis and provides a wide range of features for data connectivity, preparation, and visualization. It is a great platform for businesses to gain insights from their data and make data-driven decisions.

Now we will show how to use QuickSight to visualize the data we generated from Amazon Kinesis Firehose in the previous section:

1. **Sign up for a QuickSight account**

Log in to the AWS console, then navigate to **QuickSight**. Sign up for a QuickSight account if you haven't done so already.

Generate the QuickSight manifest file.

We will use the data file generated by Kinesis Firehose earlier. We need to find the data file URL and create a manifest file named `manifest1`, as shown in *Figure 5.18*:

```
{
    "fileLocations": [
        {
            "URIs": [
                "s3://2023-0308-firehose-output/2023/03/09/05/Stream-Firehose-S3-1-2023-03-09-05-14-56-2bf6ad5e-064a-425e-8688-bfec224f731d"
            ]
        },
    ],
    "globalUploadSettings": {
        "format": "JSON",
        "delimiter": ",",
        "textqualifier": "'",
        "containsHeader": "true"
    }
}
```

Figure 5.18 – QuickSight manifest file

2. **Define the dataset:**

Log in to your QuickSight account, click **New dataset**, and then choose **s3**. Fill in the details in the pop-up window shown in *Figure 5.19*:

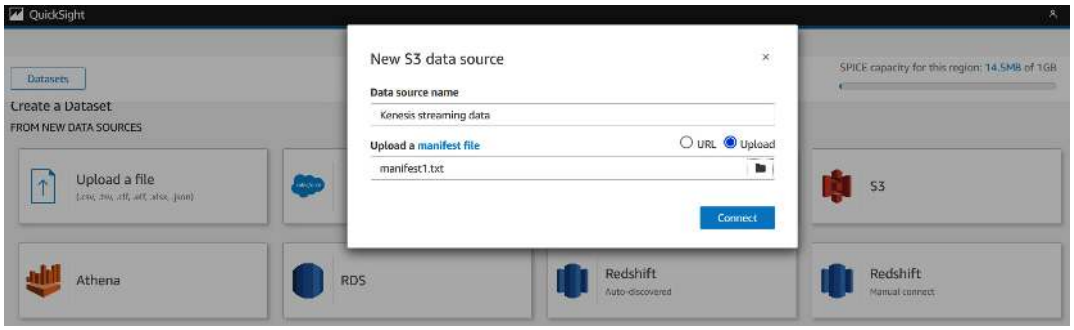


Figure 5.19 – Generate dataset

3. **Connect to the dataset:**

Click **Connect**. The new dataset is created, as shown in *Figure 5.20*. Click **Visualize**:

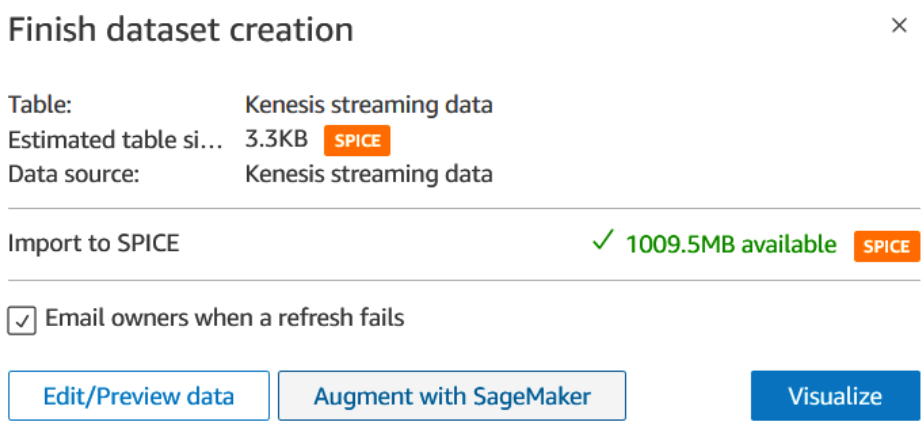


Figure 5.20 – Visualize dataset

4. **Create data visualization:**

There are four fields shown for the dataset. Choose **Bar chart** as the visual type, **Ticker symbol** as the *x* axis, and **Price(sum)** as the *y* axis. A graph will be generated, as shown in *Figure 5.21*:

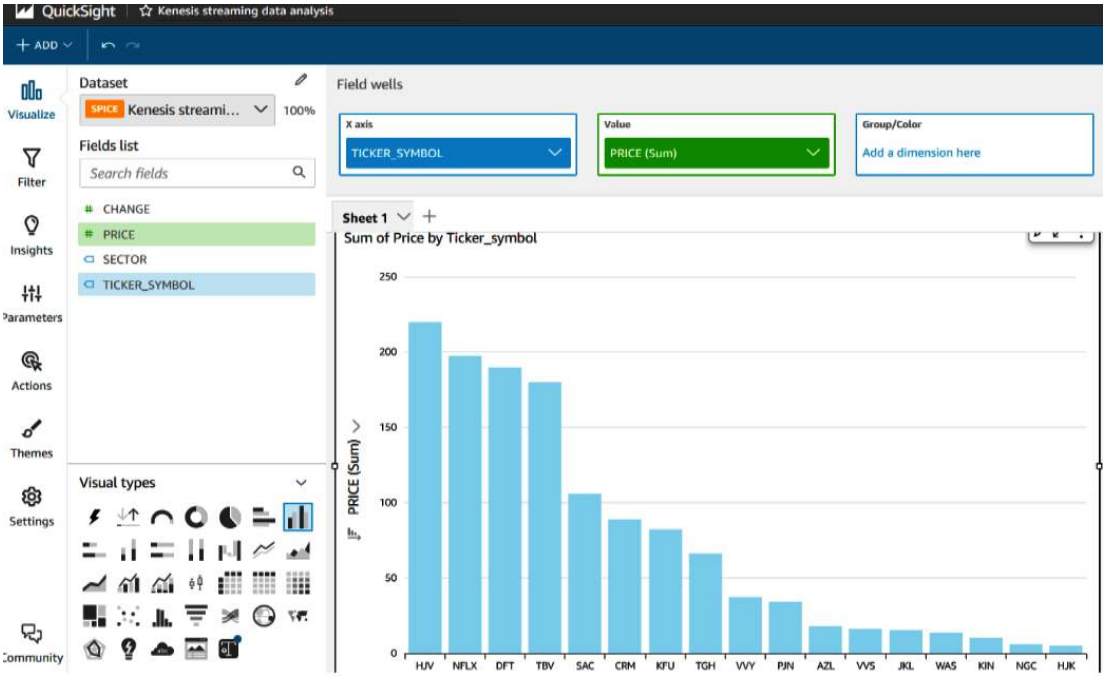


Figure 5.21 – Visualization

This concludes our hands-on exercises on data ingestion using Amazon Kinesis Firehose, storing data in S3, and visualizing data using QuickSight. In the next section, we will examine Amazon EMR, which is a powerful data processing platform.

Amazon EMR

Amazon EMR is a platform for leveraging many big data tools for data processing. We will start by looking at the concepts of MapReduce and Hadoop.

MapReduce and Hadoop

MapReduce and **Hadoop** are two related concepts in the field of distributed computing and big data processing.

The idea of MapReduce is "divide and conquer": decompose a big dataset into smaller ones to be processed in parallel on distributed computers. It was originally developed by Google for its search engine to handle the massive amounts of data generated by web crawling. The MapReduce programming model involves two functions: a map function that divides and processes in parallel the datasets and a map function that aggregates the map outputs.

Hadoop is an open source software framework that implements the MapReduce model. Hadoop consists of two core components: **Hadoop Distributed File System** (**HDFS**) and MapReduce. HDFS is a distributed filesystem that can rapidly transfer data between Hadoop cluster nodes. MapReduce can process big data on distributed nodes and scale massively.

In summary, MapReduce is a programming model that enables parallel processing of large datasets, while Hadoop is a software framework that implements MapReduce and provides a distributed filesystem for storing and managing large datasets.

AWS EMR

AWS EMR is a fully managed cloud service that allows you to easily process large amounts of data using open source tools such as Apache Hadoop, Spark, Hive, Presto, and Flink. With EMR, you can quickly and easily create and configure a Hadoop cluster on AWS infrastructure, allowing you to perform big data processing tasks without the need for upfront hardware investment or management. EMR also provides several useful features, including the following:

- **Pre-installed applications**: EMR comes pre-installed with many popular big data processing tools, allowing you to get started quickly
- **Autoscaling**: EMR automatically scales the cluster based on the workload, allowing you to efficiently use resources and reduce costs
- **Integration with AWS services**: EMR integrates with other AWS services, such as S3, EC2, and CloudWatch, making it easy to move data into and out of the cluster and monitor its performance
- **Security**: EMR provides several security features, including encryption at rest and in transit, secure network configuration, and integration with AWS IAM
- **Storage**: EMR provides different types of storage options, including HDFS and **EMR File System** (**EMRFS**, which extends HDFS to S3)

EMR is a powerful and flexible tool that allows you to easily process large amounts of data using open source tools on AWS infrastructure. The components of an EMR cluster can be classified into four categories: core components, optional components, data sources, and external interfaces.

EMR core components are the main components of an EMR cluster. They include the following:

- **Master nodes**, which act as the entry point to the cluster and manage HDFS, job scheduling, and coordination with other cluster nodes.
- **Core nodes**, which provide compute and storage resources for processing big data jobs. They store data in HDFS, which is the distributed filesystem of the cluster.
- **Task nodes**, which provide additional compute resources to run parallelized tasks in the cluster. Task nodes do not store data in HDFS and are used to offload processing from the core nodes. For cost saving, spot instances can be used for task nodes.

EMR optional components can be added to the cluster based on the use case. Example optional components are the following:

- **Apache HBase**: A distributed, scalable, and NoSQL database system on top of Hadoop
- **Hive**: A data warehousing and SQL-like query engine for Hadoop
- **Pig**: A high-level language for querying large datasets
- **Hue**: A web-based user interface for interacting with Hadoop services
- **Presto**: A distributed SQL query engine designed for interactive analytics
- **Flink**: A real-time streaming data processing framework
- **Spark**: An in-memory big data processing framework

Let's examine two optional EMR components: Apache Hive and Apache Spark.

Apache Hive

Apache Hive is a data warehousing and SQL-like query engine built on top of Hadoop. It provides a high-level abstraction of HDFS and MapReduce, allowing users to write SQL-like queries to analyze large datasets stored in HDFS. Hive is designed to make it easier for analysts and data scientists to work with large datasets without having to write low-level MapReduce code. It supports various data formats, including CSV, JSON, Avro, Parquet, and ORC. Some of the key features of Hive include the following:

- **Schema-on-read**: Hive supports schema-on-read, which means that it can read and interpret data stored in different formats
- **Partitioning**: Hive allows users to partition data based on specific columns, making it easy to query large datasets
- **Data processing**: Hive supports a wide range of data processing functions, such as filtering, sorting, joining, and aggregating
- **User-defined functions** (**UDFs**): Hive allows users to write custom UDFs to perform complex data processing tasks

Hive is a powerful tool for data analysis and processing, especially for SQL-literate users who are familiar with the SQL language. Hive enables users to work with large datasets stored in Hadoop, using a SQL-like language, which makes it an ideal tool for data warehousing and data analysis tasks.

Apache Spark

Apache Spark is an open source big data processing engine designed to perform fast, in-memory data processing. It is built on top of Hadoop and uses HDFS for distributed storage. Spark provides a programming model called **Resilient Distributed Dataset** (**RDD**), which allows developers to perform distributed data processing in a fault-tolerant manner. RDD is an immutable distributed collection of objects that can be processed in parallel across a cluster of machines. Spark provides a wide range of libraries and APIs to perform various data processing tasks, including the following:

- **Spark Core**: Provides the basic functionality of Spark, including RDD and distributed task scheduling
- **Spark SQL**: A module for structured data processing
- **Spark Streaming**: A module for the real-time processing of streaming data
- **MLlib**: A library for machine learning and data mining tasks
- **GraphX**: A library for processing graph data

Some of the key features of Spark include the following:

- **In-memory processing**: Spark uses in-memory processing to speed up data processing tasks
- **Fault tolerance**: Spark provides fault tolerance through RDD, which can be reconstructed if a node fails
- **Scalability**: Spark can scale to thousands of nodes in a cluster, making it suitable for processing large datasets
- **Compatibility**: Spark can run on Hadoop YARN, Mesos, and standalone clusters

Apache Spark is a powerful big data processing engine that provides fast, in-memory processing of large datasets. It provides a wide range of libraries and APIs to perform various data processing tasks, making it an ideal tool for big data analytics, machine learning, and real-time processing of streaming data.

Now we will create an EMR cluster and submit a workload to an Amazon EMR cluster:

1. **Launch an EMR cluster**:

Log in to the AWS console and select the EMR service. From the left navigation pane, choose **Clusters | Create Cluster | Advanced Options**.

First, fill in the **Software and Steps** section, as shown in *Figure 5.22*:

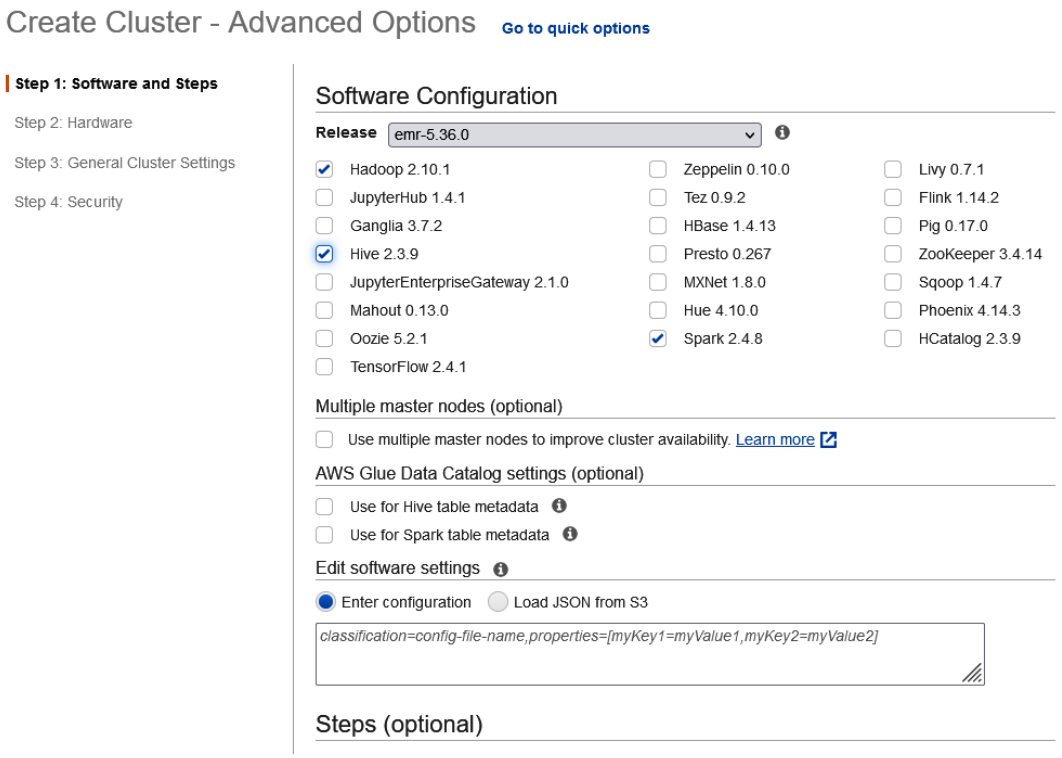


Figure 5.22 – EMR cluster creation step 1

Then, move on to step 2, which is filling in the hardware details, as shown in *Figure 5.23*:

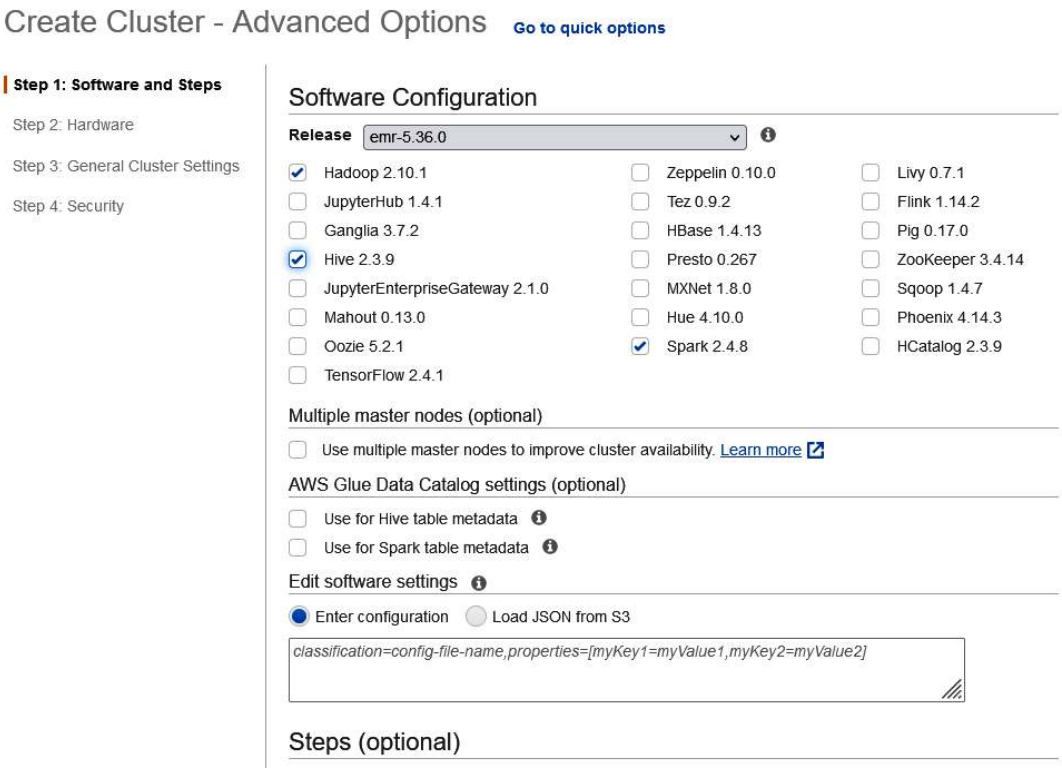


Figure 5.23 – EMR cluster creation step 2

For the third step, fill in the general cluster settings, as shown in *Figure 5.24*:

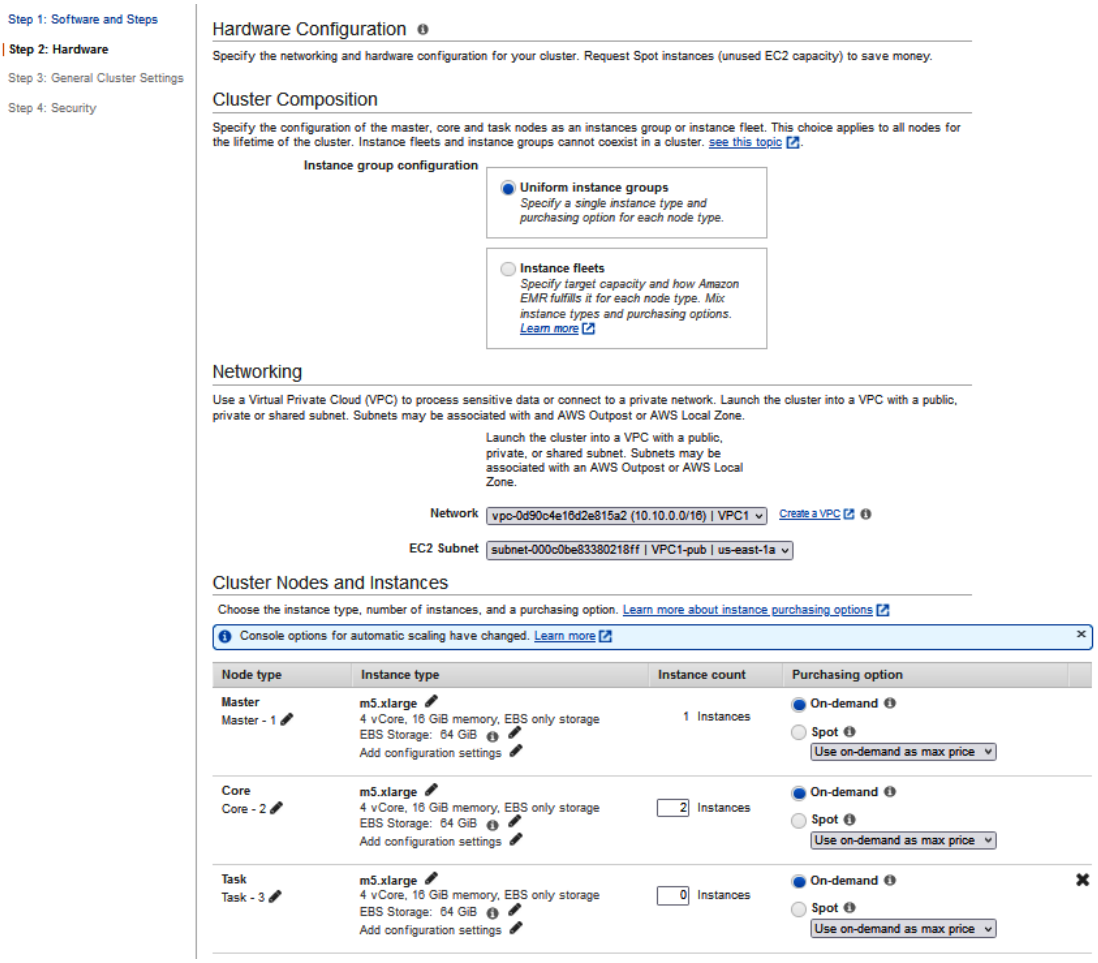


Figure 5.24 – EMR cluster creation step 3

For the fourth step, fill in the security options, as shown in *Figure 5.25*:

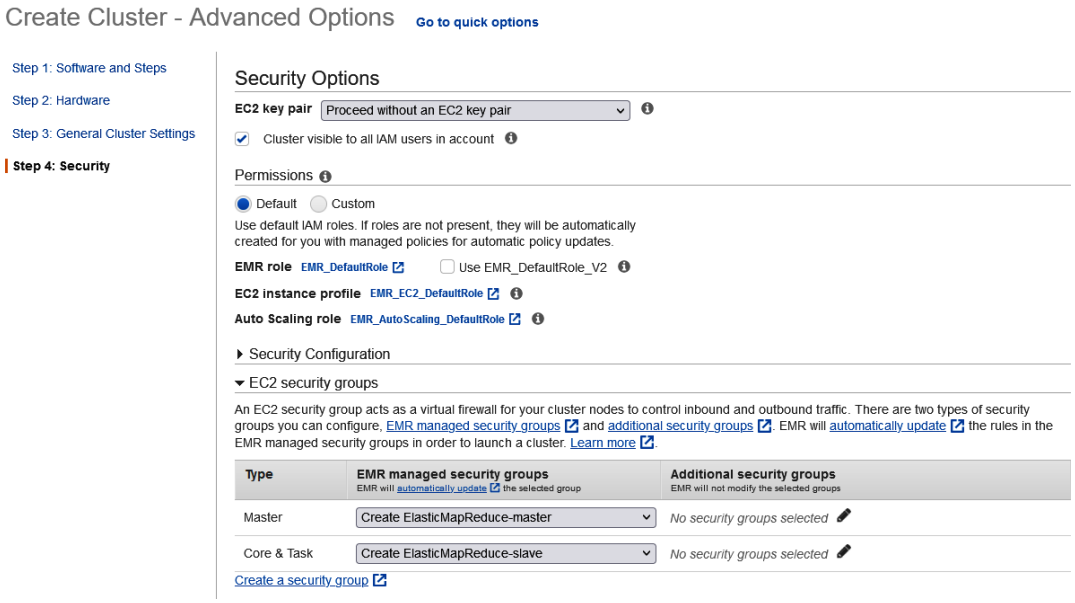


Figure 5.25 – EMR cluster creation step 4

Create the EMR cluster. It will show the state as **Starting**, as shown in *Figure 5.26*:

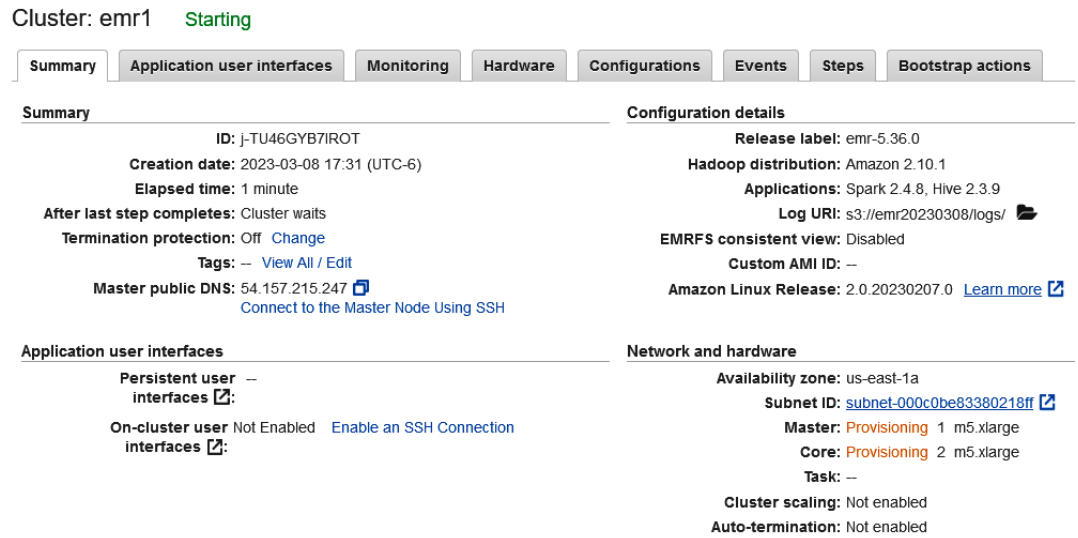


Figure 5.26 – EMR cluster Starting state

The nodes (EC2 instances) and S3 buckets will be created, as shown in *Figure 5.27*:

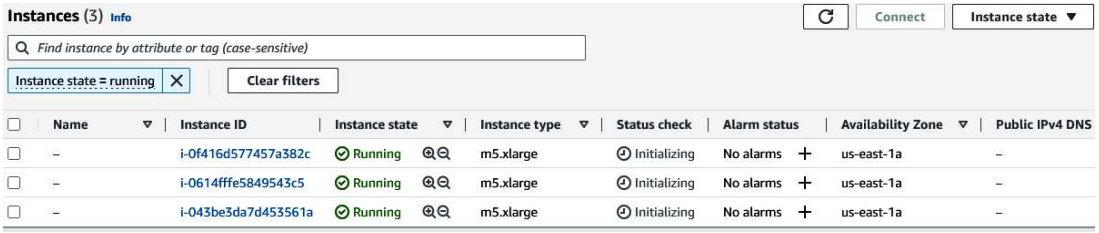


Figure 5.27 – EMR cluster nodes

The S3 buckets are created as the output locations for the cluster, as shown in *Figure 5.28*.

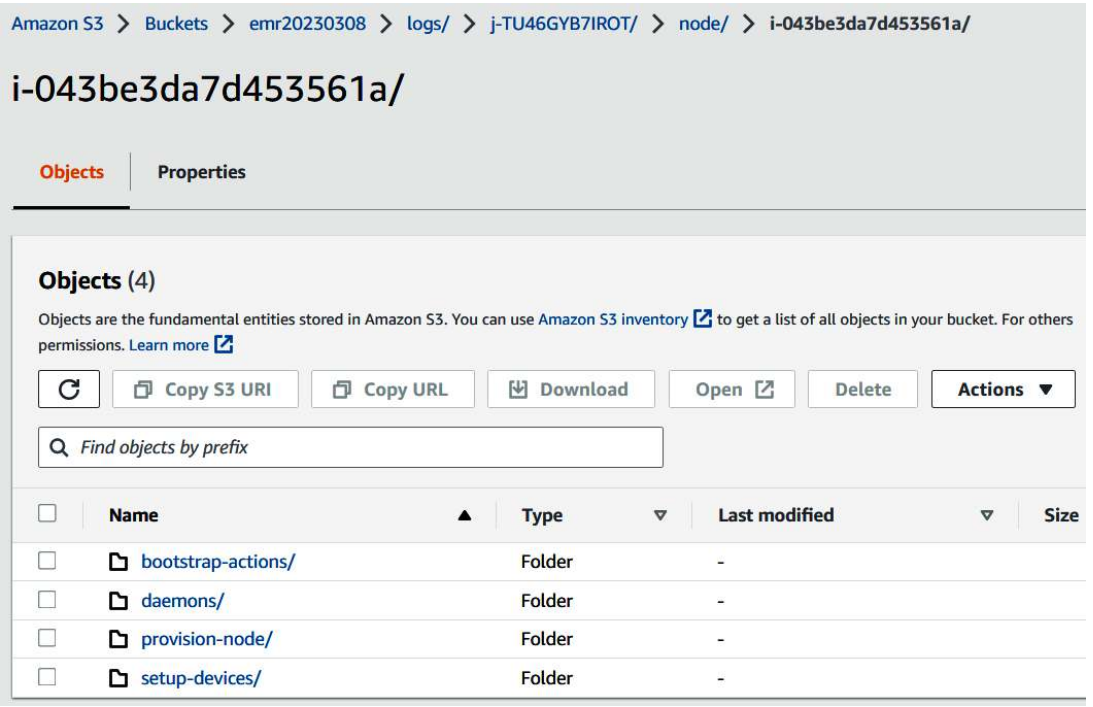


Figure 5.28 – EMR cluster S3 buckets

The cluster status changes from **Starting** to **Waiting** when the cluster is up, running, and ready to accept work, as shown in *Figure 5.29*:

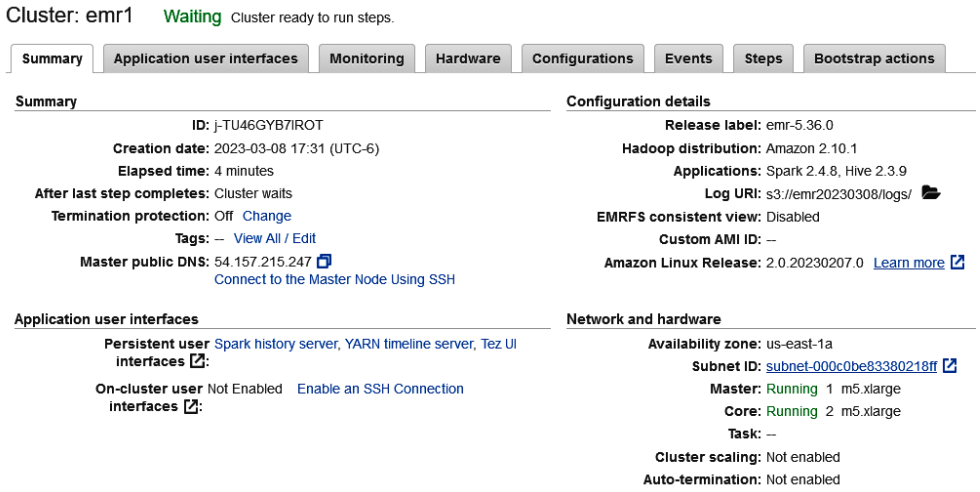


Figure 5.29 – EMR cluster in the Waiting state

2. **Submit Spark work to process food inspection data**

We will now use Apache Spark in the EMR cluster to process a big data CSV spreadsheet called `food_inspection_data.csv`, which has 200,000 rows. We will find the top 10 names that have the most violations. The table columns are shown in *Figure 5.30*:

name	inspection_result	inspection_closed_business	violation_type	violation_points
100 LB CLAM	Incomplete	FALSE		0
100 LB CLAM	Unsatisfactor	FALSE	BLUE	5
100 LB CLAM	Unsatisfactor	FALSE	RED	5
100 LB CLAM	Unsatisfactor	FALSE	RED	10
100 LB CLAM	Unsatisfactor	FALSE	RED	5
100 LB CLAM	Complete	FALSE		0
100 LB CLAM	Complete	FALSE		0
100 PERCENT NUTRICION	Unsatisfactor	FALSE	BLUE	5
100 PERCENT NUTRICION	Unsatisfactor	FALSE	BLUE	5
100 PERCENT NUTRICION	Unsatisfactor	FALSE	RED	10
100 PERCENT NUTRICION	Unsatisfactor	FALSE	RED	5
1000 SPIRITS	Satisfactory	FALSE	BLUE	5
1000 SPIRITS	Satisfactory	FALSE		0
1000 SPIRITS	Unsatisfactor	FALSE	RED	5
1000 SPIRITS	Complete	FALSE		0
1000 SPIRITS	Satisfactory	FALSE	BLUE	5
1000 SPIRITS	Satisfactory	FALSE		0
1000 SPIRITS	Unsatisfactor	FALSE	BLUE	5
1000 SPIRITS	Unsatisfactor	FALSE	BLUE	2
1000 SPIRITS	Unsatisfactor	FALSE	RED	25
1000 SPIRITS	Unsatisfactor	FALSE	RED	25
1000 SPIRITS	Unsatisfactor	FALSE	BLUE	5
1000 SPIRITS	Unsatisfactor	FALSE	RED	5

Figure 5.30 – Input big data spreadsheet

Since the EMR cluster is launched and ready, we will submit a Spark script to the cluster to process our data, as a step (EMR Step is a unit of work that contains instructions to manipulate data for processing in the EMR cluster).

The `file emr_process.py` Spark script is shown here:

```
import argparse
from pyspark.sql import SparkSession
def calculate_red_violations(data_source, output_target):
    with SparkSession.builder.appName("Calculate Red Health
Violations").getOrCreate() as spark:
        # Load the violation CSV data
        if data_source is not None:
            restaurants_df = spark.read.option("header",
"true").csv(data_source)
        # Create an in-memory DataFrame to query
        restaurants_df.createOrReplaceTempView("restaurant_
violations")
        # Create a DataFrame of the top 10 restaurants with the
most Red violations
        top_red_violation_restaurants = spark.sql("""SELECT
name, count(*) AS total_red_violations
          FROM restaurant_violations
          WHERE violation_type = 'RED'
          GROUP BY name
          ORDER BY total_red_violations DESC LIMIT 10""")
        # Write the results to the specified target
        top_red_violation_restaurants.write.option("header",
"true").mode("overwrite").csv(output_target)
if __name__ == "__main__":
    parser = argparse.ArgumentParser()
    parser.add_argument(
        '--data_source', help="Data Source location.")
    parser.add_argument(
        '--output_target', help="Output target location.")
    args = parser.parse_args()

    calculate_red_violations(args.data_source, args.output_
target)
```

Upload the Spark script, `emr_process.py`, to the S3 bucket, `s3://emr20230308/`.

Upload the source spreadsheet, `s3://emr20230308/source/food_inspection_data.csv`, and create a target S3 folder, `s3://emr20230308/target`. We are now ready for the next step.

Click the cluster, click the **Steps** tab, and then select **Add step**. Fill in the step details as shown in *Figure 5.31*:

- For **Step type**, choose **Spark application**.
- For **Name**, enter `Spark application`.
- For **Deploy mode**, keep the default "**Cluster**".
- For **Application location**, enter the Spark script, `s3://emr20230308/emr_process.py`.
- In the **Arguments** field, enter the following arguments and values:
  - `--data_source s3://emr20230308/source/food_inspection_data.csv`
  - `--output_target s3://emr20230308/target`

This is shown in the following screenshot:

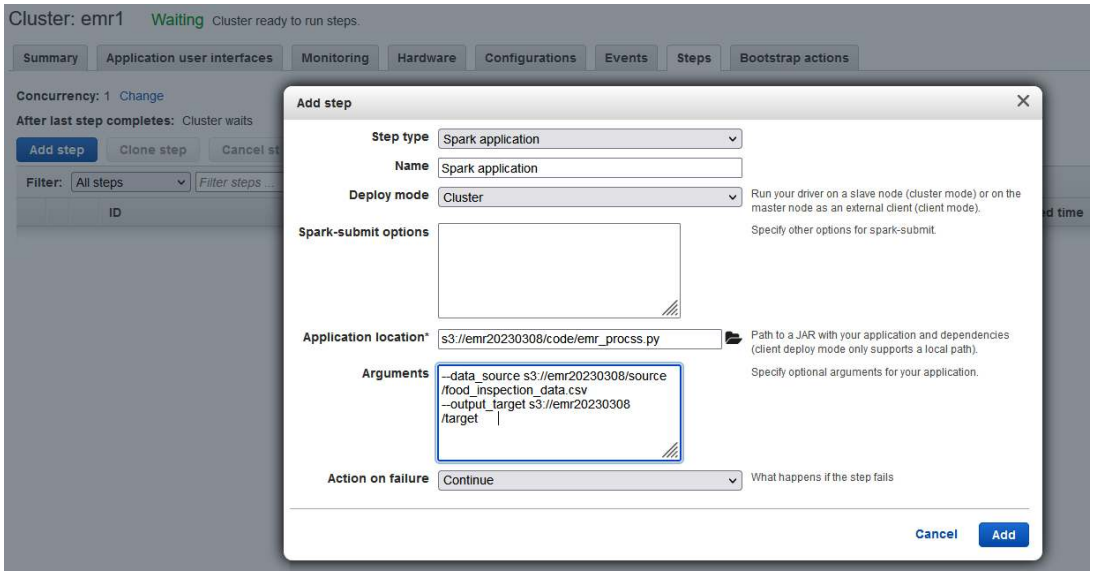


Figure 5.31 – Fill in the step details

Click **Add** to submit the Spark step. Initially, the status will show as **Pending**, but it will change to **Running** and then **Completed**, as shown in *Figure 5.32*:

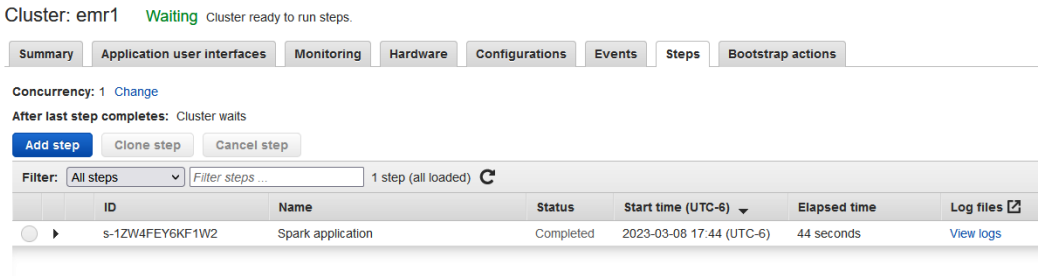


Figure 5.32 – Spark step is complete

Now, you can view its output results in your Amazon S3 output folder. As shown in *Figure 5.33*, there are two files generated from the Spark step:

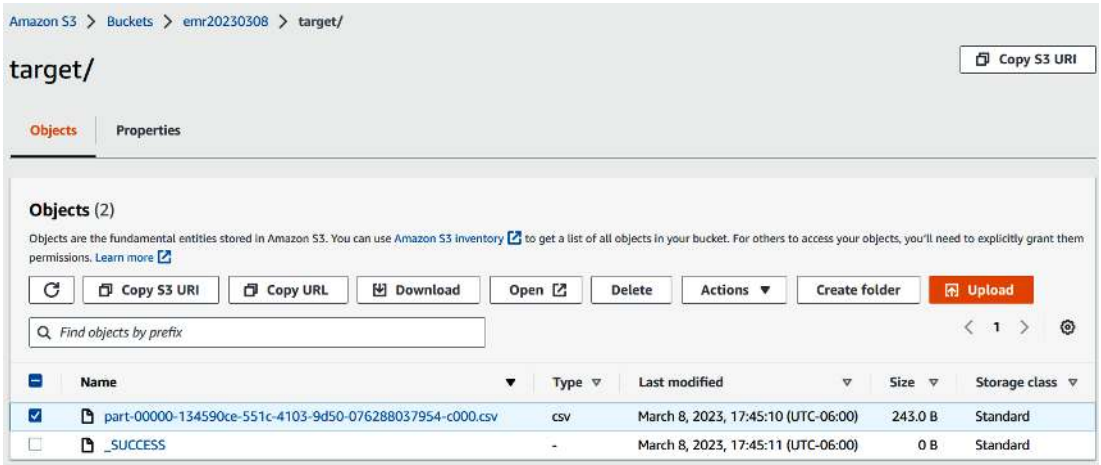


Figure 5.33 – Spark step target folder

Download the results to your local filesystem. *Figure 5.34* shows the content of the CSV spreadsheet – the EMR processing result of the submitted Spark step:

	A	B	C
1	name	total_red_violations	
2	PCC COMMUNITY MARKETS	251	
3	MCDONALD'S	177	
4	SAFEWAY INC #1508	143	
5	HIMITSU TERIYAKI	128	
6	NASAI TERIYAKI	119	
7	SAFEWAY # 1965	119	
8	SAFEWAY STORES INC #1550	118	
9	SAFEWAY STORE #1477	115	
10	SAFEWAY #1993	115	
11	FRED MEYER INC #179	111	
12			

Figure 5.34 – Spark step processing result

3. **Submit a Hive step to process CloudFront data**

With the same procedure, we submit a Hive step to process some CloudFront data, with the following code, source, target, and step submission shown in *Figure 5.35*:

`s3://us-east-1.elasticmapreduce.samples/cloudfront/code/Hive_CloudFront.q`

`s3://us-east-1.elasticmapreduce.samples`

`s3://emr20230308/hive/target`

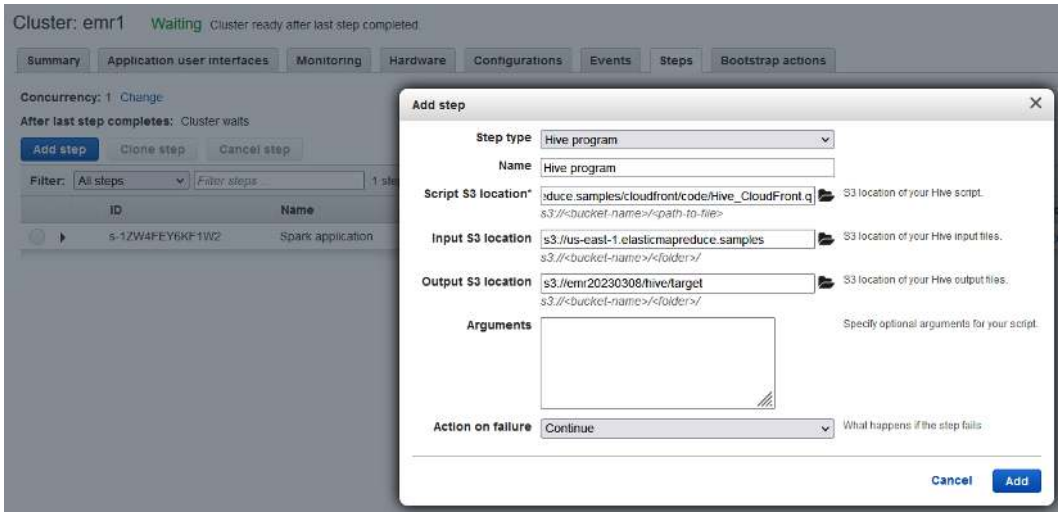


Figure 5.35 – Hive step submission

As shown in *Figure 5.36*, there are two files generated from the Hive step. Download them to your local filesystem. Please compare the source data and target processing results.

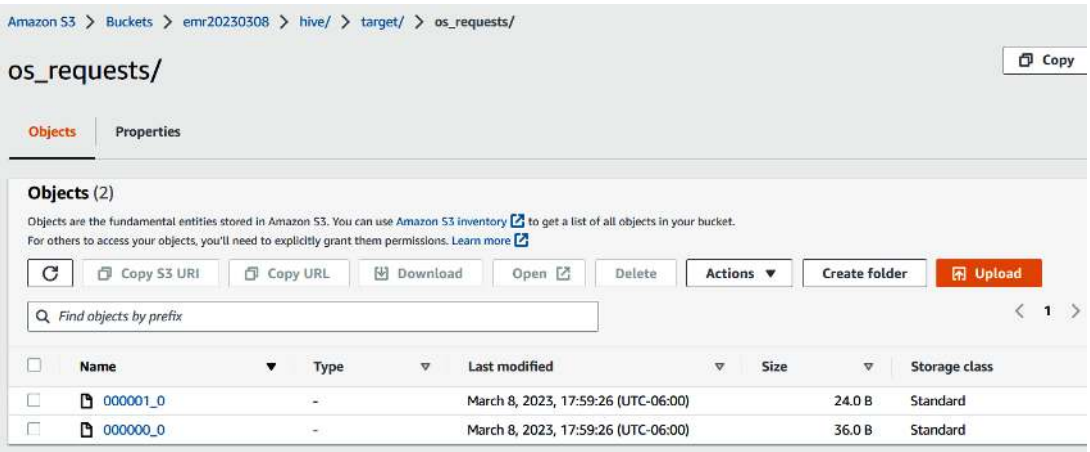


Figure 5.36 – Hive step output files

To recap, we have launched an EMR cluster and added two steps for the big data process: a Spark step and a Hive step. As you can see, both steps of big data processing takes less than a minute to process a big amount of data.

Summary

In this chapter, we explained big data analytics in the AWS cloud: ingestion, storing, processing, and visualization. We introduced AWS big data services including Glue, Kinesis, Athena, EMR, and QuickSight. We have demonstrated big data ingestion using AWS Glue and Kinesis, big data processing using Amazon Athena and EMR, and visualization using Quicksight, S3 stores the big datasets.

In the next chapter, we will discuss the Amazon machine learning services.

Practice questions

Questions 1-8 are based on the data analytics pipeline in the AWS cloud shown in *Figure 5.37*. An engineer is designing a pipeline that will ingest long-term, big-volume streaming data from the web using Kinesis Data Streams, then make two copies: one copy pass to Kinesis Firehose and stored in an Amazon S3 bucket, the other data copy will be processed with Amazon EMR and then queried by Athena and visualized using Amazon QuickSight. Performance and costs are the main factors to be taken into account.

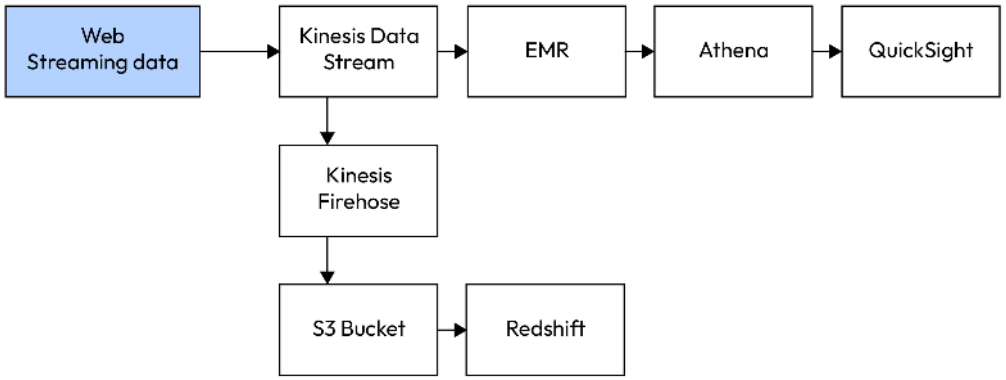


Figure 5.37 – Data analytics pipeline in the AWS cloud (redraw)

1. What instances would you recommend for the EMR cluster?

    A. Reserved Instances for the cluster

    B. Spot Instances for core and task nodes and a Reserved Instance for the master node

    C. Spot Instances for the cluster

    D. On-demand instances for the cluster

2. What filesystem would you recommend for the EMR cluster?

    A. HDFS with a consistent view

    B. EMRFS with a consistent view

    C. HDFS

    D. EBS on the cluster nodes

3. A senior manager needs to see the web data traffic trends for weekends from QuickSight. What is your recommendation?

    A. A line graph plotting traffic versus time

    B. A pie chart plotting traffic per day of the week

    C. A heatmap overlay to show the volume of traffic

    D. A bar graph plotting location versus web traffic

4. Several rows in a Redshift table were accidentally deleted. What is your recommendation to restore the rows from a snapshot?

    A. Restore from the snapshot to a new Redshift cluster. Truncate the table in the original cluster and copy the table from the new cluster.

B. Restore to a new table from the snapshot. Drop the original table and rename the new table to the original table name.

C. Restore from the snapshot to a new cluster. Create a link between the two clusters and copy the data from the new cluster.

D. Restore from the snapshot and overwrite the original table.

5. Right after the data is output from Kinesis Firehose to S3, it will be sent to Redshift, and the S3 data will be kept for 30 days before moving to the Infrequent Access tier and being deleted in a year. What's your recommendation for the S3 data storage?

A. Archive it in Glacier till deletion

B. Use standard S3 till it's deleted

C. Leverage S3 life cycle management

D. Enable S3 versioning

6. New regulation requires that only authorized staff can access customers' Social Security numbers in the data ingested from the social media.

What's your recommendation for handling this sensitive information?

A. Mask the Social Security numbers in Kinesis data stream ingestion

B. Store a cryptographic hash of the Social Security numbers

C. Encrypt the Social Security numbers with a key and share the key only with authorized staff

D. Encrypt the Social Security numbers with a key and give the decryption key only to authorized staff

7. A Spark step will be added to the EMR cluster for machine learning model training. What instances will you choose?

A. C instance types

B. R instance types

C. T instance types

D. D instance types

8. Senior management needs QuickSight visual reports every Monday morning, regarding the previous weekend's social media engagement. What's your recommendation for the EMR cluster?

A. Keep the EMR up and generate reports every Monday morning

B. Use a transient EMR cluster to generate reports every Monday morning

C. Use Spark Streaming on EMR to aggregate and generate reports every Monday morning

D. Use the EMR cluster to aggregate media data each night and use QuickSight to report on Monday morning

Answers to the practice questions

1. B
2. B
3. A
4. B
5. C
6. B
7. A
8. B

Further reading

For further insights into what you've learned in this chapter, refer to the following links:

- `https://aws.amazon.com/glue`
- `https://aws.amazon.com/kinesis/`
- `https://aws.amazon.com/athena/`
- `https://aws.amazon.com/emr/`
- `https://aws.amazon.com/quicksight/`
- `https://docs.aws.amazon.com/emr/index.html`
- `https://docs.aws.amazon.com/quicksight/index.html`

6

Amazon Machine Learning Services

We discussed cloud databases and big data analytics in previous chapters. Part of the data analytics spectrum, **machine learning** (**ML**) involves building models or algorithms that enable computers to analyze and learn from data, identify patterns, relationships, and trends that can be used to make predictions or decisions.

Cloud-based ML platforms provide a range of tools and services to support ML workflows of data preparation, feature engineering, model training, tuning, and deployment. Cloud ML can be used for **computer vision**, **natural language processing** (**NLP**), and many other predictive analytics tasks. The Amazon cloud provides platforms for engineers and data scientists to develop ML models from end to end. In this chapter, we will discuss the following topics:

- **ML basics**: What is ML? What are the objectives of ML? What problems can be solved using ML? What are some basic ML problems?
- **Amazon SageMaker**: A fully managed AWS ML service that allows users to build, train, and deploy ML models from end to end and at scale.
- **Deep learning (DL) basics**: What are neural networks and DL models? What are their components, and how do we construct and train a DL model?
- **Amazon computer vision** solutions using DL, mainly Amazon Rekognition – a DL-based image and video analysis service.
- **Amazon NLP solutions** using DL, including the following:
  - **Amazon Comprehend**, which uncovers valuable insights and connections in text
  - **Amazon Transcribe**, which is a speech-to-text service that can transcribe audio and video recordings into text

- **Amazon Polly**, which is a text-to-speech service
- **Amazon Translate**, which translates text between languages
- **Amazon Lex**, which can be used to build application interfaces that are based on voice and text

During our discussions, we will use some examples. The sample code is available in the GitHub repository for this book: `https://github.com/PacktPublishing/Self-Taught-Cloud-computing-Engineer`.

The AWS ML services can be used individually or in combination to build a wide range of ML applications, such as recommendation systems, chatbots, and predictive systems. Let's start with an introduction to ML basics and ML pipelines.

ML basics and ML pipelines

What is ML? ML is a subfield of **artificial intelligence** (**AI**) that focuses on building models and algorithms to learn patterns and relationships from data and make predictions or decisions. A typical ML project involves the following process – the so-called ML pipeline:

- **Problem framing**: Define ML problems from business projects
- **Data collection**: Collect data from various sources, which may involve data labeling
- **Data evaluation**: Examine the data using statistical tools
- **Feature engineering**: Select and extract model features and targets
- **Model training**: Train the model with the training dataset
- **Model verification**: Verify the model with the verification dataset
- **Model testing**: Test the model with the testing dataset
- **Model deployment**: Deploy the ML model to production

Figure 6.1 shows the ML pipeline, which is an iterative process to collect data and develop ML models for deployment:

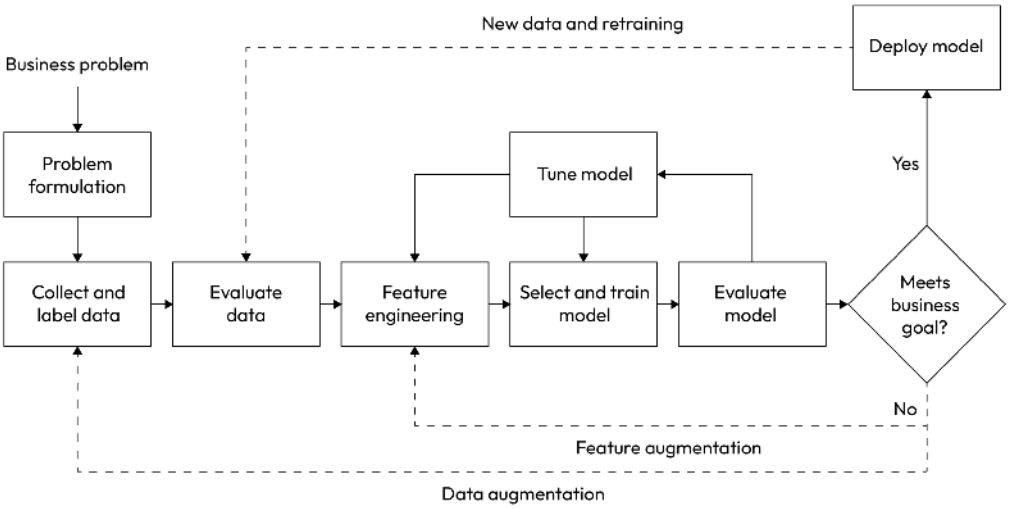


Figure 6.1 – ML pipeline

In the next subsections, we will examine the ML pipeline and discuss each stage of the pipeline in more detail.

ML problem framing

The first stage in the ML pipeline is defining the problem we need to solve and the goal we need to reach. Understanding the business goal of the problem is key in this stage since we will use the defined goal to measure the performance of our solution. During this stage, we will examine the problem and decide whether ML is the right approach to solve the problem. While ML is very useful for many business projects, it may not be the best solution for all problems. To decide whether ML is a good solution for a problem, we need to ask the following questions:

- What is the success measurement of the problem?
- What are the traditional ways of solving the problem?
- Is there enough quality data to solve the problem using ML?

After we have fully explored these questions and drawn the conclusion that ML is the best approach for the problem, we will further review the problem and data and see what type of ML problem it is. ML problems can be broadly classified into three categories:

- **Supervised learning** is training a model based on labeled data and then using the trained model to predict the output for new input data. For example, we can predict house prices based on historical sales data.

- **Unsupervised learning** involves training a model on unlabeled data to identify patterns and relationships.
- **Reinforcement learning** involves training a model based on feedback from the environment, where the algorithm learns to maximize a reward signal by taking steps toward the highest reward.

Once we have framed the ML problem and determined the ML model type, we will collect and prepare the dataset.

Data collection and preparation

The objective of this stage is to make sure that the datasets represent the real ML problem and are in the right format for ML model training. Since data usually comes from many different sources in different formats, we often use statistical techniques to sample, balance, and scale datasets and handle missing values and outliers in the datasets. Python data science libraries are powerful tools to manipulate data at this stage. This includes NumPy, Pandas, Matplotlib, and Seaborn:

- **NumPy** is a general-purpose array-processing Python library that is very good at carrying out array operations.
- **Pandas** is considered a powerful data analysis and manipulation library. It contains data structures for storing and manipulating multi-dimensional arrays.
- **Matplotlib** is a graphics Python library for data visualization. It is well integrated with NumPy and pandas.
- **Seaborn** is another data visualization library. It supports built-in Python types, such as lists and dictionaries, and objects from pandas and NumPy.

We will leverage these Python data science libraries in this chapter.

Feature engineering

After we have explored the data, we need to select and extract the model features, which are the columns of data that have the most impact on the model. **Feature selection** refers to selecting the *features* that are most relevant to the model *target*. We want to select a good number of features to avoid model underfitting or overfitting, and also build up valuable information by formatting, transforming, or combining features.

For example, **feature crossing** is a feature extraction method to synthesize two or more features into one, which will provide predictive abilities beyond what the original features can provide individually. *Figure 6.2* shows the relationship between the *target* and *features* (x and y) of a model. As we can see, it is difficult to build a model on these features, but if we synthesize a new feature from the original using a formula ($x*x + y*y$), then the model will be much easier to understand and process:

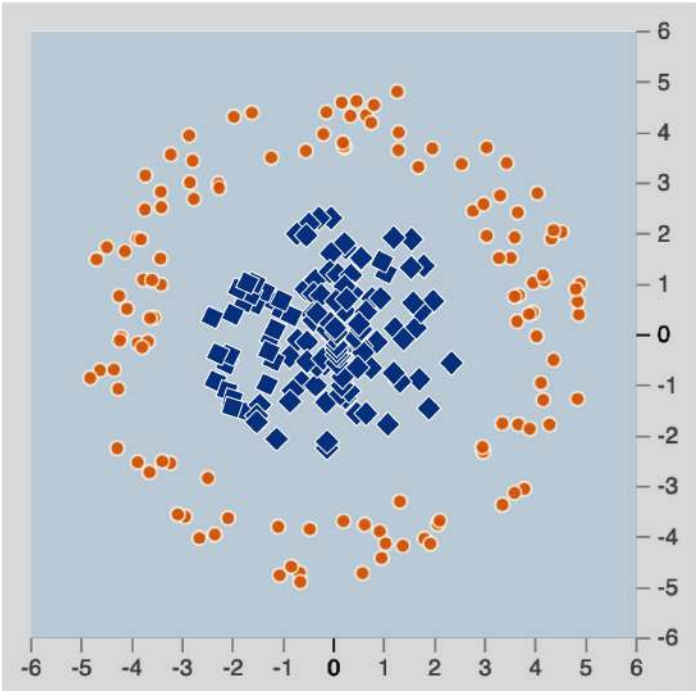


Figure 6.2 – Feature crossing

Another example is transforming categorical feature values into numerical, since computers only understand numbers. For ordinal categories such as cost, we can encode them using numbers, for example, *Low* to 1, *Medium* to 2, *High* to 3, and *Very High* to 4. But for non-ordinal categories, such as color, we need to use *one-hot encoding* to transform the different colors, as shown in *Figure 6.3*:

Color
Red
Blue
Green
Blue
Green

→

Red	Blue	Green
1	0	0
0	1	0
0	0	1
0	1	0
0	0	1

Figure 6.3 – One-hot encoding

There are also times when we need to handle missing values and outliers in the dataset. Depending on the case, we can either drop the missing values or impute them with the mean or median value for the feature. Outliers are values that lie far from other values, and we may need to delete, scale, or impute them based on the specific situation.

After we have prepared the data and extracted the features, we are ready for the next stage: model development.

ML model development

The ML model development process is a pipeline itself, including model training, model validation, and model hyperparameter tuning.

ML model training is an iterative process with the objective to minimize the *loss function* (also called the cost function), which measures the gap between the forecasted target value and the actual target value.

For regression models, we often use the **mean absolute error** (**MAE**) and **mean squared error** (**MSE**) as loss functions. `Denote N` is the number of samples. (x_i, y_i) is the coordinate of the `i`th sample data point; that is, if y_i is the actual value for x_i, and $\hat{y}$ is the predicted value for x_i, then the loss function can be defined as MAE or MSE.

MAE is the sum of the absolute differences between the predicted and the true values:

$$MAE = \frac{1}{N}\sum_{i=1}^{N}|y_i - \hat{y}_i|$$

MSE is the sum of the squared differences between the predicted and the true values:

$$MSE = \frac{1}{N}\sum_{i=1}^{N}(y_i - \hat{y}_i)^2$$

For classification models, the cost function is the difference between the probability distributions for different classes. For binary classification models where the model outputs are binary (`1` for yes or `0` for no), we use **binary cross-entropy**; for multi-class classification models, we use **categorical cross-entropy** or **sparse categorical cross-entropy**, based on the input dataset labels. More details are available at `https://gombru.github.io/2018/05/23/cross_entropy_loss/`.

To minimize the loss function, we leverage many ML algorithms, such as **linear regression**, **logistic regression**, **gradient descent**, **support vector machine**, **decision trees**, and **random forest**. For more details about these algorithms and how to choose the right one, please refer to `https://learn.microsoft.com/en-us/azure/machine-learning/how-to-select-algorithms`.

Among these ML algorithms, there is a popular one that we will use in this chapter – called **Extreme Gradient Boosting** (**XGBoost**). XGBoost is a class of boosting algorithms that iteratively adds weak learners to a model to improve its performance. Building on decision trees and using a gradient-boosting framework, XGBoost starts from a very general model and then refines it by adding weak learners using gradient descent methods. Over the years, XGBoost has become a popular choice in the ML community, and it is available in several programming languages, including Python, R, Java, and Scala.

For more details, please refer to `https://www.nvidia.com/en-us/glossary/data-science/xgboost/`.

ML model validation is the stage to verify the performance of the trained model. Typically, at the beginning of an ML model development process, we divide the dataset into training, validation, and testing datasets. These datasets are randomly split and are independent of each other. In the validation process, we also use the loss function to measure the gap between the predicted and actual target values for the validation dataset, and thus validate the model performance.

As we discussed earlier, the MAE and MSE can be used to validate regression models. For classification models, a **confusion matrix** is usually created to measure the model's performance. *Figure 6.4* shows a confusion matrix example for a binary classification problem of predicting whether an image is a cat. As you can see, **true positive** (**TP**) refers to cases where the image is predicted to be a cat and it is a cat; **false positive** (**FP**) refers to when the image is predicted to be a cat but it is not in fact a cat; **false negative** (**FN**) refers to when the image is predicted to not be a cat but it is a cat; and **true negative** (**TN**) is when the image is predicted not to be a cat and it is not a cat.

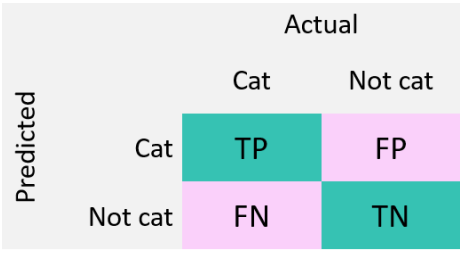


Figure 6.4 – Confusion matrix

Once we have created the confusion matrix, we can calculate the model performance stats for validation. The most used stats are as follows:

- **Recall** (**sensitivity**) measures the proportion of actual positives that were identified correctly:

  Recall = TP/(TP+FN)

- **Specificity** measures the proportion of actual negatives that were identified correctly:

  Specificity = TN/(FP+TN)

- **Precision** measures the proportion of positive identifications that are correct:

  Precision=TP/(TP+FP)

More details on model validation and the confusion matrix can be found at `https://www.sciencedirect.com/topics/engineering/confusion-matrix` and `https://towardsdatascience.com/supervised-machine-learning-model-validation-a-step-by-step-approach-771109ae0253`.

Many times during model training and validation, we come across model underfitting and overfitting. **Model underfitting** describes the situation where the prediction error is not minimized, and model overfitting is when the model fits the training dataset very well but does not fit the validation dataset. We want to avoid both underfitting and overfitting and make a good fit/robust model. There are many techniques we can use.

For more details, please refer to `https://www.geeksforgeeks.org/underfitting-and-overfitting-in-machine-learning/`.

ML model hyperparameter tuning is the process of selecting the best set of hyperparameters for an ML model to maximize its performance on a given dataset. Hyperparameters are not learned by the model during training but are specified by the user at the beginning of the training process, such as the learning rate, number of epochs, and batch size.

For more details, please refer to `https://cloud.google.com/ai-platform/training/docs/hyperparameter-tuning-overview`.

ML model deployment, testing, and monitoring

After the model is trained, tuned, and validated, we will deploy it in a production environment, with the necessary hardware and software to host the prediction service. Model testing means testing a model in a production-like environment and monitoring its performance to detect any issues. After the model is deployed to the production environment and tested, we still need to monitor the model performance and retrain it as needed.

Now that we have introduced the basic ML concepts and ML pipeline, let's take a look at Amazon SageMaker and go through the ML pipeline process under SageMaker.

Amazon SageMaker

Amazon SageMaker provides a fully managed cloud platform for users to develop ML models from end to end. Some of the key features of Amazon SageMaker are as follows:

- **Data preparation**: Amazon SageMaker provides various tools to preprocess and prepare data
- **Model training algorithms**: SageMaker provides built-in algorithms for supervised learning, unsupervised learning, and reinforcement learning
- **Model deployment**: After the ML model is trained and validated, SageMaker provides tools for model deployment, either as a batch transform job or a real-time endpoint
- **Scalability**: SageMaker is a fully managed service, which means that AWS takes care of all the infrastructure and scaling, so the data scientists can focus on building better models rather than worrying about infrastructure

- **Integration**: SageMaker integrates with other AWS services, such as S3, AWS Glue, and AWS Lambda, so data scientists can easily access and use datasets stored in AWS

Next, we will use Amazon SageMaker to solve a real-life problem. The details of the problem are as follows:

- **Problem definition**: A healthcare provider wants to improve the success rate of detecting abnormalities in orthopedic patients. The problem will be solved using ML. The dataset contains six biomechanical features and a target of normal or abnormal. We will use it to train an ML model and predict whether a patient will have an abnormality.
- **The dataset**: We will use the public vertebral column dataset from the UCI Machine Learning Repository (`https://archive.ics.uci.edu/ml/datasets/vertebral%2Bcolumn`).
- **The platform**: We will use Amazon SageMaker to collect and prepare the datasets, conduct model training and validation, deploy the model and perform batch transformation for the testing dataset, and fine-tune the model.

Are you ready? Let's get our hands dirty to develop an ML pipeline using Amazon SageMaker:

1. **Launch a Jupyter notebook**:

Log in to the AWS Management Console. From the **Services** menu, choose **Amazon SageMaker**. In the navigation menu on the left, expand the **Notebook** section and choose **Notebook instances**. Click **Create notebook instance**.

In the **Notebook instance name** box, enter a name for the notebook, such as `notebook1`. From the **Notebook instance type** drop-down list, choose **ml.t3.medium**. Set **Platform identifier type** to the latest one (**notebook-al2-v2**). Leave the remaining settings at their default values. Click **Create notebook instance**, as shown in *Figure 6.5*:

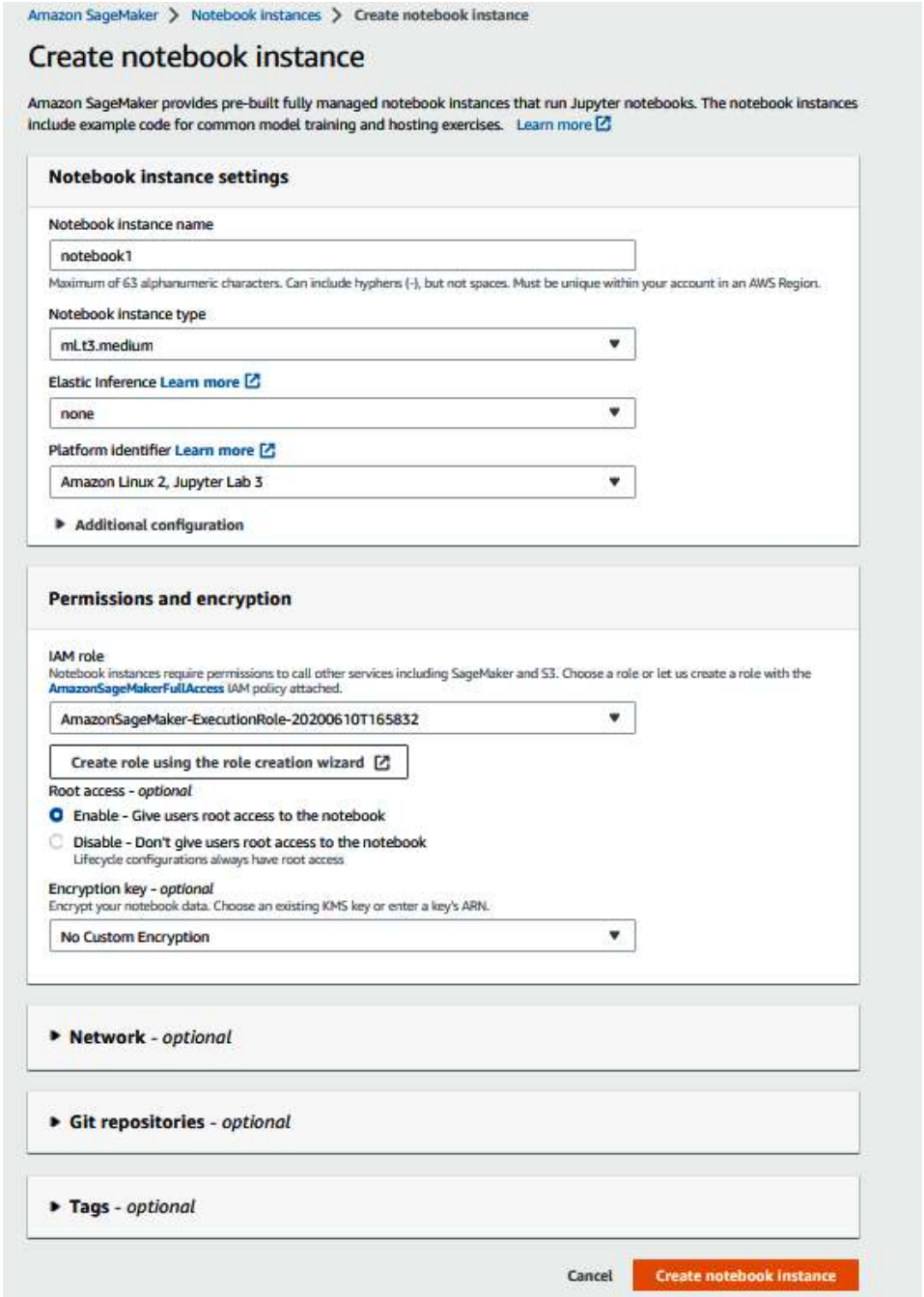


Figure 6.5 – Launch a SageMaker notebook instance

When it's initially created, the new notebook instance will show as **Pending**. After it changes to **InService**, choose **Open JupyterLab** at the end of the row. A new window opens with the launcher. Choose **conda_python3**.

2. **Working in Jupyter Notebook**

   Now, the Jupyter notebook is ready to execute the ML pipeline process, using Python code. We will develop the pipeline step by step:

   I. **Import the Python data science libraries**:

```
import warnings, requests, zipfile, io
warnings.simplefilter('ignore')
import pandas as pd
from scipy.io import arff
import boto3
```

   II. **Import the dataset and load data into a pandas DataFrame**:

```
f_zip=
'http://archive.ics.uci.edu/ml/machine-learning-databases/00212/
vertebral_column_data.zip'
r=requests.get(f_zip, stream=True)
Vertebral_zip=zipfile.ZipFile(io.BytesIO(r.content))
Vertebral_zip.extractall()
```

The data is imported and ready for use, and you will see four files show up on the left panel, as shown in *Figure 6.6*. We can load them into pandas DataFrames:

```
data = arff.loadarff('column_2C_weka.arff')
df = pd.DataFrame(data[0])
class_mapper = {b'Abnormal':1,b'Normal':0}
df['class']=df['class'].replace(class_mapper)
```

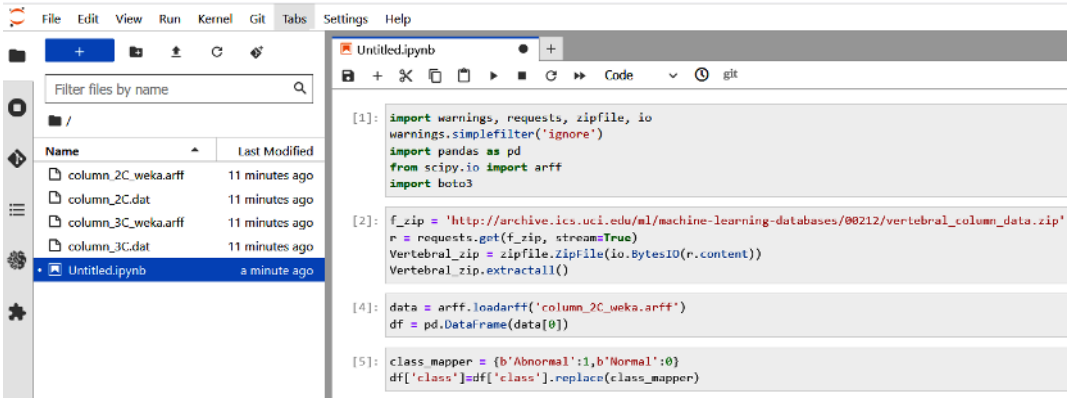


Figure 6.6 – Import the dataset and load data into DataFrames

III. **Explore the data**

Use `df.shape` to examine the number of rows and columns and `df.columns` to list the six biomechanical features. The target column is named `class`.

IV. **Prepare the data**

Since XGBoost requires the training data to be in a single file with the first column as the target value, we need to move the target column to the first position. Then, we split the dataset into training, validate, and test datasets and examine the three datasets.

Figure 6.7 shows the execution results of steps III and IV:

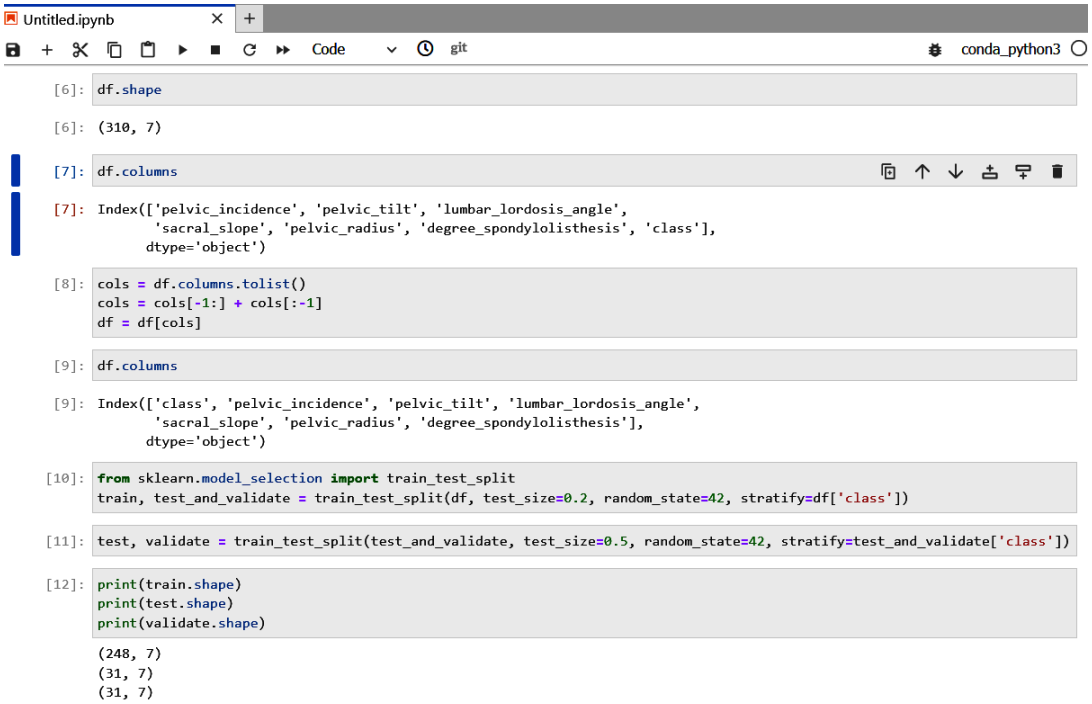


Figure 6.7 – Explore and prepare data

V. **Upload the data to Amazon S3**

Since XGBoost loads the training data from S3, we need to create an S3 bucket, write the data to a **comma-separated values** (**CSV**) file, and then upload the file to Amazon S3:

```
bucket='arn:aws:s3:::juyper03172023'
prefix='lab'
train_file='vertebral_train.csv'
test_file='vertebral_test.csv'
validate_file='vertebral_validate.csv'
```

```
import os
s3_resource = boto3.Session().resource('s3')
def upload_s3_csv(filename, folder, dataframe):
    csv_buffer = io.StringIO()
    dataframe.to_csv(csv_buffer, header=False, index=False)
    s3_resource.Bucket(bucket).Object(os.path.join(prefix,
folder, filename)).put(Body=csv_buffer.getvalue())
```

Figure 6.8 shows the execution results of step V:

```
[23]: bucket='juyper03172023'
prefix='lab'

train_file='vertebral_train.csv'
test_file='vertebral_test.csv'
validate_file='vertebral_validate.csv'

[24]: import os
s3_resource = boto3.Session().resource('s3')

[25]: def upload_s3_csv(filename, folder, dataframe):
    csv_buffer = io.StringIO()
    dataframe.to_csv(csv_buffer, header=False, index=False)
    s3_resource.Bucket(bucket).Object(os.path.join(prefix, folder, filename)).put(Body=csv_buffer.getvalue())

[26]: upload_s3_csv(train_file, 'train', train)
upload_s3_csv(test_file, 'test', test)
upload_s3_csv(validate_file, 'validate', validate)
```

Figure 6.8 – Upload data to S3

Now we are ready to train the model!

VI. **Train the model using XGBoost**

The first step is to get the XGBoost container URL:

```
import boto3
from sagemaker.image_uris import retrieve
container = retrieve('xgboost',boto3.Session().region_name,'1.0-
1')
```

Set initial hyperparameters for the model and use the estimator function to set the model up:

```
hyperparams={"num_round":"42",
             "eval_metric": "auc",
             "objective": "binary:logistic"}

import sagemaker
s3_output_location="s3://{}/{}/output/".format(bucket,prefix)
xgb_model=sagemaker.estimator.Estimator(container,
                                        sagemaker.get_execution_
role(),
instance_count=1,
```

```
                                                    instance_type='ml
.m4.xlarge',
                                                    output_path=s3_
output_location,
                                                     hyperparameters=
hyperparams,
                                                     sagemaker_session=
sagemaker.Session())
```

The estimator needs **channels** to feed data into the model. We will use `train_channel` and `validate_channel`:

```
train_channel = sagemaker.inputs.TrainingInput(
    "s3://{}/{}/train/".format(bucket,prefix,train_file),
    content_type='text/csv')

validate_channel = sagemaker.inputs.TrainingInput(
    "s3://{}/{}/validate/".format(bucket,prefix,validate_file),
    content_type='text/csv')

data_channels = {'train': train_channel, 'validation':
validate_channel}
```

Figure 6.9 shows the execution in the notebook of these steps.

[27]:
```
import boto3
from sagemaker.image_uris import retrieve
container = retrieve('xgboost',boto3.Session().region_name,'1.0-1')
```

[28]:
```
hyperparams={"num_round":"42",
             "eval_metric": "auc",
             "objective": "binary:logistic"}
```

[29]:
```
import sagemaker
s3_output_location="s3://{}/{}/output/".format(bucket,prefix)
xgb_model=sagemaker.estimator.Estimator(container,
                                        sagemaker.get_execution_role(),
                                        instance_count=1,
                                        instance_type='ml.m4.xlarge',
                                        output_path=s3_output_location,
                                         hyperparameters=hyperparams,
                                         sagemaker_session=sagemaker.Session())
```

[30]:
```
train_channel = sagemaker.inputs.TrainingInput(
    "s3://{}/{}/train/".format(bucket,prefix,train_file),
    content_type='text/csv')

validate_channel = sagemaker.inputs.TrainingInput(
    "s3://{}/{}/validate/".format(bucket,prefix,validate_file),
    content_type='text/csv')

data_channels = {'train': train_channel, 'validation': validate_channel}
```

Figure 6.9 – Split dataset and define estimator

Now, train the model:

```
xgb_model.fit(inputs=data_channels, logs=False)
```

Figure 6.10 shows a screenshot of the model training:

```
[31]: xgb_model.fit(inputs=data_channels, logs=False)

INFO:sagemaker:Creating training-job with name: sagemaker-xgboost-2023-03-17-22-16-09-934

2023-03-17 22:16:10 Starting - Starting the training job.......
2023-03-17 22:16:50 Starting - Preparing the instances for training.............
2023-03-17 22:17:53 Downloading - Downloading input data.....
2023-03-17 22:18:23 Training - Downloading the training image........
2023-03-17 22:19:09 Training - Training image download completed. Training in progress....
2023-03-17 22:19:29 Uploading - Uploading generated training model..
2023-03-17 22:19:45 Completed - Training job completed
```

Figure 6.10 – Model training

We can see that the model training has completed.

VII. **Conduct a batch transform on the testing dataset**

We will now construct a batch transformation, as seen in *Figure 6.11*.

```
batch_X = test.iloc[:,1:];

batch_X_file='batch-in.csv'
upload_s3_csv(batch_X_file, 'batch-in', batch_X)

batch_output = "s3://{}/{}/batch-out/".format(bucket,prefix)
batch_input = "s3://{}/{}/batch-in/{}".format(bucket,prefix,batch_X_file)

xgb_transformer = xgb_model.transformer(instance_count=1,
                                        instance_type='ml.m4.xlarge',
                                        strategy='MultiRecord',
                                        assemble_with='Line',
                                        output_path=batch_output)

xgb_transformer.transform(data=batch_input,
                          data_type='S3Prefix',
                          content_type='text/csv',
                          split_type='Line')
xgb_transformer.wait()

s3 = boto3.client('s3')
obj = s3.get_object(Bucket=bucket, Key="{}/batch-out/{}".format(prefix,'batch-in.csv.out'))
target_predicted = pd.read_csv(io.BytesIO(obj['Body'].read()),',',names=['class'])
```

```
INFO:sagemaker:Creating model with name: sagemaker-xgboost-2023-03-18-04-02-54-790

INFO:sagemaker:Creating transform job with name: sagemaker-xgboost-2023-03-18-04-02-55-529

2023-03-18T04:08:52.134:[sagemaker logs]: MaxConcurrentTransforms=4, MaxPayloadInMB=6, BatchStrategy=MULTI_RECORD
```

Figure 6.11 – Batch transformation

After the batch transformation step, we can build a confusion matrix.

VIII. **Create a confusion matrix**

Build a function to convert the positive probability into binary (`0` or `1`):

```
def binary_convert(x):
    threshold = 0.3
    if x > threshold:
        return 1
    else:
        return 0

target_predicted_binary = target_predicted['class'].
apply(binary_convert)

print(target_predicted_binary.head(5))
test.head(5)
```

Figure 6.12 shows the execution in a notebook.

```
[5]: def binary_convert(x):
         threshold = 0.3
         if x > threshold:
             return 1
         else:
             return 0

     target_predicted_binary = target_predicted['class'].apply(binary_convert)

     print(target_predicted_binary.head(5))
     test.head(5)
```

```
0    1
1    1
2    1
3    1
4    1
Name: class, dtype: int64
```

[5]:

	class	pelvic_incidence	pelvic_tilt	lumbar_lordosis_angle	sacral_slope	pelvic_radius	degree_spondylolisthesis
136	1	88.024499	39.844669	81.774473	48.179830	116.601538	56.766083
230	0	65.611802	23.137919	62.582179	42.473883	124.128001	-4.083298
134	1	52.204693	17.212673	78.094969	34.992020	136.972517	54.939134
130	1	50.066786	9.120340	32.168463	40.946446	99.712453	26.766697
47	1	41.352504	16.577364	30.706191	24.775141	113.266675	-4.497958

Figure 6.12 – Forecast testing dataset

Then, create a confusion matrix using the target values from the test dataset and the predicted value:

```
test_labels = test.iloc[:,0]
test_labels.head()
from sklearn.metrics import confusion_matrix
matrix = confusion_matrix(test_labels, target_predicted_binary)
df_confusion = pd.DataFrame(matrix,
index=['Normal','Abnormal'],columns=['Normal','Abnormal'])
df_confusion
```

Figure 6.13 shows the execution in a notebook:

```
[6]: test_labels = test.iloc[:,0]
     test_labels.head()

[6]: 136    1
     230    0
     134    1
     130    1
     47     1
     Name: class, dtype: int64
```

Now, you can use the *scikit-learn* library, which contains a function to create a confusion matrix.

```
[7]:
     from sklearn.metrics import confusion_matrix

     matrix = confusion_matrix(test_labels, target_predicted_binary)
     df_confusion = pd.DataFrame(matrix, index=['Nnormal','Abnormal'],columns=['Normal','Abnormal'])

     df_confusion
```

[7]:

	Normal	Abnormal
Nnormal	7	3
Abnormal	2	19

Figure 6.13 – Create a confusion matrix

Now, we can calculate the performance stats for the model.

IX. **Calculate the performance stats**

Now calculate the stats:

```
Sensitivity  = float(TP)/(TP+FN)*100
print(f"Sensitivity or TPR: {Sensitivity}%")
Specificity  = float(TN)/(TN+FP)*100
print(f"Specificity or TNR: {Specificity}%")
```

```
Precision = float(TP)/(TP+FP)*100
print(f"Precision: {Precision}%")
```

Figure 6.14 shows the execution in a notebook.

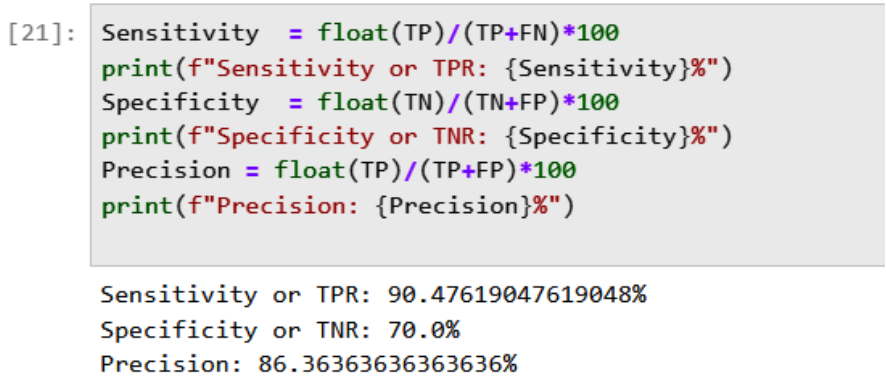


Figure 6.14 – Performance stats

In this section, we introduced Amazon SageMaker and showed the ML pipeline, from data collection and preparation, to model training and validation, to model deployment, testing, and fine-tuning, using SageMaker. In the next sections, we will introduce DL and explore the Amazon computer vision and NLP solutions using DL.

DL basics

DL was introduced in 2012. The basic idea is to mimic the human brain and construct **artificial neural networks** (**ANNs**) to train models. A typical multi-layer ANN has three types of layers: an **input layer**, one or more **hidden layers**, and an **output layer**. *Figure 6.15* shows an ANN that has one input layer, two hidden layers, and an output layer. In the ANN, a circular node represents a perceptron, and a line represents the connection from the output of one perceptron to the input of another.

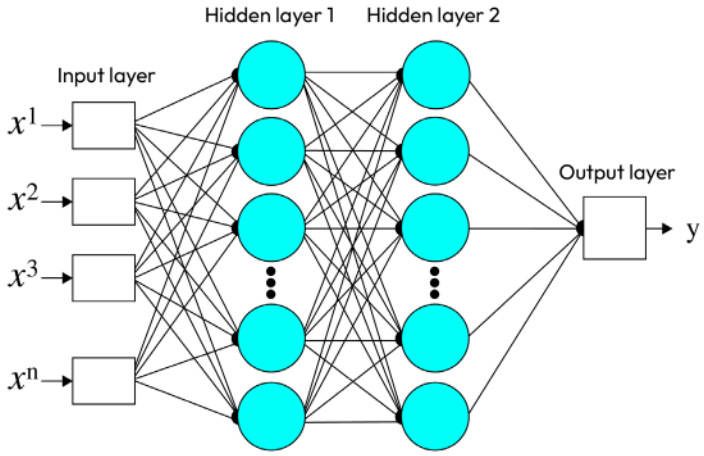


Figure 6.15 – A multi-layer ANN

The objective of DL model training is the same as ML: minimize the loss function, which is defined as the gap between the model's predicted value and the actual value. Different from traditional ML algorithms, DL uses the activation function to add nonlinearity to the model training process.

In a typical DL model, we define the following to construct a neural network:

- The **layers of the model** (input layer, hidden layers, and output layers)
- The **activation function** for each layer (such as ReLU or softmax)
- The **optimizer**, which is the DL algorithm used to train the model
- The **loss function** (such as MAE, MSE, and `categorical_crossentropy`)
- The **dropout rate**, which is the percentage of nodes and their incoming/outgoing connections to be temporarily removed from the network – to avoid model overfitting

The following code snippet shows an example of building and training a DL model using **Keras**, which is a software library for constructing DL models. As we can see, it builds a neural network of three layers: the input layer with 16 nodes, 2 hidden layers with 128 and 24 nodes (`0.25` dropout), and an output layer of 3 nodes (softmax activation). The optimizer algorithm is **stochastic gradient descent** (**SGD**), and the loss function is `categorical_crossentropy`, which fits multi-classification models:

```
#Import keras
model = keras.sequential
model.add(layers.Dense(128,activation='relu',input_shape=(16,
)))
model.add(layers.Dense(24,activation='relu'))
model.add(layers.Dropout(rate=0.25))
model.add(layers.Dense(3,activation='softmax'))
```

```
model.compile(sgd(lr=0.5), loss='categorical_crossentropy',
metrics=['accuracy'])
model.fit(train_set, train_label, batch_size=20, epochs=30,
shuffle=True)
```

Since DL was introduced, it has made breakthroughs in a lot of AI areas, including computer vision and NLP. Many applications are developed using pretrained neural DL models. In the next section, we will introduce the Amazon DL solutions in computer vision and NLP.

Amazon computer vision solutions

Computer vision is the automated extraction of information from digital images. To solve computer vision problems, Amazon provides **Rekognition** – a fully managed service using DL to analyze images and videos. Here are some key features of Amazon Rekognition:

- **Object and scene detection**: Rekognition can identify objects and scenes within an image or video frame, including vehicles, buildings, animals, and landscapes.
- **Facial analysis and facial comparison**: Rekognition can detect faces in images and videos and perform facial analysis, including facial recognition, gender identification, age estimation, and facial expression analysis. It can compare and match faces from different images.
- **Text detection**: Rekognition can detect and extract text in images and videos, including printed and handwritten text.
- **Custom labels**: Rekognition also allows you to create custom labels for specific objects or scenes that are important to your business or use case.
- **Video analysis**: Rekognition can analyze videos and extract specific frames or segments based on your criteria, such as facial recognition or object detection.

Amazon Rekognition provides a powerful set of image and video analysis capabilities that can be used in a variety of applications, such as security, media analysis, customer engagement, and content moderation. Next, we will show two of its functions: label detection and facial recognition and matching.

Label detection

In the AWS Management Console, select **Amazon Rekognition** and go to the **Rekognition** console. Select **Demos | Label detection**. When you upload an image, it analyzes the content and returns a list of labels that describe the visual elements of the content. *Figure 6.16* shows the label detection results:

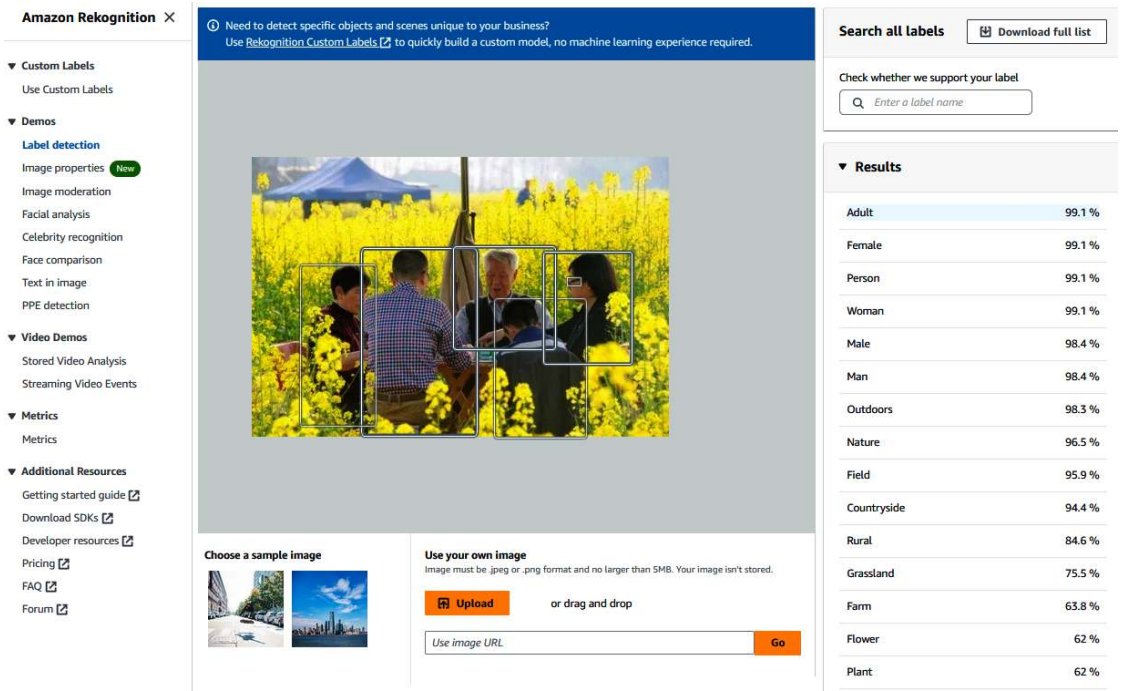


Figure 6.16 – Label detection

Facial recognition and matching

In the AWS Management Console, select **Amazon Rekognition** and go to the **Rekognition** console. Select **Demos | Face comparison**. Upload an image as a reference face and another image for the comparison faces. Rekognition compares the reference face with each of the comparison faces and returns the results. *Figure 6.17* shows the face comparison results:

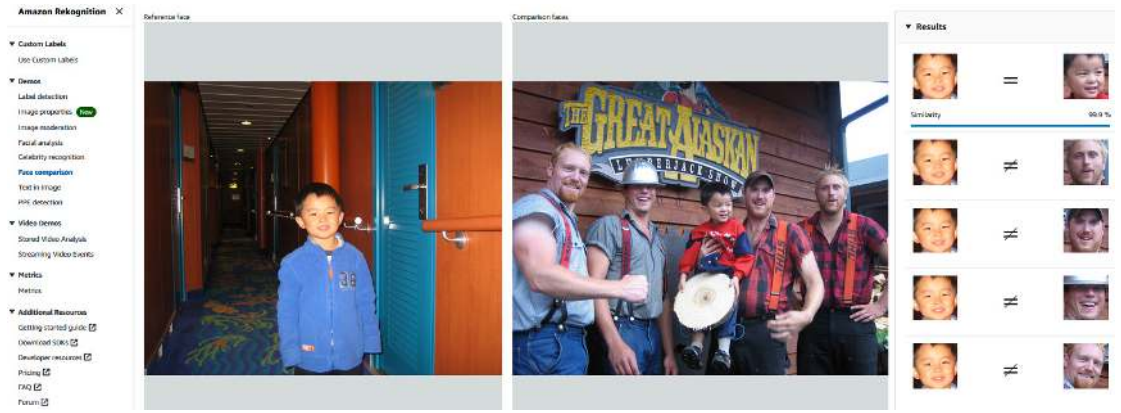


Figure 6.17 – Face comparison

Due to space limits, we have only shown some Amazon Rekognition features. Please feel free to explore more computer vision solutions and have fun!

In the next section, we will look at Amazon's NLP services.

Amazon's NLP solutions

Amazon offers a range of NLP solutions:

- **Amazon Comprehend**, which is a service to perform sentiment analysis, entity recognition, and topic modeling on large volumes of unstructured text
- **Amazon Transcribe**, which converts speech to text and supports multiple languages and a variety of audio formats
- **Amazon Polly**, which is a text-to-speech service
- **Amazon Translate**, which provides high-quality translations for a variety of languages
- **Amazon Lex**, which is a service for building chatbots and conversational interfaces

Amazon Comprehend

Amazon Comprehend uses DL algorithms to analyze and understand text data in multiple languages. Amazon Comprehend can perform the following functions:

- **Language detection**: Automatically detect the language of the text data, which is useful in multilingual applications
- **Sentiment analysis**: Determine the sentiment of text data: positive, negative, or neutral
- **Entity recognition**: Identify and extract entities from text data, such as people, organizations, locations, and dates
- **Key phrase extraction**: Extract key phrases from text data, such as important topics or keywords
- **Topic modeling**: Identify topics in text data and group them based on their similarity
- **Custom classification**: Allows users to create custom classifiers for specific use cases, such as categorizing customer feedback into different categories

Amazon Comprehend provides a powerful set of NLP capabilities that can be used in a variety of applications, such as customer service, social media monitoring, content analysis, and compliance monitoring.

Amazon Transcribe

Amazon Transcribe is a speech recognition service that uses advanced ML algorithms to convert audio and video files into text transcripts in real time or asynchronously. Here are some key features of Amazon Transcribe:

- **Speech-to-text conversion**: It can transcribe audio and video files into text transcripts, with support for multiple languages and dialects
- **Real-time transcription**: It can transcribe live audio and video streams in real time, making it useful for applications such as call centers and live events
- **Speaker identification**: It can identify individual speakers in a multi-speaker audio or video file and label each spoken word with the corresponding speaker ID
- **Automatic punctuation**: It can add appropriate punctuation to the transcribed text, making it easier to read and understand
- **Custom vocabulary**: It allows you to upload custom vocabularies that can be used to improve the accuracy of the transcription for a domain-specific language
- **Compliance and security**: It is designed with strong security and compliance features, such as encryption, access controls, and compliance with GDPR and other regulations

Amazon Transcribe provides powerful speech-to-text capabilities that can be used in a variety of applications, such as call transcription, captioning, subtitling, and voice search.

Amazon Polly

Amazon Polly is a text-to-speech service that uses advanced DL technologies to create natural-sounding speech from text. Amazon Polly supports a wide range of languages and voices, including male and female voices with different accents and styles. The service can generate speech in real time, allowing applications to provide dynamic and responsive voice output. Amazon Polly also supports the use of **Speech Synthesis Markup Language** (**SSML**), which allows developers to fine-tune the pronunciation and intonation of the generated speech. Some of the key benefits of using Amazon Polly include the following:

- **High-quality speech output**: Amazon Polly uses advanced neural text-to-speech technology to create natural-sounding speech with lifelike intonation and pronunciation.
- **Customizability**: Developers can control various aspects of the speech output, such as voice, intonation, and pronunciation, to create a more personalized and engaging experience.
- **Cost-effectiveness**: Amazon Polly offers pay-as-you-go pricing, which means that you only pay for what you use.
- **Easy integration**: Amazon Polly provides a simple API that developers can use to integrate speech capabilities into their applications. The service can be used with a variety of programming languages and platforms, including Java, Python, and .NET.

Amazon Polly can be used in e-learning, gaming, accessibility, and more. It can also be used in conjunction with other AWS services, such as Amazon Lex and Amazon Comprehend, to create more sophisticated and intelligent voice-based applications.

Amazon Translate

Amazon Translate is a fully managed machine translation service that translates text in multiple languages. Some key features of Amazon Translate are as follows:

- **Language translation**: Translate can translate text from one language to another, with support for over 70 languages
- **Real-time translation**: Translate can translate text in real time, making it useful for applications such as chatbots and customer support
- **Batch translation**: Translate can translate large volumes of text in batches, making it useful for tasks such as website localization
- **Custom terminology**: Translate allows you to upload custom terminology that can be used to improve the accuracy of the translation for a domain-specific language
- **Neural machine translation**: Translate uses a neural machine translation engine that provides high-quality translations that are more accurate and natural sounding than traditional machine translation methods
- **Automatic language detection**: Translate can automatically detect the language of the input text, making it easier to use in multilingual applications
- **Compliance and security**: Translate is designed with strong security and compliance features, such as encryption, access controls, and compliance with GDPR and other regulations

Amazon Translate provides a powerful set of machine translation capabilities that can be used in a variety of applications, such as e-commerce, customer service, and content localization. It allows businesses to expand their reach globally by providing quick and accurate translations of their content in multiple languages.

Amazon Lex

Amazon Lex is a service that enables developers to build conversational interfaces and chatbots using NLP and **automatic speech recognition** (**ASR**) technologies. Amazon Lex can be used to create chatbots for a wide range of applications, including customer service, e-commerce, and education. Some of the key features of Amazon Lex include the following:

- **Natural language understanding**: Amazon Lex uses advanced NLP technology to understand natural language input and map it to intents and slots

- **Automatic speech recognition**: Amazon Lex can process spoken language and convert it into text, enabling users to interact with chatbots through voice commands
- **Multi-platform support**: Amazon Lex provides SDKs for several popular platforms, including iOS, Android, and JavaScript, enabling developers to build chatbots for web and mobile applications
- **Integration with other AWS services**: Amazon Lex can be integrated with other AWS services, such as Amazon Lambda, Amazon DynamoDB, and Amazon S3, to create more sophisticated chatbots
- **Scalability**: Amazon Lex is designed to handle large volumes of requests and can scale automatically based on demand

Using Amazon Lex, developers can create chatbots that can handle simple and complex interactions with users, such as answering questions, providing recommendations, and processing transactions. Chatbots built with Amazon Lex can be deployed across multiple channels, including web, mobile, and messaging platforms, providing a seamless and consistent user experience.

These AWS NLP services are easy to access and set up from the console or CLI. We will not show any hands-on examples here. Please feel free to explore these services by yourself.

Summary

In this chapter, we have discussed AWS ML services. We started by introducing ML concepts and the ML pipeline, then dove into Amazon SageMaker, which provides fully managed end-to-end ML services. We then introduce DL concepts and examined the AWS computer vision and NLP solutions using DL pretrained models.

So far, we have explored AWS cloud services such as compute, storage, networking, databases, big data, and ML. In the next chapter, we will discuss another important cloud topic: Amazon cloud security.

Practice questions

Questions 1-4 are based on the following use case.

ML case #1

An engineer is training an Amazon SageMaker model to detect as many true **malignant tumors** (**MTs**) from MRI images as possible. The model features are shown in *Figure 6.18*.

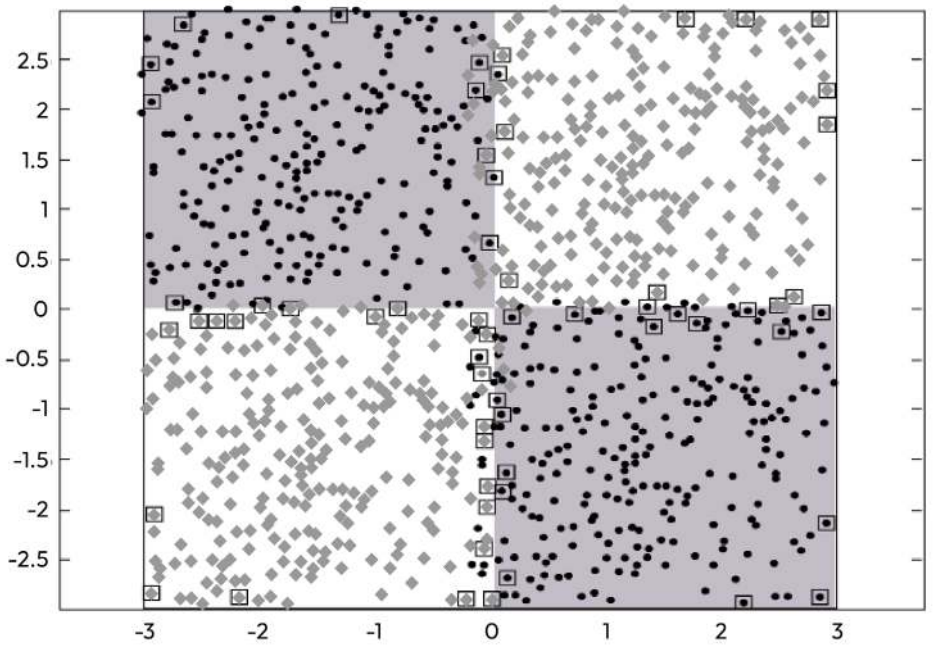


Figure 6.18 – Model features: x and y

The initial models were underfitting, so they put in a lot of effort and finally got two models working. Their confusion matrixes are shown in *Figure 6.19*:

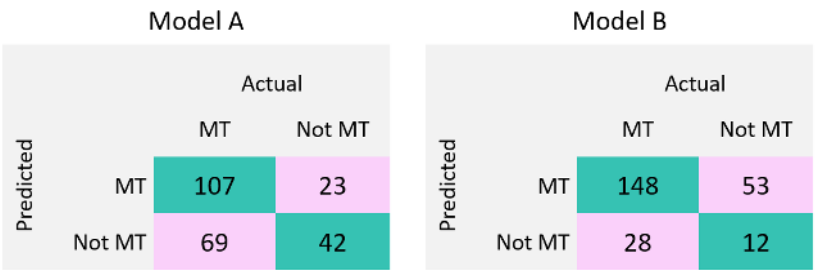


Figure 6.19 – Confusion matrixes for models A and B

1. How should they synthesize the two features, *x* and *y*?

A. *x*x + y*y*

B. *x+y*

C. *x*y*

D. *x*10 + y*10*

2. What is the precision for model B?

A. 74%

B. 84%

C. 18%

D. 50%

3. What may have helped them improve the initial model?

A. Add more features to the model

B. Add L1 regularization

C. Add L2 regularization

D. Increase the learning rate

4. Which of the following statements is true?

A. Model B is better

B. Model A is better

C. We need an ROC curve to decide

D. We need an F1 core to decide

Questions 5-10 are based on the following use case.

ML case #2

An engineer is building a DL model to predict whether images contain a driver's license, passport, or credit card. The code and initial training results are shown in *Figure 6.20*:

```
#Import keras
model = keras.sequential
model.add(layers.Dense(128,activation='relu',input_shape=(16,
)))
model.add(layers.Dense(24,activation='relu'))
model.add(layers.Dropout(rate=0.25))
model.add(layers.Dense(3,activation='softmax'))
model.compile(sgd(lr=0.5), loss='categorical_crossentropy',
metrics=['accuracy'])
model.fit(train_set, train_label, batch_size=20, epochs=30,
shuffle=True)
```

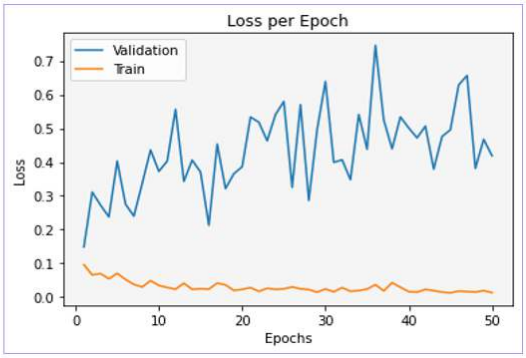


Figure 6.20 – DL model and initial training results

5. What optimizer did they use?

a. Sequential

b. ReLU

C. Softmax

D. Stochastic gradient descent

6: What kind of problem are they likely to solve?

A. Binary classification

B. Regression

C. Multi-classification of three: a dog, a cat, or a giraffe

D. Multi-classification of "a combination of three": a dog, a cat, and a giraffe

7: How many trainable weights does the model have?

A. 16x128+128x24x0.25+24x3

B. 16x128x24x3

C. 16+128+24x0.25+3

D. 16x128+128x24+24x3

8: How can they improve the model generality?

A. Decrease the learning rate to 0.2

B. Apply regularization

C. Increase epochs to 60

D. Decrease the batch size to 10

9. How can they make the model converge?

A. Decrease the learning rate to 0.2

B. Apply regularization

C. Increase epochs to 60

D. Decrease the batch size to 10

10. Which of the following is likely a label for the training dataset?

A. `drivers_license`

B. `passport`

C. `credit_card`

D. `[drivers_license, passport, credit_card]`

Questions 11-14 are based on the use case and diagrams shown in *Figure 6.21*:

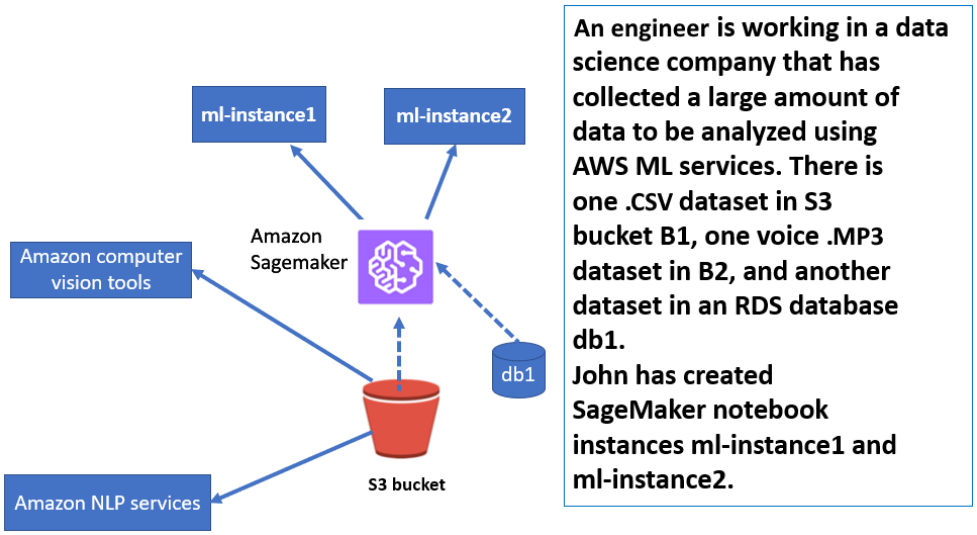


Figure 6.21 – DL model training architecture

11. They are using `ml-instance1` to train ML models using `.csv` files in B1. It has taken a long time and they want to improve the performance. What is your suggestion?

A. Use SageMaker Pipe mode

B. Copy the `.csv` files to `ml-instance1`

C. Use Amazon Kinesis to stream data from B1 to `ml-instance1`

D. Use AWS Glue to transform the CSV dataset to JSON format first

12. They want to analyze the voice recordings in B2 to understand the topics with minimum effort. What is your suggestion?

A. Amazon Transcribe + a custom NLP algorithm with Amazon SageMaker

B. SageMaker BlazingText algorithm + Amazon Transcribe

C. A custom NLP algorithm with Amazon SageMaker + Amazon Transcribe

D. Amazon Transcribe + Amazon Comprehend

13. They and their coworkers have deployed many SageMaker notebook instances, and each team member only needs access to their personal instances. What is your recommendation?

A. Create an IAM policy for each member and grant access to their personal instances only

B. Use port forwarding to prevent all internet traffic from being forwarded to the notebook instances

C. Use Amazon CloudWatch to monitor and restrict unauthorized access

D. Attach an Amazon S3 bucket policy to restrict access to the buckets that contain other users' notebook instances

14. They checked all the VPCs and could not find `ml-instance1`. What is the reason?

A. `ml-instance1` is hidden in the VPCs of John's account

B. `ml-instance1` is run in the ECS service of John's account

C. `ml-instance1` is run in SageMaker-managed VPCs

D. `ml-instance1` is run in the root user's VPCs

15. They wants to use the dataset in `db1` to train a model on `ml-instance2`. What is your recommendation?

A. Build a connection from `db1` to `ml-instance2`

B. Transform data from `db1` to S3 and provide the S3 location to `ml-instance2`

C. Move data to Amazon Redshift and build a connection between Redshift and `ml-instance2`

D. Move data to `ml-instance2` directly from `db1`

Answers to the practice questions

1. C

2. A

3. A

4. A

5. D

6. D

7. A

8. B

9. A

10. D

11. A

12. D

13. A

14. C

15. B

Further reading

For further insights into what you've learned in this chapter, refer to the following links:

- `https://aws.amazon.com/sagemaker/`
- `https://docs.aws.amazon.com/sagemaker/index.html`
- `https://aws.amazon.com/rekognition/`
- `https://aws.amazon.com/comprehend/`
- `https://aws.amazon.com/transcribe/`
- `https://aws.amazon.com/polly/`
- `https://aws.amazon.com/translate/`
- `https://aws.amazon.com/lex/`

7

Amazon Cloud Security Services

Information security is protecting data and resources including sensitive information, computer systems, networks, and so on from unauthorized access, disruption, theft, or damage. Security also prevents attacks with a quick and effective response if an attack does occur. Effective security requires a combination of people, technologies, and processes.

Amazon Cloud Security protects data and resources on the AWS cloud platform. AWS provides a comprehensive cloud security model and a set of services to help customers secure their cloud-based applications and infrastructure. In this chapter, we will discuss the following topics:

- **AWS cloud security model**: The customer is responsible for the security of the cloud, and the provider is responsibility for security in the cloud.
- **AWS Identity and Access Management**: A cloud security service that enables customers to centrally manage access to AWS resources and services. Access is the first line of security defense, and this is where we practice the *least privilege* and *minimum attack surface* security principles.
- **AWS infrastructure security**: The security of Amazon cloud infrastructure, including cloud *endpoint* resources such as EC2, RDS, S3, and cloud *network* resources such as VPCs and subnets. This is where we practice the *zero-trust* security principle and the *multi-layer protection* security principle.
- **AWS data security**: Cloud data protection, including data encryption at rest and in transit, and encryption key management. This is where we enforce the *most encryption* security principle.
- **AWS cloud logging and monitoring**: Tracing all cloud assets and activities, all the time. This is where we enforce the *traceability* security principle.
- **AWS cloud threat detection and remediation**: Threat detection and remediation in the cloud. We will conduct a case study about *a threat auto-detection and auto-remediation ecosystem*.

We will start our journey with the AWS cloud security model.

Amazon cloud security model

The **AWS shared responsibility model** is about the responsibilities of AWS and its customers. AWS is responsible for the *security of the cloud*, including the physical infrastructure, network, hypervisor, and so on that supports the customer's applications and data. The customer is responsible for *security in the cloud*, including customers' data, applications, and other configurations that are hosted on the AWS infrastructure, such as access management, firewall configurations, data encryptions, and so on.

Based on the shared responsibilities, AWS provides a multi-layered security model to protect customer data and resources in the cloud, including the following layers:

- **Physical/hardware**: AWS data centers are designed and managed to comply with security standards and regulations by employing physical security equipment such as access control systems, surveillance cameras, and perimeter fencing to prevent unauthorized access. These are Amazon's responsibility and AWS provides an on-demand service called **AWS Artifact** that offers access to a central repository of physical security and compliance reports audited by third parties.
- **IAM**: AWS gives customers the ability to manage user access and permissions to AWS services and resources. With IAM, customers can create and manage IAM users, groups, and roles to control access to AWS services.
- **Network security**: AWS provides network security measures such as VPCs, SGs, and NACLs to ensure that data traffic between resources is protected and controlled. Customers are responsible for configuring the cloud VPCs, SGs, and NACLs.
- **Data encryption**: AWS offers multiple encryption options, including server-side encryption, client-side encryption, and **Key Management Service** (**KMS**), to protect data at rest and in transit.
- **Compliance and auditing**: AWS provides compliance and auditing capabilities to meet various industrial regulatory requirements and standards, such as HIPAA, SOC 2, PCI DSS, and ISO 27001.
- **Application security**: AWS offers security tools and services, such as **AWS Web Application Firewall** (**WAF**) to protect against web application attacks, and **AWS Shield** to protect against **Distributed Denial of Service** (**DDoS**) attacks.

AWS's multi-layered cloud security model provides a comprehensive approach to securing cloud resources and allows customers to build and deploy applications securely in the cloud. Let's explore Amazon IAM first.

Amazon IAM

IAM manages resource identity and accessibility, including authentication, authorization, and accounting.

Authentication is authenticating an identity to access an information system. One of the important security features of IAM is that it supports **Multi-Factor Authentication** (**MFA**), which requires users to provide a second form of authentication, such as a one-time token, or biometric identity, in addition to their username and password. IAM also supports *identity federation*, which allows customers to integrate their existing identity management systems with AWS, enabling users to sign into AWS using their existing credentials, such as Google or Meta logins, and so on.

Authorization is the user's permission once they are authenticated in the system. With IAM, customers can create and manage AWS users and groups, and define permissions that grant or restrict access to specific AWS resources. Authentication defines who can perform which actions on what resources. The *Who* can be a user, a group, or a role. IAM supports **Role-Based Access Control** (**RBAC**), which allows customers to assign permissions to roles rather than individual users. The *What* is cloud resources including EC2, EBS, EFS, S3, VPC, and so on, and the *Which* is the actions that the *Who* can take on *What*.

Auditing is logging and tracking user activities in the AWS cloud. We will explore more about AWS auditing in the *Monitoring and logging* portion of this chapter.

IAM policies

In AWS IAM, *every permission is a policy*. IAM permissions are defined with an AWS policy – a JSON document. The following is a sample policy:

```
{
    "Version": "2012-10-17",
    "Statement": [
        {
            "Sid": "AllowReadAccess",
            "Effect": "Allow",
            "Action": [
                "s3:*"
            ],
            "Resource": [
                "arn:aws:s3:::bucket1",
                "arn:aws:s3:::bucket1/*"
            ]
        }
    ]
}
```

The preceding policy defines the permissions as "*any S3 actions against an S3 bucket named bucket1*." If we attach this policy to a user, then the user will have all the permissions to act against *bucket1*. Since this policy defines permissions on specific resources, it is a *resource-based IAM policy*. There is another type of policy that defines permissions on the principal (user, group, role, identities), and we call it an *identity-based IAM policy*. The following example shows an identity-based IAM policy:

```
{
    "Version": "2012-10-17",
    "Statement": {
        "Effect": "Deny",
        "Action": "*",
        "Resource": "*",
        "Condition": {
            "NotIpAddress": {
                "aws:SourceIp": [
                    "10.10.0.0/16",
                    "8.8.0.0/16"
                ]
            }
        }
    }
}
```

We will create several IAM policies and see how they are used in managing S3 objects

1. Log in to the AWS console as an admin, and create the following four policies:

- **Policy A "userjohn"**: This policy defines read-only resource permissions and assume-role permissions:

```
{
    "Version": "2012-10-17",
    "Statement": [
        {
            "Action": [
                "iam:Describe*",
                "iam:GetAccountAuthorizationDetails",
                "iam:GetPolicy",
                "iam:GetRole",
                "iam:GetRolePolicy",
                "iam:GetUser",
                "iam:GetUserPolicy",
                "iam:List*",
                "logs:Desc*",
                "logs:Get*",
                "logs:List*",
```

```
                "s3:ListAllMyBuckets",
                "s3:ListBucket",
                "s3:PutAccountPublicAccessBlock",
                "s3:PutBucketOwnershipControls",
                "s3:PutBucketPublicAccessBlock",
                "sts:AssumeRole"
            ],
            "Resource": "*",
            "Effect": "Allow"
        }
    ]
}
```

- **Policy B "switchrole"**: This policy defines `list bucket` and `get bucket` permissions for all S3 buckets, and `list, get (download) objects` permissions for an S3 bucket named `03252023-bucket1`:

```
{
    "Version": "2012-10-17",
    "Statement": [
        {
            "Action": [
                "s3:GetBucketPolicy",
                "s3:ListBucket"
            ],
            "Resource": "*",
            "Effect": "Allow"
        },
        {
            "Action": [
                "s3:GetObject",
                "s3:ListObjects",
                "s3:ListBucket"
            ],
            "Resource": [
                "arn:aws:s3:::03252023-bucket1",
                "arn:aws:s3:::03252023-bucket1/*"
            ],
            "Effect": "Allow"
        }
    ]
}
```

- **Policy C "trustpolicy"**: This allows the user `userjohn` to assume the role assigned to it:

```
{
    "Version": "2012-10-17",
```

```
    "Statement": [
        {
            "Effect": "Allow",
            "Principal": {
                "AWS": "arn:aws:iam::317332158300:root"
            },
            "Action": "sts:AssumeRole",
            "Condition": {}
        },
        {
            "Effect": "Allow",
            "Principal": {
                "AWS": "arn:aws:iam::317332158300:user/userjohn"
            },
            "Action": "sts:AssumeRole"
        }
    ]
}
```

- **Policy D "bucket2-permission"**: This gives the `switchrole` role `list bucket` and `get/put objects` permissions on `03252023-bucket2`:

```
{
    "Version": "2008-10-17",
    "Statement": [
        {
            "Sid": "S3Write",
            "Effect": "Allow",
            "Principal": {
                "AWS": "arn:aws:iam::317332158300:role/
switchrole"
            },
            "Action": [
                "s3:GetObject",
                "s3:PutObject"
            ],
            "Resource": "arn:aws:s3:::03252023-bucket2/*"
        },
        {
            "Sid": "ListBucket",
            "Effect": "Allow",
            "Principal": {
                "AWS": "arn:aws:iam::317332158300:role/
switchrole"
            },
            "Action": "s3:ListBucket",
```

```
            "Resource": "arn:aws:s3:::03252023-bucket2"
        }
    ]}
```

2. As the AWS account admin, create a user, a role, and some S3 buckets:

   I. Under IAM, create a user named `userjohn` with AWS console access, and assign permission policy A, `userjohn`, to the `userjohn` user.

   II. Create a role named `switchrole` with permission policy B, `switchrole`, and trust policy C, `trustpolicy`, as shown in *Figure 7.1*.

   III. Under the S3 console, create two buckets named `03252023-bucket1` and `03252023-bucket2`:

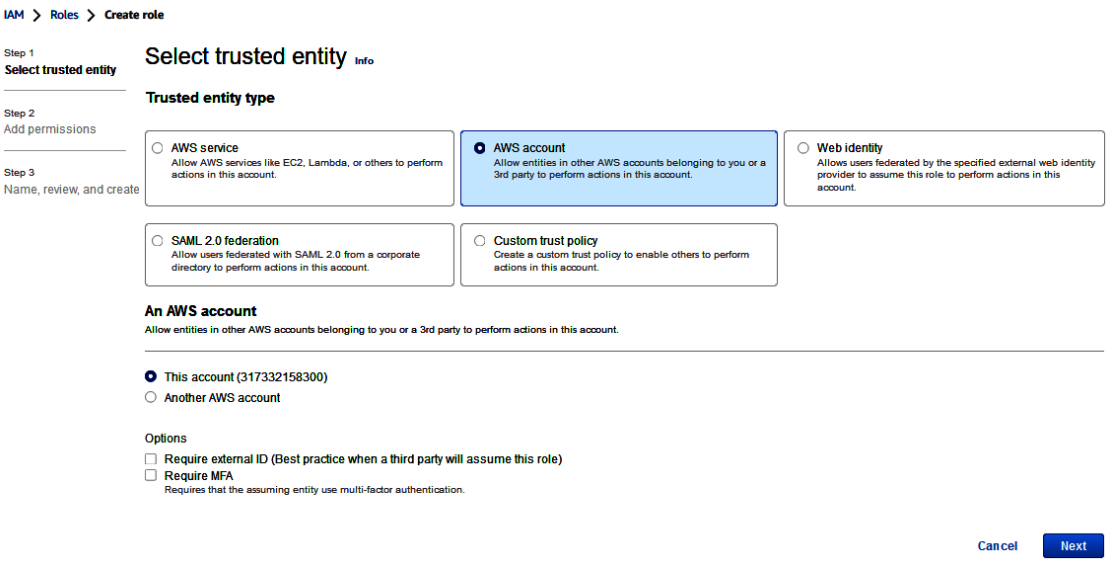


Figure 7.1 – Create an IAM role called "switchrole"

3. **Log in to the AWS console as the userjohn user**:

Based on the authorization defined in the policy, `userjohn` will have read-only permission in the EC2 dashboard or S3 console, as shown in *Figure 7.2*:

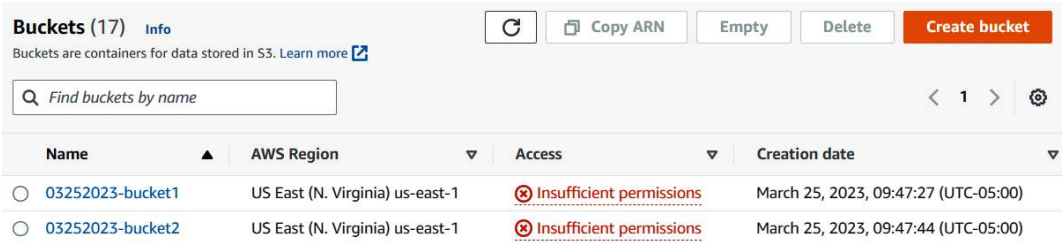


Figure 7.2 – userjohn has read-only permissions

Go to the S3 console and try to upload an object to the two S3 buckets. It will fail since the user has read-only permissions to the S3 bucket. This is shown in *Figure 7.3*:

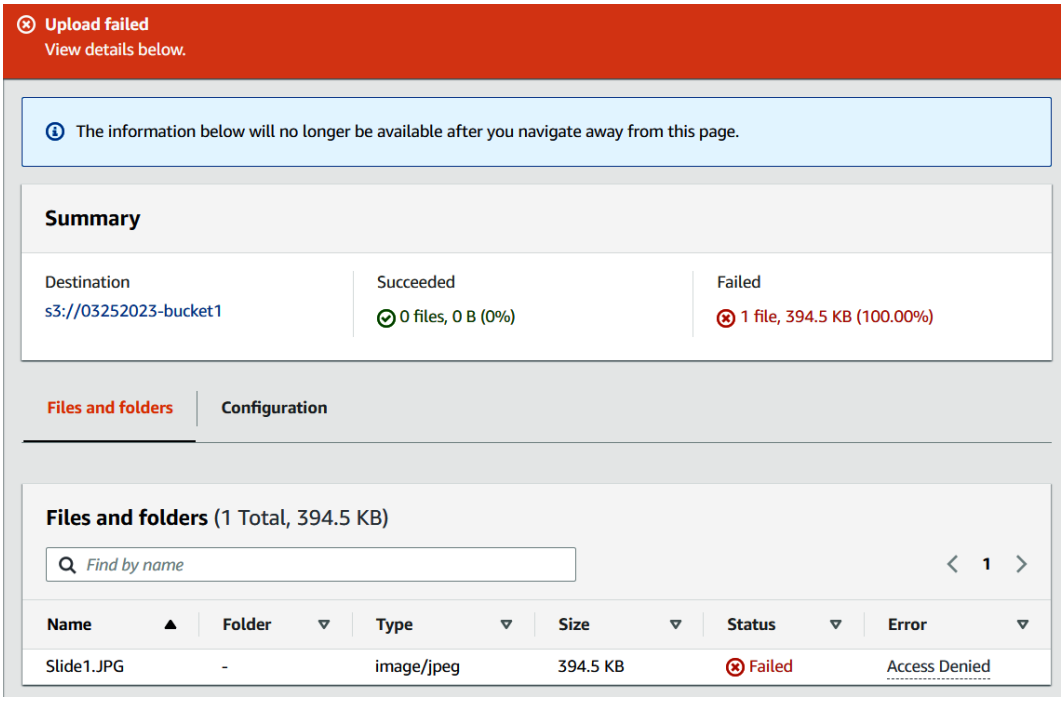


Figure 7.3 – userjohn uploading an image to bucket1 failed

4. Switch role and upload the object to **bucket1**:

   Go to the AWS console and click **userid** in the top-right corner; select **Switch Role**. Fill in the AWS account number and enter `switchrole` as the role name, as shown in *Figure 7.4*:

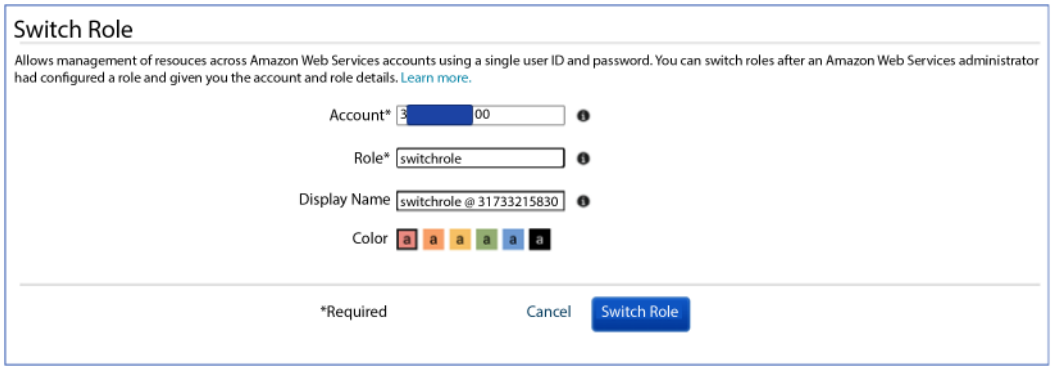


Figure 7.4 – Switch role from userjohn to switchrole

   After switching to the role, you will be able to upload objects to the `03252023-bucket1` S3 bucket since `switchrole` has the right permissions assigned to it. However, you still cannot upload objects to the `03252023-bucket2` S3 bucket since no permissions are granted to it. We will fix that with the admin account.

   Open another window, log in to the AWS console as `admin`. Go to bucket `03252023-bucket2`, and add policy D, `bucket2-permission`, to it

- Go back to the AWS console window where you're logged in as `userjohn`.

Upload an object to bucket `03252023-bucket2` again, and now it succeeds since `03252023-bucket2` is assigned the `bucket2-permission` policy, which permits `switchrole` to put objects. This is shown in *Figure 7.5*:

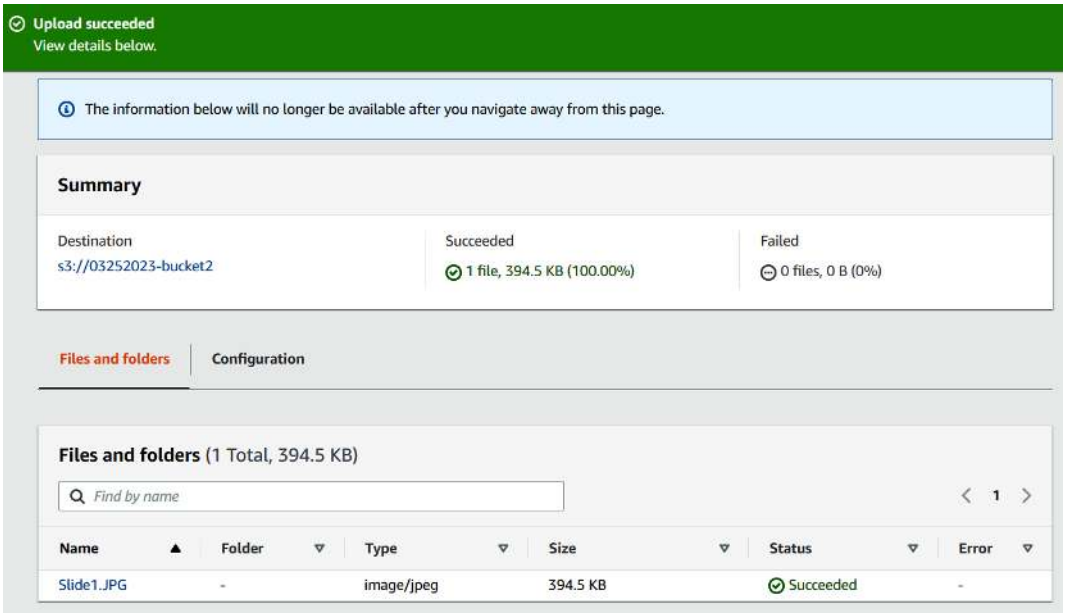


Figure 7.5 – userjohn uploading to bucket2 succeeds

From the preceding process, we can see that all the IAM permissions are defined as policies, so we can assign permissions to users, groups, roles, and S3 buckets, and we can switch roles to get different permissions for AWS resources.

In summary, AWS IAM provides customers with a powerful set of tools for managing AWS cloud resources. In the next section, we will further explore AWS infrastructure security.

AWS infrastructure security

The basic unit of AWS infrastructure is the *12-digit AWS account* that we have been logging in to and configuring our cloud services with. When you have many AWS accounts, it is necessary to have an infrastructure hierarchy – called **AWS Organizations** – to manage these accounts. In this section, we will first discuss the AWS resource organization hierarchy and security policies, and then inspect security for the AWS basic infrastructure components: EC2, S3, VPC, databases, and many others.

AWS Organizations

AWS Organizations consolidates multiple accounts into a central management unit, to manage business budgets, security, and compliance. With AWS Organizations, you can do the following:

- Automate AWS account creation and management using AWS APIs
- Consolidate billing and perform cost management across many AWS accounts, at various levels of your organization

With IAM policies, you can manage permissions for AWS users, groups, or roles, but you cannot restrict the AWS account root user. However, with Organizations, you can use **service control policies** (**SCPs**) to manage access to AWS services for individual AWS accounts, or for groups of accounts in an **Organization Unit** (**OU**), as shown in *Figure 7.6*:

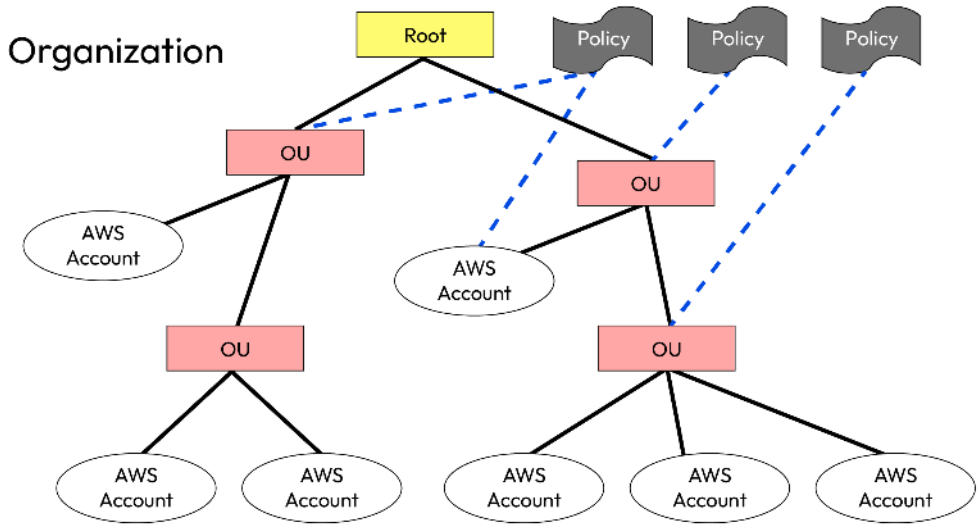


Figure 7.6 – AWS Organizations

Having reviewed security at the OU and account levels, now let's look at security management at the resource and service levels.

AWS resource security

We will discuss AWS resource security in the following basic domains:

- AWS compute security, mainly EC2
- AWS storage security, mainly S3

- AWS network security (VPC)
- AWS data security, including databases, big data, and machine learning

Amazon compute security

We discussed EC2 in *Chapter 1*. EC2 instances are virtual machines that customers can launch in the AWS cloud to run applications and services. The key security features of AWS EC2 include the following:

- **Instance isolation**: EC2 instances are isolated from each other using virtualization technology. This ensures that a security breach in one instance does not affect other instances running on the same host.
- **EBS encryption**: EBS is a block-level storage service used by EC2 instances. EBS volumes can be encrypted to ensure that data is protected at rest.
- **AMIs**: AMIs are pre-configured templates for EC2 instances that include operating systems, applications, and other software. Customers can create their own custom AMIs to ensure that their instances are pre-configured with the necessary security settings.
- **IAM**: IAM enables customers to create IAM policies that control who can launch and terminate instances, as well as access their instances using the AWS Management Console.
- **SGs**: EC2 instances are secured using security groups, which act as virtual firewalls. Customers can define inbound and outbound rules for each security group to control access to their instances.
- **Key pairs**: EC2 instances are accessed using key pairs, which consist of a public and private key. Customers can use key pairs to securely log in to their instances.

By following best practices and using these features, customers can secure and protect compute resources from unauthorized access.

Amazon storage security

We discussed S3 in *Chapter 2*. Amazon S3 is a cloud-based storage service that is designed to provide secure and scalable storage for businesses and developers. The key security features of AWS S3 are as follows:

- **Access controls**: S3 enables customers to set access controls on their buckets, including bucket policies and access control lists. We discussed bucket-level permission policies earlier in this chapter.
- **MFA delete**: This requires an authentication code from an MFA device before allowing the deletion of objects in an S3 bucket.
- **Versioning**: This supports multiple versions of objects to protect against the accidental deletion or modification of objects.

- **Encryption**: S3 supports server-side encryption for data at rest. Customers can choose to encrypt their data using different encryption methods.
- **Access logging**: S3 provides access logging, which enables customers to log all requests made to their buckets, to help with audit and compliance requirements.
- **Cross-region replication**: S3 provides cross-region replication, which enables customers to replicate their data across multiple regions. This can help with disaster recovery and data resilience.

Amazon storage provides a range of security features and controls to secure cloud storage from unauthorized access.

Amazon network security

We discussed VPC in *Chapter 3*. Amazon VPC is a cloud network service that allows customers to create an isolated network within the AWS cloud, to deploy cloud resources such as Amazon EC2 instances, databases, and so on. Here are some of the key security features of AWS VPC:

- **Network isolation**: VPC enables customers to create a private network within the AWS cloud. This network is isolated from the public internet and other VPCs, providing an additional layer of security.
- **Private subnets**: VPC allows customers to create private subnets within their VPC that have no direct access to the internet. Resources in private subnets can only communicate with other resources within the VPC.
- **Network ACLs**: VPC provides network **Access Control Lists** (**ACLs**), which are stateless and allow customers to control inbound and outbound traffic at the subnet level. Network ACLs can be used in conjunction with security groups to provide layered security.
- **VPN connections**: VPC provides the ability to establish VPN connections between the customer's on-premises network and their VPCs, to securely access resources within their VPC from their on-premises network.
- **VPC Flow Logs**: This enables you to record the traffic flowing to and from resources in VPCs, to analyze, troubleshoot, and audit network traffic flows.

AWS VPC and VPC peering secure cloud networks in multiple layers, including VPC routers and routing tables, firewalls (NACLs and SGs), and monitoring and logging tools (such as Flow Logs). Third-party tools such as Palo Alto virtual firewall appliances can also be deployed into VPCs for secure traffic management.

Amazon data security

We discussed AWS databases in *Chapter 4*, data analytics in *Chapter 5*, and ML in *Chapter 6*. These data services provide built-in security features to help customers protect their data stored in the cloud, including the following:

- **Encryption**: AWS provides various encryption options to help customers protect their data at rest and in transit. For example, RDS supports encryption at rest using **AWS Key Management Service** (**KMS**), DynamoDB supports server-side encryption, and Kinesis supports the encryption of data in transit using SSL/TLS, and also provides the option to encrypt data at rest using server-side encryption or customer-managed keys with AWS KMS.
- **Access controls**: AWS database services provide various access control mechanisms, such as IAM policies, database-specific access controls, and VPC security groups. IAM policies can be used to restrict access to Glue, EMR, Athena, and other resources. These access controls enable customers to restrict access to their databases and data.
- **Auditing and logging**: AWS database and data analytics services provide various auditing and logging features, such as AWS CloudWatch, CloudTrail, RDS audit logs, DynamoDB streams, and EMR logs. These features allow customers to track and monitor database activity and can be used for compliance and auditing purposes.
- **Backup and recovery**: AWS database and data analytics services provide backup and recovery features to help customers protect against data loss. For example, Amazon RDS provides automated backups and snapshots, and Amazon DynamoDB provides point-in-time recovery.
- **Data replication**: AWS database and data analytics services provide various data replication options, such as multi-AZ deployments, read replicas, and global tables. These replication features can help improve database performance and availability while also providing data redundancy and disaster recovery capabilities.
- **Compliance**: AWS database services comply with various industry standards and regulations, such as HIPAA, PCI DSS, and GDPR. Customers can use these services to help meet their compliance requirements.

Overall, AWS database services provide a range of security features and controls to help customers protect their data stored in the cloud. In the next section, we will discuss data encryption.

Amazon data encryption

Data encryption is a must for securing sensitive data in the cloud. As we have discussed, almost all the AWS cloud data services provide data encryption. In this section, we will spend time introducing AWS KMS and explain how it is leveraged in S3 object encryption using an example.

KMS is a fully managed service to manage encryption keys. It is designed to simplify the process of creating and managing encryption keys, whether they are stored in Amazon S3, EBS, RDS, or other services. AWS KMS provides the following:

- **Centralized key management**: With AWS KMS, you can centrally manage encryption keys used to protect your data across multiple AWS services and applications.
- **Customizable key policies**: You can set fine-grained access controls on your encryption keys to define who can use them and under what conditions.
- **Encryption key creation**: AWS KMS enables you to create new encryption keys, import your own keys, and manage the lifecycle of your keys.
- **Integration with other AWS services**: AWS KMS is tightly integrated with other AWS services, making it easy to use encryption to protect your data across your entire cloud environment.
- **Auditing and compliance**: The AWS KMS service provides detailed logging and auditing capabilities that help you meet regulatory and compliance requirements.

Now let us dive into the encryption process of an S3 object, to understand how KMS is leveraged in securing AWS data in the cloud:

1. **Create a KMS key**:

   The *AWS KMS master key* is used to generate, encrypt, and decrypt *data keys* that will be shared with other AWS services, such as S3 and EC2, to encrypt the actual data stored in an S3 bucket and on EBS volumes.

   Log in to the AWS Management Console, use the IAM service to add the user group `keyadmin` as key administrators who will *manage access* to the encryption key, and add another group, `keyusers`, for key users who will *use the key* to encrypt and decrypt data.

   Go to the AWS KMS console and then **Customer Managed Keys** | **Create Key**:

- For **Key type**, choose **Symmetric**.
- For **Alias**, enter the name of the master key, `mk`.
- For **Key administrators**, select **keyadmin**.
- For **Define key usage permissions**, select **keyusers**.
- At the bottom of the **Review** page, choose **Finish**.

2. **Create an S3 bucket and upload an encrypted object**:

   Go to the S3 console and create a bucket named `data`. Click the bucket and choose the **Properties** tab. In the **Default encryption** section, notice that the setting is currently disabled for the bucket. We will upload a file to the bucket and store it as an encrypted object:

   i. At the top of the page, go to the **Objects** tab. Choose **Upload**, then **Add files**.

   ii. Browse to and select the `IMG2.jpg` file on your computer.

   iii. Expand the **Properties** section, and configure the following:

- In the **Server-side encryption settings** section, choose **Specify an encryption key**.
- For **Encryption key type**, choose **AWS Key Management Service key (SSE-KMS)**.
- For **AWS KMS key**, select **Choose from your AWS KMS keys**.
- From the **Available AWS KMS keys** drop-down menu, choose `mk`.

Figure 7.7 shows the encryption options:

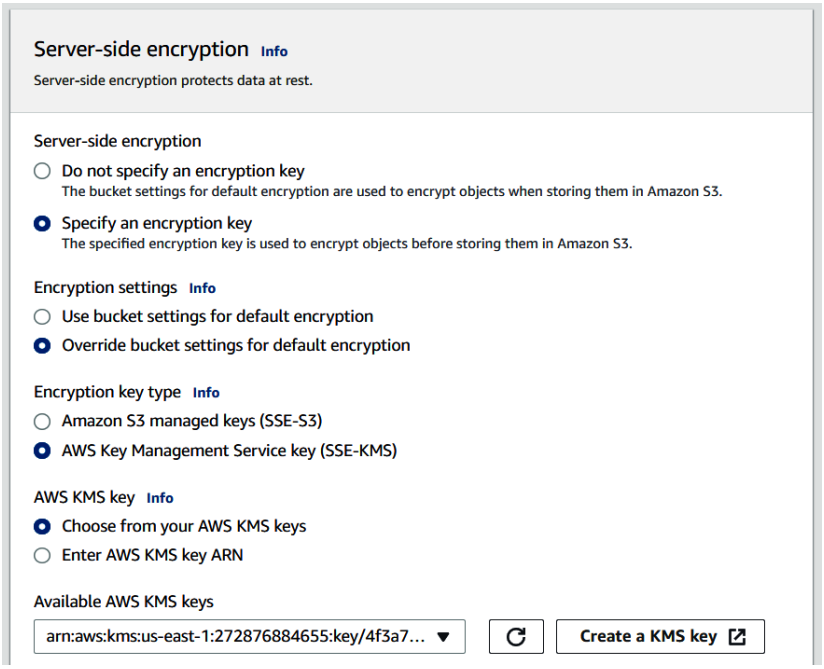


Figure 7.7 – Server side encryption

At the bottom of the page, choose **Upload**. Then click **Close** in the upper-right corner. Now, `IMG2.jpg` is listed as an object in the `data` bucket. Examine the object property and you will notice that server-side encryption using SSE-KMS is enabled on this object:

The following steps explain what transpired in the process of loading `IMG2.jpg` to `data`:

- The user requested to upload and store the `IMG2.jpg` file as an encrypted object in the data `bucket`.
- Amazon S3 requested a data key from AWS KMS to use to encrypt the file.
- AWS KMS generated a plaintext data key and encrypted the data key by using the customer-managed key `mk`.
- AWS KMS sent both copies of the data key to Amazon S3.
- Amazon S3 encrypted the object by using the plaintext data key, stored the object, and then deleted the plaintext data key. The encrypted key was kept in the object metadata.

When an object is stored in S3, the data key and the encrypted data (object) are both stored in S3. *Figure 7.8* gives an illustration.

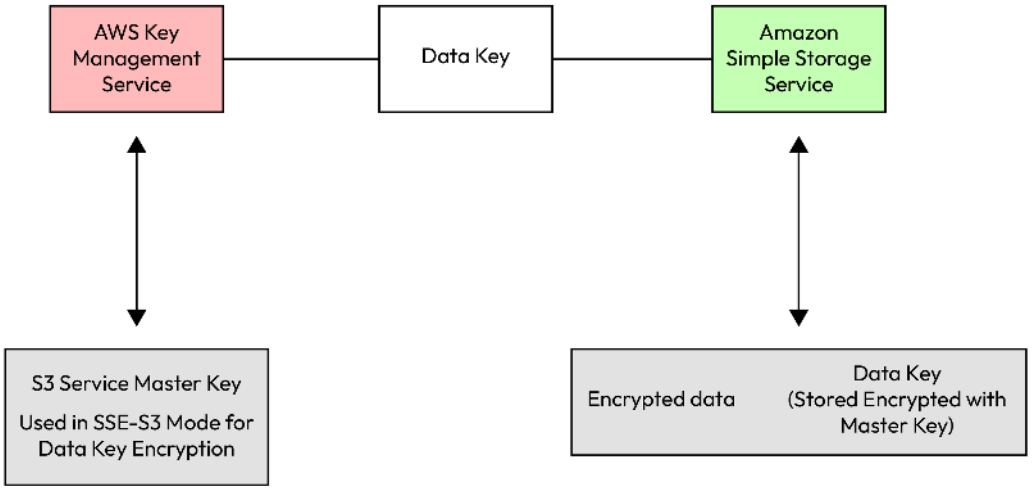


Figure 7.8 – Both data key and encrypted data are stored in S3

3. **Try to access the encrypted object**:

In the **Object overview** section at the top of the page, copy the object URL to your clipboard. Paste the object URL into a new browser tab and attempt to load the page. You will receive an **Access Denied** error, as shown in *Figure 7.9*:

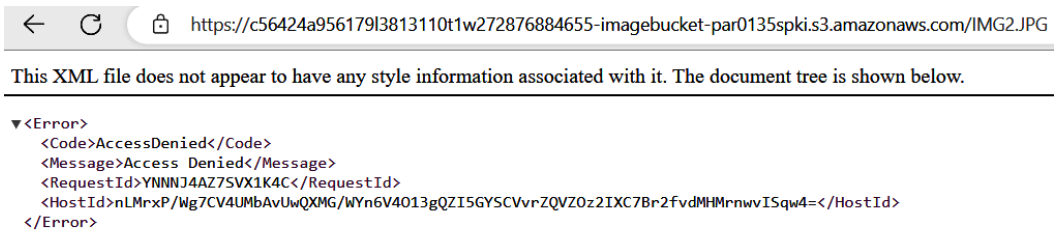


Figure 7.9 – Access Denied due to S3 bucket permissions

Now let's try to fix the problem by opening the S3 bucket and object permissions:

I.Go back to the S3 bucket and modify the public access permissions `bucket data`:

i.Choose the **Permissions** tab.

ii. In the **Block public access** section, choose **Edit**.

iii.Clear **Block all public access** and click **Save changes**.

iv.Also modify the access settings for the `IMG2.jpg` object:

- Choose the **Objects** tab and then select **IMG2.jpg**.
- Choose **Actions | Make public using ACL**.
- Choose **Make public**.

II.Return to the browser tab that you opened earlier and attempt to load the S3 object URL and refresh the page. You'll now see a different error as shown in *Figure 7.10*:

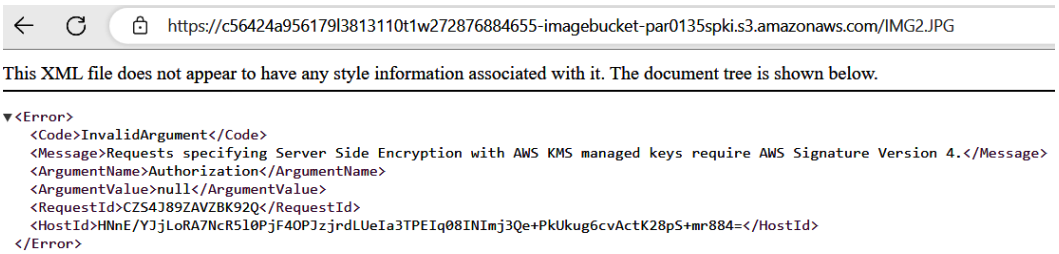


Figure 7.10 – Access Denied due to object encryption

4. **Access the encrypted object URL**:

In the Amazon S3 console, go to bucket `data`. On the **Objects** tab, select `IMG2.jpg`, and then choose **Open**. The image opens in a new tab or window. Why is that? If you analyze the URL that was used to successfully open the object, you will notice the format is something similar to the following:

```
https://c56424a956179l3813110t1w272876884655-imagebucket-
par0135spki.s3.us-east-1.amazonaws.com/IMG2.JPG?response-content
-disposition=inline&X-Amz-Security-Token=IQoJb3JpZ2luX2VjEC0aCXV
zLWVhc3QtMiJGMEQCIFlnR7JdNb%2BzVYg6onN9TAJnJbuBzkjTolw%2Frf%2BAA
4v8AiByWi%2BoCDH4NjN3kscEngRdMhS8PEQQxs6yWTEcMZFPair0Agj2%2F%2F%
2F%2F%2F%2F%2F%2F%2F%2F8BEAAaDDI3Mjg3Njg4NDY1NSIM%2BOXEy7qW4Ltud
kqZKsgCUDjCFWSoYDnEsuVFS3YzlARzGQnX%2FSNdy3EBYpXCw9cCsLuivYap9nn
f8FpYhTQpjw4Q5iHd7XZxBjsIFxwxWxftmM7GFR8pr3Bj33NCRckPshQ7%2FopYJ
%2FDulh5q3XOaXz5laSv6BzAfm1LTsXCRabgDwv0HKmsDvVcOfClt6%2BdJAuw2k
p5ipPNh1nA8F0GUyQly6w297lsF%2Bd8nblSqru4GFkuXQ90ioEm5B%2Fo3tDxDD
nOrzEXIXXfntnlcknr3Fov1e5TtrUKgln1BfOCnO0AdZvzgIncDTxsmpRonWWqK%
2FfWe7pMIX%2FxrSEpMZfHv5U6oACkEsm0nu6nfU2uOdXqbMfV1ijKowKY4DAdD0
goFJ1KBk%2BKi%2Fc86YIHndWjij%2BJlJe3Wxcf9sl%2F7fLpV5c3L9zM4sf1yb
rXZgiqRY7VB2PJzB3QTbzDuvv2gBjqIArm8e4LAAdY14psHogc%2FzaoF7xGd0Wy
9mLB9gWPru9wUmuDeP%2BS0737GQZXe50SvPGPuAUNOw1lxyAq87G04p62oKvkcF
n4j%2FEGKGHwVbdmtToVM%2BqlxtBbDBq%2BNoydhvBnUroXLx2fF2JyViodFPvM
YVJCvuAIRox9KKSvLH7oP8%2FuC2bm6cwjPGL04OhcftmKS%2BaRK0%2BcY0c9vN
%2FvkkNUswKsLoBoMDuso7TSBfXMEdxK5iW%2BQqORNKTs1Io051QyCqO0dvJ%2F
rJz5q0iki%2FqCNVUqP%2FQNPlUVrXvFtZVNJHh792jTVbE8KyUbBsu240uYPzr9
dbF%2FfKQlF%2FSgPey6rPbifBpnWuA%3D%3D&X-Amz-Algorithm=AWS4-HMAC-
SHA256&X-Amz-Date=20230325T212511Z&X-Amz-SignedHeaders=host&X-Amz
-Expires=300&X-Amz-Credential=ASIAT7CF22KX7N6F64VX%2F20230325%2
Fus-east-1%2Fs3%2Faws4_request&X-Amz-Signature=b8cbcea71f497aa8
9222025e7135026e6fc62d35e38bca020e479718fcc20624
```

The following steps explain what transpired in the preceding process of accessing `IMG2.jpg`:

- You requested to open an object.
- Next, Amazon S3 noticed that the requested object was encrypted. Because you were authenticated to the AWS account when using the Amazon S3 console, the signature version 4 authentication information was automatically included in the request.
- Amazon S3 then sent the encrypted copy of the data key that the object was encrypted with to AWS KMS.
- AWS KMS then decrypted the data key by using the AWS KMS key (which never leaves the AWS KMS service).
- AWS KMS then sent the plaintext data key back to Amazon S3.

Finally, Amazon S3 decrypted the ciphertext of the data object, allowed you to open the object, and deleted the plaintext copy of the data key.

5. **Verify the events from the CloudTrail event history**:

CloudTrail provides an audit log of API calls that are made in the AWS account, and its event history provides access to events from the last 90 days of account activity. Each time an API call is made to an AWS service within the Region that you have selected, if that service reports such events to CloudTrail, then the event and the AWS service that reported the event are listed.

In the search box to the right of **Services**, search for and choose **CloudTrail** to open the CloudTrail console. In the navigation pane, choose **Event history**.

Click on the drop-down menu on the left that currently displays **Read-only** and choose **Event source**. In the **Enter an event source** search box, search for `kms` and choose **kms.amazonaws.com**, as shown in *Figure 7.11*:

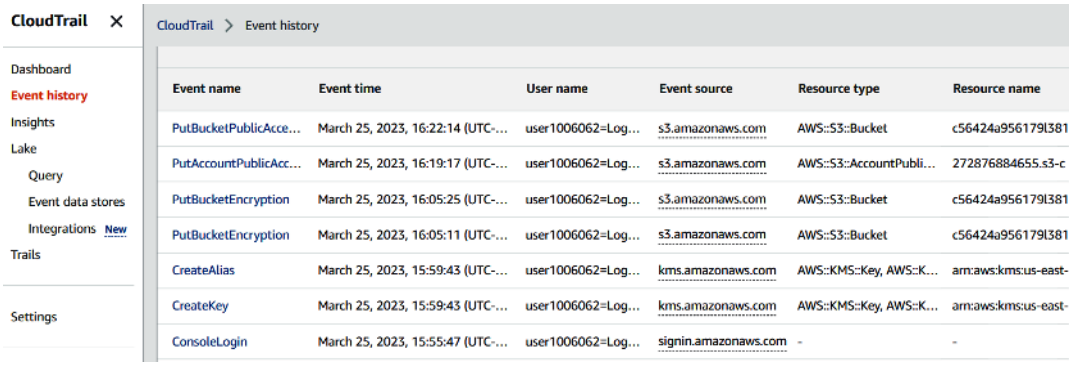


Figure 7.11 – CloudTrail event history

Analyze the `GenerateDataKey` event by choosing the **GenerateDataKey** link. In the **Event record** section, observe the details of the event, as shown in *Figure 7.12*:

Figure 7.12 – CloudTrail GenerateDataKey event

Use the same steps and analyze the **Decrypt** event by choosing the link for the **Decrypt** event name, as shown in *Figure 7.13*:

Analysis: This event was generated when you successfully opened the `img2.jpg` file from the Amazon S3 console. Notice that the record again details who made the request, which AWS KMS key provided the unencrypted data key back to Amazon S3, and which S3 object was decrypted with the plaintext data key.

Figure 7.13 – CloudTrail Decrypt event

In this section, we have dived into the encryption process of S3 object uploading and the decryption process of object opening. CloudTrail logs all AWS KMS API activity and helps to examine the past usage of AWS KMS keys.

In the next section, we will closely look at AWS logging and monitoring services, including AWS CloudTrail and others.

AWS logging, monitoring, and incident handling

Logging and monitoring are everywhere in the AWS cloud. As we discussed earlier, the third A in AWS cloud's AAA provides traceability of all activities in the cloud. We also introduced CloudTrail and analyzed the CloudTrail logs generated in the encryption and decryption process. In this section, we will explore further the AWS security services related to cloud resource logging and monitoring.

While **CloudTrail** provides a record of API calls made within a customer's AWS account, thus enabling customers to monitor and audit activity within their accounts, Amazon CloudWatch is a managed service that enables customers to monitor, store, access, and analyze log files from AWS services and their own applications, such as EC2 instances, RDS databases, Lambda functions, and more, to gain insights into the health and performance of their applications and infrastructure. Some of the most important features of the AWS cloud are elasticity and auto-scaling, and **CloudWatch** is the service that monitors unit utilization, sets threshold alarms, and integrates with other AWS services such as AWS Lambda and AWS EC2 to enable automatic scaling of resources based on application demand.

AWS Config is a service that allows users to assess, audit, and evaluate the configurations of their AWS resources. It provides a historical record of configuration changes to AWS resources and can be used to simplify compliance auditing and reporting. It can also be integrated with other AWS services such as AWS CloudTrail and AWS Lambda to enable automated remediation of non-compliant resources. AWS Config can be used to track changes to resource configurations over time and to troubleshoot issues by pinpointing the root cause of changes or issues.

AWS Trusted Advisor checks four cloud infrastructure pillars, including security, performance, resilience, and cost. These checks analyze a user's AWS infrastructure and provide recommendations for improving resource utilization, security, and cost efficiency. For example, Trusted Advisor can identify security vulnerabilities in AWS S3 configurations and suggest ways to improve security settings for S3 buckets and objects. In addition, Trusted Advisor detects AWS service limits in users' environments, such as the number of instances that can be launched in a region, and provides users with direct access to AWS technical support to increase the limit. It can also be configured to provide automatic notifications when changes or issues are detected in a user's AWS environment.

Amazon Inspector is a security assessment service used to scan vulnerabilities, by providing a list of security findings and recommendations to help customers remediate potential vulnerabilities. Amazon Inspector supports a wide range of assessments, including checks for common security issues such as insecure communication protocols, vulnerabilities in software libraries, and misconfigurations in network and application components. It also supports assessments for compliance with industry standards such as the **Payment Card Industry Data Security Standard** (**PCI DSS**) and the **Health Insurance Portability and Accountability Act** (**HIPAA**). For example, when an EC2 instance is compromised, we can isolate the instance and run Inspector against it to assess the vulnerability and security risks.

Amazon Macie scans storage to detect personal information such as Social Security numbers, including Amazon S3, Amazon RDS, and Amazon Redshift. It can also provide users with a detailed inventory of their data assets, including the location and risk level of sensitive data. Macie can also monitor data access patterns and alert users to potential data breaches or unauthorized access to sensitive data. It can also provide recommendations for improving data security, such as access control policies, encryption, and data retention policies.

AWS Shield is a managed service that provides protection against **Distributed Denial of Service** (**DDoS**) attacks. While AWS Shield Standard is a free service that is automatically enabled for all AWS customers and provides protection against most common network and transport layer DDoS attacks, including SYN/ACK floods, UDP floods, and reflection attacks, Shield Advanced is a paid service that provides additional protection against more sophisticated DDoS attacks, including application layer attacks. AWS Shield Advanced includes 24/7 access to the AWS **DDoS Response Team** (**DRT**), for assistance in mitigating DDoS attacks.

Amazon GuardDuty is a threat detection service that uses ML technology to continuously monitor customers' AWS accounts for malicious activity and unauthorized behavior. In the next section, we will fully discuss GuardDuty and see how it can be integrated and built into a security ecosystem for security hardening.

Case study – an AWS threat detection and incident handling ecosystem

After the introduction of Amazon logging and monitoring services in the last section, we will conduct a case study on an actual security incident and details on how it was handled, by introducing an **automatic threat detection and remediation system** that the author developed for an AWS customer.

CloudSpace is an Amazon enterprise customer that functions as a reseller of AWS services to end customers, with over 4,000 AWS accounts in total. During 2017-2018, CloudSpace experienced three cases of account compromise. Three accounts were compromised in the first attack in November 2017, and four more in the second attack in March 2018. The third incident occurred in August 2018, when another five accounts were compromised. These incidents led to about $200,000 in losses. Investigations thereafter revealed that no threat-detection services were enabled and the Amazon fraud detection team's customer notifications went to their company emails and voice mails manually and thus were not acted upon in a timely manner.

To defend against these attacks, we have developed an automated threat detection and remediation ecosystem. The architecture of the system is shown in *Figure 7.14*:

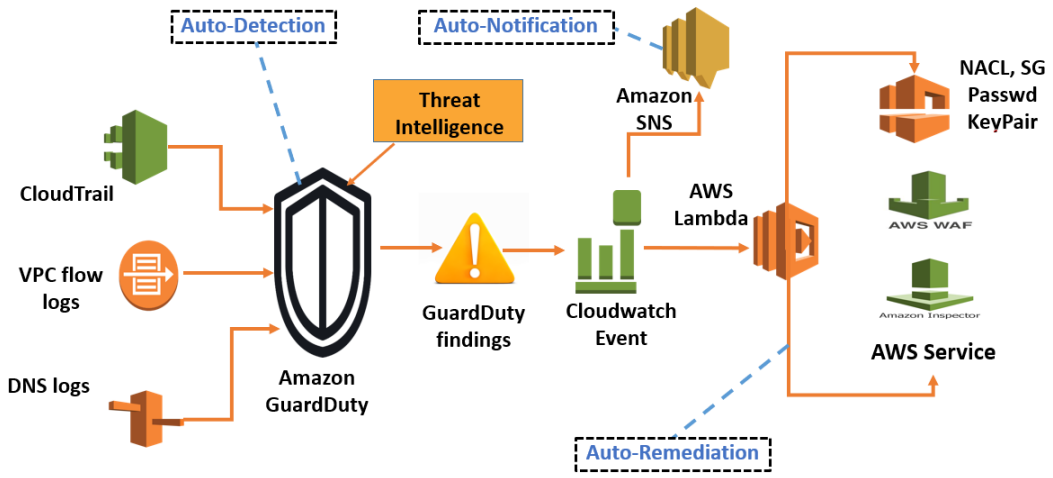


Figure 7.14 – Architecture of the threat detection and remediation ecosystem

The ecosystem has the following functions.

Automatic threat detection

Enabling Amazon GuardDuty is the first step for the ecosystem to work. As we discussed earlier, GuardDuty uses machine learning to monitor and generate the activity patterns of the AWS account, such as the normal and peak times and scope, and leverages threat intelligence to analyze and correlate data from various sources, such as AWS CloudTrail, Amazon VPC Flow Logs, and DNS logs, to detect and prioritize potential security threats. Once GuardDuty is enabled, it will continuously monitor the AWS accounts for malicious activity and unauthorized access automatically. GuardDuty can detect a variety of threats, including botnets, port scanning, cryptocurrency mining, and unauthorized API access. It can also provide users with detailed information about the nature of the threat, including the source IP address and the affected AWS resources.

Automatic notification

When GuardDuty detects a threat, it generates a finding in the GuardDuty console and creates a Cloudwatch event, which can be used to automatically notify the customer. In the ecosystem, GuardDuty integrates with **Simple Notification Service** (**SNS**) and some third-party tools, enables timely notifications about possible threats, and facilitates notifications to multiple parties, via Slack and its ticketing system.

Automatic remediation

In addition to notifications, CloudWatch events can trigger Lambda functions that serve as the basis for remediation. Depending on the attack, a customer can choose to automatically terminate a compromised instance if it is part of a non-critical development sandbox account, or to be notified only if the instance is part of a production workload. Following are some remediation actions we explored in the ecosystem:

- Blocking bad actor access with NACL and SG modifications
- Enabling MFA for accounts if not yet done
- Changing account user passwords
- Deleting and rotating account access keys (while being cautious about production accounts and ensuring applications are not using the keys before rotating them)
- Snapshotting compromised EC2 instances for forensic investigation
- Running Amazon Inspector assessments on compromised EC2 instances (or forensic instances launched based on snapshots)
- Terminating compromised EC2 instances (be cautious with production instances, termination is best suited for stateless applications that are deployed using Auto Scaling)
- Deleting all images (AMIs) created during the compromise
- Deleting all snapshots created during the compromise

The ecosystem was deployed successfully in the customer's environment. It guard-railed the customer against several successive attacks, and the customer loves the ecosystem and became one of the top 10 GuardDuty consumers in 2018.

Summary

In this chapter, we started with the Amazon cloud security model, then discussed IAM, which manages authentication, authorization, and auditing. We dived into AWS cloud infrastructure security, which protects cloud resources such as EC2, S3, and RDS, and data security, which is about data encryption and key management. We further explored the AWS data encryptions, cloud monitoring and logging services, and ended with a case study about an AWS automatic cloud threat detection and remediation ecosystem.

We have now concluded *Part 1* of the book: *Learning the Amazon Cloud*. In the next part, we will explore Google Cloud Platform.

Practice questions

Questions 1-10 are based on the AWS architecture shown in *Figure 7.15*. There is a cloud admin in company ABC, which has 10,000 EC2 instances in its AWS cloud. The diagram shows the three VPCs in the cloud admin account. All networks are configured correctly. The cloud admin created an EC2 role, R3, that can access the S3 bucket named `B3` in `us-east-1`. EC2-1 has a security group named `sg`. `Subnet1` has a network access control list named `nacl`:

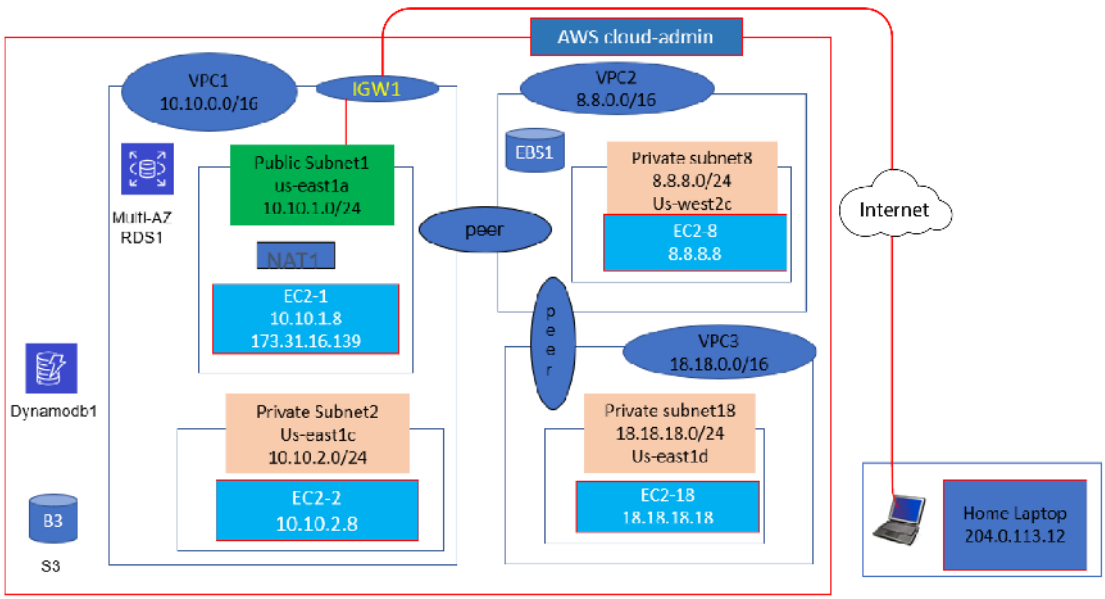


Figure 7.15 – AWS Networking Architecture

1. They are looking for a place to securely store a connection string to RDS1. What do you suggest?

    A. EBS

    B. Parameter store

    C. DynamoDB

    D. RDS

2. They couldn't ping EC2-1 from their home laptop, and he found the following in the AWS VPC flow log:

```
2 123456789010 eni-1235b8ca123456789 204.0.113.12 173.31.16.139
0 0 1 4 336 1432917027 1432917142 ACCEPT OK
```

```
2 123456789010 eni-1235b8ca123456789 173.31.16.139 204.0.113.12
0 0 1 4 336 1432917094 1432917142 REJECT OK
```

    What is the likely reason the "ping" did not work?

    A. NACL outbound rule blocked the traffic

    B. SG inbound rule blocked the traffic

    C. NACL inbound rule blocked the traffic

    D. SG outbound rule blocked the traffic

3. How can they block the contractors/developers from accessing the EC2-18 instance's metadata?

    A. Modify EC2-18's GuestOS route table

    B. Modify Subnet18's NACLs

    C. Modify EC2-18's SG

    D. Modify EC2-18's GuestOS `/etc/passwd` file

4. How can they set the correct date/time on all 10,000 EC2 instances?

    A. Use AWS Systems Manager

    B. Use AWS Security Center

    C. Use AWS Config

    D. Use AWS Inspector

5. No one in the company can access the Linux instance EC2-8. What can they do to log into it?

    A. Generate a new keypair and utilize EC2-8's user data to copy the public key to EC2-8

    B. Generate a new keypair and utilize EC2-8's metadata to copy the key to EC2-8

    C. Generate a new keypair and `scp` the public key to EC2-8 to `ssh` into it

    D. `ssh` into a third Linux instance, EC2-1, and break into EC2-8 from there

6. Which of the following is not true?

A. EC2-1 can ping EC2-8

B. EC2-8 can ping EC2-18

C. EC2-1 can ping EC2-18

D. EC2-2 can ping EC2-8

7. C2-18 needs to access the internet for patching. Which one of these options is true?

A. It can be done via IGW1

B. It can be done via NAT1

C. It cannot be done via IGW1 or NAT1

D. It can be done via IGW1 and NAT1

8. They want to allow EC2-18 access to B3. What is your suggestion?

A. Assign R3 to EC2-18. Create an S3 endpoint in VPC3

B. Assign R3 to EC2-18

C. Create an S3 endpoint in VPC3

D. Assign R3 to EC2-18, then create an S3 endpoint in VPC1

9. EC-1 needs to access an external web server via port `888` with minimum exposure to the internet. How can it be done? (Choose two answers.)

A. NACL needs a rule that allows outgoing traffic on port `888`

B. NACL needs rules that allow outgoing traffic on port `888` and incoming traffic on ephemeral ports

C. SG needs a rule that allows outgoing traffic on port `888`

D. SG needs rules that allow outgoing traffic on port `888` and incoming traffic on ephemeral ports

E. SG needs rules that allow outgoing traffic on port `888` and incoming traffic on port `888`

10. Which one of these options is not recommended to protect the data in DynamoDB1?

A. Data encryption

B. SG

C. IAM users/roles

D. VPC endpoint

Answers to the practice questions

1. B

2. A

3. A

4. A

5. A

6. C

7. C

8. A

9. B and C

10. B

Further reading

For further insights into what you've learned about in this chapter, refer to the following links:

- `https://docs.aws.amazon.com/security/`
- `https://aws.amazon.com/iam/`
- `https://aws.amazon.com/guardduty/`
- `https://aws.amazon.com/inspector/`
- `https://aws.amazon.com/config/`
- `https://aws.amazon.com/premiumsupport/technology/trusted-advisor/`
- `https://docs.aws.amazon.com/whitepapers/latest/introduction-aws-security/data-encryption.html`
- `https://docs.aws.amazon.com/whitepapers/latest/introduction-aws-security/security-of-the-aws-infrastructure.html`
- `https://docs.aws.amazon.com/whitepapers/latest/introduction-aws-security/monitoring-and-logging.html`
- `https://aws.amazon.com/security/continuous-monitoring-threat-detection/`

Part 2: Comprehending GCP Cloud Services

This second part of the book dives into **Google Cloud Platform** (**GCP**). We will compare GCP cloud services with AWS cloud services. Starting with foundational discussions of the GCP services, we will then explore the GCP data services, including managed database services and big data services. We will then examine the GCP ML services, including Vertex AI, ML APIs, and the recently emerged Google generative AI services. This part ends by looking at Google Cloud security services, with a focus on GCP **Security Command Center** (**SCC**).

This part comprises the following chapters:

- *Chapter 8, Google Cloud Foundation Services*
- *Chapter 9, Google Cloud Data Services*
- *Chapter 10, Google Cloud AI Services*
- *Chapter 11, Google Cloud Security Services*

8

Google Cloud Foundation Services

In *Part 1* of the book, we dived into the Amazon cloud, explored and provisioned cloud services for compute, storage, networking, databases, big data, and machine learning. Now, in this second part, we are switching to another cloud platform: **Google Cloud Platform** (**GCP**). GCP has many similarities with AWS but also has many of its own features. Finding the similarities and examining the differences are what we will do in the second part of the book. In this chapter, we will focus on GCP's foundation services, including the following:

- Google Cloud resource hierarchy – organization, folders, projects, and resources
- Google compute services – **Google Compute Engine** (**GCE**), **Google App Engine** (**GAE**), **Google Kubernetes Engine** (**GKE**), and Google Cloud Functions (serverless)
- Google storage services – **Persistent Disk** (**PD**), **Filestore**, and **Google Cloud Storage** (**GCS**)
- Google Cloud networking services – **Virtual Private Cloud** (**VPC**), firewalls, etc.

During our discussions, we will use some examples. The sample code is available in the GitHub repository for this book: `https://github.com/PacktPublishing/Self-Taught-Cloud-computing-Engineer`.

Cloud Shell is an extremely useful tool for running cloud command lines to provision and manage cloud resources. It has a wide range of resource-managing commands and also an editor to write/edit files. In the first part of the book, we introduced and used AWS Cloud Shell for many use cases. In this part of the book, we will leverage the Cloud Shell tool heavily. In this chapter, we will use Google Cloud Shell to create and manage resources including compute, storage, and networking.

We will start by looking at the Google Cloud resource hierarchy.

Google Cloud resource hierarchy

Very similar to AWS's global infrastructure, **Google Cloud** has global data centers where the physical facilities and data resides. Each data center has redundant power, networking, and connectivity, and there are Google backbone networks connecting them. These data centers compose the Google Cloud, which is divided into **regions** and **zones**, like AWS Regions and AZs. *Figure 8.1* shows the Google global regions at the time of writing this book:

Region	City	Region	City	Region	City
asia-east1	Changhua County, Taiwan, APAC	europe-central2	Warsaw, Poland, Europe	northamerica-northeast1	Montreal, Quebec, North America
asia-east2	Hong Kong, APAC	europe-north1	Hamina, Finland, Europe	northamerica-northeast2	Toronto, Ontario, North America
asia-northeast1	Tokyo, Japan, APAC	europe-west1	St. Ghislain, Belgian, Europe	southamerica-east1	Osasco, Sao Paulo, Brazil, South America
asia-northeast2	Osaka, Japan, APAC	europe-west2	London, England, Europe	us-central1	Council Bluffs, Iowa, North America
asia-northeast3	Seoul, South Korea, APAC	europe-west3	Frankfurt, Germany, Europe	us-east1	Moncks Corner, South Carolina, North America
asia-south1	Mumbai, India APAC	europe-west4	Eemshaven, Netherlands, Europe	us-east4	Ashburn, Virginia, North America
asia-south2	Delhi, India APAC	europe-west6	Zurich, Switzerland, Europe	us-west1	The Dalles, Oregon, North America
asia-southeast1	Jurong West, Singapore, APAC			us-west2	Los Angeles, California, North America
asia-southeast2	Jakarta, Indonesia, APAC			us-west3	Salt Lake City, Utah, North America
australia-southeast1	Sydney, Australia, APAC			us-west4	Las Vegas, Nevada, North America
australia-southeast2	Hong Kong, APAC				

Figure 8.1 – Google global regions

In the cloud, there are **Cloud Service Consumers** (**CSCs**), each having their own resource hierarchy. The GCP resource hierarchy structure is quite different from AWS's.

In the previous chapter, we discussed the AWS resource hierarchy, which consists of a root organization, **Organization Units** (**OUs**), and AWS accounts, from top to bottom. In GCP, the resource hierarchy consists of four main layers, as shown in *Figure 8.2*:

- **Organization (Org Node)**: This is the top level of the hierarchy and represents a company. The organization provides centralized control over billing, resource management, and access control.
- **Folders**: These represent departments or divisions in a company. Folders can be used to organize resources based on departments or divisions within an organization, with policies applied to all resources within them.
- **Projects**: These are the lowest layers in the hierarchy that manage GCP resources, such as **Virtual Machines** (**VMs**), storage, and databases. Projects are used to isolate and manage access to resources.
- **Resources**: These are the services and tools provided by GCP, such as VMs, storage buckets, databases, and APIs.

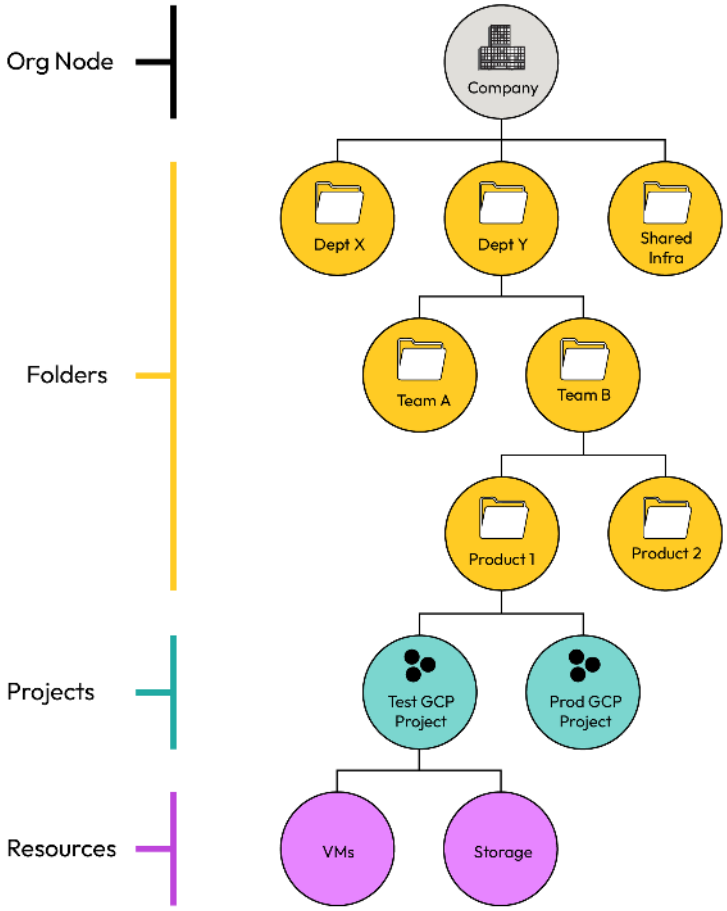


Figure 8.2 – Google Cloud resource hierarchy

In the GCP organization hierarchy, projects are managed and billed separately, although multiple projects may be associated with the same billing account. Each project is a separate partition and is isolated from other projects. Each resource belongs to exactly one project. We will start with our first GCP resource, GCE, which is part of the Google Cloud compute services.

Google Cloud compute

We learned about EC2 instances in *Chapter 1*, which was about Amazon cloud compute services. Switching to Google Cloud, we will first discuss GCE VMs, which are like the EC2 instances in AWS, and then GKE, which was originally developed at Google and released as open source in 2014.

Google Compute Engine

GCE offers VMs running in Google's cloud as a computing resource. Just like provisioning an AWS EC2 instance, we need to make choices about the computer hardware and software when provisioning a GCE VM in Google Cloud. Let us go to the Google Cloud console, provision a GCE instance, and add some cloud storage to it:

1. Log in to the Google Cloud console.
2. Go to the Google Cloud console: `https://console.cloud.google.com`. As we mentioned in an earlier section, each GCP resource belongs to a project, so you need to create a project first:

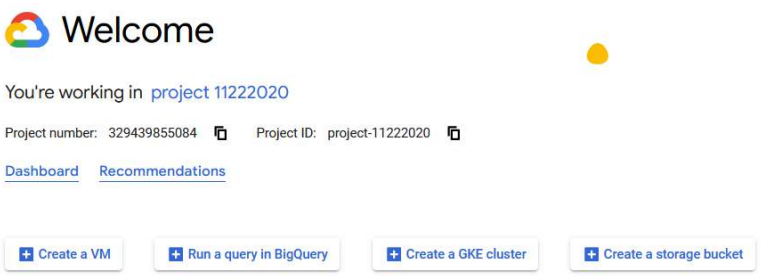


Figure 8.3 – Google Cloud console welcome page

Once a project is created, in this case, **project 11222020**, you will land on the welcome page, as shown in *Figure 8.3*.

3. Create a VM in the cloud:

From the welcome page, select **Create a VM**. Fill in the following details, as shown in *Figure 8.4*:

- **Name**: This is the VM's name, whatever you may want to call it.
- **Labels**: This is a key-value tag for the VM, such as `Name: "vm1"` or `Department: "math"`.
- **Region** and **Zone**: This is the location where you want to create the VM, such as `US-east1d`.
- **Machine type**: This determines the VM's hardware. *Figure 8.4* shows our choice of the N1 series f1-micro machine type. You can also customize the hardware configurations.
- **Boot disk | Image**: This determines the VM's software, including the operating system and applications.

In our case, we chose **f1.micro** in the **N1** family as the machine type, **centOS** as the disk image (the Figure below shows Debian which is another Linux OS), and take the **default** for the rest. Click **Create** to provision a VM in Google Cloud:

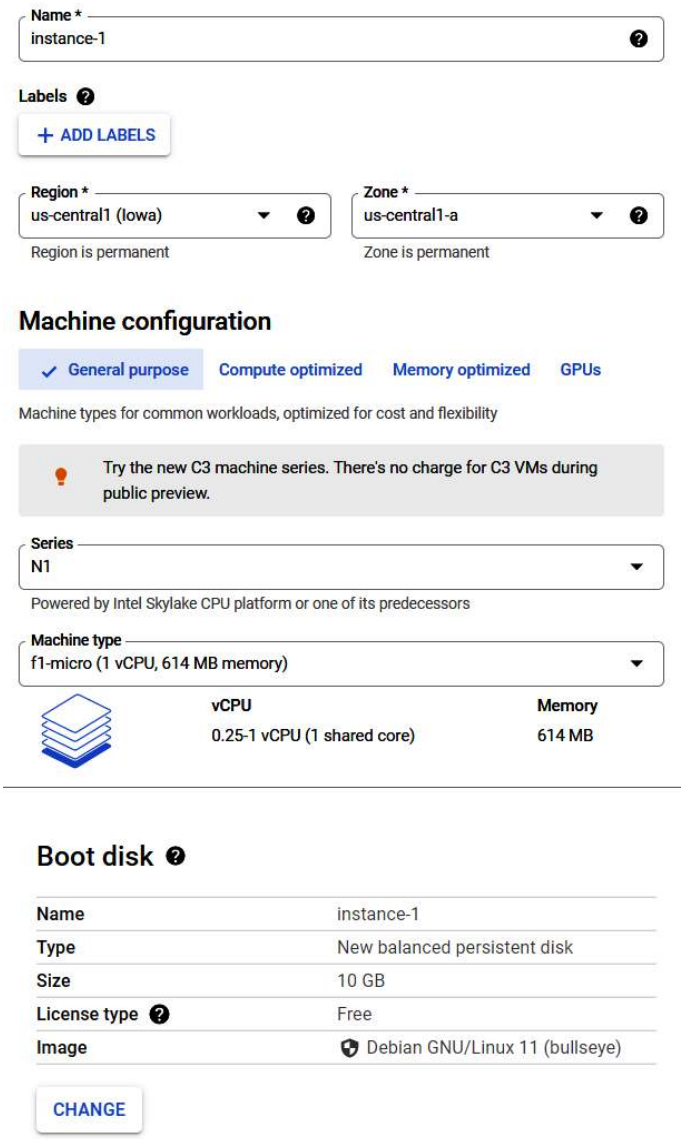


Figure 8.4 – Create a Google Cloud VM

The VM instance is created, showing a green status and the available actions you can take, as shown in *Figure 8.5*:

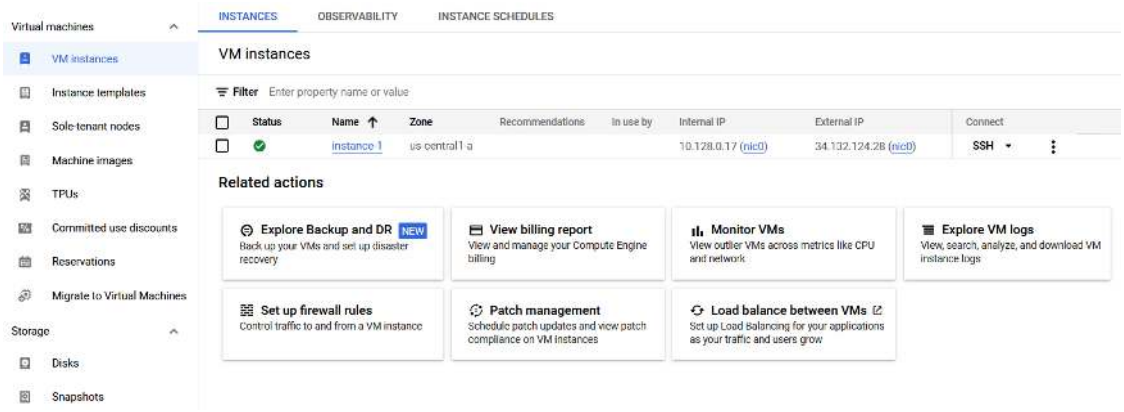


Figure 8.5 – A VM is created

To connect to the VM, click the **SSH** button and a new ssh session window pops up:

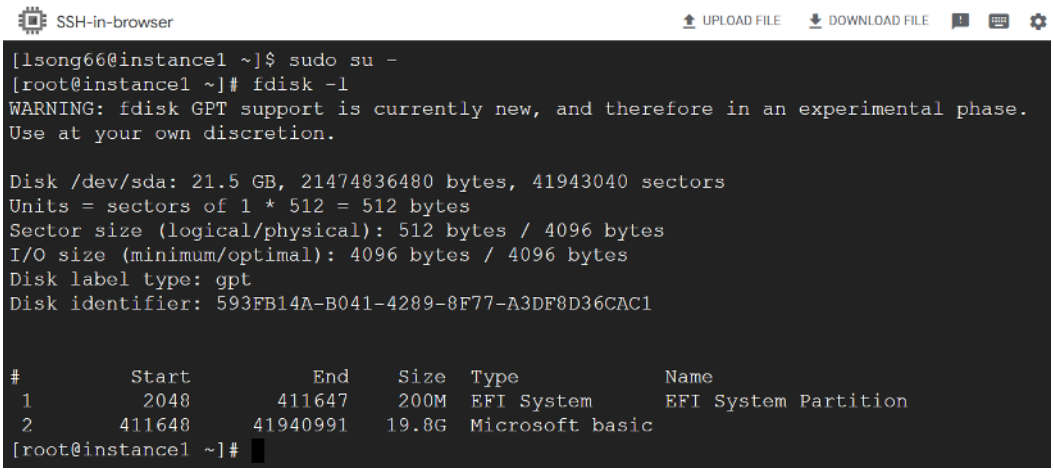


Figure 8.6 – SSH into the VM instance and check disks

Within the `ssh` session window, switch to the `root` super user and run `fdisk -l`. We can see there is one disk with a size of 20 GB in this Linux VM, as shown in *Figure 8.6*.

4. Add a disk (block storage) to the VM:

Just as we added an EFS to an EC2 instance in *Chapter 1*, we can add block storage to the Google Cloud VM. The block storage volume here is called a PD.

I. Create a PD:

Click **Disks** under **Storage** on the VM dashboard (as shown in *Figure 8.5*), then select **CREATE DISK**. Fill in the details as shown in *Figure 8.7*. In our case, we have chosen a **Single zone** disk that is 10 GB in size:

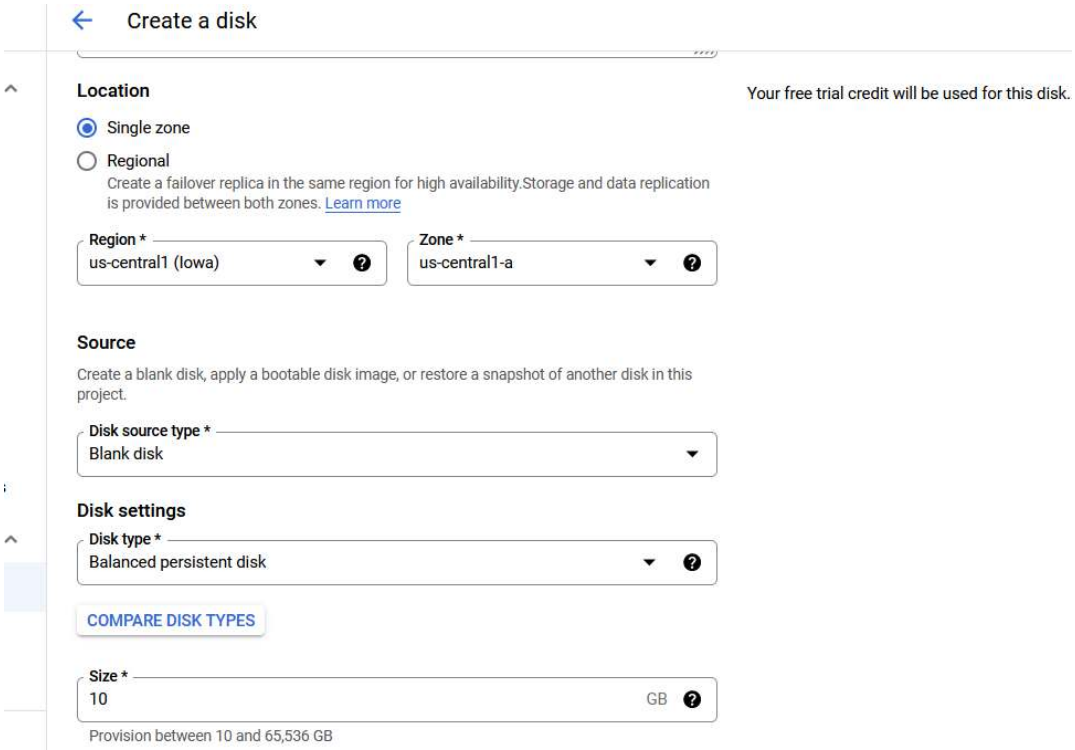


Figure 8.7 – Create a persistent disk

Click **Create**. Now, it will show two PDs (20 GB for the root disk and 10 GB for the one just created).

II. Attach the PD to the VM:

Go back to the instance dashboard and click the instance name to edit the instance. Scroll down and click **ATTACH EXISTING DISK**. Choose the **disk-1** PD, which we created earlier, as shown in *Figure 8.8*. Then, click **SAVE** and then **SAVE** again:

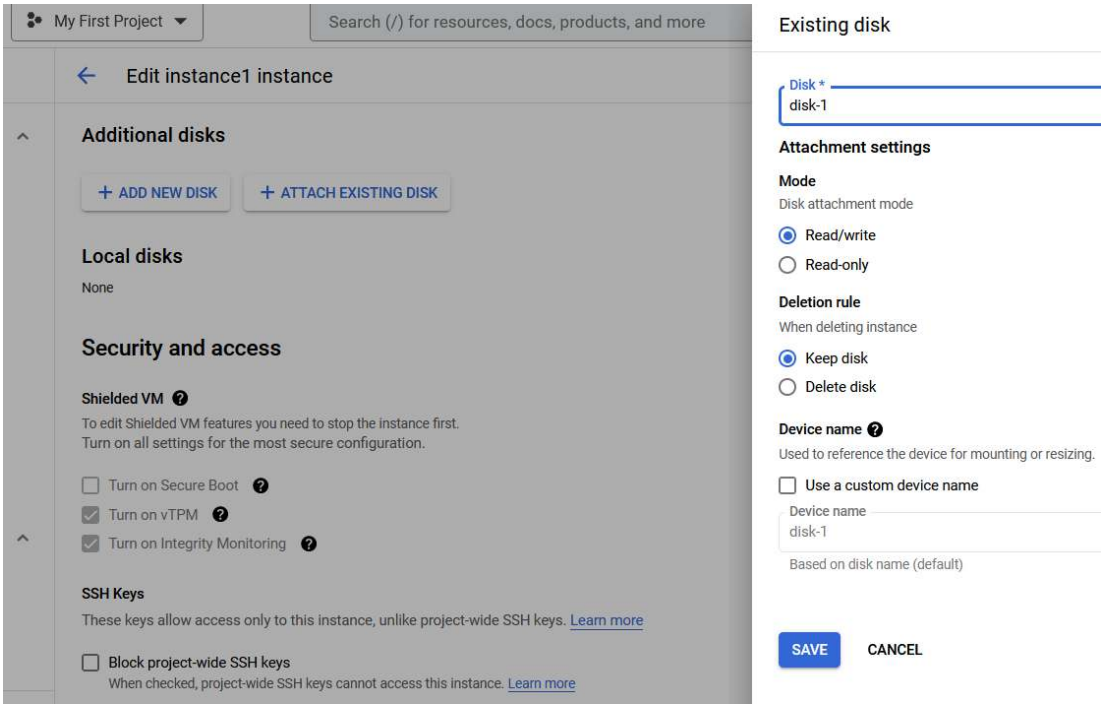


Figure 8.8 – Attach Disk-1 to the VM instance

Now, go back to the SSH session. Run `fdisk -l` again and we can see that `disk-1` (10 GB) is added to the instance, as shown in *Figure 8.9*. Now, you can use the `mkfs` and `mount` Linux commands to format the disk and make it available for the operating system to read/write:

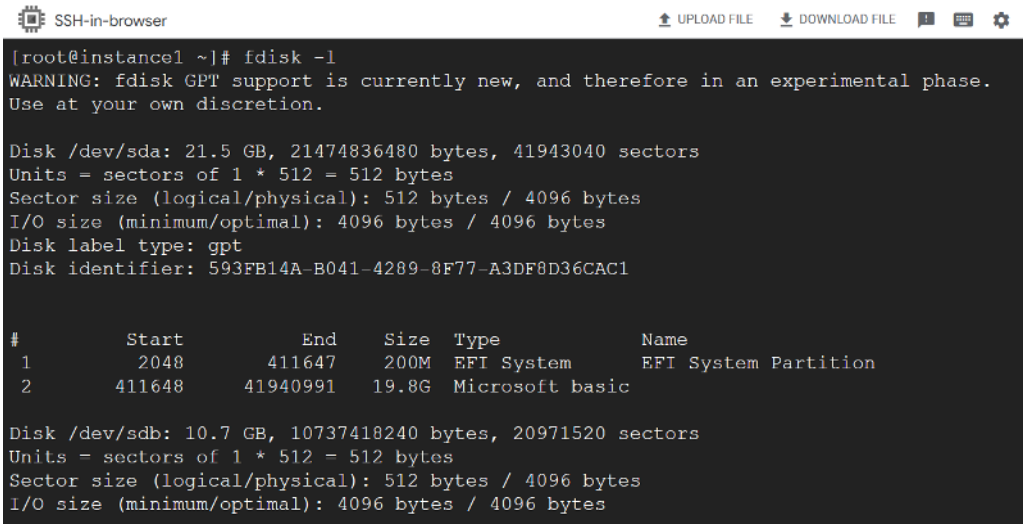


Figure 8.9 – Disk1 is added to the VM instance and visible to the operating system

In addition to PDs, which are block storage, we can also add network filesystems to Google Cloud VM instances. Like EFS in the AWS cloud, there is fully managed filesystem storage in Google Cloud, called **Filestore**, which can be created and shared by many VMs. More details are available at `https://cloud.google.com/filestore`.

From the preceding process of provisioning a GCE VM instance and adding a PD to the instance, we can see that the concepts and operations are very similar to that of the AWS EC2 instance and adding an EFS. *Figure 8.10* shows a comparison of GCE and Amazon EC2:

Features	Google GCE	Amazon EC2
Hardware (RAM,CPU,Disk)	Machine Types	Instance Types
Software (VM Images)	Disk Images	AMI
Local attached disk	Local SSD	Instance Store
Block Storage	PD (Persistent Disks)	EBS (Elastic Block Storage)
Network File System	FileStore	EFS (Elastic File System)

Figure 8.10 – Comparison of GCE and Amazon EC2

Within GCP, there are also the concepts of load balancing and scaling groups. GCP load balancing accepts the load and balances them among the instances in the group, which can be set up for autoscaling.

More details are available at `https://cloud.google.com/load-balancing` and `https://cloud.google.com/compute/docs/instance-groups`.

Having learned about GCE, we will now introduce GKE, a fully managed container orchestration service in the Google Cloud compute service spectrum.

Google Kubernetes Engine

First, let us recap some basic computing platform concepts, from physical computers to VMs, to containers, to serverless:

- **Physical computers**: These are physical machines with their own hardware components, such as CPUs, memory, storage, and network interfaces. Each physical computer runs a single operating system, and applications are installed and run directly on the hardware.
- **VMs**: These are virtual computers that emulate a physical computer. The virtualization technology makes it possible to create and run multiple VMs on the same physical host and share the hardware resources. Each VM is isolated from other VMs running on the same host, and the operating system running inside the VM has no knowledge of the underlying hardware.

- **Container**: This is a lightweight, standalone executable application software package that includes the application code, runtime, system tools, libraries, and settings. Containers provide an isolated environment for running applications, but they share the same operating system kernel as the host, which allows them to be more lightweight and faster to start up and shut down than VMs. Containers also consume fewer system resources and are easier to manage than VMs. To run and manage containers, you need to have **Docker**, which is a tool that provides a container runtime, an image format, and a set of tools to manage containers. With Docker, developers can build container images and run them on any system that supports Docker.
- **Serverless**: This refers to the practice of running applications and code without the underlying infrastructure or servers. In a serverless environment, the cloud provider manages the infrastructure and automatically scales resources up or down based on demand, so developers can focus on writing and submitting code without worrying about the underlying infrastructure.
- A container is a running instance of a Docker image, and it runs the same way on different machines. GKE is a container orchestration and management system. A GKE cluster is a group of GCE VM nodes working together to deploy applications by running containers on the cluster nodes. Some of the key features of GKE include the following:
    - **Automatic scaling**: GKE can automatically scale applications based on demand, ensuring that they have the resources they need to handle traffic spikes and scale down when traffic decreases
    - **Automatic upgrades**: GKE can automatically upgrade Kubernetes clusters to the latest version, ensuring that applications are running on the most up-to-date platform
    - **Built-in security**: GKE provides built-in security features, such as network policies, automatic encryption, and **Identity and Access Management** (**IAM**), to help protect applications and data
    - **Integrated monitoring**: GKE provides integrated monitoring and logging features, allowing developers to monitor the health and performance of their applications in real time
    - **Hybrid and multi-cloud support**: GKE can run applications in hybrid or multi-cloud environments, enabling developers to run their applications on-premises or in other cloud environments

Now that we understand the key GKE concepts, let us build a Docker image for a simple web server that will display a greeting message, create a GKE cluster, deploy the image to the cluster, and serve the web server on the internet:

1. Clone the source code from GitHub:

Open Google Cloud Shell and run the following command to clone the code from GitHub:

```
git clone https://github.com/PacktPublishing/Self-Taught-Cloud-
computing-Engineer.git
```

Change the directory to `gke-lab-01` and list the files in the directory:

```
cd chapter8; ls
```

There are three files in the directory:

- `requirement.txt` is a Python file that stores information about all the libraries, modules, and packages that are needed to build the Docker image.
- `app.py` is a Python file that defines the `webserver1` containerized application. More details about `webserver1` are available in the book's GitHub repository.
- `dockerfile` provides step-by-step instructions for building a Docker image for the application.

These files will be used in the following steps:

2. Containerize the application – build the Docker image and push it to **Google Container Registry** (**GCR**):

```
docker build -t gcr.io/$DEVSHELL_PROJECT_ID/webserver1 .
docker images
docker push gcr.io/$DEVSHELL_PROJECT_ID/webserver1
```

3. Create a two-node GKE cluster and deploy the containerized `webserver1`:

   I. Set up the environment:

```
gcloud config set compute/zone us-central1-a
gcloud services enable container.googleapis.com
```

   II. Create the GKE cluster:

```
gcloud container clusters create hello-cluster --num-nodes=2
```

   III. Deploy the container application (`webserver1`) to listen on port `80`:

```
kubectl create deployment hello-web --image=gcr.io/$DEVSHELL_
PROJECT_ID/webserver1 --port 80
kubectl get deployments hello-web
```

   IV. Check out our Pods on the nodes:

```
kubectl get pods
```

4. Create a load balancer and expose the service to the internet:

   Create a load balancer and expose the application to the internet on port `8080`:

```
kubectl expose deployment hello-web --type=LoadBalancer --port
8080 --target-port 80
```

> **Note**
>
> At this point, you can verify, from the Google Cloud console, the following resources are provisioned:
>
> GCE (two VMs; they are the cluster nodes), instance groups (one instance group that has the two VMs), and the load balancer.

5. Find the load balancer's public IP address and port:

```
kubectl get service
```

Open a new browser to access the service/web server.

6. Set up autoscaling for the cluster pods and nodes now:

> **Note**
>
> A Kubernetes pod is the smallest execution unit in a cluster. It groups the containers of an application. For example, a web service application pod may have two containers – a web server and web server logging.

I. Set up autoscaling for the application Pods:

```
kubectl autoscale deployment hello-la --max 6 --min 4
--cpu-percent 50
```

II. Enable autoscaling for the cluster nodes:

```
gcloud container clusters update hello-cluster --enable-
autoscaling --min-nodes 2 --max-nodes 8
```

7. Clean up the resources we have provisioned earlier:

I. Delete the GKE cluster:

```
gcloud container clusters delete hello-cluster
```

II. Delete the container images in GCR:

```
gcloud container images delete gcr.io/$DEVSHELL_PROJECT_ID/
webserver1
```

In this example, we have built a Docker image, created a GKE cluster, and deployed the image to run on the GKE cluster as a container, and then created a global load balancer service pointing to the container. We then enabled the cluster for autoscaling.

GCP offers other cloud compute services apart from GCE and GKE, including GAE and Google Cloud Functions. GAE is a fully managed, serverless cloud platform for developing and hosting web applications at scale. After you develop an application with a program language, libraries and frameworks, GAE will deploy the apps by provisioning and scaling compute services, based on the workload demand. More details are available at `https://cloud.google.com/appengine`. Like AWS Lambda, Google Cloud Functions is a serverless compute service in which users only define and deploy the source function code to be triggered by certain events/conditions and executed at the backend. We will explore this in later chapters of the book, and more details are available at `https://cloud.google.com/functions`.

In this section, we examined the GCP compute services. We explored GCE and GKE and briefly discussed GAE and Google Cloud Functions. We launched GCE VM instances and a GKE cluster that deployed a load-balancing web server based on container deployment. We also enabled autoscaling for the GKE cluster. In the next section, we will discuss the GCS service.

Google Cloud Storage

Like Amazon S3, GCS offers multiple tiers for different cloud storage use cases, depending on the access frequency and durability requirements. *Figure 8.11*shows the comparison of GCS and S3:

Storage Features	Google Cloud Storage (GCS)	Amazon Simple Storage Service (S3)
Standard Storage	**GCS Standard** (Regional, Dual-regional, Multi-regional)	**S3 Standard** (Regional)
Cool Storage	**GCS Nearline** (Regional, Dual-reginal, Multi-regional, 30-days minimum duration)	**S3 Standard-IA** (Regional, 30-days minimum duration
	GCS Coldline (Regional, Dual-reginal, Multi-regional, 90-days minimum duration)	**S3 Standard One-zone-IA** (Zonal, 30-days minimum duration)
Cold/Archival Storage	**GCS Archieve** (Regional, Dual-reginal, Multi-regional, 365-days minimum duration, millisecond retrieval time)	**Glacier** (Regional, 90-days minimum duration, minutes to hours retrieval time)
Move to the cloud	**Data Transfer Appliance**	**Snowball and Snow Mobile**

Figure 8.11 – GCS tiers

In the AWS cloud, we have the concept of an IAM EC2 role, which, when attached to an EC2 instance, will entail the applications running on EC2 to have the same permission as assigned to the role. In GCP, we have a similar concept called a service account. Each GCE VM has a default service account, which is created at the same time as the VM to define GCP service permissions of the vm. As shown in *Figure 8.12*, the default permission for GCS is **Read Only** for a GCP VM instance, and we can change it to **Read and Write** at instance creation time or after it is created. For the latter, we need to shut down the instance in order to modify its permissions and restart it:

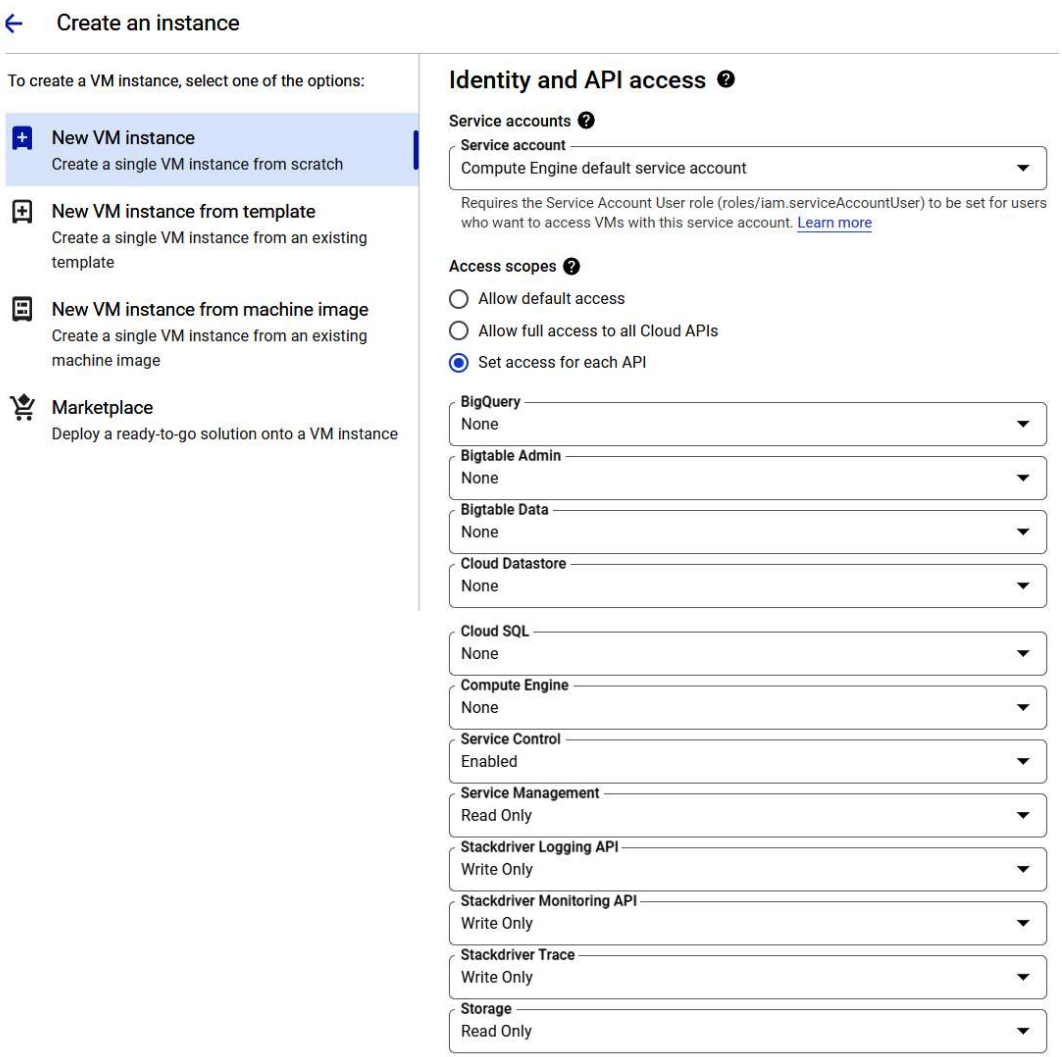


Figure 8.12 – Fill in the Identity and API access settings for a VM

We can use the Cloud Shell `gsutil` command to create a GCS bucket, copy files into it, and delete it. `gsutil` is a Python application that lets you access and manage GCS resources from the command line, such as creating and deleting GCS buckets, listing buckets and objects, uploading, downloading, and deleting GCS objects, and moving, copying, and renaming these objects. *Figure 8.13* shows several `gsutil` commands and their executions:

```
logan_song@cloudshell:~/GCP/gke-lab-01 (dito-contact-center-ai-sandbox)$
logan_song@cloudshell:~/GCP/gke-lab-01 (dito-contact-center-ai-sandbox)$ gsutil mb gs://z04092023-unsafe
Creating gs://z04092023-unsafe/...
logan_song@cloudshell:~/GCP/gke-lab-01 (dito-contact-center-ai-sandbox)$ gsutil cp /etc/hosts gs://z04092023-unsafe
Copying file:///etc/hosts [Content-Type=application/octet-stream]...
/ [1 files][  218.0 B/  218.0 B]
Operation completed over 1 objects/218.0 B.
logan_song@cloudshell:~/GCP/gke-lab-01 (dito-contact-center-ai-sandbox)$ gsutil ls gs://z04092023-unsafe
gs://z04092023-unsafe/hosts
logan_song@cloudshell:~/GCP/gke-lab-01 (dito-contact-center-ai-sandbox)$ gsutil rm gs://z04092023-unsafe/*
Removing gs://z04092023-unsafe/hosts...
/ [1 objects]
Operation completed over 1 objects.
logan_song@cloudshell:~/GCP/gke-lab-01 (dito-contact-center-ai-sandbox)$ gsutil rb gs://z04092023-unsafe/
Removing gs://z04092023-unsafe/...
logan_song@cloudshell:~/GCP/gke-lab-01 (dito-contact-center-ai-sandbox)$
```

Figure 8.13 – Cloud Shell commands for GCS

After the compute and storage discussions, let us switch to the GCP networking topic. We will use Google Cloud Shell commands to implement and manage GCP networking resources.

Google Cloud networking

Like AWS VPC, Google VPC provides network traffic management, segmentation, and isolation. The difference between them is that AWS VPC is regional and thus subnets in the same VPC are in the same region, while GCP VPC is global and thus subnets in the same VPC may be in different regions. In this section, we will use Cloud Shell to build up a GCP network. *Figure 8.14* shows the architecture of the network:

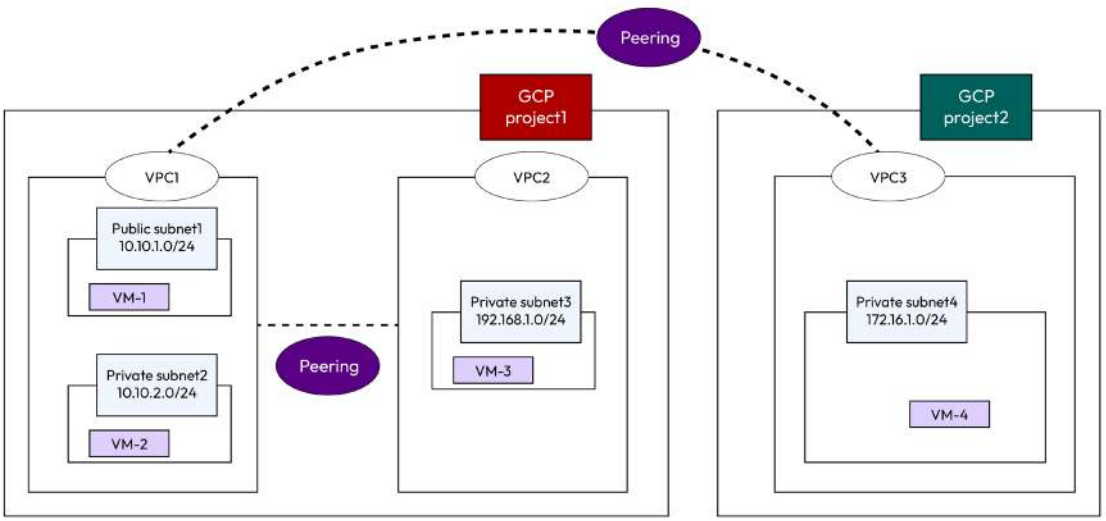


Figure 8.14 – GCP networking infrastructure

We will implement the preceding infrastructure next:

1. Create projects, networks and VMs.

   Go to the Google Cloud console, `console.cloud.google.com`, and go to **IAM | Manage Resources | Create or Delete projects**. Create two projects: `project1` and `project2`.

   I. Launch Cloud Shell and build up the Google Cloud networks:

   List the created projects (you will need to replace `project1` and `project2` with their actual project IDs):

```
gcloud projects list
```

   II. Create the VPC and subnets.

```
gcloud compute networks create vpc1 --project
project1  --subnet-mode=custom
gcloud compute networks subnets create subnet1 --network=vpc1
--range=10.10.1.0/24 --project project1 --region us-west1
gcloud compute networks subnets create subnet2 --network=vpc1
--range=10.10.2.0/24 --project project1 --region us-east1
gcloud compute networks create vpc2 --project project1 --subnet-
mode=custom
gcloud compute networks subnets create subnet3 --network=vpc2
--range=192.168.1.0/24 --project project1 --region us-central1
gcloud compute networks create vpc3 --project
project2  --subnet-mode=custom
gcloud compute networks subnets create subnet4 --network=vpc3
--range=172.16.1.0/24 --project project2 --region us-central1
gcloud projects list
```

   III. Create VMs in the VPC/subnets and record their information:

```
gcloud compute instances create vm-1 --project project1
--machine-type=f1-micro --zone=us-west1-a --subnet=subnet1
gcloud compute instances create vm-2 --project project1
--machine-type=f1-micro --network-interface=subnet=subnet2,no-
address  --zone=us-east1-b
gcloud compute instances create vm-3 --project project1
--machine-type=f1-micro --network-interface=subnet=subnet3,no-
address  --zone=us-central1-b
gcloud compute instances create vm-4 --project project2
--machine-type=f1-micro --network-interface=subnet=subnet4,no-
address --zone=us-central1-b
gcloud compute instances list --project project1
gcloud compute instances list --project project2
```

IV. Open a firewall for vpc1:

```
gcloud compute firewall-rules create fw1 --network vpc1 --allow
tcp:22,icmp --source-ranges 0.0.0.0/0 --project project1
```

2. Now, we can SSH to `vm-1`. From `vm-1`, you will be able to ping `vm-2` since they are in the same VPC, but not `vm-3`, which is in a different VPC. How can we enable pinging from `vm-1` to `vm-3`?

I. Peering vpc1 and vpc2 (in the same project) and open a firewall for vpc2:

```
gcloud compute networks peerings create peer12
--project=project1  --network=vpc1 --peer-project=project1
--peer-network=vpc2
gcloud compute networks peerings create peer21 --peer-
project=project1  --network=vpc2 --project=project1 --peer-
network=vpc1
gcloud compute networks peerings list --project=project1
gcloud compute firewall-rules create fw2 --network vpc2 --allow
tcp:22,icmp --source-ranges 0.0.0.0/0 --project project1
```

Now, you will be able to ping `vm-3` from `vm-1`. With the same procedure, we can also enable pinging from `vm-1` to `vm-4`:

II. Peering vpc1-vpc3 (a different project) and open a firewall for vpc3:

```
gcloud compute networks peerings create peer13
--project=project1  --network=vpc1 --peer-project=project2
--peer-network=vpc3
gcloud compute networks peerings create peer31
--project=project2 --network=vpc3 --peer-project=project1
--peer-network=vpc1
gcloud compute networks peerings list --project=project1
gcloud compute firewall-rules create fw3 --network vpc3 --allow
tcp:22,icmp --source-ranges 10.10.1.0/24 --project project2
```

3. Clean up the cloud resources we have provisioned.

I. Clean VPC peering:

```
gcloud compute networks peerings delete peer13
--project=project1  --network=vpc1
gcloud compute networks peerings delete peer31
--project=project2 --network=vpc3
gcloud compute networks peerings delete peer12
--project=project1  --network=vpc1
gcloud compute networks peerings delete peer21
--project=project1  --network=vpc2
```

II. Clean the VMs:

```
gcloud compute instances delete vm-1 --project project1
gcloud compute instances delete vm-2 --project project1
gcloud compute instances delete vm-3 --project project1
gcloud compute instances delete vm-4 --project project2
```

In the preceding example, we used GCP Cloud Shell commands to create VPCs, subnets, and VM instances, peer VPCs, and configure VPC firewall rules. Practicing these commands will help us understand the GCP networking concepts.

During our AWS cloud discussions, we examined the *VPC endpoint for S3 storage*. There is also a comparable situation in Google Cloud, where security requirements demand that the VM instances in a VPC access GCS buckets/objects without trespassing the internet. This time, we enable **private Google access** to a subnet in a VPC, so the VMs there will be able to access the other GCP services, such as GCS, within Google's internal network. More details about private Google access are available at `https://cloud.google.com/vpc/docs/private-google-access`.

Summary

In this chapter, we learned about GCP's foundation services: compute, storage, and networking. We launched GCE VM instances, GKE clusters, and VPC networks. We also explored service accounts, containers, and their deployments in GKE clusters. We compared GCP's foundations with AWS's to understand their similarities and differences. We hope you enjoyed it!

In the next chapter, we will examine the GCP data analytics services, including databases and big data. It is a very interesting chapter. Let's get ready to explore these services!

Practice questions

Questions 1-8 are based on the GCP foundation architecture shown in *Figure 8.15*. Default configurations are used:

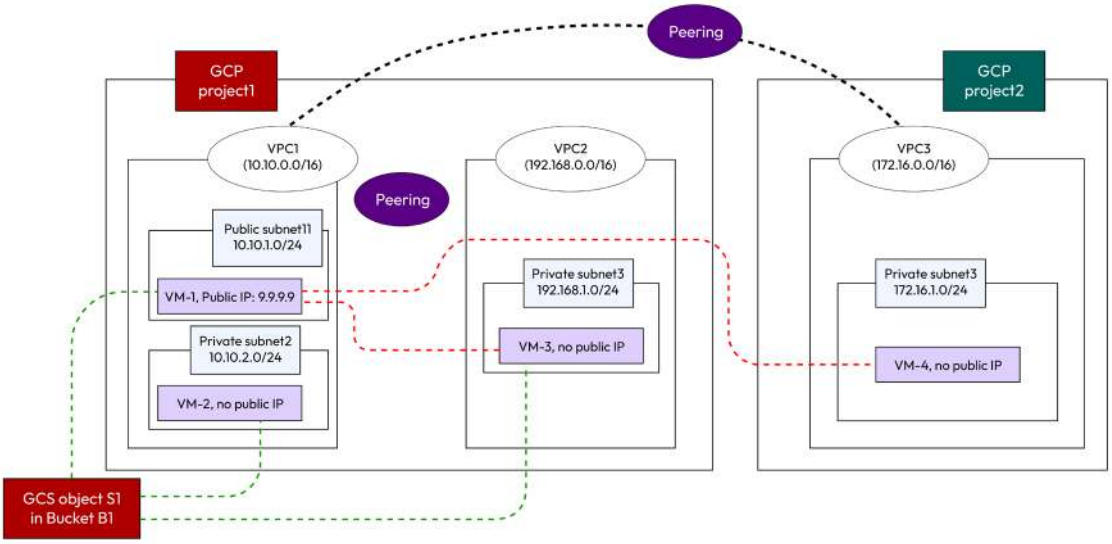


Figure 8.15 – GCP foundation infrastructure

1. How many VMs (with at least one IP address for each VM) can you create in a VPC1 subnet1 in GCP?

    A. 252

    B. 255

    C. 256

    D. 24

2. How many IP addresses are there in `subnet3`?

    A. 256

    B. 252

    C. 255

    D. 24

3. Which of the following statements is not true?

    A. **VM1** can ping VM3

    B. **VM1** can ping VM4

C. **VM2** can ping VM4

D. **VM3** can ping VM4

4. What needs to be done for VM1 to process (read/write) objects in B1?

A. Nothing

B. VM1's service account needs read/write access to B1

C. VM1 needs to have a public IP address

D. VM1 needs to have a private IP address and its service account needs read/write access to B1

5. VM1 needs to read object S1. What needs to be done?

A. Nothing

B. Enable Google private access for `subnet11`

C. Enable Google private access for `subnet12`

D. Enable Google private access for `subnet2`

6. VM2 needs to read object S1. What needs to be done?

A. Nothing

B. Enable Google private access for `subnet11`

C. Enable Google private access for `subnet12`

D. Enable Google private access for `subnet2`

E. Peer VPC1 with VPC2

7. VM3 needs to read object S1. What needs to be done?

A. Nothing

B. Enable Google private access for `subnet11`

C. Enable Google private access for `subnet12`

D. Enable Google private access for `subnet2`

8. VM4 needs to read object S1. What needs to be done? (Choose two)

A. Enable Google private access for `subnet3`

B. Grant `project2`'s compute service account access to bucket `B1`

C. Grant `project1`'s compute service account access to bucket `B1`

D. Peer `VPC1` with `VPC3`

E. Enable Google private access for `project2`

Answers to the practice questions

1. A
2. A
3. D
4. B
5. A
6. C
7. D
8. A, B

Further reading

- For further insights into what you've learned in this chapter, refer to the following links:
- `https://cloud.google.com/compute`
- `https://cloud.google.com/load-balancing`
- `https://cloud.google.com/compute/docs/instance-groups`
- `https://cloud.google.com/kubernetes-engine`
- `https://cloud.google.com/storage`
- `https://cloud.google.com/vpc`
- `https://cloud.google.com/vpc/docs/private-google-access`

9

Google Cloud's Database and Big Data Services

Data plays a very important role in modern industry. Just as petroleum oil has been a primary energy resource for almost all industries, data has become a primary digital asset in modern companies. As more and more of our lives are lived online, more and more businesses are conducted online, and our interactions with technology generate more and more data, companies have realized the power of data in making informed business decisions, improving products and services, and ultimately adding value to businesses.

As a data company, Google provides varied data services on its cloud platform, from data ingestion, data storing, data processing, to data visualization. In this chapter, we will focus on the following topics:

- **Google Cloud's database services**, including Cloud SQL, Cloud Spanner, Cloud Firestore, Cloud Bigtable, and Cloud Memorystore
- **Google Cloud's big data services**, including Cloud Pub/Sub, Cloud Dataflow, Cloud BigQuery, Cloud Dataproc, and Looker

During our discussions, we will use some examples and the sample code is available in the GitHub repository for this book: `https://github.com/PacktPublishing/Self-Taught-Cloud-computing-Engineer`. Let us start our GCP data journey with Google Cloud database services.

Google Cloud database services

We have discussed Amazon's cloud database services, mainly the AWS RDS, and DynamoDB. Now switching to Google Cloud, we will also focus on the relational Cloud SQL service and the NoSQL Cloud Firestore service.

Google Cloud SQL

Google Cloud SQL is a fully managed service that allows users to create, manage, and administer relational databases in Google Cloud. It is a MySQL- and PostgreSQL-compatible database service and includes key managed database features such as automated backups, data replication, flexible pricing, and integration with other GCP services. Cloud SQL provides strong security measures such as encryption at rest and in transit, and role-based access control. It is a powerful tool for managing and storing data in Google Cloud. To make it simple, here we will demonstrate how to use GCP Cloud Shell to create a MySQL database, connect to it, and use it:

1. Launching Google Cloud Shell and creating a Cloud SQL instance:

   From the Google Cloud console, launch Cloud Shell and execute the following commands:

   ```
   gcloud config set compute/region us-central1
   gcloud sql instances create cloudsql1 --database-
   version=MYSQL_5_7 --cpu=1 --memory=4GB --region=us-central1
   --root-password=password123
   ```

2. Connecting to the MySQL instance:

   Use the following command to connect to the Cloud SQL instance from Cloud Shell:

   ```
   gcloud sql connect cloudsql1 --user=root --quiet
   ```

   As shown in *Figure 9.1*, we have created a SQL instance and logged in to it:

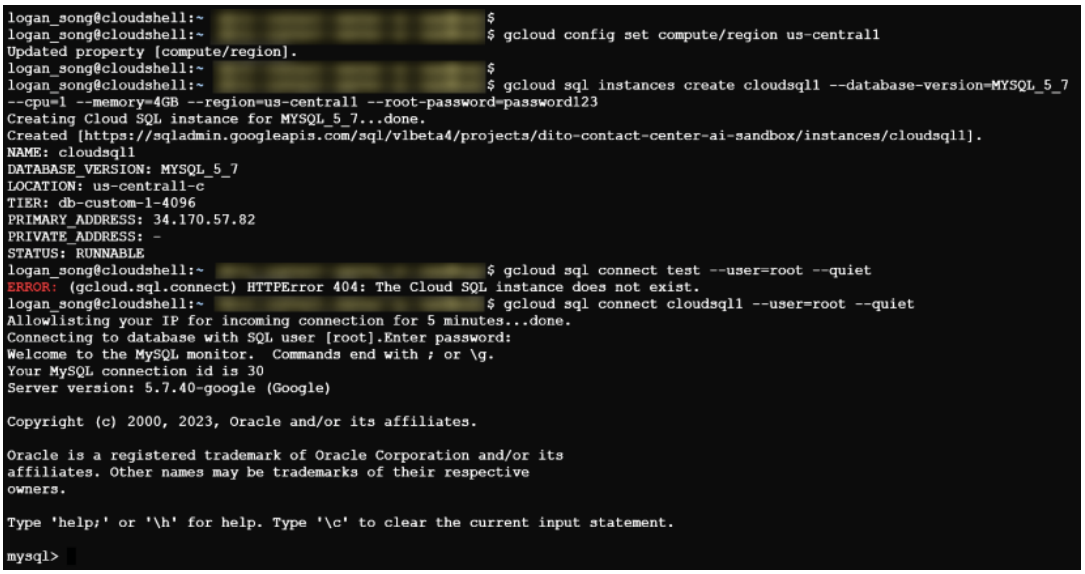


Figure 9.1 – Create and log in to the Cloud SQL instance

3. Creating a database and a table:

   After logging in to the MySQL database, run the following SQL statements:

```
Create database test;
Create table test.students (StudentID int,
    LastName varchar(100),
    FirstName varchar(100),
    City varchar(100)  );
INSERT INTO test.students values (101, "Smith", "John",
"Houston");
INSERT INTO test.students values (102, "Smith", "Jim", "Plano");
INSERT INTO test.students values (201, "Armstrong", "Neil",
"Dallas");
INSERT INTO test.students values (202, "Smith", "Neil",
"Dallas");
Select * from test.students;
```

Figure 9.2 shows the query execution in the SQL instance:

```
mysql> Create database test;
Query OK, 1 row affected (0.00 sec)

mysql> Create table test.students (
    ->     StudentID int,
    ->     LastName varchar(100),
    ->     FirstName varchar(100),
    ->     City varchar(100)  );
Query OK, 0 rows affected (0.03 sec)

mysql> INSERT INTO test.students values (101, "Smith", "John", "Houston");
Query OK, 1 row affected (0.01 sec)

mysql> INSERT INTO test.students values (102, "Smith", "Jim", "Plano");
Query OK, 1 row affected (0.00 sec)

mysql> INSERT INTO test.students values (201, "Armstrong", "Neil", "Dallas");
Query OK, 1 row affected (0.01 sec)

mysql> INSERT INTO test.students values (202, "Smith", "Neil", "Dallas");
Query OK, 1 row affected (0.00 sec)

mysql> Select * from test.students;
+-----------+-----------+-----------+---------+
| StudentID | LastName  | FirstName | City    |
+-----------+-----------+-----------+---------+
|       101 | Smith     | John      | Houston |
|       102 | Smith     | Jim       | Plano   |
|       201 | Armstrong | Neil      | Dallas  |
|       202 | Smith     | Neil      | Dallas  |
+-----------+-----------+-----------+---------+
4 rows in set (0.00 sec)

mysql>
```

Figure 9.2 – Executing SQL statements in the Cloud SQL instance

While Cloud SQL is a popular relational database service, it has limitations in size and horizontal scaling. To meet high-end relational database requirements, Google provides Cloud Spanner.

Google Cloud Spanner

Google Cloud Spanner is a fully managed, globally distributed, and strongly consistent relational database management system. It is designed to provide users with a scalable, reliable, and high-performance database solution that can support mission-critical applications.

Cloud Spanner combines the benefits of traditional relational database systems with the advantages of NoSQL databases and provides automatic scaling and rebalancing, high availability, fault tolerance, automatic backups, and point-in-time recovery. It supports SQL queries and ACID transactions. Cloud Spanner integrates seamlessly with other GCP services such as BigQuery, Dataflow, Cloud Functions, and so on.

Cloud Spanner fits well with applications that require low latency, big datasets, and global scaling. As a high-end Google Cloud database, it is for large, mission-critical business use cases and is pricey compared to Cloud SQL. We will not create a sample Cloud Spanner database here. For more details on Spanner and its prices, please refer to `https://cloud.google.com/spanner`.

After our discussion of Cloud SQL and Cloud Spanner, we will now look at the GCP NoSQL database services, starting with Google Cloud Firestore.

Google Cloud Firestore

Google Cloud Firestore is a fully managed, NoSQL document database that is designed to store, synchronize, and query data for mobile, web, and IoT applications. Firestore stores data in documents, using `JSON`-like structures, with the following features:

- It provides real-time updates for data changes across multiple devices and platforms, fitting for real-time collaborative application development
- It provides a serverless service where Google handles scaling, patching, and infrastructure management
- It provides many security features, such as SSL/TLS encryption and OAuth and Firebase authentication for user authentication and authorization
- It scales automatically for large data and high traffic volumes
- It supports multiple platforms such as Android, iOS, web, and many programming languages such as Node.js, Java, Python, and so on

Firestore fits well for small to medium-sized applications that require real-time data synchronization, offline data access, and scalability. Firestore supports two modes for its database: Native mode and Datastore mode:

- **Native mode** – In this mode, Firestore provides a more flexible data model, richer queries, and real-time updates. Along with API and client libraries, Firestore Native mode provides offline data access and real-time synchronization.

- **Datastore mode** – This mode is compatible with Cloud Datastore, which is a NoSQL document database built for automatic scaling, high performance, and ease of application development, so you can migrate applications from Cloud Datastore to Firestore without code changes.

We recommend enabling Firestore Native mode for more features and flexibility unless your existing applications use Cloud Datastore and have compatibility requirements.

To get you more familiar with the Cloud Firestore database, we will now create a Google Cloud Firestore instance from the Google Cloud console:

1. Choosing the Cloud Firestore mode:

   Navigate to **Google cloud console | Databases | Datastore | Entities**, and you will land on the starting page explaining the two Firestore modes, as shown in *Figure 9.3*. We will select **Datastore mode** in this lab:

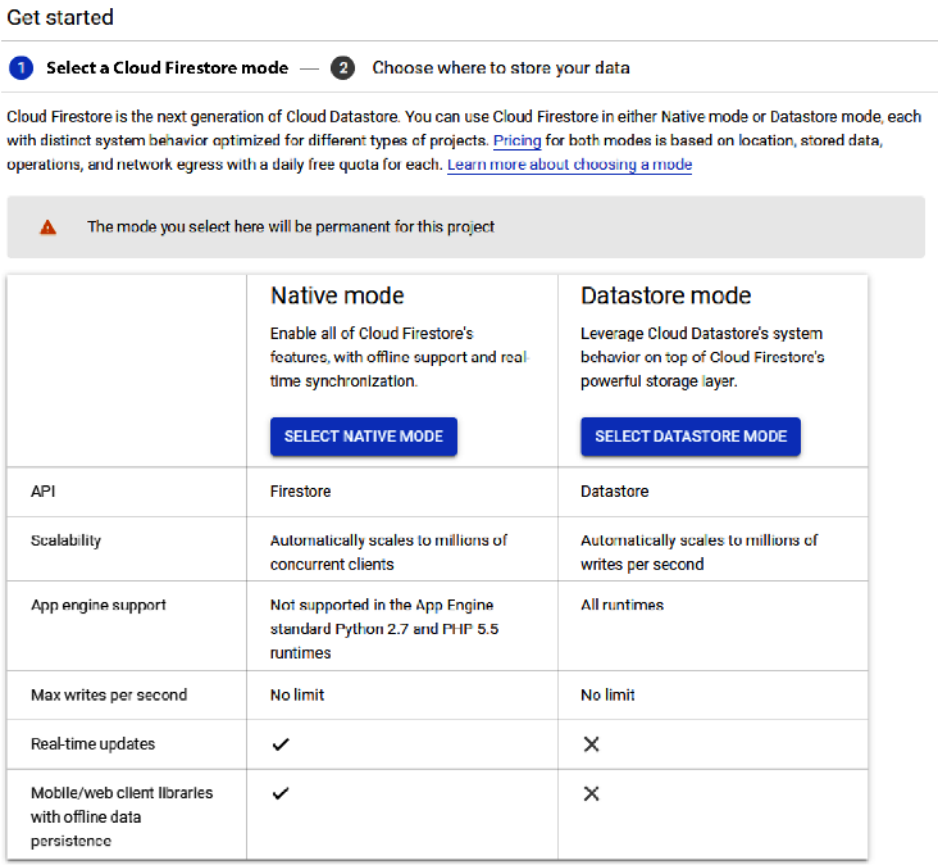


Figure 9.3 – Choose Cloud Firestore modes

Note the warning: **The mode you select here will be permanent for this project**.

2. Choosing where to store data:

   We select the **us-west1 (Oregon)** region and then **CREATE DATABASE**, as shown in *Figure 9.4*:

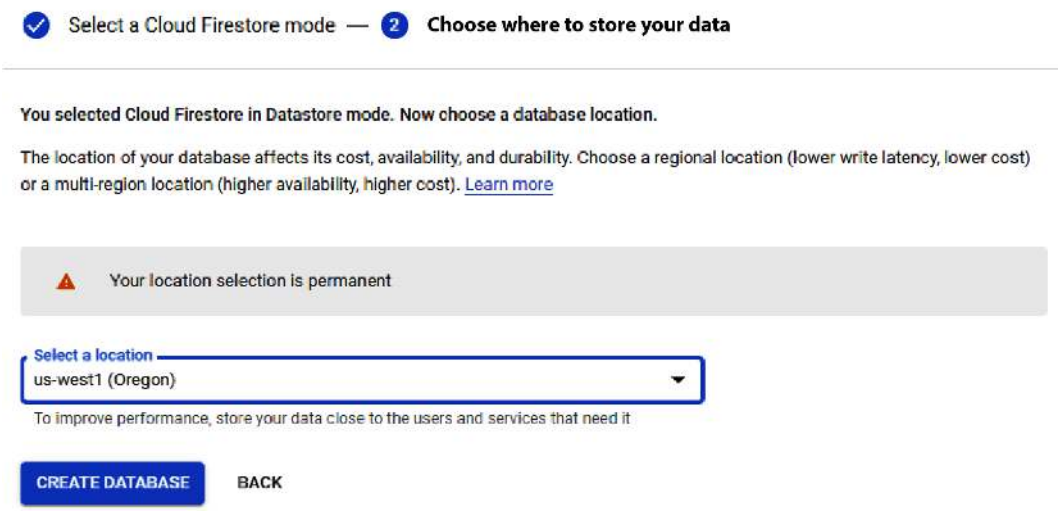


Figure 9.4 – Choosing a database location

3. Creating entities:

   The next step is to create entities. In a Cloud datastore, a **namespace** is like a partition; a **kind** is like a table; an **entity** is like an item in the table; and the **properties** are like table columns. Fill in **Properties** for an entity and click **CREATE**, as shown in *Figure 9.5*:

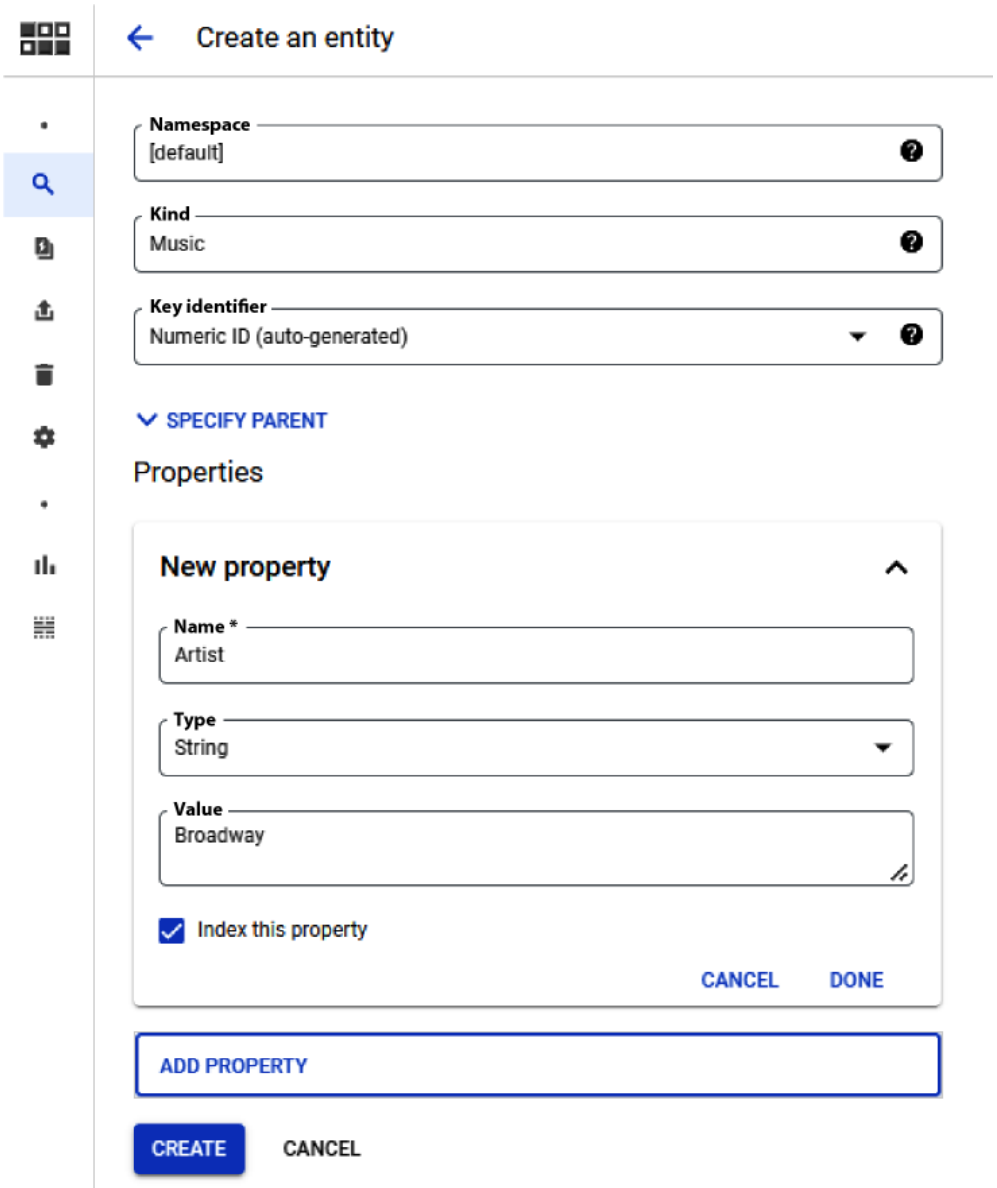


Figure 9.5 – Creating the Datastore kind and entities

More entities can be created in the same kind, and you have the flexibility to add more properties when adding new entities.

Figure 9.6 shows the two entities created for a kind called **Music**. With more entities added, you can query the kind using **QUERY BY KIND**, or **QUERY BY GQL**, which is a limited SQL-like query language – details about it can be found at `https://cloud.google.com/datastore/docs/concepts/queries`:

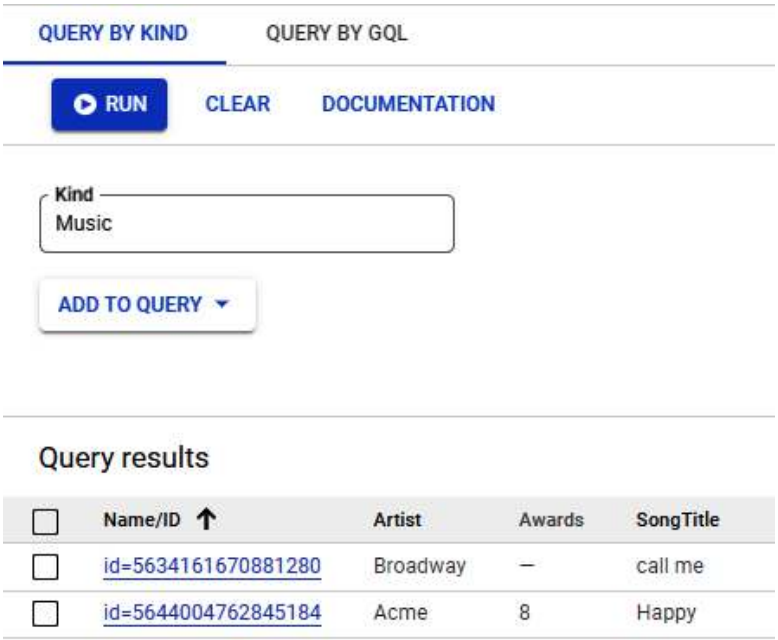


Figure 9.6 – Entities of a kind in Datastore

As we discussed earlier, the Firestore Native mode provides real-time updates. In the next example, we will create a sample three-tier web application. The frontend is the web tier, which accepts images from web users; at the backend, the app tier will move the images into a cloud storage bucket; and the database tier is a Firestore database in Native mode, which will update the image metadata in real time. We will use **Google Cloud Run** and **Google Cloud Firestore** to implement this sample application. Google Cloud Run is a serverless computing platform that allows developers to build application containers, run them based on triggers, and scale them based on workloads/traffic. Cloud Run only charges for the actual usage time, and more details about it are available at `https://cloud.google.com/run`. We will build the application and show its usage in five steps:

1. Enabling Firestore Native mode, and creating a GCS bucket in Google Cloud Shell:

   Choose Native mode from the Firestore starting page, and run the following Cloud Shell command to create a new GCS bucket:

   ```
   gsutil mb gs://04092023-target
   ```

2. Cloning the source code from GitHub:

   Execute the following command to copy the application code from GitHub:

   ```
   git clone https://github.com/PacktPublishing/Self-Taught-Cloud-computing-Engineer.git
   ```

   The cloned source code directory has the following three files:

   I. `requirements.txt` defines the software needed for the application. In our case, it reads as follows:

   ```
   Flask
   google-cloud-storage
   google-cloud-firestore
   ```

   II. `app.py` is a Python file that defines the web application process: it takes web user uploads and moves them into the bucket defined by the `BUCKET_NAME` variable – in our case, it is the bucket we created earlier. So, we need to modify the `app.py` file and replace `BUCKET_NAME` with the following:

   ```
   BUCKET_NAME = "04092023-target"
   ```

   III. `Dockerfile` is the instruction file for generating the Docker image.

3. Building the application (webserver2) container image:

   In the previous chapter, we built the `webserver1` container image with docker build. Now, we will use Google **Cloud Build** to create another web server container image: `webserver2`. Cloud Build is a service that produces artifacts such as Docker containers or Java archives.

   Execute the following command in Cloud Shell to build the `webserver2` container image:

   ```
   gcloud builds submit --tag gcr.io/$DEVSHELL_PROJECT_ID/webserver2
   ```

4. Deploying webserver2:

   Execute the following command in Cloud Shell to set up the environment and deploy the container with Google Cloud Run:

   ```
   gcloud config set run/platform managed
   gcloud config set run/region us-west1
   gcloud run deploy webserver2 --image gcr.io/$DEVSHELL_PROJECT_ID/webserver2
   ```

Figure 9.7 shows the execution results for *steps 3* and *4* in Google Cloud Shell.

```
logan_song@cloudshell:~/Firestore/content-google-cloud-run-deep-dive/image-gallery/3-firestore
$ gcloud builds submit --tag gcr.io/$DEVSHELL_PROJECT_ID/webserver2 .
Creating temporary tarball archive of 4 file(s) totalling 2.4 KiB before compression.
Uploading tarball of [.] to [gs://dito-contact-center-ai-sandbox_cloudbuild/source/1681920847.260641-51c20b989fc24f9f96ef52ef0c
66b204.tgz]
Created [https://cloudbuild.googleapis.com/v1/projects/dito-contact-center-ai-sandbox/locations/global/builds/36dea169-fce9-445
7-bf03-504d742738e7].
Logs are available at [ https://console.cloud.google.com/cloud-build/builds/36dea169-fce9-4457-bf03-504d742738e7?project=254979
162583 ].
------------------------------------------------------------------------ REMOTE BUILD OUTPUT ------------------------------------------------------------------------
starting build "36dea169-fce9-4457-bf03-504d742738e7"


------------------------------------------------------------------------
ID: 36dea169-fce9-4457-bf03-504d742738e7
CREATE_TIME: 2023-04-19T18:27:28+00:00
DURATION: 37S
SOURCE: gs://dito-contact-center-ai-sandbox_cloudbuild/source/1681920847.260641-51c20b989fc24f9f96ef52ef0c66b204.tgz
IMAGES: gcr.io/dito-contact-center-ai-sandbox/webserver2 (+1 more)
STATUS: SUCCESS
logan_song@cloudshell:~/Firestore/content-google-cloud-run-deep-dive/image-gallery/3-firestore
$ gcloud config set run/platform managed
Updated property [run/platform].
logan_song@cloudshell:~/Firestore/content-google-cloud-run-deep-dive/image-gallery/3-firestore
$ gcloud config set run/region us-west1
Updated property [run/region].
logan_song@cloudshell:~/Firestore/content-google-cloud-run-deep-dive/image-gallery/3-firestore
$ gcloud run deploy webserver2 --image gcr.io/$DEVSHELL_PROJECT_ID/webserver2
Allow unauthenticated invocations to [webserver2] (y/N)?  y

Deploying container to Cloud Run service [webserver2] in project [dito-contact-center-ai-sandbox] region [us-west1]
OK Deploying new service... Done.
  OK Creating Revision... Creating Service.
  OK Routing traffic...
  OK Setting IAM Policy...
Done.
Service [webserver2] revision [webserver2-00001-tur] has been deployed and is serving 100 percent of traffic.
Service URL: https://webserver2-inpf2htcya-uw.a.run.app
```

Figure 9.7 – Creating and deploying the webserver2 container

From **Google Cloud console** | **Cloud Run**, we can see the Cloud Run deployments, as shown in *Figure 9.8*:

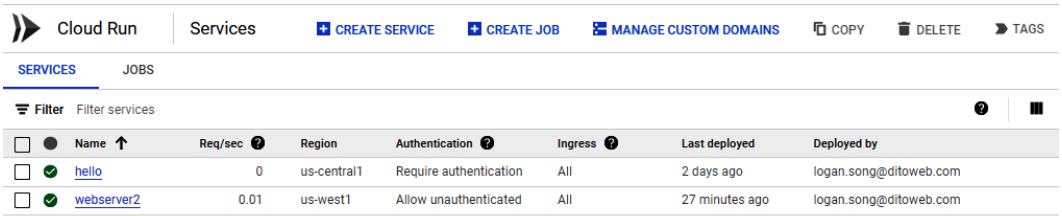


Figure 9.8 – Cloud Run service is deployed

5. Access webserver2 to test the application:

   From the Cloud Run deployment shown in *Figure 9.7*, we have got the web service URL, which is `https://webserver2-inpf2htcya-uw.a.run.app`, and now we can use it to test the application in three sub-steps:

   I. Access the URL from a new browser, and upload an image, as shown in *Figure 9.9*:

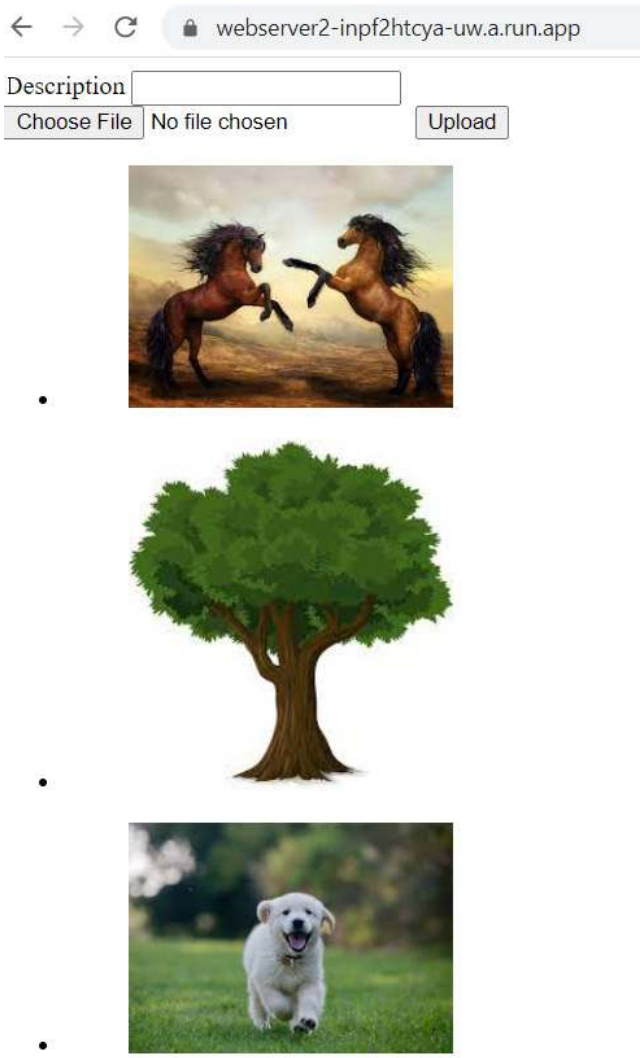


Figure 9.9 – Uploading images to the web service from the Cloud Run deployment

II. Verify that the uploaded images have been put into the GCS bucket we created earlier by the Cloud Run application. The verification is shown in the GCS commands in *Figure 9.10*:

```
$ gsutil ls gs://04092023-temp
gs://04092023-temp/image4.jpg
gs://04092023-temp/image6.jpg
gs://04092023-temp/image7.jpg
```

Figure 9.10 – Images are moved into a GCS bucket

III. Check the backend Firebase database is updated, as shown in *Figure 9.11*:

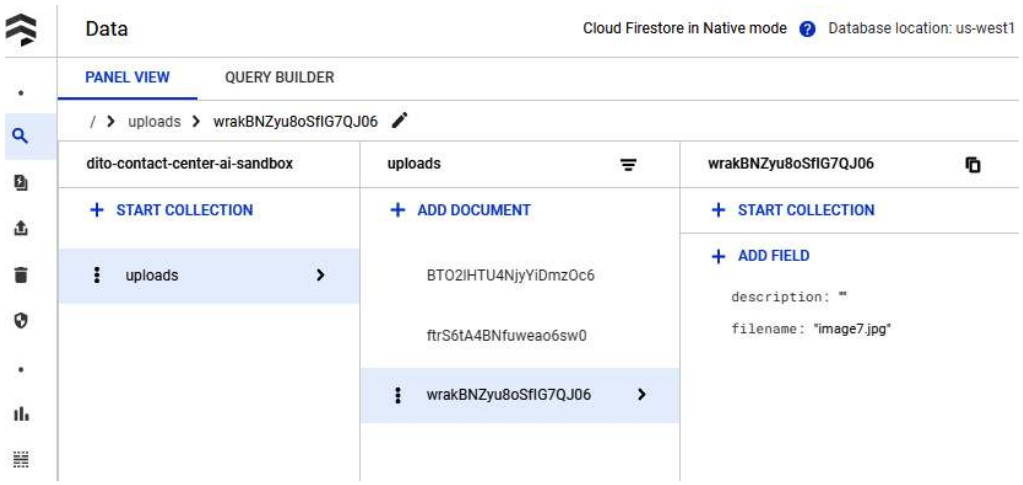


Figure 9.11 – Firestore database updated

In this section, we demonstrated the two Google Cloud Firestore modes and showed how to use them in different use cases. In the next sections, we will briefly discuss Google Cloud Bigtable and Google Cloud Memorystore.

Google Cloud Bigtable

Google Cloud Bigtable is a fully managed, scalable NoSQL database service that can handle massive workloads at high speeds. Bigtable's features include load balancing and auto-scaling, high availability, fault tolerance, support for consistent and strongly consistent reads and writes, and integration with other GCP services. Bigtable fits well with applications that store and process large amounts of data with minimum latency, such as IoT analytics and ad technology.

In general, Bigtable might be best for performance-sensitive use cases that have simple lookups or can tolerate data being potentially inconsistent across tables. Compared to Firestore, it scales better, accommodates larger amounts of data, and costs more. On the other hand, Spanner may perform slightly worse and cost more than Bigtable but will provide strong consistency. More details are available at `https://cloud.google.com/bigtable`.

Google Cloud Memorystore

Google Cloud Memorystore is a fully managed in-memory data store service that provides users with a fast, scalable, and highly available solution for storing and managing data in memory. Google Cloud Memorystore has scaling and load balancing features, high availability, fault tolerance, support for Redis and Memcached protocols, and integration with other GCP services. Google Cloud Memorystore is particularly well suited to applications that require low-latency access to frequently accessed data,

such as e-commerce, gaming, and social media apps. More details are available at `https://cloud.google.com/memorystore`.

After the Google Cloud database service discussions, we will examine Google Cloud's big data services.

Google Cloud's big data services

Google provides a suite of big data analytics tools and services for users to use to collect, process, and analyze large amounts of data in the cloud. Some key services include the following:

- **Pub/Sub**: A cloud messaging service that allows applications to exchange messages reliably, quickly, and asynchronously
- **Dataflow**: This is a fully managed, serverless data processing service that enables users to create data pipelines for real-time and batch processing
- **BigQuery**: This is a fully managed, serverless data warehouse that enables users to store and analyze massive amounts of structured and unstructured data
- **Cloud Dataproc**: This is a managed Hadoop and Spark service that enables users to process large-scale datasets in a scalable and cost-effective manner
- **Looker**: A data visualization tool that allows users to create and share interactive dashboards and reports

Google Cloud's big data services are used for a variety of applications, including business intelligence, machine learning, fraud detection, and more. Let's start with Google Cloud Pub/Sub.

Google Cloud Pub/Sub

GCP's pub/subs are essentially channels where messages can be published by publishers and subscribed to by subscribers. Publishers publish and send messages to a topic, and subscribers can receive those messages by subscribing to that topic. The publishers communicate with subscribers asynchronously, a publisher can have multiple subscribers, and a subscriber can subscribe to multiple publishers. *Figure 9.12* shows a use case where many users upload objects into a GCS bucket. Upon completion of an upload, a message is sent to the topic and received by two subscribers: one triggers a cloud function that processes the uploaded object, another notifies parties via email, and so on:

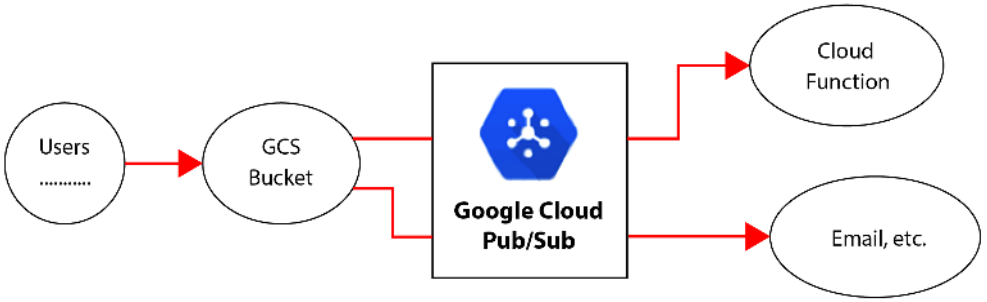


Figure 9.12 – Pub/Sub example

Pub/Sub supports push/pull subscriptions, which allow different ways of receiving messages, and message retention, which allows subscribers to receive messages even if they weren't subscribed at the time the message was published. More details are available at `https://cloud.google.com/pubsub`.

Google Cloud BigQuery

Google Cloud BigQuery is a fully managed, serverless data warehouse service that is designed to enable users to store and analyze massive amounts of structured and unstructured data using SQL queries. BigQuery uses a distributed, columnar storage format for efficient querying and large dataset processing, and thus is a good fit for real-time data analysis and machine learning workloads at the petabyte scale. BigQuery has the following key features:

- It automatically scales to handle petabyte-scale datasets
- It supports standard SQL queries so that users can implement familiar tools
- It integrates with a variety of data sources such as GCS, Cloud Datastore, Cloud SQL, and many third-party visualization tools
- It supports security features including access controls, encryption, and logging

Using Google Cloud Shell, you can use the `bq` command to load data into a BigQuery database and query the tables. *Figure 9.13* shows `bq` commands running in Google Cloud Shell: it makes a `sales` dataset in BigQuery, uploads it to a `sales.sale` table from a CSV file, `sale.csv`, and runs a query against the table.

```
logan_song@cloudshell:~ (halogen-premise-390605)$ cat sale.csv
Sub-Saharan-Africa,Fruits,443368995
Middle-East-Morocco ,Clothes,667593514
Australia ,Meat,940995585
logan_song@cloudshell:~ (halogen-premise-390605)$ bq mk sales
Dataset 'halogen-premise-390605:sales' successfully created.
logan_song@cloudshell:~ (halogen-premise-390605)$ bq ls
  datasetId
 -----------
  sales
logan_song@cloudshell:~ (halogen-premise-390605)$ bq load sales.sale sale.csv Region:string,product:string,count:integer
Upload complete.
Waiting on bqjob_r525542c5e73b5347_00000188e19f4fd3_1 ... (1s) Current status: DONE
logan_song@cloudshell:~ (halogen-premise-390605)$ bq query --use_legacy_sql=false 'SELECT * FROM  `sales.sale`;'
+----------------------+---------+-----------+
|        Region        | product |   count   |
+----------------------+---------+-----------+
| Sub-Saharan-Africa   | Fruits  | 443368995 |
| Middle-East-Morocco  | Clothes | 667593514 |
| Australia            | Meat    | 940995585 |
+----------------------+---------+-----------+
logan_song@cloudshell:~ (halogen-premise-390605)$
```

Figure 9.13 – bq command example

BigQuery is very popular and widely used for many applications in business intelligence, machine learning, and real-time analytics, especially in business use cases that require low latency for processing large amounts of data, such as e-commerce, advertising, and finance. More details are available at `https://cloud.google.com/bigquery`.

Google Cloud Dataflow

Google Cloud Dataflow is a fully managed service for stream data processing and batch execution, thus enabling users to create, deploy, and manage data processing pipelines at scale. Dataflow offers a range of connectors to integrate with various data sources and sinks and supports multiple languages, including Python, Java, and Go. Dataflow features auto-scaling, dynamic work rebalancing, and fault tolerance. Dataflow integrates with other GCP services seamlessly, including Pub/Sub, BigQuery, and Cloud Storage.

Now that we have learned about the concepts of Cloud Pub/Sub, Dataflow, and BigQuery, we will use an example to see how these cloud services can integrate to form a data pipeline. In the next example, we will create a pipeline that will process real-time simulated data.

As shown in *Figure 9.14*, the pipeline starts with the simulation of a real-time data generator, which involves executing a Python script that reads from a large Excel spreadsheet, row by row, and generates a message per row, to ingest into Cloud Pub/Sub. The Dataflow job will then get input from Pub/Sub, process the data, and output it to the BigQuery dataset/table, where we can run queries and visualize them using third-party tools:

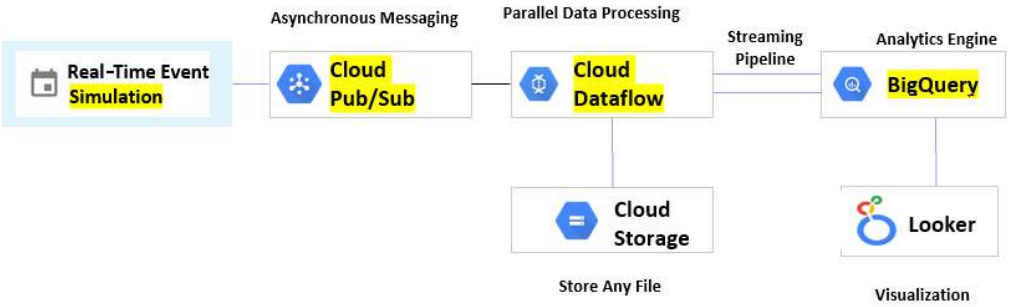


Figure 9.14 – GCP big data pipeline

Let's implement the data pipeline step by step now:

1. Preparing the data generator:

   Go to the Google Cloud console and open a Cloud Shell terminal.

   Upload the `sales.csv` file to Cloud Shell. The file is available in the book's repository: `https://github.com/PacktPublishing/Self-Taught-Cloud-computing-Engineer/chapter9/bigdata/`.

   Copy the data generator from GitHub:

   ```
   git clone https://github.com/PacktPublishing/Self-Taught-Cloud-computing-Engineer.git
   ```

   The root directory now has two files: first, `Sales.csv` is a Microsoft CSV file containing all the sales data records.

   Figure 9.15 shows the columns for `Sales.csv`:

	A	B	C	D	E	F	G
1	**Region**	**Country**	**Item_Type**	**Order_ID**	**Units_Sold**	**Unit_Price**	**Total_Revenue**
2	Sub-Saharan Africa	South Africa	Fruits	443368995	1593	9.33	14862.69
3	Middle East and North Africa	Morocco	Clothes	667593514	4611	109.28	503890.08
4	Australia and Oceania	Papua New Guinea	Meat	940995585	360	421.89	151880.4
5	Sub-Saharan Africa	Djibouti	Clothes	880811536	562	109.28	61415.36

Figure 9.15 – Sales.csv data schema

   Second, `datagen.py` is the data generator Python script that scans an Excel spreadsheet named `Sales.csv` and generates a data message for each row.

2. Creating a Pub/Sub topic and subscriptions:

   Cloud Pub/Sub is the queue to ingest the real-time data coming from the data generator.

   Go to the **Google Cloud Pub/Sub** console and create a publisher topic called `sales`, noting the topic identifier: `projects/dito-contact-center-ai-sandbox/topics/sales`.

   For the **sales** topic, create a subscription called **demographics**.

> **Note**
>
> There can be many subscriptions, such as shipping, supply, demographics, trends, and so on. Note the subscription name: `projects/dito-contact-center-ai-sandbox/subscriptions/demographics`.

Figure 9.16 shows the Pub/Sub topic and subscriptions:

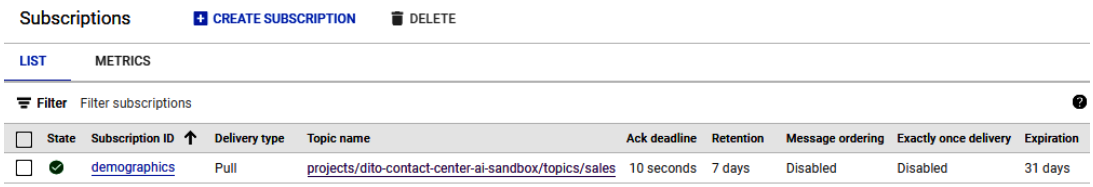


Figure 9.16 – Pub/Sub topic and subscriptions

3. Creating an empty table in BigQuery:

   BigQuery is the destination for our data pipeline. Go to the **Google Cloud BigQuery** console and create a BigQuery dataset, `sales`, and a table, `sales_demographics`. Note the table schema needs to match the data source's schema shown in *Figure 9.15*. Record the table ID of **sales.sales_demographics**.

Figure 9.17 shows the empty BigQuery table creation:

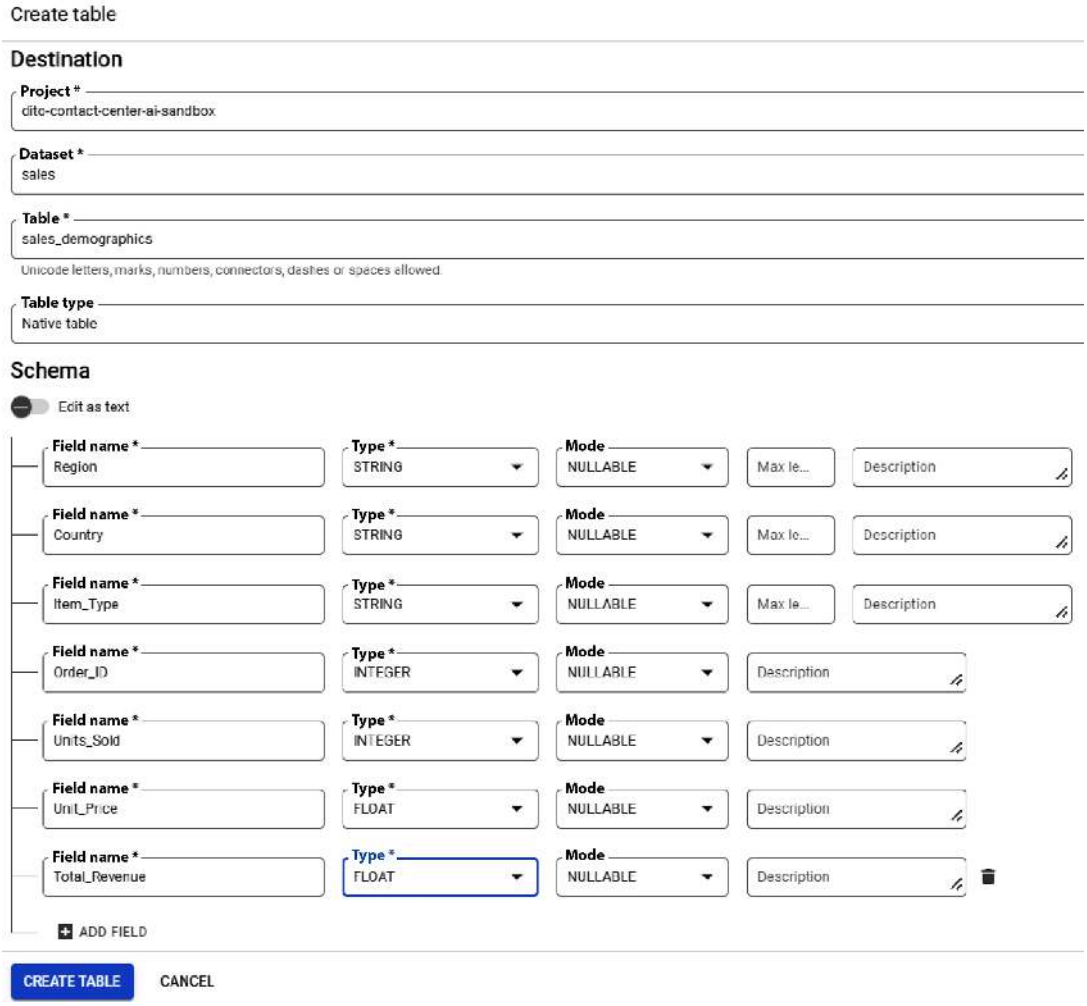


Figure 9.17 – Create the empty BigQuery table

4. Creating a Dataflow job:

   The Dataflow job will make ends meet: the Pub/Sub subscription and the BigQuery empty table. It takes Pub/Sub data as input and outputs it into the BigQuery table.

   Go to the **Google Cloud Dataflow** console and create a Dataflow job, `sub2bq`. Choose the **Pub/Sub subscription to BigQuery** template, and fill it with the Pub/Sub subscription we created earlier for the input, the BigQuery empty table for the output, and the previously created GCS bucket, `04092023-temp/tmp`, for the temporary location for the Dataflow job. Click **RUN JOB**, as shown in *Figure 9.18*:

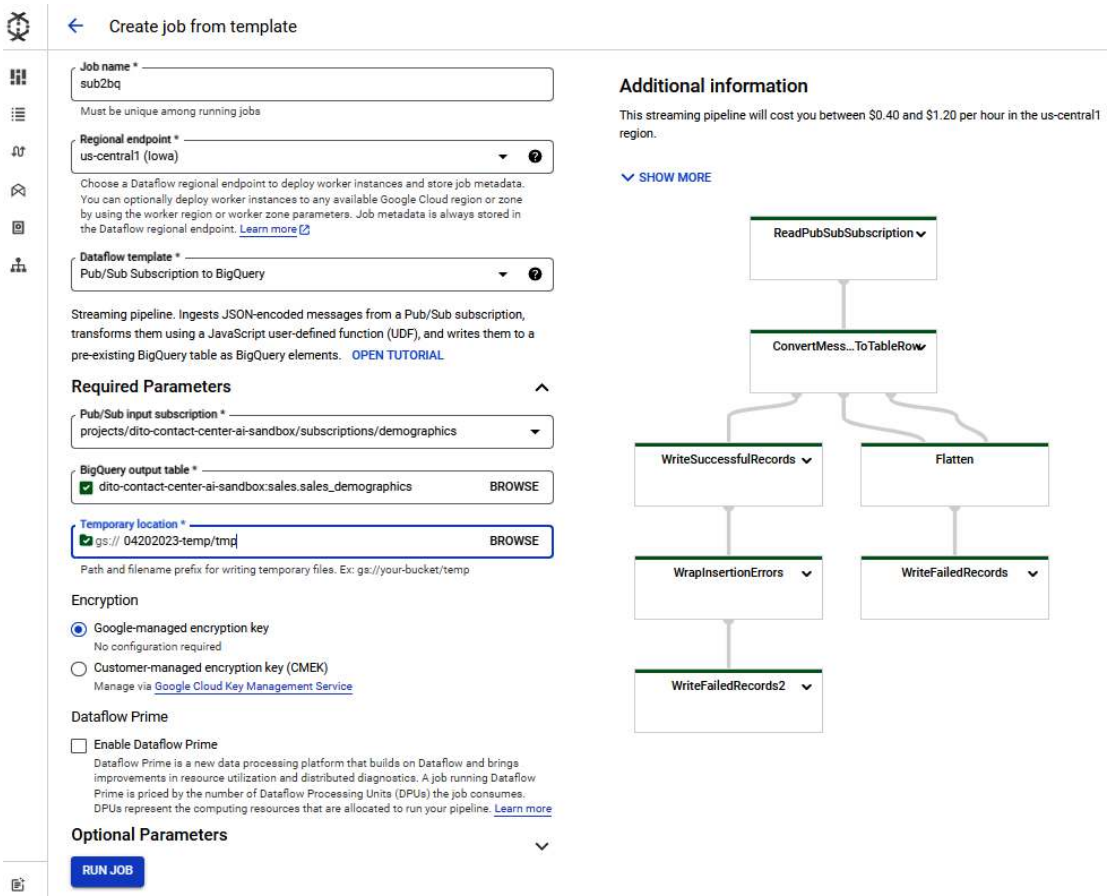


Figure 9.18 – The Dataflow job

So far, we have built the data pipeline, `data generator -> pub/sub -> dataflow -> BigQuery`, and now it's time to light it up!

5. Lighting up the data pipeline:

   We need to light up the data generator using three sub-steps within Cloud Shell:

   I. Install the Pub/Sub library:

   ```
   sudo pip3 install google-cloud-pubsub
   ```

   II. Run the `datagen.py` script:

   ```
   python datagen.py
   ```

III. Verify from the Dataflow console that the data traffic flows through the pipeline, as shown in *Figure 9.19*:

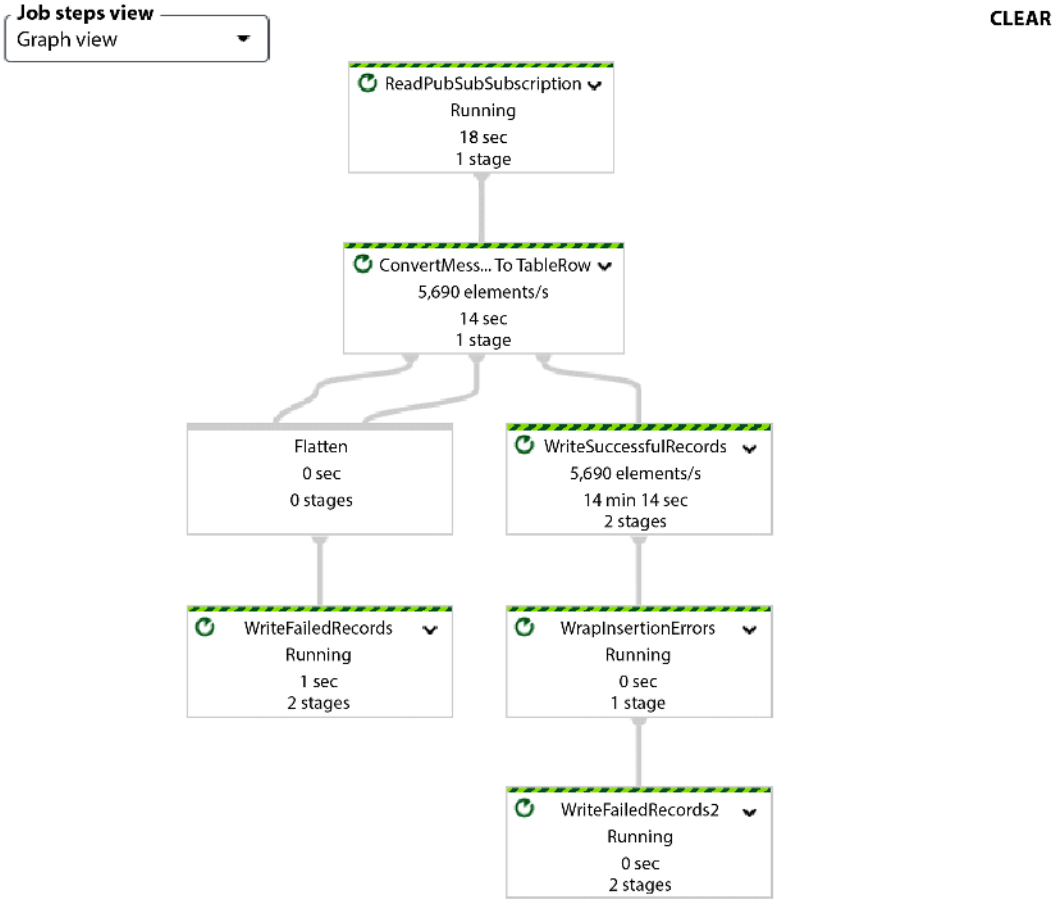


Figure 9.19 – Dataflow job shows the traffic

6. Querying the BigQuery table:

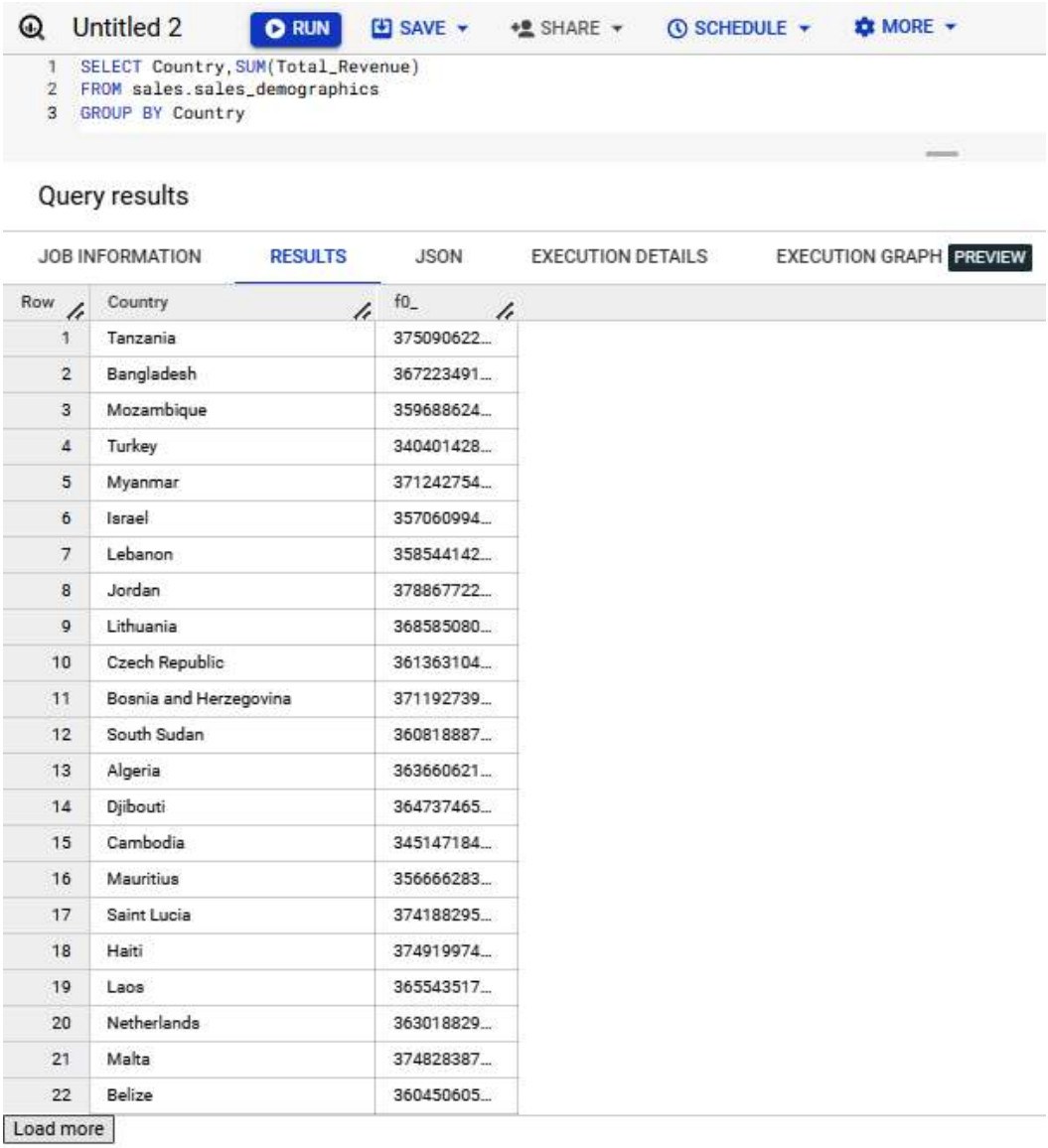
Go to the Google Cloud BigQuery console and preview the **sales_demographics** table. You will see that it was filled by the Dataflow job, as shown in *Figure 9.20*:

Row	Region	Country	Item_Type	Order_ID	Units_Sold	Unit_Price	Total_Revenue
1	Europe	Serbia	Meat	762112843	4981	421.89	2101434.09
2	Europe	Georgia	Beverages	585567700	1350	47.45	64057.5
3	Australia and Oceania	Solomon Islands	Baby Food	979315984	217	255.28	55395.76
4	Central America and the Caribb...	Dominica	Meat	941500270	9707	421.89	4095286.23
5	Sub-Saharan Africa	Mozambique	Baby Food	397630250	6482	255.28	1654724.96
6	Central America and the Caribb...	Jamaica	Beverages	330011117	6478	47.45	307381.1
7	Central America and the Caribb...	Saint Lucia	Meat	666885411	5068	421.89	2138138.52
8	Sub-Saharan Africa	Mozambique	Meat	518784987	8861	421.89	3738367.29
9	Europe	Macedonia	Vegetables	185797536	475	154.06	73178.5
10	Sub-Saharan Africa	Chad	Clothes	885809886	9685	109.28	1058376.8
11	Sub-Saharan Africa	Uganda	Baby Food	121046006	9058	255.28	2312326.24
12	Asia	Japan	Snacks	956860959	5276	152.58	805012.08
13	Australia and Oceania	New Zealand	Clothes	821347606	3864	109.28	422257.92
14	Europe	Albania	Cosmetics	347431313	1501	437.2	656237.2
15	Sub-Saharan Africa	South Africa	Office Supplies	175072562	6717	651.21	4374177.57

Figure 9.20 – BigQuery table preview

Run a sample SQL query; the result is partially shown in *Figure 9.21*:

```
SELECT Country,SUM(Total_Revenue)
FROM sales.sales_demographics
GROUP BY Country
```



Row	Country	f0_
1	Tanzania	375090622...
2	Bangladesh	367223491...
3	Mozambique	359688624...
4	Turkey	340401428...
5	Myanmar	371242754...
6	Israel	357060994...
7	Lebanon	358544142...
8	Jordan	378867722...
9	Lithuania	368585080...
10	Czech Republic	361363104...
11	Bosnia and Herzegovina	371192739...
12	South Sudan	360818887...
13	Algeria	363660621...
14	Djibouti	364737465...
15	Cambodia	345147184...
16	Mauritius	356666283...
17	Saint Lucia	374188295...
18	Haiti	374919974...
19	Laos	365543517...
20	Netherlands	363018829...
21	Malta	374828387...
22	Belize	360450605...

Figure 9.21 – BigQuery query result

The data pipeline is built, and it processed data successfully. Now let's clean the lab.

7. Cleaning up the lab:

Clean up the lab by deleting the Pub/Sub topic and subscriptions, stopping/canceling the Dataflow job, and deleting the BigQuery dataset and table.

Through the previous example, we have built a data pipeline, including Pub/Sub ingesting the real-time data stream and the Dataflow job reading from the subscription and writing to the empty BigQuery table, which can be queried as needed. In the next sections, we will briefly discuss the other GCP big data services, including Dataproc and Looker.

Google Cloud Dataproc

Google Cloud Dataproc is a fully managed, cloud-native big data processing service that enables users to easily process large-scale datasets using open source technologies such as Hadoop, Spark, and Hive. Dataproc offers the following benefits:

- It scales up or down automatically based on demand, allowing users to process large-scale datasets in a cost-effective manner
- It integrates with a variety of Google Cloud Platform services, including Cloud Storage, BigQuery, and Cloud SQL, as well as third-party tools such as Apache Zeppelin and Jupyter
- It supports a variety of open source tools and frameworks including Hadoop, Spark, Hive, and Pig, allowing users to choose the best tool for their use case
- It provides security features such as encryption and access control

Dataproc is used in many use cases, such as real-time analytics, fraud detection, and recommendation systems. It fits applications that process large-scale datasets with popular open source Hadoop tools and frameworks. More details about Dataproc are available at `https://cloud.google.com/dataproc`.

Google Cloud Looker

Google Cloud Looker is a cloud-based business intelligence and data analytics platform that enables users to create and share data visualizations, dashboards, and reports with others, and to analyze large-scale datasets in real time. Looker has the following key features:

- It enables non-technical users to create and share reports and dashboards
- It allows users to collaborate on reports and dashboards in real time, enabling teams to work together more efficiently
- It integrates with a variety of data sources and third-party tools, making it easy to analyze and visualize data from a variety of sources

Looker helps visualize data and supports many business use cases, such as sales and marketing analytics, financial reporting, and product analytics. More details are available at `https://cloud.google.com/looker`.

Summary

In this chapter, we learned about Google Cloud's database and big data services. We have explored Google Cloud SQL, Cloud Datastore, Pub/Sub, Dataflow, and BigQuery with two sample business use cases and hands-on labs. By the end of this chapter, you will have acquired skills in creating and managing databases, ingesting and processing large-scale datasets, and performing data analysis using Google Cloud's big data services.

In the next chapter, we will examine Google Cloud's machine learning services.

Practice questions

Questions 1 to *4* are based on the data pipeline shown in *Figure 9.22*. The pipeline has the default configurations and the following resources:

- Pub topic = `t1`, and subscription = `s1`
- Dataflow job = `df1`, with a GCS bucket called `b1`
- BigQuery dataset = `ds1`, and table = `ds1-table`

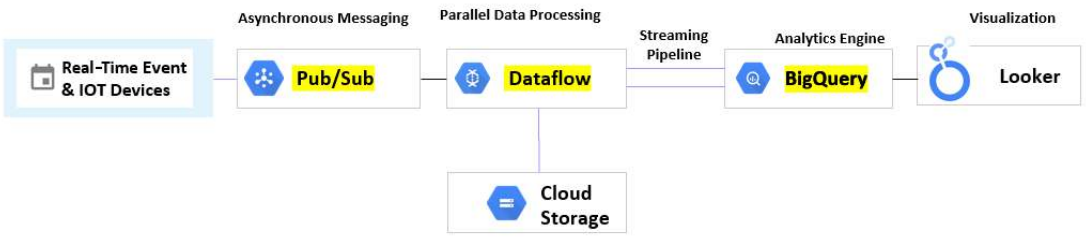


Figure 9.22 – GCP data pipeline

1. Which of the following is not part of `df1`'s metrics?

    A. Latency

    B. CPU

    C. Memory

    D. Storage

2. What machine types will be used by `df1`'s workers?

    A. `n1-standard`

    B. `f1-micro`

    C. `e2-medium`

    D. `g1-small`

3. When defining BigQuery table names, what's your recommendation?

    A. Use delimited identifiers

    B. Use different versions of SQL

    C. It doesn't matter since you can change the table name on the fly

    D. Use something related to the pipeline

4. We need to update `df1` without losing any existing data. What's your recommendation?

    A. Update `df1` with the `drain` flag

    B. Update `df1` and provide the transform mapping JSON object

    C. Create a new Dataflow, `df2`, with `s1` as input and cancel `df1`

    D. Create a new Dataflow, `df2`, with a new subscription, `s2`, and cancel the old pipeline

Questions 5 to *8* are based on the GCP database diagram in *Figure 9.23*:

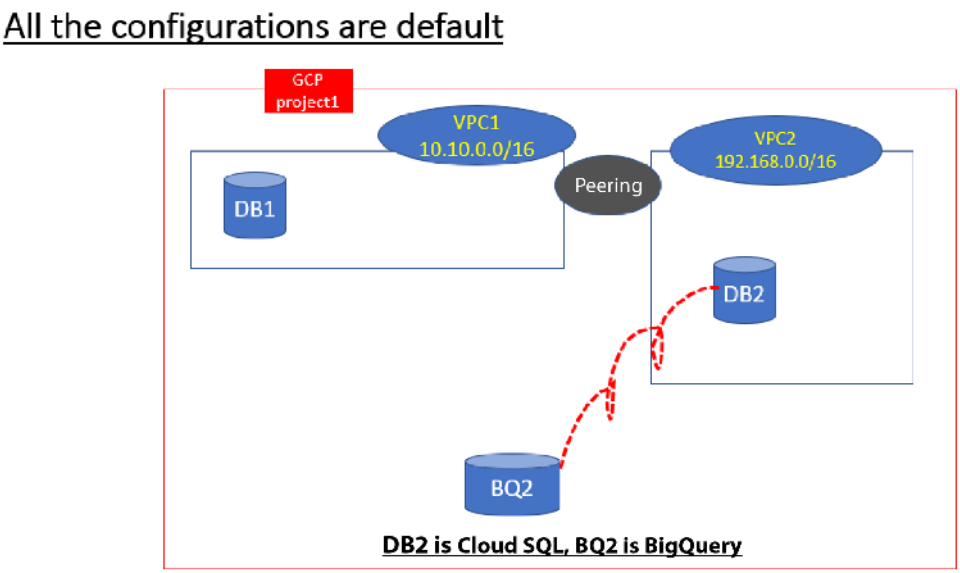


Figure 9.23 – GCP database diagram

5. Applications have performance issues in reading from **DB2**. What is your recommendation?

    A. Create a read replica

    B. Create a memory store

    C. Upgrade to Spanner

    D. Upgrade to Bigtable

6. Applications have performance issues in writing to table XYZ in **DB2**. What is your recommendation?

    A. Create a read replica

    B. Create a memory store

    C. Upgrade to Spanner

    D. Upgrade to Bigtable

7. **BQ2** needs to read data from **DB2**. What is your recommendation?

    A. A read replica

    B. Memorystore

    C. Federated queries

    D. Integrated queries

8. An application needs to read/write DB2 very frequently. What is your recommendation?

    A. A materialized view

    B. A session view

    C. A logical view

    D. A physical view

Answers to the practice questions

1. D
2. A
3. A
4. A
5. A
6. B
7. C
8. A

Further reading

For further insights into what you've learned in this chapter, refer to the following links:

- https://cloud.google.com/products/databases
- https://cloud.google.com/sql
- https://cloud.google.com/spanner
- https://cloud.google.com/firestore
- https://cloud.google.com/memorystore
- https://cloud.google.com/learn/what-is-big-data
- https://cloud.google.com/pubsub/docs/overview
- https://cloud.google.com/pubsub/
- https://cloud.google.com/dataflow
- https://cloud.google.com/bigquery
- https://cloud.google.com/dataproc
- https://www.looker.com/

10
Google Cloud AI Services

Google Cloud provides a set of AI tools and services for developers to build, train, and deploy ML models at scale. Google Cloud AI services provide the ability to build custom **machine learning** (**ML**) models using Vertex AI, which is a fully managed machine learning platform that allows developers and data scientists to build, train, and deploy machine learning models from end to end. Google Cloud AI also offers services based on pre-trained models and APIs for common ML tasks, such as image and speech recognition, **natural language processing** (**NLP**), and other predictive analytics. Google Cloud AI services integrate seamlessly with other GCP services and tools for data preprocessing, training, monitoring, and evaluation. In this chapter, we will cover the following topics:

- **Google Vertex AI**: This is a suite of services for users to develop ML models, including data collection, labeling, training, deploying **automated machine learning** (**AutoML**), and other AI capabilities.
- **Google Cloud ML API**: This is a suite of pre-trained ML models that developers can use to add advanced AI functionality to applications without ML model training. These modules can be integrated into applications to perform various AI tasks.
- **Google Cloud Generative AI**: An AI service newly added to the Vertex AI suite. Since this is an evolving area and some services are still in preview at the time of writing this book, we will briefly discuss them in a separate section.

During our discussions, we will use some examples, and the sample code is available in the GitHub repository for this book: `https://github.com/PacktPublishing/Self-Taught-Cloud-computing-Engineer`. Let us jump into the powerful Google Cloud Vertex AI platform.

Google Cloud Vertex AI

Vertex AI is an integrated set of products, features, and a management interface that simplifies the management of Google Cloud ML services. Vertex AI lets users build, train, and deploy ML models. As shown in *Figure 10.1*, Vertex AI unifies a set of disparate features and has a user interface that makes it easy to develop and integrate ML-related applications:

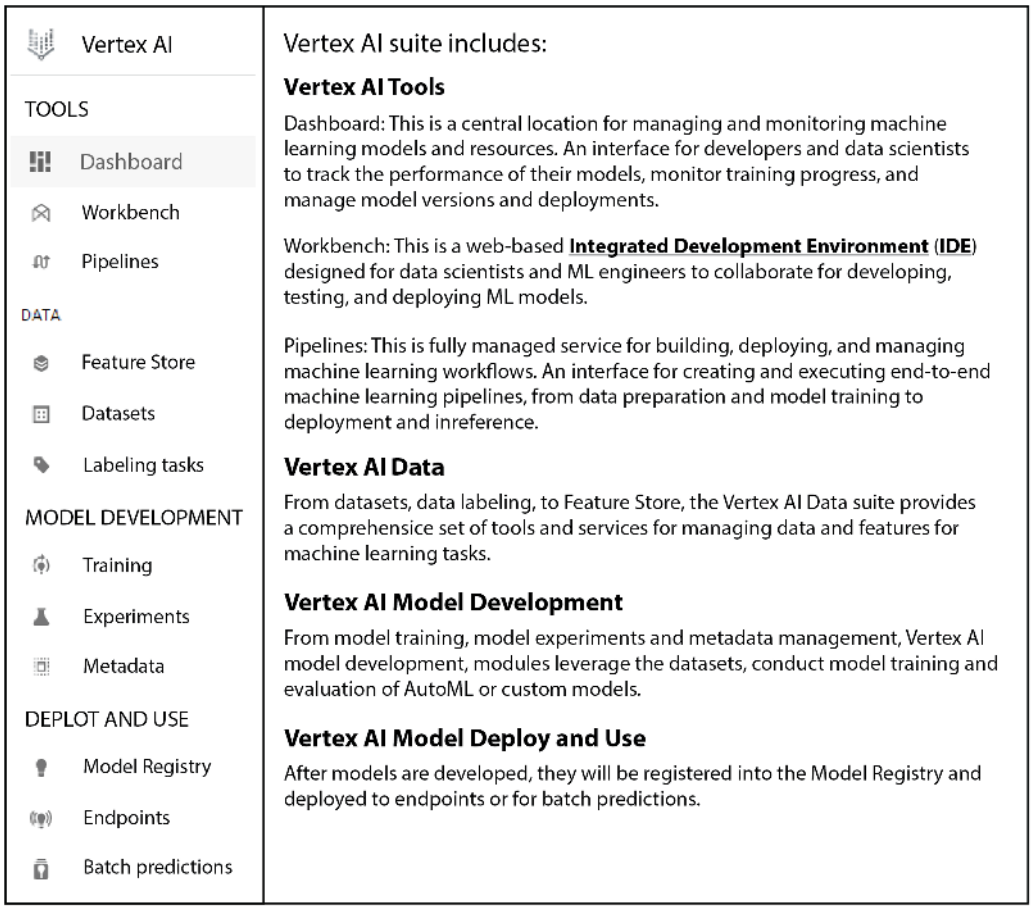


Figure 10.1 – Google Vertex AI suite

In this section, we will briefly discuss the following Vertex AI concepts first and then spotlight Vertex AI AutoML with a lab to train a simple ML model:

- Vertex AI datasets
- Vertex AI dataset labeling
- Vertex AI Feature Store
- Vertex AI Workbench and notebooks
- Vertex AI custom models
- Vertex Explainable AI
- Vertex AI prediction

- Vertex AI model monitoring
- Vertex AI Pipelines
- Vertex AI TensorBoard
- Vertex AI Metadata
- Vertex AI AutoML

Let us start looking at Vertex AI by looking at datasets.

Vertex AI datasets

Data plays a significant role in any ML process, and the quality of datasets is essential for ML model performance, the so-called *garbage in, garbage out*. With Google Vertex AI, we can create and manage datasets directly from the Vertex AI platform. **Vertex AI datasets** provide users with the ability to upload data of varying types (structured and unstructured) to develop models.

Data uploaded via Vertex AI datasets is automatically stored in Vertex-created, Vertex-managed GCS buckets, and the permissions of the buckets can be managed through GCP IAM configurations within either Cloud Storage or Vertex AI.

Dataset labeling

Vertex AI dataset labeling lets users work with human forces to generate labels for a collection of data used to train ML models. Users that have access to this service can provide instructions directly to human labelers, provided by Google or selected by the user, to review and label the uploaded datasets.

Vertex AI Feature Store

Vertex AI Feature Store is a fully managed service that provides a centralized repository for organizing, storing, and serving ML features. With Vertex AI Feature Store, you can create and manage a feature store, which is a top-level container for the model features and their values. With a central feature store, users in an organization can share and reuse ML features to speed up ML application development and deployment. Vertex AI Feature Store is a central feature store that can be shared with teams for training or to serve tasks in different projects or use cases. Consistency can be maintained across your organization to reduce duplicate efforts, particularly for high-value features. It provides feature search and filter functions for team members to check and reuse features in the store.

Workbench and notebooks

Vertex AI Workbench is a development environment to query and explore data and develop and train ML models. Vertex AI Workbench provides two options: managed notebooks and user-managed notebooks:

- Google managed notebooks provide a convenient and powerful managed environment for data scientists and developers to work on their projects in a collaborative and scalable manner, leveraging the capabilities of Google Cloud Platform. Google takes care of the underlying infrastructure, including provisioning and managing virtual machines, so you can focus on your work without worrying about server management. It offers a JupyterLab interface, which is a web-based **integrated development environment** (**IDE**), where you can work on ML-related tasks without leaving the JupyterLab interface.
- User-managed notebooks allow users to create and manage JupyterLab notebooks within the Vertex AI environment. They are customizable deep learning VM instances that have preinstalled DL packages, providing a flexible and collaborative environment for developers and data scientists to develop and run machine learning experiments and workflows.

With Vertex Workbench and notebooks, you can access and explore your data within a Jupyter notebook. Vertex AI custom models allow us to have complete authority over data processing, model training, and prediction.

Vertex AI custom models

Building a custom ML model provides the ability to deliver highly accurate and robust models. There are two ways you can train a custom model:

- Use a Google Cloud prebuilt container and install a Python package that contains your code for training a custom model.
- Use your own model that has your code for training a custom model.

With a Vertex AI custom model, you can build customized ML models that fit your own business use cases.

Vertex Explainable AI

Vertex Explainable AI provides insights into how much each feature in the data/model contributed to the predicted result to help you with feature selection and researching how to improve your model and training data.

Vertex AI prediction

Vertex AI prediction manages computing resources in the cloud to run your models – it allocates nodes to handle online or batch predictions. When you deploy an ML model, either to endpoints or

batch transformations, you can customize the node VM types for the prediction service and optionally configure GPUs for these nodes.

Vertex AI Model Monitoring

Vertex AI Model Monitoring helps you track the performance and behavior of your deployed machine learning models. It allows you to ensure that your models are performing as expected and identify any issues or anomalies in their predictions. It can monitor your model's input data and detect data drift – changes in the statistical properties of the input data over time. It can monitor the predictions made by your deployed model and detect prediction drifting, which occurs when the model's behavior changes over time. It provides metrics and insights into your model's performance. You can monitor key metrics such as latency, error rates, throughput, and resource utilization.

Vertex AI offers interactive dashboards that provide a visual representation of the monitored metrics and insights. It integrates with Google Cloud Monitoring, which allows you to centralize and manage your monitoring data alongside other Google Cloud services. You can leverage Cloud Monitoring's advanced capabilities, such as creating custom dashboards, setting up alerting policies, and analyzing your monitoring data in a unified manner.

Vertex AI Pipelines

Vertex AI Pipelines automates, monitors, and governs your ML systems in a serverless manner. It provides a way to orchestrate and automate the end-to-end machine learning workflow, encompassing tasks such as data preparation, model training, evaluation, and deployment. Vertex AI Pipelines enables you to create scalable and repeatable workflows that streamline the development and deployment of machine learning models.

Vertex AI TensorBoard and Metadata

Vertex AI TensorBoard lets you track, visualize, and compare ML experiments and share them with your team. Vertex AI TensorBoard provides visualizations including the following:

- Metrics such as loss and accuracy over time
- Model computational graphs
- Histograms of weights, biases, or other tensors as they change over time
- Image, text, and audio samples
- Profiling TensorFlow programs

By integrating with TensorBoard, Vertex AI enables you to monitor and analyze the training progress, model performance, and other relevant metrics of your TensorFlow models directly within the Vertex AI environment.

Google Cloud Vertex AI Metadata is a service that allows you to capture, store, and manage metadata associated with your machine learning projects and artifacts within the Vertex AI environment. Metadata provides valuable context and information about the various components and processes involved in your machine learning workflows.

Vertex AI AutoML

Google **AutoML** reduces or eliminates the need for skilled data scientists to build ML models. It enables users with limited ML expertise to train and build their own high-quality models fitting their business needs. Google AutoML allows you to train models on image, tabular, text, and video datasets without writing code.

In the following example, we will use Vertex AI AutoML to train an image classification model. The dataset has 22 images (images 1-22), which are available in the GitHub repository for this book: `https://github.com/PacktPublishing/Self-Taught-Cloud-computing-Engineer`.

We will use Vertex AI Data to prepare the dataset, train an AutoML model using Vertex AI model training, deploy the model to an endpoint using Vertex AI, and test the model with a new image. Let's start with the dataset images:

1. To collect datasets and label them, go to **Google Cloud console | Vertex AI console | Datasets**.

   Import the 22 images and label them – if an image has contents belonging to any of five categories (adult, spoof, medical, violence, or racy), then it is labeled **unsafe**; otherwise, it is labeled **safe**:

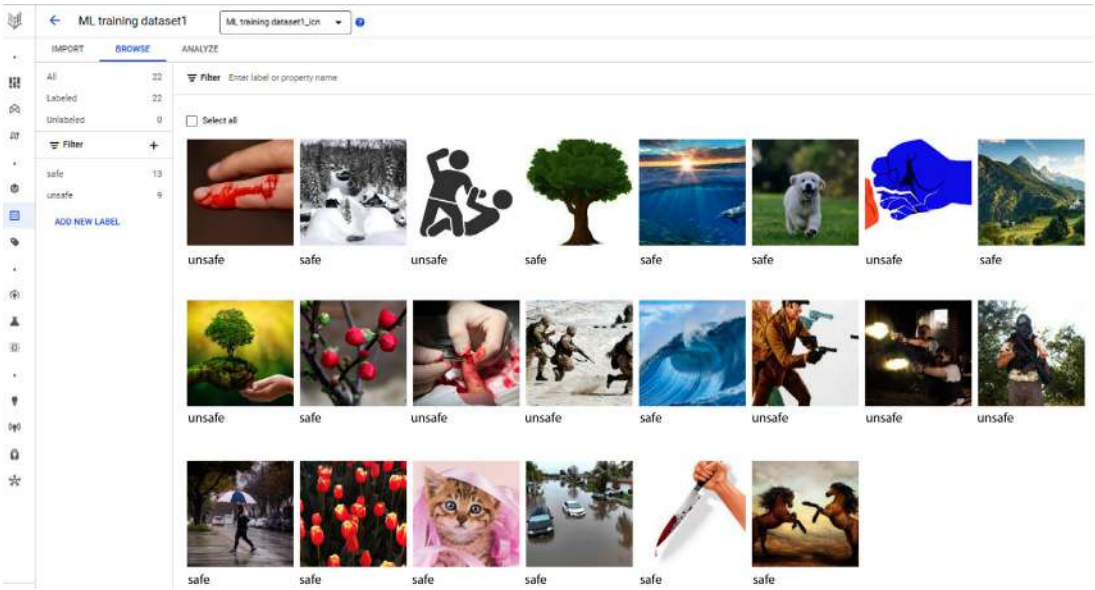


Figure 10.2 – Upload and label the dataset

2. To train the model with AutoML, take these steps:

   I. Creating an ML model:

      i. Go to **Vertex AI console** | **Training** | **Create** to generate a new model:

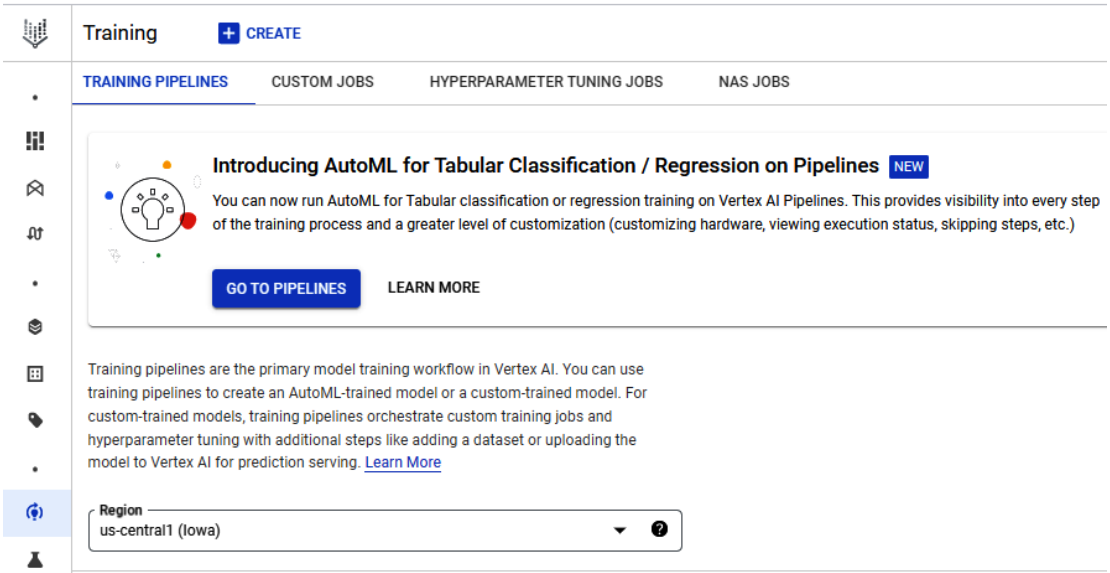


Figure 10.3 – Create a training ML model

ii. Select **AutoML** as the training method and keep the defaults for the rest, as shown in *Figure 10.4*:

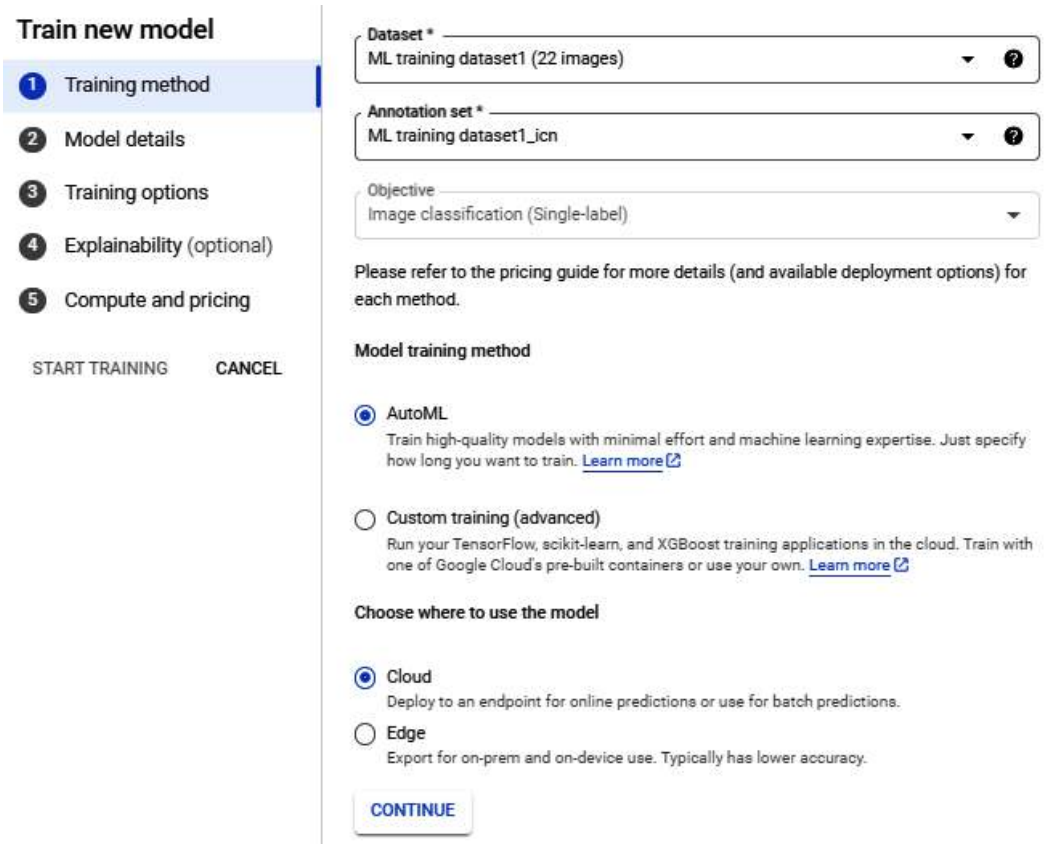


Figure 10.4 – Choose AutoML for Model training method

iii. Fill in more model details. For **Budget**, you can put the maximum node hours to limit the model training time. In our case, we use 8 hours as the limit. Click **START TRAINING**, as shown in *Figure 10.5*:

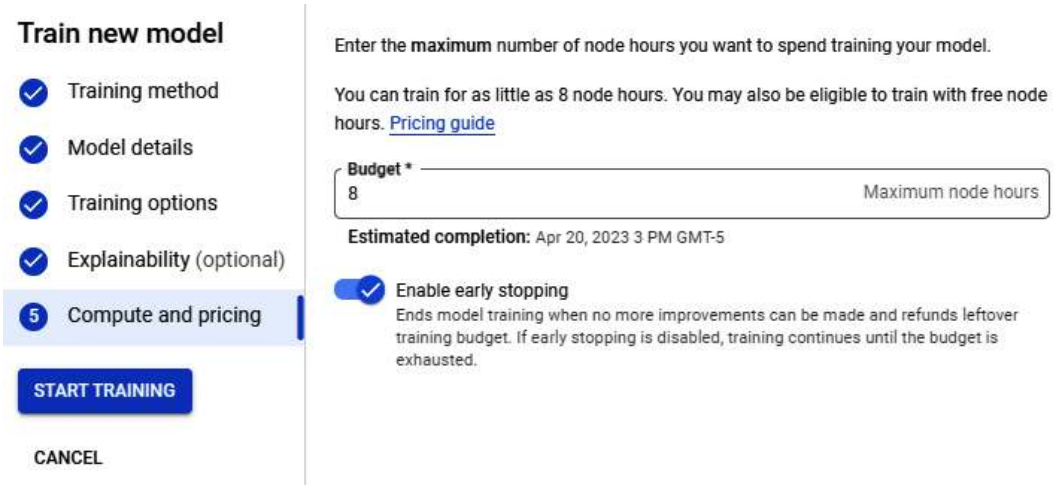


Figure 10.5 – Start model training

II. Training the ML model:

It will take some time to do the AutoML training. Once the training is complete, it will send an email to the user indicating the ML training has been completed.

3. Deploying the model:

After the model is trained, we need to deploy it. In our case, we will deploy it to an endpoint. Go to **Vertex AI console | Online prediction | Create Endpoint**. Then define the endpoint as shown in *Figure 10.6(a)*:

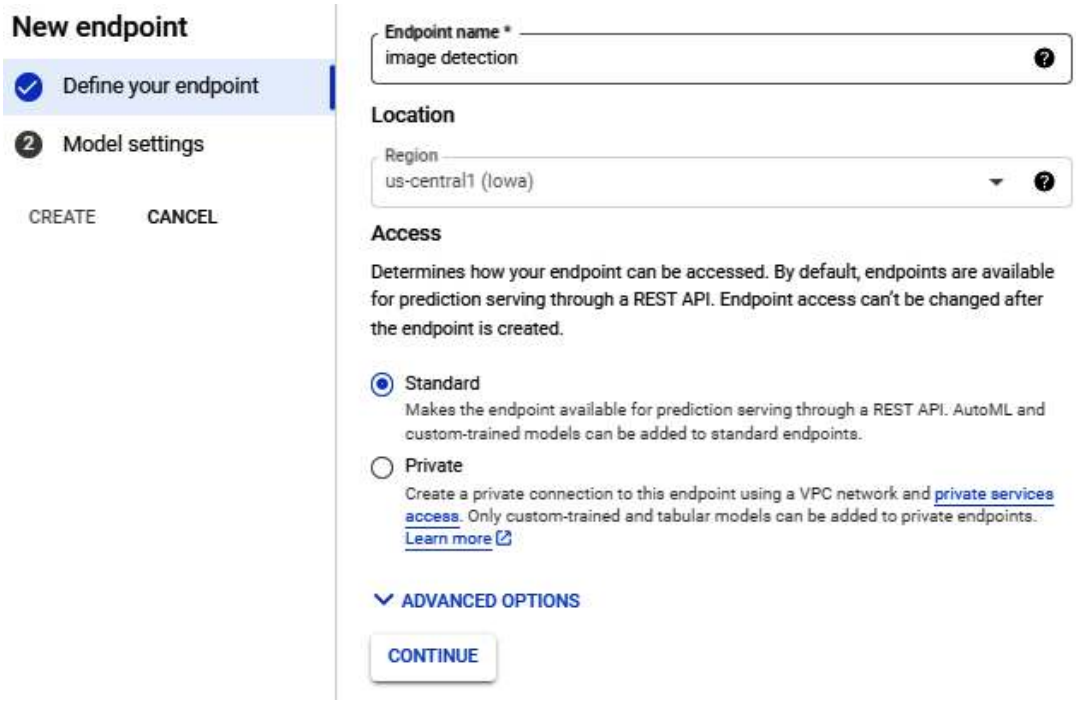


Figure 10.6a – Deploy model to endpoint (1)

Continue to **Model settings** and fill in the details as shown in *Figure 10.6(b)*. We will use one node for the deployment:

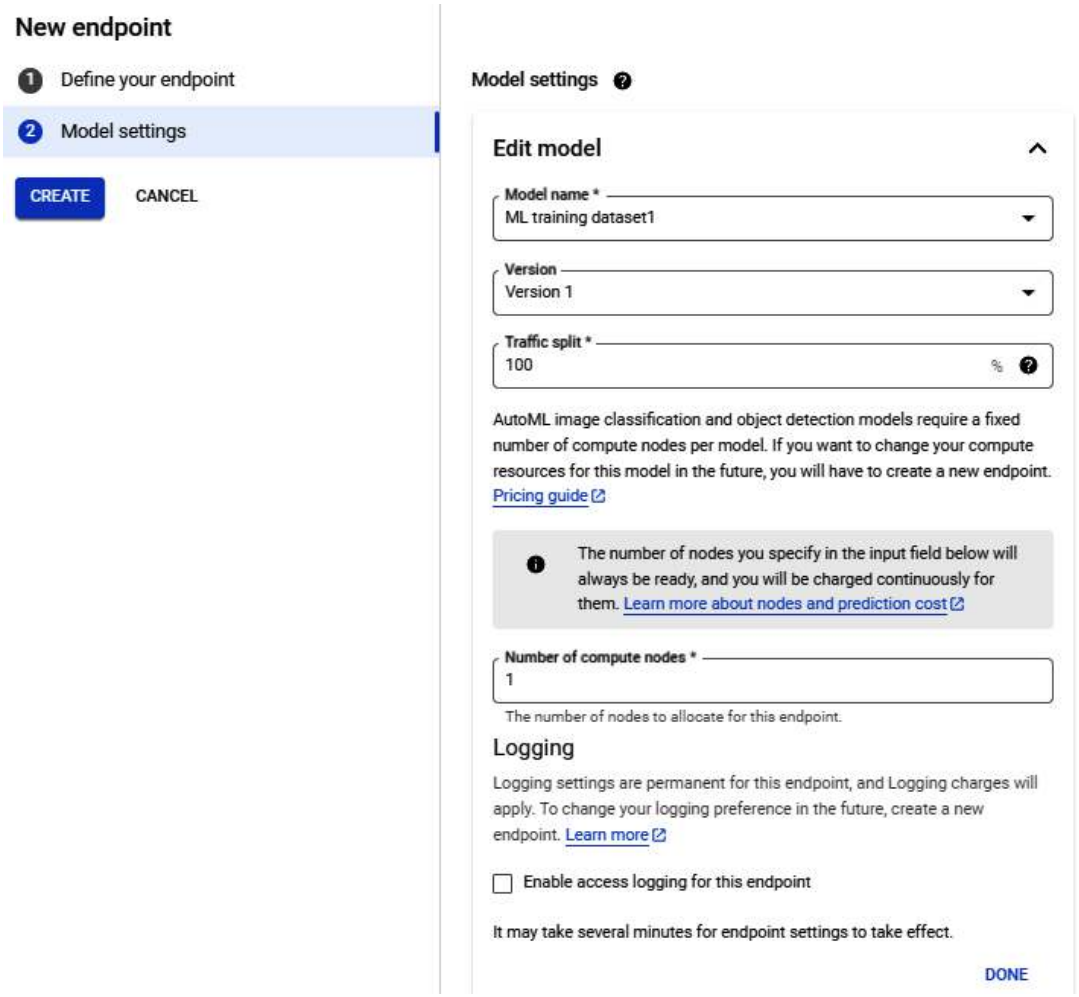


Figure 10.6b – Deploy model to endpoint (2)

It will take some time to deploy the model to an endpoint. After it's done, you will get an email notification and you can then use the endpoint to predict a new image.

4. Predicting content safety for a new image:

   After the model is deployed, we will test it with a new image. Go to **Vertex AI console | Training** and click on the model we have created and deployed. The new page will show four tabs: **EVALUATE**, **DEPLOY & TEST**, **BATCH PREDICT**, and **VERSION DETAILS**. Enter the **DEPLOY & TEST** tab, and we'll upload a new image to test the model and detect whether the image is safe. *Figure 10.7* shows the result of testing a sample image that is 100% safe:

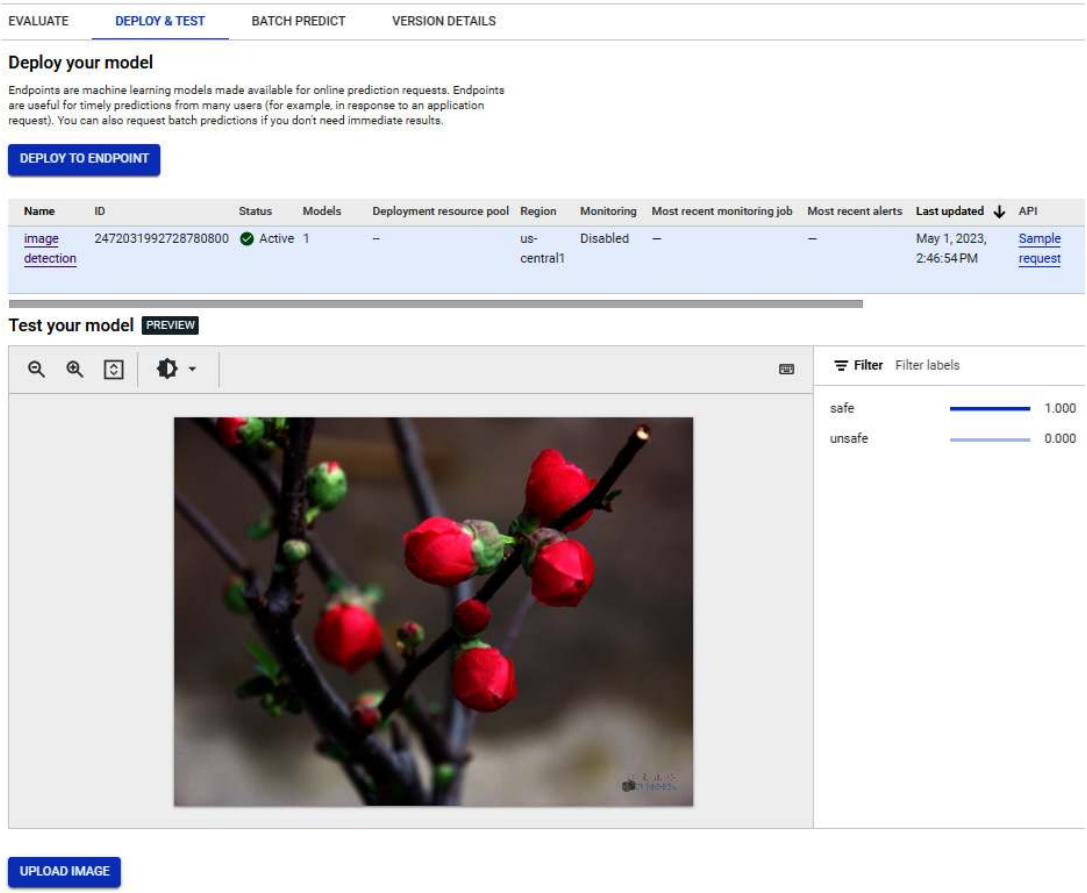


Figure 10.7 – Use the ML model to detect new image content

In the preceding lab, we have shown a Vertex AI AutoML model training process, where we developed a simple model that can classify images, using a small dataset of 22 images. As you can see, Vertex AI provides a comprehensive suite for developers and data scientists to develop ML models easily.

In this section, we introduced the Vertex AI suite, which provides an end-to-end Google Cloud AI suite, from data preparation to feature engineering to model development and deployment. Using Vertex AI, ML model training is the most time and money consuming part and it relates to choosing the notebook/instance types, using CPU/GPU/TPUs, and other factors. For more information about Vertex AI price calculations, please refer to `https://cloud.google.com/vertex-ai/pricing` and `https://cloud.google.com/products/calculator`.

As we discussed earlier, after your ML models are trained and deployed in Vertex AI, they must keep up with changing data from the environment to perform optimally and consistently. **ML operations** (**MLOps**) is a set of practices that improves the stability and reliability of your ML systems (more information about MLOps is available at `https://services.google.com/fh/files/misc/practitioners_guide_to_mlops_whitepaper.pdf`) Google's Vertex AI modules provide services that help you implement MLOps with your ML workflow:

- Vertex AI Monitoring monitors models for data skew drifting and alerts when the incoming prediction data skews too far from baselines
- Vertex AI Feature Store provides a centralized repository for organizing, storing, and serving ML features
- Vertex AI Model Registry provides an overview of your models so you can better organize, track, and train new versions
- Vertex AI Experiments lets you track, analyze, and measure different model architectures to identify the best model for your use case
- Vertex AI TensorBoard helps you track, visualize, and compare ML experiments to measure model performance
- Vertex ML Metadata lets you record and query metadata to analyze, debug, and audit the performance of your ML system
- Vertex AI Pipelines helps you automate, monitor, and govern your ML workflows

In the next section, we will introduce the Google Cloud ML APIs that leverage Google's pre-trained models, and we will also conduct the same image detection/categorizing use case, but with Cloud ML APIs.

Google Cloud ML APIs

The Google Cloud ML APIs are a set of ML API services that provides pre-trained models and tools for developers and data scientists to build custom ML models and ML applications. *Figure 10.8* shows a diagram of the Cloud ML APIs that we will cover next:

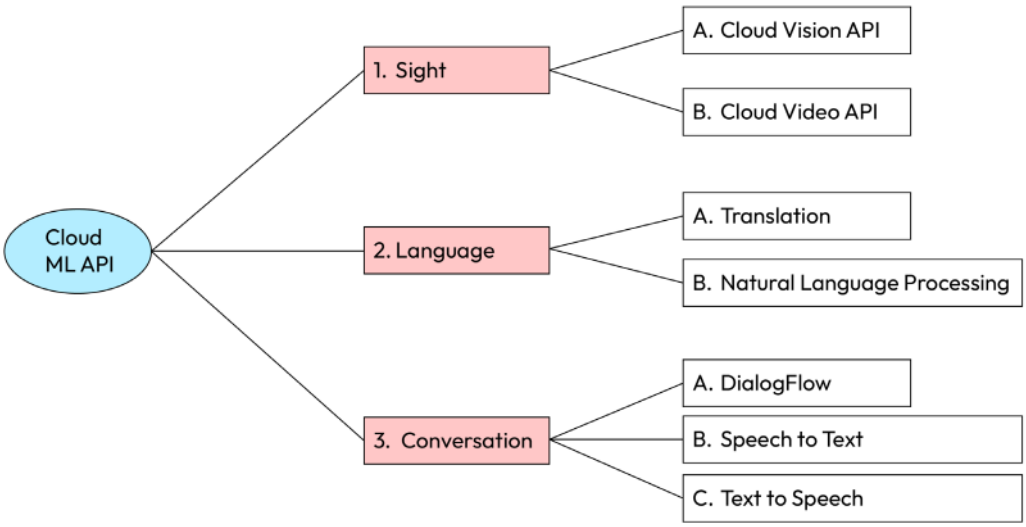


Figure 10.8 – Google Cloud ML APIs

Sight API

Google Cloud Sight API includes Cloud Vision API and Cloud Video API. The former analyzes static images and the latter learns from videos.

Cloud Vision API

Google Cloud Vision API is a cloud-based image analysis tool that helps developers to build applications that can understand the content of images, leveraging pre-trained computer vision models. Here are some key features of Cloud Vision API:

- **Label detection**: It helps to identify objects and the context within an image
- **Optical Character Recognition** (**OCR**): It detects and extracts text from images
- **Face detection**: It detects faces and facial features within images
- **Landmark detection**: It identifies popular landmarks within images
- **Image attributes**: It detects attributes of an image, such as contents, colors, and so on

While Cloud Vision API is tailored to image analysis, Cloud Video Intelligence API is specifically designed for video analysis. Both APIs leverage machine learning models to provide powerful capabilities for understanding visual content. The choice between the two depends on whether you need to analyze individual images or analyze video content. Let's look at Cloud Video API.

Cloud Video API

Google Cloud Video API is a machine learning-powered video analysis service that enables developers to integrate video intelligence and analysis capabilities into their applications. Google Cloud Video API provides the following:

- **Label detection**: It analyzes videos and labels them with categories and keywords
- **Shot detection**: It detects changes in the camera angle or scene within a video
- **Object tracking**: It tracks the movements of objects in a video
- **Face detection**: It detects face positions and facial expressions
- **Explicit content detection**: It detects content that may be inappropriate or objectionable

The development of sight and language has played crucial roles in shaping human evolution, cognition, culture, and progress. These faculties have empowered humans to perceive and interpret the world, communicate with one another, and create rich and diverse societies. The fundamentals of AI are to teach machines/computers to learn sight intelligence and language intelligence.

Language API

Language APIs allow developers to incorporate **NLP** and translation capabilities into their applications. GCP Language API offers various features for text analysis, understanding, and language translation.

NLP API

Google Cloud Natural Language API allows users to perform text analysis tasks such as these:

- **Sentiment analysis**: It analyzes the sentiment of a given text and provides a score ranging from `-1.0` (negative) to `1.0` (positive), as well as a magnitude that indicates the overall emotional intensity of the text
- **Entity recognition**: It identifies and classifies entities within a given text, such as people, places, organizations, and products
- **Syntax analysis**: It parses the grammatical structure of a sentence, providing information on parts of speech, dependency relationships, and more
- **Content classification**: It classifies text into predefined categories, such as news, politics, or sport

Using text in one language to interpret a text in another language is language translation. GCP provides Cloud Translation API.

Translation API

Google Cloud Translation API enables developers to easily integrate language translation capabilities into their applications. The API supports translation between over 100 languages and provides the following:

- Auto-detection of source language from a given text
- High-quality translations that are contextually accurate and natural-sounding
- Customizable translations for developers to train and deploy custom translation models

Other than text, conversation is an important format in human communications. Google offers Cloud Conversational API for developers to integrate conversations into intelligence applications.

Conversational API

Google Cloud provides several services and APIs that can be used to develop conversational applications. Google Cloud Conversational API includes Dialogflow, Text-to-Speech, and Speech-to-Text. Let's check each of them.

Dialogflow

Google Cloud Dialogflow is a language understanding platform that allows developers to build conversational interfaces for various applications such as chatbots, voice assistants, and other interactive experiences. Dialogflow understands user inputs in natural language and can generate responses in real time. The platform provides tools to understand the meaning behind user inputs and generate appropriate responses. It provides pre-built agents for common use cases such as customer support, e-commerce, and booking systems, which can be customized and extended to meet specific requirements. It provides a drag-and-drop interface for building conversational experiences, as well as analytics and insights into user behavior, including metrics such as user engagement, session duration, and message counts.

Text-to-Speech

Google Cloud Text-to-Speech allows developers to convert written text into spoken audio. Powered by pre-trained ML models, it supports a variety of input audio formats, including MP3, WAV, and Ogg Opus, and generates lifelike voices that sound natural and expressive. The API supports over 30 languages and provides fine-grained control over audio settings, such as speaking rate, pitch, and volume.

Speech-to-Text

Google Cloud Speech-to-Text allows developers to transcribe spoken audio into text. Powered by pretrained Google ML models, the API can transcribe real-time streaming audio or pre-recorded audio files in a variety of formats and transcribe speech with high accuracy. It supports over 120 languages

and dialects and can transcribe real-time streaming audio. It can automatically identify and separate different speakers in a conversation and automatically insert punctuation and formatting.

In summary, Google Cloud ML APIs enable developers to integrate the pre-trained ML model services into their applications. The Cloud ML APIs also integrate with other Google Cloud services, such as Google Cloud Storage, Google Kubernetes Engine, Google BigQuery, and so on, to provide a complete end-to-end solution for machine learning projects.

Having explored the Google Cloud ML APIs, we need to practice some hands-on skills. In the next section, we will implement a new solution to the business use case we discussed earlier: detecting input image content and labeling it as *safe* or *unsafe*. Last time, our solution leveraged Vertex AI datasets to import the images and label them, then used Vertex AI AutoML to train an ML model, and used Vertex Endpoint to deploy the model to an endpoint for image detection. This time, we have a different solution – we will use Google Cloud API and leverage the Google pre-trained Cloud Vision models to solve the issue.

We will first create a GCS bucket. Upon uploading an image to the bucket, a cloud function will be triggered. The function will call Cloud Vision API functions to detect whether the image has unsafe contents or not, then move the image to different GCS folders labeled as **unsafe** or **safe** respectively. *Figure 10.9* shows the solution workflow diagram:

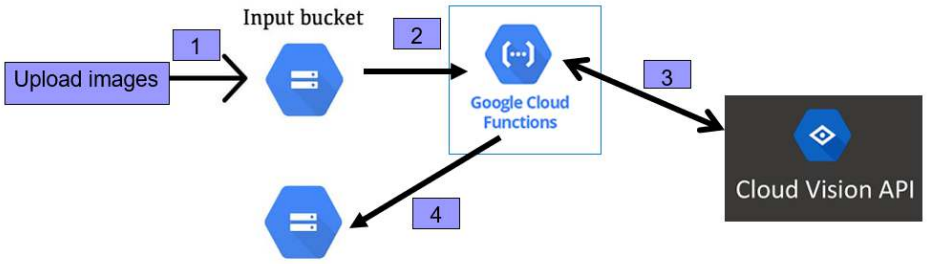


Figure 10.9 – Detect image contents using Cloud Vision API

We will implement the solution in four steps:

1. Create GCS buckets using Cloud Shell:

```
gsutil mb gs://04092023-upload
gsutil mb gs://04092023-safe
gsutil mb gs://04092023-unsafe
```

Check the buckets created:

```
gsutil ls
```

2. Create three files in Cloud Shell:

- `requirements.txt`
- `target.json`
- `main.py`
  - The `requirements.txt` file defines the library requirements. In our case, it reads as follows:

```
google-cloud-storage
google-cloud-vision
```

  - The `target.json` file includes the target bucket variable in JSON format:

```
{"SAFE_BUCKET": "z04092023-safe",
"UNSAFE_BUCKET": "z04092023-unsafe"}
```

  - The `main.py` file defines a cloud function called `image_checking`.

  Google Cloud Functions is a serverless computing platform that allows developers to write and deploy small functions that automatically scale based on demand. Cloud functions can be triggered by various events, including HTTP requests, Cloud Pub/Sub messages, Cloud Storage changes, and more.

  In our case, the `image_checking` cloud function basically takes the image in the upload bucket folder, calls the Google Cloud API `SafeSearch Detection` function to check whether the image has explicit content (adult, spoof, medical, violence, or racy), and moves the image to the `unsafe` folder if it does; otherwise, it moves the image to the `safe` folder. Details about the Cloud Vision API `SafeSearch Detection` function are available at `https://cloud.google.com/vision/docs/detecting-safe-search`.

3. Deploying the `image_checking` cloud function in Cloud Shell:

   Use the following command in Cloud Shell to deploy `image_checking`:

```
gcloud functions deploy image_checking  --trigger-
resource  z04092023-upload --trigger-event google.storage.
object.finalize --runtime python37
```

4. Testing with new images:

   Now, when you upload the images into the `z04092023-upload` bucket, the `image_checking` cloud function will perform content detection and move the image to the appropriate folders based on the Cloud Vision detection result.

This concludes our Cloud ML API example. Compared to the solution we had for the same use case in the Vertex AI section, where we trained and deployed our own model using Vertex AI AutoML, this time, we used Google Cloud ML API, which is very powerful since it's based on pre-trained ML models. As a matter of fact, Google ML API is one of the most popular libraries for developers to form business AI applications.

Google Cloud ML API has different price models for sight (vision/video), language (NLP and so on), and other services. Please refer to Google Cloud Pricing Calculator at `https://cloud.google.com/products/calculator` for more details.

Google Cloud generative AI services

Google Cloud generative AI services use **large language models** (**LLMs**) to recognize, predict, and generate human languages. They can be used in many business applications to drive new business opportunities. *Figure 10.10* lists some generative AI use cases in Google Workspace applications.

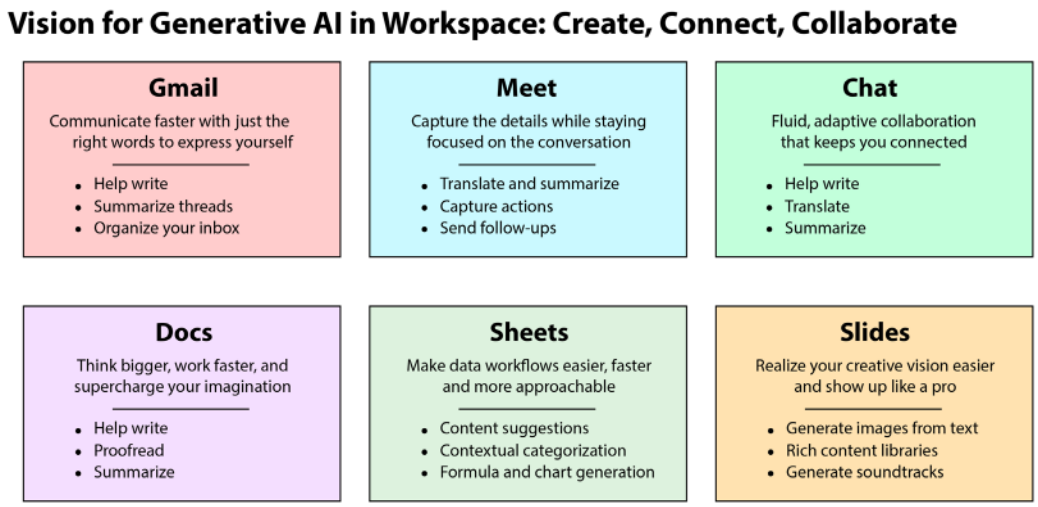


Figure 10.10 – Generative AI use cases in Google Workspace

Since the needs of enterprise customers are different from individual consumers and enthusiasts, Google Cloud generative AI focuses on enterprise business cases and environments. At this time, it offers **Generative AI Studio**, which includes three tabs: **Overview**, **Language**, and **Speech**, as shown in *Figure 10.11*.

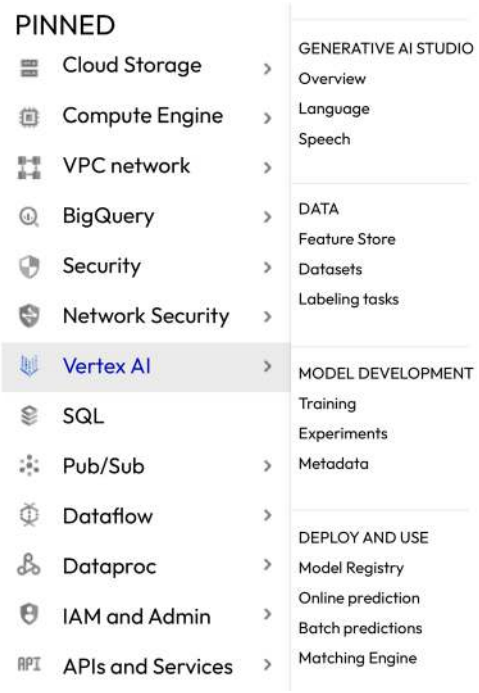


Figure 10.11 – Generative AI Studio in Vertex AI

In the **Language** tab, it provides starting points for prompts, conversations, and model tuning, as shown in *Figure 10.12*:

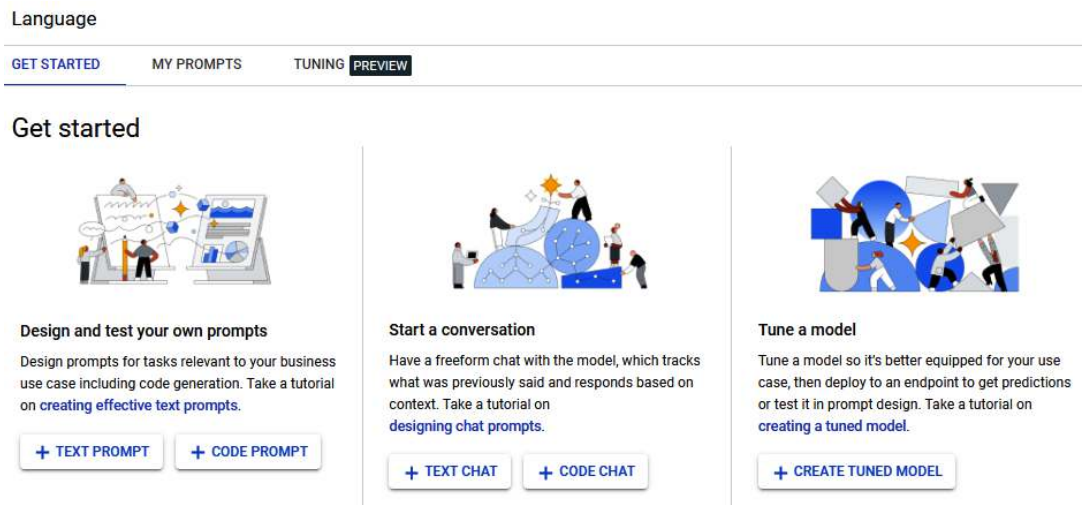


Figure 10.12 – Generative AI Studio Language tab

It provides many prompts, some of them are shown in *Figure 10.13*:

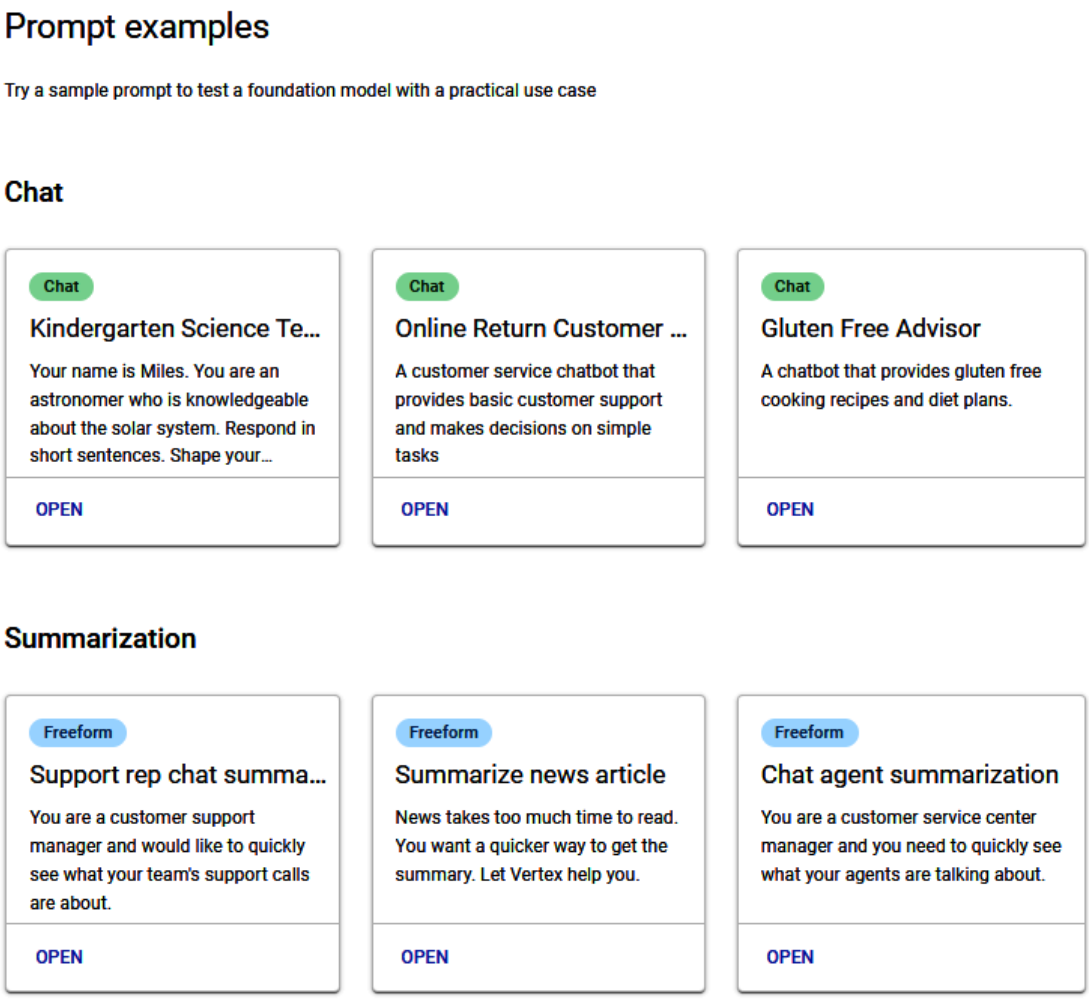


Figure 10.13 – Generative AI language prompts

Google Cloud generative AI services are part of the Google Cloud AI portfolio to support Generative centric enterprise AI development for business users, developers, and AI practitioners. *Figure 10.14* shows the Google Cloud AI portfolio:

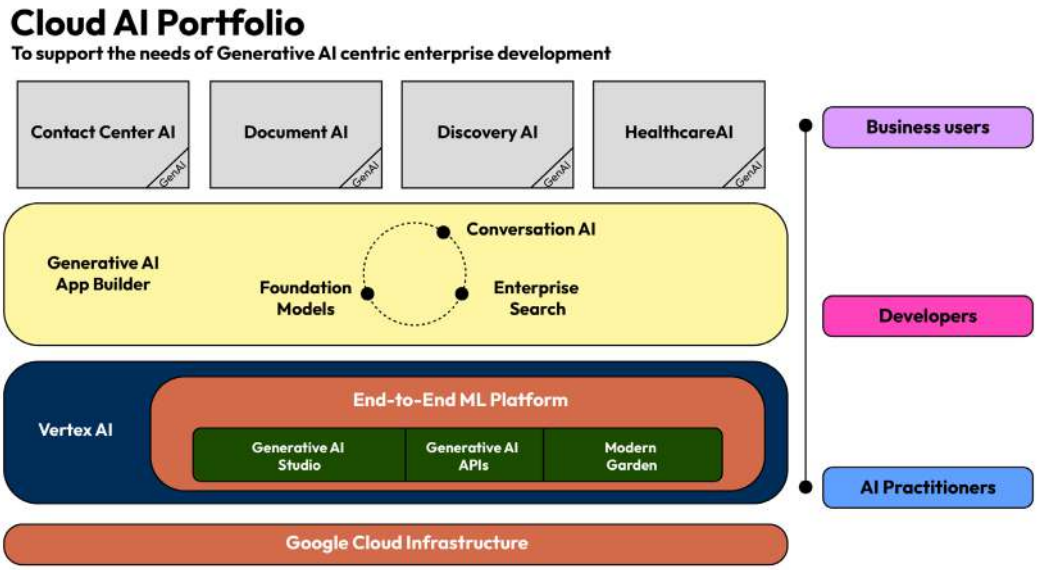


Figure 10.14 – Generative AI is part of the Google Cloud AI portfolio

More services are being added to it. It would be a great idea to keep track of the generative AI services as they are developed and applied to business use cases.

Summary

In this chapter, we discussed the two main topics in Google Cloud ML: Google Cloud Vertex AI, which provides an end-to-end suite for developing and deploying ML models, and Google ML API, which provides programming interfaces by leveraging pre-trained ML models. We have also covered Google generative AI, which is an emerging AI service added to Vertex AI recently.

In this chapter, you have acquired ML model training and ML application development skills using the Google Vertex AI suite and Google ML API. In the next chapter, we will discuss Google Cloud security.

Practice questions

Questions 1-4 are based on *Figure 10.15*, which is a Cloud Vision system to detect unsafe content in input images.

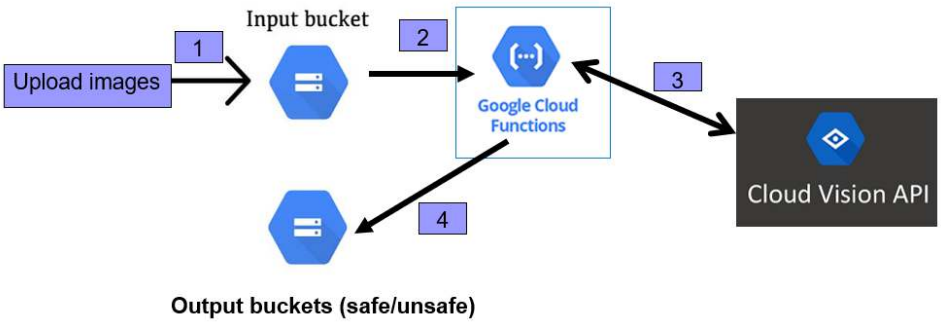


Figure 10.15 – Cloud Vision detection system

We have created three files:

- `target.json`
- `main.py`
- `requirements.txt`

And the following is a snippet of the `main.py` file:

```
def image_checking(data, context):
    uri = "gs://" + data['bucket'] + "/" + data['name']
    image = vision.Image()
    image.source.image_uri = uri
    response = vision_client.safe_search_detection(image=image)
    result = response.safe_search_annotation
```

1. What is the `requirements.txt` file?

    A. It includes the required modules to import

    B. It can be renamed to requirements

    C. It is only for illustration purposes

    D. It is needed for GCP Cloud Vision

2. What is the `target.json` file?

    A. It includes the buckets to put classified images

    B. It includes the dataset for training the model

    C. It is only for illustration purposes

    D. It is needed for GCP Cloud Vision

3. What is `result` in the code snippet?

A. It is the result of the image safety detection processing

B. It is the result of image safety dataset labeling

C. It is the result of the image model training

D. It is the result of the Vision model validation

4. What is `data` in the code snippet?

A. It is the input from the cloud function deployment

B. It is the input for the model dataset

C. It is the data structure of the image

D. It is the data for model analytics

Questions 5-8 are based on the following use case:

An engineer is working in a customer support/ticket center for a financial firm and is designing an ML system that will preprocess users' tickets before they are routed to a support agent, as shown in *Figure 10.16*:

The system aims to perform the following tasks:

- Predict ticket priority
- Predict ticket resolution time
- Perform sentiment analysis to help agents make strategic decisions when they process support requests

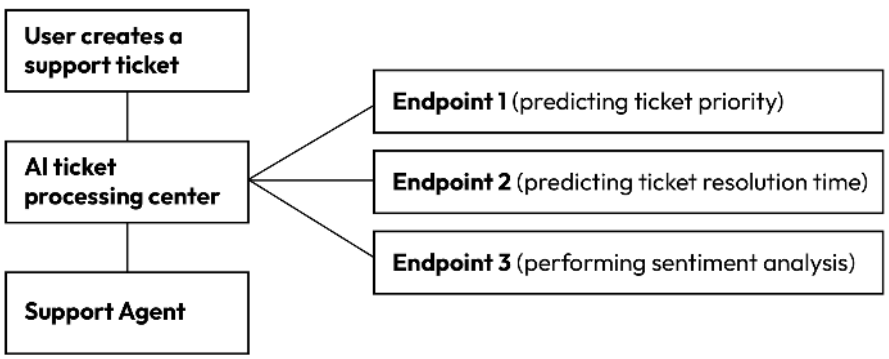


Figure 10.16 – Customer support ML preprocessing system

5. What do you choose for Endpoint 1?

    A. GCP Vertex AI Workbench

    B. GCP Cloud Dialogflow

    C. GCP Cloud Vision

    D. GCP Cloud NLP

6. What do you choose for Endpoint 2?

    A. GCP Vertex AI Workbench

    B. GCP Cloud Dialogflow

    C. GCP Cloud Vision

    D. GCP Cloud NLP

7. What's your recommendation to deal with high call volumes?

    A. Use Vertex AI Workbench distributed training

    B. Use a Dataproc cluster for training

    C. Create a MIG with autoscaling

    D. Use Kubeflow Pipelines to train on a GKE cluster

8. What do you choose for Endpoint 3?

    A. GCP Vertex AI Workbench

    B. GCP Cloud dialogflow

    C. GCP Cloud Vision

    D. GCP Cloud NLP

Answers to the practice questions

1. A
2. A
3. A
4. A
5. A
6. A
7. A
8. D

Further reading

For further insights into what you've learned in this chapter, refer to the following links:

- https://cloud.google.com/products/ai
- https://cloud.google.com/vertex-ai-workbench
- https://cloud.google.com/automl
- https://cloud.google.com/vertex-ai
- https://cloud.google.com/vision
- https://cloud.google.com/video-intelligence
- https://cloud.google.com/natural-language
- https://cloud.google.com/translate

11

Google Cloud Security Services

As we discussed in *Part 1* of this book, cloud security is all about securing the cloud – addressing the challenges and using risk detection, remediation, and prevention in the cloud. Starting with the shared responsibility model, in which the **cloud service providers** (**CSPs**) are responsible for securing the underlying infrastructure and the customers are responsible for securing their data and applications, Google takes cloud security as a top priority and has built multiple layers of protection in following industry best practices. In this chapter, we will cover the following topics:

- **Google Cloud IAM**: Google has enabled granular control over access and permissions to GCP resources and services
- **Google Cloud endpoint security**: Google provides secure protection for GCP endpoints and services, such as **virtual machines** (**VMs**), **Google Cloud Storage** (**GCS**), and **virtual private cloud** (**VPC**) networks
- **Google Cloud data security**: We will discuss data classification, data encryption, and data loss prevention
- **Google Cloud monitoring and logging**: Google offers various tools for monitoring and logging security events, such as Google Cloud's operations suite
- **Google Cloud Security Command Center** (**SCC**): This is a comprehensive security tool that integrates many GCP security services, and we will have a deep dive into its components and configurations

We will start our Google Cloud security journey with Google Cloud IAM.

Google Cloud IAM

Google Cloud IAM defines cloud identities, resources, and their relationships. It specifies who (users, groups, or service accounts) has what kind of access (roles) to what cloud resources in the GCP resource hierarchy. Key features of Google Cloud IAM include the following:

- **GCP resource hierarchy**: Google Cloud IAM leverages a resource hierarchy (organization, folder, project, and resource) to inherit permissions from higher levels. This allows you to manage access control more efficiently by applying policies at the appropriate level in the hierarchy.
- **Fine-grained access control with roles and permissions**: Google Cloud IAM uses roles, which are a collection of permissions, to grant access to GCP resources. Google provides predefined roles (viewer, editor, and owner) as well as the ability to create custom roles tailored to your organization's needs.
- **Identity federation**: Google Cloud IAM supports identity federation, allowing you to integrate with external identity providers, such as Google Workspace, Cloud Identity, or third-party solutions. This enables you to manage access control in a centralized manner across different systems.
- **Service accounts**: Service accounts are special types of accounts used by Google Cloud applications or VMs to interact with GCP services. GCP IAM enables you to manage and control access to applications through service accounts, ensuring that they have the necessary permissions to function correctly.

We have discussed many cloud IAM concepts in this book, and here we will focus on some key concepts in the GCP IAM domain: users, groups, service accounts, and roles.

Google Cloud users and groups

Google Cloud user accounts here refer to human and not programmatic users, and are usually provisioned and synchronized using the existing company user identity services such as **Microsoft Active Directory** (**AD**), Google **Workspace**, and Okta **identity providers** (**IdPs**), which serve as the *single source of truth* for user/group data. Synchronizing from a single source of truth ensures that users and groups are centrally managed in a consistent manner through their lifecycle. And during their lifecycles, all user/group authentications should be done enforcing MFA, including GCP and other CSP console access, along with any other SSO implementations. Usernames and passwords are simply ineffective for protecting user access these days. Further details on AD and GCP federation can be found at `https://cloud.google.com/architecture/identity/federating-gcp-with-active-directory-introduction`.

Google Cloud groups should be the primary entity to which IAM roles are assigned. It is highly recommended that IAM roles are *not* assigned directly to users but to groups. Once project owners have properly associated groups with their required roles in a GCP project, granting and revoking a user's access to projects should be managed via group membership. Google Cloud groups will be

pushed into Google Cloud Identity from the central Cloud Identity management source, such as an AD instance.

Google Cloud service accounts

A Google Cloud service account is a specialized account that can be used by applications to access GCP services. Service accounts are like *programmatic access users* in other public cloud platforms, such as service roles in AWS. Applications can use service account credentials to authorize themselves to cloud APIs and perform actions within the permissions granted to the service account. Specifically, applications running on **Google Compute Engine** (**GCE**) instances use service accounts to interact with other Google services and their underlying APIs.

Google Cloud IAM roles

GCP supports three types of IAM roles: Primitive (basic), Predefined, and Custom:

- **Primitive (basic) roles**: These include the **Owner**, **Editor**, and **Viewer** roles that existed in GCP prior to IAM. Primitive roles such as Owner and Editor should be used sparingly as they confer significant privileges and will likely run afoul of the least privilege requirements.
- **Predefined roles**: These provide very granular access for specific services following role-based permission needs. These are managed by Google and provide what Google believes are the least privileged permissions needed to perform a role for said service.
- **Custom roles**: These roles provide granular access according to the user-specified permissions. They should be used sparingly as the user is responsible for maintaining the permissions.

For GCE VMs, both roles and access scopes can be used to control the access that the VM has to other Google Cloud resources, by following the best practices:

- Creating a new service account rather than using the GCE VM's default service account. Service accounts can be found in the GCP console using the **Service Accounts** page.
- Granting IAM permissions to the service account for only the resources it needs.
- Granting the VM instance service account scope to allow full access to all Google Cloud service APIs so that the instance's IAM permissions are determined by the IAM roles of the service account.

We have highlighted some of the IAM key concepts. More details can be found at `https://cloud.google.com/iam`. In the next section, we will discuss Google Cloud endpoint security.

Google Cloud endpoint security

Google Cloud offers a variety of security features and best practices to help protect Google Cloud endpoints including GCE VMs, GCS, and VPC networks.

GCE VM security

VMs run on GCE, which has security measures designed to secure the underlying infrastructure, protect VM data, and minimize potential vulnerabilities. Key aspects of Google Cloud VM security include the following:

- **Firewall rules**: These allow you to control inbound and outbound network traffic to VM instances. Configuring firewall rules can limit access to specific IP addresses, ports, and protocols, thereby reducing the VM attack surface.
- **Service accounts**: VM instances can use service accounts to authenticate and access other GCP services securely.
- **Secure boot**: This is a technology that helps ensure the integrity of the boot process by verifying that the VM boot firmware and OS have not been tampered with.
- **OS patch management**: This is crucial for security. Google Cloud offers tools such as OS patch management to automate the process of updating and patching VMs.
- **Vulnerability scanning services**: Google Cloud SCC and third-party solutions help identify potential vulnerabilities in your VM instances and suggest remediation actions.
- **Logging and monitoring services**: Cloud Logging and Cloud Monitoring help track VM activities and detect potential security threats in real time.

For GCP VM security, we recommend the following best practices:

- Where possible, prohibit the assignment of public IP addresses. GCE instances that do not have external IP addresses can be configured to use **Identity-Aware Proxy** (**IAP**) or private Google access and leverage existing on-premises remote access services.
- Configure a route egress through a custom firewall solution if needed, and disable VM serial port access.
- Utilize OS Login (`https://cloud.google.com/compute/docs/oslogin`) and leverage MFA/2FA for user access to VMs.
- Within production environments, utilize a bastion host as a jump point for SSH and RDP access. Shut down the host when not in use for added security. Limit source IP access using firewall ingress rules.
- Do not use the GCE default service account. Create service accounts based on instance roles.

- Encrypt disks containing sensitive data with customer-supplied keys if Google-managed keys do not fit the compliance standards.
- When possible, adopt the immutable infrastructure pattern, which leverages automation for provisioning and de-provisioning VM instances.
- Only allow machine image creation from approved base images using **Google Trusted Image Policies**.

By leveraging the security features and following best practices, you can enhance the security of your Google Cloud VM instances and protect your data and applications from potential threats.

GCS security

As we discussed in *Chapter 8*, GCS is a highly scalable and durable object storage service. It is designed with security in mind, offering several features to help protect data and ensure the privacy and compliance of stored information. Key aspects of GCS security include the following:

- Google Cloud IAM allows you to control access to your GCS buckets and objects by assigning roles and permissions to users, groups, or service accounts.
- GCS supports both bucket-level IAM policies and object-level **access control lists** (**ACLs**) for fine-grained access control. You can configure policies and ACLs to allow or deny access based on the user, group, or domain.
- Private Google access allows your GCS resources to be accessed privately from your VPC network or on-premises network without trespassing the internet.
- GCP **Data Loss Prevention** (**DLP**) can be integrated with GCS to automatically discover, classify, and protect sensitive data stored in your buckets.
- GCS provides data retention policies and object versioning to help preserve data integrity and prevent accidental deletion or overwriting of objects.
- GCS integrates with Google Cloud's audit Logging and Monitoring services to provide visibility into access patterns and help detect potential security threats.

For GCP GCS security, we recommend the following best practices:

- IAM roles should be used to control access at the bucket level. The uniform bucket-level access organization policy can be used to disable ACLs. If control is needed at the object level, ACLs may be used. However, it requires significant management overhead.
- Don't use public buckets unless explicitly required. Compliance tooling should be used to ensure public buckets do not exist and are not created. Leverage signed URLs, (details are available at `https://cloud.google.com/storage/docs/access-control/signed-urls`.)

- Limit the number of publicly accessible GCS buckets. Utilize lifecycle management to automate archival and deletion.
- Apply bucket-level retention rules to data stored within GCS that requires retention policies.
- Leverage customer-managed keys especially for sensitive data (in lieu of Google-managed keys)

By leveraging the GCS security features and following best practices, you can protect your data stored in GCS and maintain a secure storage environment. Now, let us look at the Google Cloud network security.

Google Cloud network security

GCP offers a variety of network security features and best practices to help protect your resources and applications in the cloud. Google provides VPC network security including the following:

- GCP VPCs create isolated and secure virtual networks within GCP. By using VPCs, you can control the network topology, IP address ranges, and routing tables, enabling you to isolate your resources and manage access effectively.
- GCP provides built-in firewalls that enable you to control inbound and outbound network traffic to your resources, such as GCE instances and **Google Kubernetes Engine** (**GKE**) clusters.
- Google Cloud IAM enables granular control over who has access to specific network resources and services.
- VPC service controls create a secure perimeter around your GCP resources, limiting access to only specific VPC networks or authorized users with appropriate context.
- Private Google access allows your GCP resources to be accessed privately from your VPC network or on-premises network without exposing data to the public internet.
- Cloud **Network Address Translation** (**NAT**) is a managed NAT gateway that allows your private instances to access the internet for updates and patches without exposing them to inbound internet traffic.
- VPC network peering connects VPC networks across GCP projects, ensuring low-latency, secure communication between resources without transiting the public internet.
- Shared VPC enables you to centrally manage network resources across multiple GCP projects, allowing for efficient resource sharing and simplified network management.
- Cloud VPN and Cloud Interconnect solutions securely connect your on-premises networks and cloud networks. These options ensure private, encrypted communication between your resources, even across geographical distances.

By leveraging the network security features, you can protect your cloud resources and maintain a secure, well-managed network environment. Among the networking security features, we want to spotlight **GCP Cloud Armor**, which is a cloud network security service integrating with Google's Global HTTP(S) load balancing service. Cloud Armor protects your infrastructure and applications from **Distributed Denial-of-Service** (**DDoS**) attacks. To mitigate attacks on your GCP resources, Cloud Armor is deployed at the edge of your Google Cloud network, to allow or deny access to your load balancers as close as possible to the source of the incoming traffic. This prevents any unwanted traffic from reaching your network. More details can be found at `https://cloud.google.com/armor/`.

We have discussed Google Cloud endpoint security by examining VM security, GCS security, and network security. The objective of all these Google Cloud security options is to protect our data in the cloud. Let's dive into Google Cloud data security now.

Google Cloud data security

GCP offers a robust set of security features to protect customer data. Many of the data security services are based on basic data security enablement. We will start with data classification.

Data classification and data lineage

Industry data security best practices recommend starting with a classification standard and then assigning a data/resource owner to identify each data resource's classification. We recommend utilizing data classification and maintaining a unified level of permissions on GCP projects and resources, to prevent misconfigurations and unauthorized access to sensitive information.

Data lineage is the practice of tracking the data origin, what happened to it, and where it moves over time. **Data provenance** can be defined as the origins, custody, and ownership of data. It is the documentation of where a piece of data comes from and the processes/methodology by which it was produced. Establishing a data labeling/tagging standard to deal with data lineage and provenance requirements is viewed as a highly recommended practice in data security.

Data encryption

Google encrypts all data channels that it uses to communicate between the cloud services. Customers are responsible for ensuring that communication of their data within the applications is over an encrypted channel.

Google encrypts all data on storage devices to prevent anyone with access to physical devices from being able to inspect the data contained on those devices. Customers can provide their own encryption keys to encrypt **GCE Persistent Disks** and **GCS buckets**. All data stored within Google-managed databases is encrypted at the storage level by default. However, additional encryption is advisable at the application level to prevent users from accessing content and limiting spillage in the event of intrusion.

Google Cloud's virtual network infrastructure enables encryption when data moves among networks/VPCs and encryption is performed at the network layer within the same VPC or across peered VPCs. For additional information on how Google protects data in transit, please refer to `https://cloud.google.com/docs/security/encryption-in-transit`.

GCP DLP

DLP can be utilized to ensure sensitive data is identified and properly protected. The tool can scan existing datasets and utilize various techniques to obscure sensitive data, including redaction, tokenization, and format-preserving encryption. This ensures that the data is obfuscated before it is stored. With Google Cloud DLP, you can scan objects in GCS, BigQuery, Datastore, and many other data sources, workloads, and applications. Cloud DLP also can be leveraged to transform, mask, or tokenize sensitive data.

When storing PII or other sensitive information, use multiple projects or GCS buckets, and assign permissions based on data sensitivity accordingly. At the project level, the best practice is to create two or more different projects, each with its own data sensitivity. At the GCS bucket level, the best practice is to create two or more different buckets, each with its own data sensitivity. Use DLP to replicate data from sensitive projects/buckets into non-sensitive ones and use IAM to restrict users from accessing sensitive projects/buckets.

Security for the Google Cloud VMs, GCS buckets/objects, VPC networks, and data is all related to cloud resource access activities. In the next section, we will discuss the monitoring and logging of these resource access activities.

Google Cloud Monitoring and Logging

The **Google Cloud operations suite** is a collection of tools and services that help customers monitor, troubleshoot, and improve the performance of their applications and infrastructure on Google Cloud. It is an aggregation suite for Google Cloud Monitoring and Logging. The Google Cloud operations suite offers the following security features:

- **Cloud Monitoring** provides visibility into the performance and availability of cloud applications and infrastructure. It collects and analyzes metrics, logs, and traces to provide insights into the health and performance of applications and services.
- **Cloud Logging** provides real-time log management and analysis for applications and infrastructure. It collects, stores, and analyzes log data from Google Cloud services, third-party applications, and custom applications.
- **Cloud Trace** provides in-depth visibility into application performance by tracing requests across distributed systems. It provides detailed latency information for individual requests, as well as insights into service dependencies.

- **Error Reporting** automatically collects and aggregates errors from Google Cloud services, third-party applications, and custom applications. It provides insights into the root causes of errors and allows customers to prioritize and fix issues quickly.
- **Debugger** allows customers to debug applications running in production without disrupting users. It provides a snapshot of the application state at any point in time, allowing customers to analyze and diagnose issues quickly.
- **Profiler** provides insight into the performance of applications by identifying and analyzing performance bottlenecks. It can help customers optimize application performance and reduce resource usage.
- **Alerting** allows customers to set up alerts based on metrics, logs, and events. Alerts can be sent via email, SMS, or other notification channels.

With all these features, the Google Cloud operations suite provides a comprehensive set of tools to monitor, analyze, troubleshoot, and optimize cloud applications and infrastructure.

In the previous sections, we discussed IAM, endpoint security, network security, data security, and Cloud Monitoring and Logging. Integrating all these security features, Google Cloud **Security Command Center** provides a comprehensive tool for managing Google Cloud security. If there is one service I must recommend for Google Cloud security, it is the Security Command Center. We will closely examine its features and functions thoroughly with some examples in the next section.

Google Cloud Security Command Center (SCC)

Google Cloud **SCC** is a comprehensive security management platform that provides visibility, insights, and tools to help you manage security risks across your GCP resources and applications. Key features of SCC include the following:

- SCC provides a centralized dashboard that gives you an overview of your GCP assets, vulnerabilities, and security findings, enabling you to monitor and respond to potential risks in real time.
- SCC automatically discovers and inventories all the GCP resources, such as GCE instances, **Google App Engine** (**GAE**) applications, and GCS buckets, to understand the scope of your cloud environment and manage resource configurations effectively.
- SCC integrates with various vulnerability scanning and management tools, such as Google Cloud Web Security Scanner and third-party solutions, to identify and remediate vulnerabilities in your web applications and infrastructure.
- SCC collects security findings from various GCP services and third-party security tools, such as Web Security Scanner, DLP, and third-party vulnerability scanners. These findings help you detect potential security issues, such as misconfigurations, policy violations, and threats.

- SCC uses ML algorithms to analyze your GCP resources and activities, detecting and alerting you to potential anomalies and security risks, such as unusual data access patterns or unauthorized API usage.
- SCC enables you to define, enforce, and manage security policies across your GCP resources, ensuring that your environment remains compliant with your organization's security requirements and industry standards.
- SCC provides insights into your security posture by analyzing your GCP assets and security findings, identifying trends, and recommending best practices for improving your overall security.
- SCC integrates with various GCP and third-party security tools, such as Google Cloud Armor, Cloud IAM, and **Security Information and Event Management** (**SIEM**) and **Security Orchestration, Automation, and Response** (**SOAR**) solutions, enabling you to manage and respond to security events effectively.
- SCC allows you to set up notifications for specific security findings or events, enabling you to respond quickly to potential risks. It also integrates with GCP's Cloud Functions to automate remediation actions, such as updating firewall rules or revoking access permissions.

Google Cloud SCC is a basic risk dashboard and analytics system for Google Cloud security and risk management. By leveraging SCC, you can gain visibility into your GCP environment, manage security risks effectively, and maintain a secure, compliant cloud infrastructure. SCC has two tiers: Standard and Premium.

The **SCC Standard tier** is free and provides a good asset inventory capability for the security team. The standard tier has the following features:

- **Security Health Analytics** (**SHA**) provides managed vulnerability assessment scanning that can automatically detect Google Cloud resource vulnerabilities and misconfigurations
- **Web Security Scanner** supports custom scans of deployed applications with public URLs and IPs that aren't behind a firewall
- Integration with many Google Cloud services:
  - Works with DLP to discover, classify, and protect sensitive data
  - Works with Google Cloud Armor to protect against threats and attacks
  - Uses ML to identify security anomalies for your projects, VMs, and other resources
  - Integrates with SIEM and SOAR applications

The **SCC Premium tier** is available via self-service activation in the GCP console. It offers pay-as-you-go pricing at the organization level and individual project levels. More details about SCC pricing are available at `https://cloud.google.com/security-command-center/pricing`. SCC Premium offers the following, in addition to the Standard tier features:

- **Event Threat Detection** (**ETD**) monitors the Cloud Logging stream to detect the following threats: malware, crypto mining, brute force SSH, DoS, IAM anomalous grant, data exfiltration, and so on.
- SHA provides monitoring for many more industry best practices, and compliance monitoring across your Google Cloud assets, including monitoring and reporting for the following standards: *CIS 1.1/1.0*, *PCI DSS v3.2.1*, *NIST 800-53*, and *ISO 27001*.
- Web Security Scanner provides managed scans that are automatically configured. These scans identify the following security vulnerabilities: **cross-site scripting** (**XSS**), Flash injection, mixed content, cleartext passwords, and the usage of insecure JavaScript libraries.
- Provides support for granting users IAM roles at the organization, folder, and project levels.
- Continuously and automatically exports new findings to `Pub/Sub`.

Figure 11.1 shows the core features/functions of SCC, and we will now examine these features and configurations closely:

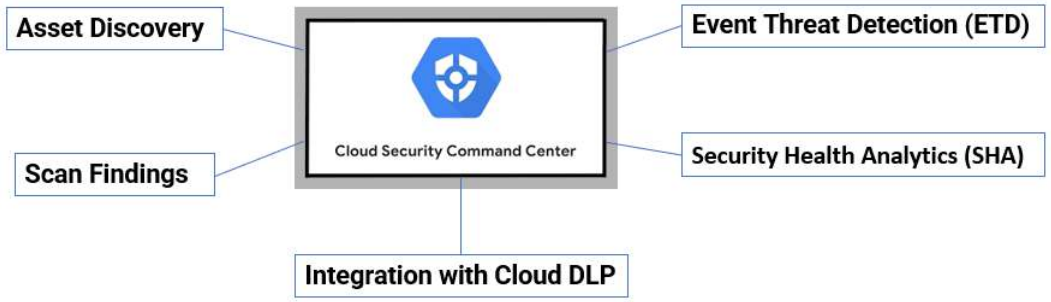


Figure 11.1 – Google Cloud SCC core features/modules

Now, let's examine the SCC modules and their functions, starting with asset discovery.

SCC asset discovery

The SCC asset discovery module discovers and inventory all the resources in your GCP organization. Let's take a look at.

1. Go to **Google Cloud Console** | **Security Command Center** | **ASSETS**, and you will see all the cloud resources for your GCP organization. By default, assets are displayed in the organization and project hierarchy. The asset types currently supported are listed at `https://cloud.google.com/security-command-center/docs/how-to-use-security-command-center`.
2. To view assets grouped by resource type, under the **ASSETS** tab, click **Resource type**. Assets are displayed in categories such as **Application**, **Bucket**, **Project**, and **Service**.

3. To view new and deleted assets, under the **ASSETS** tab, click on **ASSETS CHANGED**. All assets are displayed, including subgroups for new and deleted assets. You can select a time range by clicking the drop-down list at the top of the assets list. *Figure 11.2* shows an asset display from SCC:

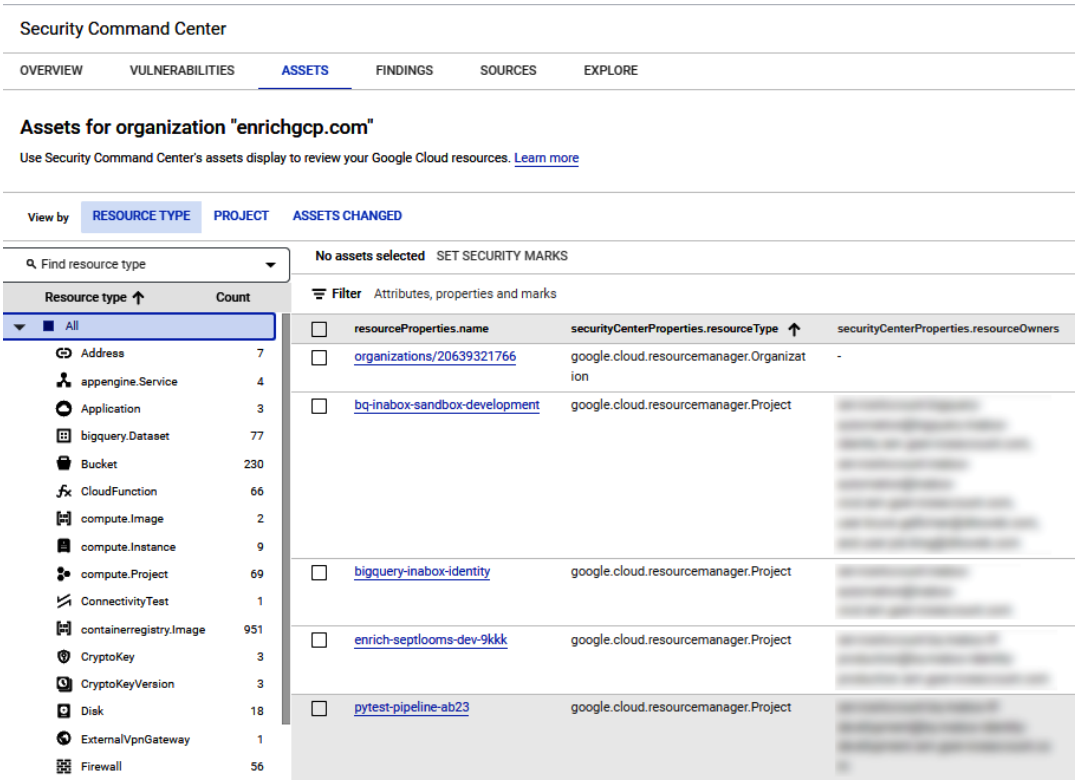


Figure 11.2 – Google Cloud SCC asset discovery

In addition to asset discovery, SCC scans and generate findings for potential risks. We will discuss scan findings in the next section.

SCC scan findings

SCC integrates with native and third-party Google Cloud scanners to surface potential security risks in assets, and findings can be viewed by finding a type or category, source, and changed findings. By default, findings are displayed in specific categories such as XSS and exposure of credit card numbers or phone numbers. If you leave the **Category** field blank while creating a finding, it doesn't have a category in the **FINDINGS** display. To view detailed information about a specific finding, click the finding under **Category**.

A finding source is a provider of findings, such as SHA. You can view findings by source in multiple ways:

- To view findings by source type, under the **FINDINGS** tab, click **source type**
- To view individual findings for a specific source type, under **View by Source type**, select the source type to be reviewed

Figure 11.3 shows an organization with no findings:

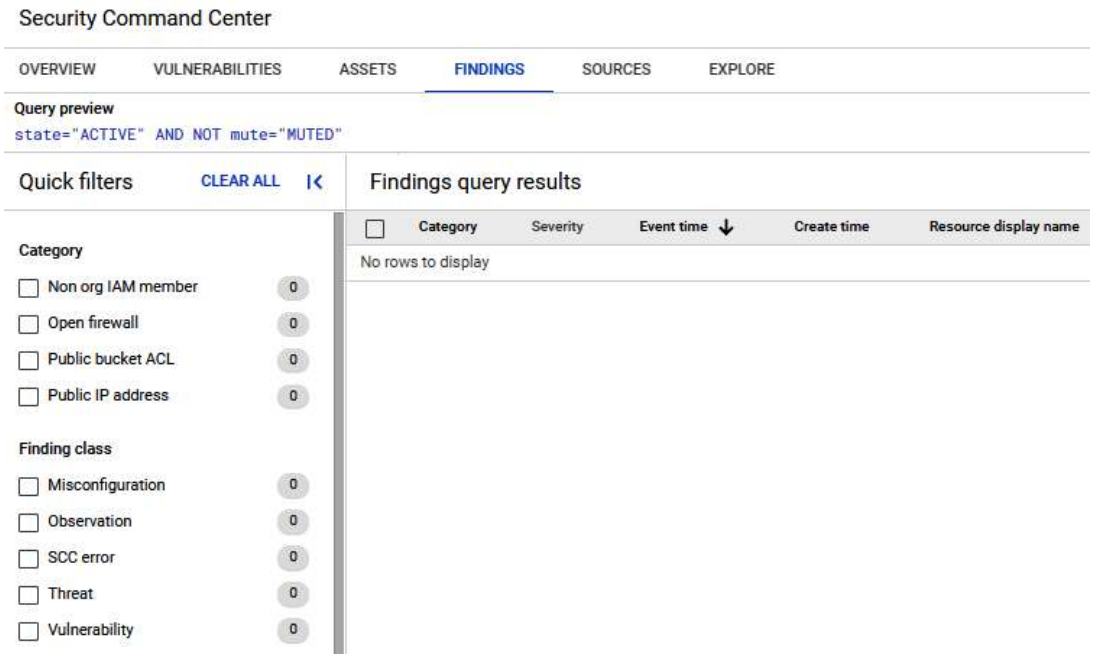


Figure 11.3 – SCC findings

To view new and inactive findings, under the **FINDINGS** tab, click on **FINDINGS CHANGED**. All findings are displayed in the following subgroups:

- **Active changed findings**: Findings that changed to active during the selected time period
- **Active unchanged findings**: Findings that are active and were active during all or part of the selected time period
- **Inactive changed findings**: Findings that changed to inactive during the selected time period
- **Inactive unchanged findings**: Findings that are inactive and were inactive during the selected time period
- **New findings**: Findings that are new during the selected time period

Any findings in a group with a **Changed** tag have changed properties during the selected time range. *Figure 11.4* shows the active findings:

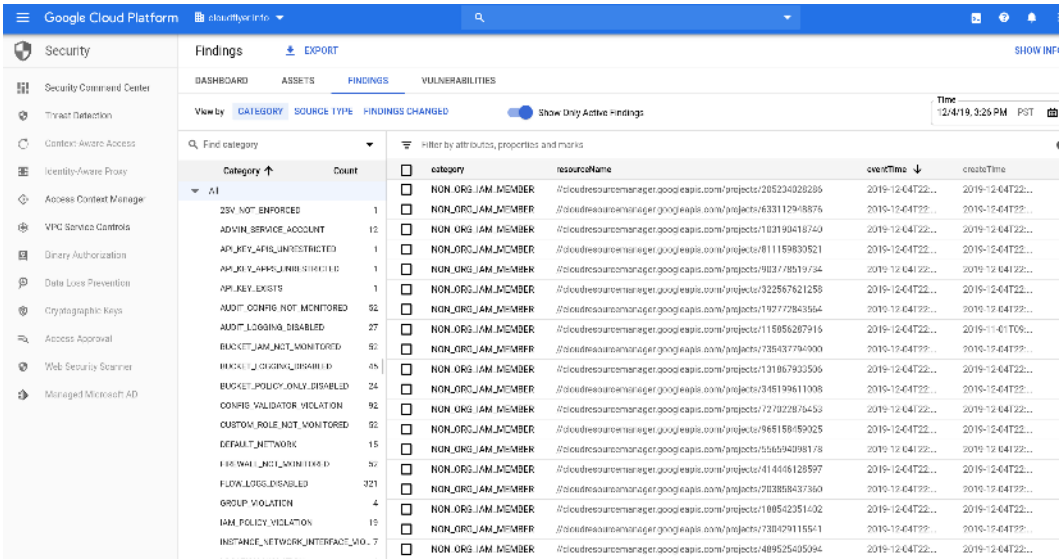


Figure 11.4 – SCC active findings

Now let's discuss how SCC integrates with other GCP services such as DLP.

SCC integration with Cloud DLP

We have discussed DLP in the previous sections, and the following are the steps to enable the integration of DLP into SCC:

1. Enable Cloud DLP by following these steps:
    I. Navigate to **Security | Data Loss Prevention** and enable the DLP API.
    II. Create a job and set it to **Publish to Google Cloud Security Command Center**:

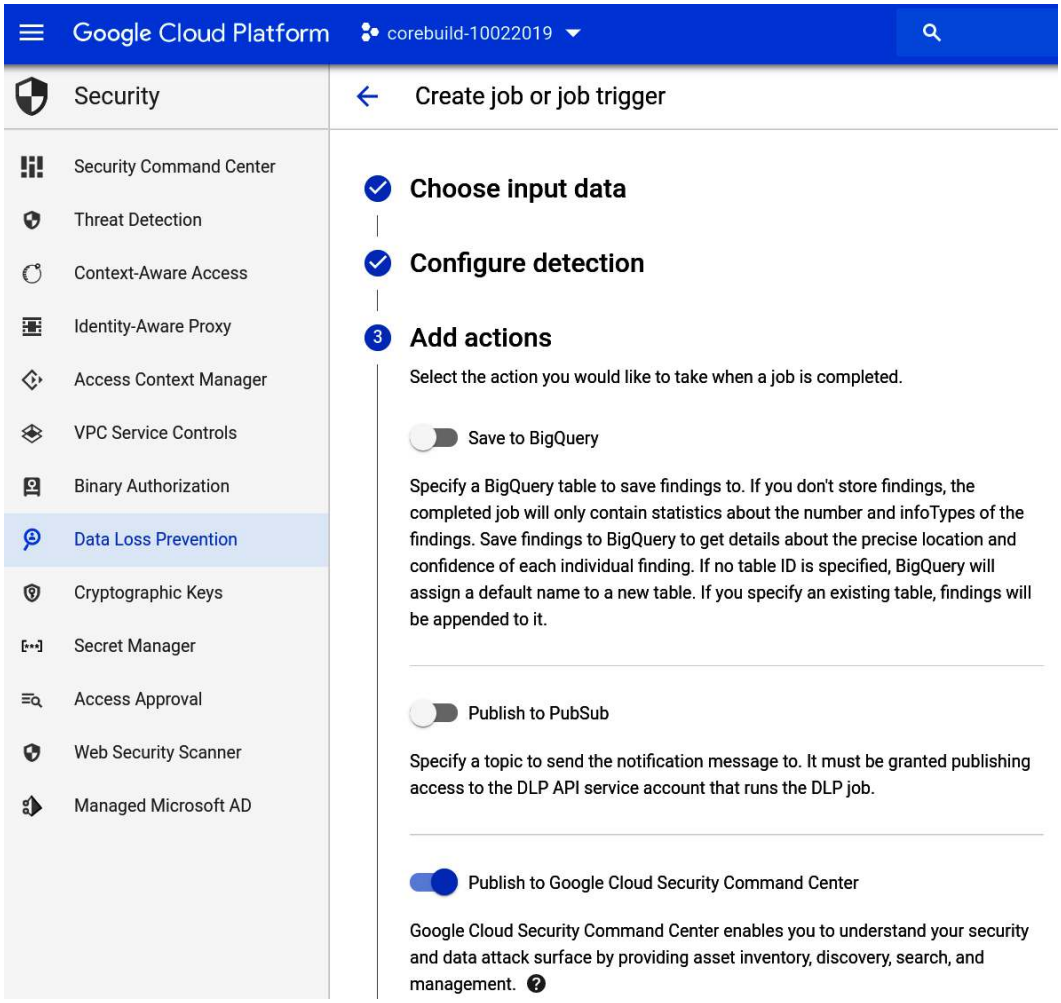


Figure 11.5 – Creating a DLP job that will publish results to SCC

2. Set DLP as a security source for Security Command Center with these steps:

   Navigate to **Security Command Center** and select **Settings**. Enable **Cloud DLP Data Discovery** by flipping the switch as shown in *Figure 11.6*:

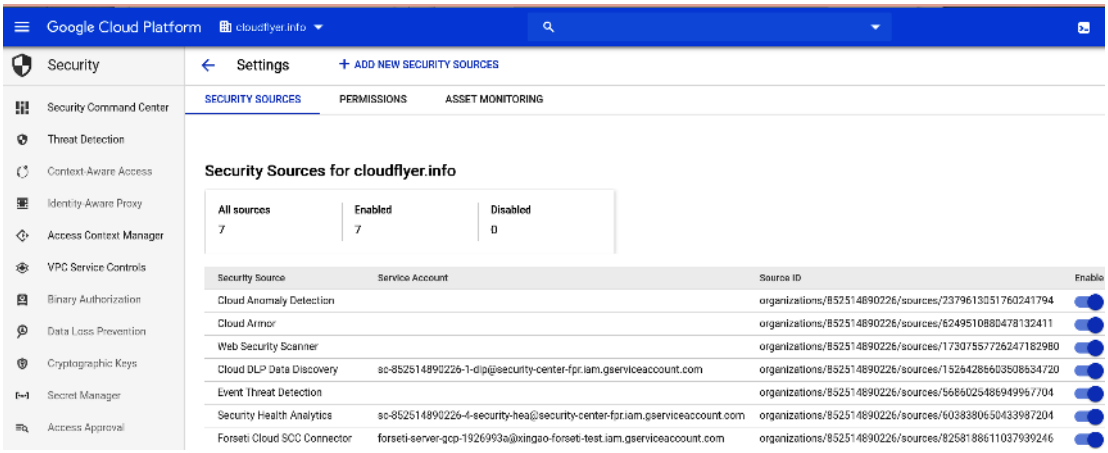


Figure 11.6 – Enabling DLP discovery in SCC

DLP findings are now visible in SCC, as shown in *Figure 11.7*. The finding can be clicked on to view their details:

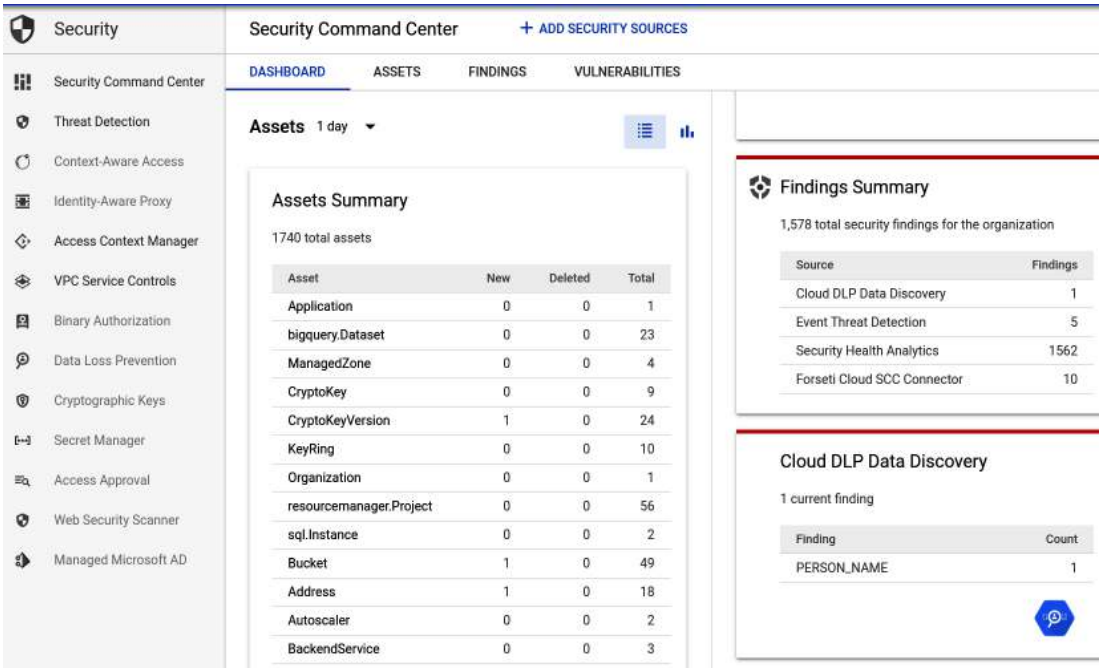


Figure 11.7 – DLP findings in SCC

So far, we have demonstrated SCC's function to discover Google Cloud assets and integrate with DLP and other GCP tools to scan various sources and generate security findings. In the next sections, we will discuss SCC SHA.

SHA

SHA manages vulnerability assessment scanning for Google Cloud. SHA scans for many vulnerability types. It can automatically detect common vulnerabilities and misconfigurations across the following:

- Cloud Monitoring and Cloud Logging
- GCE
- GKE containers and networks
- GCS
- Cloud SQL
- Cloud IAM
- Key Management Service
- Cloud DNS

When SHA is enabled, scans automatically run twice a day, 12 hours apart. More details are available at `https://cloud.google.com/security-command-center/docs/concepts-security-sources`.

1. **Enable SHA**: To view SHA findings in SCC, we need to enable it as a security source. Go to SCC, and the **SECURITY SOURCES** page in the Cloud Console. Under **Enabled**, click to enable **Security Health Analytics**, as shown in *Figure 11.8*. Note this requires the SCC Admin role:

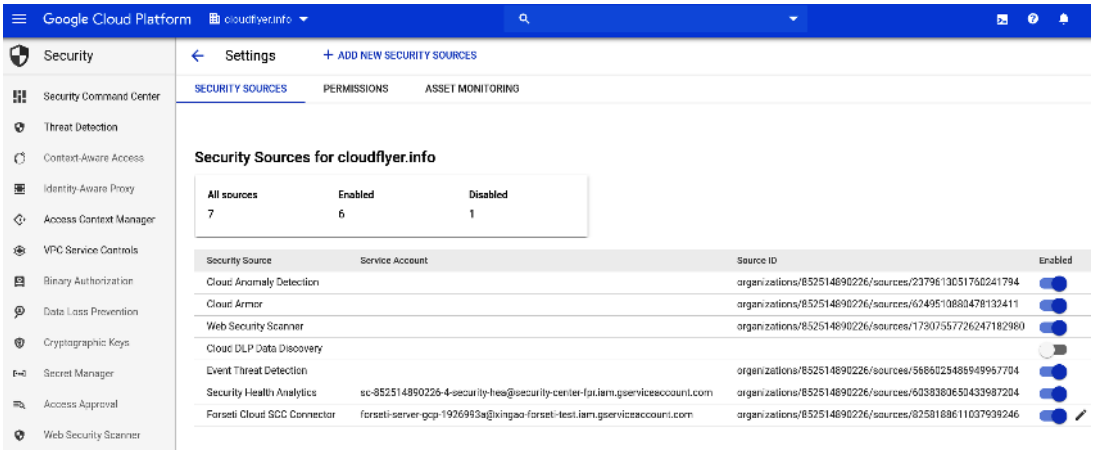


Figure 11.8 – Enabling SHA

After SHA is enabled, you can view the vulnerabilities found in the **VULNERABILITIES** tab in **Cloud Security Command Center**. SHA scans automatically run twice a day, 12 hours apart. The frequency of the scan is currently not customizable.

2. **View the findings**: By using SCC with the available filters, you can focus on the highest severity vulnerabilities, and review vulnerabilities by asset type, security mark, and more. As shown in *Figure 11.9*, the findings can be viewed by the following:

- Project
- Finding type
- Asset type
- Severity
- Security marks

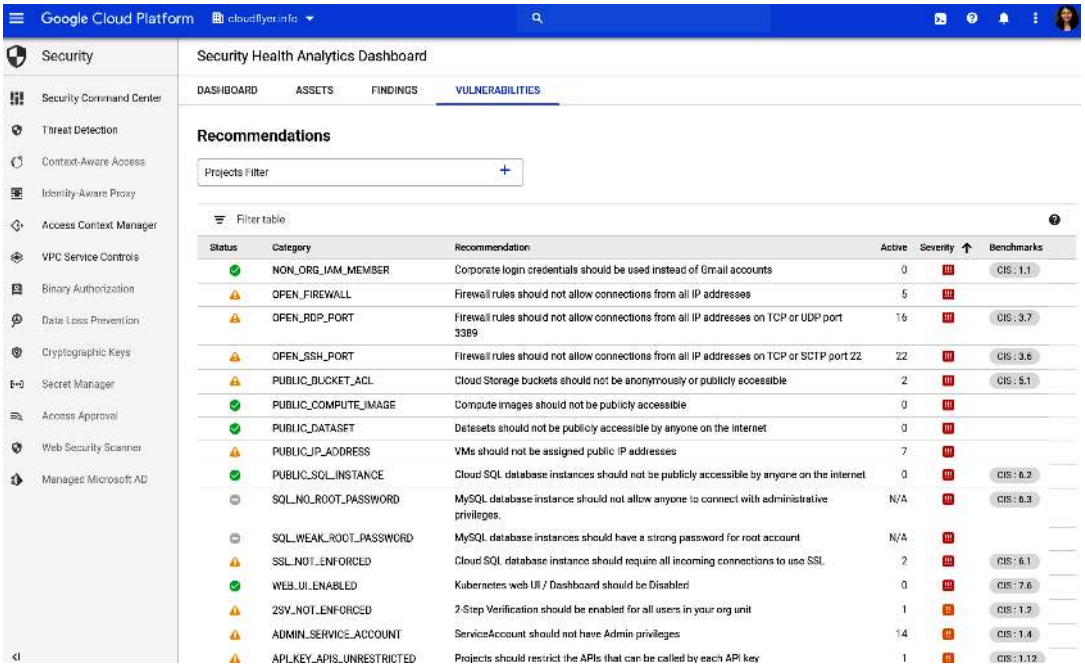


Figure 11.9 – SHA findings

Details on how to filter on findings for SHA can be found at `https://cloud.google.com/security-command-center/docs/how-to-use-security-health-analytics`.

The latest SCC features

Attack Path Simulation is a new SCC feature just announced at the time of writing. With Attack Path Simulation, SCC mimics a real-world attacker's reach and compromises the GCP environment in many ways, generates attack path graphs to provide defenders with insight into how adversaries could exploit security weaknesses or vulnerabilities to access valuable assets, and then provides detailed information on remediations to shore up defenses based on the findings. More details are available on the blog: `https://cloud.google.com/blog/products/identity-security/security-command-center-adds-attack-path-simulation-to-stay-ahead-of-cyber-risks`.

Integrating with **Chronicle SOAR, and Chronicle AI** is another new SCC feature. Chronicle SIEM delivers modern threat detection, investigation, and hunting at unprecedented speed and scale, at a disruptive and predictable price point. Chronicle SOAR enables enterprises to gather data and security alerts from various sources by ingesting orchestration and automation, to detect threats and respond to incidents promptly and effectively. Chronicle AI introduces AI-powered investigations into Chronicle Security Operations. Integrating Chronicle SIEM, Chronicle SOAR, and Chronicle AI in SCC is a great milestone in GCP security.

Summary

In this chapter, we discussed the Google Cloud security concepts, including Google Cloud IAM, endpoint security, data security, monitoring, and logging. We dived into Google Cloud Security Command Center.

This chapter ends the second part of the book: *Google Cloud*. We have covered GCP by examining its foundational services in terms of compute, storage, and the network; the data services of database and big data; the ML services of Vertex AI and ML API; and the security services. In the next chapter, we will start our journey to the Microsoft Azure cloud.

Practice questions

Questions 1 to 10 are based on *Figure 11.10*. All configurations are default.

A cloud engineer team logged in to GCE instances `VM-1`, `VM-2`, `VM-3`, and `VM-4`, in 4 windows:

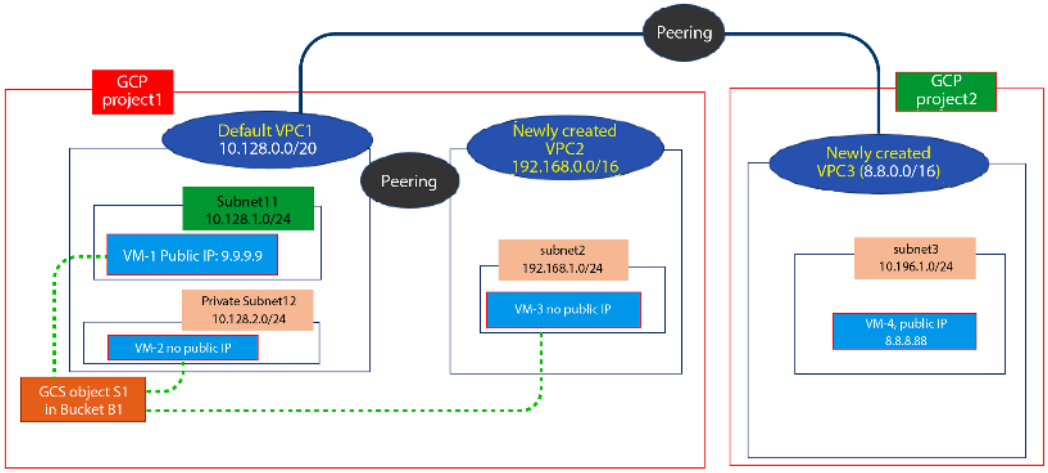


Figure 11.10 – GCP diagram

1. What will they need to do so they can ping `www.google.com` successfully from `VM-1`?

    A. Nothing

    B. Open `icmp` (ping) for the network/VPC1 firewall

    C. Open `icmp` (ping) for the VPC1/`subnet11` firewall

    D. Open IGW routes for VPC1

2. What will they need to do so they can ping `VM-1` successfully from the internet?

    A. Nothing

    B. Open `icmp` (ping) for the network/VPC1 firewall

    C. Open `icmp` (ping) for the VPC1/`subnet11` firewall

    D. Open IGW routes for VPC1

3. What will they need to do so they can ping `www.google.com` successfully from `VM-4`?

    A. Nothing

    B. Open `icmp` (ping) for the network/VPC3 firewall

    C. Open `icmp` (ping) for the VPC3/`subnet3` firewall

    D. Open IGW routes for VPC3

4. What will they need to do so they can ping `VM-4` successfully from the internet?

    A. Nothing

    B. Open `icmp` (ping) for the network/VPC3 firewall

    C. Open `ssh` for the network/VPC3 firewall

    D. Open `https` for the network/VPC3 firewall

5. What will they need to do so they can ping `www.google.com` successfully from `VM-3`?

    A. Nothing

    B. Open `icmp` (ping) for the network/VPC2 firewall

    C. It is impossible

    D. Open `icmp` (ping) for the VPC2/`subnet2` firewall

6. What will they need to do so they can ping `VM-3` successfully from the internet?

    A. Nothing

    B. Open `icmp` (ping) for the network/VPC2 firewall

    C. It is impossible

    D. Open `icmp` (ping) for the VPC2/`subnet2` firewall

7. They want to detect any changes for the GCP resources; what is the best way?

    A. Use SCC

    B. Enable VPC flow logs

    C. Enable GCP monitoring

    D. Use a third-party tool

8. They want to scan all the PII in the GCS buckets; what is the best way?

    A. Use DLP

    B. Scan all the buckets

    C. Enable GCS logging

    D. Enable GCP monitoring

Answers to the practice questions

1. A

2. A

3. A

4. B

5. C

6. C

7. A

8. A

Further reading

For further insights into what you've learned in this chapter, refer to the following links:

- `https://cloud.google.com/docs/security/infrastructure/design`
- `https://cloud.google.com/blog/topics/developers-practitioners/data-security-google-cloud`
- `https://cloud.google.com/architecture/framework/security/network-security`
- `https://cloud.google.com/armor`
- `https://cloud.google.com/security`
- `https://cloud.google.com/iam`
- `https://cloud.google.com/security-command-center`
- `https://cloud.google.com/recommender/docs/overview`