

Cloud Computing with AWS

By Adam Cordner, Christopher Perry & Evie Snuffle (Group 4)

A report submitted as part of a required module
for the degree of BSc. (Hons.) in Computer Science
at the School of Computing and Digital Technology,
Birmingham City University, United Kingdom

May 2022,
CMP6210 Cloud Computing 2021–2022
Module Coordinator: Dr Khaled Mahbub

Student IDs: 18109958, 18103708, 18128599

Contents

1 Glossary	vii
2 Introduction	1
3 Web App	2
3.1 Software Stack	2
3.2 Database Design	2
3.3 Interface Design	5
4 Virtual Private Cloud (VPC)	8
4.1 Elastic IP Address	8
4.2 VPC and Subnets	10
4.3 Internet Gateway	13
4.4 Route Tables	14
5 Elastic Cloud Compute (EC2)	18
5.1 AWS Setup	18
5.2 EC2 Login	22
5.3 Package Setup	23
5.4 Web App Setup	24
5.5 systemd Services	26
6 Simple Storage Service (S3)	27
7 CloudFront	28
8 CloudWatch	34
9 CloudTrail	42
10 Relational Database Service (RDS)	45
11 Elastic Load Balancing (ELB)	52
12 Security Practices	54
13 Cost Breakdown	56
13.1 Estimated Costs	56
13.2 Scaling Up to 10,000 Users	56
13.3 Scaling Up to One Million Users	56

13.4 Scaling Up to Ten Million Users	56
14 Testing	57
14.1 Testing EC2	57
14.2 Testing S3	59
14.3 Testing CloudFront	59
14.4 Testing RDS	62
14.5 Testing CloudWatch	66
14.6 Testing CloudTrail	67
14.7 Testing ELB	68
15 Future Enhancements	70
16 Conclusion	72
References	73

List of Figures

3.1	Database tables overview.	2
3.2	migrations table.	3
3.3	users table.	3
3.4	stories table.	4
3.5	<i>Digital-Ink</i> home page log in and sign up forms.	5
3.6	<i>Digital-Ink</i> story creation form.	6
3.7	<i>Digital-Ink</i> account page.	7
3.8	<i>Digital-Ink</i> stories page and story view.	7
4.1	Elastic IP Addresses page.	8
4.2	Configuring the Elastic IP address.	9
4.3	Created Elastic IP address.	9
4.4	VPC Management Console.	10
4.5	Selecting a VPC configuration.	11
4.6	Configuring VPC public and private subnets.	11
4.7	Generating the VPC.	12
4.8	Your VPCs page.	12
4.9	Creating an internet gateway.	13
4.10	Viewing the newly created internet gateway.	13
4.11	Creating a second public subnet.	14
4.12	Creating a second private subnet.	14
4.13	Viewing the newly created subnets.	15
4.14	Creating a public route table and a private route table.	15
4.15	Associating the public and private subnets with the public and private route tables.	16
4.16	Editing the public route table.	17
4.17	Updated public route table.	17
5.1	Selection of EC2 OS Image.	18
5.2	Selection of EC2 Instance.	19
5.3	Selection of EC2 Keypair.	19
5.4	Selection of EC2 Networking options.	20
5.5	Generated EC2 Keypair in the .pem format.	20
5.6	Selection of EC2 Storage Configuration.	21
5.7	SSH command to log into EC2 instance.	22
5.8	Logging into EC2 instance.	22
5.9	Installing Git.	23

5.10 Installing Docker.	23
5.11 Cloning the web app from Github.	24
5.12 Containers required for the web app being pulled from Docker Hub.	24
5.13 Creation of tables through <code>php artisan migrate</code> command.	25
5.14 Digital Ink shown when accessed through the IPv4 address.	25
5.15 Creation of <code>systemd</code> Service.	26
6.1 Image access through S3.	27
7.1 Applying CloudFront bucket policy.	28
7.2 Applying CloudFront origins to S3 bucket.	29
7.3 Applying CloudFront Distribution Permissions.	29
7.4 Applying CloudFront Cache Keys and Origin Requests.	30
7.5 Function Association.	30
7.6 Applying CloudFront settings.	31
7.7 Created CloudFront Distribution.	32
7.8 Image location before CloudFront.	32
7.9 Image location after CloudFront.	33
7.10 Image location after CloudFront.	33
8.1 Selection of CloudWatch metric for EC2 instance.	34
8.2 Configuration of NetworkPacketsOut Metric.	35
8.3 Configuration of SNS Topic for email alerts on alarm activation.	35
8.4 CloudWatch SNS Topic Email.	36
8.5 Successful subscription to SNS topic.	36
8.6 Configuration for EC2 instance to reboot on alarm activation.	37
8.7 CloudWatch alarm description.	37
8.8 CloudWatch network alarm in dashboard.	38
8.9 Selection of EstimatedCharges CloudWatch metric.	38
8.10 Configuration of CloudWatch alarm.	39
8.11 Configuration of CloudWatch alarm.	39
8.12 Setting CloudWatch charges SNS topic	40
8.13 Description of CloudWatch alarm.	40
8.14 CloudWatch charges alarm live in CloudWatch dashboard.	41
8.15 CloudWatch alarm example.	41
9.1 Initial CloudTrail set up.	42
9.2 Initial CloudTrail set up.	43
9.3 Configuring CloudTrail events.	43
9.4 Added CloudTrail instance.	44
9.5 CloudTrail validation message.	44
10.1 Selection of RDS Authentication Option.	45

10.2 Selection RDS Multiple Availability Zone.	45
10.3 Selection of VPC and Subnet Groups.	46
10.4 Selection of Database Engine.	46
10.5 Selection of CloudWatch metric for EC2 instance.	47
10.6 Selection of RDS Instance Size.	47
10.7 Estimated Monthly RDS Cost.	47
10.8 Selection RDS Security Group.	48
10.9 Credentials for RDS Authentication.	48
10.10Selection of Storage Parameters.	48
10.11Creation of RDS Tables.	49
10.12Selection of CloudWatch metric for EC2 instance.	49
10.13Installation of MySQL on EC2 Instance.	50
10.14Creation of database table.	50
10.15Changing Database Endpoint from Docker to AWS RDS.	50
10.16Removal of Database from Docker File.	51
 12.1 Selection of VPC and Subnet Groups.	54
12.2 Credentials for RDS Authentication.	55
 14.1 Digital Ink image whilst connected to UK IP.	60
14.2 UK IP Location.	60
14.3 Digital Ink image whilst connected to US IP.	61
14.4 US IP Location.	61
14.5 Empty users table before test.	62
14.6 Users table now populated after test.	62
14.7 Empty stories table before test.	63
14.8 Stories table now populated after test.	63
14.9 User before update.	64
14.10User after update. Notice that the hashed password remains the same.	64
14.11Stories table before deletion.	65
14.12Stories table after deletion.	65
14.13CloudWatch NetworkAlarm setup.	66
14.14CloudWatch NetworkAlarm activated.	66
14.15CloudTrail test.	67
14.16Stopped Group4-EC2 instance.	68
14.17Web app page still loading through other EC2 instance.	68
14.18Stopped Group4-EC2-Instance-2 instance.	69
14.19Web app page still loading through other EC2 instance.	69
 16.1 Major Bug Fixes Can Be Small	72

Chapter 1

Glossary

- **ACL** — Access Control List
- **ACM** — AWS Certificate Manager
- **AMI** — Amazon Machine Images
- **App** — Application
- **AWS** — Amazon Web Services
- **AZ** — Availability Zone
- **CA** — Certificate Authority
- **CDS** — Content Delivery Network
- **CIDR** — Classless Inter-Domain Routing
- **CPU** — Central Processing Unit
- **DB** — Database
- **DIG** — Domain Information Groper
- **EB** — Elastic Beanstalk
- **EC2** — Elastic Cloud Compute
- **ELB** — Elastic Load Balancing
- **.env** — Environment File Extension
- **GB** — Gigabyte
- **HTTP** — HyperText Transfer Protocol
- **HTTPS** — HyperText Transfer Protocol Secure
- **IAM** — Identity and Access Management
- **IEEE** — Institute of Electrical and Electronics Engineers
- **IP** — Internet Protocol

- **IPv4** — Internet Protocol Version 4
- **IPv6** — Internet Protocol Version 6
- **LAMP** — Linux, Apache, MySQL, PHP
- **ML** — Machine Learning
- **NAT** — Network Address Translation
- **nslookup** — Name Server Lookup
- **OS** — Operating System
- **.pem** — Privacy Enhanced Mail File Extension
- **PHP** — PHP: Hypertext Preprocessor
- **RAM** — Random Access Memory
- **S3** — Simple Storage Service
- **RAM** — Random Access Memory
- **RDBMS** — Relational Database Management System
- **RDS** — Relational Database Service
- **SaaS** — Software as a Service
- **SNS** — Simple Notification Service
- **SQL** — Structured Query Language
- **SSH** — Secure Shell
- **SSL** — Secure Sockets Layer
- **TLS** — Transport Layer Security
- **URL** — Uniform Resource Locator
- **VPC** — Virtual Private Cloud
- **VPN** — Virtual Private Network
- **WAF** — Web Application Firewall

Chapter 2

Introduction

This report details the process of designing, developing, and deploying a cloud application onto Amazon Web Services (AWS). The application is called *Digital Ink* and allows users to create, edit, and delete their own short stories. Users can then view their own short stories and other users' short stories. It was first developed locally using a LAMP stack. This consisted of Linux - hosted through Docker - for the operating system, an Apache HTTP Server, MySQL for the relational database management, and PHP as the programming language.

After the application was built locally, it was gradually integrated onto AWS. This involved implementing several AWS cloud features to enhance the application, ensure application security, and increase availability. This was accomplished by using Simple Storage Service (S3), Elastic Compute Cloud (EC2), ELB (Elastic Load Balancing), and more. The process of implementing these cloud features will be discussed throughout the report.

After the application was integrated onto AWS, an evaluation of the process was conducted. This includes a discussion of the security practices used, estimated costs for different user scales, and thorough testing. Lastly, several enhancements which could be made to the application in the future will be discussed.

Chapter 3

Web App

This chapter of the report will detail the local design and development of the *Digital Ink* web application. This chapter will first discuss the software stack used to develop the app, then the design of the database used, and, lastly, the design of the user interface.

3.1 Software Stack

Digital Ink was first developed locally using a LAMP stack. LAMP refers to a generic software stack, where each letter in the acronym stands for one the following open source building blocks: Linux, Apache HTTP Server, MySQL, and PHP (Lee and Ware, 2003). The web app is hosted within a Docker container (Anderson, 2015) which runs a minified version of the Linux operating system. Apache is an open-source web server software which is used to host the app on the web (Fielding and Kaiser, 1997). MySQL is an open-source relational database management system (Widenius, Axmark, and Arno, 2002) which is used to store all the data used within the app, including user details and story details. PHP is a programming language aimed towards web development, chosen due to its stability and reliability (Lerdorf et al., 2002). Additionally, all developers involved have prior experience with PHP.

3.2 Database Design

As mentioned before, the web app uses the MySQL relational database management system to store its data. MySQL is a relational database management system (RDBMS) which stores data in the form of tables, where Structured Query Language (SQL) is used to access the database. `users`, `stories`, and `migrations`.

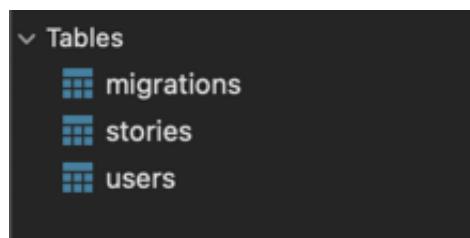


Figure 3.1: Database tables overview.

The `migrations` table (see Figure 3.2) contains records which correspond to the migrations within the Laravel web app. These migrations contain the scripts required to automatically generate the `users` and `stories` tables in SQL. It contains the following three columns:

- `id`: the unique ID for each migration.
- `migration`: points to the scripts used to create tables.
- `batch`: how many times the script has been ran.

<code>id</code>	<code>migration</code>	<code>batch</code>
1	<code>2014_10_12_000000_create_users_table</code>	1
4	<code>2020_03_13_105916_create_stories_table</code>	1

Figure 3.2: `migrations` table.

The `users` table (see Figure 3.3) contains all the information about user accounts, and it contains the following seven columns:

- `id`: the unique ID for each user account.
- `name`: the name associated with user account.
- `email`: the unique email used to log in.
- `password`: the password used to log in, encrypted with 184 bit hashing by Bcrypt (Laravel, 2022b).
- `remember_token`: keeps the user logged in if they select "Remember me".
- `created_at`: records what date and time the user account was first created at.
- `updated_at`: records what date and time the user account was last updated at.

MySQL 8.0.28 : TL5v1.2 : digital-ink : group4 : users						
stories				users		
<code>id</code>	<code>name</code>	<code>email</code>	<code>password</code>	<code>remember_token</code>	<code>created_at</code>	<code>updated_at</code>
1	Adam	adam.cordner@mail.bcu.ac.uk	\$2y\$10\$ISS.3eqO3o0dRXaK8sMy.eBqUapgD...	mDUIGRilVhyEi6...	2022-05-10 15:50:27	2022-05-10 15:50:27
2	evie	^~@snugg.ie	\$2y\$10\$vVRMmN/lRSIYTrCUjJEPu44jkVI0r5...	Mu1WdyOz1e8...	2022-05-10 15:51:29	2022-05-10 15:51:29

Figure 3.3: `users` table.

The `stories` table (see Figure 3.4) contains all the information about user-created stories, and it contains the following 11 columns:

- `id`: the unique ID for each story.
- `author_id`: the unique ID associated with the user who created the story.
- `title`: the title associated with the story.
- `genre`: the genre associated with the story, which can be one of eight different genres.
- `blurb`: a brief description of the story.
- `content`: the full content of the story.
- `cover_image`: a thumbnail image for the story.
- `file_upload`: an optional PDF upload of the story.
- `published`: 1 if the story has been made public, or 0 if it is a draft.
- `created_at`: records what date and time the story was first created at.
- `updated_at`: records what date and time the story was last updated at.

<code>id</code>	<code>author_id</code>	<code>title</code>	<code>genre</code>	<code>blurb</code>	<code>content</code>
2	1 →	Group 4 Loves AWS	Romance	Meet Group 4 and their love for AWS!	Group 4 loves using AWS' cloud features to host Di...
3	2 →	cheese savoury	Action and Adventure	nice and simple	on malted granary

<code>cover_image</code>	<code>file_upload</code>	<code>published</code>	<code>created_at</code>	<code>updated_at</code>
./storage/cover_images/7537329101652200606.j... images/digital-ink-logo.png	NULL	1	2022-05-10 16:36:46	2022-05-10 16:36:46

Figure 3.4: `stories` table.

3.3 Interface Design

The design of the web app was created using Blade, a powerful templating engine (Laravel, 2022a). When the user initially accesses the web app, they are able to log in or sign up. This can be seen in Figure 3.5. When a user has created an account, a record is written to the `users` table in the database.



Stories Create About Account

Email
Enter Email

Password
Enter Password

Login

Don't have an account already? Why not sign up?

Remember me

Sign Up

Name
Enter Name

Email
Enter Email

Password
Enter Password

Repeat Password
Repeat Password

Sign Up

Figure 3.5: *Digital-Ink* home page log in and sign up forms.

Once a user is signed in, they can create a story. Creating a story requires the user to enter a title, a genre, the story itself, a blurb, and, optionally, a thumbnail image. This can be seen in Figure 3.6. Once a story has been created, it is written to the `stories` table.

Create your story!

The figure displays a three-section form for creating a story:

- Author Reference Number:** *
1
- Title:** *
Every story needs a good title!
Group 4 Loves AWS
- Genre:** *
What type of story are you creating?
Romance

Your Story: *

Add the content of your story below.

Group 4 loves using AWS' cloud features to host Digital Ink.

Blurb: *

Add a short description of your story!

Meet Group 4 and their love for AWS!

Nearly finished! *

Do you want to save your story as a draft or publish it onto our site?

Save as a Draft
 Upload

Complete

Figure 3.6: *Digital-Ink* story creation form.

After this, the user can see all of their uploaded stories on their account page. This can be seen in Figure 3.7. From here, a story can be edited or deleted, which either updates a record in the `stories` table or removes a record from it.

The screenshot shows a user interface for managing published stories. At the top, a green banner displays the message "Yay! Your story has been published!". Below this, a heading says "Here are your published stories:". A table follows, with columns for TITLE, GENRE, and ACTIONS. The first row shows a story titled "Group 4 Loves AWS" in the Romance genre. The "Edit" button is highlighted with a green oval, while the "Delete" button is highlighted with a red oval.

TITLE	GENRE	ACTIONS
Group 4 Loves AWS	Romance	Edit Delete

Figure 3.7: *Digital-Ink* account page.

Lastly, on the Stories page, a user can view and search through all uploaded stories across all users. Each story's title, genre, and blurb is shown in a list view. A user can click into one of these stories to see the thumbnail image and read the full story. These pages can be seen in Figure 3.8.

The screenshot shows two views of the Digital-Ink application. On the left, a "Stories" page lists two stories: "Group 4 Loves AWS" (Author ID 1, Romance, blurb: "Meet Group 4 and their love for AWS!") and "cheese savoury" (Author ID 2, Action and Adventure, blurb: "nice and simple"). A search bar at the top right includes a "Search" button. On the right, a detailed view of the first story, "Group 4 Loves AWS", is shown. It features a thumbnail of a person, the title, author information ("Written by: 1 Genre: Romance"), and a blurb: "Group 4 loves using AWS' cloud features to host Digital Ink.". A "Back" button is at the bottom left of this view.

Figure 3.8: *Digital-Ink* stories page and story view.

Chapter 4

Virtual Private Cloud (VPC)

Amazon VPC allows for AWS resources to be launched in a virtual network that has been custom defined and configured. This virtual network is similar to a traditional network which operates within your own physical data center, with the added benefits of the scalable AWS infrastructure (Amazon Web Services (AWS), 2022i). A VPC can have multiple assigned subnets, which are a range of IP addresses accessible in the VPC. This chapter of the report will detail the creation of an Elastic IP address, a VPC, subnets, an internet gateway, and route tables.

4.1 Elastic IP Address

Before creating the VPC, an Elastic IP address must be created, which can then be allocated to the VPC. To do this, the **Allocate Elastic IP address** button on the Elastic IP Addresses page must be clicked.

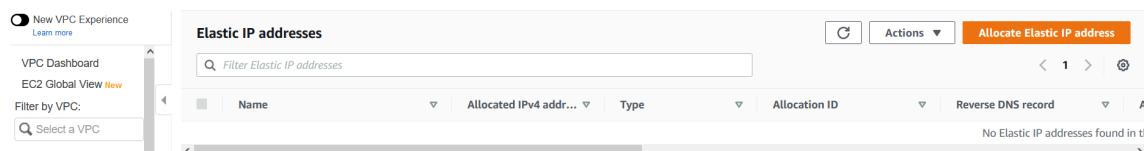


Figure 4.1: Elastic IP Addresses page.

To configure the Elastic IP address, a Network Border Group must be selected, ensuring that this is the same as the Availability Zone selected when configuring the VPC. Once this has been set, and the remaining options are set to their default values, clicking the **Allocate** button will create the Elastic IP address.

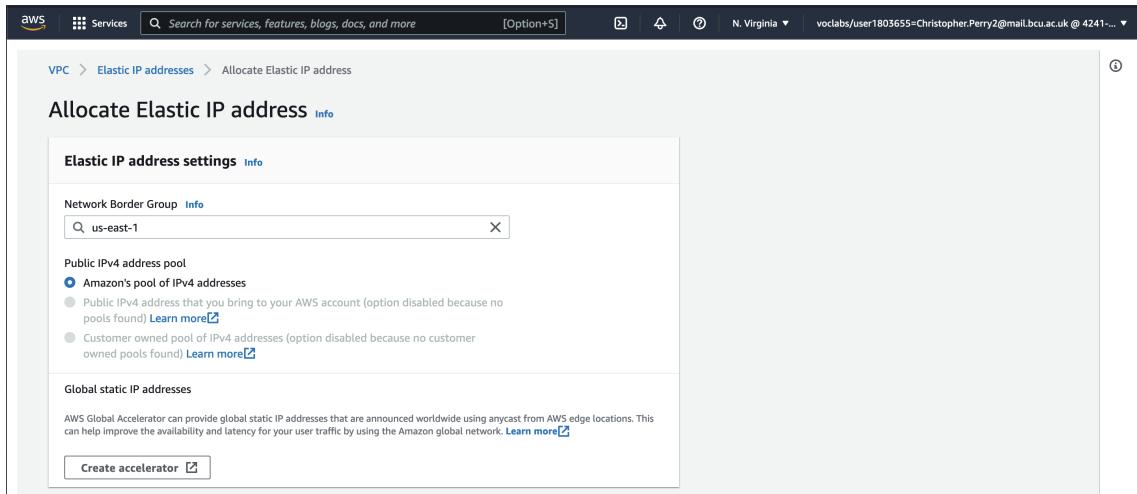


Figure 4.2: Configuring the Elastic IP address.

After this, the Elastic IP address created can be seen from the Elastic IP Addresses page.

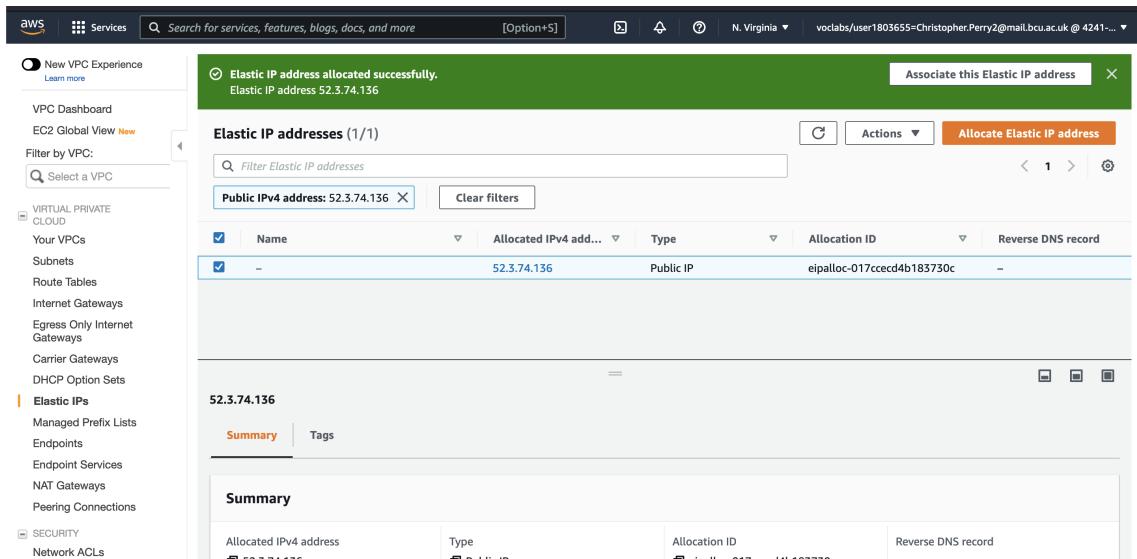


Figure 4.3: Created Elastic IP address.

4.2 VPC and Subnets

The first step of migrating the web app to the cloud was creating a VPC to deploy and manage AWS resources for the app. To do this, the VPC wizard must be used. This is accessed by navigating to the VPC Management Console and then click the **Launch VPC Wizard** button, which can be seen in Figure 4.4.

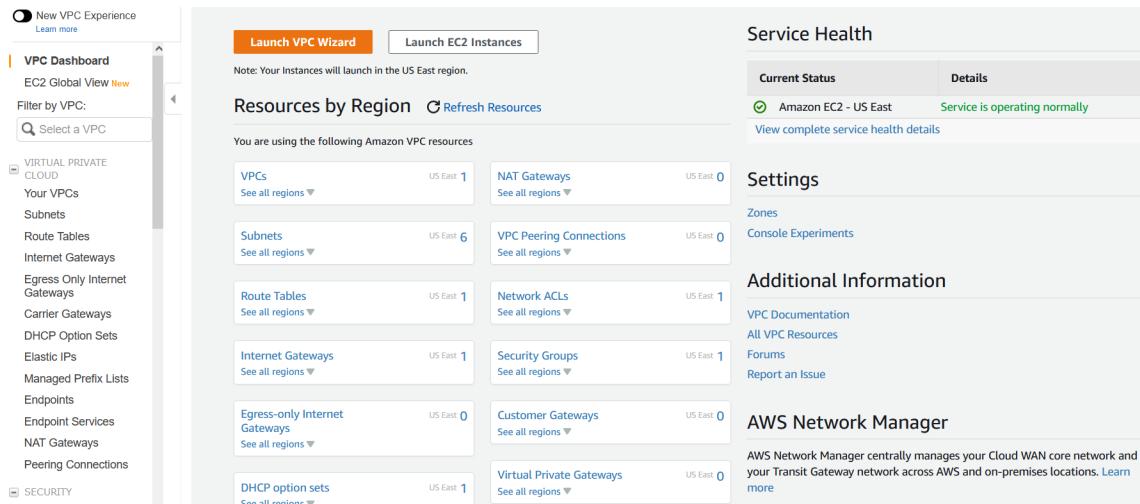


Figure 4.4: VPC Management Console.

The wizard presents us with step one of creating a VPC: selecting a VPC configuration. There are several options for this, where each configuration has the following features:

- **VPC with a Single Public Subnet:** Creates a /16 network with a /24 subnet where the subnet instances use Elastic IPs or Public IPs for internet access.
- **VPC with Public and Private Subnets:** Creates a /16 network and two /24 subnets where the public subnet instances use Elastic IPs for internet access and the private subnet instances use NAT for internet access.
- **VPC with Public and Private Subnets and Hardware VPN Access:** Creates a /16 network with two /24 subnets where one subnet is connected to the internet and another is connected to your personal network via a VPN.
- **VPC with a Private Subnet Only and Hardware VPN Access:** Creates a /16 network and a /24 subnet where the subnet is connected to your personal network via a VPN.

For the deployment of this web app, hardware VPN access is not necessary, so the VPC configuration with public and private subnets was selected, as seen in Figure 4.5.

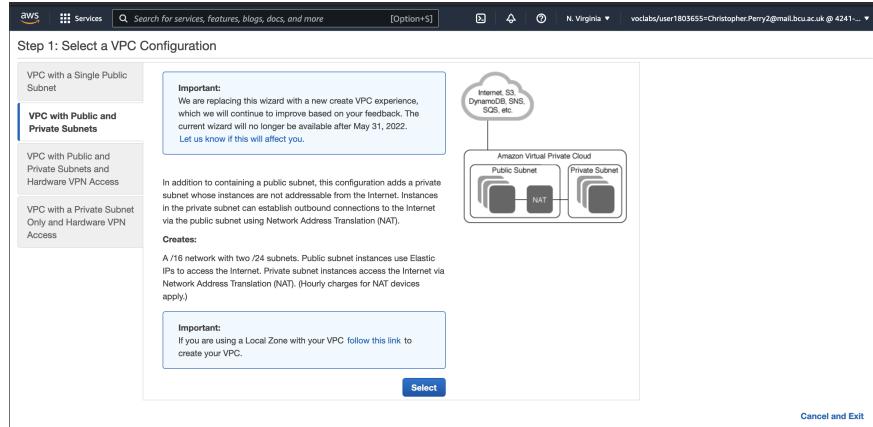


Figure 4.5: Selecting a VPC configuration.

Following this, the specific details, such as the IP address block, of the selected configuration must be entered. An IPv4 CIDR block of `10.0.0.0/16` was chosen as it provides a large amount of available IP addresses. Additionally, no IPv6 CIDR block was configured and the VPC was named `Group4_VPC`.

Next, the public and private subnets were configured. The public subnet was assigned an IPv4 CIDR of `10.0.0.0/24`, making 251 distinct IP addresses available for the public subnet. The availability zone of `us-east-1a` was chosen and the subnet was named `Public subnet 1`. The private subnet was assigned an IPv4 CIDR of `10.0.1.0/24`, making 251 distinct IP addresses available for the private subnet as well. The availability zone of `us-east-1a` was chosen and the subnet was named `Private subnet 1`.

Lastly, the previously created Elastic IP Allocation ID was selected, and the remaining settings were left at their default values. Clicking the **Create VPC** button now will generate the VPC with the specified configurations.

Figure 4.6: Configuring VPC public and private subnets.

After this, AWS takes a few minutes to generate the VPC.

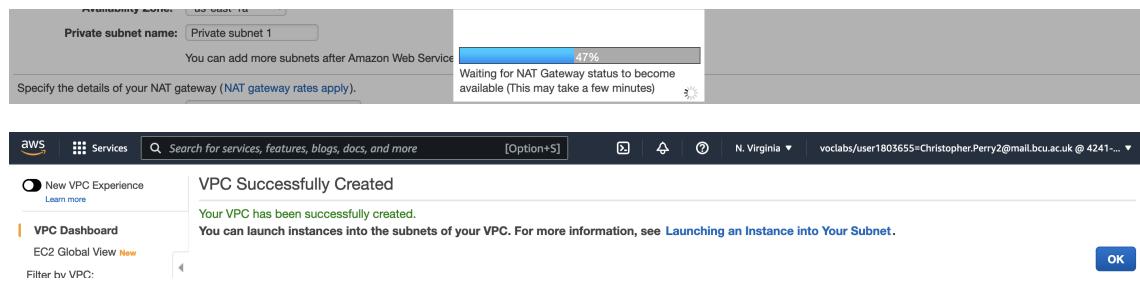


Figure 4.7: Generating the VPC.

Navigating from here to the Your VPCs page shows two available VPCs: the VPC created by the AWS sandbox environment, which will not be used, and the VPC which has just been created, named Group4_VPC.

The screenshot shows the "Your VPCs" page in the AWS Management Console. On the left, there is a navigation sidebar with options like New VPC Experience, VPC Dashboard, EC2 Global View, Filter by VPC, Select a VPC, and links to Virtual Private Cloud, Security, and Network ACLs. The main area displays a table titled "Your VPCs (2) Info". The table has columns for Name, VPC ID, State, IPv4 CIDR, and IPv6 CIDR. It lists two entries: one with VPC ID "vpc-006b19b59ed484041" and another with VPC ID "Group4_VPC". Below the table, a specific VPC entry is expanded, showing its details. The expanded section includes tabs for Details, CIDRs, Flow logs, and Tags. The "Details" tab is selected, showing information such as VPC ID (vpc-07657585bc0e3b3b5), State (Available), DNS hostnames (Disabled), and DNS resolution (Enabled).

Figure 4.8: Your VPCs page.

4.3 Internet Gateway

An internet gateway is required for resources, such as EC2, to be able to communicate with the internet, if the resource has a public IP address (Amazon Web Services (AWS), 2022f). To do this, navigate to the Internet Gateways page and click the **Create internet gateway** button. Here, enter the internet gateway name, such as Group4-Internet-Gateway.

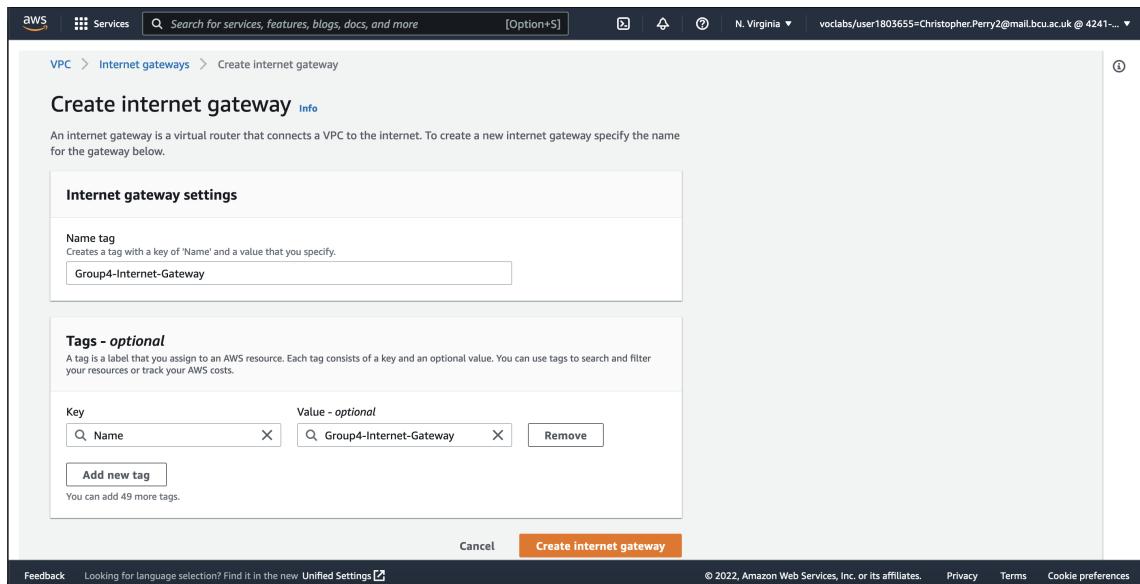


Figure 4.9: Creating an internet gateway.

After entering the internet gateway name and clicking the **Create internet gateway** button, the newly created internet gateway can be seen (as well as an automatically generated internet gateway for the default VPC, which will not be used).

Name	Internet gateway ID	State	VPC ID	Owner
-	igw-029a97e1f59b9fb65	Attached	vpc-006b19b59ed484041 -	424176735797
Group4-Internet-Gateway	igw-0b9a9bed921c1370f	Attached	vpc-0b0472507c8bf18c9 Group4_VPC	424176735797

Figure 4.10: Viewing the newly created internet gateway.

4.4 Route Tables

The newly created VPC does not currently have a sufficient level of availability, as it is only available in one Availability Zone - `us-east-1a`. The availability of the VPC can be increased by creating a new pair of public and private subnets in a different Availability Zone. This is done by navigating to the Create Subnets page from the VPC Management Console.

First, to create `Public subnet 2`, it is required to specify a VPC ID, an Availability Zone, and an IPv4 CIDR block for the subnet. For this subnet, the ID of the newly created VPC is selected as the VPC ID. Additionally, `us-east-1b` is selected as the Availability Zone and `10.0.3.0/24` is selected as the IPv4 CIDR block.

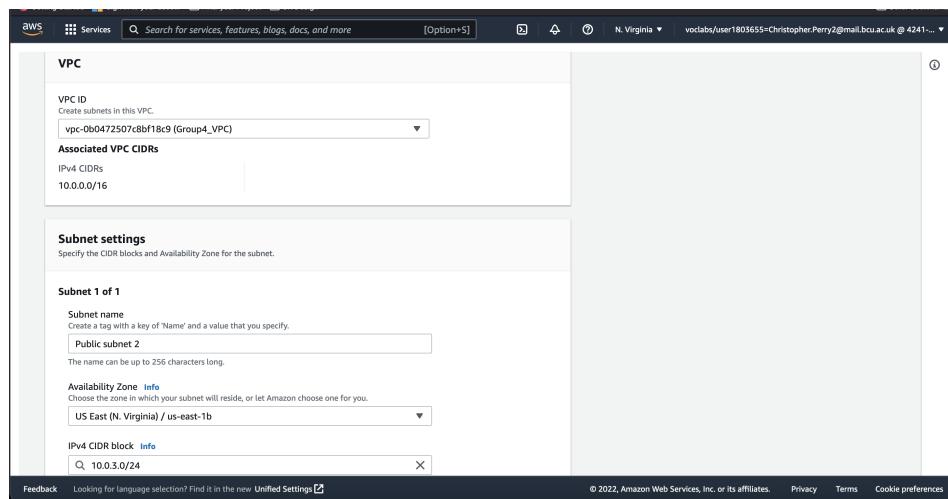


Figure 4.11: Creating a second public subnet.

Next, to create `Private subnet 2`, the ID of the newly created VPC is also selected as the VPC ID, `us-east-1b` is selected as the Availability Zone and `10.0.4.0/24` is selected as the IPv4 CIDR block.

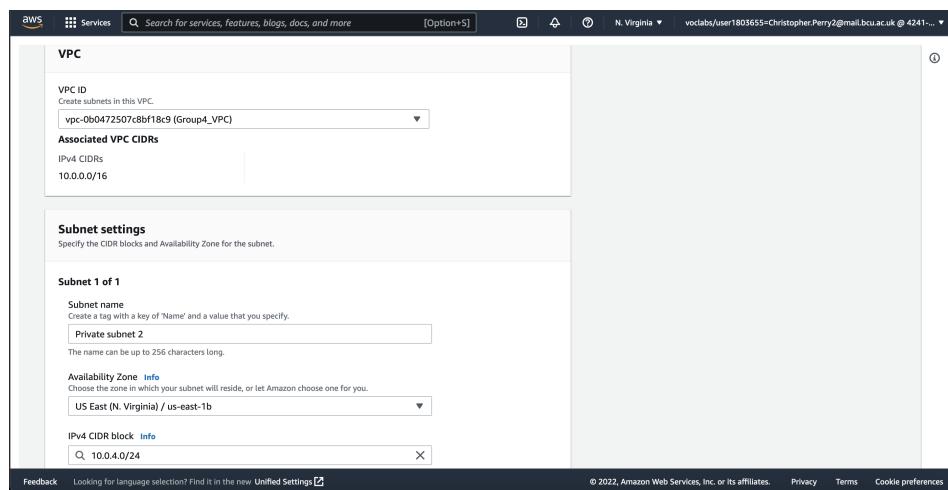


Figure 4.12: Creating a second private subnet.

Now the subnets can be filtered by Availability Zone and it can be seen that the two newly created subnets exist within us-east-1b (as well as an automatically generated default subnet, which will not be used).

The screenshot shows the AWS VPC Subnets page. At the top, a green banner says "You have successfully created 1 subnet: subnet-0ccf3a5735ad3995f". Below this, the "Subnets (3) Info" section has a "Filter subnets" input field set to "Availability Zone: us-east-1b". A "Create subnet" button is visible. The main table lists three subnets:

Name	Subnet ID	State	VPC	IPv4 CIDR
-	subnet-0b6436ace896ba7a8	Available	vpc-006b19b59ed484041 Gr...	172.31.0.0/20
Private subnet 2	subnet-0ccf3a5735ad3995f	Available	vpc-0b0472507c8bf18c9 Gro...	10.0.4.0/24
Public subnet 2	subnet-09b56eb86b73cc4c	Available	vpc-0b0472507c8bf18c9 Gro...	10.0.3.0/24

Figure 4.13: Viewing the newly created subnets.

After this, two routing tables must be created to link the two public subnets and the two private subnets. The Create Route Table page can be navigated to from the VPC Management Console. Two route tables are created, one at a time, called `Public route` and `Private route` with the previously created VPC.

The screenshots show the "Create route table" wizard. Both instances are for the same VPC, "vpc-0b0472507c8bf18c9 (Group4_VPC)".

First Screenshot (Public route):

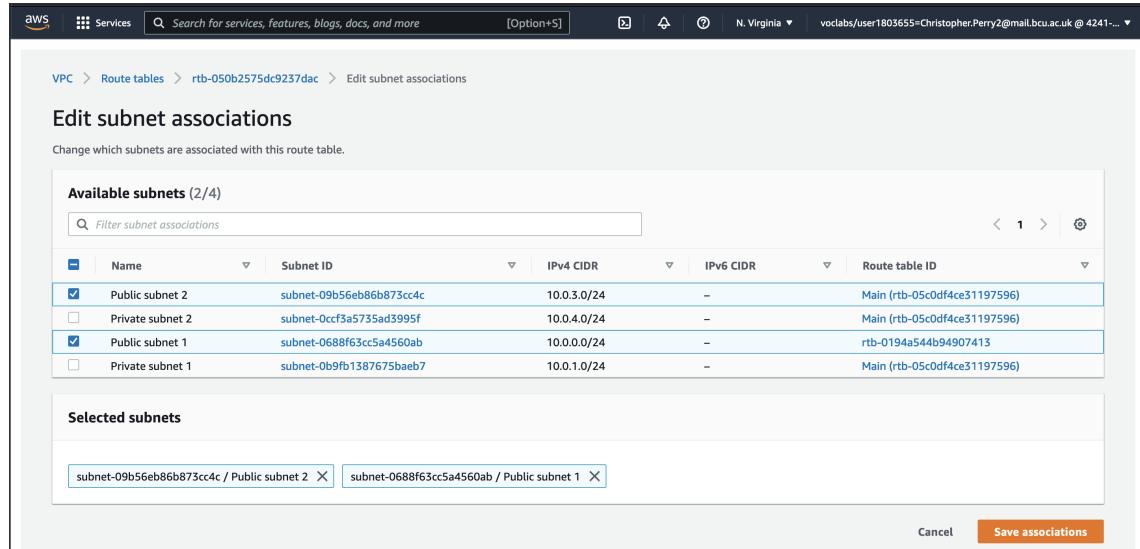
- Route table settings:**
 - Name - optional:** Public route
 - VPC:** vpc-0b0472507c8bf18c9 (Group4_VPC)

Second Screenshot (Private route):

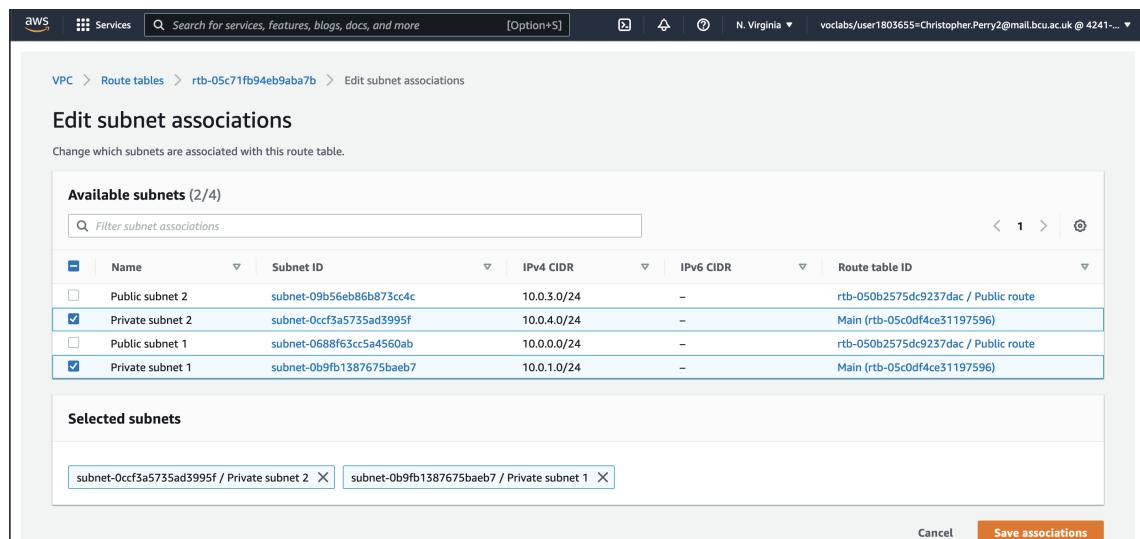
- Route table settings:**
 - Name - optional:** Private route
 - VPC:** vpc-0b0472507c8bf18c9 (Group4_VPC)

Figure 4.14: Creating a public route table and a private route table.

Once the two route tables have been created, the public and private subnets must be associated with the corresponding route table. From the Route Tables page, **Public route** is selected, and the **Edit subnet associations** button is clicked. On the Edit Subnet Associations page, the two public subnets are selected, and the **Save associations** button is clicked. This process is then repeated for **Private route**.



The screenshot shows the AWS VPC console. The URL is [VPC > Route tables > rtb-050b2575dc9237dac > Edit subnet associations](#). The page title is "Edit subnet associations". A sub-header says "Change which subnets are associated with this route table." Below is a table titled "Available subnets (2/4)". It lists four subnets: "Public subnet 2" (selected), "Private subnet 2", "Public subnet 1" (selected), and "Private subnet 1". The "Selected subnets" section contains two subnets: "subnet-09b56eb86b873cc4c / Public subnet 2" and "subnet-0688f63cc5a4560ab / Public subnet 1". At the bottom are "Cancel" and "Save associations" buttons.



The screenshot shows the AWS VPC console. The URL is [VPC > Route tables > rtb-05c71fb94eb9aba7b > Edit subnet associations](#). The page title is "Edit subnet associations". A sub-header says "Change which subnets are associated with this route table." Below is a table titled "Available subnets (2/4)". It lists four subnets: "Public subnet 2", "Private subnet 2" (selected), "Public subnet 1", and "Private subnet 1". The "Selected subnets" section contains two subnets: "subnet-0ccf3a5735ad3995f / Private subnet 2" and "subnet-0b9fb1387675baeb7 / Private subnet 1". At the bottom are "Cancel" and "Save associations" buttons.

Figure 4.15: Associating the public and private subnets with the public and private route tables.

Lastly, the `Public route` must be updated to allow all public traffic that attempts to access the VPC to be routed via the internet gateway. This is done by selecting `Public route` and clicking the "Edit routes" Action. On this page, click the **Add route** button and enter a destination of `0.0.0.0/0` and, for the target, select the previously created internet gateway.

Destination	Target	Status	Propagated
10.0.0.0/16	local	Active	No
0.0.0.0/0	igw-0b9a9bed921c1370f	-	No

Figure 4.16: Editing the public route table.

Lastly, click the **Save changes** button. This will update the route for `Public route`.

Route table ID	Main	Explicit subnet associations	Edge associations
rtb-050b2575dc9237dac	No	2 subnets	-

Destination	Target	Status	Propagated
10.0.0.0/16	local	Active	No
0.0.0.0/0	igw-0b9a9bed921c1370f	Active	No

Figure 4.17: Updated public route table.

Chapter 5

Elastic Cloud Compute (EC2)

5.1 AWS Setup

After the VPC and subnets were configured, the initial deployment of the web app began with setting up EC2. This AWS service allows for scalable computing capacity through the use of a virtual computing environment hosted in the cloud (Amazon Web Services (AWS), 2022h). The web app will be stored on an EC2 instance of Amazon Linux, known as Amazon Machine Image (AMI), which will then be launched through a docker container stored on the app.

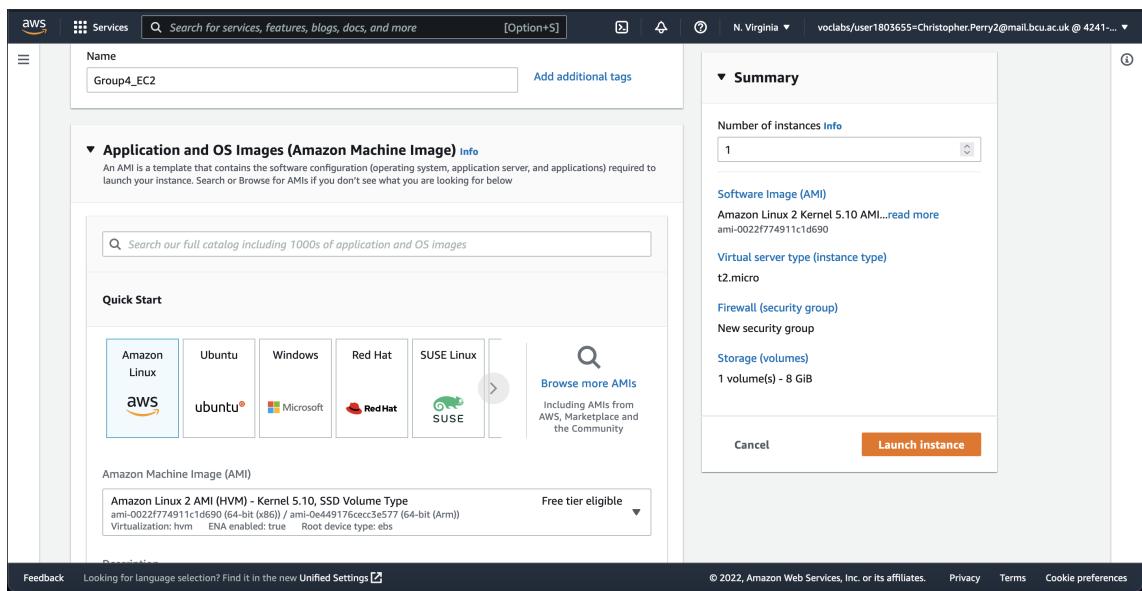


Figure 5.1: Selection of EC2 OS Image.

Figure 5.1 details the selection of the Operating System (OS) that will be used for the EC2 instance. The *Amazon Linux 2* AMI was selected, as it is already configured with Linux and does not need any more setup.

Now that an AMI has been chosen, the specific instance type that will be used within this AMI can be selected. It was decided that the instance type of *t2.micro* would be used, as it contains only 1GB of Random Access Memory (RAM), as seen in Figure 5.2.

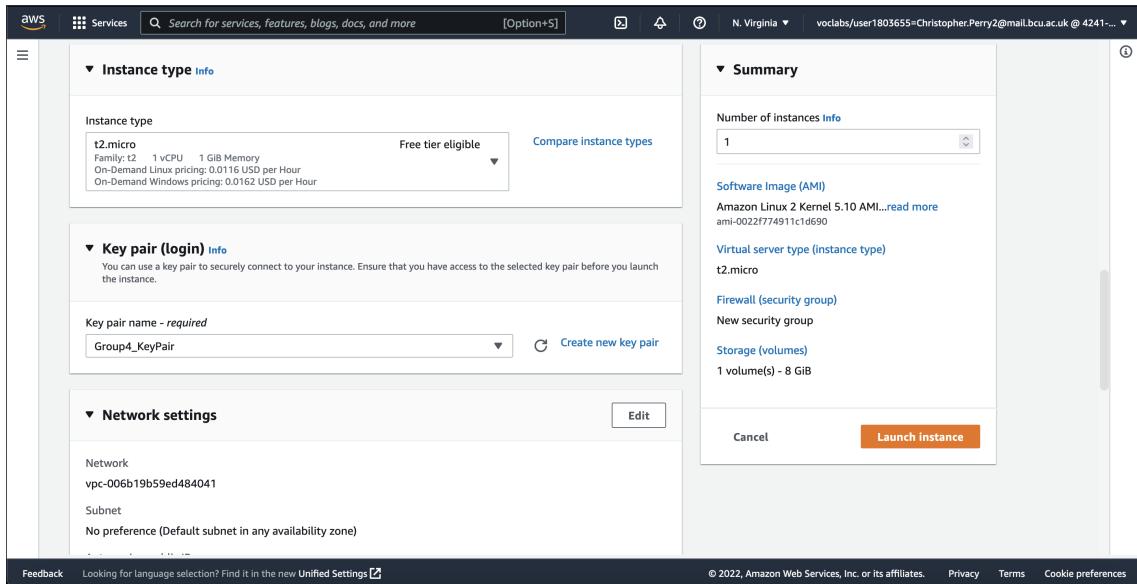


Figure 5.2: Selection of EC2 Instance.

A key pair will allow for the ability to sign in to the EC2 instance with a unique set of login credentials, heightening the security of the project.

The next stage of the setup process was to set up networking for the EC2 instance, in order for the web app to work with Docker to download relevant containers from Docker-Hub, which will allow a Laravel instance to be initialised, as discussed in Section 3. This process can be seen in Figure 5.3.

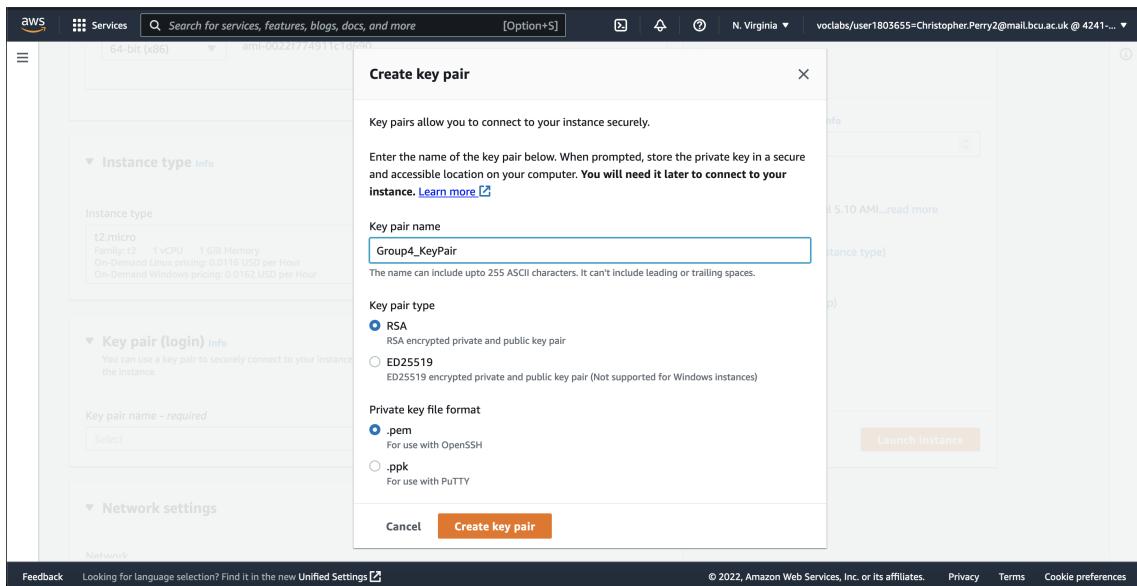


Figure 5.3: Selection of EC2 Keypair.

The instance is assigned the VPC created in Section 4, where it is assigned a subnet in the same availability zone of us-east-1.

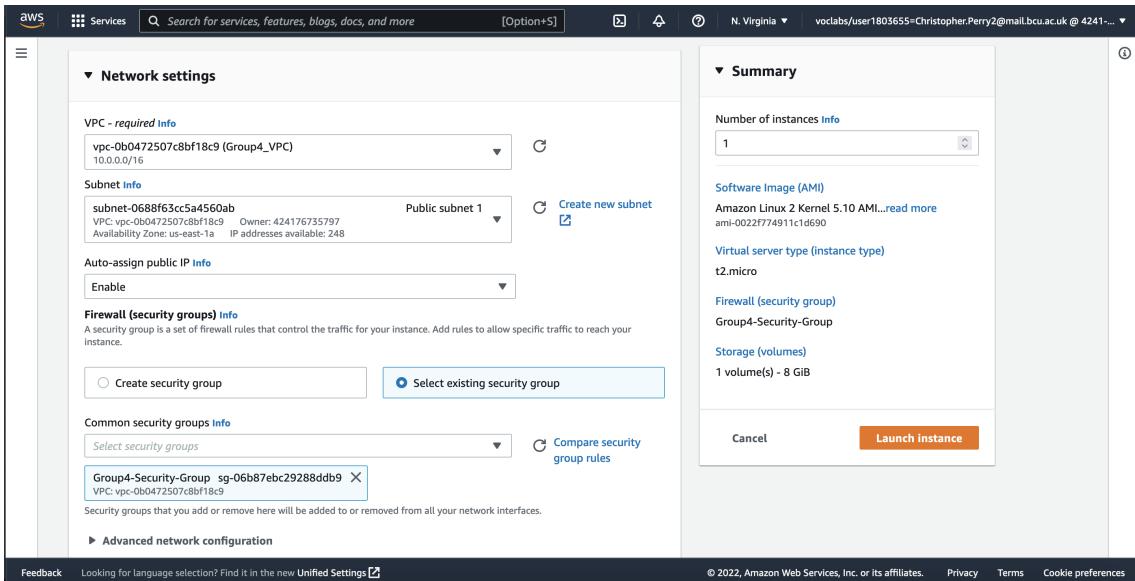


Figure 5.4: Selection of EC2 Networking options.

```
chris@Christophers-MacBook-Pro:~/Desktop/Keypair
└─ ssh -i Group4_KeyPair.pem ec2-user@52.45.13.111
```

Figure 5.5: Generated EC2 Keypair in the .pem format.

This setup can be seen in Figure 5.4. An EC2 keypair is then generated in the .pem format.

This is enough to comfortably run the web app without any issues. Storage for the AMI was subsequently chosen. It was decided that 8GB of storage would be used, as this is enough to run the web app and still provide leftover storage for any system-critical tasks.

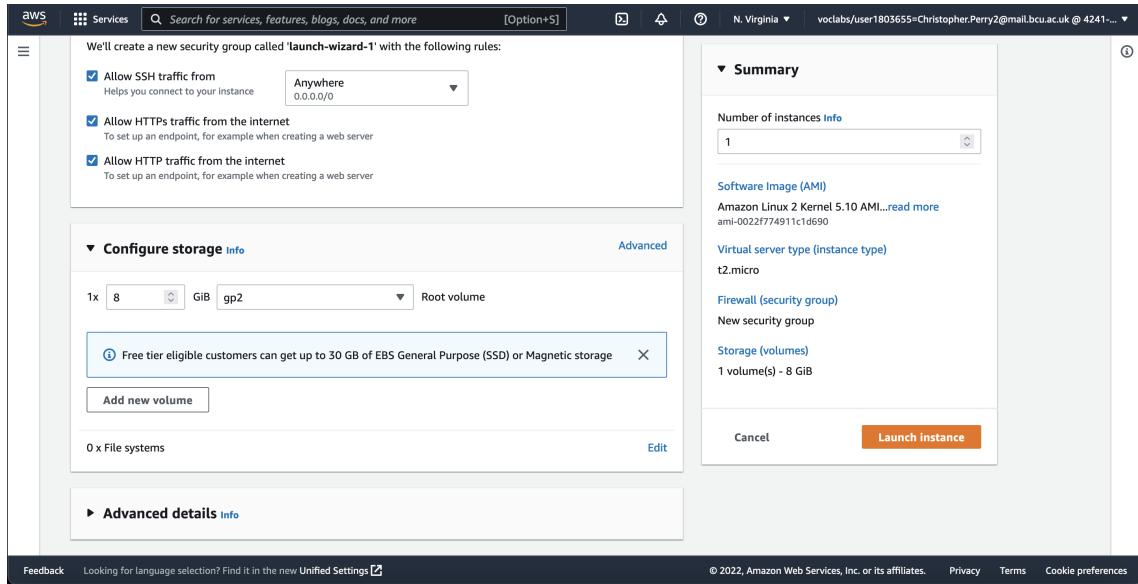


Figure 5.6: Selection of EC2 Storage Configuration.

The selection of these options can be found in Figure 5.6. In addition to this, the chosen options are eligible for "Free Tier", which means that it will use a limited amount of the \$100 budget allocated for the project.

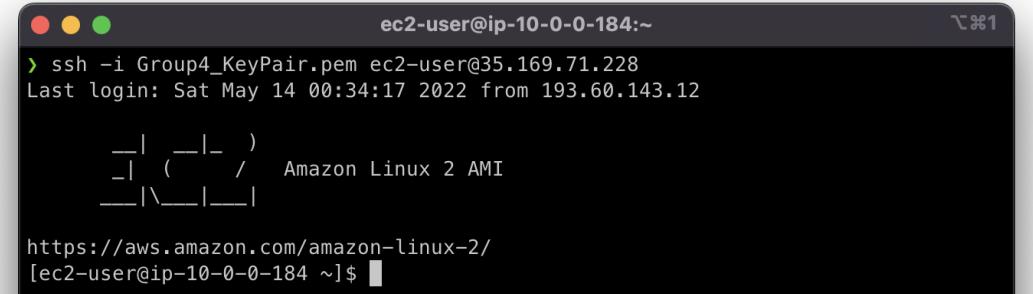
5.2 EC2 Login

The EC2 instance `group4-ec2` is now live, and the webapp can be loaded onto it. The instance is first logged in to through the use of the `ssh` command, followed by the `-i` argument to specify an identify file, which was generated earlier, and then the public ipv4 address of the instance.

```
ssh -i ~/Desktop/Group4_KeyPair.pem ec2-user@52.45.13.111
```

Figure 5.7: SSH command to log into EC2 instance.

This command can seen being executed in Figure 5.7.



A screenshot of a terminal window titled "ec2-user@ip-10-0-0-184:~". The window shows the command `ssh -i Group4_KeyPair.pem ec2-user@35.169.71.228` being run, followed by the output: "Last login: Sat May 14 00:34:17 2022 from 193.60.143.12". Below this, there is a small ASCII art logo of a tree. The prompt "[ec2-user@ip-10-0-0-184 ~]\$ " is visible at the bottom.

Figure 5.8: Logging into EC2 instance.

The logged in EC2 instance can be seen in Figure 5.8.

5.3 Package Setup

The web app is stored on GitHub, and the AMI does not come with GitHub by default. Git is subsequently installed via `yum install git`.

```

git-core.x86_64          2.32.0-1.amzn2.0.1           amzn2-core          4.8 M
git-core-doc.noarch        2.32.0-1.amzn2.0.1           amzn2-core          2.7 M
perl-Error.noarch         1:0.17020-2.amzn2             amzn2-core          32 k
perl-Git.noarch           2.32.0-1.amzn2.0.1           amzn2-core          43 k
perl-TermReadKey.x86_64   2.30-20.amzn2.0.2           amzn2-core          31 k

Transaction Summary
=====
Install 1 Package (+6 Dependent packages)

Total download size: 7.8 M
Installed size: 38 M
Is this ok [y/d/N]: y
Downloading packages:
(1/7) emacs-filesystem-27.2-4.amzn2.0.1.noarch.rpm | 67 kB 00:00:00
(2/7) git-2.32.0-1.amzn2.0.1.x86_64.rpm          126 kB 00:00:00
(3/7) git-core-doc-2.32.0-1.amzn2.0.1.noarch.rpm  2.7 MB 00:00:00
(4/7) perl-Error-0.17020-2.amzn2.noarch.rpm       13 kB 00:00:00
(5/7) perl-Git-2.32.0-1.amzn2.0.1.noarch.rpm      43 kB 00:00:00
(6/7) perl-core-2.32.0-1.amzn2.0.1.x86_64.rpm    4.8 MB 00:00:00
(7/7) perl-TermReadKey-2.30-20.amzn2.0.2.x86_64.rpm| 31 kB 00:00:00

Total
Running transaction check
Running transaction test
Transaction test succeeded
Running transaction upgrade/erase
Installing : git-core-2.32.0-1.amzn2.0.1.x86_64 1/7
Installing : git-core-doc-2.32.0-1.amzn2.0.1.noarch 2/7
Installing : 1:emacs-filesystem-27.2-4.amzn2.0.1.noarch 3/7
Installing : perl-TermReadKey-2.30-20.amzn2.0.2.x86_64 4/7
Installing : perl-Git-2.32.0-1.amzn2.0.1.noarch 5/7
Installing : git-2.32.0-1.amzn2.0.1.x86_64 6/7
Verifying : perl-TermReadKey-2.30-20.amzn2.0.2.x86_64 7/7
Verifying : git-2.32.0-1.amzn2.0.1.x86_64 1/7
Verifying : perl-Git-2.32.0-1.amzn2.0.1.noarch 2/7
Verifying : 1:emacs-filesystem-27.2-4.amzn2.0.1.noarch 3/7
Verifying : git-2.32.0-1.amzn2.0.1.x86_64 4/7
Verifying : git-core-2.32.0-1.amzn2.0.1.x86_64 5/7
Verifying : 1:perl-Error-0.17020-2.amzn2.noarch 6/7
Verifying : 1:perl-Git-2.32.0-1.amzn2.0.1.noarch 7/7

Installed:
  git.x86_64 0:2.32.0-1.amzn2.0.1

Dependency Installed:
  emacs-filesystem.noarch 1:27.2-4.amzn2.0.1  git-core.x86_64 0:2.32.0-1.amzn2.0.1  git-core-doc.noarch 0:2.32.0-1.amzn2.0.1  perl-Error.noarch 1:0.17020-2.amzn2  perl-Git.noarch 0:2.32.0-1.amzn2.0.1
  perl-TermReadKey.x86_64 0:2.30-20.amzn2.0.2

Complete!
[ec2-user@ip-172-31-27-208 ~]$ snuffleupig | snuffleupig | ls ssh * fish * bash * zsh * fish * fish * fish * -fish | spacedust
 59% ↗ 5.4 GB ↘ 19% ↗ 5-04, 1:33 PM

```

Figure 5.9: Installing Git.

The web app also requires docker, and `yum install docker` is executed to install Docker as a result.

```

[ec2-user@ip-172-31-27-208 ~]$ sudo yum update
Loaded plugins: extras_suggestions, longpacks, priorities, update-motd
amzn2-core                                         | 3.7 kB 00:00:00
No packages marked for update
[ec2-user@ip-172-31-27-208 ~]$ sudo yum install docker docker-compose
Loaded plugins: extras_suggestions, longpacks, priorities, update-motd
No package docker-compose available.
Resolving Dependencies
--> Running transaction check
--> Package docker.x86_64 0:20.10.13-2.amzn2 will be installed
--> Processing Dependency: runc >= 1.0.0 for package: docker-20.10.13-2.amzn2.x86_64
--> Processing Dependency: libcgroup >= 0.40.rci-5.15 for package: docker-20.10.13-2.amzn2.x86_64
--> Processing Dependency: containerd >= 1.3.2 for package: docker-20.10.13-2.amzn2.x86_64
--> Processing Dependency: pigz for package: docker-20.10.13-2.amzn2.x86_64
--> Running transaction check
--> Package containerd.x86_64 0:1.4.13-2.amzn2.0.1 will be installed
--> Package libcgroup.x86_64 0:0.41-21.amzn2 will be installed
--> Package pigz.x86_64 0:2.3.4-1.amzn2.0.1 will be installed
--> Package runc.x86_64 0:1.0.3-2.amzn2 will be installed
--> Finished Dependency Resolution

Dependencies Resolved

=====
Package          Arch      Version       Repository      Size
=====
Installing:
  docker          x86_64   20.10.13-2.amzn2      amzn2extra-docker  40 M
Installing for dependencies:
  containerd      x86_64   1.4.13-2.amzn2.0.1    amzn2extra-docker  23 M
  libcgroup       x86_64   0.41-21.amzn2        amzn2-core          66 k
  pigz            x86_64   2.3.4-1.amzn2.0.1    amzn2-core          81 k
  runc            x86_64   1.0.3-2.amzn2        amzn2extra-docker  3.0 M

Transaction Summary
=====
Install 1 Package (+4 Dependent packages)

Total download size: 67 M
Installed size: 289 M
Is this ok [y/d/N]: y
snuffleupig | snuffleupig | ls ssh * fish * bash * zsh * fish * fish * fish * -fish | spacedust
 64% ↗ 5.2 GB ↘ 18% ↗ 5-04, 1:31 PM

```

Figure 5.10: Installing Docker.

5.4 Web App Setup

The web app is firstly cloned from its repository via the `git clone` command, and a new `digital-ink` folder is made to store the contents.

```
[ec2-user@ip-172-31-27-208 ~]$ git clone https://github.com/ChrisP99/digital-ink
.git
-bash: git: command not found
[ec2-user@ip-172-31-27-208 ~]$ git clone https://github.com/ChrisP99/digital-ink
.git
Cloning into 'digital-ink'...
remote: Enumerating objects: 959, done.
remote: Counting objects: 100% (959/959), done.
remote: Compressing objects: 100% (324/324), done.
remote: Total 959 (delta 593), reused 959 (delta 593), pack-reused 0
Receiving objects: 100% (959/959), 3.32 MiB | 19.01 MiB/s, done.
Resolving deltas: 100% (593/593), done.
[ec2-user@ip-172-31-27-208 ~]$
```

Figure 5.11: Cloning the web app from Github.

The `cd` command is used to move into the `digital-ink` folder, and the web app is subsequently launched through the `docker-compose up -d` to launch the web app as a detached Docker container. Relevant containers that are required to be downloaded from the `dockerfile` are then pulled.

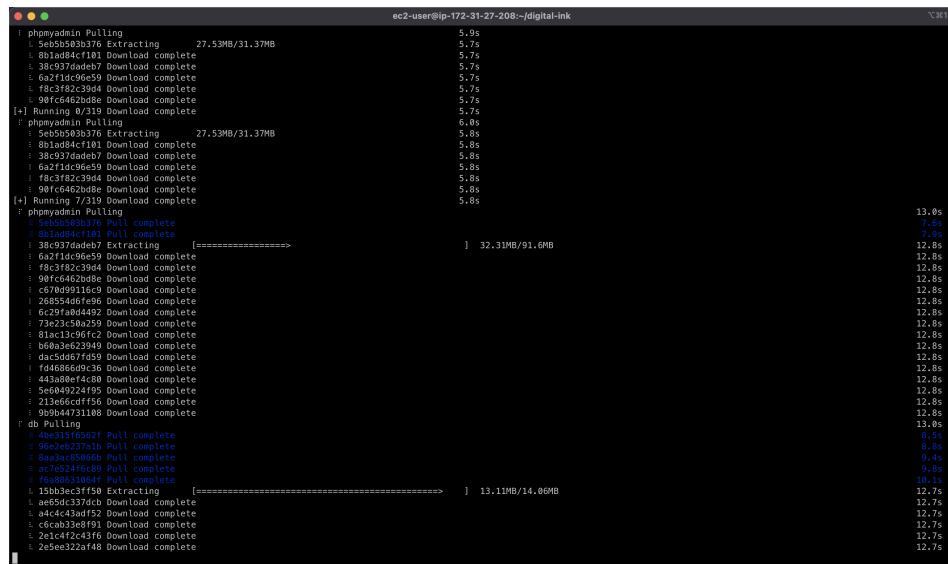


Figure 5.12: Containers required for the web app being pulled from Docker Hub.

The result of this command launches 3 containers:

1. `digital-ink`: An instance of the web app which uses a custom Laravel container.
2. `mysql`: An instance of a local database made in MySQL.
3. `phpmyadmin`: A way to locally manage the database through a UI.

At the minute, the web app is live through the `digital-ink` container, and is using a local version of MySQL as a database, stored within the `mysqlDocker` container. The database has no tables, but can be populated through the use of Laravel. The container is firstly accessed through docker `exec` app bash, and the database is populated with tables with `php artisan migrate`. This then generates tables to store users and their stories.

```
[ec2-user@ip-172-31-27-208 digital-ink]$ sudo /usr/local/bin/docker-compose exec app bash
root@d0e13abddf12:/srv/app# php artisan migrate
Migration table created successfully.
Migrating: 2014_10_12_000000_create_users_table
Migrated: 2014_10_12_000000_create_users_table (0.08 seconds)
Migrating: 2014_10_12_100000_create_password_resets_table
Migrated: 2014_10_12_100000_create_password_resets_table (0.07 seconds)
Migrating: 2019_08_19_000000_create_failed_jobs_table
Migrated: 2019_08_19_000000_create_failed_jobs_table (0.04 seconds)
Migrating: 2020_03_13_105916_create_stories_table
Migrated: 2020_03_13_105916_create_stories_table (0.16 seconds)
root@d0e13abddf12:/srv/app# ]
```

Figure 5.13: Creation of tables through `php artisan migrate` command.

The subsequent output of this command can be found in Figure 5.13. When the website is accessed at the public IPv4 address at <http://ec2-35-169-71-228.compute-1.amazonaws.com/>, Digital Ink will now be shown.

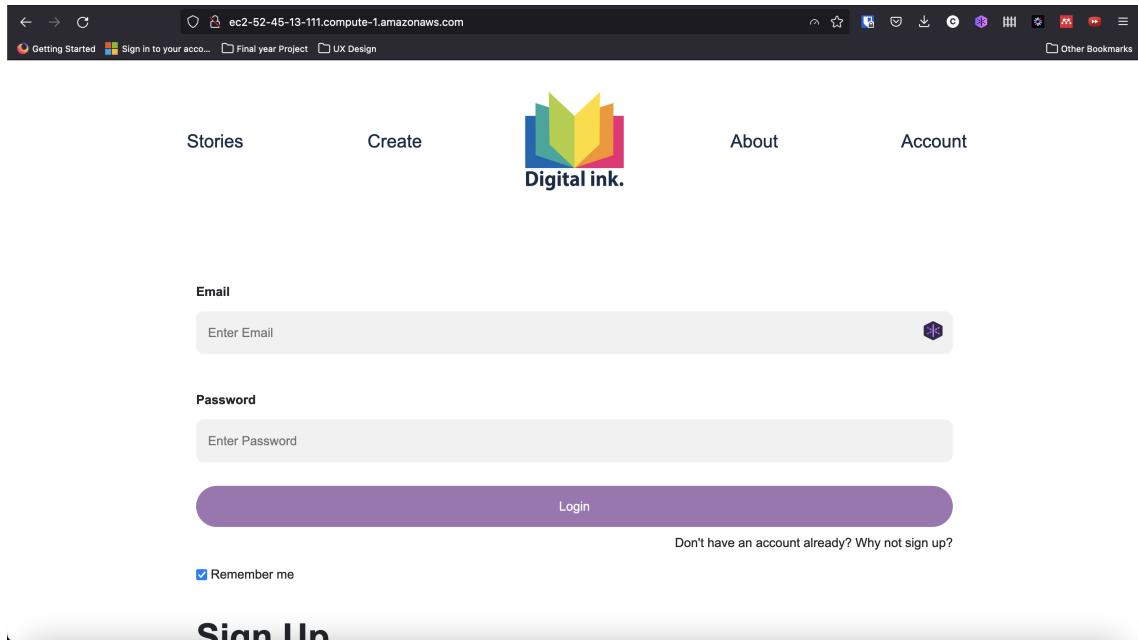
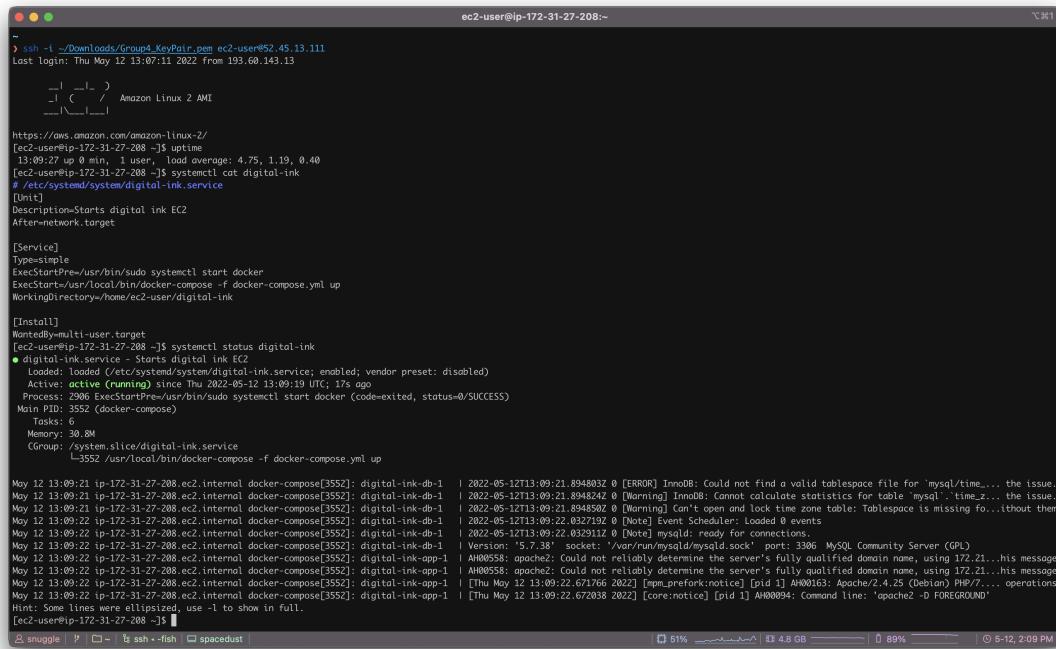


Figure 5.14: Digital Ink shown when accessed through the IPv4 address.

5.5 systemd Services

systemd is a service manager, which is a program that launches and monitors different services across the system. The digital-ink application is automatically started upon boot by the systemd process, which ensures that the application is started correctly and without errors. If any errors occur, systemd will log them in a tool known as journalctl and then follow a configuration file for instructions on how to handle those errors. This can range from simply restarting a program that has errored, to trying once again, or recording the failure and performing no action.



The screenshot shows a terminal window titled "ec2-user@ip-172-31-27-208:~". The user is navigating through their home directory and opening a file named "digital_ink.service" located at "/etc/systemd/system/digital_ink.service". The terminal displays the contents of this service configuration file, which includes details about the service type (simple), start-up dependencies (network.target), and specific parameters for Docker compose. The user then runs the command "systemctl start docker" and "systemctl start digital_ink" to start the services. The terminal also shows logs for MySQL and Apache2, indicating they are running and accepting connections. The status bar at the bottom of the terminal window shows battery level (51%), disk usage (4.8 GB), and system time (5-12, 2:09 PM).

```
~ ssh -i ~/Downloads/Group4_KeyPair.pem ec2-user@52.45.13.111
Last login: Thu May 12 13:07:11 2022 from 193.60.143.13
[ec2-user@ip-172-31-27-208 ~] $ cat /etc/systemd/system/digital_ink.service
[Unit]
Description=Starts digital ink EC2
After=network.target

[Service]
Type=simple
ExecStartPre=/usr/bin/sudo systemctl start docker
ExecStart=/usr/local/bin/docker-compose -f docker-compose.yml up
WorkingDirectory=/home/ec2-user/digital-ink

[Install]
WantedBy=multi-user.target
[ec2-user@ip-172-31-27-208 ~] $ systemctl status digital_ink
● digital_ink.service - Starts digital ink EC2
   Loaded: loaded (/etc/systemd/system/digital_ink.service; enabled; vendor preset: disabled)
     Active: active (running) since Thu 2022-05-12 13:09:19 UTC; 17s ago
       Docs: man:systemctl(1)
   Process: 2906 ExecStartPre=/usr/bin/sudo systemctl start docker (code=exited, status=0/SUCCESS)
 Main PID: 3552 (docker-compose)
    Tasks: 6
      Memory: 30.8M
        CPU: 0.000 CPU(s)
       CGroup: /system.slice/digital_ink.service
           └─ 3552 /usr/local/bin/docker-compose -f docker-compose.yml up

May 12 13:09:21 ip-172-31-27-208.ec2.internal docker-compose[3552]: digital_ink-db-1 | 2022-05-12T13:09:21.894880Z 0 [ERROR] InnoDB: Could not find a valid tablespace file for 'mysql/time.... the issue.
May 12 13:09:21 ip-172-31-27-208.ec2.internal docker-compose[3552]: digital_ink-db-1 | 2022-05-12T13:09:21.894824Z 0 [Warning] InnoDB: Cannot calculate statistics for table 'mysql'.'time z... the issue.
May 12 13:09:21 ip-172-31-27-208.ec2.internal docker-compose[3552]: digital_ink-db-1 | 2022-05-12T13:09:21.894850Z 0 [Warning] Can't open or lock table: Tablespace is missing fo...ithout them
May 12 13:09:22 ip-172-31-27-208.ec2.internal docker-compose[3552]: digital_ink-db-1 | 2022-05-12T13:09:22.032719Z 0 [Note] Event Scheduler: Loaded 0 events
May 12 13:09:22 ip-172-31-27-208.ec2.internal docker-compose[3552]: digital_ink-db-1 | 2022-05-12T13:09:22.032912Z 0 [Note] mysqld: ready for connections.
May 12 13:09:22 ip-172-31-27-208.ec2.internal docker-compose[3552]: digital_ink-db-1 | Version '5.7.38' socket: '/var/run/mysqld/mysqld.sock' port: 3306 MySQL Community Server (GPL)
May 12 13:09:22 ip-172-31-27-208.ec2.internal docker-compose[3552]: digital_ink-app-1 | AH00558: apache2: could not reliably determine the server's fully qualified domain name, using 172.21...his message
May 12 13:09:22 ip-172-31-27-208.ec2.internal docker-compose[3552]: digital_ink-app-1 | AH00558: apache2: could not reliably determine the server's fully qualified domain name, using 172.21...his message
May 12 13:09:22 ip-172-31-27-208.ec2.internal docker-compose[3552]: digital_ink-app-1 | [Thu May 12 13:09:22.671766 2022] [mpm_prefork:notice] [pid 1] AH00163: Apache/2.4.29 (Debian) PHP/7.0.32 (cli) (built: May 12 2022 13:09:22) (NTT)
May 12 13:09:22 ip-172-31-27-208.ec2.internal docker-compose[3552]: digital_ink-app-1 | [Thu May 12 13:09:22.672038 2022] [core:notice] [pid 1] AH00094: Command line: 'apache2 -D FOREGROUND'
Hint: Some lines were ellipsized, use -l to show in full.
[ec2-user@ip-172-31-27-208 ~] $
```

Figure 5.15: Creation of systemd Service.

Chapter 6

Simple Storage Service (S3)

AWS S3 is a form of cloud-based object storage. This is a style of network filesystem that treats each file as a separate object with a unique ID, which allows each object to be served individually over a network with a single URL, which can also be enhanced with a content delivery network (Amazon Web Services (AWS), 2022e).

Each S3 instance is separated into logical containers known as buckets. Each S3 bucket can have its own credentials, its own endpoint and other permissions and configuration. Object storage is particularly useful when creating an application that scales as you are billed per unit of storage that you use, and in theory are able to use infinite storage as your application demands. The only limitation with object storage is how much you are able to pay for. Each object is automatically replicated across many nodes, providing data redundancy against multiple different availability zones.

S3 is perhaps the most popular AWS service and used by many SaaS applications across the internet, for instance Instagram, Facebook, Discord and Twitter are all known for using S3 or S3-style storage. The advent of object storage has created an almost de-facto standard, which has led for the creation of many 'S3-compatible' or 'S3-like' competitor solutions, such as those run by Google Cloud and Microsoft Azure.

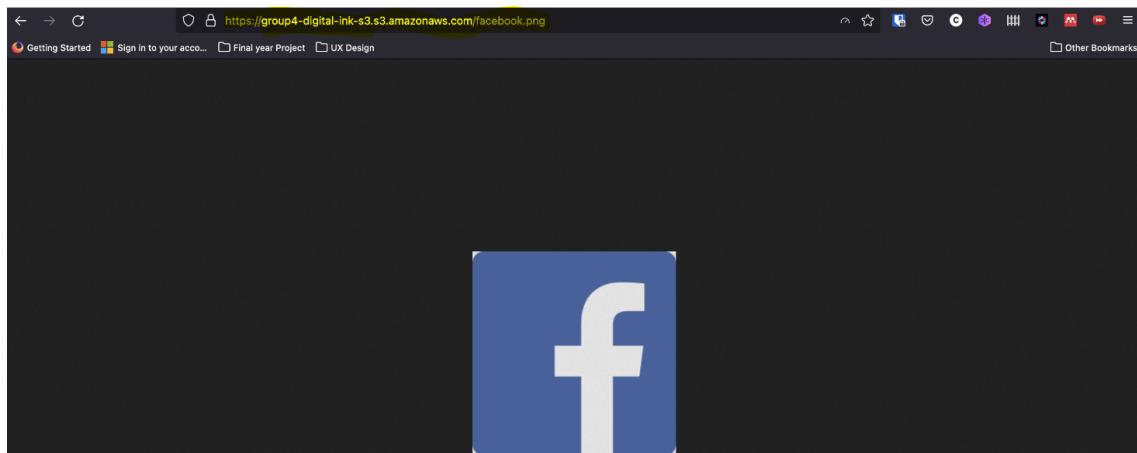


Figure 6.1: Image access through S3.

Chapter 7

CloudFront

CloudFront is a CDN which allows for the distribution of static and dynamic web images with more efficiency and availability. An international network of data centres, referred to as edge locations, are used to deliver content for CloudFront (Amazon Web Services (AWS), 2022g). An edge location which offers the lowest latency or delay in serving these files will be used. This will involve the creation of a CloudFront Distribution.

Firstly, an origin is chosen which is the S3 bucket created in Section 6. It is then given a name of `group4-digital-ink.s3.us-east-1.amazonaws.com`. The "Yes use OAI" option is selected, in order to restrict bucket access to only CloudFront. The "Bucket Policy" option is set to "Yes" to automatically update permissions on the bucket to allow read access for the OAI. These options can be seen configured in Figures 7.1 and 7.2.

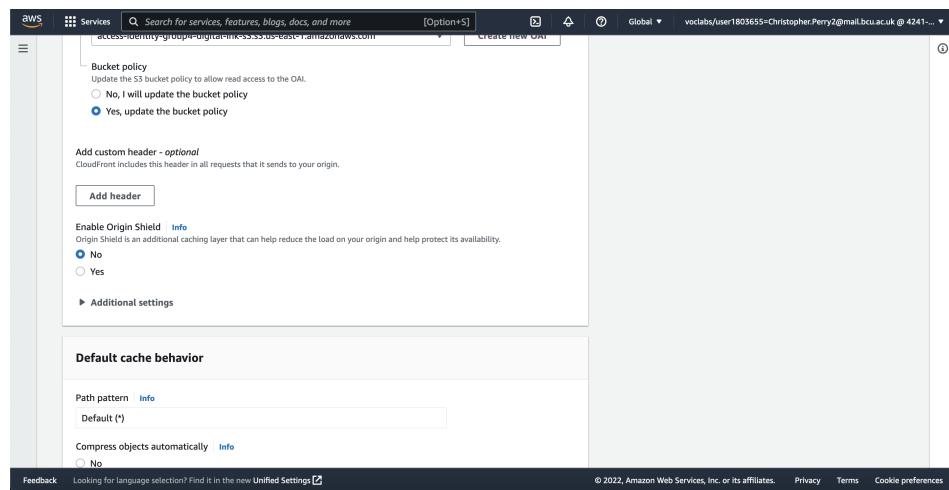


Figure 7.1: Applying CloudFront bucket policy.

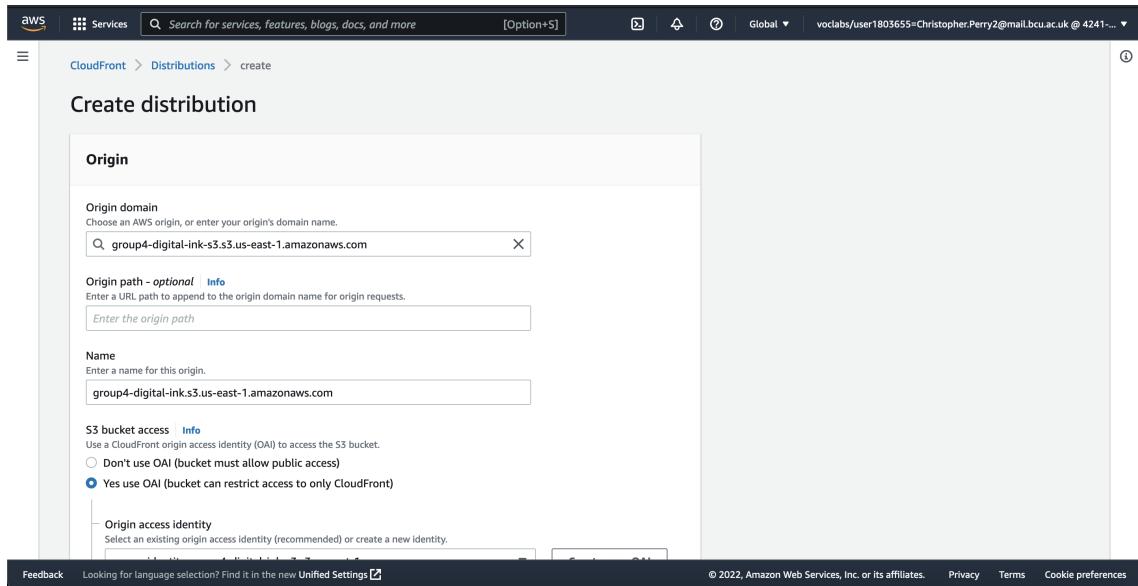


Figure 7.2: Applying CloudFront origins to S3 bucket.

Permissions are then applied to the CloudFront distribution itself. Objects are set to be compressed automatically to save space, and for viewing images, permissions are set to be in both HTTP and HTTPS, and to only allow GET and HEAD, so images can only be viewed.

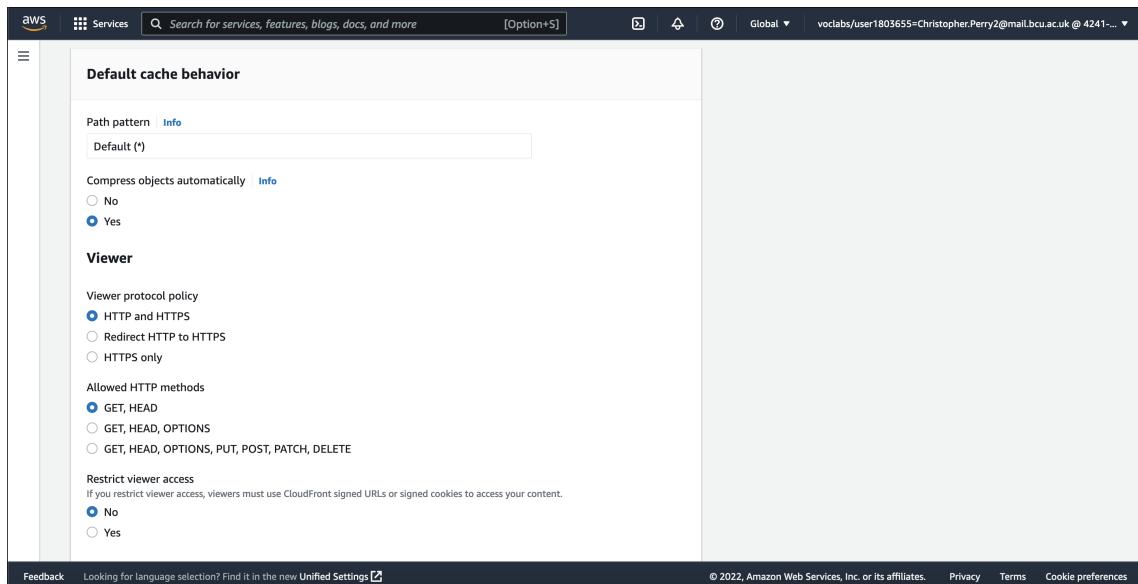


Figure 7.3: Applying CloudFront Distribution Permissions.

A cache policy and origin request policy is subsequently applied to the aforementioned permissions. The "CachingOptimized" policy is applied for compression. Origin Request policy is set to "CORS-S3Origin" in order for CORS to be automatically set up for the S3 bucket, Any GET requests are then compatible in the response headers through "SimpleCORS".

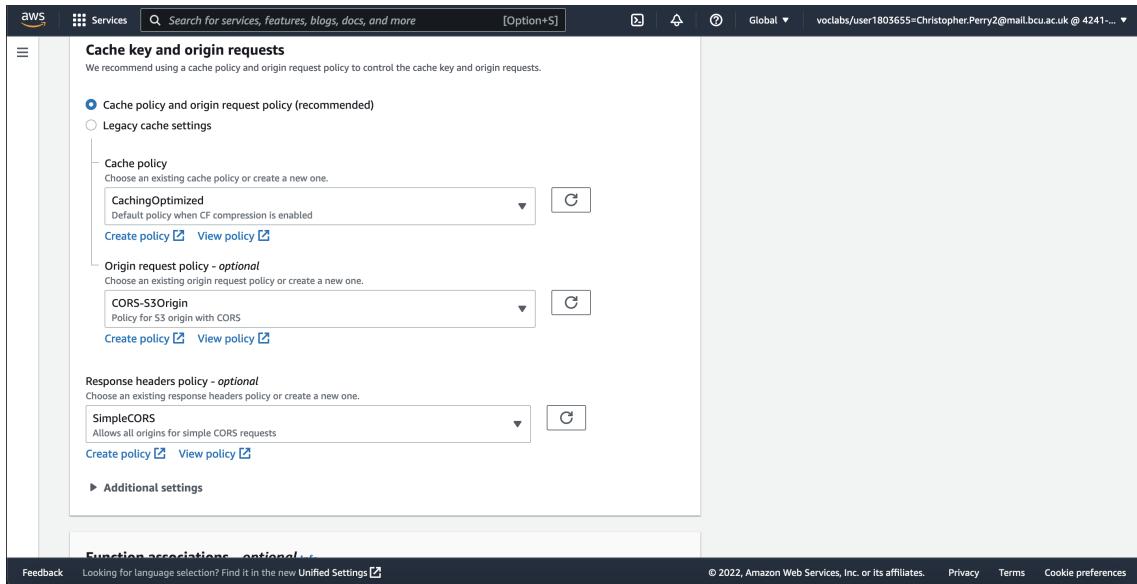


Figure 7.4: Applying CloudFront Cache Keys and Origin Requests.

No function associations are set due to the lack of CloudFront functions and Lambdas.

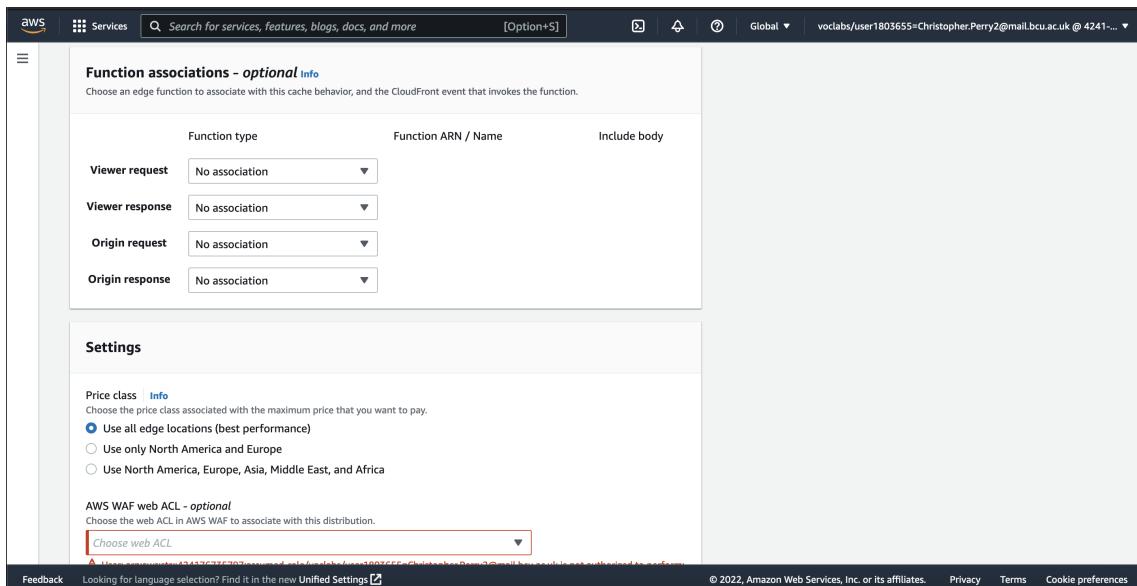


Figure 7.5: Function Association.

The settings for the CloudFront Distribution can now be set. In order to ensure high availability, the option "Use all edge locations" is selected, so that images can be distributed to the user from the closest edge location in relation to their IP address. No ACL can be added to the WAF due to permissions issues, and a SSL Certificate cannot be set as the web app is not being served from the internet. For logging purposes "Standard Logging" is set to "On", and logs are saved to the same S3 bucket. Cookie logging is enabled, and IPv6 is set to "On", to allow for more IP addresses to access the CloudFront Distributed content. These settings can be found in Figure 7.6.

The screenshot shows the AWS CloudFront Settings page. At the top, there's a note about associating a certificate from AWS Certificate Manager. Below it, there are sections for Price class (set to 'Use all edge locations'), AWS WAF web ACL (with a warning message), Alternate domain name (CNAME), and Custom SSL certificate (disabled). The main focus is on the Logging section, which includes:

- Default root object - optional:** A text input field for specifying the root object.
- Standard logging:** A section where 'On' is selected for 'Get logs of viewer requests delivered to an Amazon S3 bucket.'
- S3 bucket:** A dropdown menu showing 'group4-digital-link-s3.s3.amazonaws.com'.
- Log prefix - optional:** An input field for adding a log prefix.
- Cookie logging:** A section where 'On' is selected for 'When this is On, CloudFront includes cookies in the standard logs.'
- IPv6:** A section where 'On' is selected for 'When this is On, CloudFront uses IPv6 addresses to serve content.'
- Description - optional:** A text input field for providing a description.

At the bottom right, there are 'Cancel' and 'Create distribution' buttons.

Figure 7.6: Applying CloudFront settings.

A CloudFront Distribution has now been created, and can be found in Figure 7.7.

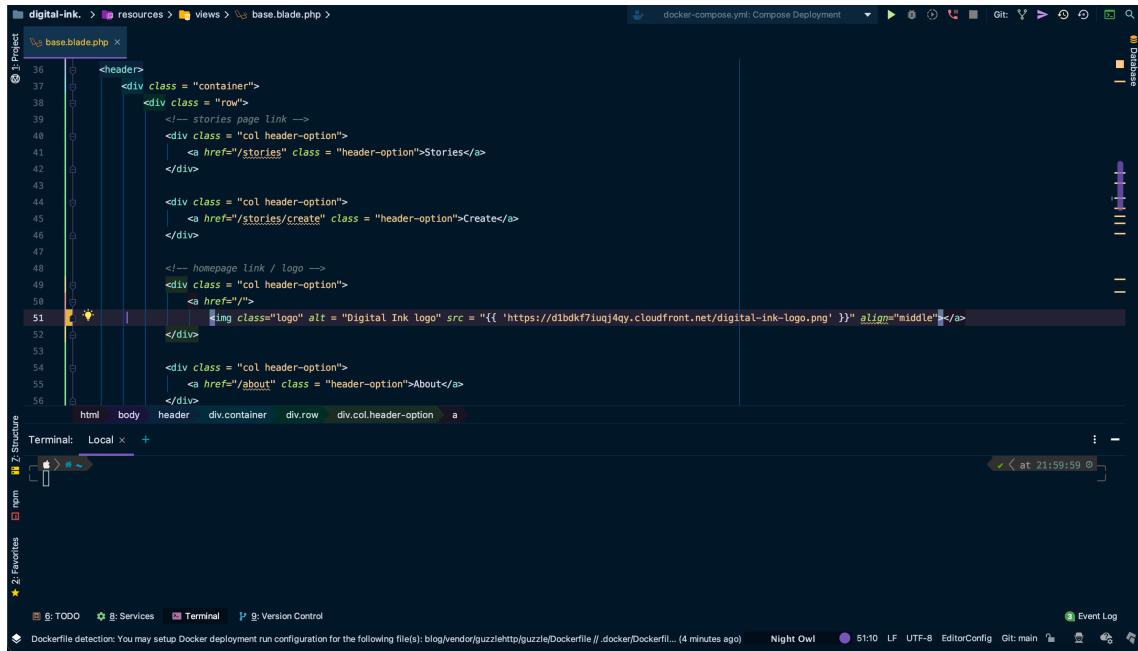
The screenshot shows the AWS CloudFront Distributions page. On the left, there's a sidebar with various navigation options like Policies, Functions, Telemetry, Reports & analytics, Security, and Key management. The main area displays a table titled 'Distributions (1) Info'. The table has columns for ID, Description, Domain name, Alternate domain..., and Origins. There is one entry: ID is E21BWNC9VESEB5, Domain name is d1bdkf7iuqj4qy.cloudfront.net, and the Origin is group4-di. At the top right of the table, there are buttons for 'Create distribution' (highlighted in orange), 'Enable', 'Disable', and 'Delete'. Below the table, there are pagination controls (1 of 1) and a refresh icon.

Figure 7.7: Created CloudFront Distribution.

Finally, the images contained within the webserver were changed from their local location to their relevant CloudFront locations. This change can be seen in Figures 7.8 and 7.9.

The screenshot shows a code editor with a dark theme. The file being edited is 'base.blade.php' under the 'resources/views' directory. The code is a Blade template with PHP syntax. On line 51, there is a line of code that includes an image tag: ``. The 'src' attribute contains a local file path. The code editor interface includes a top bar with tabs for 'docker-compose.yml - Compose Deployment', a terminal tab at the bottom, and a status bar at the bottom right.

Figure 7.8: Image location before CloudFront.



A screenshot of a code editor (Visual Studio Code) showing a file named `base.blade.php`. The code is a template for a header section. At line 51, there is a line of HTML containing a `img` tag with a source URL: `src = "{{ 'https://d1bdkf7iuqj4qy.cloudfront.net/digital-ink-logo.png' }}"`. This URL is a CloudFront distribution endpoint. The editor interface includes a sidebar with project files, a terminal tab at the bottom, and various status icons at the bottom right.

Figure 7.9: Image location after CloudFront.

As seen in the URL shown within Figure 7.10, the Digital Ink logo image is now hosted on CloudFront.

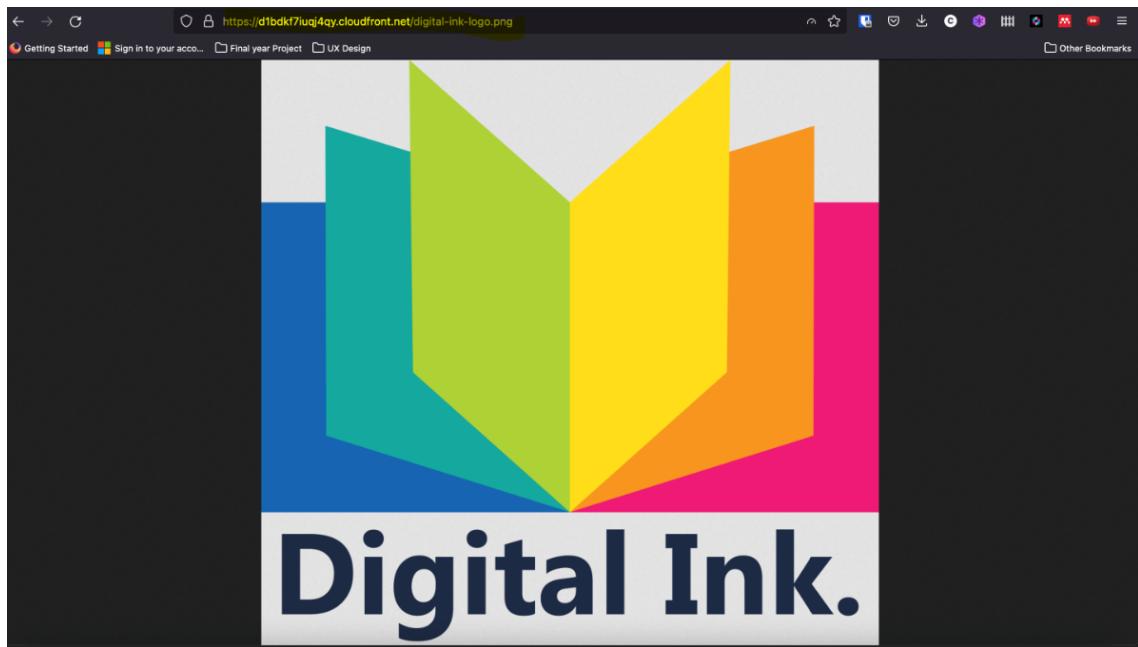


Figure 7.10: Image location after CloudFront.

Chapter 8

CloudWatch

Amazon CloudWatch is a monitoring and observation tool which can provide developers with insights to monitor applications, react to performance changes, and optimise resource consumption. CloudWatch collects monitoring and operational data about the application as logs and metrics to provide a complete overview of operation health, resource consumption, and the services currently running on AWS. This is useful for any cloud-based application as it allows developers to set alarms, visualise metric logs, troubleshoot errors and, most importantly, identify and correct anomalous behaviour (Amazon Web Services (AWS), 2022a).

An example of CloudWatch usage would be an alarm set to alert developers when a specified resource consumption level is over a certain threshold. For the purposes of the project, multiple CloudWatch alarms will be set up which will allow monitoring for budgeting and performance across the various AWS services used.

The first alarm which will be set up is a network alarm. Through selecting the NetworkPacketsOut metric on the Group4_EC2 instance, the packets which are being outputted can be monitored.

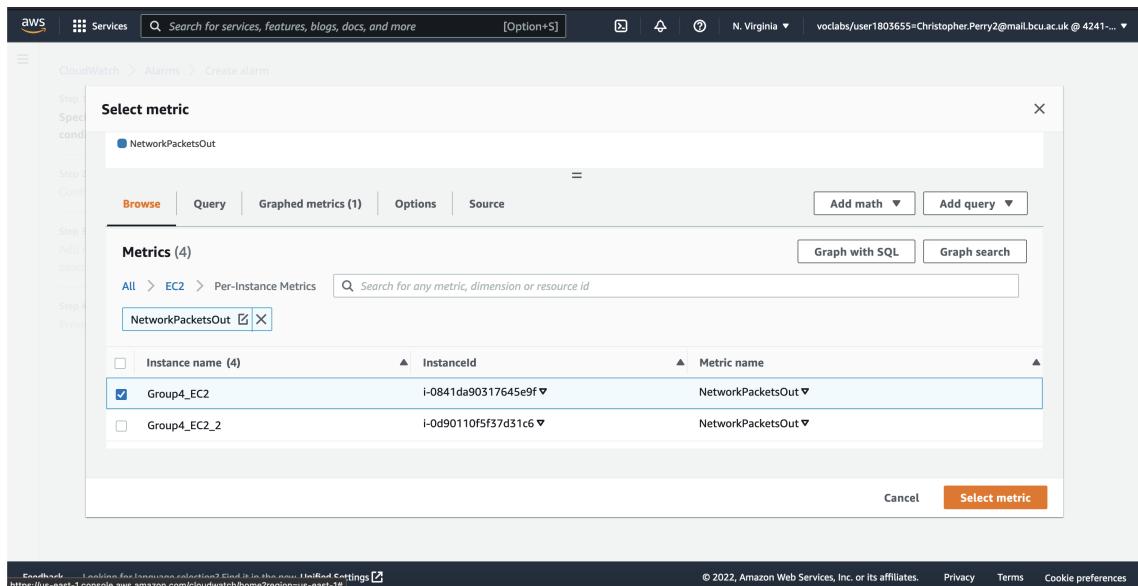


Figure 8.1: Selection of CloudWatch metric for EC2 instance.

The metric will be configured to alarm in the event that there is less than 5 packets of data sent per day from the instance. As the instance currently outputs nearly, 30,000 packets per day, this will be useful to check if the web app has failed. Figure 8.2 details the alarm being configured to activate an alarm when the sum of packets sent is less than 5 per day.

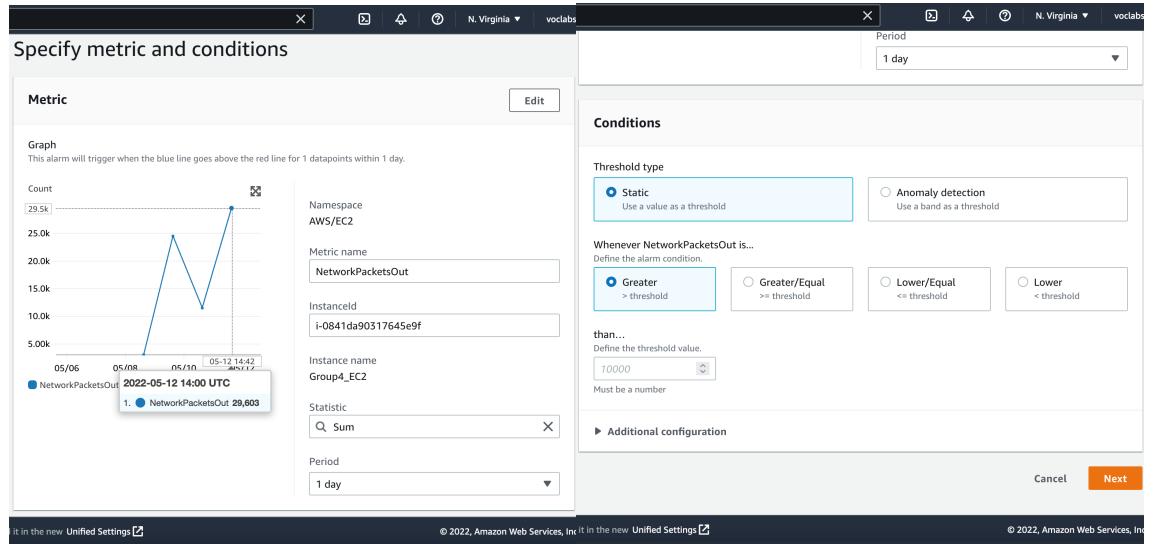


Figure 8.2: Configuration of NetworkPacketsOut Metric.

In addition to the initial configuration of these CloudWatch alarms, SNS topics will also be set up so that every member of the group will be emailed in the event that the alarms activate. Figure 8.3 details this process.

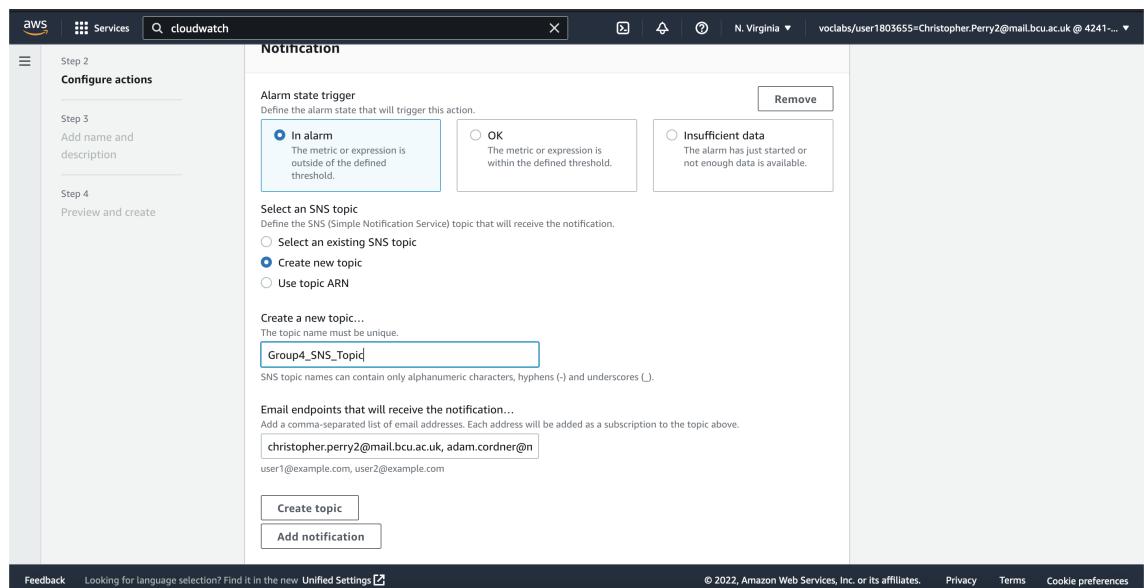


Figure 8.3: Configuration of SNS Topic for email alerts on alarm activation.

An email was then sent to all group members upon completion of this form, and the SNS topic was subsequently subscribed to, as shown in Figures 8.4 and 8.5.

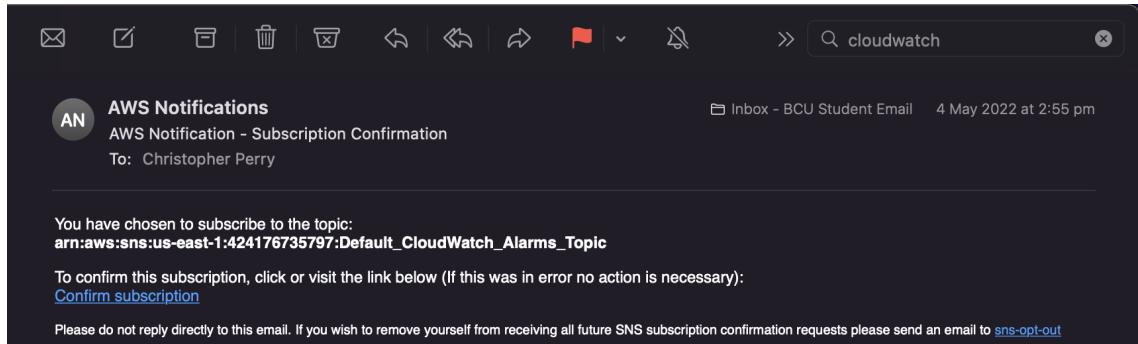


Figure 8.4: CloudWatch SNS Topic Email.

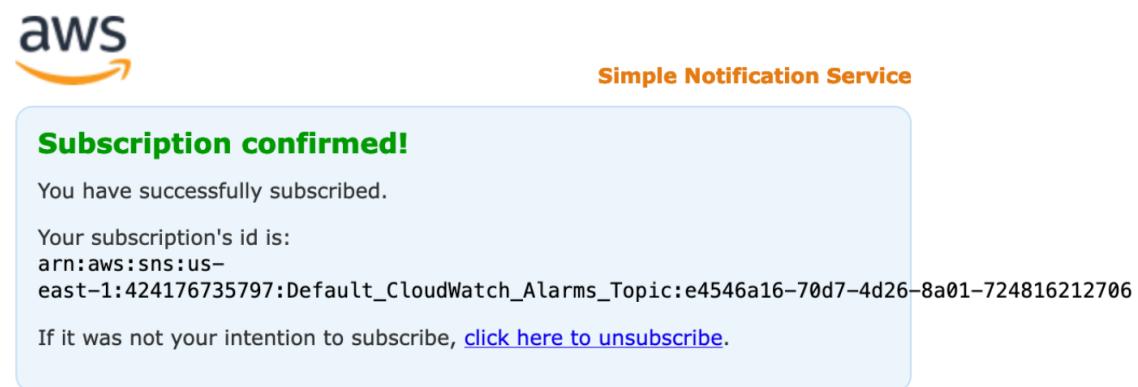


Figure 8.5: Successful subscription to SNS topic.

The EC2 instance has also been configured to restart when this alarm activates. This is done by automatically re-running the scripts used to start the web app on the instance starting up again. This process can be seen in Figure 8.6.

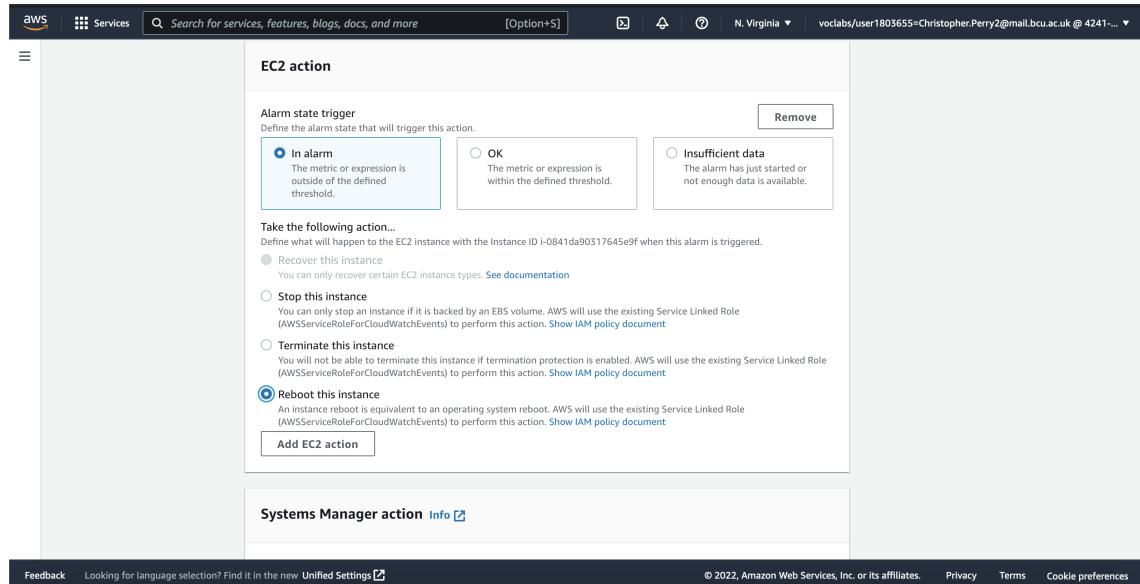


Figure 8.6: Configuration for EC2 instance to reboot on alarm activation.

A brief description of the CloudWatch alarm is then added. This can be seen in Figure 8.7.

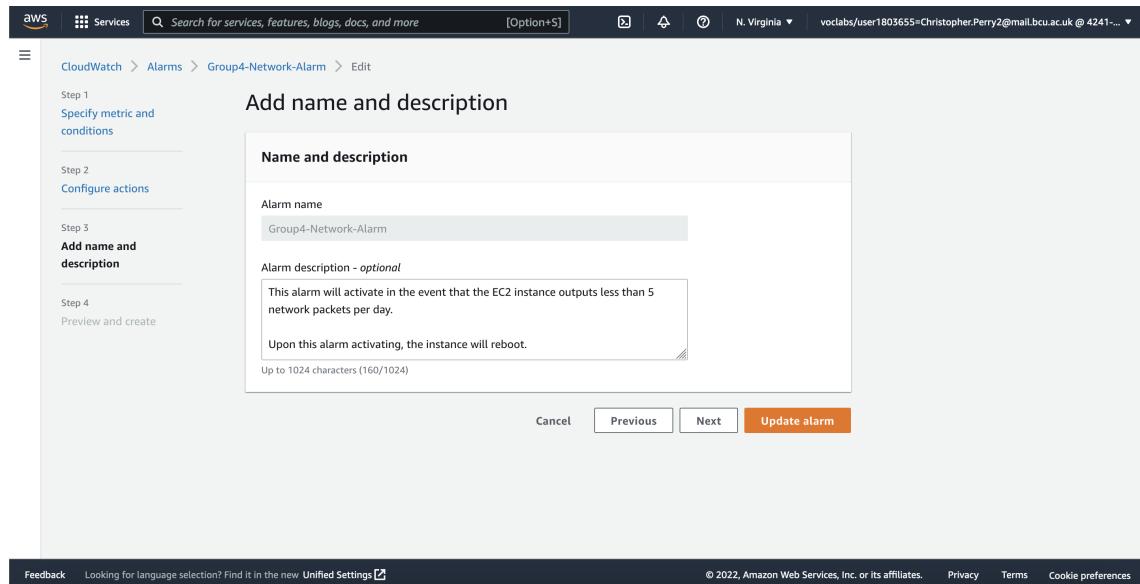


Figure 8.7: CloudWatch alarm description.

The alarm has now been set up, and can be seen in the CloudWatch Management Dashboard in Figure 8.8.

Name	State	Last state update	Conditions	Actions
TargetTracking-Group4_Autoscaling-AlarmLow-1bf16ad3-6492-4fbdbcaf-2aeeca339a99f	Insufficient data	2022-05-10 16:35:28	CPUUtilization < 35 for 15 datapoints within 15 minutes	<input checked="" type="checkbox"/> Actions enabled
TargetTracking-Group4_Autoscaling-AlarmHigh-b425c0a0-72d0-42b8-80e6-912c8518c54b	Insufficient data	2022-05-10 16:23:11	CPUUtilization > 50 for 3 datapoints within 3 minutes	<input checked="" type="checkbox"/> Actions enabled
Group4-Network-Alarm	OK	2022-05-10 13:34:43	NetworkPacketsOut <= 5 for 1 datapoints within 1 day	<input checked="" type="checkbox"/> Actions enabled
Group4-Charges-Alarm	In alarm	2022-05-10 13:22:36	EstimatedCharges > 1 for 1 datapoints within 6 hours	<input checked="" type="checkbox"/> Actions enabled

Figure 8.8: CloudWatch network alarm in dashboard.

In addition to the created network alarm, a charges alarm will also be set up. A similar process is followed whereby the metric of EstimatedCharges is applied to all AmazonEC2 instances, as detailed in Figure 8.9.

All	Billing	By Service
AmazonEC2		

Figure 8.9: Selection of EstimatedCharges CloudWatch metric.

This metric will be configured to alarm in the event that the EC2 instance uses more than \$15 every 6 hours. This process can be seen in Figures 8.10 and 8.11.

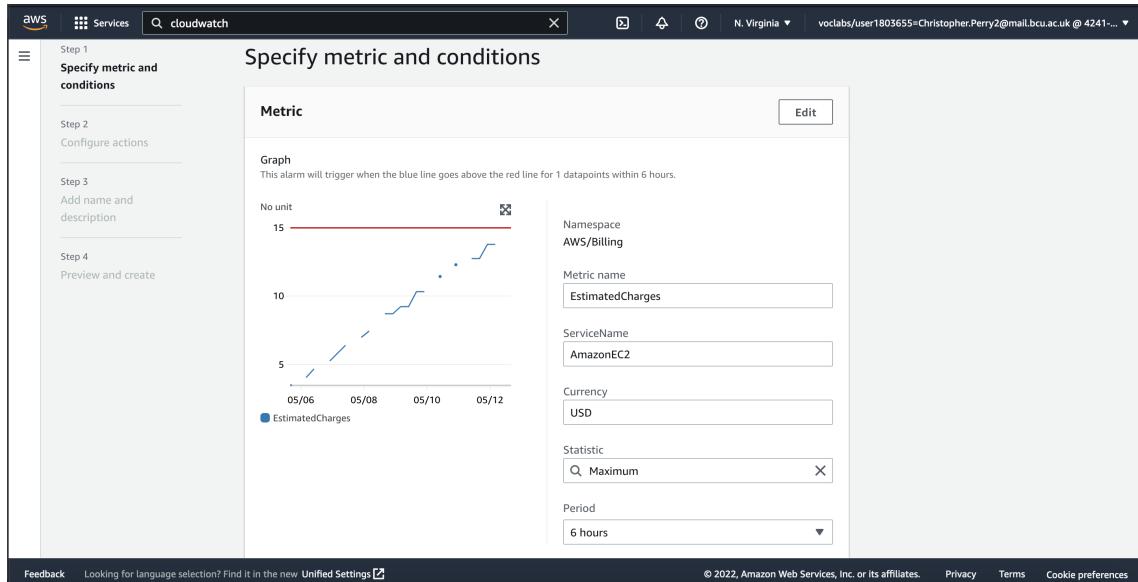


Figure 8.10: Configuration of CloudWatch alarm.

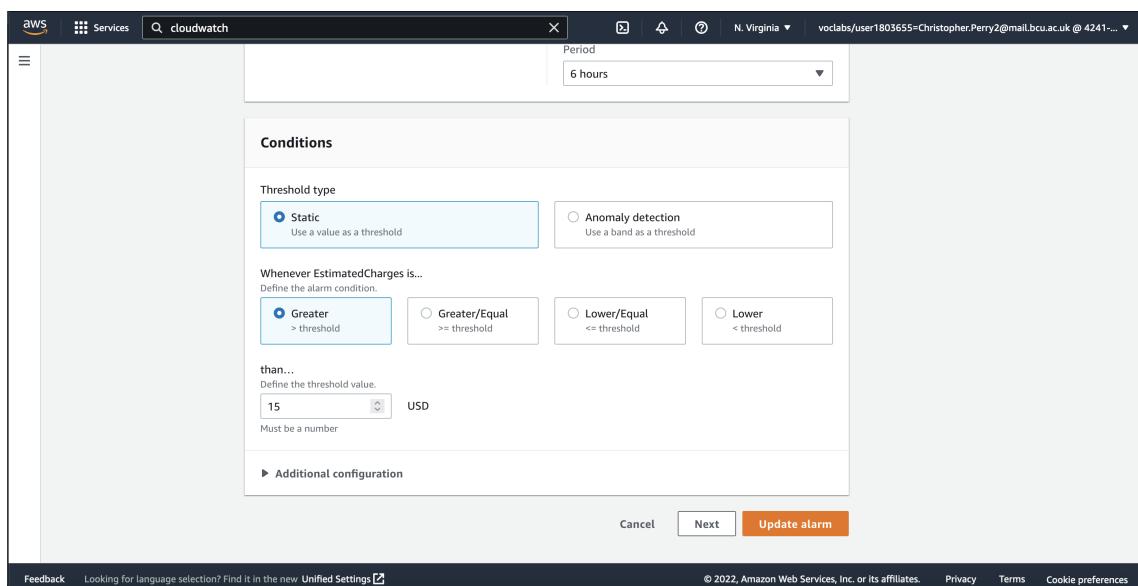


Figure 8.11: Configuration of CloudWatch alarm.

In addition to this, alerts will be sent to the same SNS topic configured earlier. This can be seen in Figure 8.12.

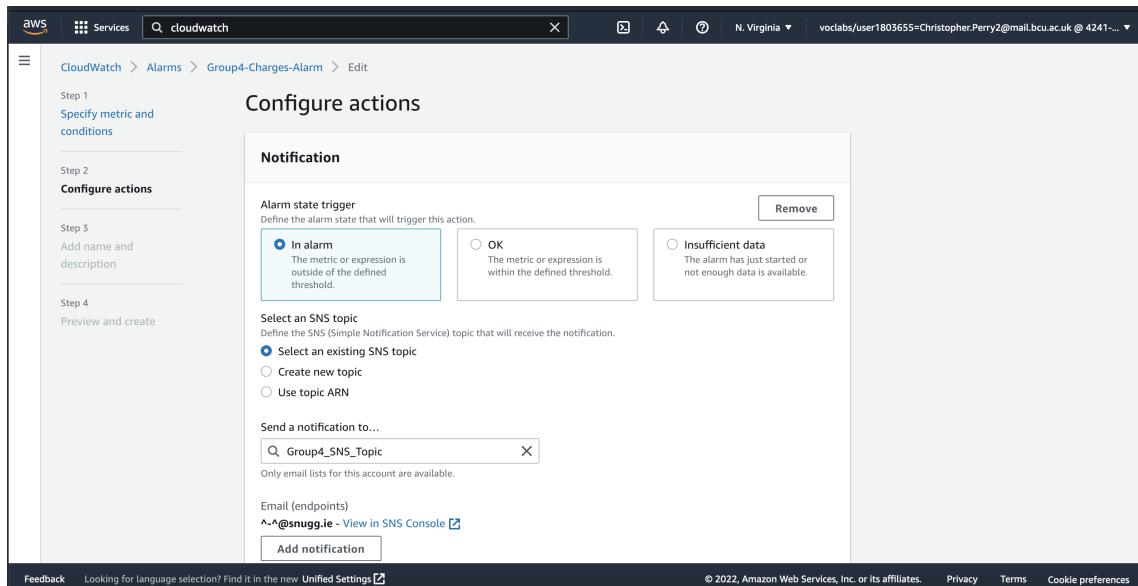


Figure 8.12: Setting CloudWatch charges SNS topic

A brief description was added to the alarm, as seen in Figure 8.13.

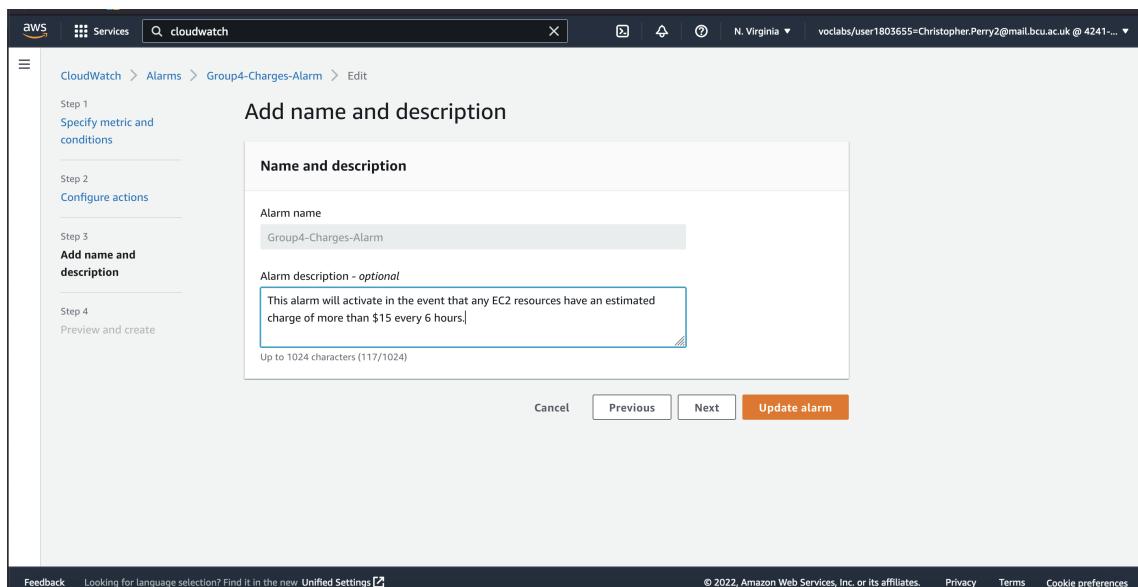


Figure 8.13: Description of CloudWatch alarm.

The alarm is now live and can be seen in Figure 8.14.

Name	State	Last state update	Conditions	Actions
Group4-Charges-Alarm	OK	2022-05-13 16:54:29	EstimatedCharges > 15 for 1 datapoints within 6 hours	Actions enabled
TargetTracking-Group4_Autoscaling-AlarmLow	Insufficient data	2022-05-10 16:35:28	CPUUtilization < 35 for 15 datapoints within 15 minutes	Actions enabled
TargetTracking-Group4_Autoscaling-AlarmHigh	Insufficient data	2022-05-10 16:23:11	CPUUtilization > 50 for 3 datapoints within 3 minutes	Actions enabled
Group4-Network-Alarm	OK	2022-05-10 13:34:43	NetworkPacketsOut <= 5 for 1 datapoints within 1 day	Actions enabled

Figure 8.14: CloudWatch charges alarm live in CloudWatch dashboard.

An example of an email generated by the CloudWatch charges alarm can be seen in Figure 8.15.

ALARM: "Group4-Charges-Alarm" in US East (N. Virginia)

AWS Notifications to ^~@snugg.ie [Show details](#) 10 May (4 days ago)

Inbox [Reply to all](#) Actions

You are receiving this email because your AmazonEC2 estimated charges are greater than the limit you set for the alarm "Group4-Charges-Alarm" in AWS Account 424176735797.

The alarm limit you set was \$ 1.00 USD. Your total estimated charges accrued for this billing period are currently \$ 9.26 USD as of Tuesday 10 May, 2022 12:22:36 UTC. The actual charges you will be billed in this statement period may differ from the charges shown on this notification. For more information, view your estimated bill at: <https://us-east-1.console.aws.amazon.com/billing/home#/bill?year=2022&month=5>

More details about this alarm are provided below:

Amazon CloudWatch Alarm "Group4-Charges-Alarm" in the US East (N. Virginia) region has entered the ALARM state, because "Threshold Crossed: 1 out of the last 1 datapoints [9.26 (10/05/22 06:22:00)] was greater than the threshold (1.0) (minimum 1 datapoint for OK -> ALARM transition)" at "Tuesday 10 May, 2022 12:22:36 UTC".

View this alarm in the AWS Management Console:
<https://us-east-1.console.aws.amazon.com/cloudwatch/deeplink.js?region=us-east-1#alarmsV2:alarm/Group4-Charges-Alarm>

Alarm Details:

- Name: Group4-Charges-Alarm
- Description:
- State Change: INSUFFICIENT_DATA -> ALARM
- Reason for State Change: Threshold Crossed: 1 out of the last 1 datapoints [9.26 (10/05/22 06:22:00)] was greater than the threshold (1.0) (minimum 1 datapoint for OK -> ALARM transition).
- Timestamp: Tuesday 10 May, 2022 12:22:36 UTC
- AWS Account: 424176735797
- Alarm Arn: arn:aws:cloudwatch:us-east-1:424176735797:alarm:Group4-Charges-Alarm

Figure 8.15: CloudWatch alarm example.

Chapter 9

CloudTrail

The use of CloudTrail will allow for logging across the project. This will give the group control over storage, analysis and any remediation actions. Visibility of AWS account activity is a recommended AWS security best practice (Amazon Web Services (AWS), 2022j).

CloudTrail will be enabled for any changes which occur within the project's S3 bucket and RDS instances. The CloudTrail is first given the name of Group4-CloudTrail. A location for the logs that CloudTrail outputs is required, so the S3 bucket created in Chapter 6 is selected as the storage location. The "Log file SSE-KMS encryption" option is Enabled, which encrypts the log files that are generated, heightening security. A KMS is required to encrypt this data, and a new one is created and named Group4-kms. These options can be seen in Figure 9.1.

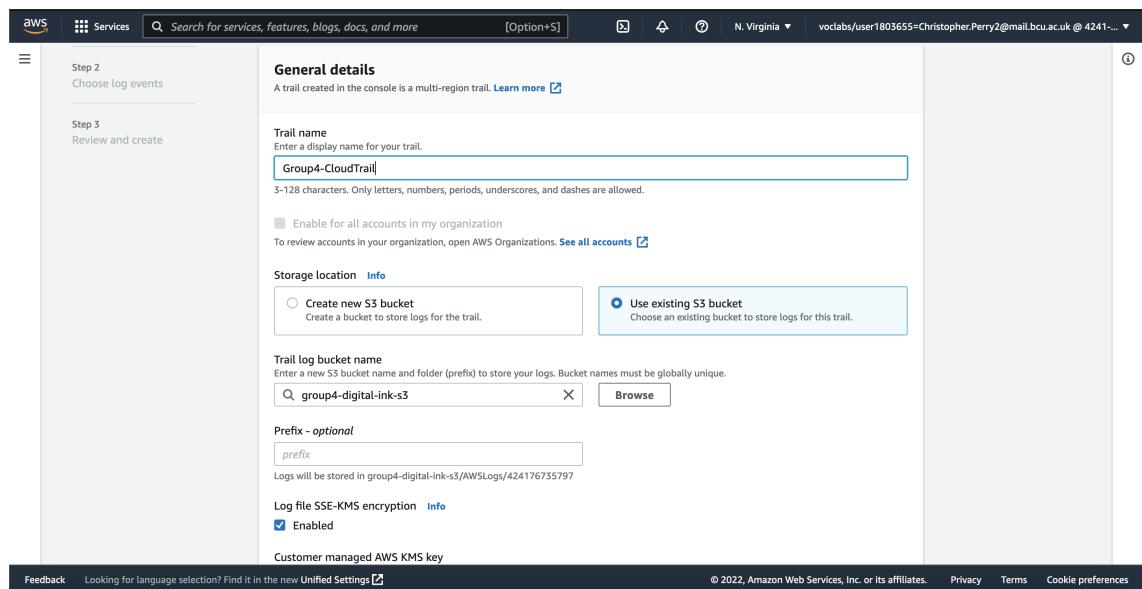


Figure 9.1: Initial CloudTrail set up.

The "Log file validation" option is selected, which ensures that any changes which have been made to the log file that are not from CloudTrail directly are notified to the group. These aforementioned notifications have been set up through the creation of new SNS topic called Group4-cloudtrail-sns. These options can be seen in Figure 9.2.

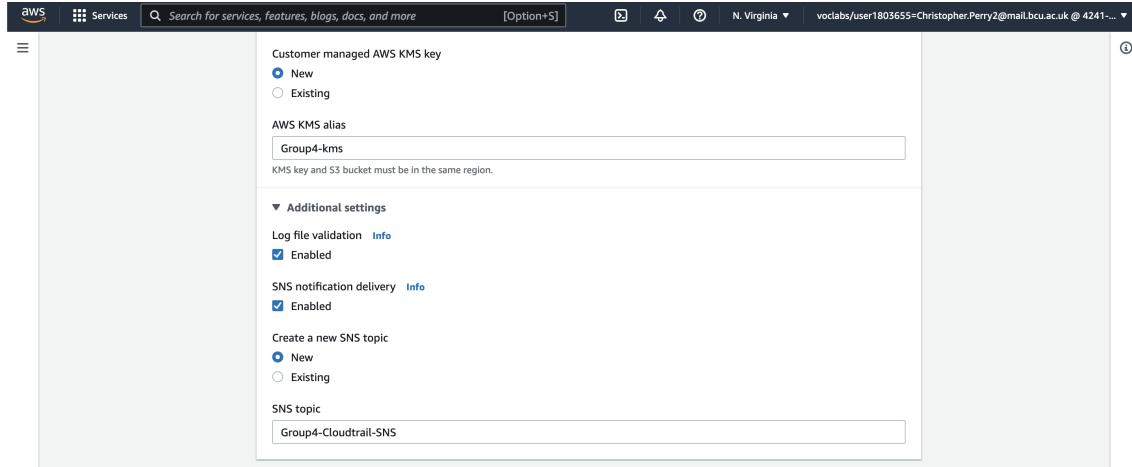


Figure 9.2: Initial CloudTrail set up.

Now that the CloudTrail initial setup is complete, the selection of the specific events which will be monitored can be configured. "Management Events" is firstly selected - this will allow for any read or write events which have been applied on the S3 and RDS services to be logged. In addition to this, "Insights Events" is also enabled, which will allow for any unusual activity on these services to also be logged through the use of the API Call Rate and Error Rate - If they are high, this will be logged via CloudTrail. which is of a security benefit to the project. These settings can be seen configured in Figure 9.3.

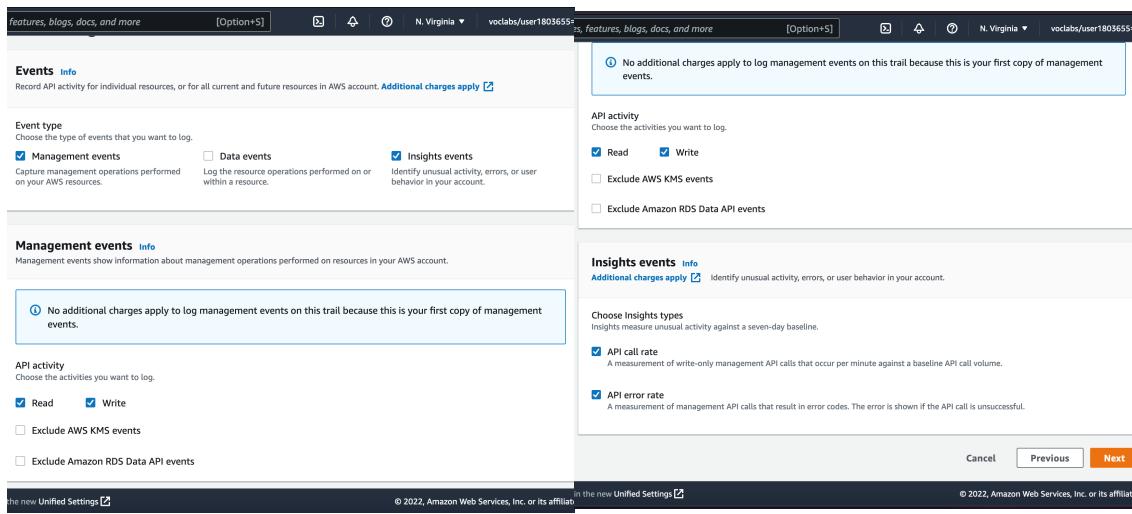


Figure 9.3: Configuring CloudTrail events.

The CloudTrail has now been added and is now monitoring for any activity. This can be seen in Figure 9.4.

The screenshot shows the AWS CloudTrail service page. In the left sidebar, under the 'Trails' section, there is a single entry: 'Group4-CloudTrail'. The main pane displays a table titled 'Trails' with the following data:

Name	Home region	Multiregion trail	Insights	Organization trail	S3 bucket	Log file prefix	CloudWatch Logs log group	Status
Group4-CloudTrail	US East (N. Virginia)	Yes	Enabled	No	group4-digital-link-s3	arn:aws:logs:us-east-1:424176735797:log-group:aws-cloudtrail-logs-424176735797-3eb99faf:*	Logging	

Figure 9.4: Added CloudTrail instance.

Like with CloudWatch, all users in the SNS topic receive a confirmation email once it has been set up. This can be seen in Figure 9.5.

The screenshot shows an AWS Notification Message window. The subject is 'AWS Notifications' and the recipient is '^-^@snugg.ie'. The message content is as follows:

CloudTrail validation message.

--

If you wish to stop receiving notifications from this topic, please click or visit the link below to unsubscribe:
https://sns.us-east-1.amazonaws.com/unsubscribe.html?SubscriptionArn=arn:aws:sns:us-east-1:424176735797:Group4_SNS_Topic:9a4b8555-3523-458f-871d-10e69138fd02&Endpoint=-^-@snugg.ie

Please do not reply directly to this email. If you have any questions or comments regarding this email, please contact us at <https://aws.amazon.com/support>

At the bottom, there are buttons for 'Reply to all', 'Reply to sender', and 'Forward'.

Figure 9.5: CloudTrail validation message.

Chapter 10

Relational Database Service (RDS)

Amazon RDS service allows a user to create a fully-featured and highly-available SQL database that is automatically replicated to another availability zone. (TODO: Oops, no multi-az) This means that if the primary database becomes unavailable, there is automatic failover providing redundancy for all the data stored within.

To create an Amazon RDS instance, a suitable name/identifier for the database is required before created as well as a selection for the resource limits for the virtual server. The database requires a username and passphrase, although for additional security there is the option to automatically generate a passphrase.

Afterwards, the type of SQL database required (such as MySQL, PostgreSQL, MariaDB or others) will be selected and then the database should begin provisioning.

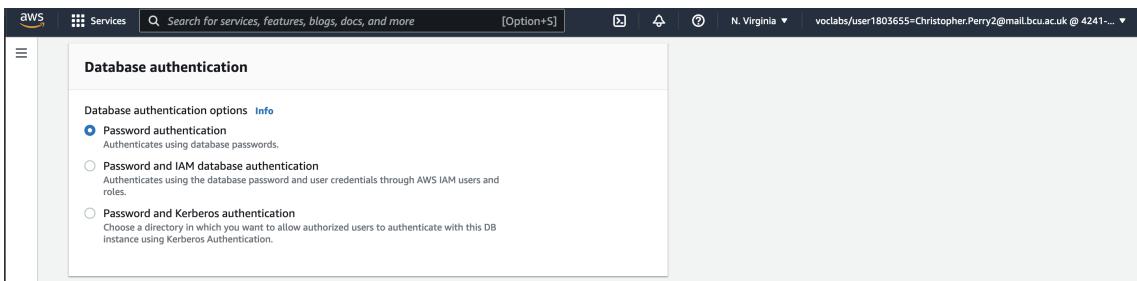


Figure 10.1: Selection of RDS Authentication Option.

Password authentication was used for the RDS instance as we did not have permission from the root user to create IAM roles within this lab environment. In the future, it would be recommended to select one of the other options to improve security, however this was not possible for the project.

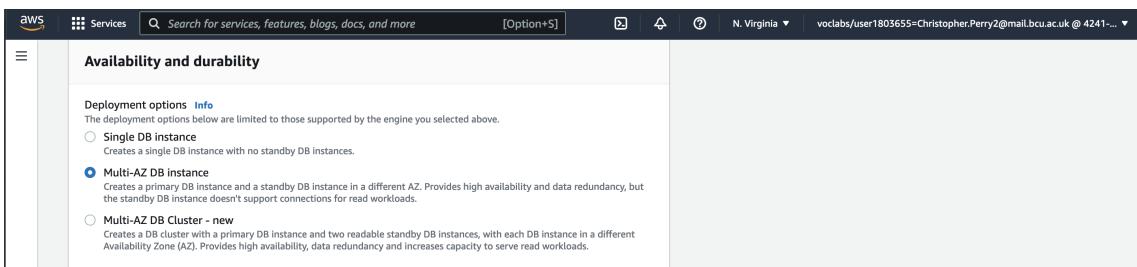


Figure 10.2: Selection RDS Multiple Availability Zone.

Multiple availability zones were selected to ensure that the database was highly available.

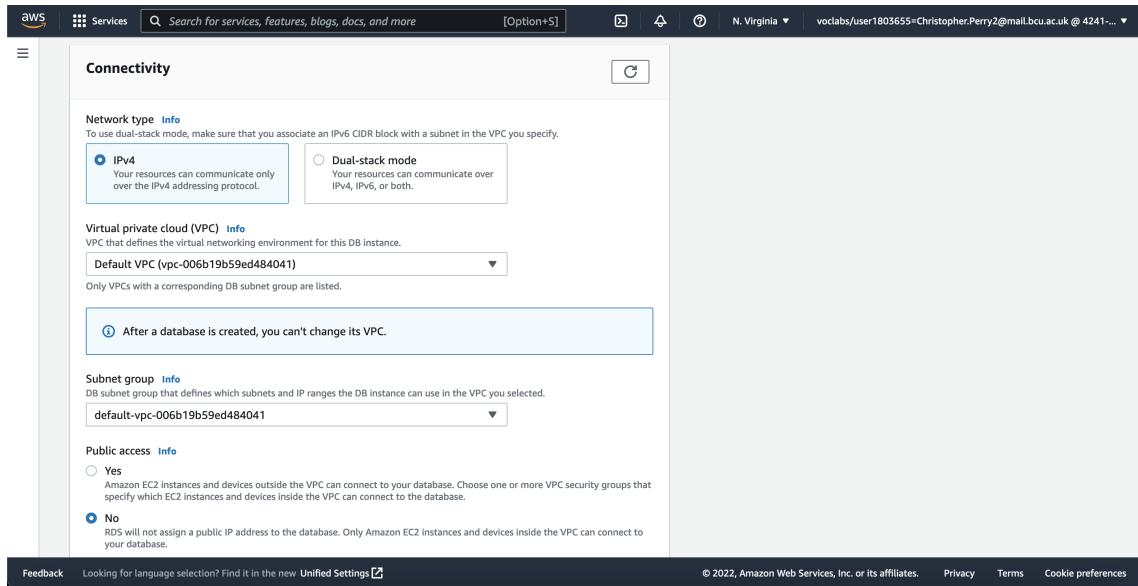


Figure 10.3: Selection of VPC and Subnet Groups.

Public access was turned off to further increase our application's security.

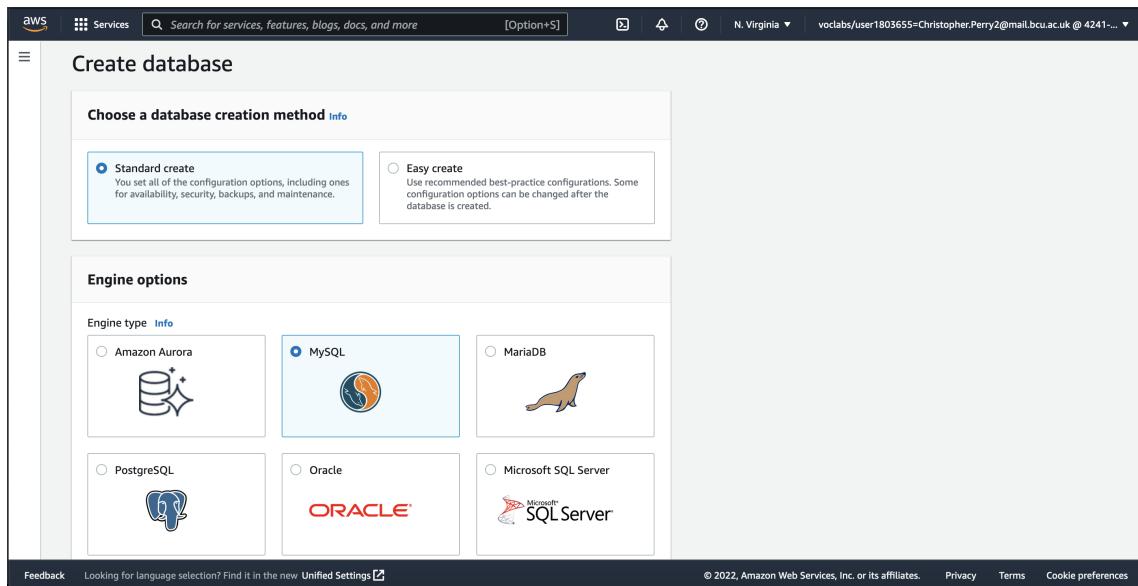


Figure 10.4: Selection of Database Engine.

A micro-sized instance was selected as we must save on AWS billing credit.

This is the estimated cost of the RDS instance for a month.

We selected an automatically generated password to ensure that it was created with current best security practices.

A selection of how much storage the RDS instance is able to access should be made. We decided that, due to billing constraints, we should go as small as possible but with

```

ec2-user@ip-10-0-0-184:~/digital-ink
..sktop/Keypair (-zsh)  *1   ec2-user@ip-10-0-0-184:~/digital-ink (ssh)  *2 + 
[ec2-user@ip-10-0-0-184 digital-ink]$ mysql -h group-4-rds.cc0ktyy6s5rq.us-east-1.rds.amazonaws.com -u admin -pCS
ZukGIA3i82H4suL2V4
Welcome to the MariaDB monitor.  Commands end with ; or \g.
Your MySQL connection id is 23
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 group4_db;
Query OK, 1 row affected (0.01 sec)

MySQL [(none)]> SHOW DATABASES;
+-----+
| Database |
+-----+
| group4_db |
| information_schema |
| mysql |
| performance_schema |
| sys |
+-----+
5 rows in set (0.00 sec)

MySQL [(none)]>

```

Figure 10.5: Selection of CloudWatch metric for EC2 instance.

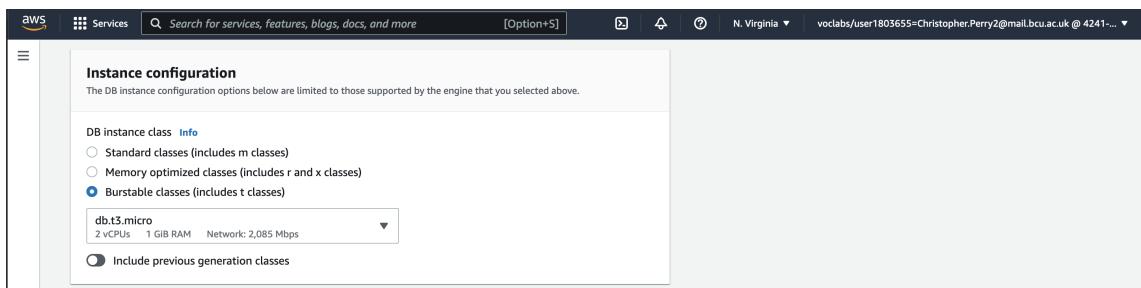


Figure 10.6: Selection of RDS Instance Size.

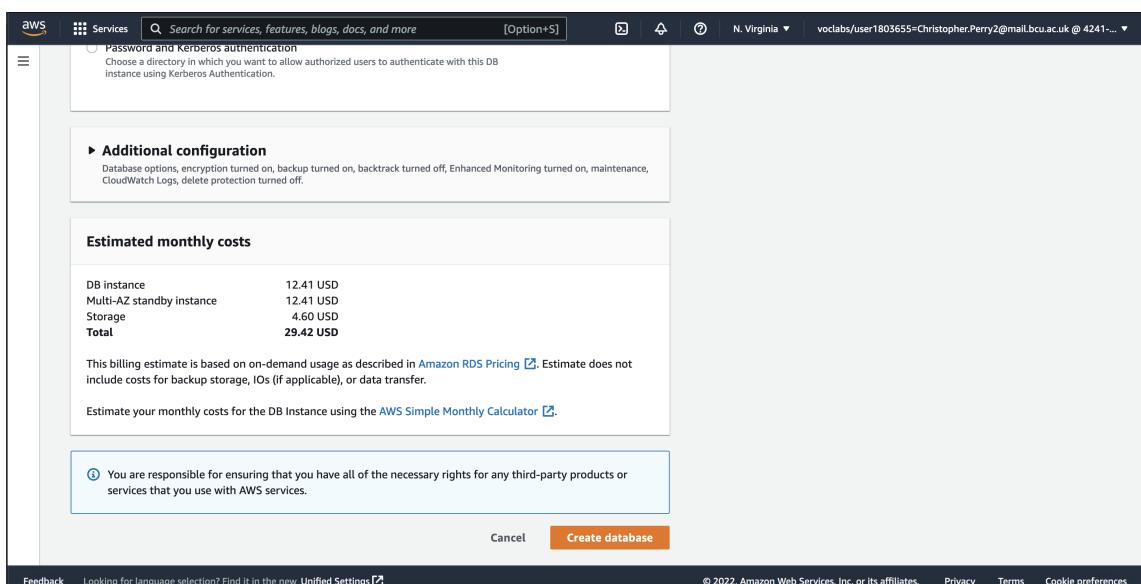


Figure 10.7: Estimated Monthly RDS Cost.

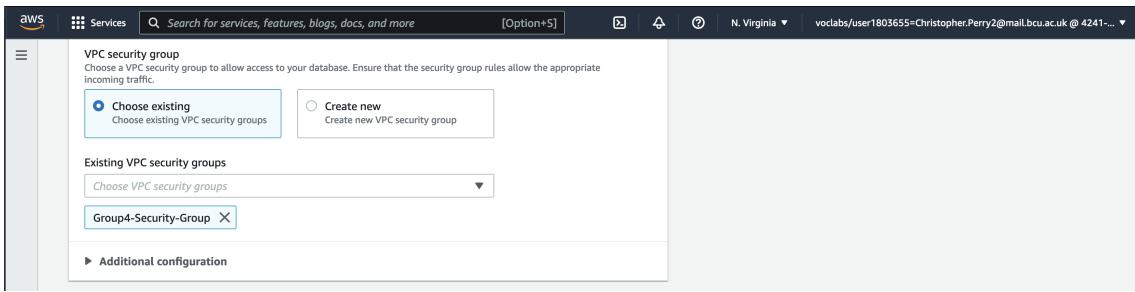


Figure 10.8: Selection RDS Security Group.

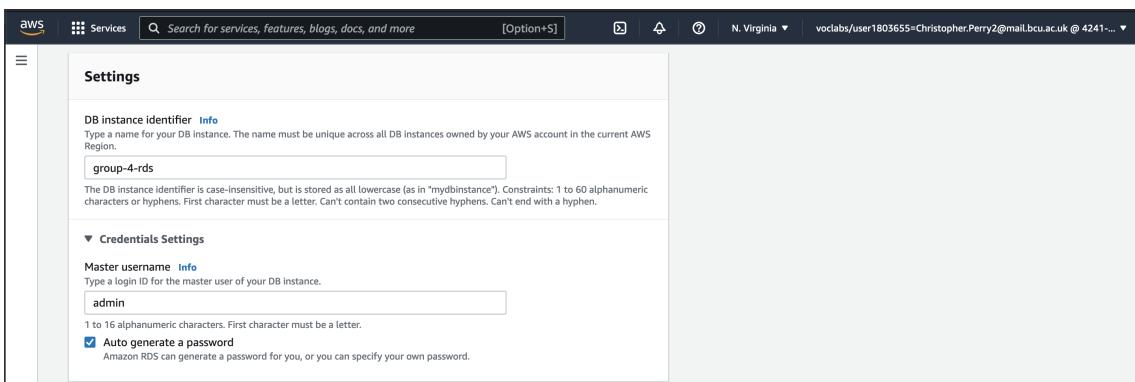


Figure 10.9: Credentials for RDS Authentication.

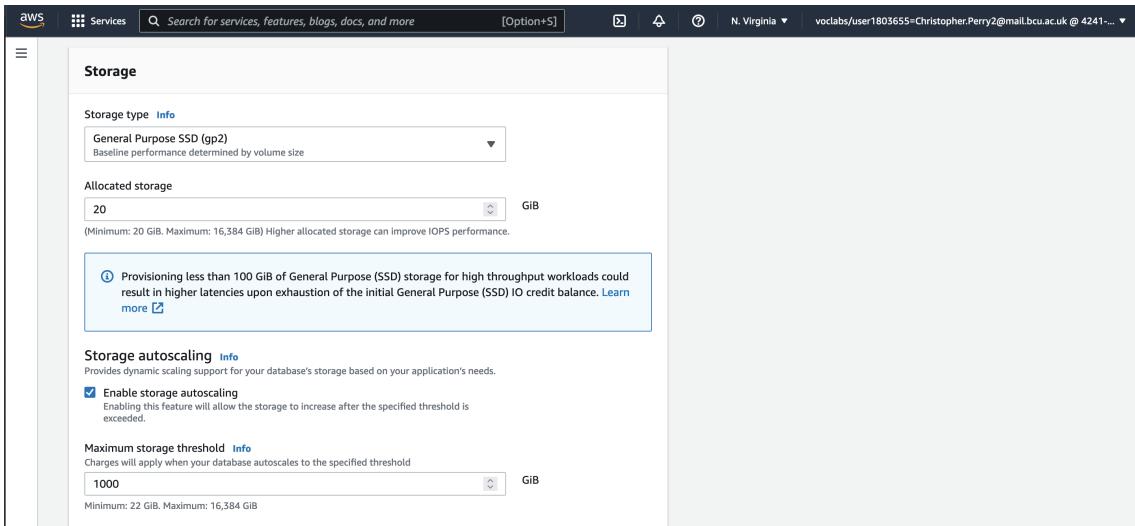
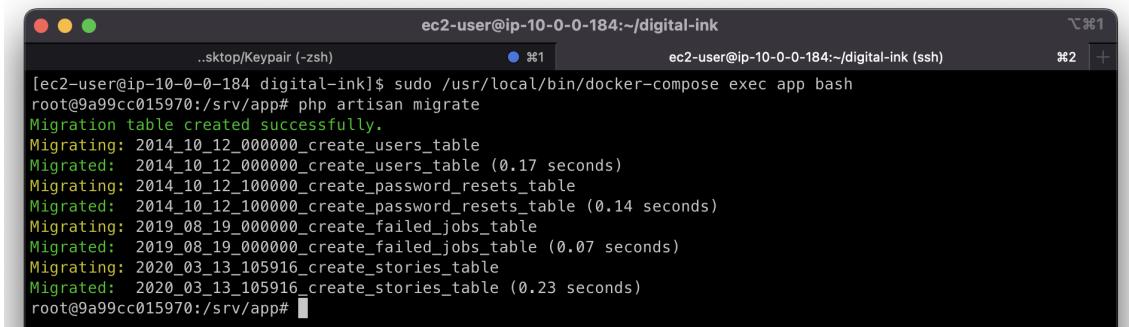


Figure 10.10: Selection of Storage Parameters.

size to automatically grow if the application was presented with more users.



```
ec2-user@ip-10-0-0-184:~/digital-ink
..sktop/Keypair (~zsh) ● %1 ec2-user@ip-10-0-0-184:~/digital-ink (ssh) %2 + 
[ec2-user@ip-10-0-0-184 digital-ink]$ sudo /usr/local/bin/docker-compose exec app bash
root@9a99cc015970:/srv/app# php artisan migrate
Migration table created successfully.
Migrating: 2014_10_12_000000_create_users_table
Migrated: 2014_10_12_000000_create_users_table (0.17 seconds)
Migrating: 2014_10_12_100000_create_password_resets_table
Migrated: 2014_10_12_100000_create_password_resets_table (0.14 seconds)
Migrating: 2019_08_19_000000_create_failed_jobs_table
Migrated: 2019_08_19_000000_create_failed_jobs_table (0.07 seconds)
Migrating: 2020_03_13_105916_create_stories_table
Migrated: 2020_03_13_105916_create_stories_table (0.23 seconds)
root@9a99cc015970:/srv/app#
```

Figure 10.11: Creation of RDS Tables.

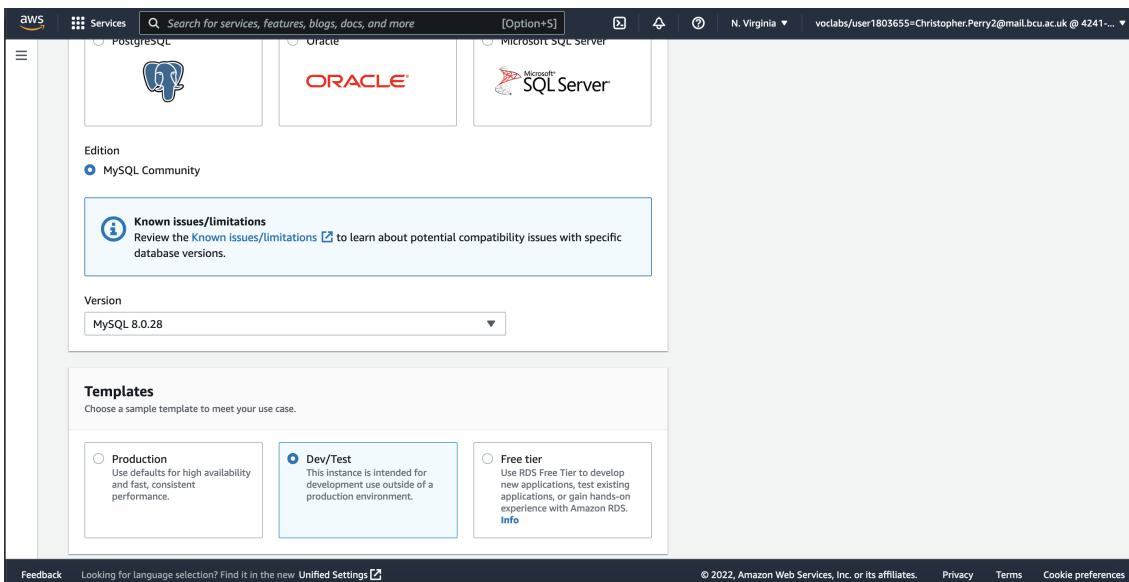


Figure 10.12: Selection of CloudWatch metric for EC2 instance.

MySQL was selected as it was the same database engine that the web application was originally using within Docker.

Then, MySQL was installed on the EC2 instance in order to sign in to the new database and create tables.

After the database was set up, tested and working, we were able to remove the old MySQL docker container from the docker-compose file.

```

ec2-user@ip-10-0-0-184:~/digital-ink
..sktop/Keypair (-zsh)          *1      ec2-user@ip-10-0-0-184:~/digital-ink (ssh)    *2 +[

[ec2-user@ip-10-0-0-184 digital-ink]$ sudo yum install mysql
Loaded plugins: extras_suggestions, langpacks, priorities, update-motd
amzn2-core
Resolving Dependencies
--> Running transaction check
--> Package mariadb.x86_64 1:5.5.68-1.amzn2 will be installed
--> Finished Dependency Resolution

Dependencies Resolved

=====
Package           Arch       Version        Repository   Size
=====
Installing:
mariadb          x86_64     1:5.5.68-1.amzn2  amzn2-core  8.8 M

Transaction Summary
=====
Install 1 Package

Total download size: 8.8 M
Installed size: 49 M
Is this ok [y/d/N]: 

```

Figure 10.13: Installation of MySQL on EC2 Instance.

```

ec2-user@ip-10-0-0-184:~/digital-ink
..sktop/Keypair (-zsh)          *1      ec2-user@ip-10-0-0-184:~/digital-ink (ssh)    *2 +[

[ec2-user@ip-10-0-0-184 digital-ink]$ mysql -h group-4-rds.cc0ktyy6s5rq.us-east-1.rds.amazonaws.com -u admin -pZukGIA3i8ZH4sul2V4
Welcome to the MariaDB monitor.  Commands end with ; or \g.
Your MySQL connection id is 23
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 group4_db;
Query OK, 1 row affected (0.01 sec)

MySQL [(none)]> SHOW DATABASES;
+-----+
| Database |
+-----+
| group4_db |
| information_schema |
| mysql |
| performance_schema |
| sys |
+-----+
5 rows in set (0.00 sec)

MySQL [(none)]> 

```

Figure 10.14: Creation of database table.

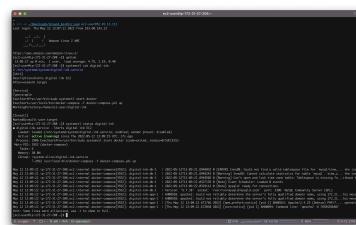


Figure 10.15: Changing Database Endpoint from Docker to AWS RDS.

Showing 1 changed file with 0 additions and 19 deletions.

```
v 19 docker-compose.yml
@@ -4,20 +4,14 @@ services:
  4   4     build:
  5   5       context: .
  6   6       dockerfile: .docker/Dockerfile
  7   7       depends_on:
  8   8         - db
  9   9       ports:
 10  10         - "80:80"
 11  11       volumes:
 12  12         - ./srv/app
 13  13         - /srv/app/vendor
 14  14       links:
 15  15         - db:db
 16  16       env_file: .docker/.docker.env
 17  17       phpmyadmin:
 18  18         image: phpmyadmin/phpmyadmin
 19  19         depends_on:
 20  20           - db
 21  21         container_name: phpmyadmin
 22  22         environment:
 23  23           - PMA_ARBITRARY=1
@@ -26,16 +20,3 @@ services:
 26  20       - 8889:80
 27  21       volumes:
 28  22         - /sessions
 29  29       db:
 30  30         image: mysql:5.7
 31  31         volumes:
 32  32           - ./dbdata:/var/lib/mysql
 33  33         ports:
 34  34           - "13306:3306"
 35  35         environment:
 36  36           - MYSQL_DATABASE=dockerphp
 37  37           - MYSQL_ROOT_PASSWORD=password
 38  38           - MYSQL_USER=dockerphp
 39  39           - MYSQL_PASSWORD=secret
 40  40         volumes:
 41  41           .dbdata:
```

Figure 10.16: Removal of Database from Docker File.

Chapter 11

Elastic Load Balancing (ELB)

Elastic Load Balancing is used to automatically scale your EC2 instances to meet any changes in demand from your users. ELB can be used to both scale up or down the instance's resources to ensure that your application is kept performant and available regardless of how many users visit. It is also possible to scale down the resources again, after the spike in usage has passed, to save money when it comes to billing and ensure you aren't paying for any additional resources that are not being used.

1. Creation of new AMI

- Selection of AMI previously created and then "Create Instance from AMI" option (elb/elb-instance-from-ami) - Given name of "Group4-EC2-Instance-2" (elb/elb-instance-2-name)
- AMI selected to use same instance as "Group4-EC2" so everything is the same (elb/elb-instance-2-name)
- Same keypair used, so it is easier to switch between both instances (elb/elb-instance-2-type-and-keypair)
- Network Settings - VPC set to be Group4 VPC (created in Section 4) (elb/elb-instance-2-network-settings)
- Subnet set to be "Public Subnet 2" (elb/elb-instance-2-network-settings)
- Public IP auto-assigned (elb/elb-instance-2-network-settings)
- Existing security group of "Group4-Security-Group" selected to allow HTTP, HTTPS, SSH and MySQL traffic on the instance (elb/elb-instance-2-network-settings)
- Storage remains the same as previous instance (elb/elb-instance-2-storage-config)
- Second instance now created (elb/elb-instance-2-created)

2. Creation of target group

Now that there is 2 instances, they both need to be stored within a target group.

- The Target Group type of "Instances" is selected - this will store both running instances of Digital-Ink in a group to be handled by the Load Balancer (elb/elb-target-group-basic-config)
- Target Group name of "Group4-Target-Group" given (elb/elb-target-group-basic-config)
- Protocol of HTTP and port 80 given (elb/elb-target-group-basic-config)
- Group4-VPC selected (elb/elb-vpc)
- The next screen asks for instances that will be registered to the Target Group to be selected - The 2 running instances of Digital Ink are shown and added as targets through the "Include as pending below" button (elb/elb-register-targets)
- Target group now created, and contains both EC2 instances within them (elb/elb-target-group-created)

3. Creation of Load Balancer

- The Target groups are not associated with a Load Balancer, so one will be created as an Application Load Balancer (elb/elb-load-balancer-created) - Given the name of "Group4-Load-Balancer" (elb/elb-basic-config) - Set to be internet facing and will handle ipv4 addresses (elb/elb-network-mapping) - The VPC is selected and public subnet 1 and 2 are applied within each, which are in us-east-1a and us-east-1b respectively (Say this makes the web app highly available) (elb/elb-vpc) - The security group of Group4-Security-Group is selected, which allows HTTP, HTTPS, SSH and MySQL traffic within the load balancer (elb/elb-security-groups-and-listeners) - In the event that either of the web apps goes down, it will be forwarded to the Group4-Target-Group, which will then display the available instance (elb/elb-security-groups-and-listeners) - Could not create Global Accelerator due to permissions issue (Future improvement) (elb/elb-accelerator) - Summary (elb/elb-summary) - Load balancer created (elb/elb-created) - When the load balancer is visited at <http://http://group4-load-balancer-1914525647.us-east-1.elb.amazonaws.com/>, the website is shown (elb/elb-working)

Chapter 12

Security Practices

Security Practices stuff to talk about:

Security groups limiting HTTP, HTTPS, SSH and MySQL. SSH Connections are limited only to one IP (Eduroam's)

KeyPair for logging into EC2

IAM (But we don't have access)

S3 bucket isn't publicly accessible from the get-go

If we do need public access, it is ONLY for GET or PUT requests (Viewing stories and uploading them)

VPC controlling inbound and outbound traffic

public and private subnets

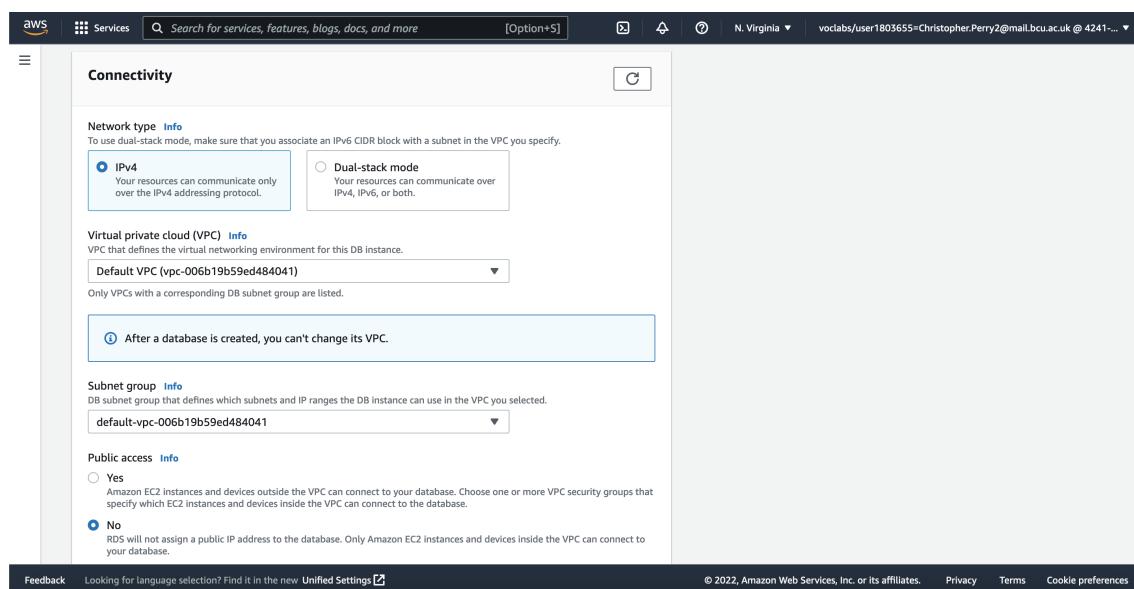


Figure 12.1: Selection of VPC and Subnet Groups.

Public access was turned off to further increase our application's security.

We selected an automatically generated password to ensure that it was created with current best security practices.

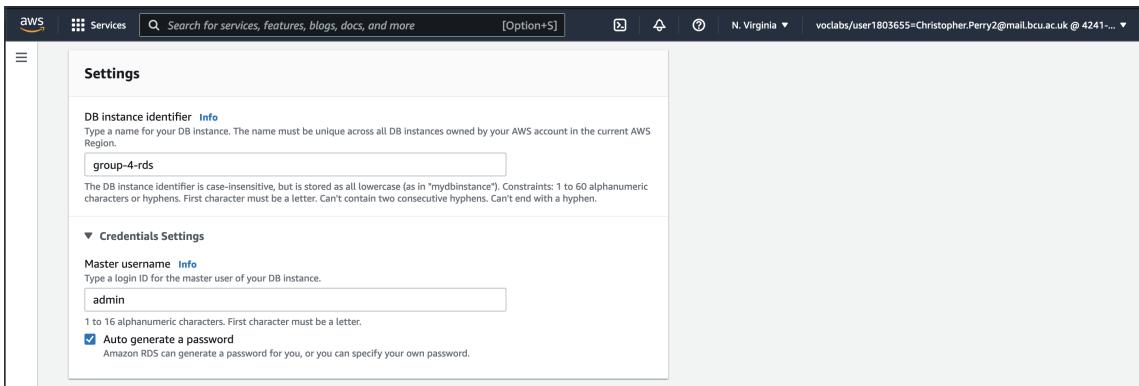


Figure 12.2: Credentials for RDS Authentication.

Chapter 13

Cost Breakdown

If this web app was to be deployed to the public, or be expanded to a larger market, it would be important to gather estimated costs for hosting the app in the cloud with all the AWS services being used. The AWS Pricing Calculator can be used to calculate current costs and predict future costs. To calculate these costs, it is required to specify every implemented feature and several projected inputs and outputs, such as amount of data transferred on the app per month (Amazon Web Services (AWS), 2022d). The monthly cost and a yearly cost of deploying the app in its current state was calculated first. Following this, the calculator was used to predict monthly and yearly costs for scaling the deployment up to larger user-bases. These figures were calculated for scaling the app up to 10,000 users, one million users, and ten million users, which would require upgrading some selected AWS features.

13.1 Estimated Costs

13.2 Scaling Up to 10,000 Users

13.3 Scaling Up to One Million Users

13.4 Scaling Up to Ten Million Users

Chapter 14

Testing

This chapter of the report will detail the testing conducted on the configured AWS services. This was done to determine the accuracy and efficiency of the configurations made during the deployment process. The testing was conducted by using Gherkin, a language used to define behaviour and test cases (Santos and Vilain, 2018). It is non-technical and is intended to be easily human-readable. Gherkin uses set keywords for structure and meaning: Given, When, and Then. An example of this structure can be seen in figure below.

```
Scenario: Does the web application work?  
    Given ...  
    When ...  
    Then ...
```

EC2, S3, CloudFront, RDS, CloudWatch, and CloudTrail were all tested using this approach. Screenshots are included to illustrate the results of these tests.

14.1 Testing EC2

```
Scenario: Accessing instance through SSH with .pem file private key.  
    Given that the EC2 instance is running on AWS and the user has EC2 keypair  
    When the user enters the command  
        "ssh -i Group4_KeyPair.pem ec2-user@35.169.71.228" in the terminal  
    Then the user will be logged into the EC2 instance
```



A screenshot of a terminal window titled "ec2-user@ip-10-0-0-184:~". The window shows the command "ssh -i Group4_KeyPair.pem ec2-user@35.169.71.228" being run, followed by the output: "Last login: Sat May 14 00:34:17 2022 from 193.60.143.12" and the Amazon Linux 2 AMI logo. The prompt "[ec2-user@ip-10-0-0-184 ~]\$ " is visible at the bottom.

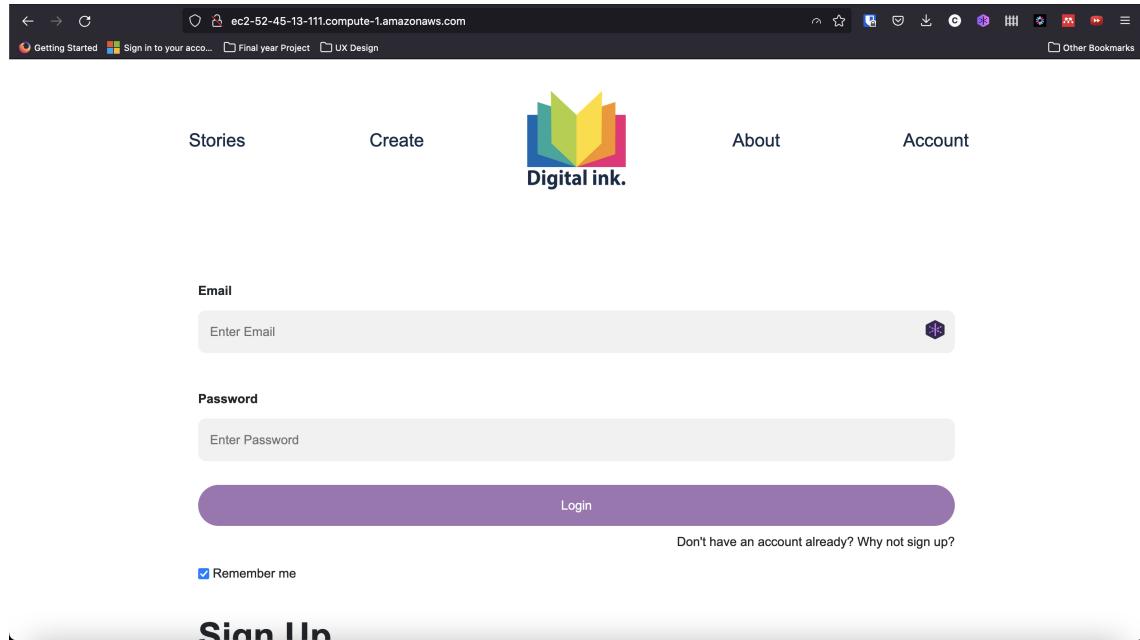
Scenario: Accessing web app through EC2 domain name.

Given that the web app is running on the EC2 instance

When the user accesses

"<http://ec2-35-169-71-228.compute-1.amazonaws.com/>" in their browser

Then the web app will be loaded



14.2 Testing S3

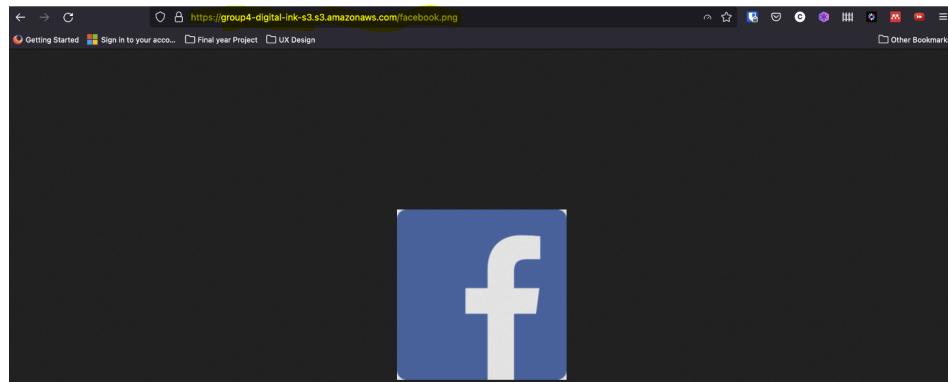
Scenario: Accessing web app image through S3 domain name.

Given that an image on the web app is in an S3 bucket

When the user accesses the URL

"<https://group4-digital-ink-s3.s3.amazonaws.com/>" followed by the name of the image

Then the user will see the image displayed from the S3 bucket



14.3 Testing CloudFront

Scenario: Accessing web app image through CloudFront domain name.

Given that an image on the web app is in a CloudFront distribution

When the user accesses the URL

"<https://d1bdkf7iuqj4qy.cloudfront.net/>" followed by the name of the image

Then the user will see the image displayed from the CloudFront distribution



Scenario: Accessing web app image through CloudFront domain name in another region.
 Given that the user is connected to the internet
 When the user accesses a resource on the web app
 Then CloudFront will distribute that content in the region closest to them

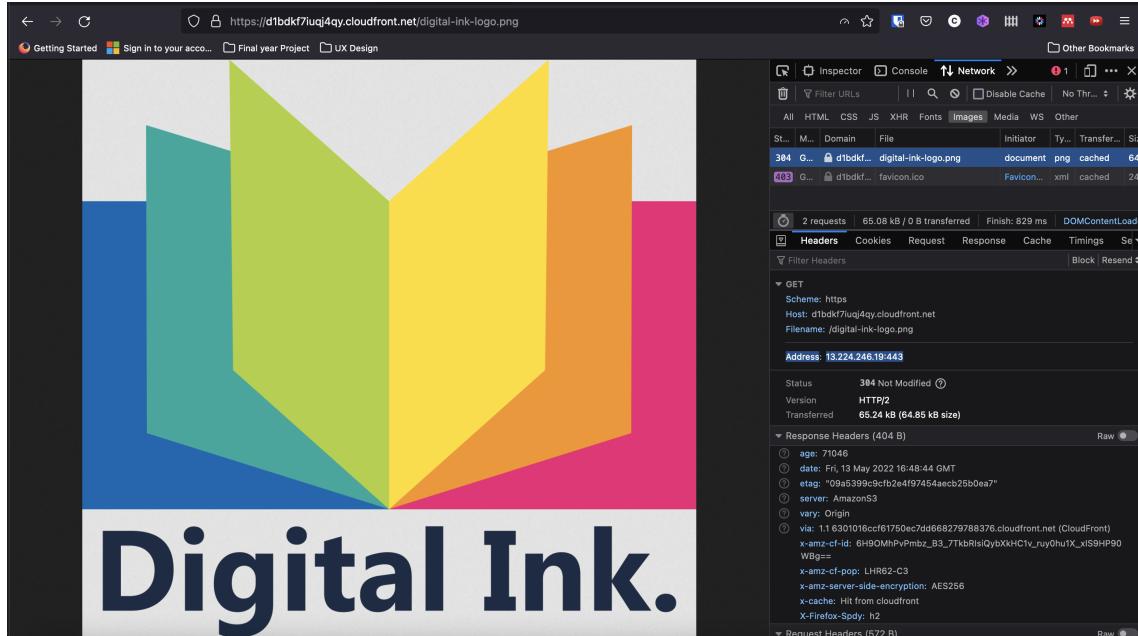


Figure 14.1: Digital Ink image whilst connected to UK IP.

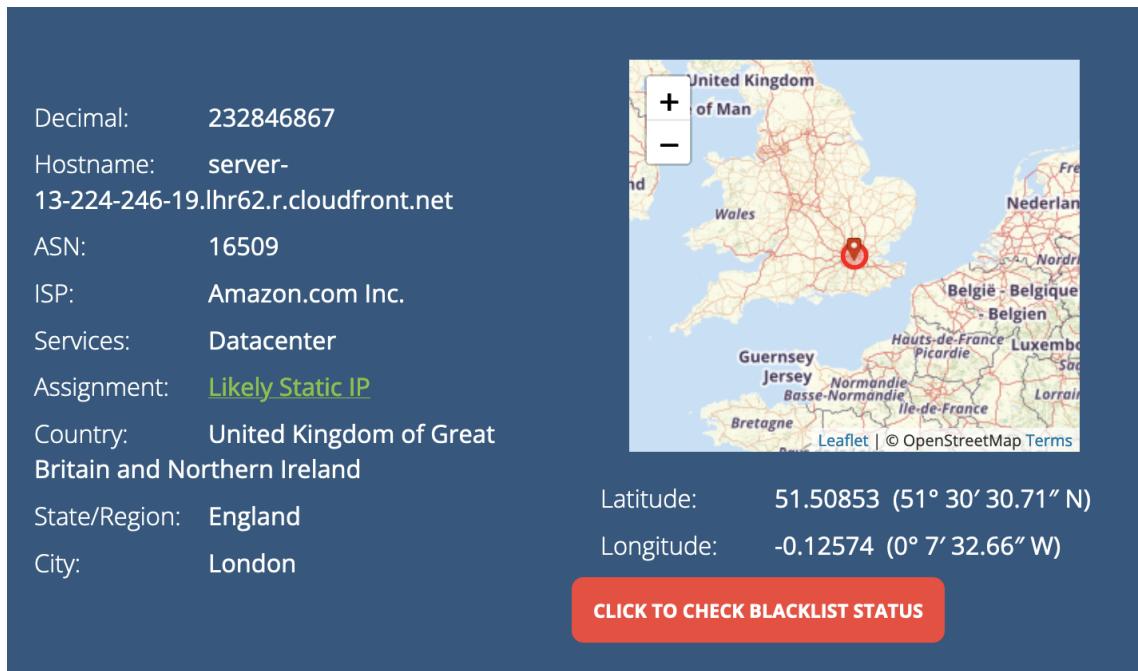


Figure 14.2: UK IP Location.

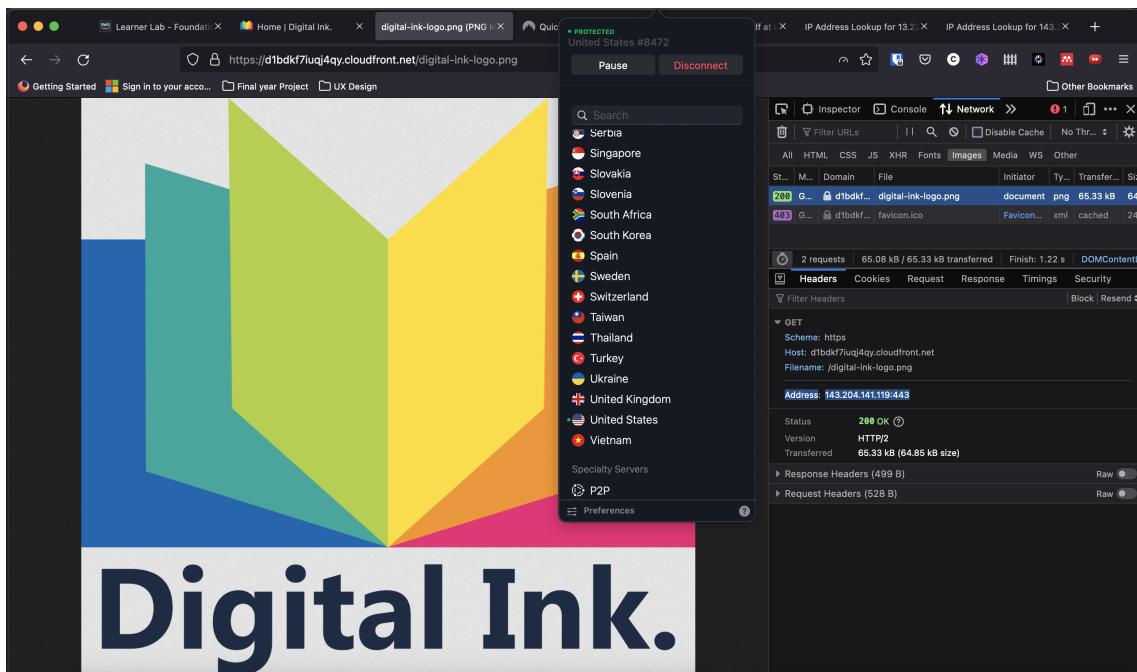


Figure 14.3: Digital Ink image whilst connected to US IP.

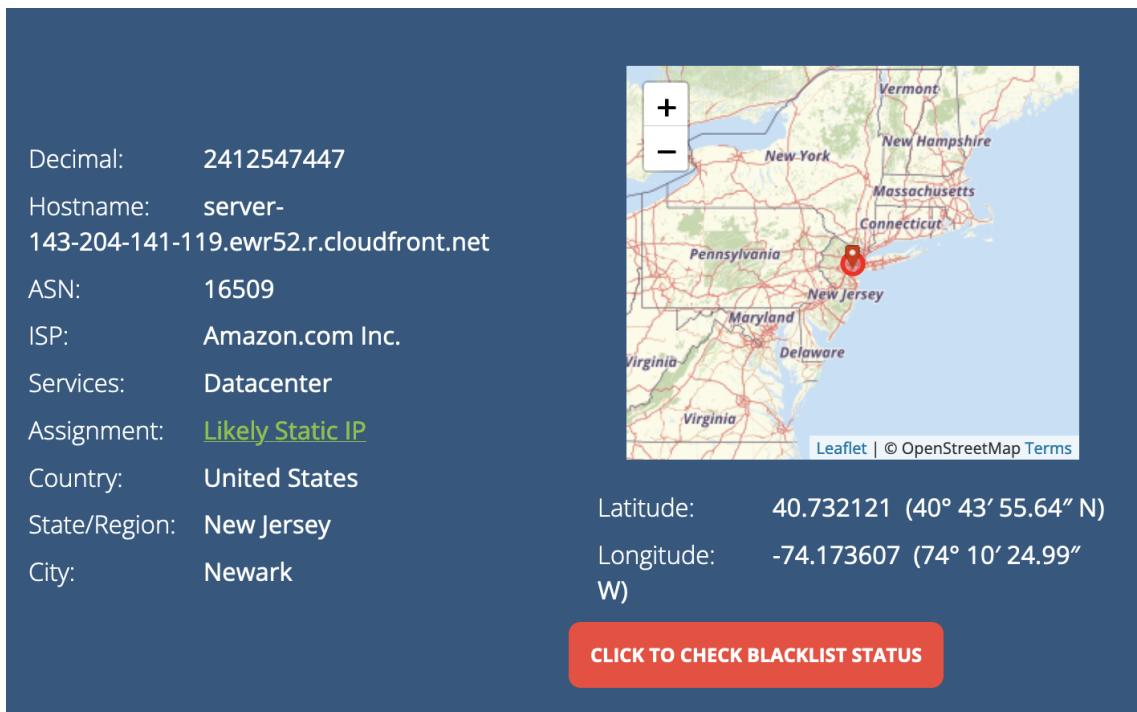


Figure 14.4: US IP Location.

14.4 Testing RDS

Scenario: Creating user information through the web app.

Given that the user does not have an account on the web app

When the user creates an account through the web app

Then their account will be added to the users table on the RDS instance

```
ec2-user@ip-10-0-0-184:~$ mysql -h group-4-rds.cc0ktyy6s5rq.us-east-1.rds.amazonaws.com -u admin -pCSZukGIA3i82H4suL2V4
Welcome to the MariaDB monitor.  Commands end with ; or \g.
Your MySQL connection id is 86
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)]> USE group4_db;
Reading table information for completion of table and column names
You can turn off this feature to get a quicker startup with -A

Database changed
MySQL [group4_db]> SELECT * FROM users;
Empty set (0.00 sec)

MySQL [group4_db]>
```

Figure 14.5: Empty users table before test.

```
ec2-user@ip-10-0-0-184:~$ mysql -h group-4-rds.cc0ktyy6s5rq.us-east-1.rds.amazonaws.com -u admin -pCSZukGIA3i82H4suL2V4
Welcome to the MariaDB monitor.  Commands end with ; or \g.
Your MySQL connection id is 121
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)]> USE group4_db;
Reading table information for completion of table and column names
You can turn off this feature to get a quicker startup with -A

Database changed
MySQL [group4_db]> SELECT * FROM users;
+----+----+----+----+----+----+
| id | name          | email           | password          | remember_token | created_at      | updated_at      |
+----+----+----+----+----+----+
| 3  | Christopher Perry | christopher.perry2@mail.bcu.ac.uk | $2y$10$K8L2arT9p7Z3J4EtSo5dPupidgn5qGujo7rQoQH8IEoj05tDCtX1. | NULL           | 2022-05-14 01:17:57 | 2022-05-14 01:32:00 |
+----+----+----+----+----+----+
1 row in set (0.00 sec)

MySQL [group4_db]>
```

Figure 14.6: Users table now populated after test.

Scenario: Creating story information through the web app.

Given the user has a digital ink account

When they create a story on the website

Then their story will be added to the stories table on the RDS instance

```

ec2-user@ip-10-0-0-184:~/digital-ink
[ec2-user@ip-10-0-0-184 digital-ink]$ mysql -h group-4-rds.cc0ktyy6s5rq.us-east-1.rds.amazonaws.com -u admin -pCSZukGIA382H4suL2V4
Welcome to the MariaDB monitor.  Commands end with ; or \g.
Your MySQL connection id is 96
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)]> USE group4_db;
Reading table information for completion of table and column names
You can turn off this feature to get a quicker startup with -A

Database changed
MySQL [group4_db]> SELECT * FROM stories;
Empty set (0.00 sec)

MySQL [group4_db]> 
```

Figure 14.7: Empty stories table before test.

```

Reading table information for completion of table and column names
You can turn off this feature to get a quicker startup with -A

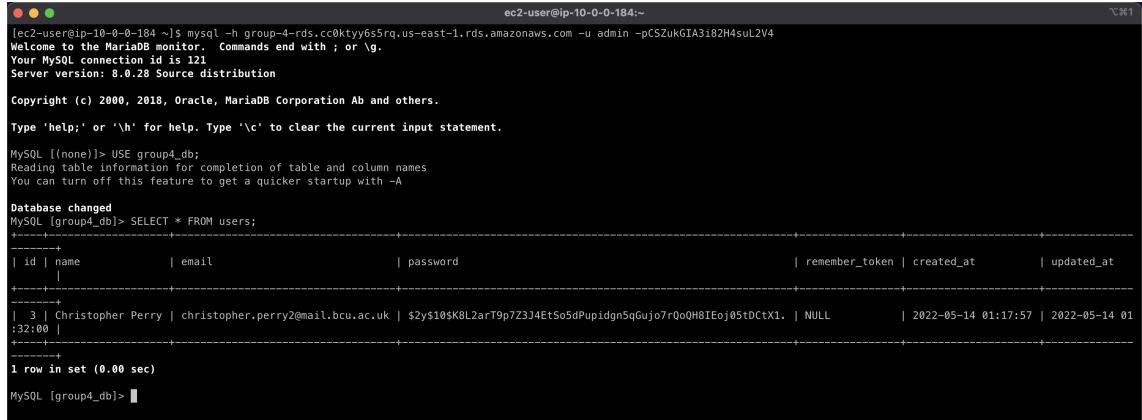
Database changed
MySQL [group4_db]> SELECT * FROM stories;
+----+-----+-----+-----+-----+-----+-----+-----+
| id | author_id | title | genre | blurb | content | cover_image | file_
| pload | published | created_at | updated_at | |
+----+-----+-----+-----+-----+-----+-----+-----+
| 1 | 3 | Mittens the Cat | Children's | Proin convallis commodo consectetur. Pellentesque varius aliquam felis id facilisis. Aenean eu commodo ex. Praesent laoreet ele-
| nentum mauris, eu aliquet risus tempus vel. Integer suscipit urna id dolor interdum scelerisque. Ut in quam ut ipsum semper sagittis eu nec orci. Nulla at suscipit ipsum. In id o-
| nare tellus, non vestibulum elit. Ut ac lacus dignissim, condimentum sapien ut, venenatis nisl. Morbi quis augue eu ipsum euismod dignissim. | Lorem ipsum dolor sit amet, consec-
| etur adipisciing elit. Suspendisse elementum quam id maximus pretium. Ut vitae sem in metus malesuada sollicitudin. Cras id ultrices nunc. Aenean eu pretium turpis, vitae porttit
| r erat. Donec eu dictum tortor, sit amet sodales tortor. Curabitur semper massa leo, nec accumsan lacus porta ut. Integer mauris ante, tincidunt sed mi sed, tincidunt pretium ni-
| i. Proin maximus euismod magna sit amet convallis. Phasellus non felis a dui consequat vulputate eget et mauris. Vivamus in mi et est suscipit aliquet. Donec augue elit, egestas
| vel arcu eget, finibus laoreet velit. Donec in vehicula nisl, nec viverra est. Morbi placerat elementum odio id luctus. | ../storage/cover_images/8804630481652491214.jpg | NULL
| 1 | 1 | 2022-05-14 01:20:14 | 2022-05-14 01:20:14 | 
```

1 row in set (0.00 sec)

MySQL [group4_db]>

Figure 14.8: Stories table now populated after test.

Scenario: Updating user information in the database through the web app.
Given the user has an account in the web app
When they change their name and email
Then the information will be updated in the users table in the RDS instance



```
[ec2-user@ip-10-0-0-184 ~]$ mysql -h group-4-rds.cc0ktyy6s5rq.us-east-1.rds.amazonaws.com -u admin -pCSZukGIA3i82H4suL2V4
Welcome to the MariaDB monitor. Commands end with ; or \g.
Your MySQL connection id is 114
Server version: 8.0.28 Source distribution

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

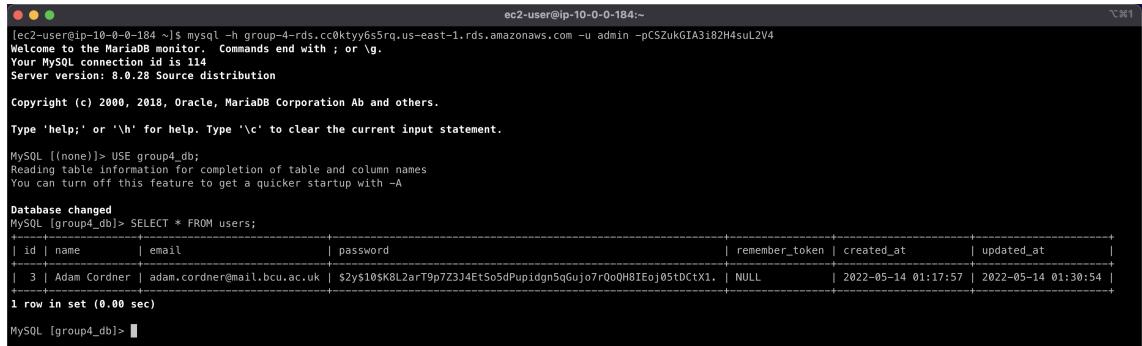
Type 'help;' or '\h' for help. Type '\c' to clear the current input statement.

MySQL [(none)]> USE group4_db;
Reading table information for completion of table and column names
You can turn off this feature to get a quicker startup with -A

Database changed
MySQL [group4_db]> SELECT * FROM users;
+----+-----+-----+-----+-----+-----+
| id | name          | email           | password          | remember_token | created_at      | updated_at      |
+----+-----+-----+-----+-----+-----+
| 3  | Christopher Perry | christopher.perry@mail.bcu.ac.uk | $2y$10$K8L2arT9p7Z3J4EtSo5dPupldgn5qGujo7r0oQH8IEoj05tDctx1. | NULL           | 2022-05-14 01:17:57 | 2022-05-14 01:17:57 |
+----+-----+-----+-----+-----+-----+
1 row in set (0.00 sec)

MySQL [group4_db]>
```

Figure 14.9: User before update.



```
[ec2-user@ip-10-0-0-184 ~]$ mysql -h group-4-rds.cc0ktyy6s5rq.us-east-1.rds.amazonaws.com -u admin -pCSZukGIA3i82H4suL2V4
Welcome to the MariaDB monitor. Commands end with ; or \g.
Your MySQL connection id is 114
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)]> USE group4_db;
Reading table information for completion of table and column names
You can turn off this feature to get a quicker startup with -A

Database changed
MySQL [group4_db]> SELECT * FROM users;
+----+-----+-----+-----+-----+-----+
| id | name          | email           | password          | remember_token | created_at      | updated_at      |
+----+-----+-----+-----+-----+-----+
| 3  | Adam Cordner | adam.cordner@mail.bcu.ac.uk | $2y$10$K8L2arT9p7Z3J4EtSo5dPupldgn5qGujo7r0oQH8IEoj05tDctx1. | NULL           | 2022-05-14 01:17:57 | 2022-05-14 01:30:54 |
+----+-----+-----+-----+-----+-----+
1 row in set (0.00 sec)

MySQL [group4_db]>
```

Figure 14.10: User after update. Notice that the hashed password remains the same.

Scenario: Deleting story information in the database through the web app.

Given the user has an account and a story on the web app
 When they delete a story associated with their account
 Then the story will be removed from the stories table in the RDS instance

```
ec2-user@ip-10-0-0-184:~
```

Reading table information for completion of table and column names
 You can turn off this feature to get a quicker startup with -A

Database changed

```
MySQL [group4_db]> SELECT * FROM stories;
```

id author_id title genre blurb content cover_image file_
1 1 Mittens the Cat Children's Proin convallis commodo consectetur. Pellentesque varius aliquam felis id facilisis. Aenean eu commodo ex. Praesent laoreet ele- entum mauris, eu aliquet risus tempus vel. Integer suscipit urna id dolor interdum scelerisque. Ut in quam ut ipsum semper sagittis eu nec orci. Nulla at suscipit ipsum. In id o- nare tellus, non vestibulum elit. Ut ac lacus dignissim, condimentum sapien ut, venenatis nisl. Morbi quis augue eu ipsum euismod dignissim. Lorem ipsum dolor sit amet, consec- etur adipiscing elit. Suspendisse elementum quam id maximus pretium. Ut vitae sem in metus malesuada sollicitudin. Cras id ultrices nunc. Aenean eu pretium turpis, vitae porttiti- er erat. Donec eu dictum tortor, sit amet sodales tortor. Curabitur semper massa leo, nec accumsan lacus porta ut. Integer mauris ante, tincidunt sed mi sed, tincidunt pretium ni- i. Proin maximus euismod magna sit amet convallis. Phasellus non felis a dui consequat vulputate eget et mauris. Vivamus in mi et est suscipit aliquet. Donec augue elit, egestas vel arcu eget, finibus laoreet velit. Donec in vehicula nisl, nec viverra est. Morbi placerat elementum odio id luctus. /storage/cover_images/8804630481652491214.jpg NULL
1 1 2022-05-14 01:20:14 2022-05-14 01:20:14

1 row in set (0.00 sec)

```
MySQL [group4_db]> []
```

Figure 14.11: Stories table before deletion.

```
ec2-user@ip-10-0-0-184:~
```

[ec2-user@ip-10-0-0-184 digital-ink]\$ mysql -h group-4-rds.cc0ktyy6s5rq.us-east-1.rds.amazonaws.com -u admin -pCSZukGIA382H4suL2V4

Welcome to the MariaDB monitor. Commands end with ; or \g.
 Your MySQL connection id is 96
 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)]> USE group4_db;
Reading table information for completion of table and column names
You can turn off this feature to get a quicker startup with -A
```

Database changed

```
MySQL [group4_db]> SELECT * FROM stories;
```

Empty set (0.00 sec)

```
MySQL [group4_db]> []
```

Figure 14.12: Stories table after deletion.

14.5 Testing CloudWatch

For the purposes of these tests, alarms were purposefully activated.

Scenario: Testing that NetworkAlarm activates

Given that the NetworkAlarm is active

When the EC2 instance outputs more than 500 packets of data
in 1 minute

Then the alarm should activate.

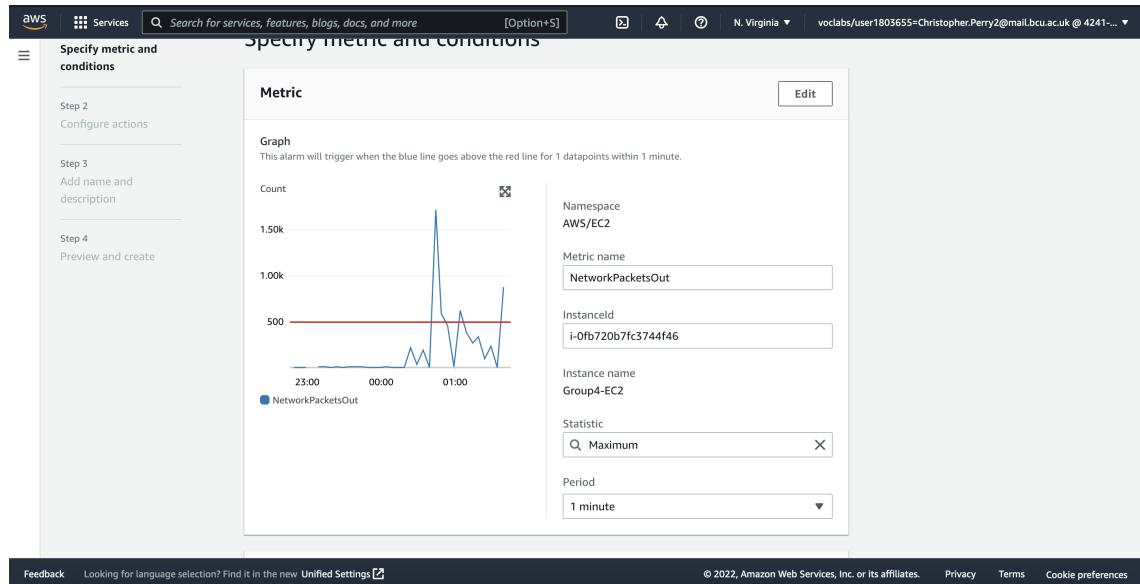


Figure 14.13: CloudWatch NetworkAlarm setup.

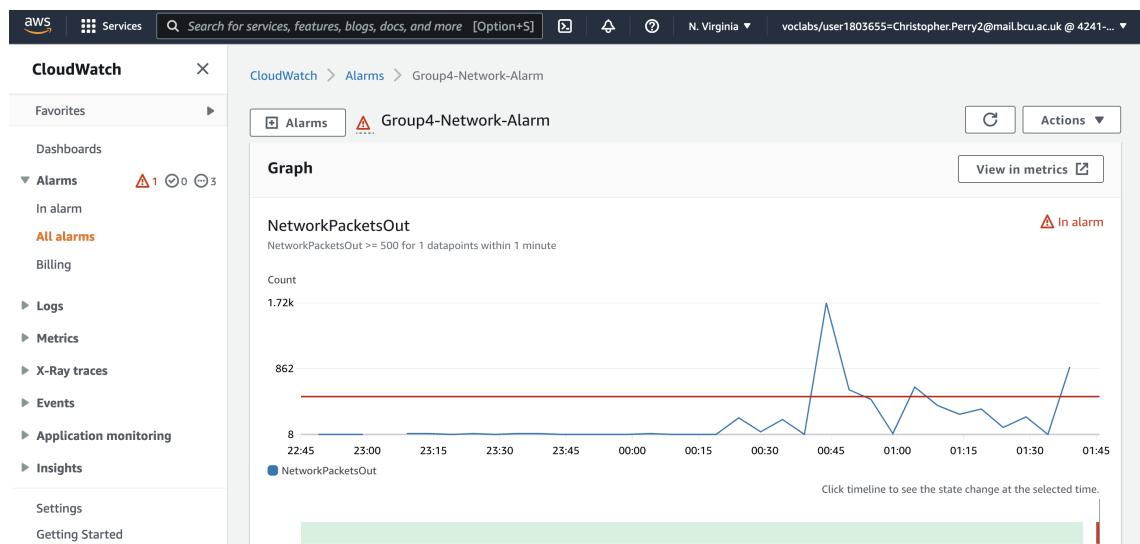


Figure 14.14: CloudWatch NetworkAlarm activated.

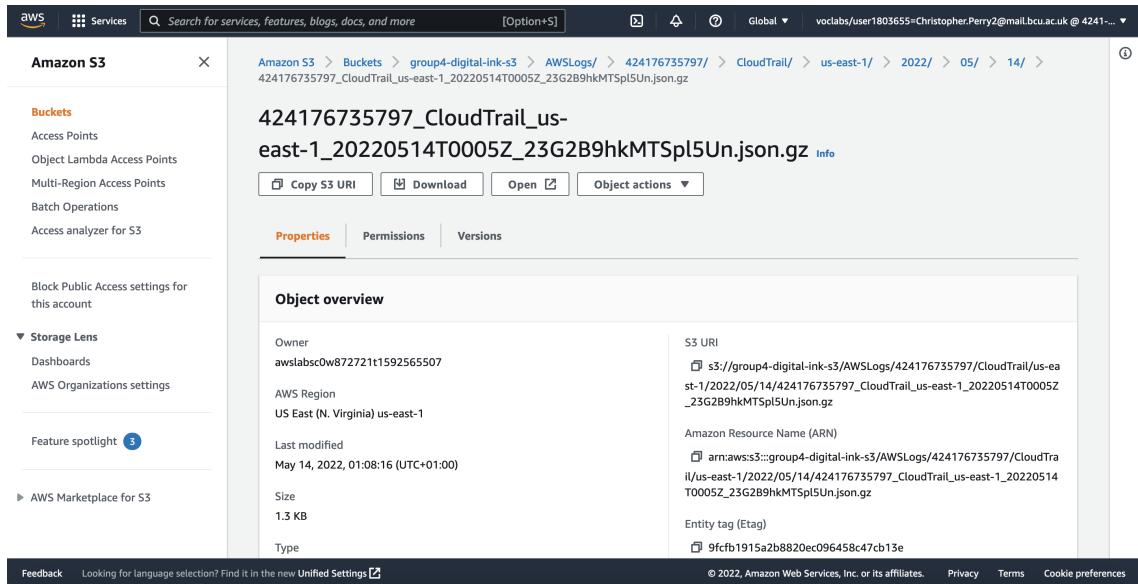
14.6 Testing CloudTrail

Scenario: Testing CloudTrail logs RDS activity.

Given that the Group4-CloudTrail service is active

When data is added to the RDS database

Then this information is logged through CloudTrail



The screenshot shows the AWS S3 console interface. On the left, there's a sidebar with navigation links like 'Amazon S3', 'Buckets', 'Storage Lens', 'AWS Organizations settings', 'Feature spotlight', and 'AWS Marketplace for S3'. The main area displays a file named '424176735797_CloudTrail_us-east-1_20220514T0005Z_23G2B9hkMTSp15Un.json.gz'. Below the file name, there are buttons for 'Copy S3 URI', 'Download', 'Open', and 'Object actions'. A tab bar at the bottom of the main area includes 'Properties' (which is selected), 'Permissions', and 'Versions'. Under the 'Properties' tab, there's a section titled 'Object overview' containing details such as Owner (awslabsc0w872721t1592565507), AWS Region (US East (N. Virginia) us-east-1), Last modified (May 14, 2022, 01:08:16 (UTC+01:00)), Size (1.3 KB), and Type. To the right of these details, there are sections for 'S3 URI', 'Amazon Resource Name (ARN)', and 'Entity tag (Etag)'. At the very bottom of the page, there are links for 'Feedback', 'Language selection', 'Privacy', 'Terms', and 'Cookie preferences'.

Figure 14.15: CloudTrail test.

(Add a screenshot here?)

14.7 Testing ELB

Scenario: Load Balancer redirect from Instance 1 to Instance 2
Given that the Group4-Load-Balancer service is active
When Group4-EC2 is shut down
Then traffic should be moved to Group4-EC2-Instance-2

The screenshot shows the AWS EC2 Instances page. On the left, there's a sidebar with 'New EC2 Experience' selected. The main area has a table titled 'Instances (1/2)'. It lists two instances: 'Group4-EC2-Instance-2' with instance ID 'i-076fe11573d1db211' in 'Running' state, and 'Group4-EC2' with instance ID 'i-0fb720b7fc3744f46' in 'Stopped' state. The table includes columns for Name, Instance ID, Instance state, Instance type, Status check, Alarm status, and Availability Zone.

Figure 14.16: Stopped Group4-EC2 instance.

The screenshot shows a web browser window. The address bar displays the URL 'group4-load-balancer-1914525647.us-east-1.elb.amazonaws.com'. The page itself is a login form for 'Digital ink.' It features fields for 'Email' and 'Password', both with placeholder text 'Enter Email' and 'Enter Password'. Below these is a large purple 'Login' button. To the right of the password field, there's a link 'Don't have an account already? Why not sign up?'. At the bottom left, there's a checked checkbox labeled 'Remember me'. A 'Sign In' button is located at the very bottom of the page.

Figure 14.17: Web app page still loading through other EC2 instance.

Scenario: Load Balancer redirect from Instance 2 to Instance 1

Given that the Group4-Load-Balancer service is active

When Group4-EC2-Instance-2 is shut down

Then traffic should be moved to Group4-EC2

The screenshot shows the AWS EC2 Instances page. On the left, there's a sidebar with 'New EC2 Experience' selected. The main area has a table titled 'Instances (1/2) Info'. It lists two instances: 'Group4-EC2-Instance-2' (running, t2.micro, 2/2 checks passed) and 'Group4-EC2' (stopped, t2.micro). The 'Actions' dropdown menu for the stopped instance has an option to 'Launch instances'.

Figure 14.18: Stopped Group4-EC2-Instance-2 instance.

The screenshot shows a web browser window. The address bar displays the URL 'group4-load-balancer-1914525647.us-east-1.elb.amazonaws.com'. The page itself is a login form for 'Digital ink.' with fields for 'Email' and 'Password', a 'Login' button, and links for 'About' and 'Account'. Below the form, there's a link to sign up and a 'Remember me' checkbox.

Figure 14.19: Web app page still loading through other EC2 instance.

Chapter 15

Future Enhancements

SSL and TLS are protocols for establishing safe and secure connections between networked computers and, today, support for these protocols is built into most browsers and web servers (Thomas, 2000). Adding an SSL or TLS certificate to the web app would greatly increase its security, however, it was not possible to implement such a feature during the deployment of the app. This was due to the restricted permissions granted to the AWS account used to create this deployment, which restricted the ability for certain features to be implemented. In future deployments of the web app, it would be greatly beneficial to the security of the app, for both users and the app itself, to add an SSL or TLS certificate to encrypt the connections to the EC2 instance. This would be especially important in a future deployment if the user-base would be expected to grow in size.

Another feature which was limited due to restricted permissions was AWS IAM roles. IAM is an AWS service which provides fine-tuned access control across the entire AWS deployment by creating a policy which specifies which users have permission to access certain features and resources (Amazon Web Services (AWS), 2022c). IAM would be very useful if the development team behind *Digital-Ink* was scaled up with future deployments, and it is especially appealing due to the fact that it is an entirely free service with no additional costs to use.

If we were to redeploy the app again from scratch, we would consider using AWS Elastic Beanstalk. EB is a service AWS provides for deploying and scaling web apps automatically. EB is currently compatible with Java, .NET, PHP, Node.js, Python, Ruby, Go, and Docker (Amazon Web Services (AWS), 2022b). Considering that *Digital-Ink* uses both PHP and Docker, using EB seems appropriate for future deployments of the app. Using EB is simple, simply upload the web app code and EB automatically deploys it, including appropriate capacity provisioning, load balancing, auto-scaling, and more. EB can also be used to automatically scale-up and scale-down the web app, which would be useful as the app grows over time. In many ways, this automatic handling of the deployment is preferable as it removes the risk of human error causing the deployment to fail. This is especially helpful as human error is one of the most significant factors in failed deployments of online services, and the risk only increases as those services become bigger and harder to manage (Kraemer and Carayon, 2007). Additionally, like IAM, EB has no additional fee to use, as payment is only necessary for the AWS resources configured by EB, not the use of EB itself.

AWS Global Accelerator being implemented to VPC... (requires IAM)

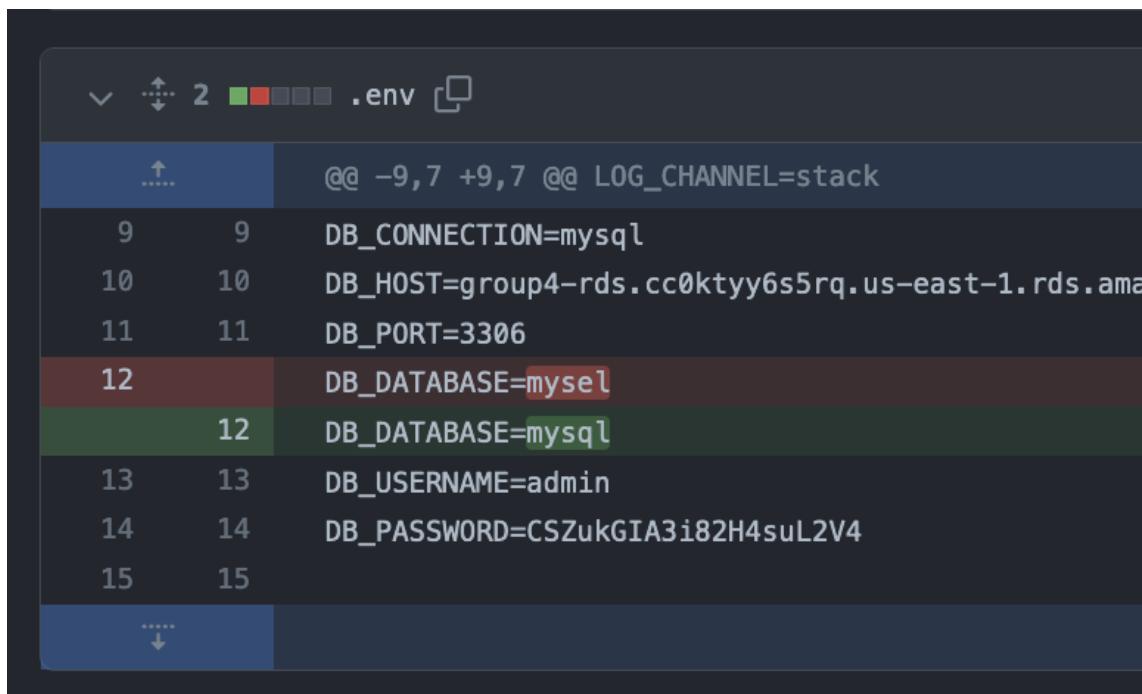
AWS Lambda...

Chapter 16

Conclusion

Everything went very well and sometimes AWS might be a good idea for your project, just be aware of how much money you're spending though!

Also be careful when typing, we spent two hours on this bug/issue:



A screenshot of a terminal window showing a file named '.env'. The file contains configuration variables for a database connection. The variable 'DB_DATABASE' is defined multiple times with different values: 'mysel' (highlighted in red), 'mysql' (highlighted in green), and 'mysql' again. Other variables shown include 'DB_CONNECTION=mysql', 'DB_HOST=group4-rds.cc0ktyy6s5rq.us-east-1.rds.amazonaws.com', 'DB_PORT=3306', 'DB_USERNAME=admin', and 'DB_PASSWORD=CSZukGIA3i82H4suL2V4'. The terminal interface includes a status bar at the top with icons for file operations and a line number indicator.

```
@@ -9,7 +9,7 @@ LOG_CHANNEL=stack
 9     9     DB_CONNECTION=mysql
 10    10    DB_HOST=group4-rds.cc0ktyy6s5rq.us-east-1.rds.amazonaws.com
 11    11    DB_PORT=3306
 12    12    DB_DATABASE=mysel
 12    12    DB_DATABASE=mysql
 13    13    DB_USERNAME=admin
 14    14    DB_PASSWORD=CSZukGIA3i82H4suL2V4
 15    15
```

Figure 16.1: Major Bug Fixes Can Be Small

References

- Amazon Web Services (AWS) (2022a). *Amazon CloudWatch - Application and Infrastructure Monitoring*. Available at: <https://aws.amazon.com/cloudwatch>.
- (2022b). *AWS Elastic Beanstalk - Deploy Web Applications*. Available at: <https://aws.amazon.com/elasticbeanstalk/>.
- (2022c). *AWS Identity and Access Management - Amazon Web Services*. Available at: <https://aws.amazon.com/iam/>.
- (2022d). *AWS Pricing Calculator*. Available at: <https://calculator.aws>.
- (2022e). *Cloud Object Storage - Amazon S3 - Amazon Web Services*. Available at: <https://aws.amazon.com/s3/>.
- (2022f). *Connect to the internet using an internet gateway*. Available at: https://docs.aws.amazon.com/vpc/latest/userguide/VPC_Internet_Gateway.html.
- (2022g). *Low-Latency Content Delivery Network (CDN) - Amazon AWS*. Available at: <https://aws.amazon.com/cloudfront/>.
- (2022h). *What is Amazon EC2?* Available at: <https://docs.aws.amazon.com/AWSEC2/latest/UserGuide/concepts.html>.
- (2022i). *What is Amazon VPC?* Available at: <https://docs.aws.amazon.com/vpc/latest/userguide/what-is-amazon-vpc.html>.
- (2022j). *What is AWS CloudTrail?* Available at: <https://docs.aws.amazon.com/awscloudtrail/latest/userguide/cloudtrail-user-guide.html>.
- Anderson, C. (2015). “Docker [software engineering]”. In: *IEEE Software* 32.3, pp. 102–c3. Available at: <https://doi.org/10.1109/MS.2015.62>.
- Fielding, R. T. and G. Kaiser (1997). “The Apache HTTP server project”. In: *IEEE Internet Computing* 1.4, pp. 88–90. Available at: <https://doi.org/10.1109/4236.612229>.
- Kraemer, S. and P. Carayon (2007). “Human errors and violations in computer and information security: The viewpoint of network administrators and security specialists”. In: *Applied ergonomics* 38.2, pp. 143–154. Available at: <https://doi.org/10.1016/j.apergo.2006.03.010>.
- Laravel (2022a). *Blade Templates*. Available at: <https://laravel.com/docs/9.x/blade>.
- (2022b). *Hashing*. Available at: <https://laravel.com/docs/9.x/hashing>.
- Lee, J. and B. Ware (2003). *Open Source Web Development with LAMP: Using Linux, Apache, MySQL, Perl, and PHP*. Addison-Wesley Professional. Available at: <https://isbnsearch.org/9780201770612>.
- Lerdorf, R. et al. (2002). *Programming Php*. " O'Reilly Media, Inc." Available at: <https://isbnsearch.org/9781565926103>.
- Santos, E. C. dos and P. Vilain (2018). “Automated acceptance tests as software requirements: An experiment to compare the applicability of fit tables and gherkin language”.

- In: *International Conference on Agile Software Development*. Springer, pp. 104–119.
- Available at: https://doi.org/10.1007/978-3-319-91602-6_7.
- Thomas, S. (2000). *SSL and TLS essentials*. Available at: <https://isbnsearch.org/9780471383543>.
- Widenius, M., D. Axmark, and K. Arno (2002). *MySQL reference manual: documentation from the source*. " O'Reilly Media, Inc." Available at: <https://isbnsearch.org/9780596002657>.