

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	12
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	36
9 CloudTrail	44
10 Relational Database Service (RDS)	45
11 Elastic Load Balancing (ELB)	50
12 Security Practices	51
13 Cost Breakdown	52
13.1 Estimated Costs	52
13.2 Scaling Up to 10,000 Users	52
13.3 Scaling Up to One Million Users	52

13.4 Scaling Up to Ten Million Users	52
14 Testing	53
14.1 Testing EC2	53
14.2 Testing S3	55
14.3 Testing CloudFront	56
14.4 Testing RDS	59
14.5 Testing CloudWatch	59
14.6 Testing CloudTrail	59
14.7 Testing ELB	60
15 Future Enhancements	61
16 Conclusion	62

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.	15
4.13	Viewing the newly created subnets.	15
4.14	Creating a public route table.	15
4.15	Creating a private route table.	16
4.16	Associating the public subnets with the public route table.	16
4.17	Associating the private subnets with the private route table.	17
4.18	Editing the public route table.	17
4.19	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
7.1	Applying CloudFront bucket policy.	29
7.2	Applying CloudFront origins to S3 bucket.	29
7.3	Applying CloudFront Distribution Permissions.	30
7.4	Applying CloudFront Cache Keys and Origin Requests.	30
7.5	Function Association.	31
7.6	Applying CloudFront Settings.	32
7.7	Applying CloudFront Settings.	32
7.8	Created CloudFront Distribution.	33
7.9	Image location before CloudFront.	33
7.10	Image location after CloudFront.	34
7.11	Image location after CloudFront.	35
8.1	Selection of CloudWatch metric for EC2 instance.	36
8.2	Configuration of NetworkPacketsOut Metric.	37
8.3	Configuration of NetworkPacketsOut Metric.	37
8.4	Configuration of SNS Topic for email alerts on alarm activation.	38
8.5	CloudWatch SNS Topic Email.	38
8.6	Successful subscription to SNS topic.	38
8.7	Configuration for EC2 instance to reboot on alarm activation.	39
8.8	CloudWatch alarm description.	39
8.9	CloudWatch network alarm in dashboard.	40
8.10	Selection of <code>EstimatedCharges</code> CloudWatch metric.	40
8.11	Configuration of CloudWatch alarm.	41
8.12	Configuration of CloudWatch alarm.	41
8.13	Setting CloudWatch charges SNS topic	42
8.14	Description of CloudWatch alarm.	42
8.15	CloudWatch charges alarm live in CloudWatch dashboard.	43
10.1	Selection of CloudWatch metric for EC2 instance.	45
10.2	Selection of CloudWatch metric for EC2 instance.	45
10.3	Selection of CloudWatch metric for EC2 instance.	46
10.4	Selection of CloudWatch metric for EC2 instance.	47
10.5	Selection of CloudWatch metric for EC2 instance.	47
10.6	Selection of CloudWatch metric for EC2 instance.	47

10.7 Selection of CloudWatch metric for EC2 instance.	48
10.8 Selection of CloudWatch metric for EC2 instance.	48
10.9 Selection of CloudWatch metric for EC2 instance.	48
10.10Selection of CloudWatch metric for EC2 instance.	49
10.11Selection of CloudWatch metric for EC2 instance.	49
10.12Selection of CloudWatch metric for EC2 instance.	49
10.13Selection of CloudWatch metric for EC2 instance.	49
14.1 Digital Ink image whilst connected to UK IP.	57
14.2 UK IP Location.	57
14.3 Digital Ink image whilst connected to US IP.	58
14.4 US IP Location.	58

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
- **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
- **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. We 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 ([lee2003open](#)). The web app is hosted within a Docker container ([anderson2015docker](#)) 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 ([fielding1997apache](#)). MySQL is an open-source relational database management system ([widenius2002mysql](#)) 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 ([lerdorf2002programming](#)). 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. As shown in Figure 3.1, the database which this web app uses consists of three tables: `users`, `stories`, and `migrations`.

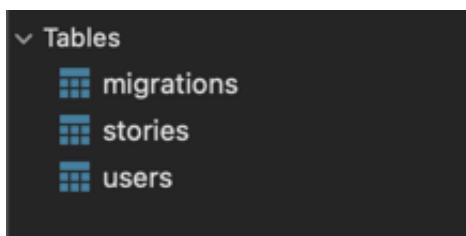


Figure 3.1: Database tables overview.

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:

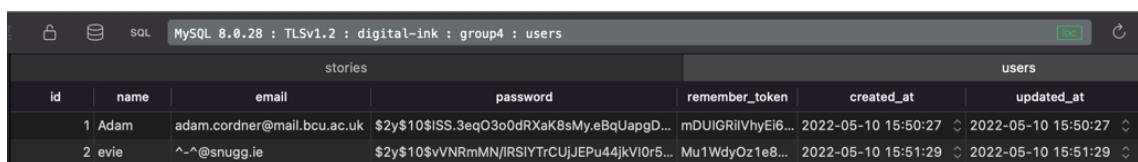
- `id`: the unique ID for each migration.
- `migration`: points to the scripts used to create tables.
- `batch`: how many times the script has been ran.

<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 (laravel2022hashing)**.
- `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.



The screenshot shows the MySQL Workbench interface with a database named 'TL5v1.2' and a schema named 'digital-ink'. The 'users' table is selected. The table has the following structure:

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>
		<code>cover_image</code>	<code>file_upload</code>	<code>published</code>	<code>created_at</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>./storage/cover_images/7537329101652200606.j...</code>	NULL	1	2022-05-10 16:36:46 ⏺ 2022-05-10 16:36:46 ⏺
		images/digital-ink-logo.png	NULL	1	2022-05-10 16:38:51 ⏺ 2022-05-10 16:38:51 ⏺

Figure 3.4: `stories` table.

3.3 Interface Design

The design of the web app was created using Blade, a powerful templating engine ([laravel2022blade](#)). 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.



The figure shows the Digital Ink home page with two forms: a login form at the top and a sign-up form below it.

Login Form:

- Email: Enter Email
- Password: Enter Password
- Remember me:
- Login button (purple rounded rectangle)
- Text: Don't have an account already? Why not sign up?

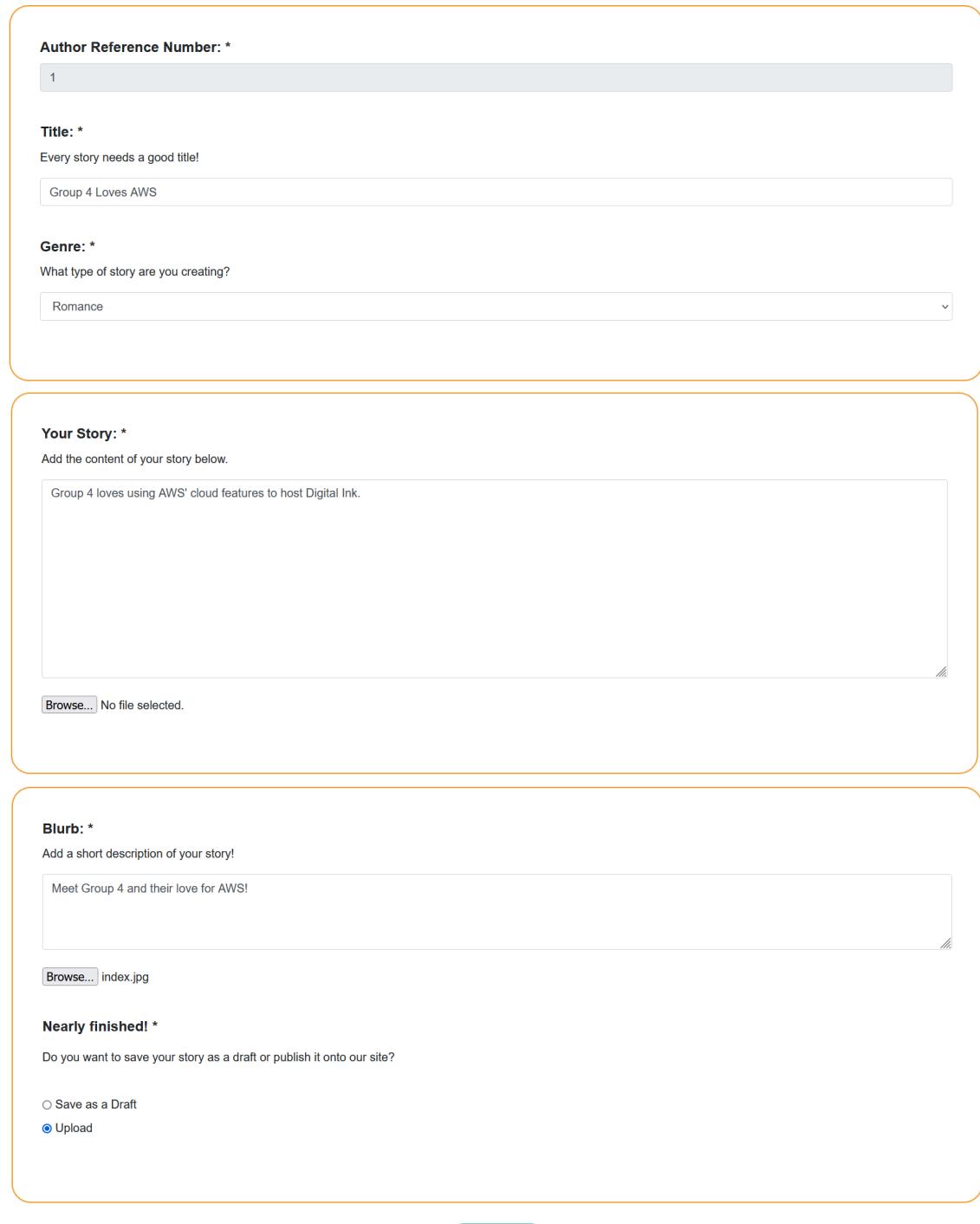
Sign Up Form:

- Name: Enter Name
- Email: Enter Email
- Password: Enter Password
- Repeat Password: Repeat Password
- Sign Up button (purple rounded rectangle)

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 shows a three-panel interface for creating a story. The top panel is titled 'Create your story!' and contains fields for 'Author Reference Number' (with value '1'), 'Title' (with placeholder 'Every story needs a good title!' and value 'Group 4 Loves AWS'), and 'Genre' (with placeholder 'What type of story are you creating?' and value 'Romance'). The middle panel is titled 'Your Story:' and contains a text area with placeholder text 'Group 4 loves using AWS' cloud features to host Digital Ink.' and a file selection button 'Browse...' showing 'No file selected.'. The bottom panel is titled 'Blurb:' and contains a text area with placeholder text 'Meet Group 4 and their love for AWS!' and a file selection button 'Browse...' showing 'index.jpg'. It also includes a section titled 'Nearly finished! *' with a question 'Do you want to save your story as a draft or publish it onto our site?' and two options: 'Save as a Draft' (unchecked) and 'Upload' (checked). A 'Complete' button is located at the bottom right of the bottom panel.

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.

Browse... No file selected.

Blurb: *

Add a short description of your story!

Meet Group 4 and their love for AWS!

Browse... index.jpg

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 header bar 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 "Actions" column contains two buttons: "Edit" (highlighted with a green oval) and "Delete" (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 the "Stories" page and a detailed view of a specific story. The top part is a table listing stories by Author ID, Title, Genre, and Blurb. The second row shows a story titled "cheese savoury" in the Action and Adventure genre with the blurb "nice and simple". The bottom part shows a detailed view for the story "Group 4 Loves AWS". It includes a thumbnail image of a person, the title "Group 4 Loves AWS", the author "Written by: 1", the genre "Genre: Romance", and a blurb: "Meet Group 4 and their love for AWS!". A back button is visible at the bottom left.

AUTHOR ID	TITLE	GENRE	BLURB
1	Group 4 Loves AWS	Romance	Meet Group 4 and their love for AWS!
2	cheese savoury	Action and Adventure	nice and simple

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 (**amazon2022what**). 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.

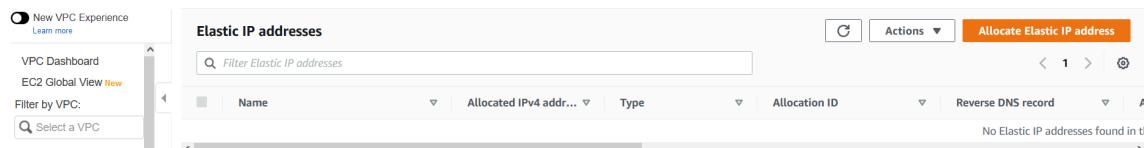


Figure 4.1: Elastic IP addresses page.

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.

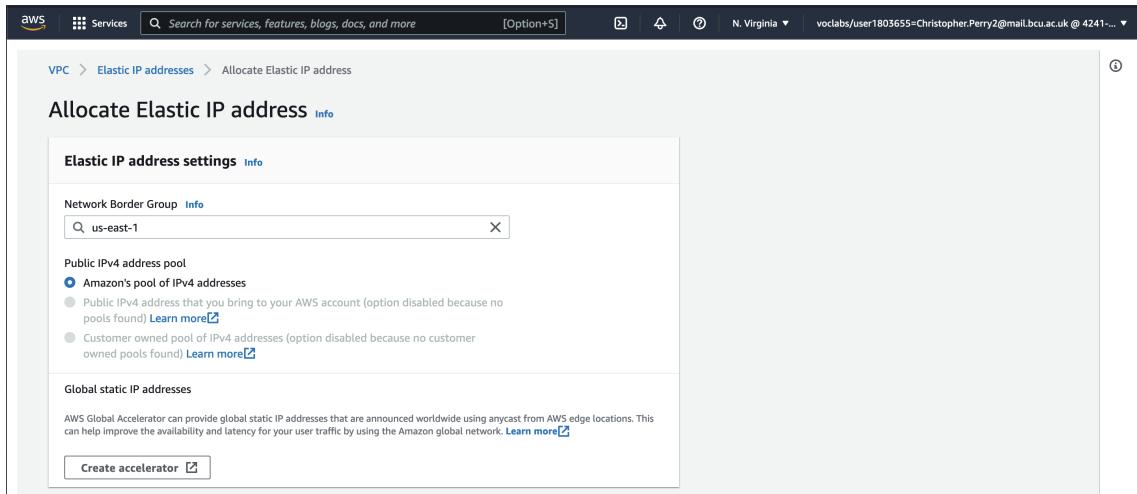


Figure 4.2: Configuring the Elastic IP address.

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

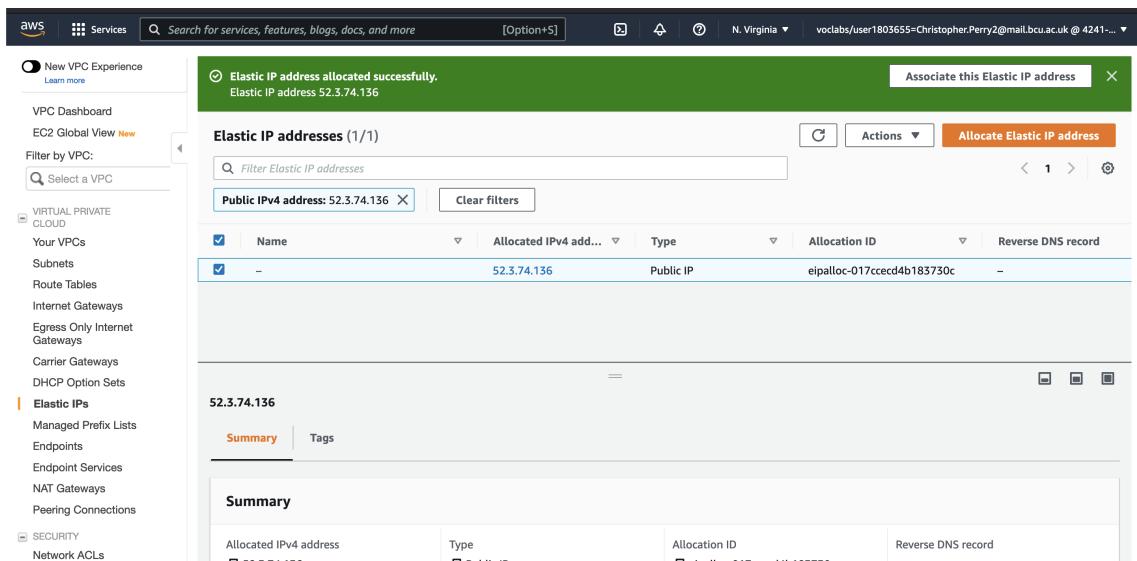


Figure 4.3: Created Elastic IP address.

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.

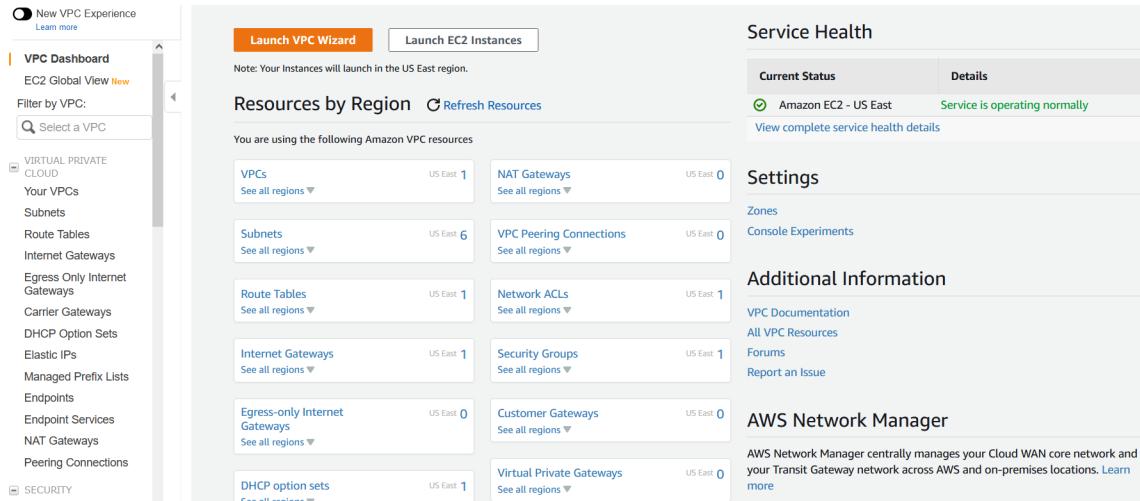


Figure 4.4: VPC Management Console.

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.

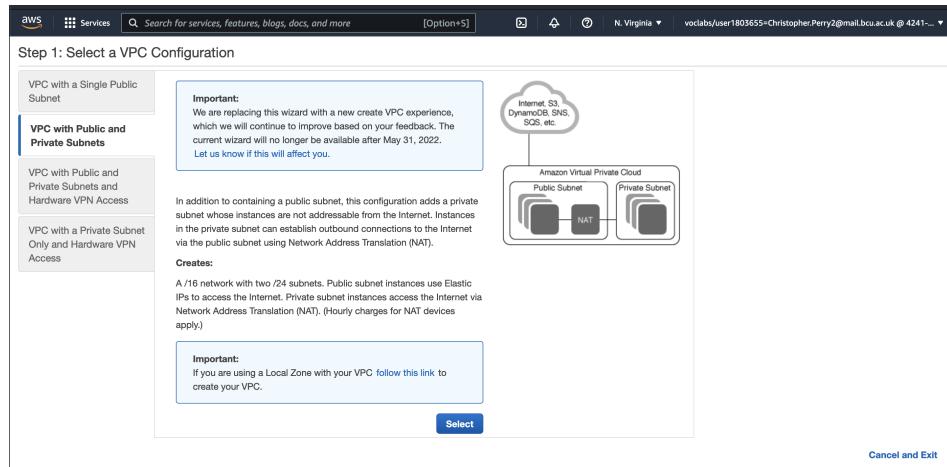


Figure 4.5: Selecting a VPC configuration.

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.

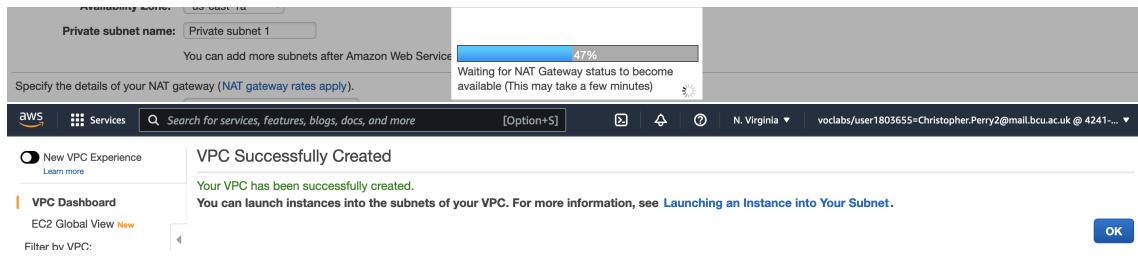


Figure 4.7: Generating the VPC.

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.

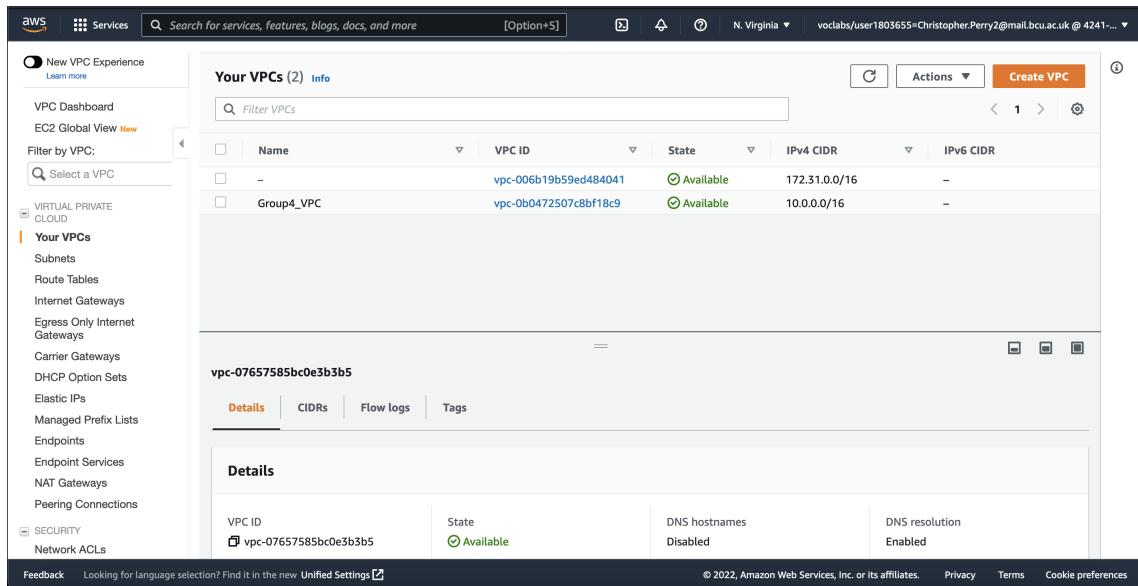


Figure 4.8: Your VPCs page.

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 (**amazon2022connect**). 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.

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).

The screenshot shows the 'Create internet gateway' wizard in the AWS VPC service. The first step, 'Internet gateway settings', is completed with a name tag 'Group4-Internet-Gateway'. The second step, 'Tags - optional', shows one tag 'Group4-Internet-Gateway' added. The third step, 'Review', shows the gateway details and a 'Create internet gateway' button.

Name tag	Value
Group4-Internet-Gateway	

Tags - optional

Key	Value - optional
Name	Group4-Internet-Gateway

Create internet gateway

Figure 4.9: Creating an internet gateway.

The screenshot shows the 'Internet gateways' list in the AWS VPC service. It displays two entries: one unnamed gateway attached to a specific VPC and the 'Group4-Internet-Gateway' created in Figure 4.9, which is attached to a 'Group4_VPC'.

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.

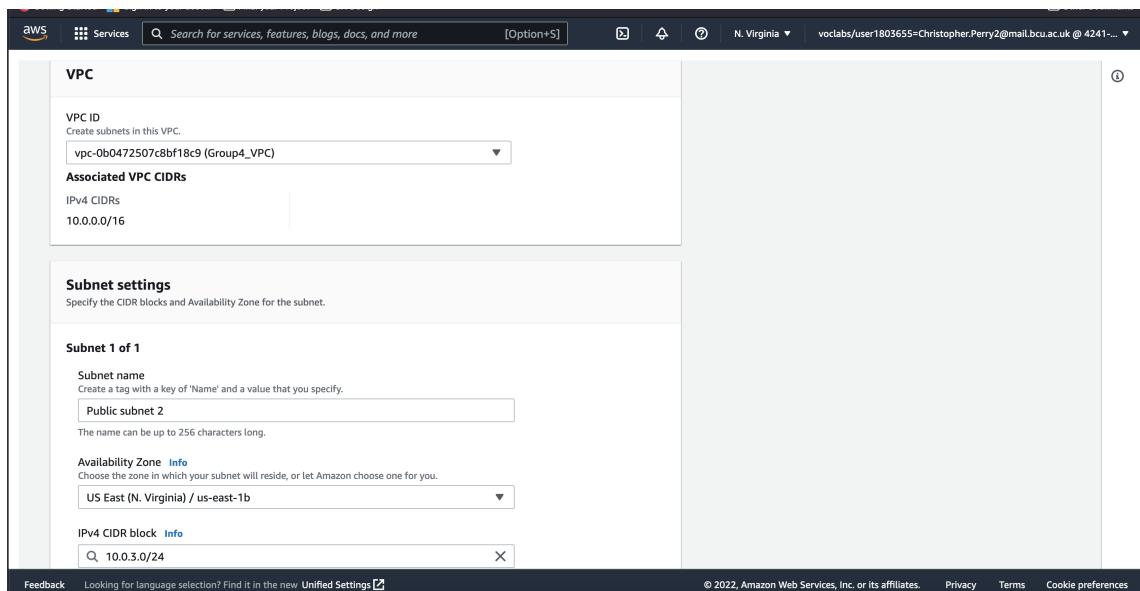


Figure 4.11: Creating a second public subnet.

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.

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).

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.

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`

The screenshot shows the AWS VPC Subnet creation interface. In the 'Associated VPC CIDRs' section, the CIDR block '10.0.0.0/16' is listed. In the 'Subnet settings' section, 'Subnet 1 of 1' is selected. The 'Subnet name' is 'Private subnet 2'. The 'Availability Zone' is set to 'US East (N. Virginia) / us-east-1b'. The 'IPv4 CIDR block' is '10.0.4.0/24'. A success message at the bottom states: 'Feedback Looking for language selection? Find it in the new Unified Settings'.

Figure 4.12: Creating a second private subnet.

The screenshot shows the AWS VPC Subnets list. A green banner at the top says: 'You have successfully created 1 subnet: subnet-0ccf3a5735ad3995f'. The table lists three subnets:

Name	Subnet ID	State	VPC	IPv4 CIDR
Private subnet 2	subnet-0ccf3a5735ad3995f	Available	vpc-0b0472507c8bf18c9 Gro...	10.0.4.0/24
Public subnet 2	subnet-09b56eb86b873cc4c	Available	vpc-0b0472507c8bf18c9 Gro...	10.0.3.0/24
-	subnet-0b6436ace896ba7a8	Available	vpc-006b19b59ed484041 Gr...	172.31.0.0/20

Figure 4.13: Viewing the newly created subnets.

The screenshot shows the AWS Route Tables creation interface. In the 'Route table settings' section, the 'Name - optional' field contains 'Public route'. The 'VPC' dropdown is set to 'vpc-0b0472507c8bf18c9 (Group4_VPC)'. The navigation bar shows 'VPC > Route tables > Create route table'.

Figure 4.14: Creating a public route table.

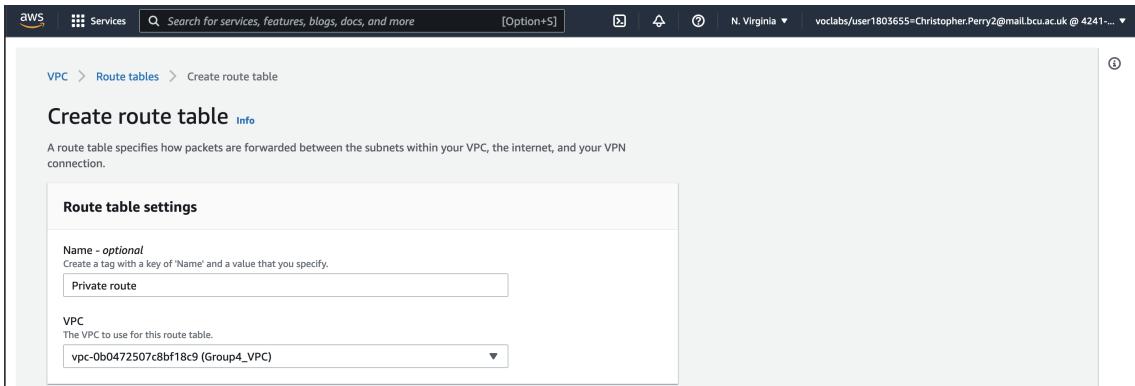


Figure 4.15: Creating a private route table.

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`.

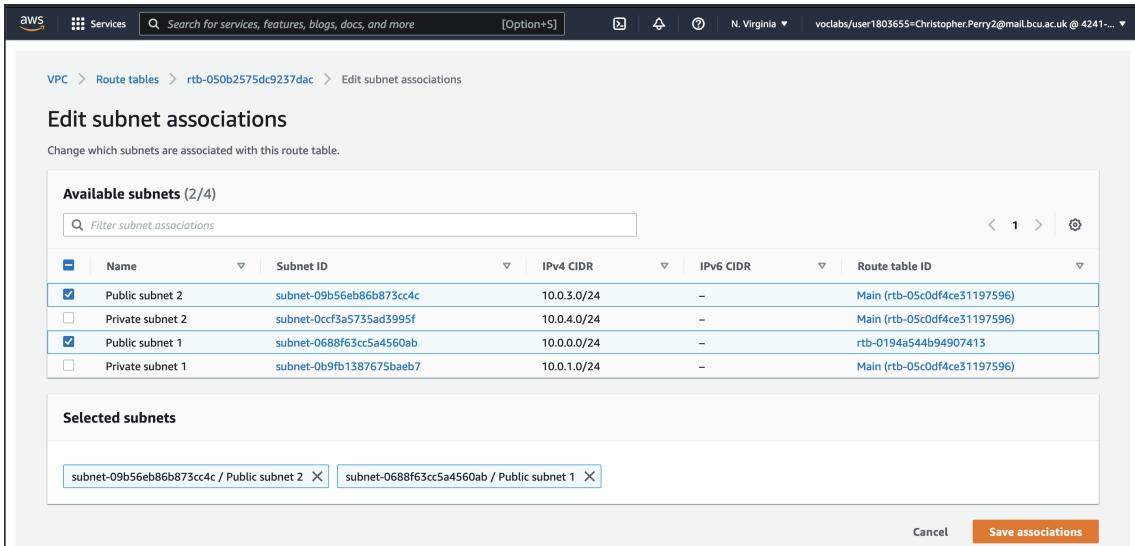


Figure 4.16: Associating the public subnets with the public route table.

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.

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

Available subnets (2/4)

Name	Subnet ID	IPv4 CIDR	IPv6 CIDR	Route table ID
Public subnet 2	subnet-09b56eb86b873cc4c	10.0.3.0/24	-	rtb-050b2575dc9237dac / Public route
Private subnet 2	subnet-0ccf3a5735ad3995f	10.0.4.0/24	-	Main (rtb-05c0df4ce31197596)
Public subnet 1	subnet-0688f63cc5a4560ab	10.0.0.0/24	-	rtb-050b2575dc9237dac / Public route
Private subnet 1	subnet-0b9fb1387675baeb7	10.0.1.0/24	-	Main (rtb-05c0df4ce31197596)

Selected subnets

- subnet-0ccf3a5735ad3995f / Private subnet 2
- subnet-0b9fb1387675baeb7 / Private subnet 1

[Cancel](#) [Save associations](#)

Figure 4.17: Associating the private subnets with the private route table.

Edit routes

Destination	Target	Status	Propagated
10.0.0.0/16	<input type="text" value="local"/> Remove	Active	No
0.0.0.0/0	<input type="text" value="igw-0b9a9bed921c1370f"/> Remove	-	No

[Add route](#) [Cancel](#) [Preview](#) [Save changes](#)

Figure 4.18: Editing the public route table.

Updated routes for rtb-050b2575dc9237dac / Public route successfully

Details

Route table ID	Main	Explicit subnet associations	Edge associations
rtb-050b2575dc9237dac	<input checked="" type="checkbox"/> No	2 subnets	-
VPC	Owner ID	424176735797	

Routes (2)

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

[Edit routes](#)

Figure 4.19: 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 (**aws2022ec2**). 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.

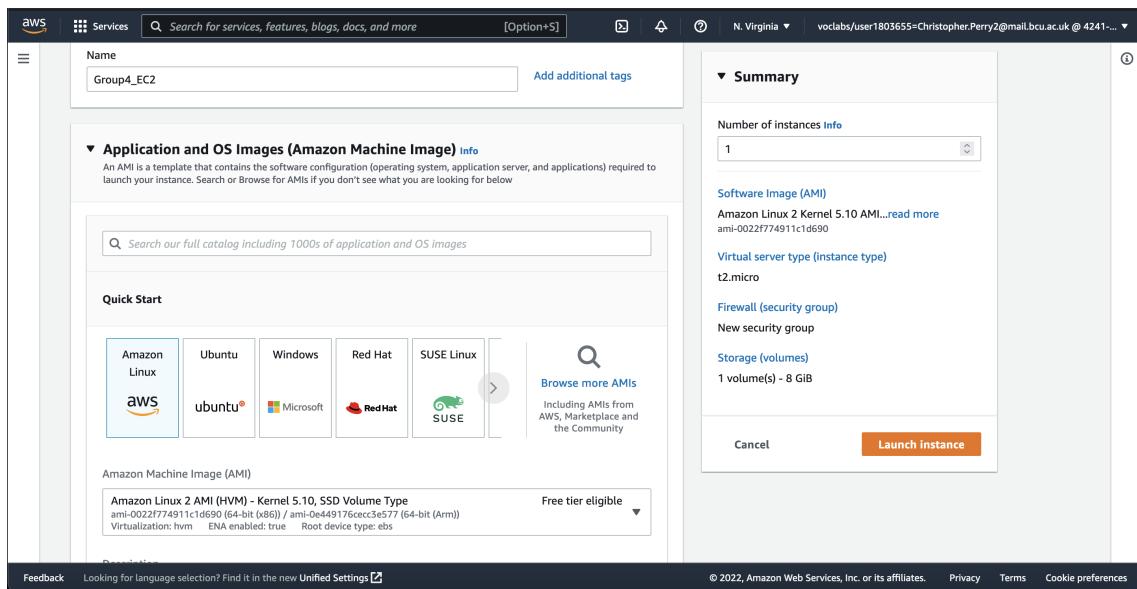


Figure 5.1: Selection of EC2 OS Image.

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.

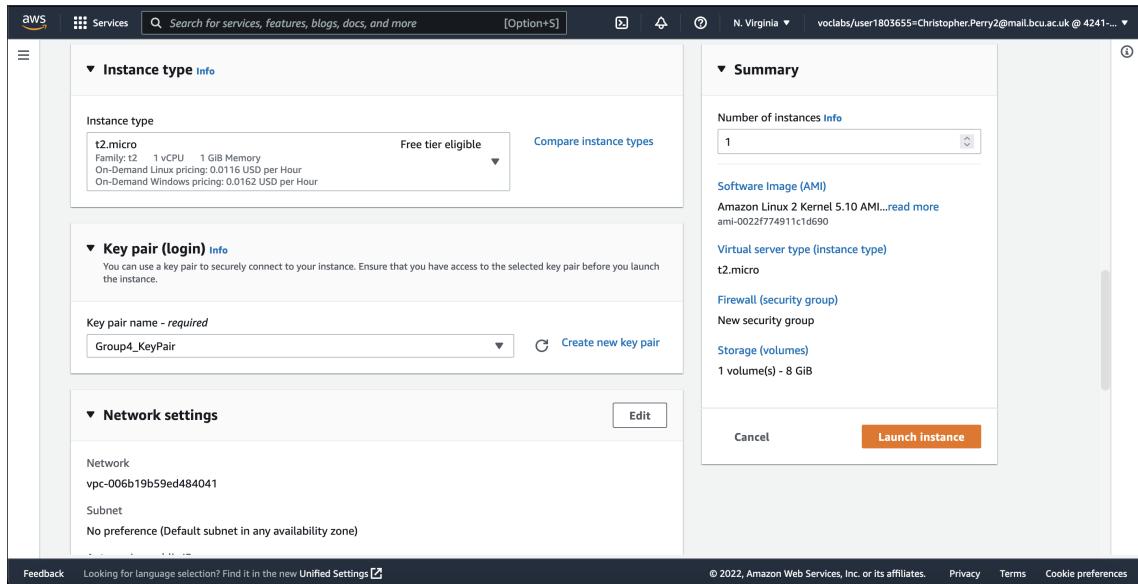


Figure 5.2: Selection of EC2 Instance.

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.

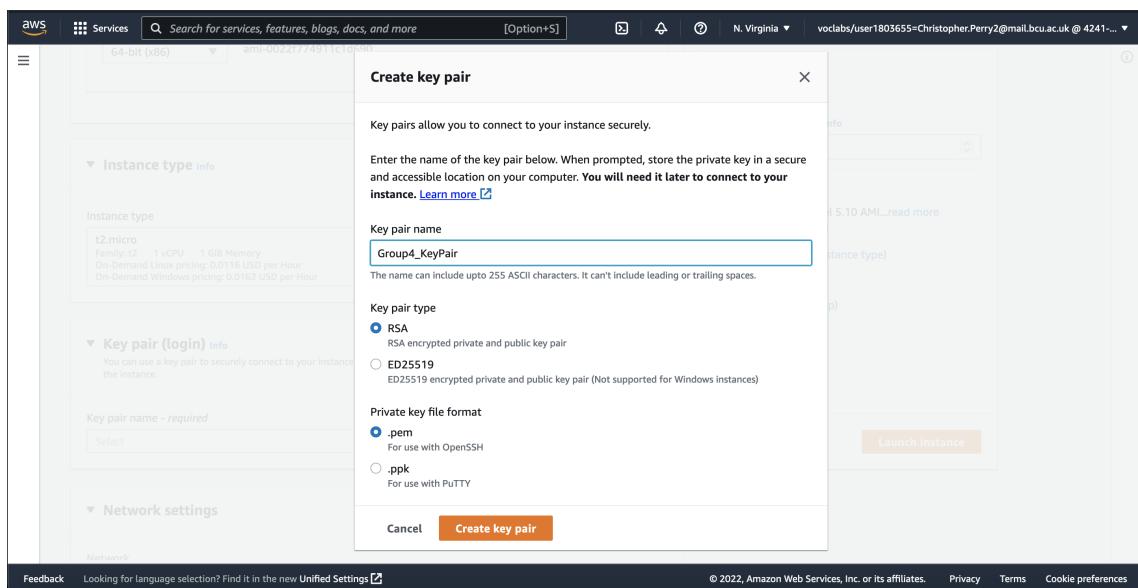


Figure 5.3: Selection of EC2 Keypair.

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.

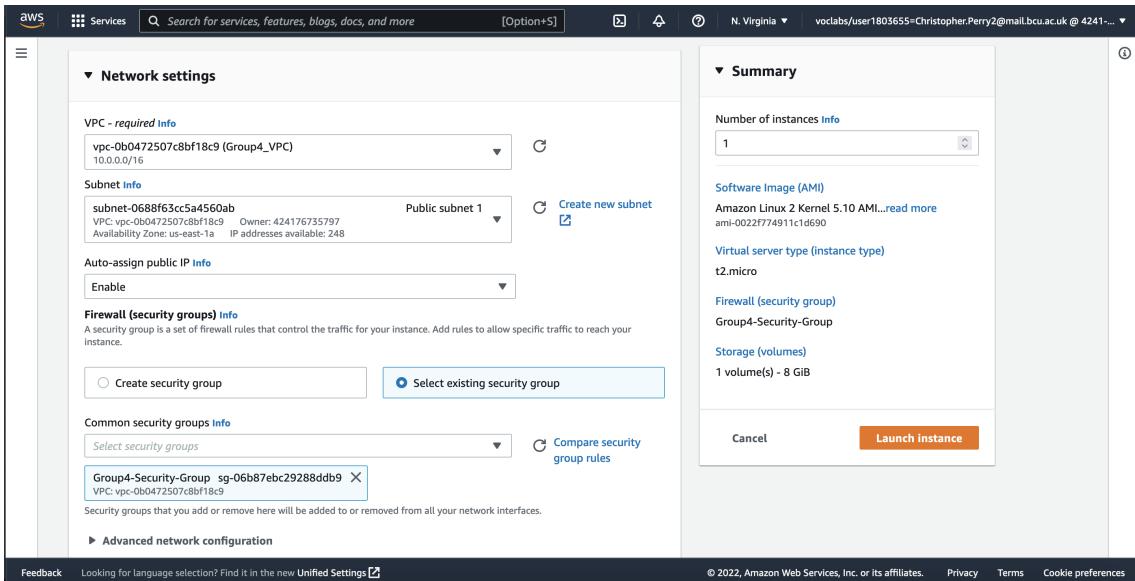


Figure 5.4: Selection of EC2 Networking options.

```
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.

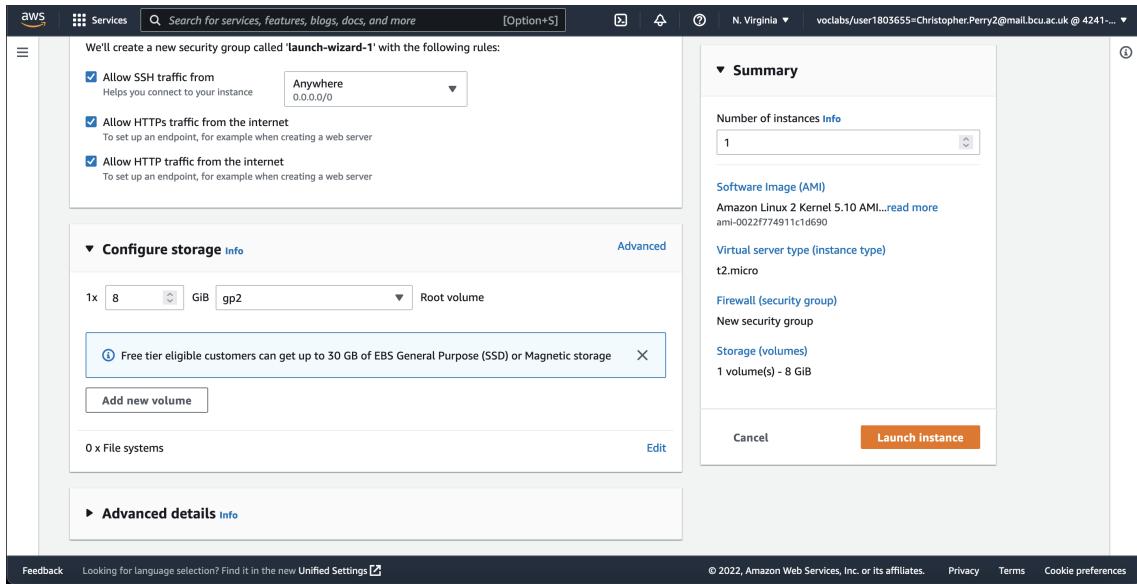


Figure 5.6: Selection of EC2 Storage Configuration.

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 macOS terminal window titled "ec2-user@ip-10-0-0-184:~". The window has two tabs: "sktop/Keypair (-zsh)" (tab 1) and "ec2-user@ip-10-0-0-184:~ (ssh)" (tab 2). The ssh tab shows the command being run: `> ssh -i Group4_KeyPair.pem ec2-user@54.145.212.82`. Below the command, the output shows the last login information: "Last login: Fri May 13 21:38:32 2022 from 193.60.143.12" and the Amazon Linux 2 AMI logo. At the bottom of the terminal, the URL `https://aws.amazon.com/amazon-linux-2/` is displayed, along with the prompt "[ec2-user@ip-10-0-0-184 ~]\$".

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-Git-2.30-20.amzn2.0.2.x86_64 4/7
Installing : perl-TermReadKey-2.30-20.amzn2.0.2.x86_64 5/7
Installing : perl-Git-2.32.0-1.amzn2.0.1.noarch 6/7
Installing : git-2.32.0-1.amzn2.0.1.x86_64 7/7
Verifying : perl-TermReadKey-2.30-20.amzn2.0.2.x86_64 1/7
Verifying : git-2.32.0-1.amzn2.0.1.x86_64 2/7
Verifying : perl-Git-2.32.0-1.amzn2.0.1.noarch 3/7
Verifying : 1:emacs-filesystem-27.2-4.amzn2.0.1.noarch 4/7
Verifying : git-2.32.0-1.amzn2.0.1.x86_64 5/7
Verifying : git-core-2.32.0-1.amzn2.0.1.x86_64 6/7
Verifying : 1:perl-Error-0.17020-2.amzn2.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.

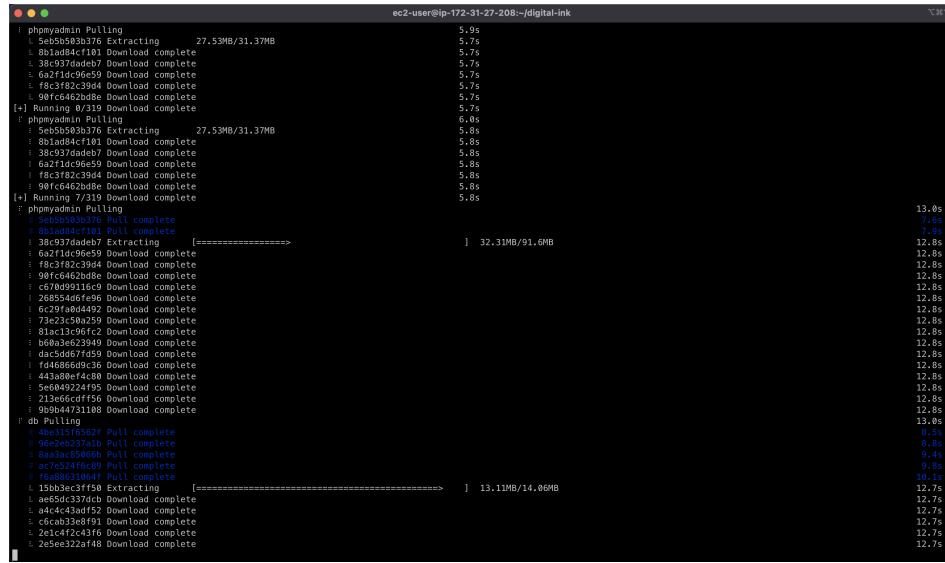


Figure 5.12: Containers required for the web app being pulled from Docker Hub.

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://ec2-52-45-13-111.compute-1.amazonaws.com/>, Digital Ink will now be shown.

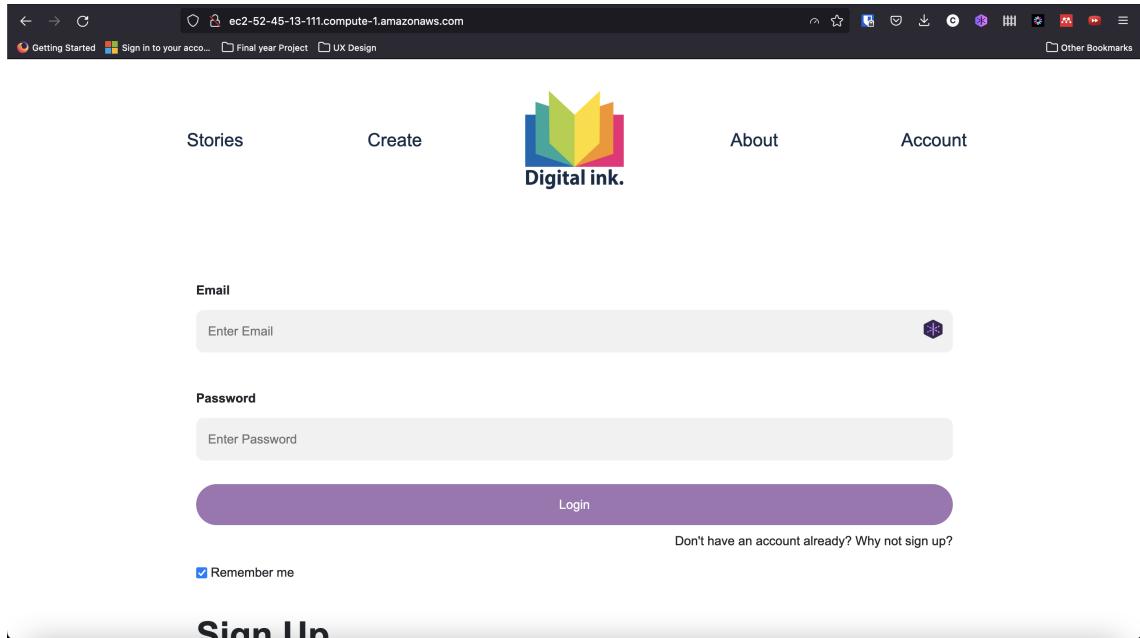
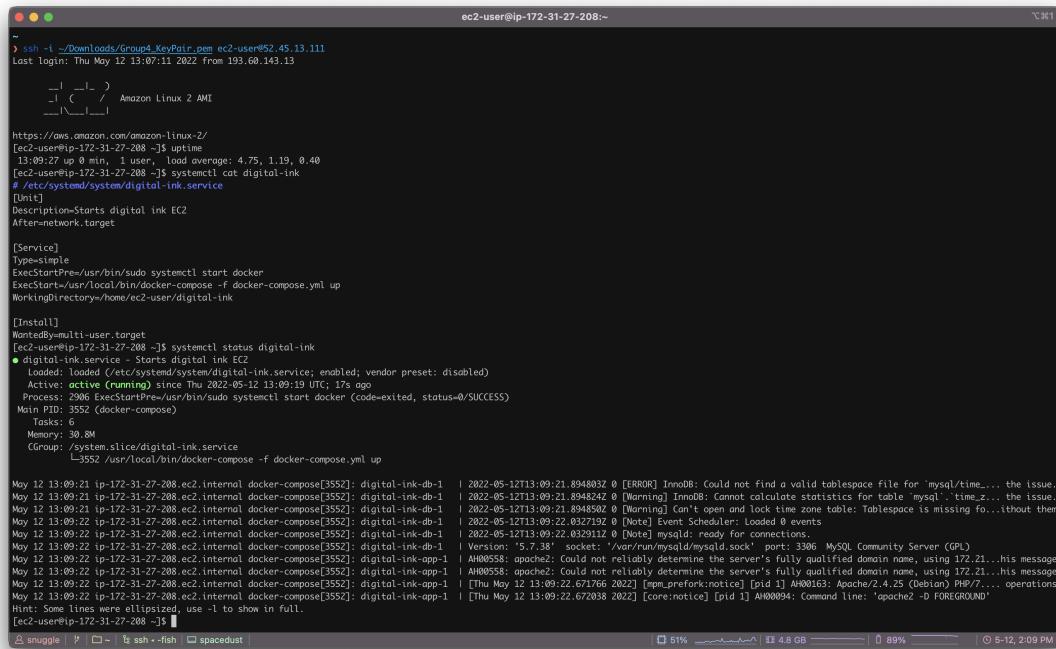


Figure 5.14: Digital Ink shown when accessed through the IPv4 address.

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 executing commands to create a systemd service. The terminal output includes:

- SSH session details: ssh -i ~/Downloads/Ground4_KeyPair.pem ec2-user@52.45.13.111
- Last login information: Thu May 12 13:07:11 2022 from 193.60.143.13
- System status: https://aws.amazon.com/amazon-linux-2/ [ec2-user@ip-172-31-27-208 ~]\$ uptime
- Uptime command: 13:09:27 up 0 min, 1 user, load average: 4.75, 1.19, 0.40
- Systemctl status command: [ec2-user@ip-172-31-27-208 ~]\$ systemctl cat digital-ink
- Service configuration file: # /etc/systemd/system/digital-ink.service
- [Unit] section: Description=Starts digital ink EC2
After=network.target
- [Service] section: 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] section: WantedBy=multi-user.target
- Systemctl status command: [ec2-user@ip-172-31-27-208 ~]\$ systemctl status digital-ink
- Service status: ● 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
 Process: 2906 ExecStartPre=/usr/bin/sudo systemctl start docker (code=exited, status=0/SUCCESS)
 Main PID: 3552 (docker-compose)
 Tasks: 6
 Memory: 8.8M
 CGroup: /system.slice/digital-ink.service
 └─3552 /usr/local/bin/docker-compose -f docker-compose.yml up
- Log entries for the digital-ink service:
 - May 12 13:09:21 ip-172-31-27-208.ec2.internal docker-compose[3552]: digital-ink-db-1 | 2022-05-12T13:09:21.894803Z 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 and lock time zone 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/mysql/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] AH001E: Apache/2.4.25 (Debian) PHP/7.0.33 PHP/7.0.33 operations
 - May 12 13:09:22 ip-172-31-27-208.ec2.internal docker-compose[3552]: digital-ink-app-1 | [Thu May 12 13:09:22.672058 2022] [core:notice] [pid 1] AH00094: Command line: 'apache2 -D FOREGROUND'
- Hint: Some lines were elided, use -l to show in full.
- Final command: [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.

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 different nodes, providing data redundancy against multiple different availability zones.

S3 is perhaps the most popular AWS service and used by many different 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 lead for the creation of many 'S3-compatible' or 'S3-like' competitor solutions, such as those run by Google Cloud and Microsoft Azure.

Chapter 7

CloudFront

CloudFront will allow for the distribution of static and dynamic web images more efficiently. An international network of data centres, referred to as edge locations, are used to deliver content for CloudFront. 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.

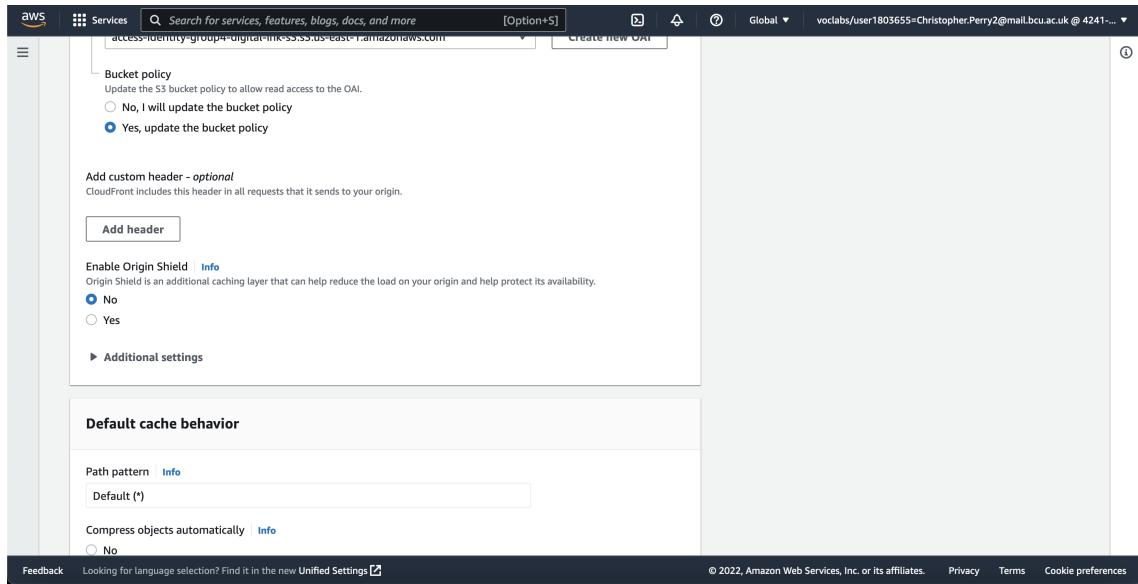


Figure 7.1: Applying CloudFront bucket policy.

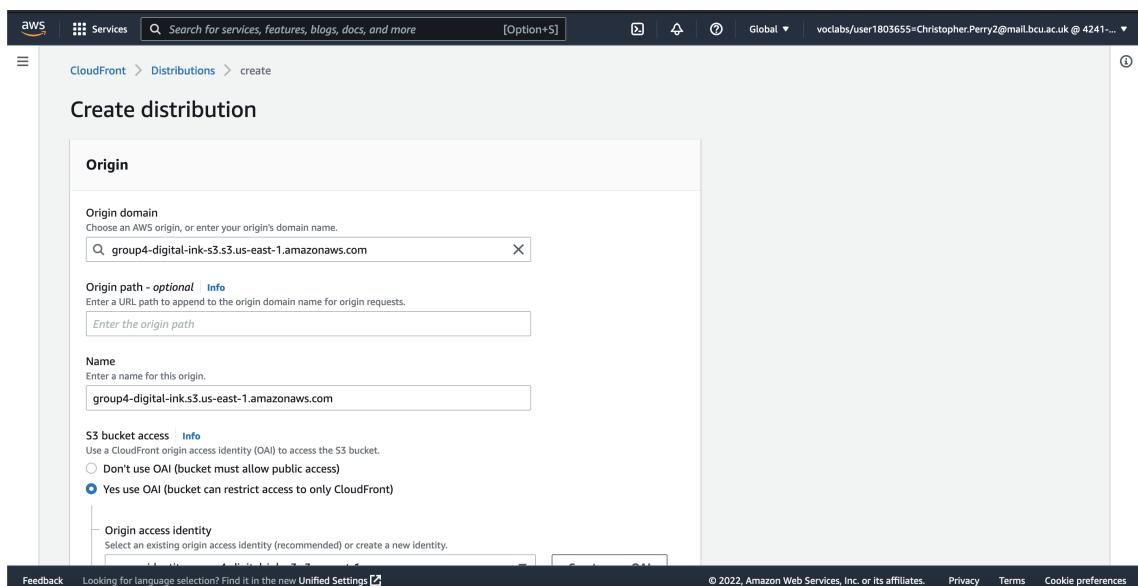


Figure 7.2: Applying CloudFront origins to S3 bucket.

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.

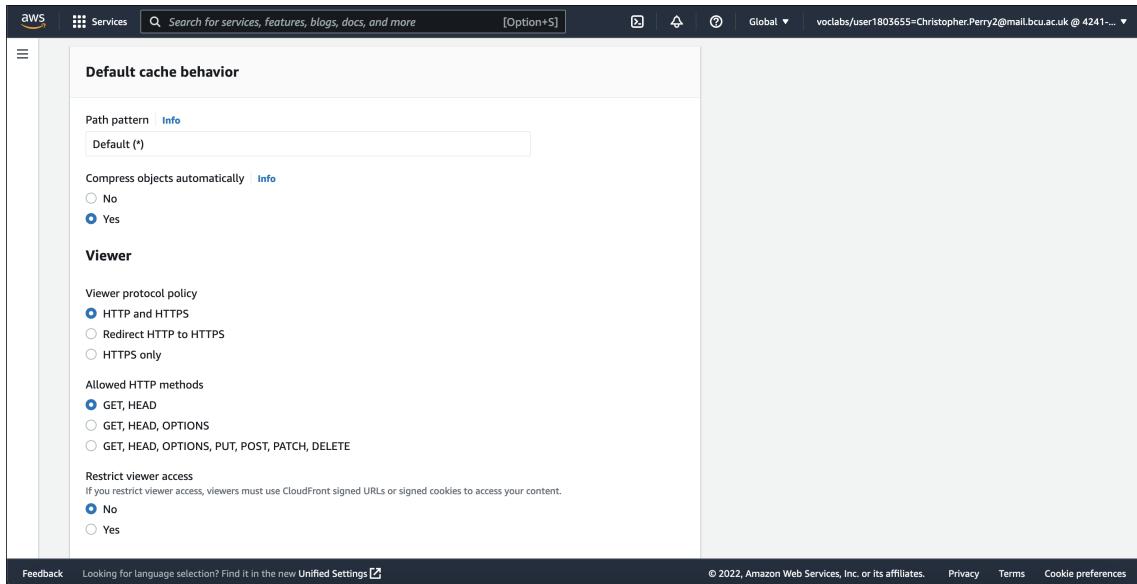


Figure 7.3: Applying CloudFront Distribution Permissions.

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".

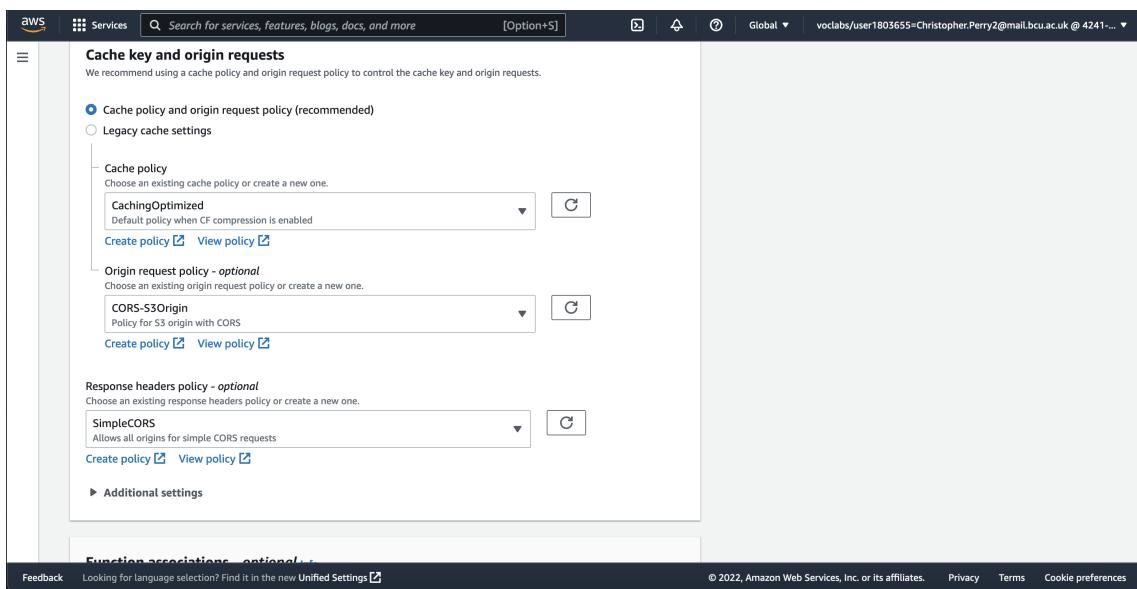


Figure 7.4: Applying CloudFront Cache Keys and Origin Requests.

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

The screenshot shows the 'Function associations - optional' section of the AWS CloudFront Distribution configuration. It includes four dropdown menus for 'Function type': 'Viewer request' (No association), 'Viewer response' (No association), 'Origin request' (No association), and 'Origin response' (No association). Below this is a 'Settings' section with 'Price class' (Info) and 'AWS WAF web ACL - optional'. The 'Price class' dropdown is set to 'Use all edge locations (best performance)'. The 'AWS WAF web ACL' dropdown is set to 'Choose web ACL'. At the bottom, there are links for 'Feedback', 'Looking for language selection? Find it in the new Unified Settings', and 'Cookie preferences'.

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 Figures ?? and 7.7.

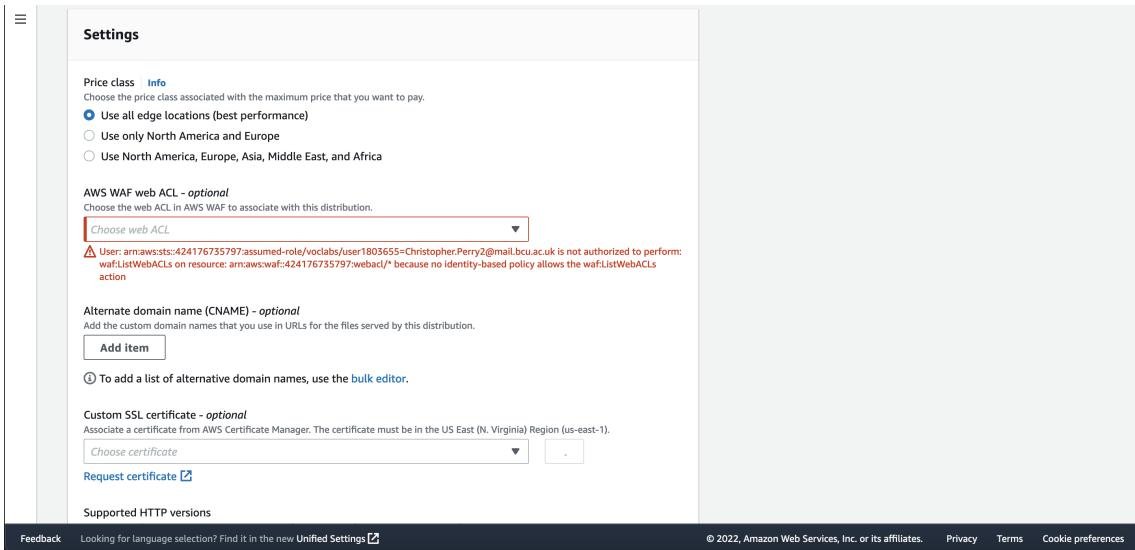


Figure 7.6: Applying CloudFront Settings.

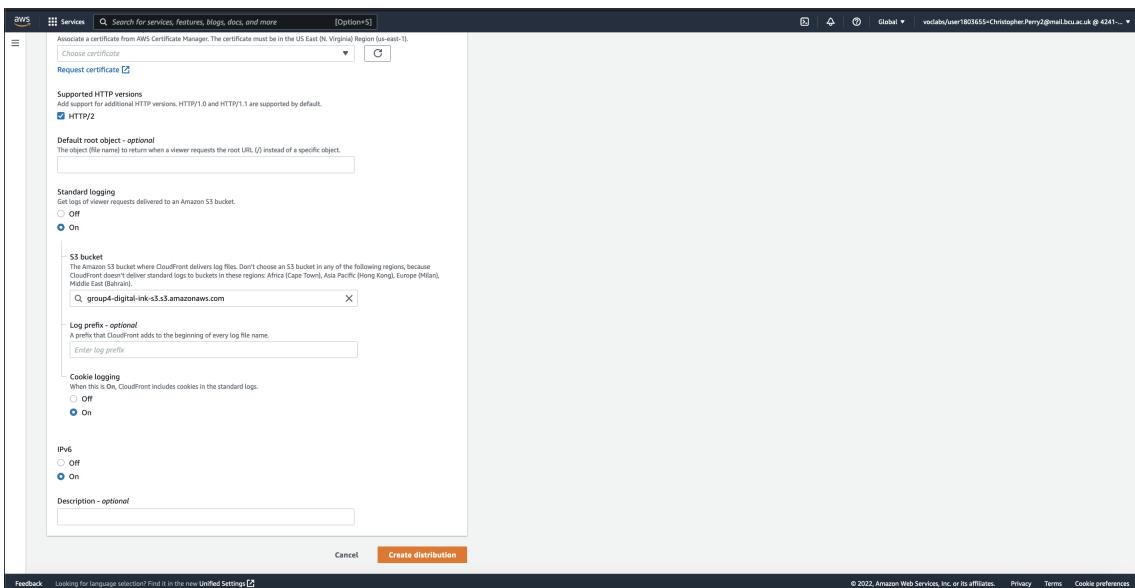


Figure 7.7: Applying CloudFront Settings.

A CloudFront Distribution has now been created, and can be found in Figure 7.8.

The screenshot shows the AWS CloudFront console under the 'Distributions' section. A single distribution is listed with the ID E21BWNC9VESEB5 and the domain name d1bdkf7iuqj4qy.cloudfront.net. The interface includes standard AWS navigation elements like search, enable/disable buttons, and a 'Create distribution' button.

Figure 7.8: 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 7.9 and 7.10.

The screenshot shows a code editor with the file 'base.blade.php' open. The code is a Blade template for a header. At line 51, there is a line of code that sets the source for an image tag to a CloudFront URL: ``. The rest of the code defines a container, a row with two columns for 'stories' and 'create' links, and another row with a homepage link and a logo image.

Figure 7.9: Image location before CloudFront.

The screenshot shows a code editor interface with a dark theme. The top bar displays the path: digital-ink. > resources > views > base.blade.php. The main area shows a portion of the `base.blade.php` file:

```
36 <header>
37   <div class="container">
38     <div class="row">
39       </-- stories page link -->
40       <div class="col header-option">
41         <a href="/stories" class="header-option">Stories</a>
42       </div>
43
44       <div class="col header-option">
45         <a href="/stories/create" class="header-option">Create</a>
46       </div>
47
48       </-- homepage link / logo -->
49       <div class="col header-option">
50         <a href="/">
51           
52         </a>
53       </div>
54
55       <div class="col header-option">
56         <a href="/about" class="header-option">About</a>
      </div>
    </div>.container .row .col.header-option a
```

The line 51 contains the source code for an `img` tag with a CloudFront URL: `src="{{ 'https://d1bdkf7iuqj4qy.cloudfront.net/digital-ink-logo.png' }}"`. The code editor's status bar at the bottom shows "Dockerfile detection: You may setup Docker deployment run configuration for the following file(s): blog/vendor/guzzlehttp/guzzle/Dockerfile // .docker/Dockerfile... (4 minutes ago)".

Figure 7.10: Image location after CloudFront.

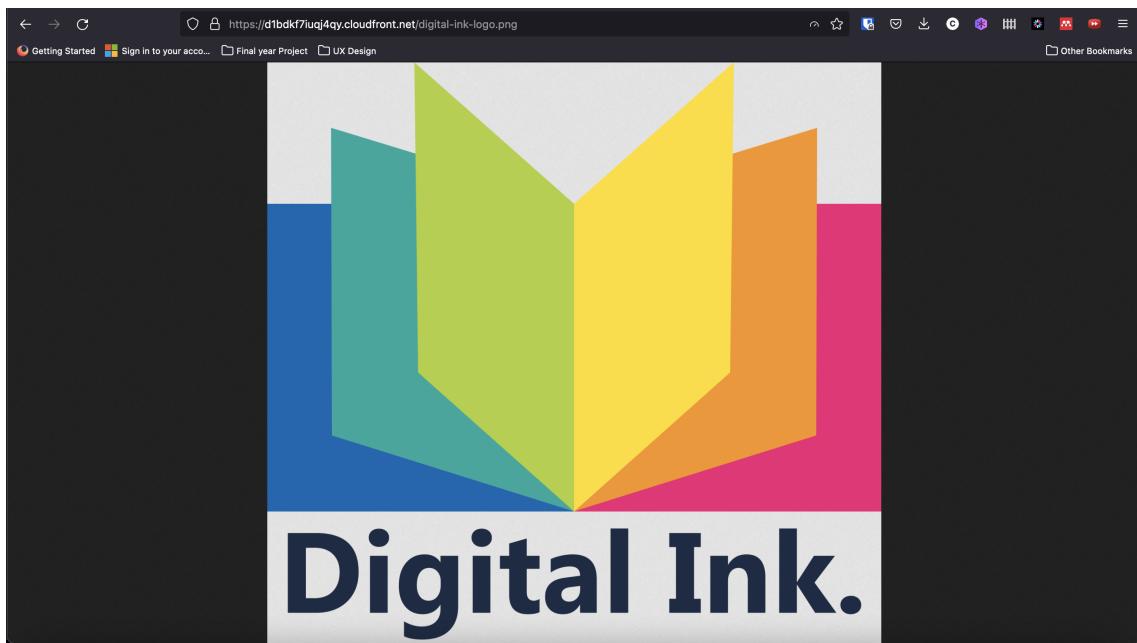


Figure 7.11: Image location after CloudFront.

As seen in Figure 7.11, the Digital Ink logo is now hosted on 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 ([amazon2022amazon](#)). 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.

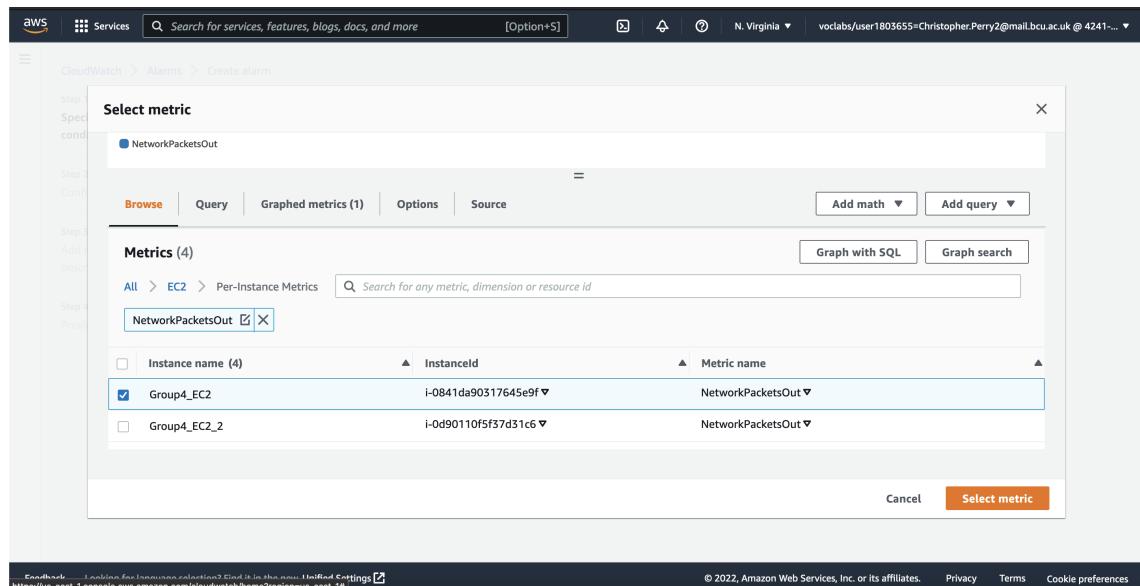


Figure 8.1: Selection of CloudWatch metric for EC2 instance.

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.

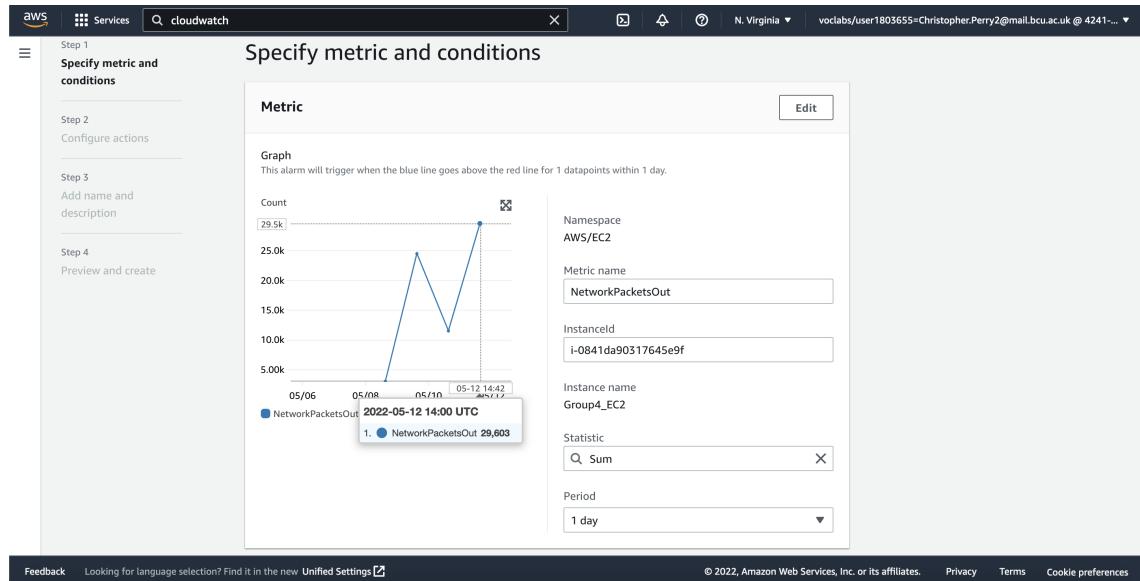


Figure 8.2: Configuration of NetworkPacketsOut Metric.

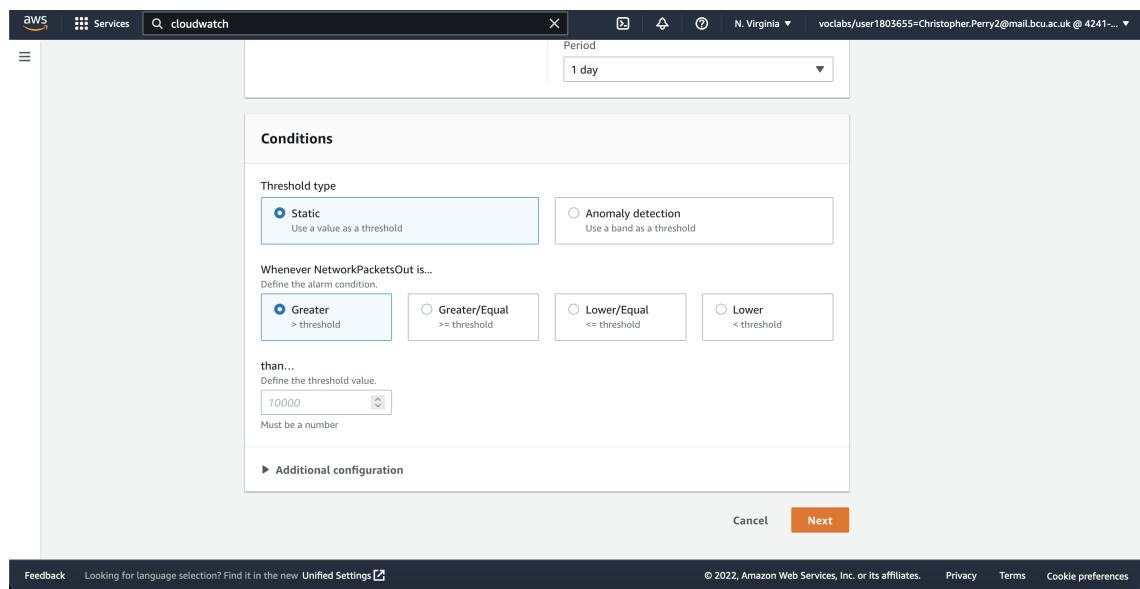


Figure 8.3: Configuration of NetworkPacketsOut Metric.

Figures 8.2 and 8.3 detail the alarm being set so that when the sum of packets sent is less than 5 per day, the alarm will activate.

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 8.4 details this process.

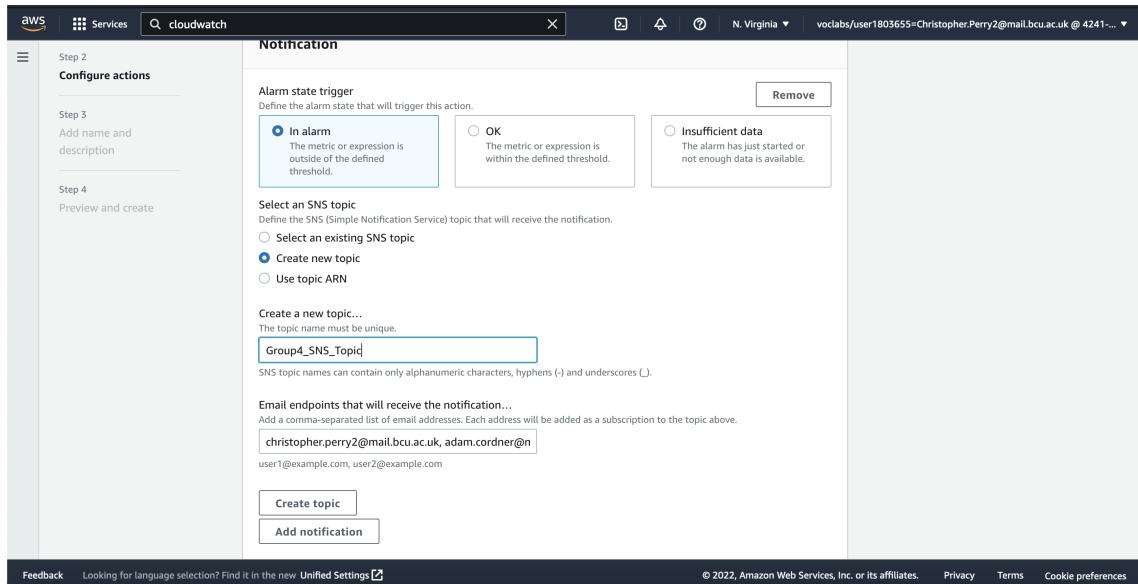


Figure 8.4: Configuration of SNS Topic for email alerts on alarm activation.

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 8.5 and 8.6.

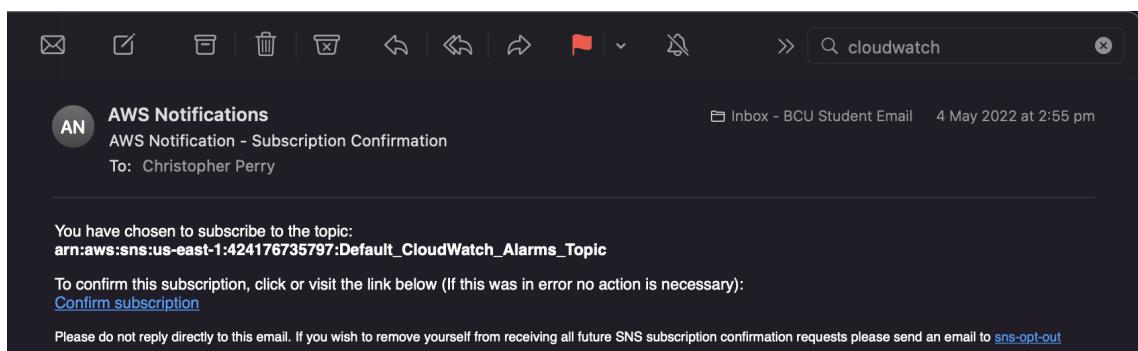


Figure 8.5: CloudWatch SNS Topic Email.

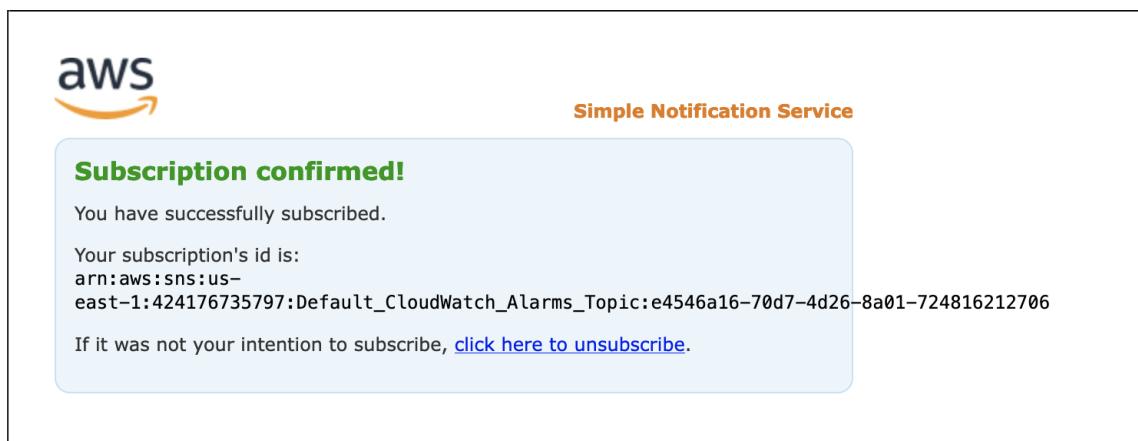


Figure 8.6: Successful subscription to SNS topic.

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 8.7.

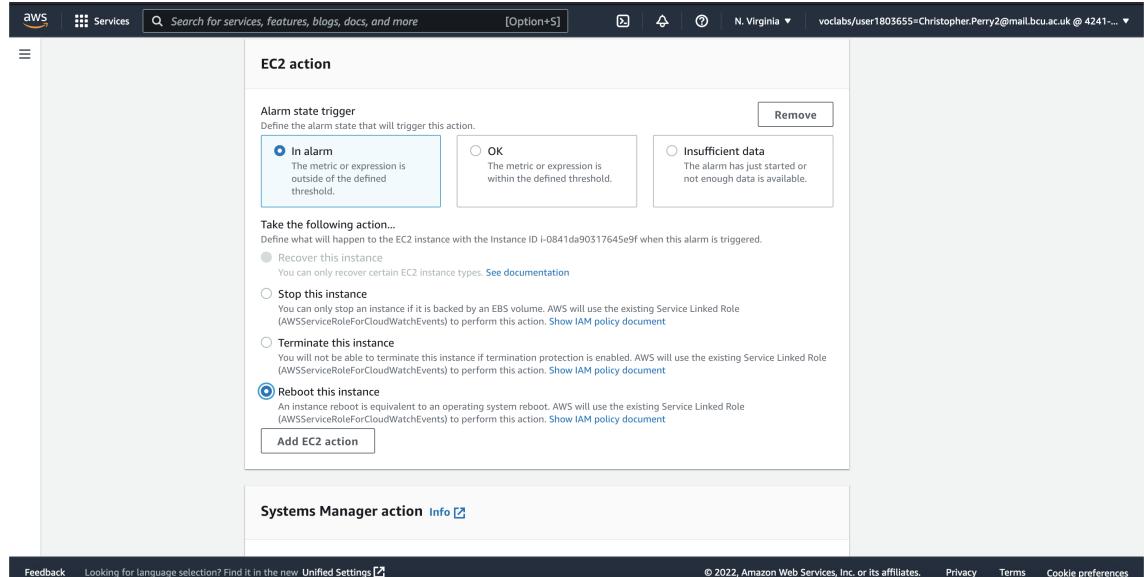


Figure 8.7: Configuration for EC2 instance to reboot on alarm activation.

A brief description of the CloudWatch alarm is then added. This can be seen in Figure 8.8.

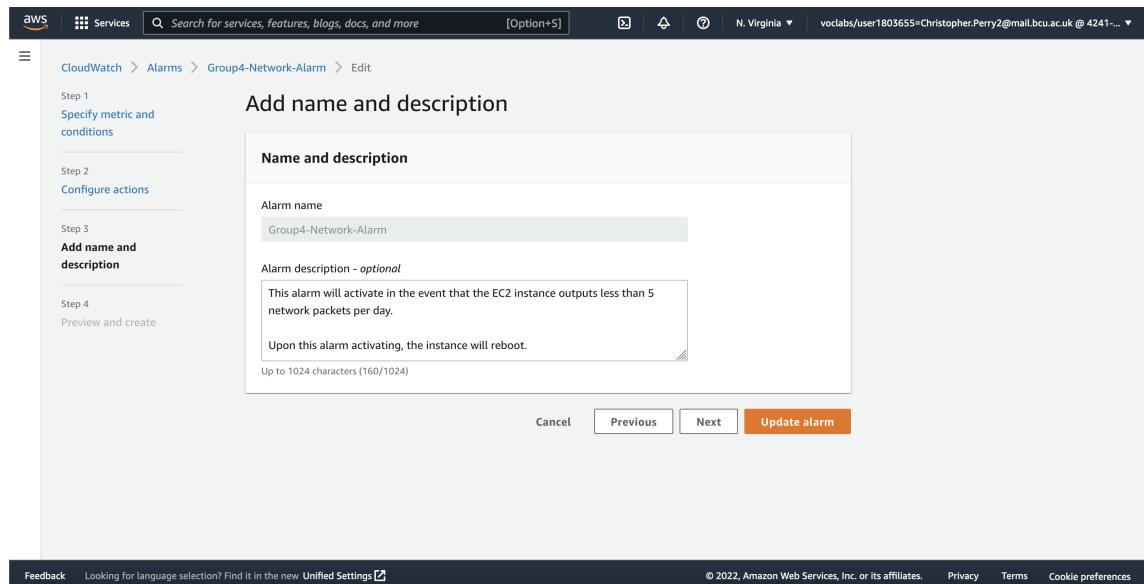


Figure 8.8: CloudWatch alarm description.

The alarm has now been set up, and can be seen in the CloudWatch Management Dashboard in Figure 8.9.

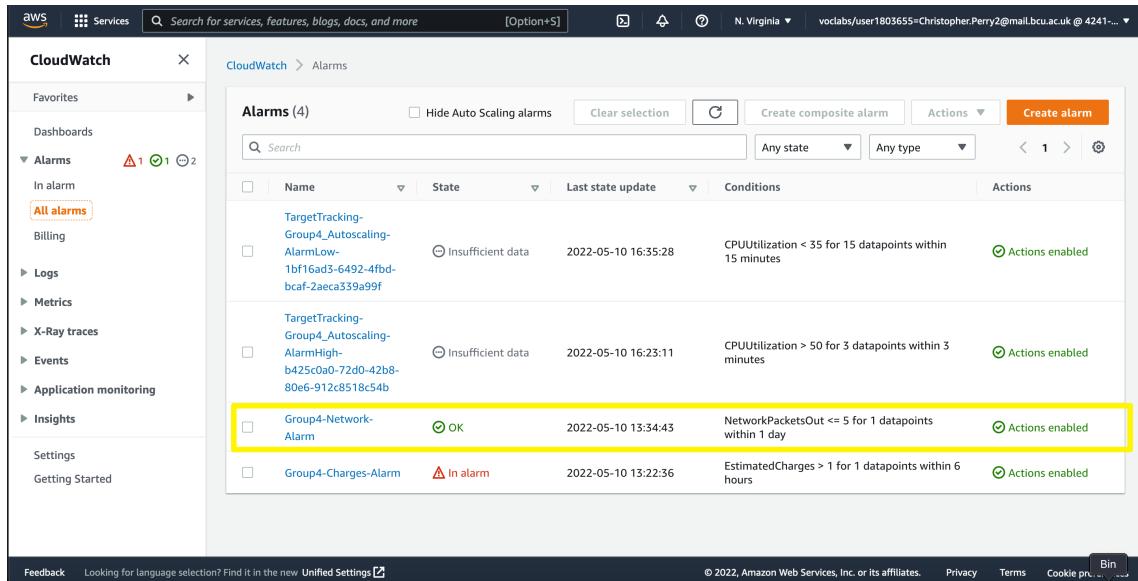


Figure 8.9: CloudWatch network alarm in dashboard.

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 8.10.

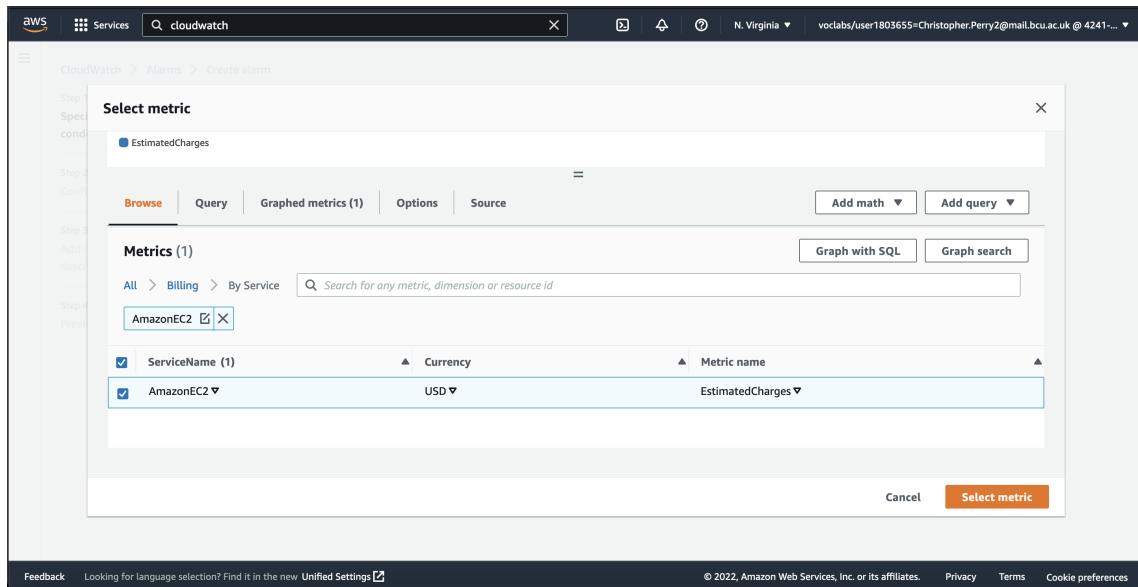


Figure 8.10: Selection of EstimatedCharges CloudWatch metric.

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 8.11 and 8.12.

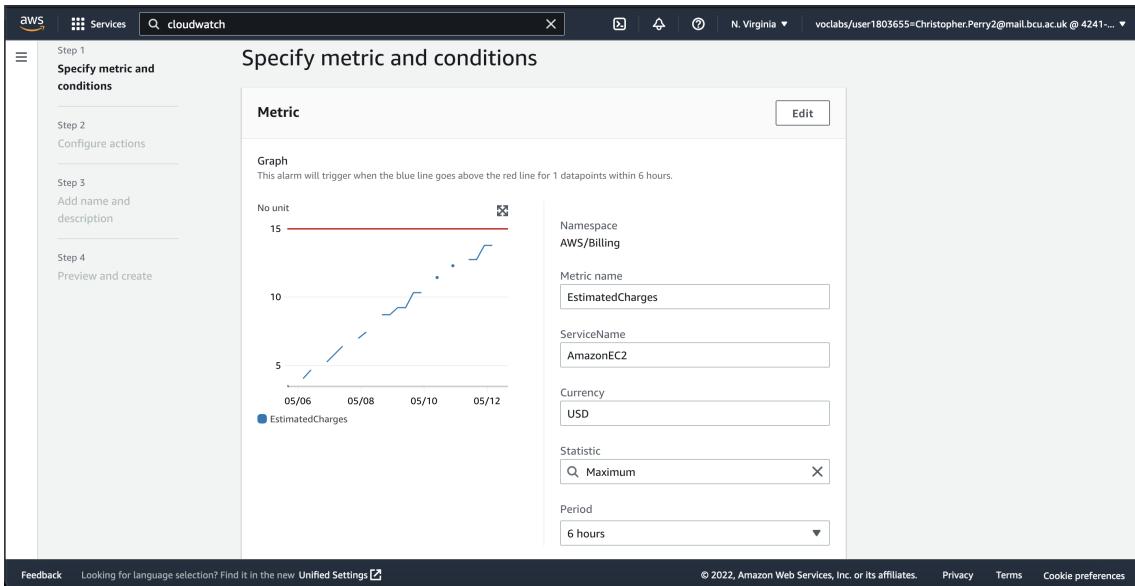


Figure 8.11: Configuration of CloudWatch alarm.

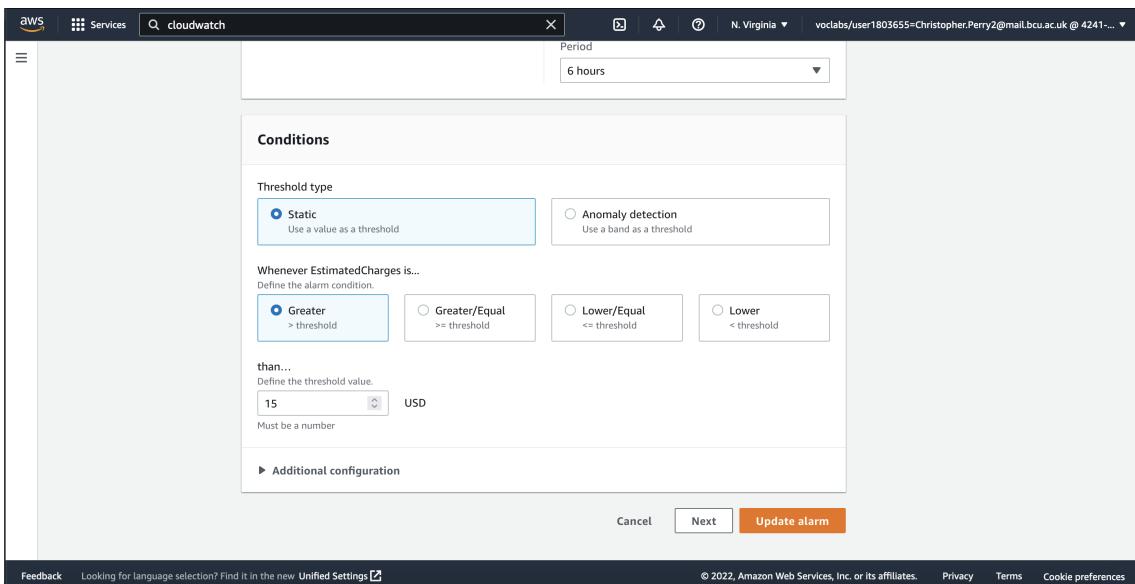


Figure 8.12: Configuration of CloudWatch alarm.

In addition to this, alerts will be sent to the same SNS topic configured earlier. This can be seen in Figure 8.13.

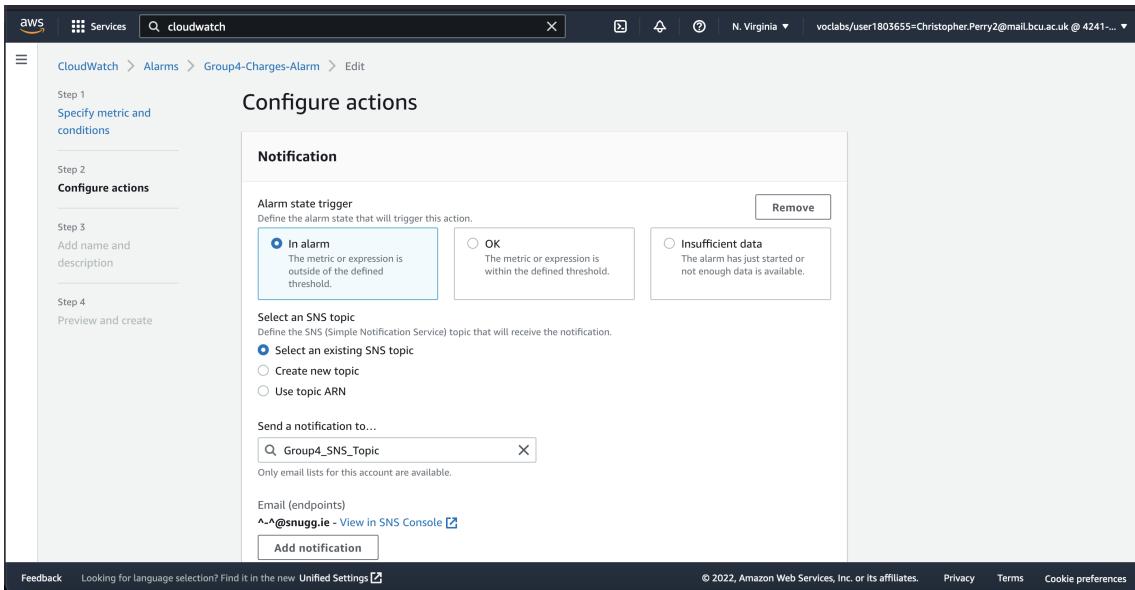


Figure 8.13: Setting CloudWatch charges SNS topic

A brief description was added to the alarm, as seen in Figure 8.14.

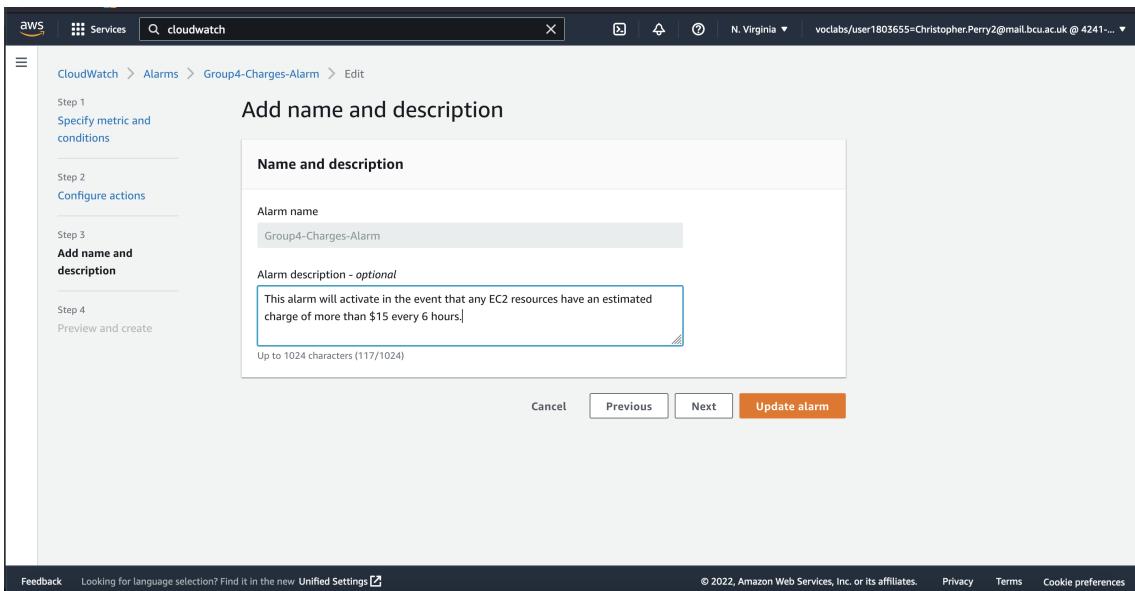
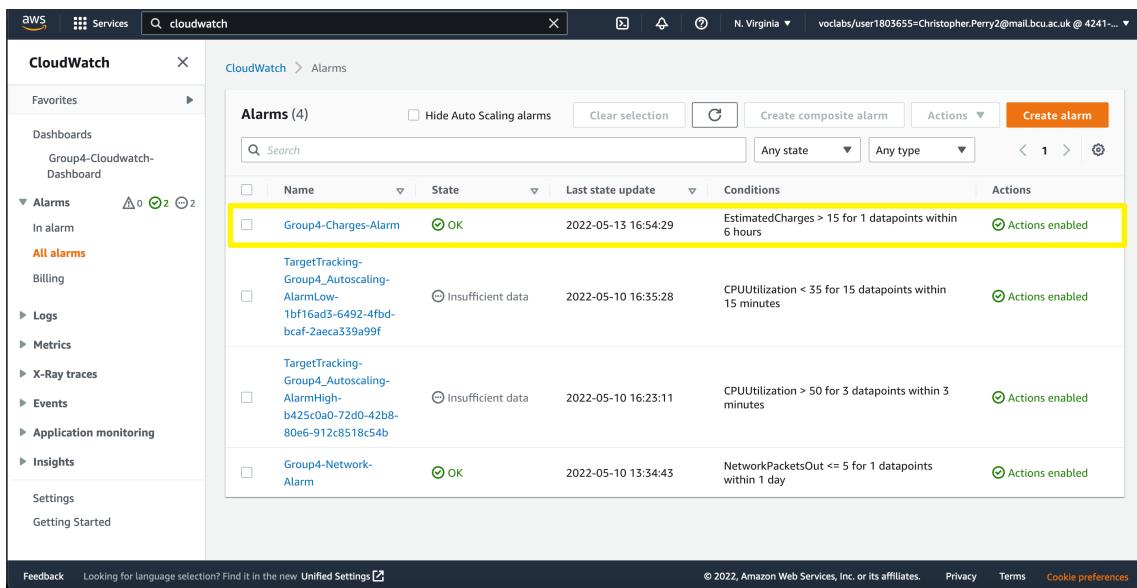


Figure 8.14: Description of CloudWatch alarm.

The alarm is now live and can be seen in Figure 8.15.



The screenshot shows the AWS CloudWatch Alarms dashboard. The left sidebar includes links for Favorites, Dashboards, Alarms (selected), In alarm, All alarms (highlighted in orange), Billing, Logs, Metrics, X-Ray traces, Events, Application monitoring, Insights, Settings, and Getting Started. The main area displays four alarms:

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

At the bottom, there are links for Feedback, Unified Settings, © 2022, Amazon Web Services, Inc. or its affiliates., Privacy, Terms, and Cookie preferences.

Figure 8.15: CloudWatch charges alarm live in CloudWatch dashboard.

Chapter 9

CloudTrail

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.

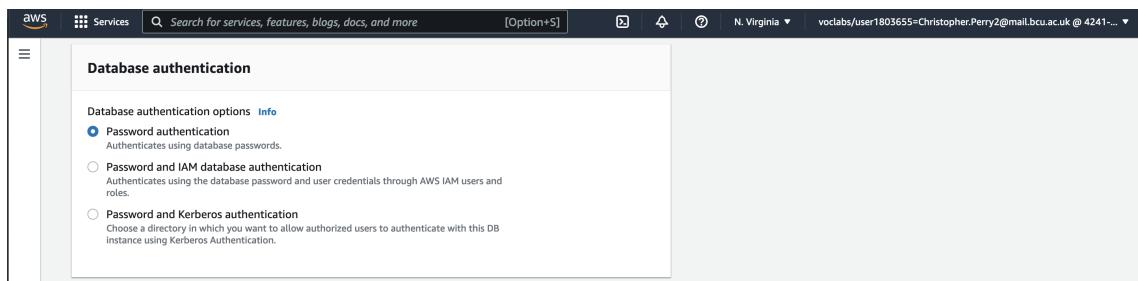


Figure 10.1: Selection of CloudWatch metric for EC2 instance.

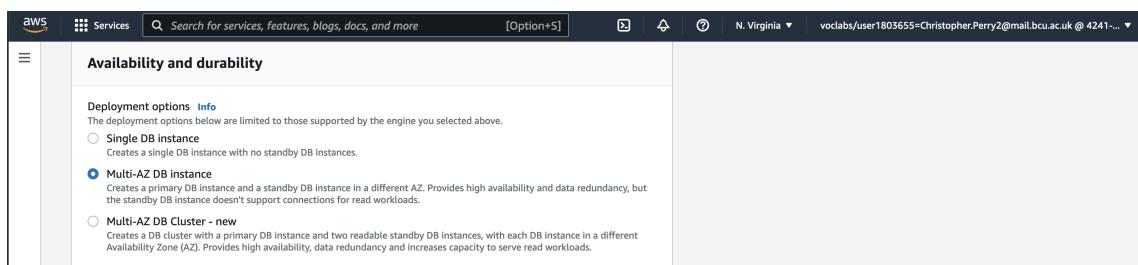


Figure 10.2: Selection of CloudWatch metric for EC2 instance.

resources/rds-connectivity-1.png

Figure 10.3: Selection of CloudWatch metric for EC2 instance.

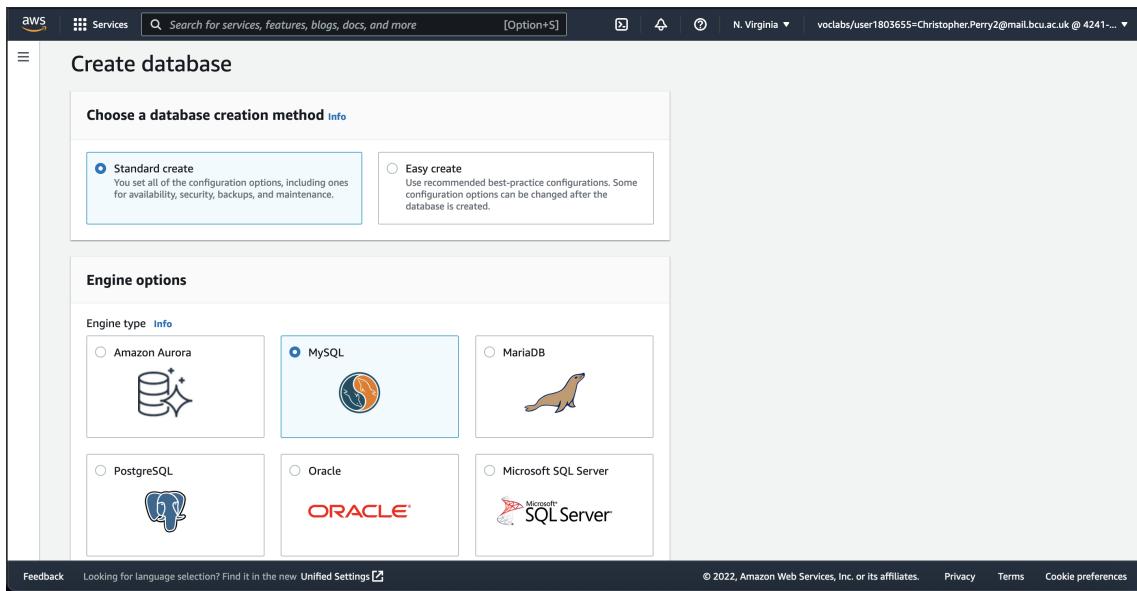


Figure 10.4: Selection of CloudWatch metric for EC2 instance.

```
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 -pC5
ZukGTA3i82H4sul2V4
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.

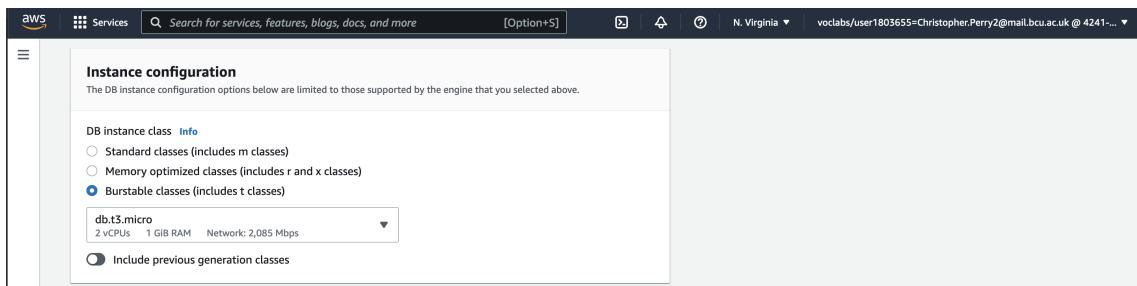


Figure 10.6: Selection of CloudWatch metric for EC2 instance.

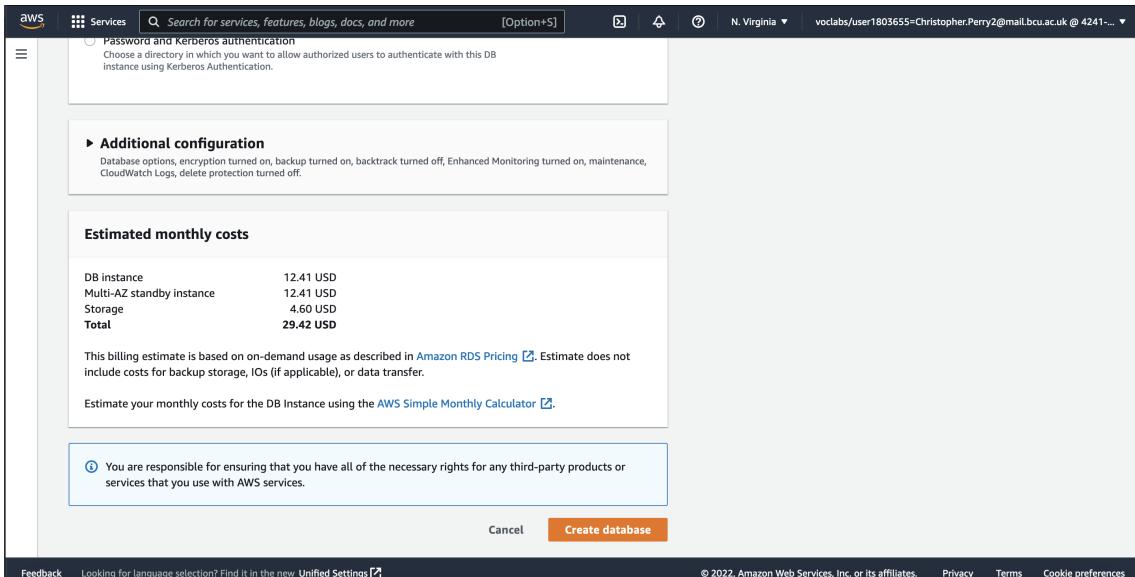


Figure 10.7: Selection of CloudWatch metric for EC2 instance.

```
ec2-user@ip-10-0-0-184:~/digital-ink
[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        | 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 10.8: Selection of CloudWatch metric for EC2 instance.

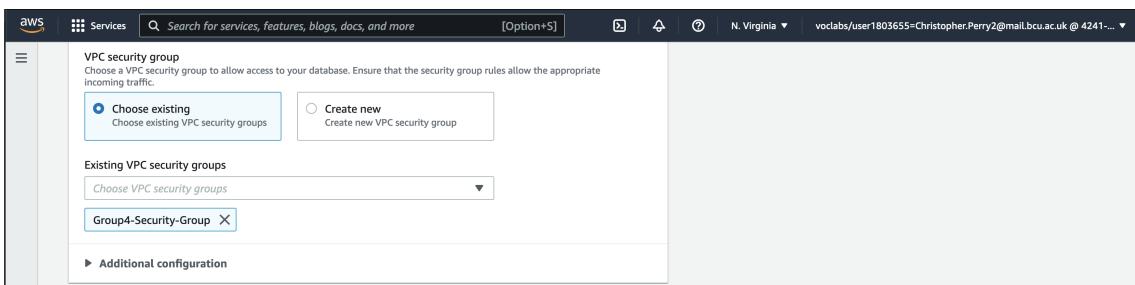


Figure 10.9: Selection of CloudWatch metric for EC2 instance.

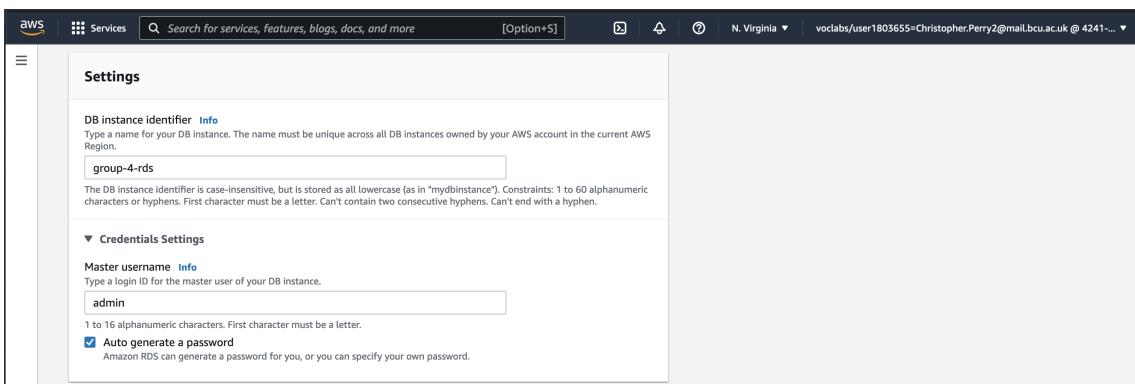


Figure 10.10: Selection of CloudWatch metric for EC2 instance.

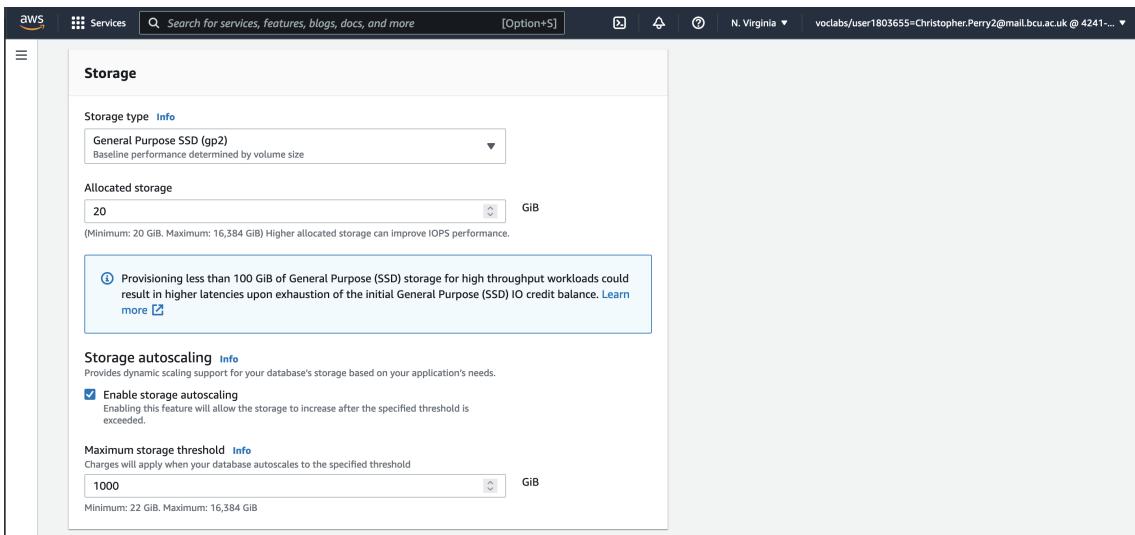


Figure 10.11: Selection of CloudWatch metric for EC2 instance.

Figure 10.12: Selection of CloudWatch metric for EC2 instance.

Figure 10.13: Selection of CloudWatch metric for EC2 instance.

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.

Chapter 12

Security Practices

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 ([amazon2022aws](#)). 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 (**dos2018automated**). 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 ??.

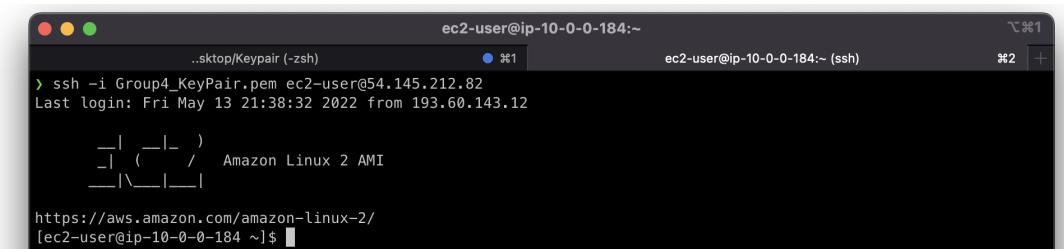
```
Scenario: ...
  Given ...
  When ...
  Then ...
```

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

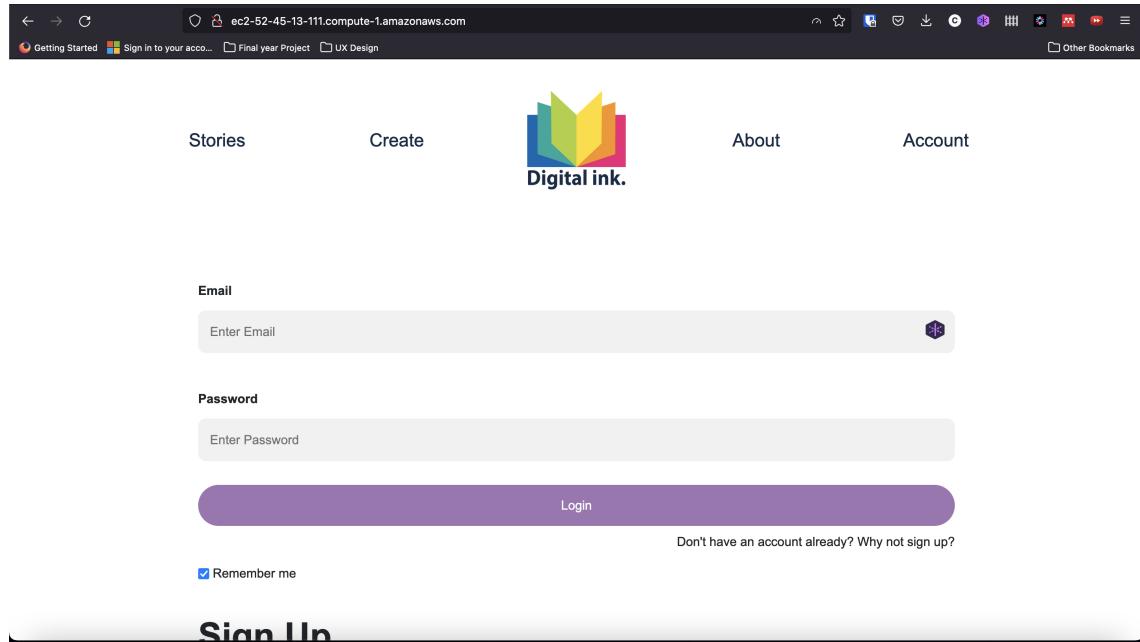
Scenario: Accessing instance through SSH with .pem file private key.

```
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@52.45.13.111" in the terminal
Then the user will be logged into the EC2 instance
```



The screenshot shows a macOS terminal window with two tabs. The active tab, labeled '#1', shows the command: 'ssh -i Group4_KeyPair.pem ec2-user@52.45.13.111'. Below it, the terminal displays the response: 'Last login: Fri May 13 21:38:32 2022 from 193.60.143.12' followed by the Amazon Linux 2 AMI logo. The second tab, labeled '#2', is titled 'ec2-user@ip-10-0-0-184:~ (ssh)' and shows the URL 'https://aws.amazon.com/amazon-linux-2/'. The bottom of the terminal shows the prompt '[ec2-user@ip-10-0-0-184 ~]\$'.

Scenario: Accessing web app through EC2 domain name.
Given that the web app is running on the EC2 instance
When the user accesses
["http://ec2-52-45-13-111.compute-1.amazonaws.com"](http://ec2-52-45-13-111.compute-1.amazonaws.com) in their browser
Then the web app will be loaded



14.2 Testing S3

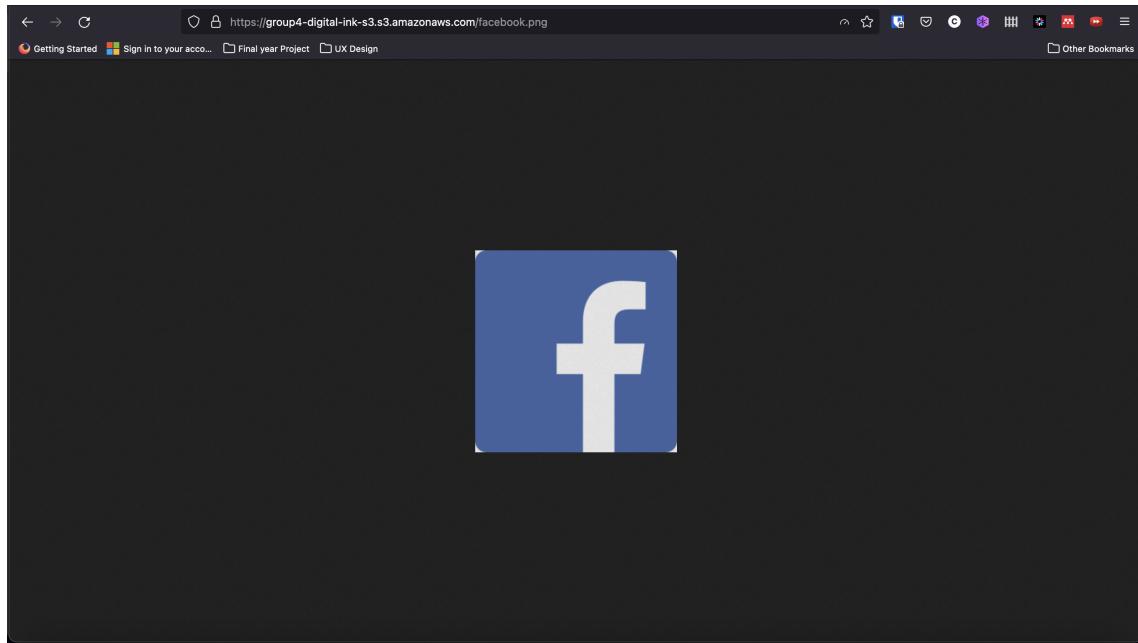
Scenario: Accessing web app image through S3 domain name.

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

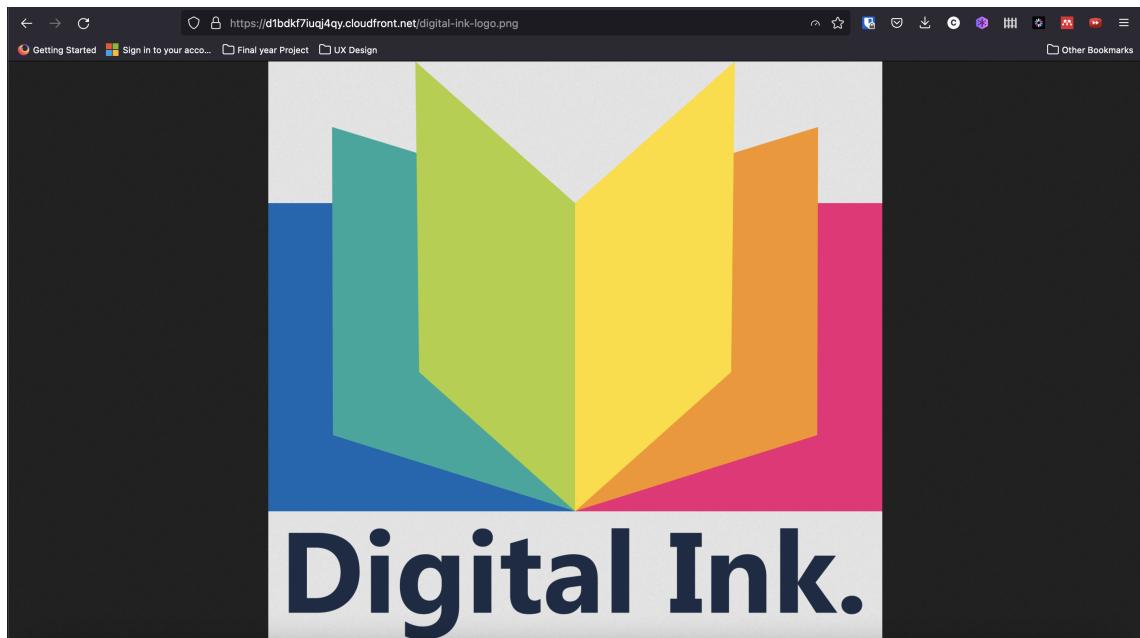
Scenario: Accessing web app image through CloudFront domain name.

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

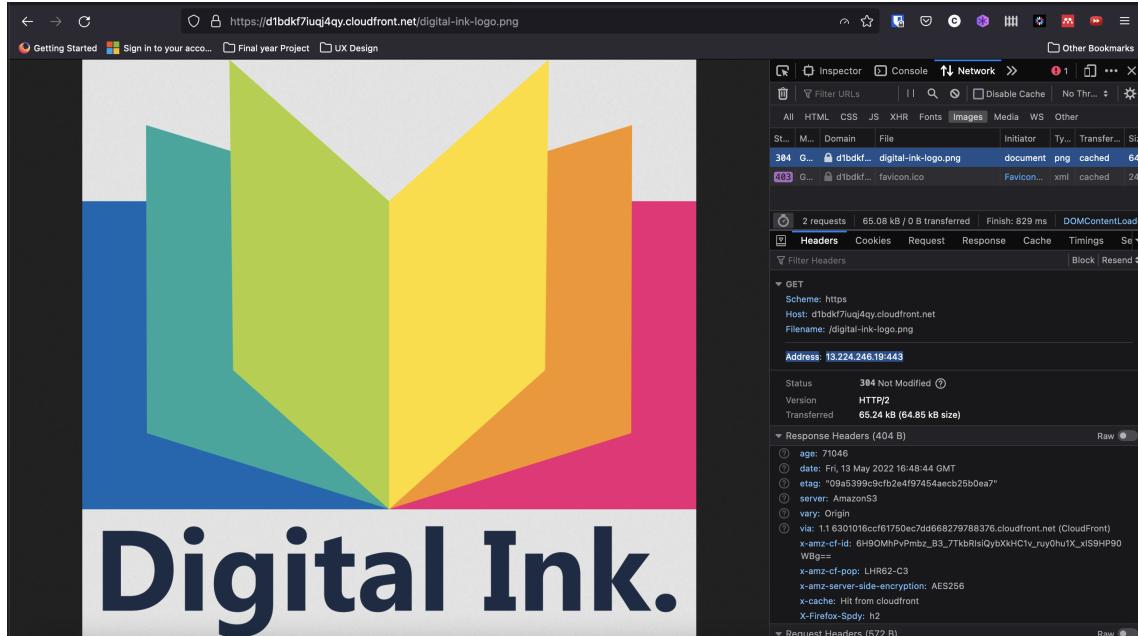


Figure 14.1: Digital Ink image whilst connected to UK IP.

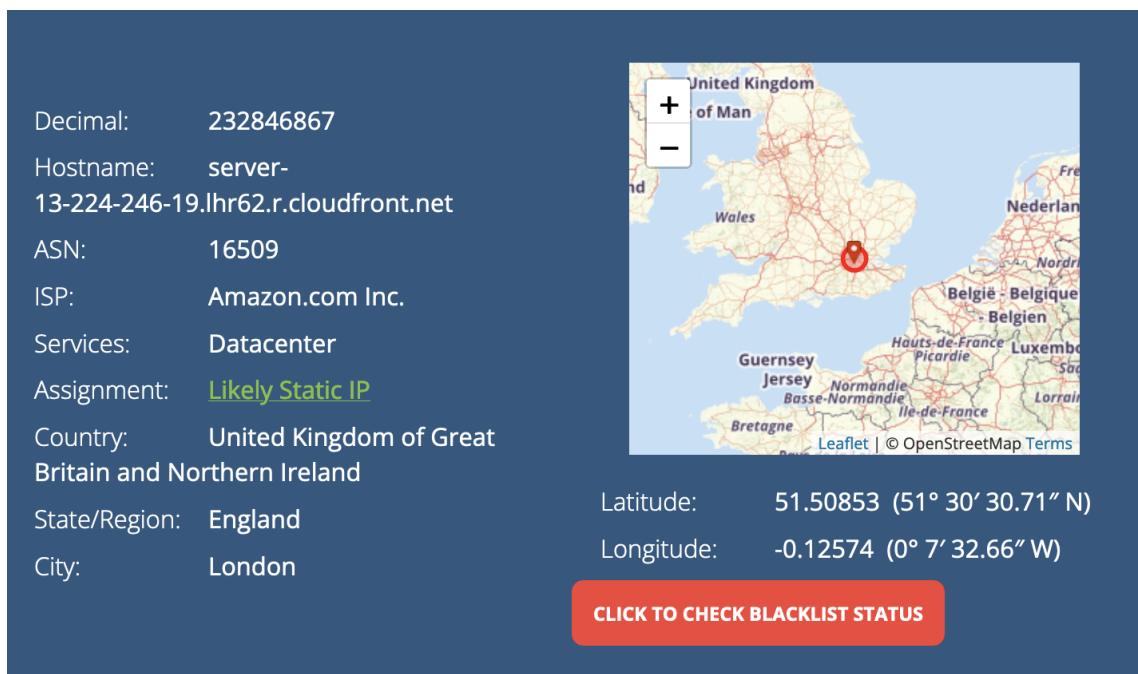


Figure 14.2: UK IP Location.

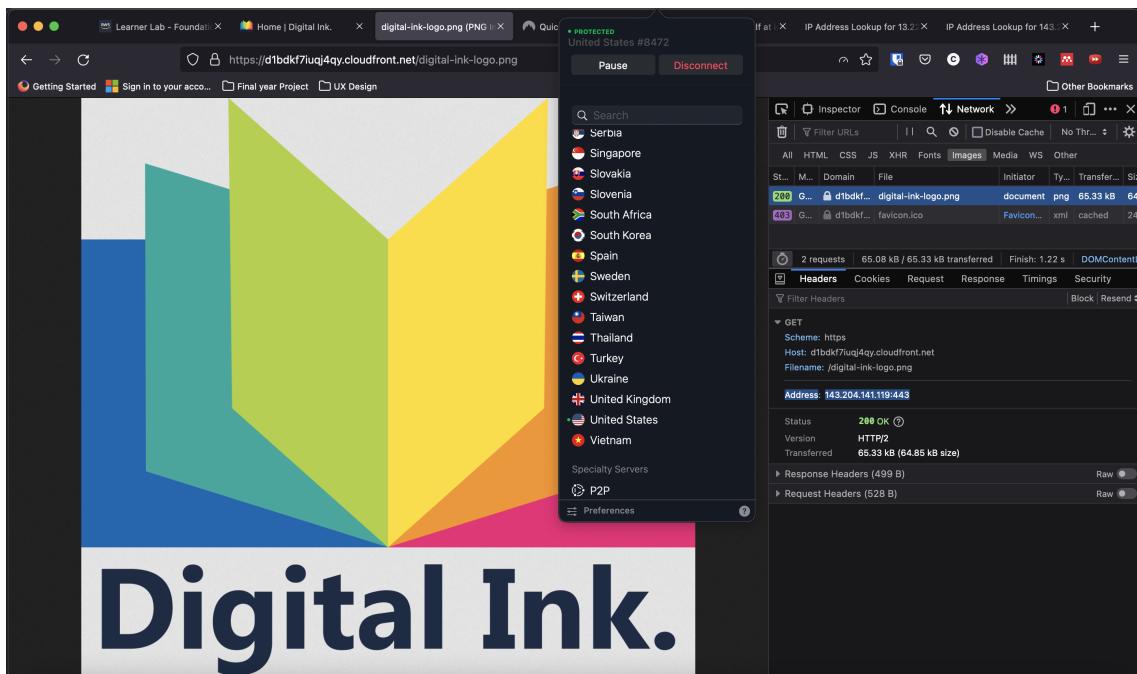


Figure 14.3: Digital Ink image whilst connected to US IP.

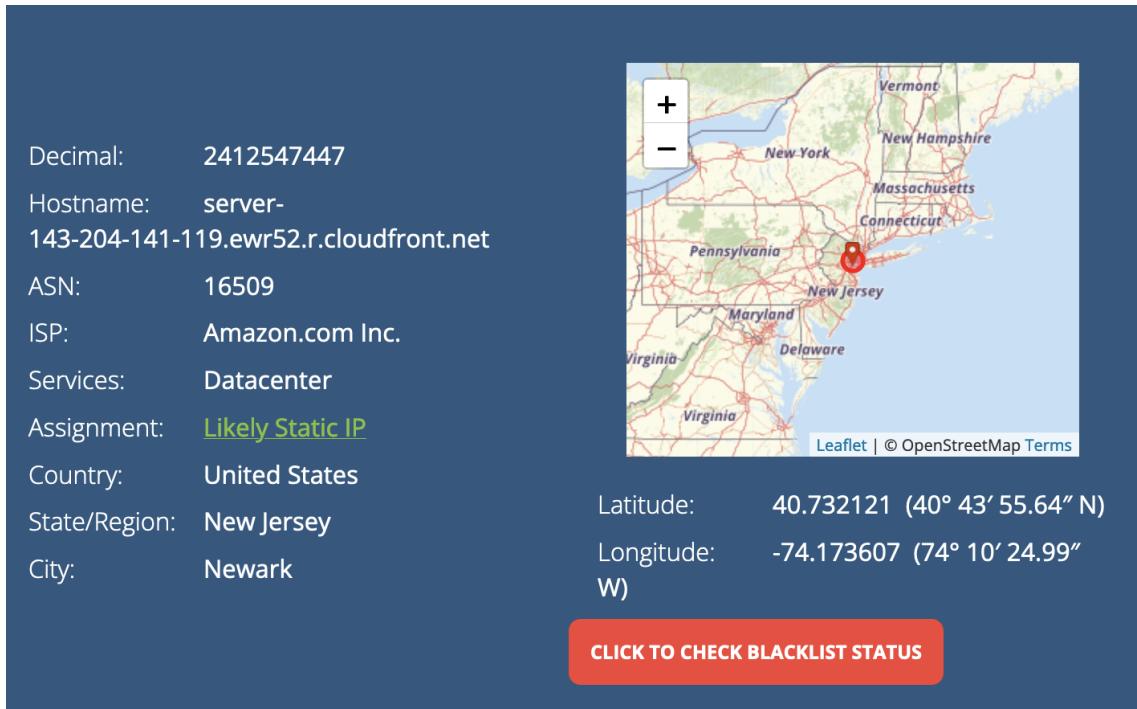


Figure 14.4: US IP Location.

14.4 Testing RDS

```
Scenario: Creating user information through the web app.  
    Given ...  
    When ...  
    Then ...  
  
Scenario: Creating story information through the web app.  
    Given ...  
    When ...  
    Then ...  
  
Scenario: Reading user information from the database into the web app.  
    Given ...  
    When ...  
    Then ...  
  
Scenario: Reading story information from the database into the web app.  
    Given ...  
    When ...  
    Then ...  
  
Scenario: Updating user information in the database through the web app.  
    Given ...  
    When ...  
    Then ...  
  
Scenario: Updating story information in the database through the web app.  
    Given ...  
    When ...  
    Then ...  
  
Scenario: Deleting user information in the database through the web app.  
    Given ...  
    When ...  
    Then ...  
  
Scenario: Deleting story information in the database through the web app.  
    Given ...  
    When ...  
    Then ...
```

14.5 Testing CloudWatch

(One test for each of the metrics we set up.)

```
Scenario:  
    Given ...  
    When ...  
    Then ...
```

14.6 Testing CloudTrail

(One test for each of the metrics we set up.)

```
Scenario:  
  Given ...  
  When ...  
  Then ...
```

14.7 Testing ELB

(Test for turning off instance 1. Test for turning off instance 2.)

Chapter 15

Future Enhancements

An SSL/TLS certificate could be added, as it was not possible to do this from within the lab tutorial due to a lack of permissions from the root AWS account. By adding a certificate we would be able to encrypt the connections to our EC2 instance and increase the security of our application for all users.

We would like to add more roles and users to our IAM, but were limited by the amount that we were able to access.

If we were to do the project again, we would use AWS Elastic Beanstalk as it allows automatic orchestration of all the resources needed for a LAMP stack style application such as ours, it also has support for Docker which is a containerization technology that we had used in our application project.

Chapter 16

Conclusion