Assignment Report

- Institution: Waterford Institute of Technology
- Program: MSc in Computing (Enterprise Software Systems)
- Module: Cloud Architecture 2020/2021
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- Activity: Assignment 1
- Screencast: https://www.youtube.com/watch?v=nWvrR08RBHk

1. Introduction

The present document describes the project created as the solution for the Assignment 1 of the Cloud Architecture Module, part of the WIT program "MSc in Computing".

The core of the Assignment is to demonstrate the deployment and the automated management of a load-balanced auto-scaling web application.

The solution presented here consists of a custom multi-tier web application that uses a database backend.

In the "Specific Objectives" sections, I describe the goals that I pursued given all the specifications and implementation levels provided for the assignment.

On the "Configuration Persistence" section we discuss the aspects and challenges related to persisting the configuration using Cloud Formation.

On the "Architecture" section you will find the top level details of the architecture, listing the infrastructure and networking deployment aspects.

The "Web Servers" section details the high-available, fault-tolerant and load-balanced implementation of the Web Servers EC2 instances.

Then on the "Web Application" section, we dive into the details of the custom application, with all the endpoints and multiple aspects of the deployment, operation, security and inter-communication with other services.

On the "Database Backend" section, you will find similar level of details, this time for the home-baked Database active/passive cluster, created using Virtual IP, Lambda function, Event Bridge trigger and EFS.

At the end, the "Conclusion" brings a final discussion on security considerations and improvement opportunities, with final comments about the implementation of the project.

2. Objectives

2.1 General Objectives

- Demonstrate the deployment and automated management of a load-balanced auto-scaling web application.
- Document the architecture and the implementation.

2.2. Specific Objectives

- Create a multi-tier web application that relies on a backend database.
- Implement auto-scaling of the application server.
- Create well thought and well tested auto-scaling triggers.
- Create a high-available active/passive database cluster.
- Implement auto-scaling of the backend service.

- Implement fine-grained network access control for all the services.
- Capture all the configuration using the Cloud Formation language.
- Automate the application interactions to the AWS services using Python/boto3.
- Use AWS Lambda in the architecture.
- Deploy the applications using containers.

2.3. Out Of Scope

Some items were intentionally kept out of the scope for this project, either for technical decision, for saving costs or for being considered next steps would this project be implemented in a real world scenario.

The items left out are:

- High-availability/fault-tolerance for the NAT Instance: the use of a NAT Instance is meant to save costs when compared to a NAT Gateway. But, in a real world scenario, a NAT Gateway would be the right choice for having that high-availability/fault-tolerance in a managed way.
- High-availability/fault-tolerance for the Bastion: this is a technical decision, considering that Bastions should not be always running. They should instead be created on demand and terminated after use to avoid having an always running machine that can potentially be exploited for gaining access to the services instances.
- HTTPS for the Web application: the web application was custom built for this academic project. It has no sensitive data flow and, as such, the HTTPS implementation for the Web Servers Load Balancer is considered out of the scope for this project. It is nonetheless an important next step, would this project be implemented in a real world scenario.

3. Configuration Persistence

The full implementation of the resources deployed to the RosettaHUB account was persisted using Cloud Formation.

You will find the Stack specification YAML file in the “CloudFormation” directory, delivered together with this report.

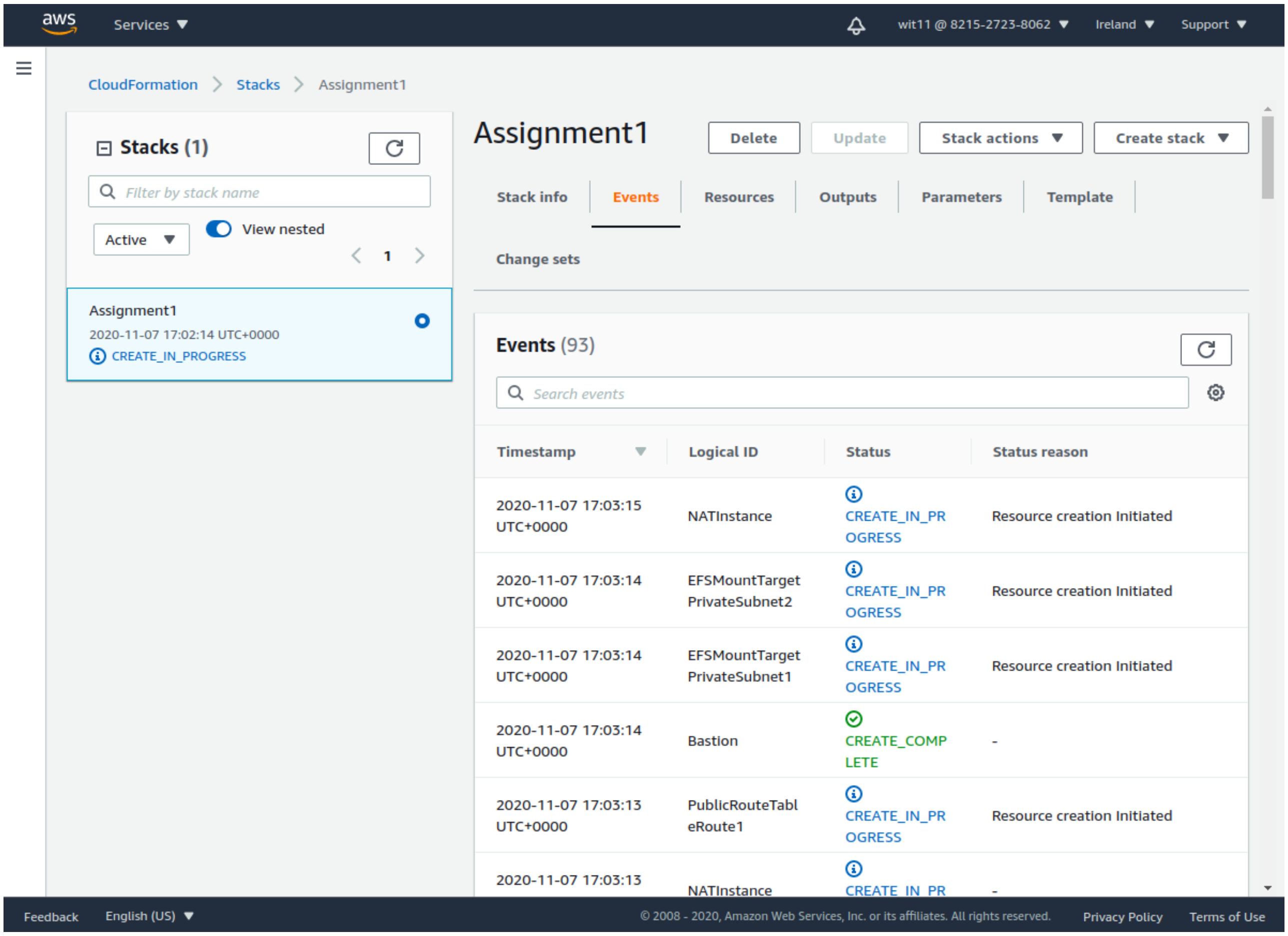
The initial learning involved with creating the specification consumed a good amount of time, but the benefits didn’t last to appear. Having the whole specification created or deleted with a couple of clicks helped a lot with the development process and enables the infrastructure-as-code as a way to have reproducibility, change management and helps not to leave unused resources behind.

An additional benefit is that we can discuss the specific aspects of the project using code snippets, a more precise and efficient method when compared to screenshots.

The only artifacts created in the RosettaHUB account for this project not using Could Formation are:

- The SSH Key Pair.
- The Webserver AMI.

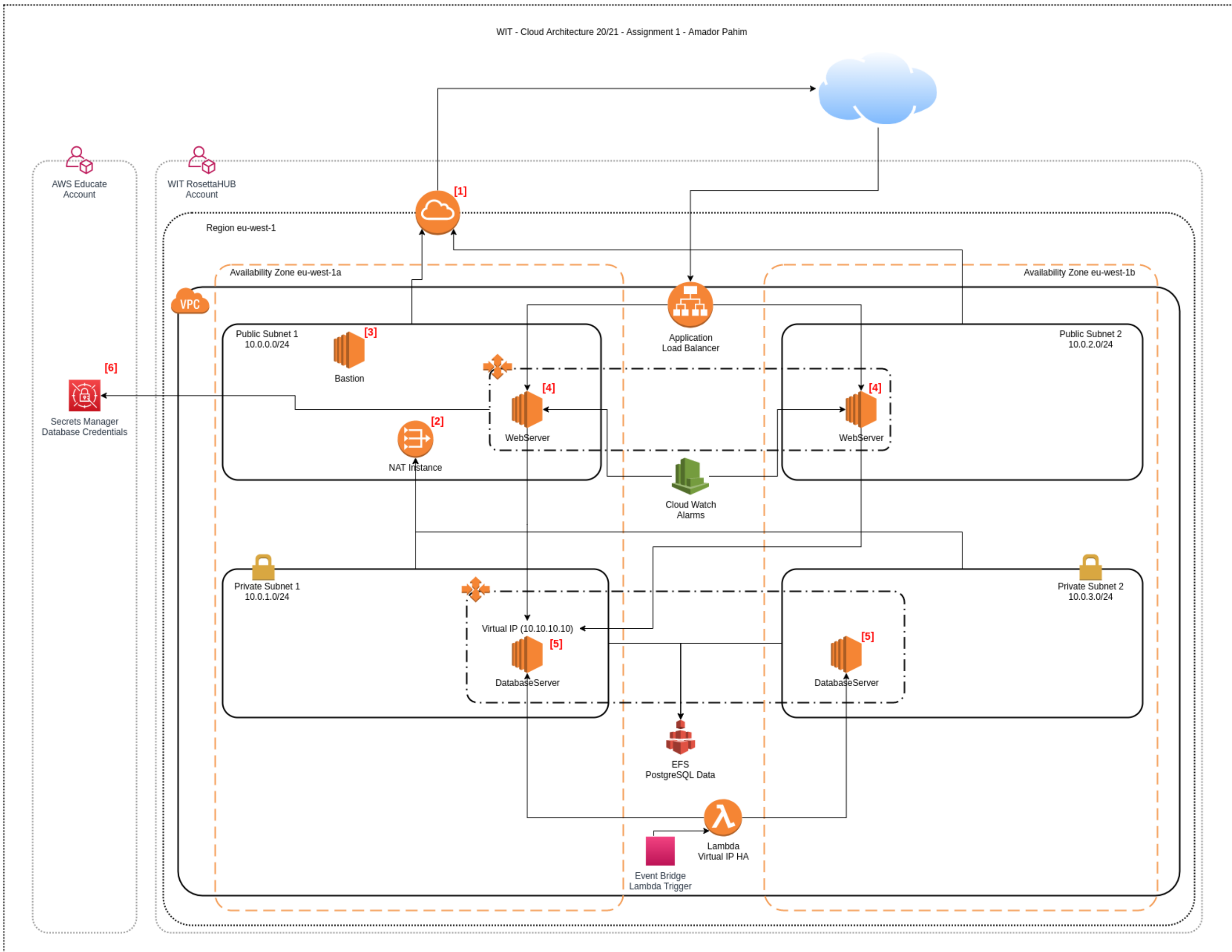
After applying to Cloud Formation the Stack.yaml file contained in the project documentation, we can see the creation process taking place:



4. Architecture

This section describes the high level architecture of the project, listing the main components and data flows.

As mentioned in the previous section, all the resources are persisted in a Cloud Formation stack specification file, provided together with this report. I will use those Cloud Formation objects throughout this report to demonstrate how those resources are being created.



The diagram above contains numbers in red that are referenced in the descriptions below.

On the WIT RosettaHUB Account, on the AWS eu-west1 region, we have:

- A VPC created for the project:

```
VPC:
  Type: AWS::EC2::VPC
  Properties:
    CidrBlock: 10.0.0.0/16
    EnableDnsHostnames: true
    EnableDnsSupport: true
    Tags:
      - Key: Name
        Value: Assignment1
```

- One Public Subnet in the Availability Zone eu-west1a:

```
PublicSubnet1:
  Type: AWS::EC2::Subnet
  DependsOn: VPC
  Properties:
```

```yaml
    AvailabilityZone: eu-west-1a
    CidrBlock: 10.0.0.0/24
    MapPublicIpOnLaunch: True
    Tags:
      - Key: Name
        Value: Public Subnet 1
    VpcId: !Ref VPC
```

- One Public Subnet in the Availability Zone eu-west1b:

```yaml
PublicSubnet2:
  Type: AWS::EC2::Subnet
  DependsOn: VPC
  Properties:
    AvailabilityZone: eu-west-1b
    CidrBlock: 10.0.2.0/24
    MapPublicIpOnLaunch: True
    Tags:
      - Key: Name
        Value: Public Subnet 2
    VpcId: !Ref VPC
```

- One Private Subnet in the Availability Zone eu-west1a:

```yaml
PrivateSubnet1:
  Type: AWS::EC2::Subnet
  DependsOn: VPC
  Properties:
    AvailabilityZone: eu-west-1a
    CidrBlock: 10.0.1.0/24
    MapPublicIpOnLaunch: False
    Tags:
      - Key: Name
        Value: Private Subnet 1
    VpcId: !Ref VPC
```

- One Private Subnet in the Availability Zone eu-west1b:

```yaml
PrivateSubnet2:
  Type: AWS::EC2::Subnet
  DependsOn: VPC
  Properties:
    AvailabilityZone: eu-west-1b
    CidrBlock: 10.0.3.0/24
    MapPublicIpOnLaunch: False
    Tags:
      - Key: Name
        Value: Private Subnet 2
    VpcId: !Ref VPC
```

- The Public Route Table and its associations:

```yaml
PublicRouteTable:
  Type: AWS::EC2::RouteTable
  Properties:
    VpcId: !Ref VPC
    Tags:
      - Key: Name
        Value: Public route table
      - Key: database
        Value: 'true'
PublicRouteTableRoute1:
  Type: AWS::EC2::Route
  DependsOn: AttachGateway
  Properties:
    RouteTableId: !Ref PublicRouteTable
    DestinationCidrBlock: 0.0.0.0/0
    GatewayId: !Ref InternetGateway
PublicSubnet1RouteTableAssociation:
  Type: AWS::EC2::SubnetRouteTableAssociation
  Properties:
    SubnetId: !Ref PublicSubnet1
    RouteTableId: !Ref PublicRouteTable
PublicSubnet2RouteTableAssociation:
  Type: AWS::EC2::SubnetRouteTableAssociation
  Properties:
    SubnetId: !Ref PublicSubnet2
    RouteTableId: !Ref PublicRouteTable
```

- The Private Route Table and its associations:

```yaml
PrivateRouteTableRoute1:
  Type: AWS::EC2::Route
  DependsOn: NATInstance
  Properties:
    RouteTableId: !Ref PrivateRouteTable
    DestinationCidrBlock: 0.0.0.0/0
    InstanceId: !Ref NATInstance
PrivateSubnet1RouteTableAssociation:
  Type: AWS::EC2::SubnetRouteTableAssociation
  Properties:
    SubnetId: !Ref PrivateSubnet1
    RouteTableId: !Ref PrivateRouteTable
PrivateSubnet2RouteTableAssociation:
  Type: AWS::EC2::SubnetRouteTableAssociation
  Properties:
    SubnetId: !Ref PrivateSubnet2
    RouteTableId: !Ref PrivateRouteTable
```

The access from the instances inside the VPC to the internet is provided by:

- An Internet Gateway[1] to access the internet from the Public Subnets:

```yaml
InternetGateway:
  Type: AWS::EC2::InternetGateway
```

```yaml
  DependsOn: VPC
AttachGateway:
  Type: AWS::EC2::VPCGatewayAttachment
  DependsOn: InternetGateway
  Properties:
    VpcId: !Ref VPC
    InternetGatewayId: !Ref InternetGateway
```

- A NAT Instance[2] to access the internet from the Private Subnets:

```yaml
NATInstance:
  Type: AWS::EC2::Instance
  DependsOn: AttachGateway
  Properties:
    ImageId: ami-6975eb1e
    InstanceType: t2.nano
    KeyName: apahim_keys
    NetworkInterfaces:
      - AssociatePublicIpAddress: 'true'
        DeleteOnTermination: 'true'
        DeviceIndex: '0'
        GroupSet:
          - Ref: NATSecurityGroup
        SubnetId:
          Ref: PublicSubnet1
    SourceDestCheck: 'false'
    Tags:
      - Key: Name
        Value: NATInstance
NATSecurityGroup:
  Type: AWS::EC2::SecurityGroup
  Properties:
    GroupDescription: NATSecutiryGroup
    GroupName: NATSecutiryGroup
    SecurityGroupEgress:
      - CidrIp: 0.0.0.0/0
        Description: Allow all outbound traffic
        IpProtocol: "-1"
    SecurityGroupIngress:
      - SourceSecurityGroupId: !Ref DatabaseSecurityGroup
        Description: Allow inbound HTTP traffic from database servers
        IpProtocol: TCP
        FromPort: 80
        ToPort: 80
      - SourceSecurityGroupId: !Ref DatabaseSecurityGroup
        Description: Allow inbound HTTPS traffic from database servers
        IpProtocol: TCP
        FromPort: 443
        ToPort: 443
    Tags:
      - Key: Name
        Value: NAT Instances Security Group
    VpcId: !Ref VPC
```

The console (SSH) access from the internet to the instances inside the VPC is provided by a Bastion[3] host, deployed in one of the Availability Zones:

```
Bastion:
  Type: AWS::EC2::Instance
  Properties:
    ImageId: ami-0bb3fad3c0286ebd5
    InstanceType: t2.nano
    KeyName: apahim_keys
    NetworkInterfaces:
      - AssociatePublicIpAddress: 'true'
        DeleteOnTermination: 'true'
        DeviceIndex: '0'
        GroupSet:
          - Ref: BastionSecurityGroup
        SubnetId:
          Ref: PublicSubnet1
    SourceDestCheck: 'true'
    Tags:
      - Key: Name
        Value: Bastion
BastionSecurityGroup:
  Type: AWS::EC2::SecurityGroup
  Properties:
    GroupDescription: BastionSecurityGroup
    GroupName: BastionSecurityGroup
    SecurityGroupEgress:
      - CidrIp: 0.0.0.0/0
        Description: Allow all outbound traffic
        IpProtocol: "-1"
    SecurityGroupIngress:
      - CidrIp: 37.228.227.79/32
        Description: Allow inbound SSH traffic from Admins
        IpProtocol: TCP
        FromPort: 22
        ToPort: 22
    Tags:
      - Key: Name
        Value: Bastion Security Group
    VpcId: !Ref VPC
```

On each Availability Zone, we have:

- An instance of the Web application[4] on a Public Subnet, described in details in the next sections.
- An instance of the backend database[5] on a Private Subnet, described in details in the next sections.

On the AWS Educate Account, we have:

- A Secrets Manager secret[6] to store the backend database credentials.

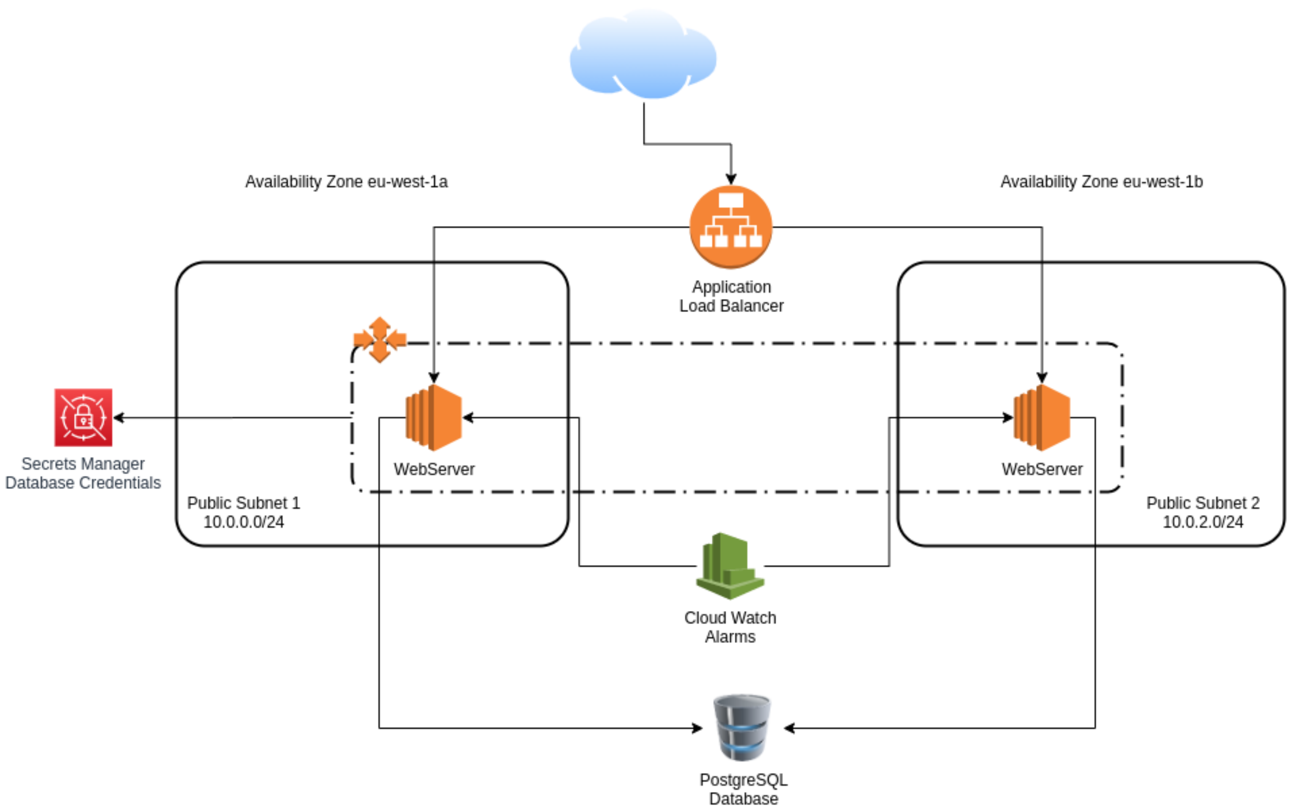
The usage of a different account for the secret creation was initially motivated by the lack of access to that AWS service on the RosettaHUB account. The Secrets Manager service was later enabled on the RosettaHUB account, but since the cross-account configuration representes a learning opportunity related to IAM and Python/boto3, it was kept in the final solution as an “Additional Feature”.

5. Web Servers

The Web Servers are the EC2 instances running the Web application. This section describes the details of the architecture and the implementation.

5.1. Architecture

This diagram shows the context of the Web Servers and their relationships to other services:



The architecture consists of a Multi-AZ, high-available, load-balanced and auto-scaled deployment of EC2 instances on Public Subnets. Those instances have access to a backend PostgreSQL database running on Private Subnets. They also have an Instance Profile with a Role to access the Secrets Manager in order to acquire the credentials for the database.

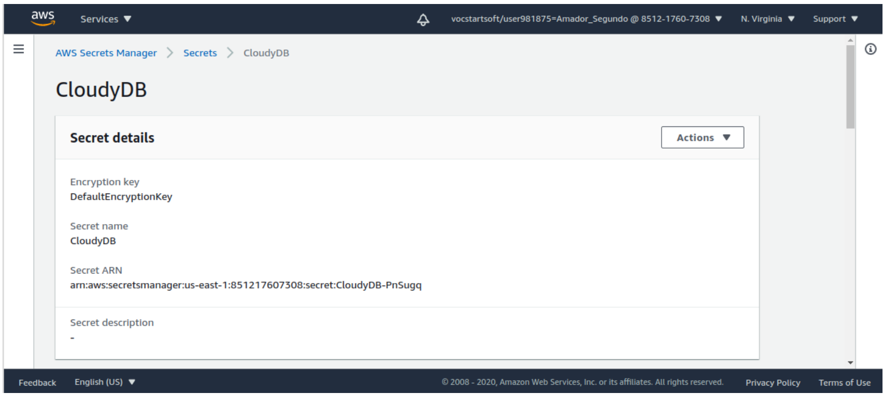
5.2. User Data

A custom AMI was created with a User Data script that sets up, among other things, the Web application installation and execution via SysV-init service.

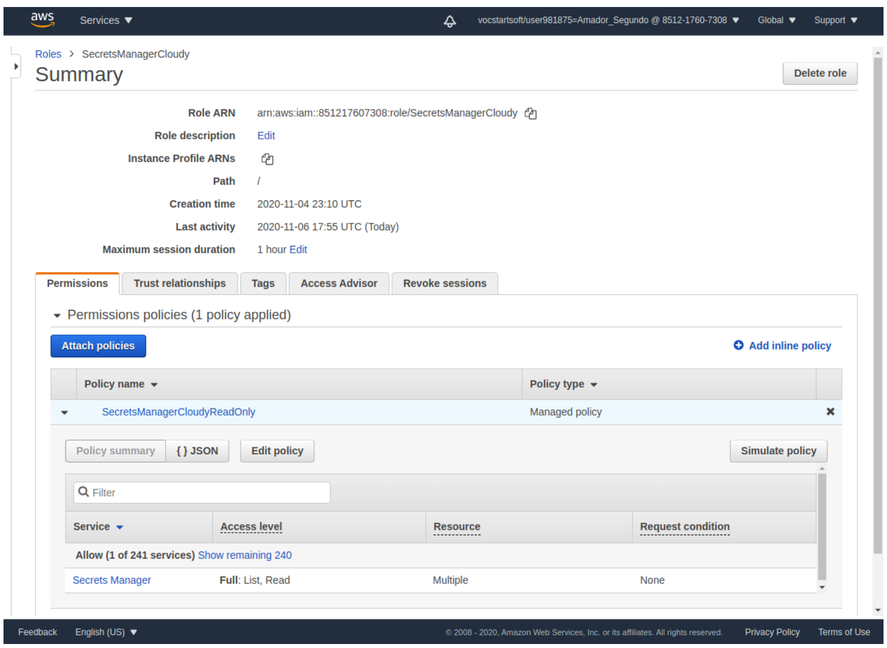
The User Data script source code is available in the directory "UserData", part of the package sent together with this report.

5.3. Database Credentials

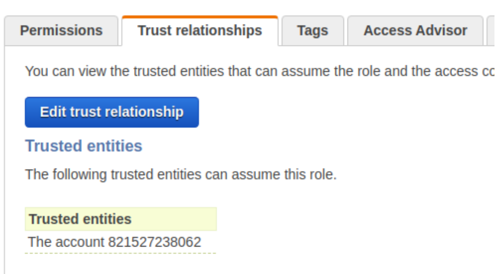
The database credentials were stored in an AWS Secrets Manager secret, on a different AWS Account (AWS Educate Starter Account):



To allow access from the RosettaHUB Account, first I created a Role with a Secrets Manager read-only Policy:



Then I added to that Role a trust relationship to the RosettaHUB account:



To access that secret, first, in the RosettaHUB Account, I created a Policy that allows Assuming the Role from the AWS Educate Account:

```
SecretManagerReadOnly:
  Type: AWS::IAM::Policy
  Properties:
```

```yaml
      PolicyName: AssumeSecretsManagerCloudy
      PolicyDocument:
        Statement:
          - Action: "sts:AssumeRole"
            Effect: Allow
            Resource: 'arn:aws:iam::851217607308:role/SecretsManagerCloudy'
      Roles:
        - Ref: WebServerSecretManager
```

Then I created a Role for the Web Server EC2 instances to access that Policy:

```yaml
  WebServerRole:
    Type: AWS::IAM::Role
    Properties:
      Path: /
      AssumeRolePolicyDocument:
        Statement:
          - Action:
              - sts:AssumeRole
            Effect: Allow
            Principal:
              Service:
                - ec2.amazonaws.com
```

After that, I created an InstanceProfile to use the Role:

```yaml
  WebServerInstanceProfile:
    Type: AWS::IAM::InstanceProfile
    Properties:
      Path: /
      Roles:
        - Ref: WebServerRole
```

That Instance Profile will is then used on the web servers Launch Configuration, described in the next section.

5.4. Auto Scaling

The Auto Scaling alarms were selected to:

- Avoid scaling up on quick load spikes: there's cost and an overhead involved with the scaling up operation. We should react only to consistent load increases.
- On the event of an instance outage, the remaining instances will be able to handle the current load until new instances come up.

To cover those requirements, the selected alarms are:

- Scale-up if CPU > 60% for 2 minutes.
- Scale-down if CPU < 40% for 2 minutes.

5.5. AWS Resources

- A Web Server Security Group, allowing SSH access from the Bastion Security Group and HTTP traffic from the Load Balancer Security Group:

```yaml
WebServerSecurityGroup:
  Type: AWS::EC2::SecurityGroup
  Properties:
    GroupDescription: WebServerSecurityGroup
    GroupName: WebServerSecurityGroup
    SecurityGroupEgress:
      - CidrIp: 0.0.0.0/0
        Description: Allow all outbound traffic
        IpProtocol: "-1"
    SecurityGroupIngress:
      - SourceSecurityGroupId: !Ref LoadBalancerSecurityGroup
        Description: Allow inbound HTTP traffic from Load Balancer
        IpProtocol: TCP
        FromPort: 8080
        ToPort: 8080
      - SourceSecurityGroupId: !Ref BastionSecurityGroup
        Description: Allow inbound SSH traffic from bastions
        IpProtocol: TCP
        FromPort: 22
        ToPort: 22
    Tags:
      - Key: Name
        Value: Web Servers Security Group
    VpcId: !Ref VPC
```

- A Load Balancer Security Group, allowing HTTP traffic from the internet:

```yaml
LoadBalancerSecurityGroup:
  Type: AWS::EC2::SecurityGroup
  Properties:
    GroupDescription: LoadBalancerSecurityGroup
    GroupName: LoadBalancerSecurityGroup
    SecurityGroupEgress:
      - CidrIp: 0.0.0.0/0
        Description: Allow all outbound traffic
        IpProtocol: "-1"
    SecurityGroupIngress:
      - CidrIp: 0.0.0.0/0
        Description: Allow inbound HTTP traffic
        IpProtocol: TCP
        FromPort: 8080
        ToPort: 8080
    Tags:
      - Key: Name
        Value: Load Balancer Security Group
    VpcId: !Ref VPC
```

- A Launch Configuration using the custom AMI to bring up the Web Server instances:

```yaml
WebServersLaunchConfig:
  Type: AWS::AutoScaling::LaunchConfiguration
  Properties:
    LaunchConfigurationName: WebServersLaunchConfiguration
    ImageId: ami-00a3419ac716c5a22
    InstanceType: t2.nano
    KeyName: apahim_keys
    IamInstanceProfile:
      Ref: WebServerInstanceProfile
    SecurityGroups:
      - Ref: WebServerSecurityGroup
```

- An Auto Scaling Group in two Availability Zones (eu-west-1a and eu-west-1b).

```yaml
WebServerAutoScalingGroup:
  Type: AWS::AutoScaling::AutoScalingGroup
  DependsOn: DatabaseAutoScalingGroup
  Properties:
    AutoScalingGroupName: WebServerAutoScalingGroup
    VPCZoneIdentifier:
      - Ref: PublicSubnet1
      - Ref: PublicSubnet2
    LaunchConfigurationName:
      Ref: WebServersLaunchConfig
    TargetGroupARNs:
      - Ref: WebServersTargetGroup
    MaxSize: '3'
    MinSize: '2'
    Tags:
      - Key: Name
        Value: WebServer
        PropagateAtLaunch: 'true'
```

- A Target Group:

```yaml
WebServersTargetGroup:
  Type: AWS::ElasticLoadBalancingV2::TargetGroup
  Properties:
    HealthCheckIntervalSeconds: 30
    HealthCheckProtocol: HTTP
    HealthCheckTimeoutSeconds: 15
    HealthyThresholdCount: 5
    Matcher:
      HttpCode: '200'
    Name: WebServersTargetGroup
    Port: 8080
    Protocol: HTTP
    TargetGroupAttributes:
      - Key: deregistration_delay.timeout_seconds
        Value: '20'
    UnhealthyThresholdCount: 3
    VpcId:
      Ref: 'VPC'
```

```
    Tags:
      - Key: Name
        Value: WebServersTargetGroup
      - Key: Port
        Value: 8080
```

- The corresponding Listener:

```
ALBListener:
  Type: AWS::ElasticLoadBalancingV2::Listener
  Properties:
    DefaultActions:
      - Type: forward
        TargetGroupArn:
          Ref: WebServersTargetGroup
    LoadBalancerArn:
      Ref: ApplicationLoadBalancer
    Port: 8080
    Protocol: HTTP
```

- The Application Load Balancer:

```
ApplicationLoadBalancer:
  Type: AWS::ElasticLoadBalancingV2::LoadBalancer
  Properties:
    Name: CloudyLB
    Scheme: internet-facing
    Subnets:
      - Ref: PublicSubnet1
      - Ref: PublicSubnet2
    SecurityGroups:
      - Ref: LoadBalancerSecurityGroup
```

- The Cloud Watch Alarm for detecting low CPU utilization:

```
CPUAlarmLow:
  Type: AWS::CloudWatch::Alarm
  Properties:
    AlarmActions:
      - Ref: WebServerScaleDownPolicy
    AlarmDescription: Scale-down if CPU < 40% for 2 minutes
    ComparisonOperator: LessThanThreshold
    Dimensions:
      - Name: AutoScalingGroupName
        Value:
          Ref: WebServerAutoScalingGroup
    EvaluationPeriods: '2'
    MetricName: CPUUtilization
    Namespace: AWS/EC2
    Period: '60'
    Statistic: Average
    Threshold: '40'
```

- The corresponding Scaling Policy for scaling down:

```yaml
WebServerScaleDownPolicy:
  Type: AWS::AutoScaling::ScalingPolicy
  Properties:
    AdjustmentType: ChangeInCapacity
    AutoScalingGroupName:
      Ref: WebServerAutoScalingGroup
    Cooldown: '60'
    ScalingAdjustment: '-1'
```

- The Cloud Watch Alarm for detecting high CPU utilization:

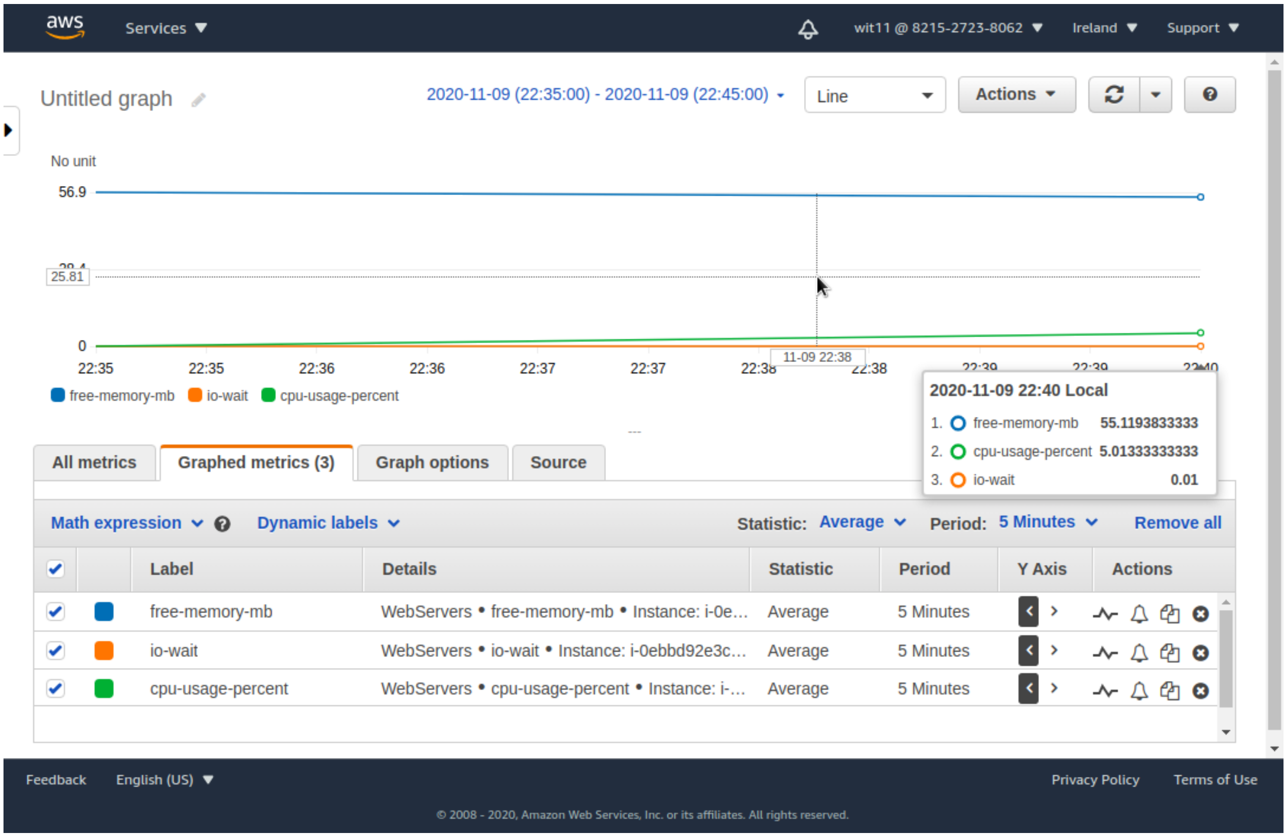
```yaml
CPUAlarmHigh:
  Type: AWS::CloudWatch::Alarm
  Properties:
    AlarmActions:
      - Ref: WebServerScaleUpPolicy
    AlarmDescription: Scale-up if CPU > 60% for 2 minutes
    ComparisonOperator: GreaterThanThreshold
    Dimensions:
      - Name: AutoScalingGroupName
        Value:
          Ref: WebServerAutoScalingGroup
    EvaluationPeriods: '2'
    MetricName: CPUUtilization
    Namespace: AWS/EC2
    Period: '60'
    Statistic: Average
    Threshold: '60'
```

- The corresponding Scaling Policy for scaling up:

```yaml
WebServerScaleUpPolicy:
  Type: AWS::AutoScaling::ScalingPolicy
  Properties:
    AdjustmentType: ChangeInCapacity
    AutoScalingGroupName:
      Ref: WebServerAutoScalingGroup
    Cooldown: '60'
    ScalingAdjustment: '1'
```

5.6. Monitoring

The monitoring script was included in the User Data configuration for the Web Servers. They will report the CPU, Memory and IO/Wait information to Cloud Watch on a regular basis.



The the monitoring script is part of the User Data script, present in the `UserData/Webserver.sh` file.

For it to work, I had also to add the AWS Client configuration file, setting it to use the credentials from the "Ec2InstanceMetadata", meaning it will use the Instance Profile, and to extend the Instance Profile "WebServerRole" with the Policy to allow the "cloudwatch:PutMetricData" action:

```
CloudWatchPutMetrics:
  Type: AWS::IAM::Policy
  Properties:
    PolicyDocument:
      Statement:
        - Action:
            - cloudwatch:PutMetricData
          Effect: Allow
          Resource: '*'
    PolicyName: CloudWatchPutMetrics
    Roles:
      - Ref: WebServerRole
```

6. Web Application

The Web Application was specifically developed to this project. It consists of a Python/Flask REST API Web Service that uses a PostgreSQL database backend to perform INSERT/SELECT operations.

You can see the full source code in the directory `App/`, provided together with this report.

6.1. Endpoints

In addition to the `/users` `GET`/`POST` endpoints that perform operations in the backend database, the application was instrumented with additional endpoints for testing and demonstration purpose. The endpoits are:

- `GET /`: used to test that the application is up and running. It returns the hostname of the Operating System that the application is running on. This is useful to demonstrate the Load Balancing mechanism.

Request:

```
$ curl --request GET http://localhost:8080/
```

Response:

```json
{
  "hostname": "localhost.localdomain"
}
```

- `POST /users`: used to add a user to the database.

Request:

```
$ curl --request POST \
--header 'Content-Type: application/json' \
--data '{"username": "demo", "email": "demo@example.com"}' \
http://localhost:8080/users
```

Response:

```json
{
  "message": "user [demo] added successfully"
}
```

- `GET /users`: used to list all user from the database.

Request:

```
$ curl --request GET http://localhost:8080/users
```

Response:

```json
[
  {
    "email": "demo@example.com",
    "id": 3,
    "username": "demo"
  }
]
```

- `GET /load?number=123`: used to make a CPU intensive request to the application. Under the hood, the application will check if the provided number is a prime number, operation that, depending on the number, might generate significant CPU load on the server. This endpoint will be used for Auto Scaling demonstrations.

Request:

```
$ curl --request GET http://localhost:8080/load?number=112272535095293
```

Response:

```
{
  "isPrime": true,
  "number": 112272535095293,
  "processingTime": 0.48329194501275197
}
```

In the application, because the database secret in placed on a different AWS account, we have to use the AWS Security Token Service client to call `assume_role()`, impersonating the Role from the other account and creating a new session object:

```
...
session = boto3.session.Session()
sts_connection = session.client('sts')
assume_role_obj = sts_connection.assume_role(
    RoleArn='arn:aws:iam::851217607308:role/SecretsManagerCloudy',
    RoleSessionName="AssumeRoleSession1"
)
new_session = boto3.session.Session(
    aws_access_key_id=assume_role_obj['Credentials']['AccessKeyId'],
    aws_secret_access_key=assume_role_obj['Credentials']['SecretAccessKey'],
    aws_session_token=assume_role_obj['Credentials']['SessionToken']
)
...
```

We now can go ahead and read the secret content:

```
...
secret_name = "CloudyDB"
region_name = "us-east-1"
client = new_session.client(
    service_name='secretsmanager',
    region_name=region_name
)
get_secret_value_response = client.get_secret_value(
    SecretId=secret_name
)
...
```

The secret content is then used to build the PostgreSQL connection URI:

```
    ...
    conn_secret = get_secret()
    DB_URI = ('postgresql://'
              f'{conn_secret["username"]}:'
              f'{conn_secret["password"]}@'
              f'{conn_secret["host"]}:'
              f'{conn_secret["port"]}/'
              f'{conn_secret["dbname"]}')
    ...
```

6.2. Database Model

The Database Model is very simplistic and consists of one table with two rows, in addition to the primary key:

```
...

class User(DB.Model):
    id = DB.Column(DB.Integer, primary_key=True)
    username = DB.Column(DB.String(80), unique=True, nullable=False)
    email = DB.Column(DB.String(120), unique=True, nullable=False)
```

That is enough for implementing the `INSERT/SELECT` interfaces.

6.3. Building and Running

The application is distributed as a Docker image. To build it, we have to run:

```
$ cd App/
$ docker build -t apahim/cloudy .
```

To publish, we run:

```
$ docker push apahim/cloudy
```

With that, the Web server can run the application with:

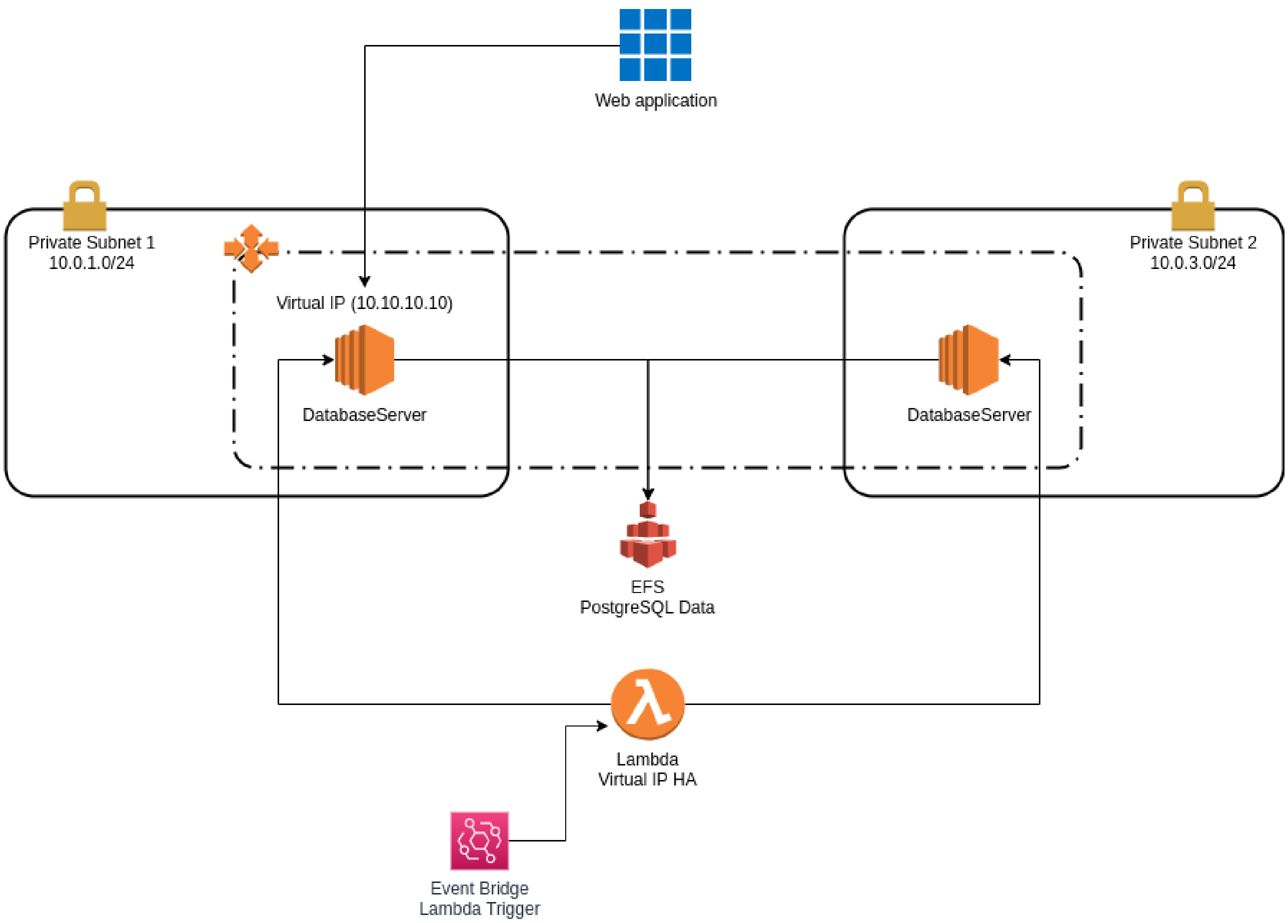
```
$ docker run -d -p 8080:8080 apahim/cloudy
```

7. Database Backend

For this project, I decided to implement a simple high-available active/passive PostgreSQL cluster. In a real world scenario, the managed RDS offering would be recommended given the complexity in manually setting up such a cluster.

Nonetheless, the manual setup is a great learning opportunity. I also opened the possibility to use AWS Lambda and AWS EFS in the final solution.

7.1. Architecture



The architecture of the database cluster consists of EC2 instances that will mount a shared EFS volume.

Regardless the number of instances, only one of them will receive traffic from the Web application.

The way to achieve that was by using a Virtual IP, present on every EC2 instance, then having a Lambda function that runs every minute to check what are the EC2 databases instances that are online, pick one and add it as the destination to a route in the "Public Route Table". Once that instance goes offline, the Lambda function will try to find a new, online, one.

Of top of that, there's an Auto Scaling Group making sure we have instances in multiple Availability Zones.

To have all the EC2 instances with a Virtual IP set up, I added to the User Data the following snippet:

```
# Adding the VIP
cat <<EOF > /etc/sysconfig/network-scripts/ifcfg-eth0:0
DEVICE=eth0:0
IPADDR=10.10.10.10
NETMASK=255.255.255.0
ONBOOT=yes
EOF
```

That will create the Virtual IP in the eth0 device when the instance comes up. Example:

```
[ec2-user@ip-10-0-1-164 ~]$ ifconfig eth0:0
eth0:0: flags=4163<UP,BROADCAST,RUNNING,MULTICAST>  mtu 9001
```

```
        inet 10.10.10.10  netmask 255.255.255.0  broadcast 10.10.10.255
        ether 06:c8:5d:49:c9:75  txqueuelen 1000  (Ethernet)
```

The User Data also includes the configuration to mount the EFS volume and to run the PostgreSQL using Docker.

Here's the full Launch Configuration, including the User Data:

```yaml
  DatabaseServersLaunchConfig:
    Type: AWS::AutoScaling::LaunchConfiguration
    DependsOn:
      - EFSMountTargetPrivateSubnet1
      - EFSMountTargetPrivateSubnet2
    Properties:
      LaunchConfigurationName: DatabaseServersLaunchConfig
      ImageId: ami-0bb3fad3c0286ebd5
      InstanceType: t2.nano
      KeyName: apahim_keys
      SecurityGroups:
        - Ref: DatabaseSecurityGroup
      UserData:
        Fn::Base64: !Sub |
          # full script content in UserData/Database.sh
```

As you might have noticed, it depends on `EFSMountTargetPrivateSubnet1` and `EFSMountTargetPrivateSubnet2`. Those are the EFS mountpoints in the two Availability Zones.

To set up the EFS volume, first I created the File System resource with a Security Group to allow NFS traffic from the database servers:

```yaml
  DatabaseEFSSecurityGroup:
    Type: AWS::EC2::SecurityGroup
    Properties:
      GroupDescription: DatabaseEFSSecurityGroup
      GroupName: DatabaseEFSSecurityGroup
      SecurityGroupEgress:
        - CidrIp: 0.0.0.0/0
          Description: Allow all outbound traffic
          IpProtocol: "-1"
      SecurityGroupIngress:
        - SourceSecurityGroupId: !Ref DatabaseSecurityGroup
          Description: Allow inbound NFS traffic from Databases
          IpProtocol: TCP
          FromPort: 2049
          ToPort: 2049
      Tags:
        - Key: Name
          Value: Database EFS Security Group
      VpcId: !Ref VPC
  DatabaseEFS:
    Type: AWS::EFS::FileSystem
    Properties:
      FileSystemTags:
        - Key: Name
          Value: DatabaseEFS
```

Then I created the two Mount Targets, one per Private Subnet:

```yaml
EFSMountTargetPrivateSubnet1:
  Type: AWS::EFS::MountTarget
  Properties:
    FileSystemId: !Ref DatabaseEFS
    SubnetId: !Ref PrivateSubnet1
    SecurityGroups:
      - !Ref DatabaseEFSSecurityGroup
EFSMountTargetPrivateSubnet2:
  Type: AWS::EFS::MountTarget
  Properties:
    FileSystemId: !Ref DatabaseEFS
    SubnetId: !Ref PrivateSubnet2
    SecurityGroups:
      - !Ref DatabaseEFSSecurityGroup
```

With the EFS volume in place and the Launch Configuration defined, the next resources created are:

- The Security Group for the databases, allowing PostgreSQL traffic from the Web Servers and SSH from the Bastions:

```yaml
DatabaseSecurityGroup:
  Type: AWS::EC2::SecurityGroup
  Properties:
    GroupDescription: DatabaseSecurityGroup
    GroupName: DatabaseSecurityGroup
    SecurityGroupEgress:
      - CidrIp: 0.0.0.0/0
        Description: Allow all outbound traffic
        IpProtocol: "-1"
    SecurityGroupIngress:
      - SourceSecurityGroupId: !Ref WebServerSecurityGroup
        Description: Allow inbound PostgreSQL traffic from Web Servers
        IpProtocol: TCP
        FromPort: 5432
        ToPort: 5432
      - SourceSecurityGroupId: !Ref BastionSecurityGroup
        Description: Allow inbound SSH traffic from bastions
        IpProtocol: TCP
        FromPort: 22
        ToPort: 22
    Tags:
      - Key: Name
        Value: Database Security Group
    VpcId: !Ref VPC
```

- The Auto Scaling Group, making sure we always have an instance in place throughout the two Availability Zones:

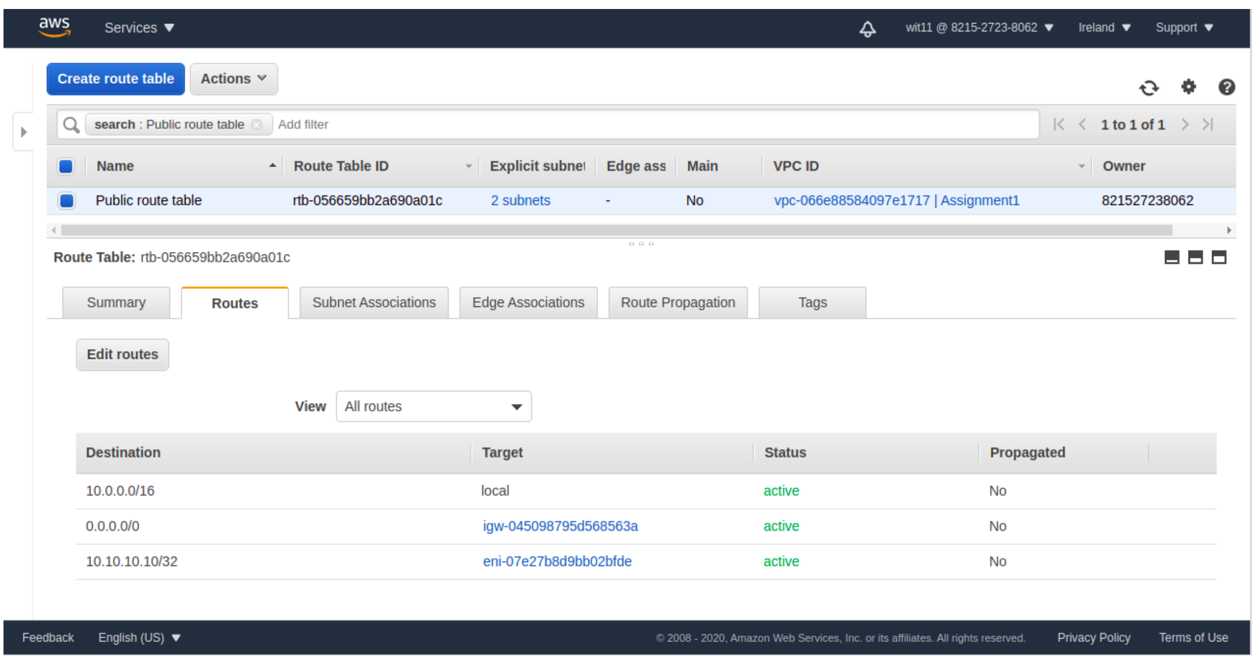
```yaml
DatabaseAutoScalingGroup:
  Type: AWS::AutoScaling::AutoScalingGroup
```

```
Properties:
  AutoScalingGroupName: DatabaseAutoScalingGroup
  VPCZoneIdentifier:
    - Ref: PrivateSubnet1
    - Ref: PrivateSubnet2
  LaunchConfigurationName:
    Ref: DatabaseServersLaunchConfig
  MaxSize: '2'
  MinSize: '1'
  Tags:
    - Key: Name
      Value: Database
      PropagateAtLaunch: 'true'
    - Key: database
      Value: 'true'
      PropagateAtLaunch: 'true'
```

7.2. High Availability

At this point, we have EC2 instances running PostgreSQL, saving data on a shared EFS volume. All the instances have one thing in common: they all have the Virtual IP 10.10.10.10.

Even though the Auto Scaling Group is making sure we have enough instances running, we still have to route traffic to one of them. To do that, we have to add a route to the “Public Route Table”, the route table used by the Web Servers, pointing to any of the database instances. Example:



In the event of a failure, we have to change that route to point to another EC2 instances running the database.

To automate the process, I created a Lambda function that is triggered every minute and will:

- Search all the EC2 instances that have the Tag “database=true”. That Tag was included in the Launch Configuration for the database instances.
- Among those instances, check which ones are with the Status “ok”. Those are the candidates.

- Next, the Lambda will find a route table that has the Tag "database=true". That Tag was included in the "Public Route Table" configuration.
- Now the Lambda has the candidates and the route table to work with, next step is to add or update the route to 10.10.10.10/32 in the route table, pointing to on of the candidates.

Here's the full Lambda definition, including the function source code:

```
LambdaDatabaseHA:
  Type: AWS::Lambda::Function
  Properties:
    Role: !GetAtt LambdaExecutionRole.Arn
    FunctionName: LambdaDatabaseHA
    Handler: "index.lambda_handler"
    Timeout: 20
    Runtime: python3.6
    Code:
      ZipFile: |
        # full script content in Lambda/DatabaseHA.py
```

The Lambda function needs some permissions to run. Here's the Role definition:

```
LambdaExecutionRole:
  Type: AWS::IAM::Role
  Properties:
    AssumeRolePolicyDocument:
      Statement:
        - Effect: Allow
          Principal:
            Service:
              - lambda.amazonaws.com
          Action:
            - sts:AssumeRole
          Condition: {}
    Path: /
    ManagedPolicyArns:
      - arn:aws:iam::aws:policy/service-role/AWSLambdaBasicExecutionRole
      - arn:aws:iam::aws:policy/AmazonVPCFullAccess
      - arn:aws:iam::aws:policy/AmazonEC2FullAccess
```

Last piece here is the Lambda trigger. For that, I'm using an Events Rule with the ScheduleExpression set to "rate(1 minute)". The proper permissions to trigger the Lambda are also part of the Events Rule specification, as seen below:

```
CloudWatchLambdaDatabaseHARule:
  Type: AWS::Events::Rule
  Properties:
    Description: "Rule to trigger lambda"
    Name: CloudWatchLambdaDatabaseHARule
    ScheduleExpression: "rate(1 minute)"
    State: ENABLED
    Targets:
      - Arn: !Sub ${LambdaDatabaseHA.Arn}
```

```
        Id: CloudWatchLambdaDatabaseHARule
  LambdaSchedulePermission:
    Type: AWS::Lambda::Permission
    Properties:
      Action: 'lambda:InvokeFunction'
      FunctionName: !Sub ${LambdaDatabaseHA.Arn}
      Principal: 'events.amazonaws.com'
      SourceArn: !Sub ${CloudWatchLambdaDatabaseHARule.Arn}
```

Here are some logs, as seen in Cloud Watch, generated from the Lambda execution. When everything is normal, we see:

```
[INFO] 2020-11-09T15:17:00.232Z 13b4e4f8-381f-4732-81d8-17d49bbe2f71
Route on rtb-056659bb2a690a01c already pointing to 10.10.10.10/32
via i-077b35fcb10d88caa
```

When the instance goes offline, and the Lambda updates the route, we see:

```
[INFO] 2020-11-09T17:51:00.734Z 5f8e9619-1859-46c4-a597-ceb811d7e019
Updated route on rtb-056659bb2a690a01c to 10.10.10.10/32
via i-05f737bd5bcd18c0d
```

7.3. Scalability

In the current architecture, there are two ways to scale the service:

1. Growing the instance type: that will allow for more CPU/Memory/IOPS power while still having a single instance. Replacing the instance size is a simple task with the current architecture.
2. Using the passive instances as read-only endpoints: no mechanism for that was implemented here, but to implement it I'd create multiple DNS "A" entries for the same domain, one per read-only instance IP, and make sure that the client applications are using that domain as endpoint for read operations.

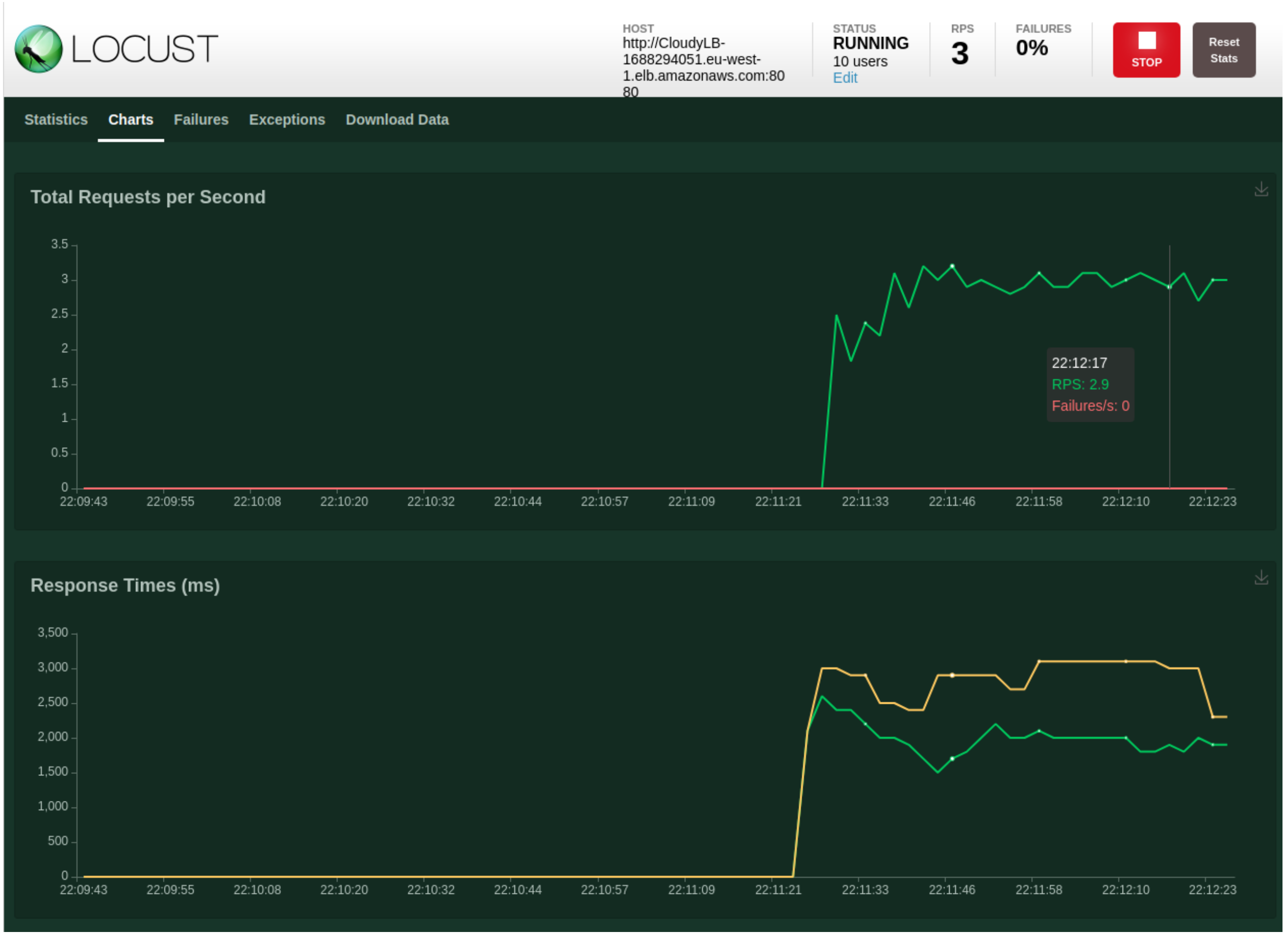
8. Load Test

For load test, I created a Python/Locust script that exercises the `/load` endpoint, triggering multiple connections at the same time.

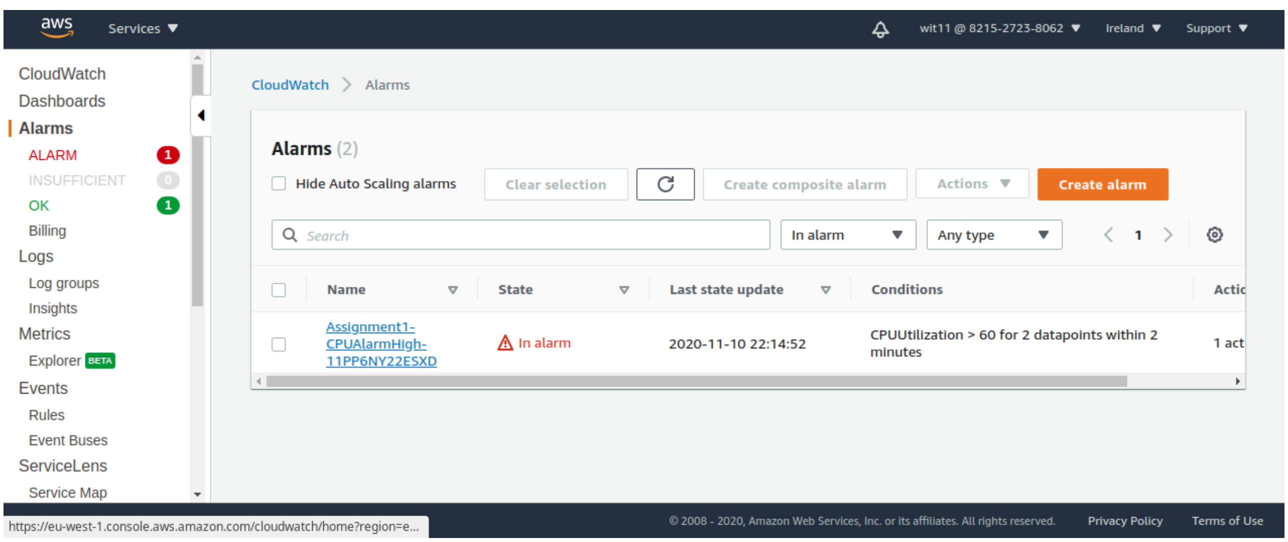
To run the script, we have to execute:

```
$ pip install locust
$ locust -f LoadTest/WebServerLoadTest.py
[2020-11-10 22:09:24,303] workstation/INFO/locust.main: Starting web
interface at http://0.0.0.0:8089 (accepting connections from all network
interfaces)
[2020-11-10 22:09:24,309] workstation/INFO/locust.main: Starting Locust 1.3.2
```

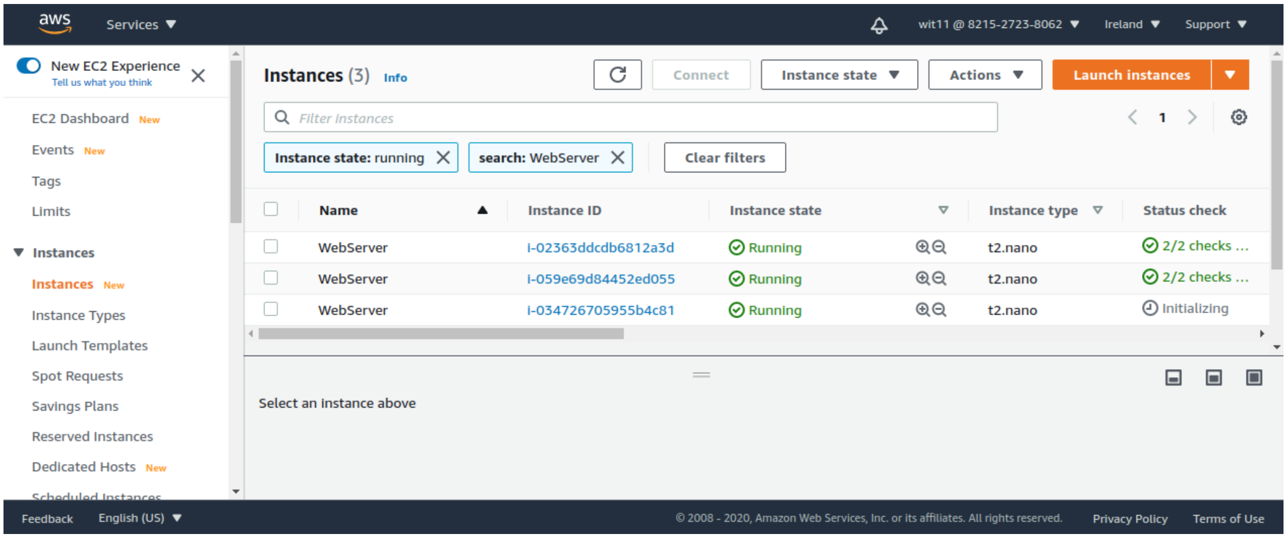
That will create a web server running the locust web interface. After entering the number of clients to simulate and the Load Balancer URL, we see the load test under execution:



After a couple of minutes, we see the High CPU alert alarming:



And a new Web Server instance being launched:



9. Conclusion

For the Security Considerations, we covered here a lot beyond the basics:

- Database credentials stored by Secrets Manager.
- Instance Profile, so the EC2 instances could interact with the AWS services without having our personal access tokens.
- Fine-grained and fine-tuned Security groups.
- Bastion instance with exclusive SSH access to the instances.
- Private subnets to host the database instances.

The improvements opportunities related to security are:

- Implement HTTPS for the Web application Load Balancer: that item was considered out of scope for this project, but it's a required feature for a real world implementation.
- The connection between the Web application and the PostgreSQL instance is also not encrypted. Implementing SSL over the PostgreSQL traffic would be a must for a project to go to production.
- The Web application used in this project has no authentication mechanism. Since it's a custom application built for this project, the authentication mechanism was not implemented. That is certainly a required feature for a real world implementation.

In addition to the security improvements listed above, there are topics that also constitute future work when thinking of a real world solution:

- Use a PostgreSQL RDS managed instance: that would massively reduce the workload and the complexity to create a highly-available and fault tolerant cluster.
- Use a NAT Gateway instead of a NAT Instance to provide internet access for the EC2 instances running on the private networks, for a high-available/fault-tolerant and managed implementation.

This project had two big personal challenges: the full Cloud Formation persistence, given it was my first contact with Cloud Formation, and the creation of a home-baked Database cluster, which involved acquiring a deeper understanding of the AWS resources management and also of the AWS client libraries. The learnings out of these exercises were massive, so I would like to thank our Lecturers for creating implementation levels that allowed us to push the boundaries of the project in the directions that are of our interest. That was really motivating.