

Storing Stuff

Software Architecture

March 14, 2022

Brae Webb



Figure 1: A map of data storage techniques from Designing Data-Intensive Applications [1].

1 This Week

This week our goal is to:

- explore the various techniques developers use to store data;
- investigate the storage options implementing these techniques on the AWS platform;
- run a small application using docker that requires a database; and
- deploy the application in AWS using Terraform.

2 Databases and Data Models

Unfortunately, to build interesting software we often need to store and use data. The storage of data introduces a number of challenges when designing, creating, and maintaining our software. However, not all data storage techniques are created equal; the choice of data storage model can have a profound impact on our software's complexity and maintainability. In this practical, we want to take a superficial exploration of our island of data storage models. For a more in-depth treatment of data storage models that is outside the scope of this course, see Chapter 2 of the *Designing Data-Intensive Applications* book [1].

2.1 Relational Storage

Relational databases what have been exposed to the most in your University career — think MySQL, Postgres, Oracle DB, etc. This type of database is good at modelling the real world which is often a highly connected environment.

Some popular offerings are below:

- MySQL/MariaDB [Amazon RDS / Amazon Aurora].
- Postgres [Amazon RDS / Amazon Aurora].

The AWS offerings of these services come in two different types, we have the traditional approach of server capacity (x cores, y ram) and we have a server-less approach. The server-less approach is a more dynamic database that can scale to large amounts of load when needed though at a cost per request.

2.1.1 ORM

Object Relational Mapping (ORM) is a fairly common tool for programmers to use to make developing with databases smoother. One fairly prevalent example of this is SQLAlchemy which is a very widely used database abstraction for python. SQLAlchemy allows us to move to a higher level of abstraction than SQL queries and perform database actions using standard python code.

The benefits of ORMs are the ability to model database objects in our existing programming language instead of having large blocks of SQL text within our source code. The disadvantages come in when we need to do specific SQL work or where the abstractions cost is greater than the benefits.

2.2 Wide-Column Storage

Wide-Column databases are a form of NoSQL or non-relational data stores. In these data stores the data model design is focused more on having efficient queries at the cost of data duplication. A warning to the reader that these models are not flexible after creation, it is much easier to answer a new use case in a relational model.

- Apache Cassandra [Amazon Keyspaces for Cassandra].
- Apache HBase.

2.3 Key-Value Storage

Key-Value stores are very popular for cache or remote config use cases, some of the most notable are Redis and Memcached. These stores allow efficient lookup of values via keys and are usually stored in-memory.

- Redis [Amazon ElastiCache for Redis].

- Memcached [Amazon ElastiCache for Memcached].
- Amazon DynamoDB.
- Amazon MemoryDB for Redis.

2.4 Time Series Storage

Time series databases are highly focused storage which is tailored to retrieving results by timestamp ranges. Many implementations also take advantage of the data model to allow efficient rollover of data and partitioning. One of the most popular time series databases is Prometheus which is used to store monitoring metrics.

- Amazon Timestream.
- TimescaleDB (Postgres + Addon).
- Prometheus.
- InfluxDB.

2.5 Document Storage

Document databases are a subset of NoSQL databases with a focus on a flexible data model. MongoDB for instance allows the user to store JSON documents and perform queries on those documents. One advantage of document databases is that they match a programmers existing mental model of storing data in formats such as JSON.

- MongoDB.
- Apache CouchDB.
- Amazon DocumentDB.
- Amazon DynamoDB.

2.6 Graph Storage

Graph Databases are relational storage with a few enhancements to allow fast neighbour look-ups. These databases also allow the implementation of graph algorithms to query data.

- Amazon Neptune.
- Neo4J.
- Janus Graph.

3 Working with Docker

So far in the course we have introduced docker as a means to package software to make it easier to work with and deploy. Today we will be using it to run a small application locally that consists of a web server and a relational database.

My Todo List

Complete CSSE6400 Prac 1	+
Complete CSSE6400 Prac 2	
Complete CSSE6400 Prac 3	
Complete CSSE6400 Prac 4	
Joined the CSSE6400 Slack	
Attended Lecture 1 of CSSE6400	
Attended Lecture 2 of CSSE6400	
Attended Lecture 3 of CSSE6400	
Attended Lecture 4 of CSSE6400	
Attended Braes tutorial	

Previous

1

2

3

Next

Figure 2: Sample Todo App made by Brae Webb

Info

You will need to have docker and docker-compose installed for this practical. Installation will depend on your operating system.

- Docker compose: <https://docs.docker.com/compose/install/>
- Docker engine: <https://docs.docker.com/get-docker/>

We also recommend installing the vscode docker plugin or the equivalent tools in IntelliJ IDEs.

Notice

For terminal examples in this section, lines that begin with a \$ indicate a line which you should type while the other lines are example output that you should expect. Not all of the output is captured in the examples to save on space.

3.1 Locally

We will be using a container that is built from the Dockerfile described below which can be found here: <https://github.com/CSSE6400/todo-app/blob/main/backend/Dockerfile>.

```
» cat Dockerfile
1 FROM ubuntu:21.10
2 RUN apt-get update \
3     && DEBIAN_FRONTEND=noninteractive apt install -y \
4         php \
5         php-mysql \
6         php-xml \
7         php-curl \
8         curl \
9         git \
10        unzip
11 RUN curl -sS https://getcomposer.org/installer | php -- --install-dir=/usr/local/bin
    --filename=composer
12 COPY . /app
13 WORKDIR /app
14 RUN composer install
15 CMD ["php", "artisan", "serve", "--host=0.0.0.0"]
```

Our goal for today is to have a running instance of the Todo App locally including the database. To get started we need to make a new directory for our work and create a Docker compose file.

```
$ mkdir prac4 && cd prac4
$ touch docker-compose.yml
```

Docker Compose is a small helper utility that allows us to more easily run docker applications without needing to remember a lot of command line parameters. Instead we define how we want our docker container to run through a YAML config file. Insert the following into your docker-compose.yml file.

```
» cat docker-compose.yml
1 version: '3.3'
2 services:
3   backend:
4     image: ghcr.io/csse6400/todo-app:latest
5     ports:
```

```

6     - '8000:8000'
7   environment:
8     APP_ENV: 'local'
9     APP_KEY: 'base64:8PQEPYGlTm1t3aqWmlAw/ZPwCiIFvdXDBjk3mhsom/A='
10    APP_DEBUG: 'true'
11    LOG_LEVEL: 'debug'

```

A few things to point out in the file. We have defined a single service called backend which uses a pre-made docker image from ghcr.io/csse6400/todo-app with the tag of latest. We then have exposed this onto our machine on port 8000 and have passed a few environment variables.

```

$ docker-compose up
Creating network "p1_default" with the default driver
Creating p1_backend_1 ... done
Attaching to p1_backend_1
backend_1 | Starting Laravel development server: http://0.0.0.0:8000
backend_1 | [Sun Mar 20 07:56:23 2022] PHP 8.0.8 Development Server (http
: //0.0.0.0:8000) started

```

Now we head to our browser and go to <http://127.0.0.1:8000>, you should be presented with the following screen.

My Todo List

Previous 1 Next



The server had a problem

To investigate this error lets hit one of the endpoints for our api. Head over to <http://127.0.0.1:8000/api/v1/todo> which should list all the todos. Once we reach that page we have a clearer idea of whats gone wrong. The page you should see is shown in Figure 3 and the quick summary is that our App is complaining that we haven't given it a database.

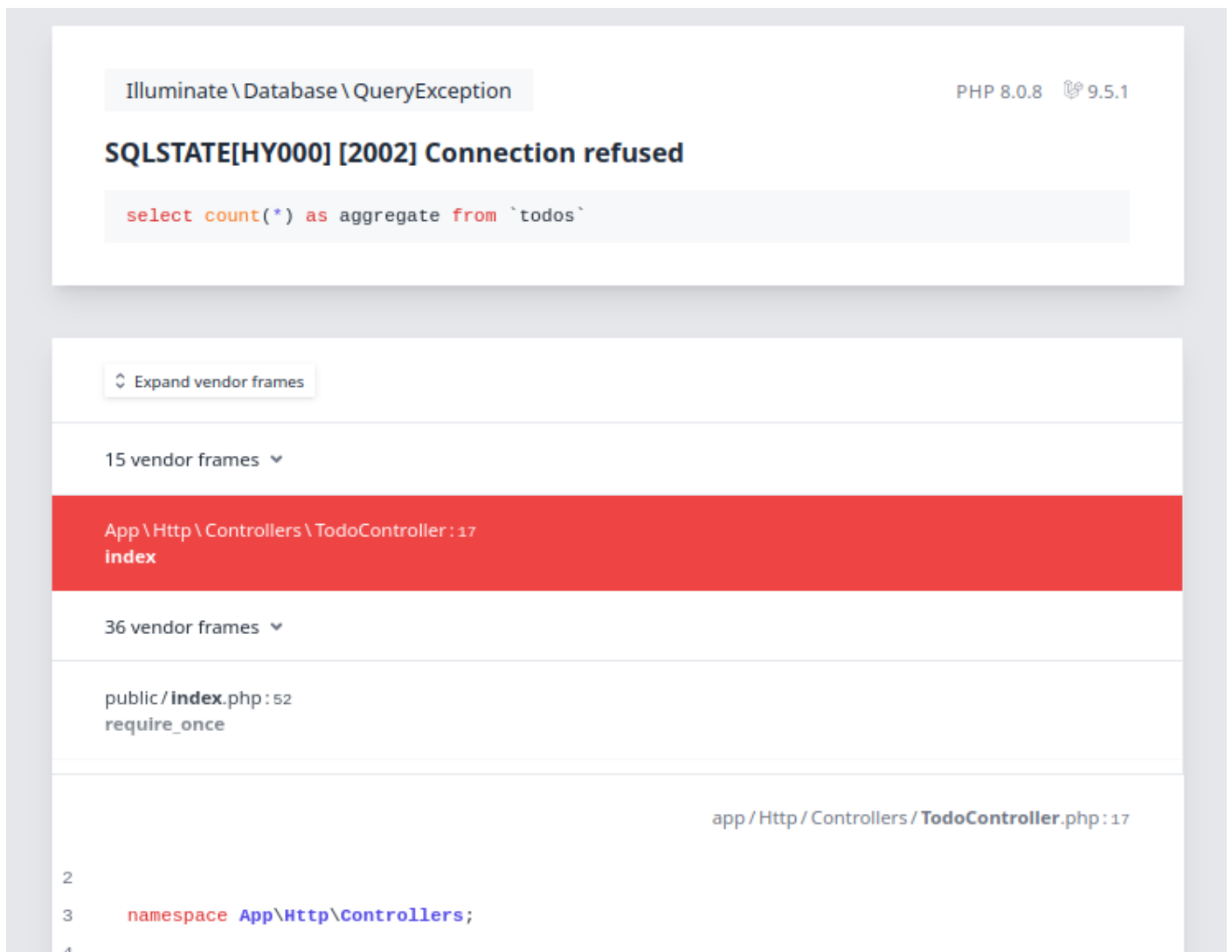


Figure 3: The expected error page when accessing <http://127.0.0.1:8000/api/v1/todo>.

To fix this lets add a popular relation database, MySQL, to our docker-compose file. Edit your docker compose file to match as shown below.

```
» cat main.tf
1 version: '3.3'
2 services:
3   db:
4     image: mysql:8-debian
5     environment:
6       MYSQL_DATABASE: 'todoapp'
7       MYSQL_USER: 'todoapp'
8       MYSQL_PASSWORD: 'password'
9       MYSQL_ROOT_PASSWORD: 'password'
10    ports:
11      - '3306:3306'
13 backend:
```

```

14 image: ghcr.io/csse6400/todo-app:latest
15 depends_on:
16   - db
17 ports:
18   - '8000:8000'
19 environment:
20   APP_ENV: 'local'
21   APP_KEY: 'base64:8PQEPYGlTm1t3aqWmlAw/ZPwCiIFvdXDBjk3mhsom/A='
22   APP_DEBUG: 'true'
23   LOG_LEVEL: 'debug'
24   DB_CONNECTION: 'mysql'
25   DB_HOST: 'db'
26   DB_PORT: '3306'
27   DB_DATABASE: 'todoapp'
28   DB_USERNAME: 'todoapp'
29   DB_PASSWORD: 'password'

```

Now we have two services for our app and we have added a few more environment variables for our backend to know how to connect to the database. The `DB_HOST` variable uses a feature of docker compose where you can refer to other services by their name. This makes it easy for us to setup communication between these two services.

From the same shell let's re-run our containers, you may need to CTRL+C to stop the current running containers. Once they have shutdown, run the up command again.

```

$ docker-compose up
Starting p2_db_1 ... done
Starting p2_backend_1 ... done
Attaching to p2_db_1, p2_backend_1
db_1 | 2022-03-20 08:11:55+00:00 [Note] [Entrypoint]: Entrypoint ....
db_1 | 2022-03-20 08:11:55+00:00 [Note] [Entrypoint]: Switching t....
db_1 | 2022-03-20 08:11:55+00:00 [Note] [Entrypoint]: Entrypoint ....
db_1 | 2022-03-20T08:11:55.438996Z 0 [System] [MY-010116] [Server....
db_1 | 2022-03-20T08:11:55.445261Z 1 [System] [MY-013576] [InnoDB....
backend_1 | Starting Laravel development server: http://0.0.0.0:8000
db_1 | 2022-03-20T08:11:55.535803Z 1 [System] [MY-013577] [InnoDB....
db_1 | 2022-03-20T08:11:55.673757Z 0 [Warning] [MY-010068] [Serve....
db_1 | 2022-03-20T08:11:55.673784Z 0 [System] [MY-013602] [Server....
db_1 | 2022-03-20T08:11:55.674810Z 0 [Warning] [MY-011810] [Serve....
db_1 | 2022-03-20T08:11:55.684729Z 0 [System] [MY-010931] [Server....
db_1 | 2022-03-20T08:11:55.684756Z 0 [System] [MY-011323] [Server....
backend_1 | [Sun Mar 20 08:11:55 2022] PHP 8.0.8 Development Serv....

```

Now when we go to <http://127.0.0.1:8000/api/v1/todo> we see a different error message, as shown in Figure 4. This error is complaining that we have a database that we can connect to but the todos table doesn't exist.

To populate the database our application comes with database migration files. One way would be to click the "RUN MIGRATIONS" button shown on the error page but we also want to pre-populate our database with some dummy data as well.

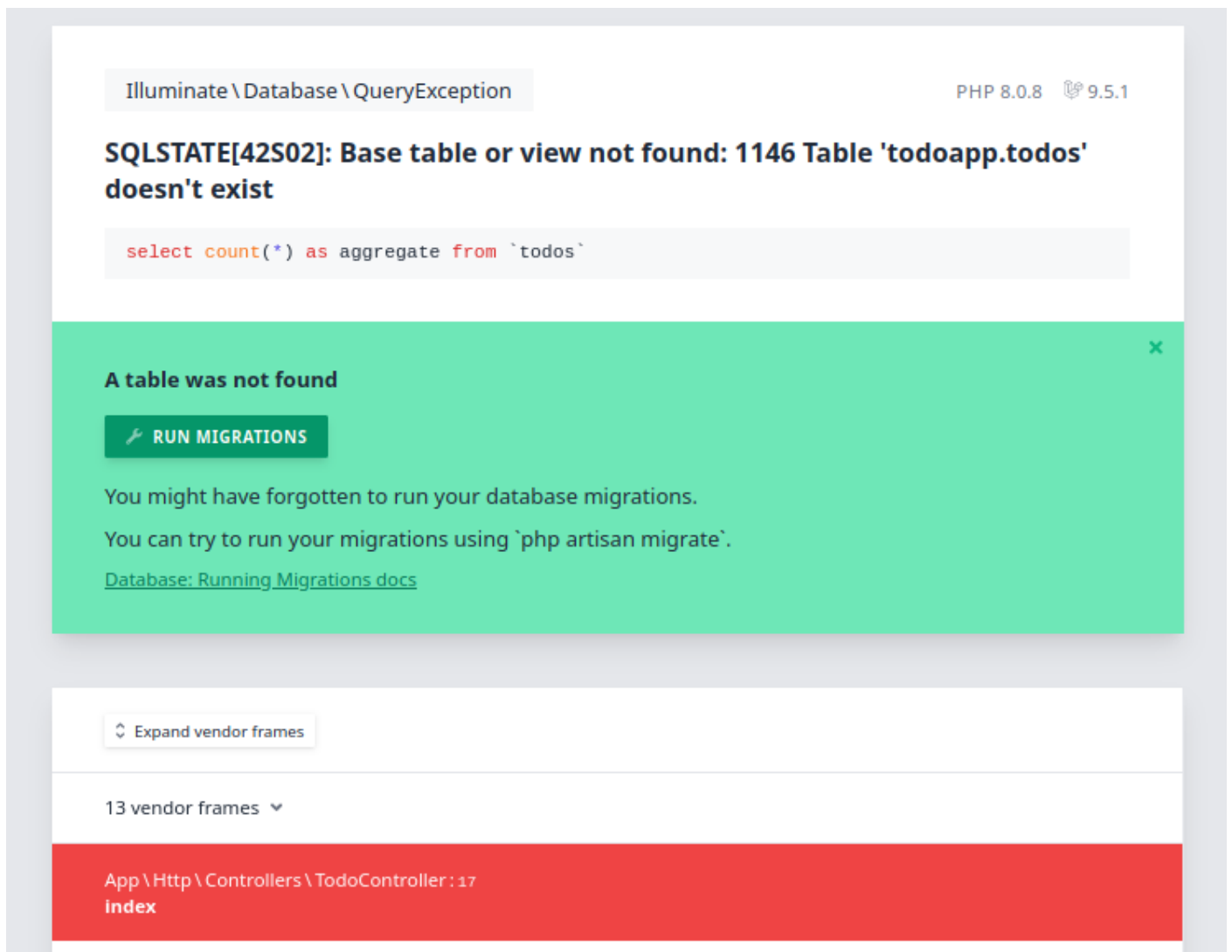


Figure 4: The expected error page when accessing <http://127.0.0.1:8000/api/v1/todo> after creating a database.

To do this we are going to jump into the running container and execute the migrations ourselves. Start by opening a new terminal so that we can leave the docker containers running. In this new terminal go to the same directory that we were just in and run the following command:

```
$ docker-compose exec backend php artisan migrate:fresh --seed
Dropped all tables successfully.
Migration table created successfully.
Migrating: 2022_03_19_041557_create_todos_table
Migrated: 2022_03_19_041557_create_todos_table (7.55ms)
Seeding: Database\Seeders\TodoSeeder
Seeded: Database\Seeders\TodoSeeder (6.56ms)
Database seeding completed successfully.
```

Now with this run we can check back at our web app and you should see a fully functional todo app.

My Todo List

Complete CSSE6400 Prac 1	+
Complete CSSE6400 Prac 2	
Complete CSSE6400 Prac 3	
Complete CSSE6400 Prac 4	
Joined the CSSE6400 Slack	
Attended Lecture 1 of CSSE6400	
Attended Lecture 2 of CSSE6400	
Attended Lecture 3 of CSSE6400	
Attended Lecture 4 of CSSE6400	
Attended Braes tutorial	

[Previous](#)[1](#)[2](#)[3](#)[Next](#)

Info

These migrations are performed by Laravel which is a popular PHP web framework. In the database it has created a table to keep track of which migrations have already been run so that it will skip them latter. To enable this functionality you will have to edit migrate:fresh to just migrate.

For a production instance you would also typically remove the `--seed` parameter as you do not want to insert dummy data into your production database.

3.1.1 Exercise: Migrations at startup

So far when we run this application we have to perform the database migrations manually. To help us get up and running we are going to make a small modification to pre-run the migrations when the web app starts. First we need to have a look at how the container is set to launch by default. In the Dockerfile attached at the start of the practical we see that we have defined the command to run on the last line with the `CMD` directive.

```
» cat Dockerfile
```

```
1 FROM ubuntu:21.10
2 ...
3 ...
4 ...
5 CMD ["php", "artisan", "serve", "--host=0.0.0.0"]
```

Info

When working with docker it can get confusing around the networking aspects. In this application I have specified that the server must listen on all network interfaces (0.0.0.0). Without this flag the default is 127.0.0.1 which even though its the localhost the forwarded traffic through the docker container would never reach it.

This command launches the laravel development server and listens on all interfaces on the host. We are going to override this in our docker-compose file so that we run the migrations then start the server. Add the following line to the docker-compose.yml that you have been developing during the practical.

```
1 command: sh -c "sleep 30 && php artisan migrate:refresh --seed && php artisan serve
    --host=0.0.0.0"
```

This new command does the following:

- Waits for the database to be ready in a simple way.
- Runs the migrations and seeds the database, as we have seen earlier.
- Starts the development server as the container originally did.

Example: condensed version of the goal docker-compose.yml attached below.

```
» cat docker-compose.yml
1 version: '3.3'
2 services:
3   db:
4     ...
5
6   backend:
7     ...
8     environment:
9       ...
10    command: sh -c "sleep 10 && php artisan migrate:refresh --seed && php artisan
    serve --host=0.0.0.0"
```

Now when we launch the docker-compose we can see that our migrations were run in the output.

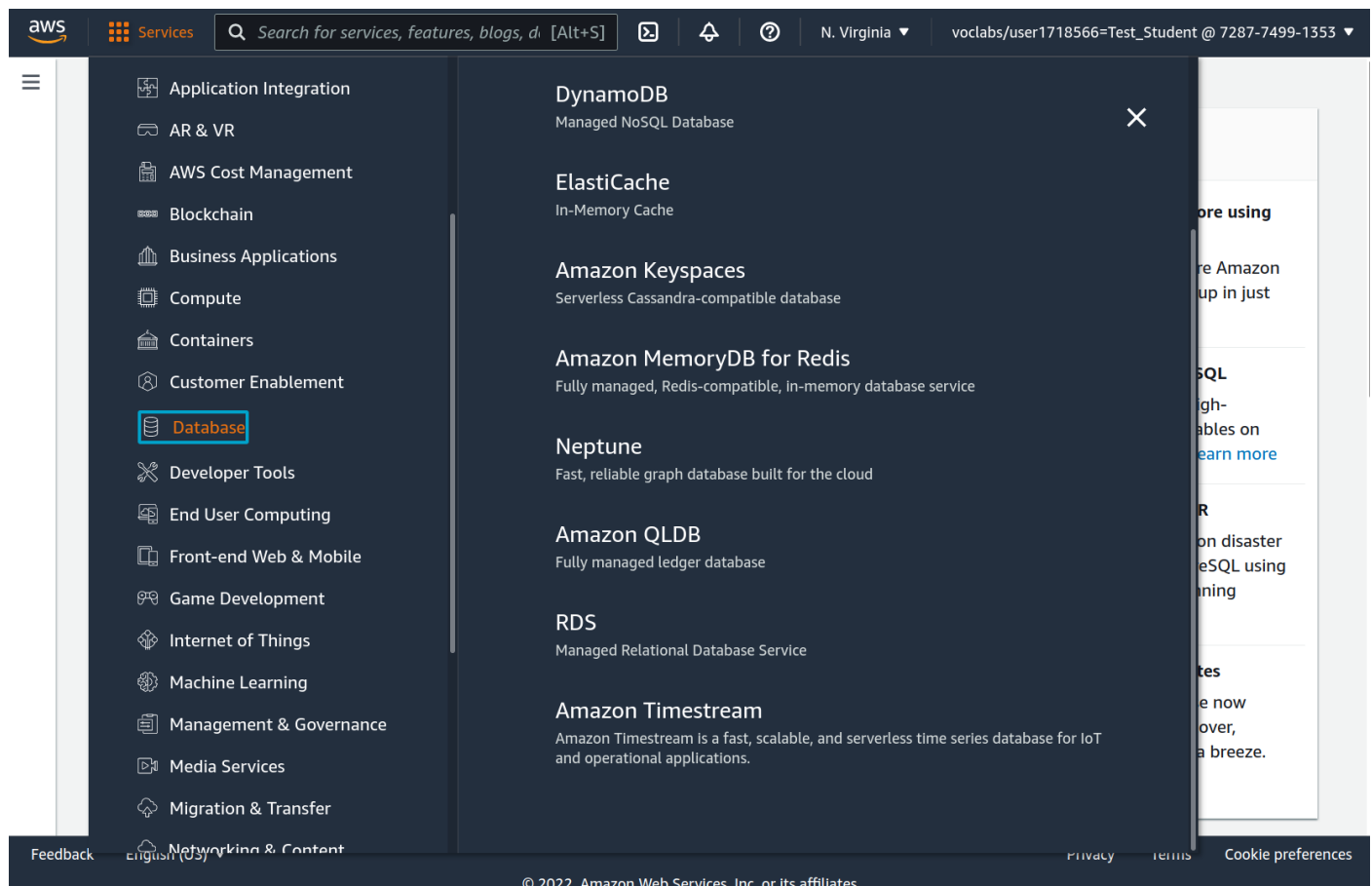
```
$ docker-compose up
...
...
backend_1 | Rolling back: 2022_03_19_041557_create_todos_table
backend_1 | Rolled back: 2022_03_19_041557_create_todos_table (8.28ms)
backend_1 | Migrating: 2022_03_19_041557_create_todos_table
backend_1 | Migrated: 2022_03_19_041557_create_todos_table (11.55ms)
backend_1 | Seeding: Database\Seeders\TodoSeeder
backend_1 | Seeded: Database\Seeders\TodoSeeder (44.77ms)
backend_1 | Database seeding completed successfully.
backend_1 | Starting Laravel development server: http://0.0.0.0:8000
backend_1 | [Sun Mar 20 12:08:41 2022] PHP 8.0.8 Development Server (http
://0.0.0.0:8000) started
```

We can also bake this into the container by extending the original, it is fairly common to see projects in the wild that run an init script when the container launches. An exercise left for the reader is to build upon the provided docker container by including an init script.

3.2 AWS

Warning

This section is still being developed.



Amazon RDS

Dashboard

Databases

Query Editor

Performance insights

Snapshots

Automated backups

Reserved instances

Proxies

Subnet groups

Parameter groups

Option groups

Custom Availability Zones

Custom engine versions

Events

Event subscriptions

Resources

Refresh

You are using the following Amazon RDS resources in the US East (N. Virginia) region (used/quota)

DB Instances (0/40)

Allocated storage (0 TB/100 TB)

Click here to increase DB instances limit

Parameter groups (0)

Default (0)

Custom (0/100)

Option groups (0)

Default (0)

Custom (0/20)

Subnet groups (0/50)

Supported platforms VPC

Default network vpc-07f8e8ea0408a9db9

DB Clusters (0/40)

Reserved instances (0/40)

Snapshots (0)

Manual (0/100)

Automated (0)

Recent events (0)

Event subscriptions (0/20)

Create database

Amazon Relational Database Service (RDS) makes it easy to set up, operate, and scale a relational database in the cloud.

Recommended for you

Time-Series Tables in PostgreSQL

Step-by-step guide to design high-performance time series data tables on Amazon RDS for PostgreSQL. [Learn more](#)

Implementing Cross-Region DR

Learn how to set up Cross-Region disaster recovery (DR) for Aurora PostgreSQL using an Aurora global database spanning multiple Regions. [Learn more](#)

Amazon RDS Backup and Restore using AWS Backup

Learn how to backup and restore Amazon RDS databases using AWS Backup in just 10 minutes. [Learn more](#)

Build RDS Operational Tasks

Feedback

English (US) ▼

Privacy

Terms

Cookie preferences

© 2022, Amazon Web Services, Inc. or its affiliates.

RDS > Databases

Databases

Group resources

Refresh

Modify

Actions ▼

Restore from S3

Create database

< 1 >

Settings

DB identifier

▲

Role ▼

Engine ▼

Region & AZ ▼

Size ▼

Status ▼

CPU

No instances found

Choose a database creation method [Info](#)

☒ Standard create

You set all of the configuration options, including ones for availability, security, backups, and maintenance.

☐ Easy create

Use recommended best-practice configurations. Some configuration options can be changed after the database is created.

Engine options

Engine type [Info](#)

☐ Amazon Aurora



☒ MySQL



☐ MariaDB



☐ PostgreSQL



☐ Oracle



☐ Microsoft SQL Server



Edition

☒ MySQL Community



Known issues/limitations

Review the [Known issues/limitations](#) [link](#) to learn about potential compatibility issues with specific database versions.

Version

MySQL 8.0.27



Templates

Choose a sample template to meet your use case.

☐ **Production**
Use defaults for high availability and fast, consistent performance.

☐ **Dev/Test**
This instance is intended for development use outside of a production environment.

☒ **Free tier**
Use RDS Free Tier to develop new applications, test existing applications, or gain hands-on experience with Amazon RDS.
[Info](#)

Availability and durability

Deployment options [Info](#)

The deployment options below are limited to those supported by the engine you selected above.

- ☐ **Single DB instance (not supported for Multi-AZ DB cluster snapshot)**
Creates a single DB instance with no standby DB instances.
- ☐ **Multi-AZ DB instance (not supported for Multi-AZ DB cluster snapshot)**
Creates a primary DB instance and a standby DB instance in a different AZ. Provides high availability and data redundancy, but the standby DB instance doesn't support connections for read workloads.
- ☐ **Multi-AZ DB Cluster - new**
Creates a DB cluster with a primary DB instance and two readable standby DB instances, with each DB instance in a different Availability Zone (AZ). Provides high availability, data redundancy and increases capacity to serve read workloads.

Settings

DB instance identifier [Info](#)

Type a name for your DB instance. The name must be unique across all DB instances owned by your AWS account in the current AWS Region.

The DB instance identifier is case-insensitive, but is stored as all lowercase (as in "mydbinstance"). Constraints: 1 to 60 alphanumeric characters or hyphens. First character must be a letter. Can't contain two consecutive hyphens. Can't end with a hyphen.

▼ Credentials Settings

Master username [Info](#)

Type a login ID for the master user of your DB instance.

1 to 16 alphanumeric characters. First character must be a letter.

☐ **Auto generate a password**

Amazon RDS can generate a password for you, or you can specify your own password.

Master password [Info](#)

Constraints: At least 8 printable ASCII characters. Can't contain any of the following: / (slash), '(single quote), "(double quote) and @ (at sign).

Confirm password [Info](#)

DB instance class

DB instance class [Info](#)

- ☐ Standard classes (includes m classes)
- ☐ Memory optimized classes (includes r and x classes)
- ☒ **Burstable classes (includes t classes)**

1 vCPUs 1 GiB RAM Not EBS Optimized



☐ Include previous generation classes

Storage

Storage type [Info](#)

General Purpose SSD (gp2)

Baseline performance determined by volume size



Allocated storage

20



GiB

(Minimum: 20 GiB. Maximum: 16,384 GiB) Higher allocated storage **may improve** IOPS performance.



You might see better baseline performance with your selected volume size by specifying General Purpose SSD storage. [Learn more about using Provisioned IOPS storage for consistent performance.](#)



Storage autoscaling [Info](#)

Provides dynamic scaling support for your database's storage based on your application's needs.

☒ **Enable storage autoscaling**

Enabling this feature will allow the storage to increase once the specified threshold is exceeded.

Maximum storage threshold [Info](#)

Charges will apply when your database autoscales to the specified threshold

1000



GiB

Minimum: 21 GiB. Maximum: 16,384 GiB

Connectivity



Virtual private cloud (VPC) [Info](#)

VPC that defines the virtual networking environment for this DB instance.

Default VPC (vpc-07f8e8ea0408a9db9) ▼

Only VPCs with a corresponding DB subnet group are listed.

After a database is created, you can't change its VPC.

Subnet group [Info](#)

DB subnet group that defines which subnets and IP ranges the DB instance can use in the VPC you selected.

default-vpc-07f8e8ea0408a9db9 ▼

Public access [Info](#)

☒ Yes

Amazon EC2 instances and devices outside the VPC can connect to your database. Choose one or more VPC security groups that specify which EC2 instances and devices inside the VPC can connect to the database.

☐ No

RDS will not assign a public IP address to the database. Only Amazon EC2 instances and devices inside the VPC can connect to your database.

VPC security group

Choose a VPC security group to allow access to your database. Ensure that the security group rules allow the appropriate incoming traffic.

☐ Choose existing
Choose existing VPC security groups

☒ Create new
Create new VPC security group

New VPC security group name

todoapp-manual

Availability Zone [Info](#)

No preference ▼

▼ Additional configuration

Database port [Info](#)

TCP/IP port that the database will use for application connections.

3306



Database authentication

Database authentication options [Info](#)

- ☒ **Password authentication**
Authenticates using database passwords.
- ☐ **Password and IAM database authentication**
Authenticates using the database password and user credentials through AWS IAM users and roles.
- ☐ **Password and Kerberos authentication**
Choose a directory in which you want to allow authorized users to authenticate with this DB Instance using Kerberos Authentication.

▼ Additional configuration

Database options, backup enabled, backtrace disabled, Enhanced Monitoring disabled, maintenance, CloudWatch Logs, delete protection disabled.

Database options

Initial database name [Info](#)

If you do not specify a database name, Amazon RDS does not create a database.

DB parameter group [Info](#)



Option group [Info](#)



Estimated monthly costs

The Amazon RDS Free Tier is available to you for 12 months. Each calendar month, the free tier will allow you to use the Amazon RDS resources listed below for free:

- 750 hrs of Amazon RDS in a Single-AZ db.t2.micro Instance.
- 20 GB of General Purpose Storage (SSD).
- 20 GB for automated backup storage and any user-initiated DB Snapshots.

[Learn more about AWS Free Tier.](#)

When your free usage expires or if your application use exceeds the free usage tiers, you simply pay standard, pay-as-you-go service rates as described in the [Amazon RDS Pricing page](#).

You are responsible for ensuring that you have all of the necessary rights for any third-party products or services that you use with AWS services.

Cancel

Create database

RDS > Databases

Databases

Group resources

Modify

Actions

Restore from S3

Create database

Filter by databases

1

	DB identifier	Role	Engine	Region & AZ	Size	Status	CPU
	todoapp-manual	Instance	MySQL Community	us-east-1f	db.t2.micro	Backing-up	100%