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Comparison analysis and efficiency evaluation of back-end frameworks in database applications

Analiza porównawcza i ocena wydajności frameworków back-endowych w aplikacjach bazodanowych

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Acronyms and abbreviations

API Application Programming Interface. 5, 6

ASGI Asynchronous Server Gateway Interface. 5

CORS Cross-Origin Resource Sharing. 9

CRUD Create Retrieve Update Delete. 7, 8, 12, 19

CSV Comma-Separated Values. 28

DB Database. 18, 20, 21, 23, 39

DRF Django Rest Framework. 4, 5, 18

HTTP Hypertext Transfer Protocol. 5

JS JavaScript. 5

JSON JavaScript Object Notation. 19, 30

LTS Long Term Support. 15

MVC Model-View-Controller. 4, 6

NPM Node Package Manager. 5

ORM Object-Relational Mapping. 11

OWASP Open Web Application Security Project. 9

PG PostgreSQL. 1, 4, 5, 6, 11, 15, 16, 17, 22, 24, 25, 39

SQL Structured Query Language. 1, 8, 10, 19, 24, 25, 26, 39

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Chapter 1

Introduction

Complex web applications keep becoming more popular in recent years. They are very easily accessible from any place in the world and can run on almost any modern device, as it requires only web browser and the Internet connection to run.

Web frameworks simplify the development process of web applications significantly improving developers productivity. There is a huge variety of choices between the mentioned software, so choosing one may be a difficult task.

The choice of server-side framework is crucial, as it is responsible for handling sensitive data and plays a key role in the overall performance of the application.

The goal of this document is to focus on three of the most popular server-side frameworks and compare their performance under high load as well as basic security measurements. The results of this thesis will be important for web developers and architects, that need to decide on which framework should they choose for their application.

Web frameworks for this comparison were chosen from the list of Stack Overflow Developer Survey 2020 Web Frameworks popularity [1]. The chosen frameworks (and their respective languages) are:

- Express.js (JavaScript)
- ASP.NET (C#)
- Django (Python)

Chapter 2 describes chosen frameworks, including their architecture and requirements. For the definition of the criteria against which the results will be measured, see Chapter 3. Chapter 4 presents design of the system - database models, application structure and environment preparation. Chapter 5 shows framework specific application implementation details. Results of the tests and comparison of the technologies can be found in chapter 6. For final conclusion of this document, see chapter 7.

Chapter 2

Technology description

2.1 PostgreSQL

TODO

2.2 Django

2.2.1 Overview

Django is a high-level Python web framework, that allows programmers build dynamic, interesting sites in an extremely short time. Django is designed to let you focus on the fun, interesting parts of your job while easing the pain of the repetitive bits [2]. Additionally the framework is being supported by a wide variety of libraries and frameworks, like Django Celery, Crispy Forms, Django Rest Framework (DRF).

Django is based on MVC architecture:

- Model - a data structure, represented by a database
- View - interfaces visible in the browser
- Controller - connects Model and View together - describes how the data should be presented to the user

In Django application there are multiple files and at first it may not be obvious what their role is. Basic structure of an application looks like this:

- apps.py - common to all django apps configuration file
- models.py - custom models
- serializers.py - define how our model objects should be converted into response
- views.py - custom controllers, which is not intuitive for most of people; as the developers explain, in their interpretation of MVC the view describes which data gets presented to the user [3]
- urls.py - defines which endpoint responds to given controller

Templates, which are not mentioned above, are the Django's custom views - in case of application for my tests, it is going to be using build in json parsers.

2.2.2 Requirements and dependencies

Fortunately Django has a built in PostgreSQL engine, so no additional packages need to be added for it to work. However, for the sake of this research, a popular package Django Rest Framework package was added (over 21k stars on github), as it provides well thought set of base components for building APIs, often reducing the amount of code that needs to be written. Deploying django can be currently done by two interfaces:

- WSGI, which is the main Python standard for communicating between servers and applications
- and ASGI, which is new, asynchronous-friendly standard, allowing to use asynchronous Python features (and Django features as they are developed) [4]

Since the applications will be tested under a heavy load, the logical choice was the ASGI interface. As recommended in the documentation [4], deploying an application with ASGI can be done using Uvicorn, which is a fast ASGI server implementation [5], which results in two additional packages being added to the list of requirements.

2.3 ExpressJS

2.3.1 Overview

To describe what Express.js is, it would be appropriate to introduce Node.js. Node is an open-source runtime environment that runs on the same engine as the JavaScript in the browsers, but it allows developers to build server-side tools and applications. Node package manager (NPM) provides hundreds of thousands of packages, and that is where we can find Express [6].

Express is the most popular web framework with almost 17 million weekly downloads from NPM. It provides mechanisms to write handlers for HTTP requests, integrate with rendering engines and handle middlewares. The minimalism of the framework is compensated by huge supply of third party libraries, which are a giant expansion to it's functionality.

Express.js is an unopinionated framework, which means theres more than one "right" way to achieve a given result - there is no strict architecture that the developer has to follow.

2.3.2 Requirements

Application for the research in this thesis is very minimalistic itself, hence there are not many additional packages that need to be added. There is only one bundle downloaded from the NPM repository, which is pg-promise. Initially it was a package that expanded the base library called node-postgres by adding promises (JavaScript way of handling asynchronous functions) to the base driver, but since then the library's functionality was vastly expanded [7]. The expanded version of the driver was chosen, because of it's popularity - at the day of accessing the libraries the number of weekly downloads of node-postgres (2k) [8] was only a tiny fraction of pg-promise's (172k) [9].

To make the application work properly for editing or creating objects, a middleware package body-parser had to be added, that parses incoming request bodies from a json format into a JS object [10].

2.4 ASP.NET Core

2.4.1 Overview

ASP.NET Core is an open-source framework for building modern Internet-connected applications. With it you can build web applications and services, IoT apps, and mobile backends. "Core" is an a new, upgraded version of ASP.NET - it includes architectural changes, that result in more modular framework [11].

ASP.NET Core MVC is a framework optimized for use with ASP.NET Core, that allows to build APIs and web applications using Model-View-Controller pattern [12].

2.4.2 Requirements

To have the PostgreSQL support in the application, it is necessary to add PG provider for the framework - Npgsql.EntityFrameworkCore.PostgreSQL.

2.5 K6 and related tools

For testing the performance of applications, a tool named k6 was chosen. It is a modern load testing tool written in Golang, which provides clean and well documented APIs for writing and running tests, while still being easily configurable to the developers needs. Test logic and configuration options are both to be written in JavaScript, which allows developers for using JavaScript modules, which aids in code reusability. The creators of k6 prepared two types of execution:

- local, through command line interface
- and cloud, which is a commercial SaaS product, made to make performance testing in bigger applications easier.

For the sake of this experiment, local testing has fulfilled all expectations.

Installation on Ubuntu operating system is fairly simple and all necessary commands were described in the documentation. However, to make the testing simpler, a k6 Docker image was used, that together with Docker Compose allowed to create a single script that would handle all test cases as described in the following section.

K6 allows to create visualizations, using built-in InfluxDB and Grafana integration, where InfluxDB is used as storage backend and Grafana to visualize the data. In this research, only InfluxDB was added to store the data and after each test the data was exported to file, which later allowed to compare the results between applications on a single chart.

2.6 Docker and Docker Compose

Docker is a software that allows virtualization on an operating system level (containerization). Containers wrap the applications code in a small virtual environment based on the provided configuration. Docker and Docker Compose were used to simplify the development. This made starting all services that had be run together possible with only one command, eg. for django performance tests - django, postgres, k6 and influx. For every application a production ready Dockerfile was created. Additionally, Docker provides applications a layer of isolation from each other and the host.

Chapter 3

Criteria description

3.1 Performance benchmark

3.1.1 Scenarios

The task for each application is to complete simple CRUD operations as fast as possible. For comparison of the performance of the applications, a few test cases were developed:

- retrieving multiple objects (getMany)
- retrieving single object (get)
- updating a single object (put)
- creating a single object (post)
- deleting a single object (delete)

They were tested with a few different application loads, which are represented by a number of Virtual Users (VUs) - as mentioned in the k6 repository description they are glorified, parallel while(true) loops [13]. The scenarios chosen for tests are:

- 1 VU
- 8 VUs
- 32 VUs
- 128 VUs
- 512 VUs

For a single virtual user case the number of concurrences does not change throughout the duration of the test, however, as suggested in a few articles and k6 documentation, for bigger numbers of concurrent users, it is recommended for the tests to include warmup and cooldown period [14] [15] [16]. All tests are 30 seconds long, and tests with more than 1 virtual user include 5 seconds of ramp up time and 5 seconds of ramp down time as shown on figure 3.1.

Longer test times did not bring any satisfactory results and only caused CPU throttling problems, thus they were shortened to the period of 30 total seconds, which also made comparison of the results much easier.

For one scenario the results could be slightly different, that is why every test was repeated X times. For creation of the graphs presented in chapter 6 for each test average response times were calculated.

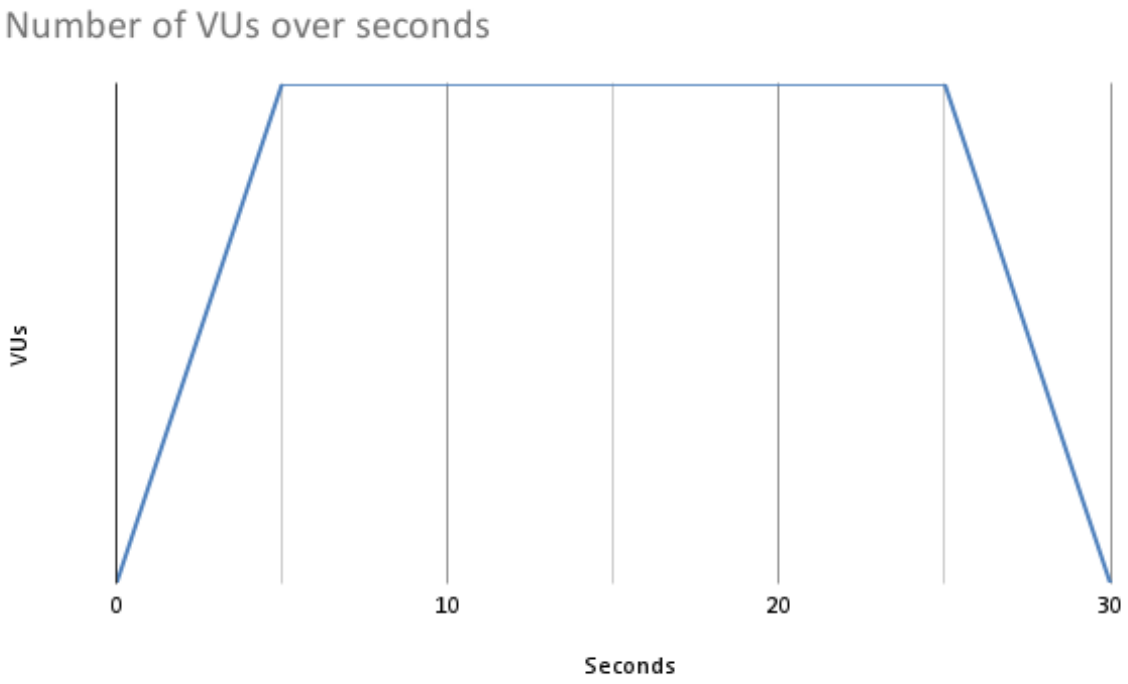

Figure 3.1: Amount of VUs per second during the tests

3.1.2 Requirements

To make the results as reliable as possible, a few requirements were introduced. Load tests need to follow the following rules:

1. Each scenario must send the same requests for each application.
2. Before each test the database must be restored to its initial state.
3. After each test request the response must be checked for its correctness.
4. Choice of users for CRUD operations must be the same for each application

Applications should be written according to the following requirements:

1. Source code and production ready environment should be based on the official documentation whenever that is possible.
2. Logging and cache must disabled.
3. Developer created database model must be the same for each application.
4. SQL commands generated by applications must return the same results from the prepared database.
5. Endpoint paths and their arguments must be equal for each application.
6. Response status and body of each endpoint must be the same for each scenario in each application.

3.1.3 Data

For the performance tests some frameworks required initial data to exist in the database (for example PUT endpoint for editing database models), thus at the beginning of the tests for each framework the database is populated. To be sure that the data is consistent, after seeding the database the docker volume that keeps the data is being stored locally, and before each test it is being restored.

3.1.4 Application isolation

To be sure that the applications are running in an isolated environment, docker containers were used. The configuration prepared for the applications included environment preparation (installing necessary packages, providing environment variables), To simplify the research, a Docker Compose configuration was prepared, that builds and starts all the necessary containers at once.

3.1.5 Software versions and hardware

The tests were run on a laptop with the specification presented in table 3.1. Frameworks used to build the application were in the versions presented in table 3.2.

Table 3.1: Hardware

Hardware	
Processor	Intel(R) Core(TM) i5-8250U CPU @ 1.60GHz
RAM memory	16 GB @ 2400MT/s
Operating system	Ubuntu 20.04.2 LTS

Table 3.2: Frameworks and libraries versions

Software versions	
Python	3.1.9
Django	3.1.4
Django REST Framework	3.12.2
gunicorn	20.0.4
uvicorn	0.13.1
C#	7.3
ASP.NET	2.1.1
Npgsql.EntityFrameworkCore.PostgreSQL	2.1.1.1
Node.js	15.12.0
Express	4.17.1
pg-promise	10.9.5
body-parser	1.19.0

3.2 Security

To try to answer the question how secure are the frameworks, three points from OWASP Top 10 API Security vulnerabilities list were chosen. To be precise:

- Security Misconfiguration, such as incomplete or unsecure default configurations, permissive CORS or error messages that expose sensitive information,

- Injection, such as SQL, NoSQL or Command Injection, where attacker can trick the interpreter into executing unintended commands,
- Insufficient Logging & Monitoring, which extends the time of detecting a breach into the system [17].

For security misconfiguration section there will be mentioned common mistakes that can be done when deploying the application and explained harm that can be done when they happen. Application security will be checked with injection attacks - malicious data will be used to try to exploit the system and return values that should not be available on given path. The last thing to mention in security part of this thesis will be logging possibilities of the package and showing how to configure it properly.

Chapter 4

System design

4.1 Database

For the tests, a database consisting of a single table was created - a model is presented in a table 4.1.

Table 4.1: Database model

User	
id	serial not null primary key
password	varchar(128) not null
username	varchar(30) not null
first_name	varchar(30) not null
last_name	varchar(30) not null
email	varchar(75) not null

For every application the operations on the PostgreSQL database may be slightly different, since in Django and ASP.NET they are handled by the Object-Relational Mapping libraries, while Express works on SQL statements.

Database creation is based on environment variables, as it makes it easier for connecting the applications to the database later. For the connection, the following variables need to be present:

- `POSTGRES_DB`, which is the name of the database, set to postgres,
- `POSTGRES_USER`, the default database user, set to postgres,
- `POSTGRES_PASSWORD` as the default user password, set to postgres,
- `POSTGRES_HOST` required only for applications - it is the hostname where the database can be found - because of how the docker networks work, it needs to be set to the container name - postgres,
- `POSTGRES_PORT` which is the port on which the database is exposed - set to 5432

4.1.1 Initial population creation

As mentioned in subsection 3.1.3, most endpoints need existing database population to work. For every application the script responsible for seeding the database looks basically the same, but for the different frameworks the piece of code had to be adjusted to three

different languages. The amount of users is parameterized and can be changed on all applications by one variable in the main script, to keep the consistency between applications and avoid potential mistakes. Users are created in bulk in a single transaction to speed up the process.

Each framework (or library providing database support) has it's own built in methods for CRUD operations, and they may be slightly different from each other. For example, Express.js and ASP.NET Core framework automatically wrap statements in a transaction. ASP.NET in each transaction sets the transaction isolation level and uses prepared statements, which then are executed with required parameters. In listings 4.1 4.2 and 4.3 there are presented example log queries from initial user population creation.

```
LOG:  statement: BEGIN
LOG:  statement: SET TRANSACTION ISOLATION LEVEL READ COMMITTED
LOG: execute: INSERT INTO users (id, email, first_name, last_name,
   password, username) VALUES ($1, $2, $3, $4, $5, $6)
DETAIL: parameters: $1 = '1', $2 = 'First0@Last0.com', $3 = 'First0'
   , $4 = 'Last0', $5 = 'Pass0!', $6 = 'First0Last0'
LOG: execute: INSERT INTO users (id, email, first_name, last_name,
   password, username) VALUES ($1, $2, $3, $4, $5, $6)
DETAIL: parameters: $1 = '2', $2 = 'First1@Last1.com', $3 = 'First1'
   , $4 = 'Last1', $5 = 'Pass1!', $6 = 'First1Last1'
LOG:  statement: COMMIT
```

Listing 4.1: Log of ASP.NET initial user population creation

```
LOG:  statement: BEGIN
LOG:  statement: INSERT INTO "app_myuser" ("id", "password", "
   username", "first_name", "last_name", "email") VALUES (1, 'Pass0!
   ', 'First0Last0', 'First0', 'Last0', 'First0@Last0.com'), (2, '
   Pass1!', 'First1Last1', 'First1', 'Last1', 'First1@Last1.com')
   RETURNING "app_myuser"."id"
LOG:  statement: COMMIT
```

Listing 4.2: Log of Express.js initial user population creation

```
LOG:  statement: insert into "public"."users"("id","password","
   username","first_name","last_name","email") values('1','Pass0!','
   First0Last0','First0','Last0','First0@Last0.com'),('2','Pass1!','
   First1Last1','First1','Last1','First1@Last1.com')
```

Listing 4.3: Log of Django initial user population creation

4.2 Applications endpoints

For the load tests, applications were prepared with 6 endpoints:

- GET /status/
  - Description: required for the script, allows to check if the server has properly started and can properly respond to requests
  - Response code: 200
  - Response body: empty
- GET /users/{id}/

  - Description: retrieves user with given id from the database
  - Database operation: retrieve
  - Parameters:
    - id - path parameter, id of the user to be retrieved
  - Response code: 200
  - Response body: User model

- GET /users/?limit={limit}&offset={offset}
  - Description: retrieves multiple users - allows to check the frameworks serialization speed
  - Database operation: retrieve
  - Parameters:
    - limit - query parameter, amount of users returned
    - offset - query parameter, amount of rows to skip from the beginning
  - Response code: 200
  - Response body: User model array

- DELETE /users/{id}/
  - Description: Removes user with given id
  - Database operation: delete
  - Parameters:
    - id - path parameter, id of the user to be removed
  - Response code: 204
  - Response body: empty

- POST /users/
  - Description: Creates user from details provided in body
  - Database operation: create
  - Request body: User model to be created
  - Response code: 201
  - Response body: User model

- PUT /users/{id}/
  - Description: Updates user with given id from details provided in body
  - Database operation: update
  - Request body: User model to be created
  - Parameters:
    - id - path parameter, id of the user to be removed
  - Response code: 201
  - Response body: User model

"User model" mentioned above is the JSON object consisting of fields shown in table 4.1, and "User model array" is an array of these objects.

4.3 Environment

The main script prepared for this thesis, that gathers all the measurements is described in the algorithm 1.

Algorithm 1: Pseudocode describing load testing process

```
frameworks = [aspnet django express];
scenarios = [1 8 32 128 512];
iterations = [1 2 3 4 5 6 7 8 9 10];
test cases = [get post put delete getMany];
forall frameworks do
    start application and database;
    populate database;
    kill application and database;
    store snapshot;
    forall scenarios do
        forall iterations do
            forall test cases do
                if application is running then
                    kill application and database;
                remove volumes;
                if test case is not post then
                    restore snapshot;
                start application and database;
                while application is not responding do
                    wait for application;
                for 30 seconds do
                    measured test;
                store k6 result ;
                store influxDB result ;
                for 30 seconds do
                    cooldown before next test;
merge results;
```

Cooldown near the end of the algorithm is necessary for the CPU - all frameworks required a lot of resources and the processor increased its temperature - to avoid overheating that could result in throttling, it was decided to put a 30 seconds long cooldown. Monitoring the resources during the test proved that this was enough for the temperature to go back to normal before starting the next scenario.

Chapter 5

Implementation

5.1 Docker and Docker Compose

5.1.1 PostgreSQL

PostgreSQL is built straight from the image without the need of Dockerfile, thus only the Docker Compose configuration is present. It places environment variables described in section 4.1 from the file, creates a named volume containing the database files, reserves memory and creates a healthcheck, which allows to determine whether the container is ready to be connected to. Configuration for this service is presented in listing 5.1

```
postgres:
  image: postgres:13.1-alpine
  env_file:
    - env/postgres.env
  volumes:
    - pgdata:/var/lib/postgresql/data/
  mem_reservation: 4gb
  healthcheck:
    test: ["CMD-SHELL", "pg_isready -U postgres"]
    interval: 5s
    timeout: 5s
    retries: 5
```

Listing 5.1: PostgreSQL Docker Compose configuration

5.1.2 Applications

It made utmost sense to place this section standalone and not explain each application separately, since the configurations for all of them are very alike. Dockerfiles are configured to install all necessary packages, place the code in suitable folders, specify a non-root user for the container to run as and set the entrypoint to a script that starts the application. The main differences between the Dockerfiles are the chosen images:

- Django Dockerfile was inspired by Anuj Sharma, who created one for his series of Django development guide articles [18] - image used is python:3.9.1-slim,
- For Express.js, a latest slim image of LTS node version was chosen - node:14.17.0-slim,

- ASP.NET Core has a Dockerfile suggested by the documentation, so it was used in the application - images dotnet:2.1-sdk and dotnet:2.1-aspnetcore-runtime (multi-stage build) [19].

Dockerfiles were also checked by Hadolint, which is a linter that helps to build best practice Docker images [20]. It verifies if the Dockerfile follows the rules presented in official docker documentation [21]. Example Dockerfile is presented in listing 5.2. Docker Compose configuration points to the build folder, imports the environment variables for connection with PG and variable with amount of users to create, ensures that the application starts after the database has started (makes the app wait for PostgreSQL healthcheck) and reserves memory for the application. To see an example of Docker Compose configuration check listing 5.3.

```
FROM node:14.17.0-slim

RUN apt-get update -y \
    && apt-get install --no-install-recommends -y curl \
    && apt-get clean \
    && rm -r /var/lib/apt/lists/*

WORKDIR /app
COPY package*.json ./
RUN npm install
COPY src ./src
USER node

CMD npm start
```

Listing 5.2: Express.js Dockerfile

```
express:
    profiles: ["express"]
    build: express
    env_file:
        - env/postgres.env
    environment:
        - NODE_ENV=production
        - USER_AMOUNT=${USER_AMOUNT}
    depends_on:
        postgres:
            condition: service_healthy
    mem_reservation: 4gb
```

Listing 5.3: Express.js Docker Compose configuration

5.1.3 K6 and related tools

Developers of k6 prepared instructions for usage with Docker [22]. as well as an example Docker Compose configuration, including InfluxDB and Grafana integration [23]. In the interest of the performance tests the latter was introduced, with small adjustments to fit the needs of test environment. For example, Grafana configuration was not needed in our case, since the results are later exported to a file for drawing custom graphs.

5.2 Django

5.2.1 Model

Django offers a built in User model, however it was decided not to use it in this case. The reason for that is that the built in model handles extra operations for the User, like creating groups, permissions, authentication and a few additional fields. Instead of using it, the implementation of model presented in listing 5.4 was created. It does not contain the primary key definition, as django.db.models.Model class handles it automatically.

```
class MyUser(models.Model):
    password = models.CharField(max_length=128)
    username = models.CharField(max_length=30)
    first_name = models.CharField(max_length=30)
    last_name = models.CharField(max_length=30)
    email = models.CharField(max_length=75)
```

Listing 5.4: Django user model

5.2.2 Database connection and initialization

Django handles a lot of things for the user - connection is very simple - in initial project generation a file settings.py is created, which consists of all the necessary variables for the system to work. In the file we can find a variable named Databases, initially with SQLite backend. All that needs to be done to connect to our PostgreSQL is to change the engine to built-in PG backend and change the remaining fields - name, user, password, host and port, as presented in listing 5.5. With that done, the connection is automatically done on the system startup.

```
DATABASES = {
    'default': {
        'ENGINE': 'django.db.backends.postgresql',
        'NAME': os.environ.get('POSTGRES_DB', 'postgres'),
        'USER': os.environ.get('POSTGRES_USER', 'postgres'),
        'PASSWORD': os.environ.get('POSTGRES_PASSWORD', 'postgres'),
        'HOST': os.environ.get('POSTGRES_HOST', 'postgres'),
        'PORT': os.environ.get('POSTGRES_PORT', 5432),
    }
}
```

Listing 5.5: Django database connection object, fragment of settings.py file

Creating the table is handled by migration system - to create the migrations the command `python3 manage.py makemigrations` had to be run. This creates the tables based on the model presented in models.py files through the whole project. In this case, it only created one table. For creating the initial population a management function was prepared, that is being executed from the main script. Seeding the database was presented in listing 5.6.

```
amount = int(os.environ.get("USER_AMOUNT"))
users = []
for id in range(amount):
    first_name = f"First{id}"
    last_name = f"Last{id}"
    user = MyUser(
        id=id+1,
        username=first_name+last_name,
        first_name=first_name,
```

```
            last_name=last_name,
            email=f"{first_name}@{last_name}.com",
            password=f"Pass{id}!"
        )
        users.append(user)
    MyUser.objects.bulk_create(users)
```

Listing 5.6: Populating django DB

5.2.3 Routing and serialization

Django routing is to be placed in urls.py files. There is one main file in the project configuration folder, and one in each module. Since this application consists of only one modules, two urls.py files exist - presented in listings 5.7 and 5.8.

```
urlpatterns = [
    path('', include('app.urls'))
]
```

Listing 5.7: Fragment of Django route configuration file - config/urls.py

```
from .views import UserViewSet, status

router = routers.DefaultRouter()
router.register(r'users', UserViewSet)

urlpatterns = [
    path('', include(router.urls)),
    path('status', status),
]
```

Listing 5.8: Fragment of Django route configuration file - app/urls.py

Serialization is another great thing about Django and Django Rest Framework - DRF has built in abstract ModelSerializer class - to create a serializer for our model, all that needs to be done is to specify which model and which fields we want to serialize, as presented in listing 5.9.

```
class UserSerializer(serializers.ModelSerializer):
    class Meta:
        model = MyUser
        fields = ['id', 'username', 'email', 'first_name', '
            last_name', 'password']
```

Listing 5.9: Django User serialization class

5.2.4 Endpoints

It is pretty certain at this point that django offers a lot of functionality. It should come with no surprise that the endpoints can also be implemented with a few lines of code using the built in methods. As shown in the listing 5.10, creating views does not require much, only the queryset containing all user models and a serializer class. With this ViewSet and one standalone function we get all the endpoints described in section 4.2 of this document. UserViewSet class was used in the routing in file presented in listing 5.8.

```
class UserViewSet(viewsets.ModelViewSet):
    queryset = MyUser.objects.all()
```

```
        serializer_class = UserSerializer

    @api_view(['GET'])
    def status(r):
        return Response()
```

Listing 5.10: Controllers for django endpoints

5.3 Express

5.3.1 Model

User model in express.js needs to contain all the necessary logic for handling CRUD operations. Implementation of the model is shown in listing 5.11 - it shows all SQL statements except include, which is placed in separate file. Database queries return JSON object that is ready to be

```
class UsersModel {
  constructor(db, pgp) {
    this.db = db;
    this.pgp = pgp;

    createColumnsets(pgp);
  }

  async insert(user) {
    return this.db.one(sql.insert, user);
  }

  async update(fields, id) {
    const user = await this.retrieve(id);
    if (user) {
      const updateFields = `(${Object.keys(fields)}) = ROW(${Object.
          values(
        fields
      ).map((value) => `'${value}'`)
        })`;

      return this.db.one("UPDATE users SET $1^ WHERE id = $2 RETURNING *
          ", [
        updateFields,
        +id,
      ]);
    } else {
      return null
    }
  }

  async delete(id) {
    const user = await this.retrieve(id);
    if (user) {
      return this.db.any("DELETE FROM users WHERE id = $1", [+id]);
    }
    else {
      return null
    }
  }
```

```
  async retrieve(id) {
    return this.db.oneOrNone(
      "SELECT * FROM users WHERE id = $1",
      [+id]
    );
  }

  async get(limit, offset) {
    return this.db.multi(
      "SELECT * FROM users LIMIT $1 OFFSET $2",
      [+limit, +offset]
    );
  }
}
```

Listing 5.11: Express.js user model

5.3.2 Database connection and initialization

Work with express is a bit more difficult, as most of the configuration needs to be done by the developer. To connect with the database, a postgres promise instance needs to be created. Because there is no migration system, creating the table also needs to be done manually on DB initialization. To do so, a database configuration file was created (listing 5.12) and imported into the entrypoint file. It contains all the necessary information about the connection and creation of the table.

```
const DBCONFIG = {
    host: process.env.POSTGRES_HOST,
    password: process.env.POSTGRES_PASSWORD,
    database: process.env.POSTGRES_DB,
    user: process.env.POSTGRES_USER,
    port: process.env.POSTGRES_PORT,
};

const initOptions = {
    extend(obj, dc) {
        obj.users = new Users(obj, pgp);
    }
};
const pgp = pgPromise(initOptions);
const db = pgp(DBCONFIG);

(async () => { await db.users.createTable(); })();

module.exports = { db, pgp };
```

Listing 5.12: Express.js database connection

Initialization of the database is handled by function presented in listing 5.13.

```
const users = [];
for (var id = 0; id < USER_AMOUNT; id++) {
  const first_name = `First${id}`;
  const last_name = `Last${id}`;
  const user = {
    id: `${id + 1}`,
    first_name,
    last_name,
```

```
      username: first_name + last_name,
      email: `${first_name}@${last_name}.com`,
      password: `Pass${id}!`,
    };
    users.push(user);
}
const query = this.pgp.helpers.insert(users, cs.insert);
await this.db.none(query);
```

Listing 5.13: Populating Express.js DB

5.3.3 Routing and endpoints

Unlike in Django, routes and endpoints are not separated in two files. In this case it made more sense to keep them in a single file as shown in listing 5.14, since the endpoints logic is not too long. All they do is registering a route on the provided path in the first argument and registering the callback provided in the second argument. The mentioned functions call the respective method from User model sends appropriate response based on the return data of the query.

```
app.get("/status", (req, res) => res.sendStatus(200));

app.get("/users/:id", async (req, res) => {
    const data = await db.users.retrieve(req.params.id);
    return data ? res.json(data) : res.sendStatus(400);
});

app.get("/users", async (req, res) => {
    const limit = req.query.limit;
    const offset = req.query.offset;
    const data = await db.users.get(limit, offset);
    return data ? res.json(data) : res.sendStatus(400);
});

app.post("/users", async (req, res) => {
    const data = await db.users.insert(req.body);
    return data ? res.status(201).json(data) : res.sendStatus(400);
});

app.delete("/users/:id", async (req, res) => {
    await db.users.delete(req.params.id);
    return res.sendStatus(204);
});

app.put("/users/:id", async (req, res) => {
    const data = await db.users.update(req.body, req.params.id);
    return data ? res.json(data) : res.sendStatus(400);
});
```

Listing 5.14: Express.js routing and endpoint logic

5.4 ASP.NET

5.4.1 Model

Model in ASP.NET Core is a class that serves a similar purpose to Django model (shown in subsection 5.2.1). It defines all the fields that need to be placed in the database model, including the names, types and constraints, using `Required` and `Column` decorators. In addition to that, using `JsonProperty` decorator we can describe a field name that is later used in serialization and deserialization, so we do not have to specify a serializer manually later. Model is presented in listing 5.15.

```
public class User {
    [DatabaseGenerated(DatabaseGeneratedOption.Identity)]
    public int Id { get; set; }

    [Required]
    [Column(TypeName = "varchar(128)")]
    public string Password { get; set; }

    [Required]
    [Column(TypeName = "varchar(30)")]
    public string Username { get; set; }

    [Required]
    [JsonProperty("first_name")]
    [Column(TypeName = "varchar(30)")]
    public string FirstName { get; set; }

    [Required]
    [JsonProperty("last_name")]
    [Column(TypeName = "varchar(30)")]
    public string LastName { get; set; }

    [Required]
    [Column(TypeName = "varchar(75)")]
    public string Email { get; set; }
}
```

Listing 5.15: ASP.NET Core user model

5.4.2 Database connection and initialization

Connection to the database looked more similar in Express.js - we need to get all environment variables, create a connection string string using them and pass them to the PostgreSQL provider, as shown in listing 5.16. Initial population generation is shown in 5.17.

```
var db = Environment.GetEnvironmentVariable("POSTGRES_DB");
var user = Environment.GetEnvironmentVariable("POSTGRES_USER");
var pass = Environment.GetEnvironmentVariable("POSTGRES_PASSWORD");
var host = Environment.GetEnvironmentVariable("POSTGRES_HOST");
var port = Environment.GetEnvironmentVariable("POSTGRES_PORT");
var connectionString = $"host={host};port={port};database={db};
   username={user};password={pass};";
services.AddDbContext<ApiDbContext>(options =>
    options.UseNpgsql(connectionString)
```

```
);
```

Listing 5.16: ASP.NET Core database connection

```
var users = new List<User>();
for (var id = 0; id < user_amount; id++) {
    var first_name = $"First{id}";
    var last_name = $"Last{id}";
    var user = new User();
    user.Id = int.Parse($"{id + 1}");
    user.Username = first_name + last_name;
    user.FirstName = first_name;
    user.LastName = last_name;
    user.Email = $"{first_name}@{last_name}.com";
    user.Password = $"Pass{id}!";
    users.Add(user);
}
this.AddRange(users);
this.SaveChanges();
```

Listing 5.17: Populating ASP.NET Core DB

5.4.3 Routing and Endpoints

The code for controllers is quite lengthy, but that is because routing and endpoint definition is a part of database context class - using `Route`, `HttpGet`, `HttpPost`, `HttpPut` and `HttpDelete` decorators we are able to define routes for given functions. Request parameters are placed directly into the function arguments, using `FromQuery`, `FromBody` clauses or by putting the argument in the decorator (for example `HttpGet({id})`). Controllers definition can be found in listing 5.18.

```
[Route("status")]
[ApiController]
public class StatusController : ControllerBase {
    [HttpGet]
    public object Status() {
        return Ok();
    }
}

[Route("users")]
[ApiController]
public class UserController : ControllerBase {
    private ApiDbContext _context;

    public UserController(ApiDbContext context) {
        _context = context;
    }

    [HttpGet("{id}")]
    public object GetById(int id) {
        return _context.Users.Single(b => b.Id == id);
    }

    [HttpGet]
    public object Get(
        [FromQuery] int limit, [FromQuery] int offset) {
        return _context.Users
```

```
                .Skip(offset)
                .Take(limit)
                .ToList();
        }

        [HttpPost]
        public object Post([FromBody] User _user) {
            _context.Add(_user);
            _context.SaveChanges();
            Response.StatusCode = 201;
            return new JsonResult(_user);
        }

        [HttpDelete("{id}")]
        public object Delete(int id) {
            var user = (from a in _context.Users where a.Id == id select
                a).FirstOrDefault();
            if (user != null) {
                _context.Remove(user);
                _context.SaveChanges();
                return NoContent();
            } else {
                return NotFound();
            }
        }

        [HttpPut("{id}")]
        public object Edit(int id, [FromBody] User _user) {
            var user = (from a in _context.Users where a.Id == id select
                a).FirstOrDefault();
            if (user != null) {
                user.Password = _user.Password;
                user.Username = _user.Username;
                user.FirstName = _user.FirstName;
                user.LastName = _user.LastName;
                user.Email = _user.Email;
                _context.SaveChanges();
                return Ok(user);
            } else {
                return NotFound();
            }
        }
    }
```

Listing 5.18: ASP.NET Core routing and endpoint logic

5.5 SQL queries comparison

SQL queries are being generated differently by ASP.NET Core and Django. In case of Express.js with PostgreSQL, it is developers role to create them, so they were prepared to try to match the queries from the other frameworks while still being relatively simple. Logs were gathered from PostgreSQL in a separate test with logging turned on (for performance tests logging was completely turned off). Tables are created in the same fashion, except the primary key constraint in Django and Express.js is added right next to the definition of id field, and not separately as shown for ASP.NET in listing 5.19.

```
CREATE TABLE users (
```

```
    id serial NOT NULL,
    password varchar(128) NOT NULL,
    username varchar(30) NOT NULL,
    first_name varchar(30) NOT NULL,
    last_name varchar(30) NOT NULL,
    email varchar(75) NOT NULL,
    CONSTRAINT "PK_users" PRIMARY KEY (id)
)
```

Listing 5.19: Table creation SQL command

ASP.NET Core uses parameterized queries (in PostgreSQL PREPARE and EXECUTE clauses), so log of the query is followed by parameters that the query was called with.

In get queries, presented in listing 5.20, the interesting part to note is the LIMIT clause - it was added automatically by both ASP.NET and Django to a value bigger than 1 - this safety limit for GET requests was introduced in case provided filters in WHERE clause matched more than exactly one object (which in this case is not intended), to be able to provide a meaningful error message.

Updates and deletes (listings 5.22 and 5.23 respectively) are preceded by select statements, that are exactly the same as in listing 5.20.

```
ASP.NET Core:
SELECT b.id, b.email, b.first_name, b.last_name, b.password, b.username
    FROM users AS b WHERE b.id = $1 LIMIT 2
parameters: $1 = '501'

Express.js:
SELECT * FROM users WHERE id = 501

Django:
SELECT "app_myuser"."id", "app_myuser"."password", "app_myuser"."
    username", "app_myuser"."first_name", "app_myuser"."last_name", "
    app_myuser"."email" FROM "app_myuser" WHERE "app_myuser"."id" = 501
    LIMIT 21
```

Listing 5.20: SQL commands for retrieving objects

```
ASP.NET Core:
SELECT u.id, u.email, u.first_name, u.last_name, u.password, u.username
    FROM users AS u LIMIT $1 OFFSET $2
parameters: $1 = '100', $2 = '0'

Express.js:
SELECT * FROM users LIMIT 100 OFFSET 0

Django:
SELECT "app_myuser"."id", "app_myuser"."password", "app_myuser"."
    username", "app_myuser"."first_name", "app_myuser"."last_name", "
    app_myuser"."email" FROM "app_myuser" LIMIT 100
```

Listing 5.21: SQL commands for retrieving multiple objects

```
ASP.NET Core:
UPDATE users SET username = $1 WHERE id = $2
parameters: $1 = 'Changed501', $2 = '502'

Express.js:
UPDATE users SET (id,password,username,first_name,last_name,email) = ROW
    ('502','Pass501!','Changed501','First501','Last501','First501@Last501
    .com') WHERE id = 502 RETURNING *
```

```
Django:
UPDATE "app_myuser" SET "password" = 'Pass501!', "username" = '
    Changed501', "first_name" = 'First501', "last_name" = 'Last501', "
    email" = 'First501@Last501.com' WHERE "app_myuser"."id" = 502
```

Listing 5.22: SQL commands for updating objects

```
ASP.NET Core:
DELETE FROM users WHERE id = $1
parameters: $1 = '501'

Express.js:
DELETE FROM users WHERE id = 501

Django:
DELETE FROM "app_myuser" WHERE "app_myuser"."id" IN (501)
```

Listing 5.23: SQL commands for deleting objects

```
ASP.NET Core:
INSERT INTO users (id, email, first_name, last_name, password, username)
     VALUES ($1, $2, $3, $4, $5, $6)
parameters: $1 = '502', $2 = 'First501@Last501.com', $3 = 'First501', $4
     = 'Last501', $5 = 'Pass501!', $6 = 'First501Last501'

Express.js:
INSERT INTO users ("id", "password", "username", "first_name", "
    last_name", "email") VALUES(502, 'Pass501!', 'First501Last501', '
    First501', 'Last501', 'First501@Last501.com') RETURNING *

Django:
INSERT INTO "app_myuser" ("password", "username", "first_name", "
    last_name", "email") VALUES ('Pass501!', 'First501Last501', 'First501
    ', 'Last501', 'First501@Last501.com') RETURNING "app_myuser"."id"
```

Listing 5.24: SQL commands for creating objects

5.6 Performance tests

Tests implementation is divided into 6 files:

- config.js,
- delete.test.js,
- get.test.js,
- getMany.test.js,
- post.test.js,
- put.test.js.

Configuration file config.js is a module that contains common code for all tests, utility functions such as waiting for container, preparing scenarios, parsing environment variables, creating users (in the same fashion as ones existing in the database) or exporting results to a file.

5.6.1 Environment variables

From the main script, the following test variables are passed:

- TEST_TIME - defines the length of a performance test,
- VU_AMOUNT - shows with how many concurrent VUs the test will be run,
- USER_AMOUNT - describes amount of users existing in the database,
- SCENARIO - is the current scenario (according to what was said in subsection 3.1.1, for 1 VU the scenario is constant-vus and for the other cases it is ramping-vus),
- FRAMEWORK - shows which framework is currently started,
- RESULTS_PATH - defines a path to a file for exporting final results.

5.6.2 Scenarios

K6 have a few executors defined. For this research only two of them will be used:

- Constant VUs, where a fixed number of Virtual Users try to execute as many iterations as possible within a specified period of time,
- and Ramping VUs, which is very alike to the Constant VUs executor, but works on a variable number of Virtual Users [24].

To further demonstrate the meaning of code in listing 5.25, it needs to be mentioned that graceful stop and graceful ramp down variables allow to finish currently running requests after the time limit has passed and stages in 'ramping-vus' case statement describe the VU chart from figure 3.1.

```
const getScenario = () => {
  const scenario = __ENV.SCENARIO
  switch (scenario) {
    case "constant-vus": {
      return {
        executor: "constant-vus",
        vus: VU_AMOUNT,
        duration: TEST_TIME + "s",
        gracefulStop: '1m',
      };
    }
    case "ramping-vus": {
      const target = VU_AMOUNT;
      return {
        executor: 'ramping-vus',
        startVUs: 0,
        stages: [
          { duration: TEST_TIME / 3 + "s", target },
          { duration: TEST_TIME / 3 + "s", target },
          { duration: TEST_TIME / 3 + "s", target: 0 },
        ],
        gracefulRampDown: "1m"
      }
    }
    default: {
      return;
```

```
    }
  }
}
```

Listing 5.25: K6 scenarios definition

5.6.3 Setup

Setup function is the first user-defined thing that runs when the k6 application is started. It needs to be run from the test file, but the code that is common for all tests is shown in 5.26. This function sends requests every 3 seconds, trying to get a response from applications' status endpoint.

```
const waitForServer = () => {
  let r;
  while (!r || r.status !== 200) {
    try {
      r = http.get(`${baseUrl}/status`);
    } catch (e) { }
    sleep(3);
  }
};
```

Listing 5.26: K6 setup functions

5.6.4 Get and delete tests

Listing 5.27 shows get test, which belongs to the group of tests with the simplest implementations, so it is going to be used to explain the whole k6 test structure. Delete test is almost the same - it differs in the request method (it sends DELETE instead of GET) and the response status checked (204 instead of 200). Variable `options` is used by k6 to determine scenarios for the tests and timeout for the setup function. Setup function was mentioned in the previous subsection, it waits for the application to be started. Handle summary function is executed at the end of the test, it is configured to export the results to the CSV file. And finally default function exists to be run by the VUs. Choosing the user for a request is based on two variables:

- `__VU` - identification number of the VU that executes this function,
- and `__ITER` - which is the number of iteration that the current VU is running.

Function that chooses the id for the user is presented in listing 5.28. After the request is finished a status is checked for verification if the responses were correct. Each test file contains a request function, it helped during development phase of this project, as this is the main part that is different between the tests. Get test sends a simple GET request to the endpoint based on chosen user id. Code common for all tests has been cut from listings 5.29, 5.30 and 5.33.

```
export const options = config.baseOptions;

function request(id) {
  const r = http.get(config.userUrl + id + "/");
  return r;
}
```

```
export function setup() {
  config.waitForServer();
}

export function handleSummary(data) {
  return config.csvHandler(data);
}

export default function () {
  group("get", () => {
    const id = config.getElementId(__ITER, __VU);
    const r = request(id);
    config.checkStatus(r, 200);
  });
}
```

Listing 5.27: K6 Get test

```
const USERS_PER_VU = parseInt(USER_AMOUNT / (VU_AMOUNT + 1), 10)
const getElementId = (iter, vu) => USERS_PER_VU * vu + iter + 1
```

Listing 5.28: K6 Get user ID

5.6.5 Get many test

Retrieving multiple users from the database operates on two variables - limit and offset. Limit was set to 100 in these tests - as presented in the chapter 6, this already caused high stress for the applications compared to the other tests and allowed to create meaningful results. Offset variable changes with iteration - each iteration increases the variable by 100 resulting in next 100 rows being queried from the database. The exact methods are presented in listing 5.29.

```
function request(limit, offset) {
  const r = http.get(
    config.userUrl + `?limit=${limit}&offset=${offset}`);
  return r;
}

const limit = 100;

export default function () {
  group("getMany", () => {
    const offset = parseInt(
      (limit * __ITER) % (config.USER_AMOUNT - 1), 10);
    const r = request(limit, offset);
    config.checkStatus(r, 200);
  });
}
```

Listing 5.29: K6 GetMany test

5.6.6 Put test

Put test introduce two new functions called `getUser` and `changeUser`. The first one, presented in listing 5.31, creates a user unique for given iteration of VU id, and the second

one, shown in listing 5.32, introduces a small change to the user - changes its username for update. What is more, a `Content-Type` header had to be set to `application/json`, as we are sending a JSON content in the request.

```
function request(changedUser) {
  const payload = JSON.stringify(changedUser);

  var params = {
    headers: {
      "Content-Type": "application/json",
    },
  };
  const r = http.put(
    config.userUrl + changedUser.id + "/",
    payload, params
  );
  return r;
}

export default function () {
  group("put", () => {
    const id = config.getElementId(__ITER, __VU);
    const changedUser = config.changeUser(
      config.getUser(id), id
    );
    const r = request(changedUser);
    config.checkStatus(r, 200);
  });
}
```

Listing 5.30: K6 Put test

```
const getUser = (id) => {
  const first_name = `First${id}`;
  const last_name = `Last${id}`;
  return {
    id: id + 1,
    password: `Pass${id}!`,
    username: first_name + last_name,
    first_name: first_name,
    last_name: last_name,
    email: `${first_name}@${last_name}.com`,
  };
};
```

Listing 5.31: K6 Get user function

```
const changeUser = (user, i) => {
  user.username = `Changed${i}`;
  return user;
}
```

Listing 5.32: K6 Change user function

5.6.7 Post test

This test uses mentioned in the previous section function `getUser` to create a new user in the database. Users will not collide with each other since post test starts its execution on an empty database.

```
function request(newUser) {
  const payload = JSON.stringify(newUser);
  var params = {
    headers: {
      "Content-Type": "application/json",
    },
  };
  const r = http.post(config.userUrl, payload, params);
  return r;
}

export default function () {
  group("post", () => {
    const id = config.getElementId(__ITER, __VU);
    const newUser = config.getUser(id);
    const r = request(newUser);
    config.checkStatus(r, 201)
  });
}
```

Listing 5.33: K6 Post test

Chapter 6

Results

6.1 Performance

WIP

6.2 Security

6.2.1 Security Misconfiguration

Django

Django has one configuration file, generated automatically at the project creation. At the starting lines of settings.py a few important variables and comments are placed (listing 6.1).

```
# Quick-start development settings - unsuitable for production
# See https://docs.djangoproject.com/en/3.1/howto/deployment/
    checklist/

# SECURITY WARNING: keep the secret key used in production secret!
SECRET_KEY = 'k!vv90$1&z+%fhv!+c^#1pfe_f&jim&tv7$yk%d9wspv=)#$x+'

# SECURITY WARNING: don't run with debug turned on in production!
DEBUG = True

ALLOWED_HOSTS = []
```

Listing 6.1: Fragment of unchanged newly generated Django settings file

. As we can see, the creators of Django clearly want the developers to prevent some security vulnerabilities, by placing `SECURITY WARNING` comments above two crucial variables - `SECRET_KEY` and `DEBUG`. `SECRET_KEY` is used in:

- Generating session tokens
- Generating password reset tokens
- Ensuring that data passed from django forms is not changed
- Generating secret URLs for temporary access to a protected resource (for example a file)
- And any other cryptographic signing, unless a developer provides a different key

. All of them are very serious risks and should be avoided by any means. App created for this research is tiny does not have any serious logic other than working on a database model, so cryptographic signing is not used at all. For any commercial applications leaking this variable could cause a lot of harm. The second risky variable - `DEBUG` - is responsible for turning on and off a debug mode. When set to True, whenever an error happens Django will display a detailed traceback, including parts of the applications source code and environment variables (such as Django settings). Django developers thought about it being a little secure in case of accidental leakage by excluding from the message variables containing the following strings:

- 'API'
- 'KEY'
- 'PASS'
- 'SECRET'
- 'SIGNATURE'
- 'TOKEN'

Third important variable that cannot be forgotten is `ALLOWED_HOSTS` (without `SECURITY WARNING` comment, as it is set to an empty array by default). This variable is meant to be a list of strings presenting host names that Django can send responses to. If a given host is not on the list and tries to request a resource, response with status 400 is sent immediately. When `DEBUG` is set to True and this variable is empty, the only way to reach the app is by requesting localhost.

To help the developers, Django offers a command `python3 manage.py check --deploy` command.

```
> python3 manage.py check --deploy
System check identified some issues:

WARNINGS:
?: (security.W004) You have not set a value for the
    SECURE_HSTS_SECONDS setting. If your entire site is served only
    over SSL, you may want to consider setting a value and enabling
    HTTP Strict Transport Security. Be sure to read the documentation
     first; enabling HSTS carelessly can cause serious, irreversible
    problems.
?: (security.W008) Your SECURE_SSL_REDIRECT setting is not set to
    True. Unless your site should be available over both SSL and non-
    SSL connections, you may want to either set this setting True or
    configure a load balancer or reverse-proxy server to redirect all
     connections to HTTPS.
?: (security.W012) SESSION_COOKIE_SECURE is not set to True. Using a
     secure-only session cookie makes it more difficult for network
    traffic sniffers to hijack user sessions.
?: (security.W016) You have 'django.middleware.csrf.
    CsrfViewMiddleware' in your MIDDLEWARE, but you have not set
    CSRF_COOKIE_SECURE to True. Using a secure-only CSRF cookie makes
     it more difficult for network traffic sniffers to steal the CSRF
     token.
?: (security.W018) You should not have DEBUG set to True in
    deployment.
```

```
?: (security.W020) ALLOWED_HOSTS must not be empty in deployment.

System check identified 6 issues (0 silenced).
```

Listing 6.2: Warnings shown by Django check deploy command on fresh project

ASP.NET

Express.js

6.2.2 Injection

Django

ASP.NET

Express.js

6.2.3 Insufficient Logging

Django

ASP.NET

Express.js

Chapter 7

Conclusion

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List of Figures

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