Hung Viet Nguyen

End-to-end E-commerce web application, a modern approach using MERN stack

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Over the last decade, web development has gone through significant changes in every aspect. The rapid development of web technologies in general as well as front-end library and framework have taken web development to a new level which facilitate developer job considerably. One of the most widely used and modern full-stacks is the MERN stack, which plays a leading role in web development nowadays. The four components included in MERN stack are MongoDB database, Express as back-end web framework, React.js serves as front-end library and Node.js as JavaScript environment.

The purpose of this thesis was to study the usability and functionality of each technology in the MERN stack and as a consequence, to develop a fully functional E-commerce web application by utilizing MERN as well as some other additional modules.

The thesis presented the development process of the application, with all the essential parts noted and explained. The outcome of this project is an e-commerce web application with all the necessary and fundamental features of an online bookstore. The product aimed to be an essential part in the business strategy of the author’s parents startup. The application is a beta version and focused mainly in development process, therefore deployment process is not carried out in this thesis but will be concerned further in the future.

Keywords	MERN stack, E-commerce, React, JavaScript, Node, Express, MongoDB, web development

Contents

List of Abbreviations

ASP	Active Server Pages
JSON	JavaScript Object Notation
BSON	Binary JavaScript Object Notation
PHP	Hypertext Preprocessor
MERN	MongoDB, Express, React.js, Node.js
JSX	JavaScript Syntax Extension
HTTP	Hypertext Transfer Protocol
HTML	Hypertext Markup Language
CSS	Cascading Style Sheets
REST	Representational State Transfer
API	Application programming interface
URL	Uniform Resource Locator
NPM	Node Package Manager
NoSQL	Non-Structured Query Language
MVC	Model View Controller
UI	User Interface
ODM	Object Data Modeling
DOM	Document Object Model

JWT	JSON Web Token
B2C	Business to Customer

1 Introduction

Nowadays, technology is growing incredibly fast. The rapid innovation of hardware devices makes software technologies to advance as well, automatically take place of old technologies. Because of the significant expanding in the number of electronic devices that use Internet and real-time feature, performance is key. By tradition, web development has been carried out by technologies such as JAVA servlets, ASP.NET or PHP. While those technologies are quite widespread and have good features with many years of development and are supported by a large community, they still have some limitations concerning about today's need which is performance. The MERN stack (MongoDB, Express, React and Node) with their simplicity and uniformity, has been recently developed to become a better solution for this performance issue.

The objectives of this thesis were to illustrate and understand the fundamental concepts and usage of each technology in the MERN stack, as well as their compatibilities and advantages as a complete stack in web application development. The thesis achieved that goal by utilizing these modern technologies and implementing a web application. The idea of this web application was toward a startup running by the author's parents as they decided to open a book retail store. By researching, the author realized how e-commerce – an enormous platform is emerging at an extraordinary speed over the last decades all over the world and providing more advantages and conveniences as compared to physical stores. Ecommerce has changed permanently the way business and consumer interact, which allows users to connect with their favorite shops and brands whenever and wherever they want and also helps stores to more actively approach consumers. It is believed that the growth of e-commerce for the next incoming years is increasing beyond measure rate with the release of modern technologies. Understanding this need, the author's solution was to create an e-commerce web application as an online bookstore in order for the startup to develop its business strategy.

This document structure was organized as follow. The first section brought in the goal of the thesis and technologies used. Next, essential concepts and theoretical background of each technology in the stack was introduced along with example, followed by the third section which demonstrated carefully and thoroughly the application development process, from back-end to front-end. In the end, this paper provided discussion of the project with further improvements and gave conclusion about the final product.

2 Application Infrastructure – The MERN stack

The MERN stack is basically a JavaScript-based stack which is created to facilitate the development process. MERN comprises of four open-source elements: MongoDB as the database, Express as server framework, React.js serves as client library and Node.js is an environment to run JavaScript on the server. These technologies introduce an end-to-end web stack for developers to utilize in web development. [1.]

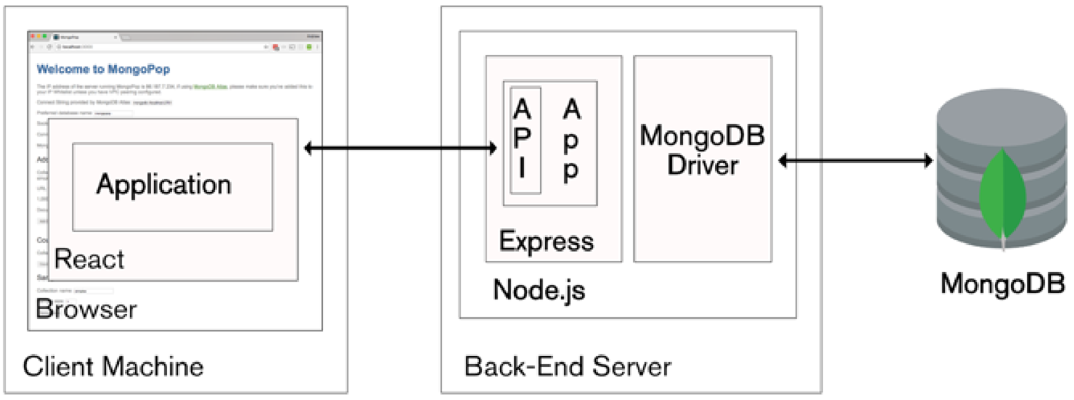


Figure 1. MERN stack architecture

Figure 1 explains the architecture of MERN stack. Firstly, Express with Node.js create API which is used for logic and to interact with MongoDB. When React client sends a HTTP request to the back-end server. The server analyzes the request, retrieves data from the database and responses with that data. React client is updated based on that returned data.

2.1 Node.js

Node.js is JavaScript environment provider and the most essential core of the MERN stack. Node.js is now the most widely used free open source web server environment created by Ryan Dahl. It allowed to execute JavaScript code on the server. It is able to run on multiple platforms like windows, Linux and mac OS. Node.js is dependent on Google V8 engine which is the core of Chrome browser. C and C++ run both Node and V8 which is better in performance speed and memory consumption. [2.]

A Node app runs in an individual process with event looping, without the need of a new thread for each operation. This is opposed to traditional servers which make use of limited thread to handle requests. Node is a non-blocking, asynchronous and event-driven engine aimed for scalable application development. Generally, Node libraries are created using non-blocking pattern. Application calls a request and then move on to work on next task rather than stalling while waiting for a response. When the request is completed, a callback function informs the application about the results. This allows multiple connections or requests to a server to be executed simultaneously which is important when scaling applications. MongoDB is also invented to be used asynchronously, therefore it is compatible with Node.js applications. [3.]

Table 1. A popular web server task (reading a file on server and send the content as response to the client) handled by PHP and Node.js

How PHP handles a file request	How Node handles a file request
1. Sends the task to the computer's file system	1. Sends the task to the computer's file system
2. Waits while the file system opens and reads the file	2. Ready to handle the next request
3. Returns the content to the client	3. When the file system has opened and read the file, the server returns the content to the client
4. Ready to handle the next request	

Node terminate the waiting time between handling requests and move on to the next request as table 1 illustrates [4].

2.1.1 Node Module

Node module is similar to JavaScript libraries which consists of a package of functions to be included in application when needed [5]. Node has a variety of modules that offer fundamental features for web applications implementation.

While developers can customize their own modules for personal project, Node has many built in modules that can be used instantly without installation.

One of the most popular built in modules is http module, which can be used to create an HTTP client for a server.

```
var http = require('http');

//create a server object:
http.createServer(function (req, res) {
  res.write('This is shown in client'); //write a response to the client
  res.end(); //end the response
}).listen(8080); //the server object listens on port 8080
```

Listing 1. A simple code in Node.js to create a server

Listing 1 demonstrates the usage of http module and 'createServer' function to initiate a server running on port 8080. A text string is shown in the client as a response.

2.1.2 Node Package Manager

Node Package Manager (NPM) offers two essential functionalities:

- Command line for performing NPM commands such as package installation and version management of Node packages
- Downloadable repositories for Node package [6.]

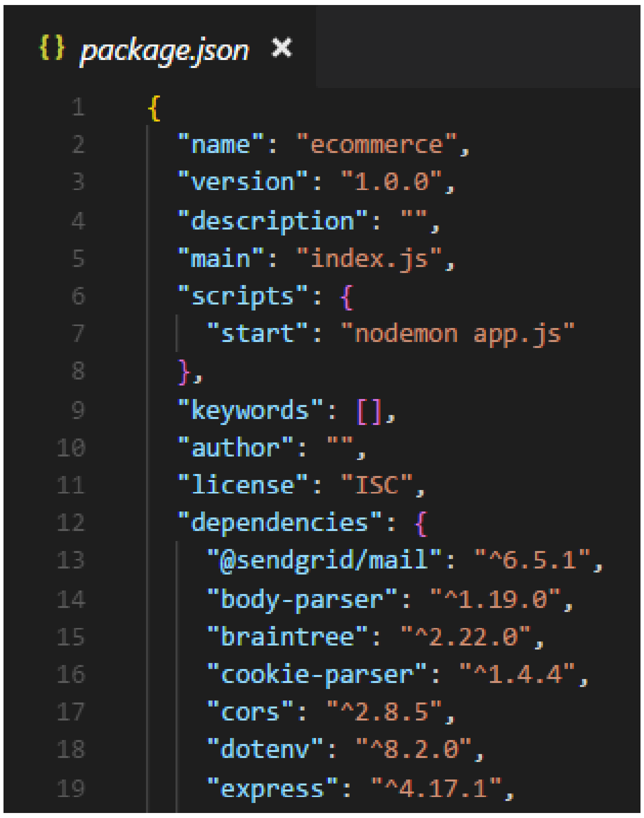
In 2017, statistic showed that more than 350 000 packages are found in the npm registry, make it the largest software repository on Earth [7]. Due to being an open source and having a basic structure, the Node ecosystem has prospered dramatically, and currently there are over 1 million open source free package, which facilitates development process a lot. Beginning with being a method to download and manage Node dependencies, npm has become a powerful means in front-end JavaScript.

There are two types of Node packages installation, globally or locally by the npm install command. The package then is downloaded from the NPM registry and presented in a folder named node_modules. The package is also added to the package.json file under property dependencies. By using require function follow with the package name, it is usable in the project as the example below in listing 2: [8]

```
$ npm install <Module Name>

var name = require('Module Name');
```

Listing 2. Installation and usage of Node package

Package.json is an obligatory file in all JavaScript/Node project. It is a JSON format file which displays pair value of names and versions of all the packages that required to run the project as well as other commands. Sometimes when a package got outdated, it will show up by running the command ‘npm outdated’. If those updates are main releases, common ‘npm outdated’ do not work because a core release usually comes up with crucial changes which can cause the project trouble. In this case, Node package ‘npm-check-updates’ need to be installed globally and then running command ‘ncu-u’ will upgrade all the version noted in package.json. Now ‘npm update’ is ready to handle all the updates. [9.]



```
{
  "name": "ecommerce",
  "version": "1.0.0",
  "description": "",
  "main": "index.js",
  "scripts": {
    "start": "nodemon app.js"
  },
  "keywords": [],
  "author": "",
  "license": "ISC",
  "dependencies": {
    "@sendgrid/mail": "^6.5.1",
    "body-parser": "^1.19.0",
    "braintree": "^2.22.0",
    "cookie-parser": "^1.4.4",
    "cors": "^2.8.5",
    "dotenv": "^8.2.0",
    "express": "^4.17.1",
```

Figure 2. A screenshot of package.json file in E-commerce application

Figure 2 illustrates some Node package used in the application under dependencies property such as body-parser, Braintree, cookie-parser, etc.

2.1.3 Node Event Loop

Event Loop is one of the most essential concepts to master Node.js. Node.js takes advantage of events heavily and it is literally one of the reasons why Node has pretty high-speed compared to other technologies. As this paper mentions above, Node.js code runs on a single thread, there is only one thing occurring at a time. This seems like a drawback but turns out to be helpful because developers do not have to worry about concurrency problems but only have to care mainly if anything could block the thread such as infinite loops or synchronous requests. The execution flow of JavaScript code will be blocked if there is a piece of code that takes too long to return back to the event loop [10.]. The event loop constantly looks for all the function calls in the call stack and execute one by one respectively.

```
const hello = () => console.log('hello')
const hey = () => console.log('hey')
const run = () => {
    console.log('run')
    setTimeout(hello, 0)
    hey()
}
run()
//run
//hey
//hello
```

Listing 3. Example about function call in event loop

Listing 3 presents the surprising output. When this code executes, first run() is called. Inside run(), setTimeout() is called first with hello as an argument. It is instructed to run instantly as 0 is passed as timer and finally hey() is called.

This is happening because the callback function of setTimeout() which is hey() is put in the Message Queue after the timer expire (immediately). Message queue is simply where functions are queued before code can reach them. The loop process prioritizes everything in the call stack and when there is nothing left, functions in the message queue are selected to run. [10.]

2.2 Express.js

Express is a micro and flexible prebuilt framework based on Node that can provide faster and smarter solution in creating server-side web applications. Express is made of Node so it inherits all Node's features like simplicity, flexibility, scalability and performance as well. In brief, what Express does to Node is the same as Bootstrap does to HTML/CSS and responsive design [11.]. It makes programming in Node a piece of cake and provides developers some additional tools and features to improve their server-side coding. Express is literally the most famous Node framework so that whenever people mention about Node, they usually imply Node combined with Express. TJ Holowaychuk released Express the first time in 2010 and currently it is maintained by the Node foundation and developers who contribute to the open source code.

Despite the fact that Express itself is completely minimalist, developers have programmed many compatible middleware packages to solve almost all issues in web development [12]. Express offers a quick and straightforward way to create a robust API with a set of helpful HTTP methods and middleware.

2.2.1 Basic Routing

Routing determine the way how an application's endpoints (URIs) interact with client requests. The basic syntax consists of an object as instance of Express and the correspondent HTTP request method such as app.get(), app.post() to handle GET and POST request respectively. [13.]

Routing methods take a callback function as parameter. The specified function is called when the HTTP requests match the defined routes and methods.

```
var express = require('express')
var app = express()// create instance of express

//respond with 'hello' when a GET request is made to the route :/hello
app.get('/hello', function(req, res) {
    res.send('hello') //response method
})
```

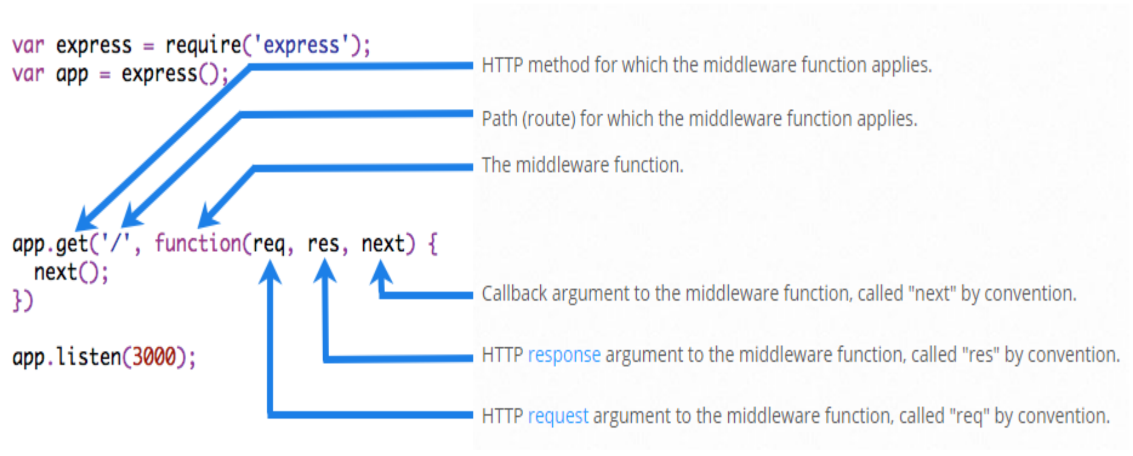
```
var callback1 = function(req, res, next) {
    //
    next()
}
var callback2 = function(req, res, next) {
    //
    next()
}
app.get('/multiple', [callback1, callback2])
```

Listing 4. Example of Routing functions

As can be seen from listing 4, routing method in line 17 has more than 1 callback function as parameters. In this case, it is crucial to add ‘next’ to each callback function arguments and call it later in the body to switch control to the next callback. ‘next’ function will be discussed more in the next section.

2.2.2 Writing and Using Middleware

Middleware functions have the ability to approach request object, response object and the ‘next’ function in the application’s request-response phase. Middleware execution return an output which could be either the final outcome or could be passed as an argument to the next middleware until the end of the cycle [14.]. The ’next’ function belongs to the Express router which starts the following middleware right after the current middleware finished. If a middleware does not finish the req-res cycle, next() must be called to pass control to the next one. Otherwise, the request will be suspended.



```
var express = require('express');
var app = express();

app.get('/', function(req, res, next) {
  next();
})

app.listen(3000);
```

HTTP method for which the middleware function applies.
Path (route) for which the middleware function applies.
The middleware function.
Callback argument to the middleware function, called "next" by convention.
HTTP response argument to the middleware function, called "res" by convention.
HTTP request argument to the middleware function, called "req" by convention.

Figure 3. Middleware function components

Figure 3 illustrates middleware concepts in details.

An Express application is basically a sequence of middleware calls. The call orders is based on the order which they are declared

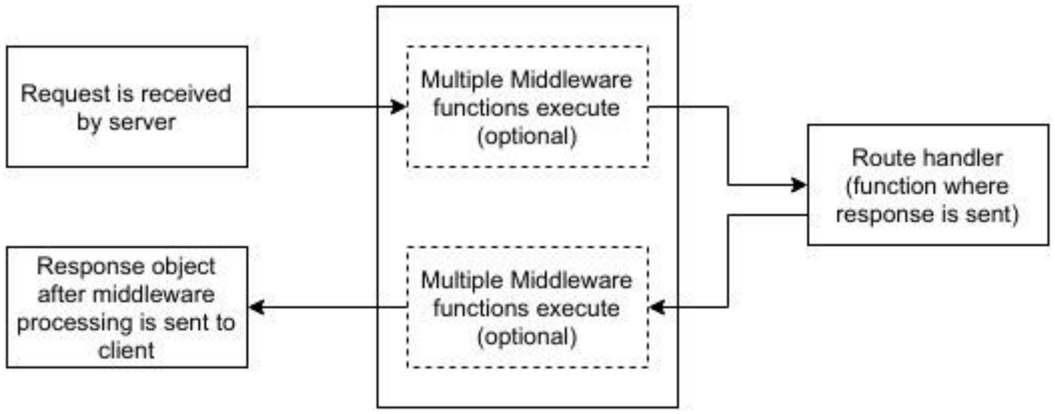

Request is received by server
Multiple Middleware functions execute (optional)
Route handler (function where response is sent)
Response object after middleware processing is sent to client
Multiple Middleware functions execute (optional)

Figure 4. Diagram of middleware execution order

Figure 4 explains that Express treats all middlewares in the same way so that the order in which your route handlers and other middleware functions are written is exactly the execution order [15].

2.3 MongoDB

MongoDB is a document-based NoSQL database used mainly for scalable high-volume data applications and data involved jobs which does not work well in a relational model. It is among the most popular non-relational database which emerged in the mid-2000s. MongoDB architecture comprises of collections and documents replacing the use of tables and rows from traditional relational databases point of view. One of the most essential functionalities of MongoDB is its ability to store dynamic data in flexible BSON documents, which means documents sharing the same collection can have different fields and key-value pairs, while data structure can be changed without any restrictions at any time [16.]. Therefore, this removes the necessity of storing strictly structured data which is obligatory in other relational databases and improves database operation speed significantly. Indexing and aggregation offer robust method to access and work with data easily. Whatever field in a document can be indexed, leading to a much better search performance. MongoDB also provides numerous operations on the documents such as inserting, querying, updating as well as deleting. With the diversity of field value and strong query languages, MongoDB is great for many use cases and can horizontally scale-out to provide storage for larger data volumes, make it stably be the most popular NoSQL database globally [17].

2.3.1 NoSQL Database

There are big differences between the mechanism NoSQL databases store data and relational databases do. NoSQL databases are differentiated based on their data model. There are 4 main types:

- Document databases
- Key-value databases
- Wide-column databases
- Graph databases

They share one common thing which is dynamic schema and can scale easily with large data loads and high user volumes. A popular misunderstanding is that NoSQL databases do not handle relationship data well. While in fact, many developers believed that data modeling relationship is easier for NoSQL databases due to the nested individual data structure.

During the late 2000s, as a result of the considerable decrement in storage price, there is no need to create a complicated data model just to avoid data duplication. NoSQL databases took a big step forward and became a good option for developers and large data volume applications [18.].

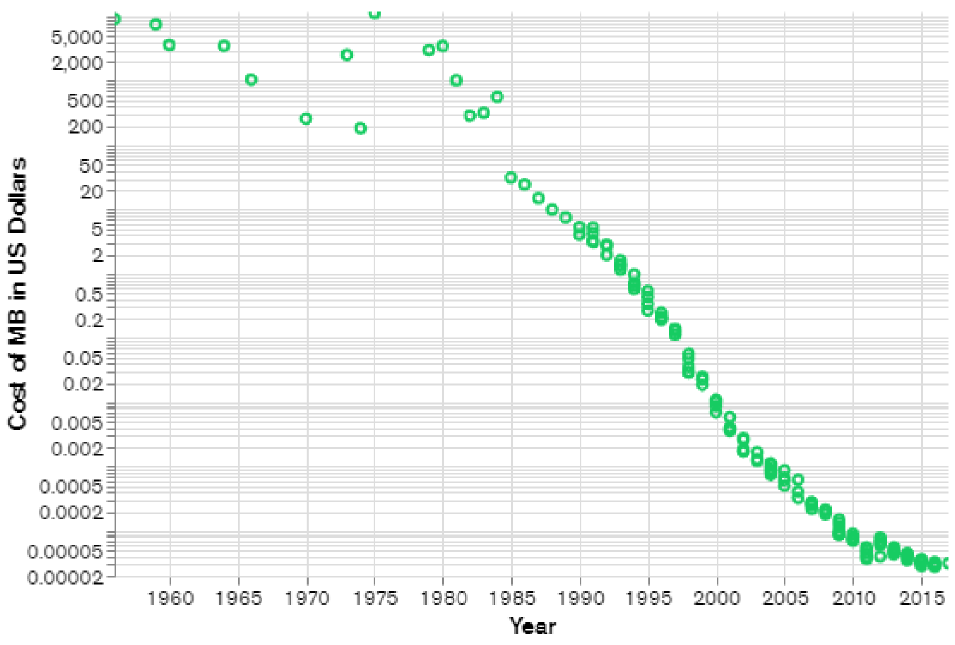


Figure 5. Cost per MB of data overtime

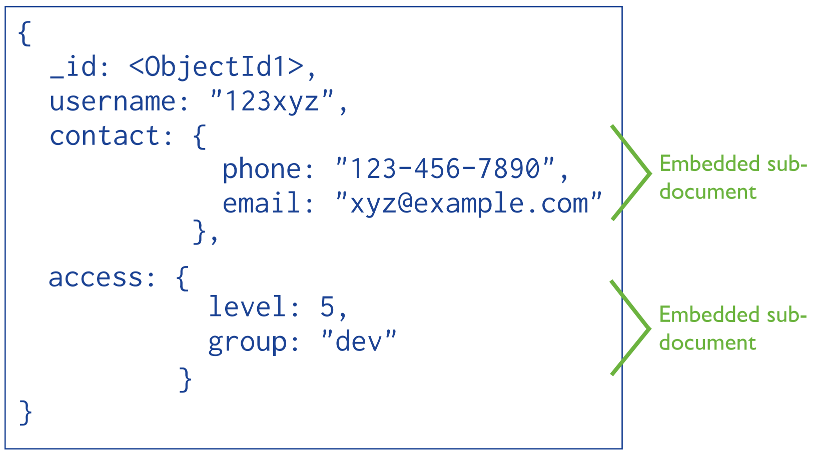
As price of storage critically decreased as figure 5 demonstrates, the number of applications along with the data needed to store increased incredibly. Defining the schema beforehand for all those data is almost impossible. Therefore, NoSQL databases provide developers flexibility to save a large amount of unstructured data.

2.3.2 Data Models

Data model design is determined by the document's structure and relationships between data. Related data can be embedded into a single document.

2.3.2.1 Embedded data model

Embedded documents present the connection between data by attaching related data in a single structure. Related data then can be fetched and manipulated in a single operation [19].



```
{
  _id: <ObjectId1>,
  username: "123xyz",
  contact: {
              phone: "123-456-7890",
              email: "xyz@example.com"
            },
  access: {
             level: 5,
             group: "dev"
           }
}
```

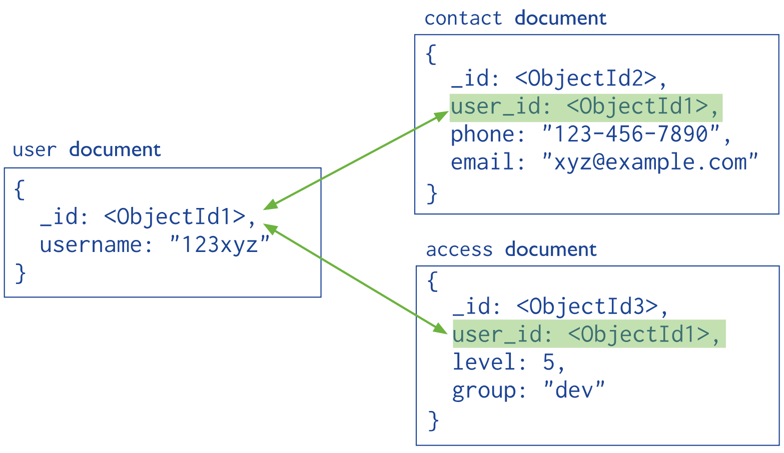
Figure 6. A picture of an embedded document

Figure 6 illustrates how related information is stored in the same database record. As a consequence, fewer queries are needed to handle operations leading to a better performance, especially with read operation [20].

In conclusion, embedded data models should be used when there are relationships between entities or when one to many relationships exists, as long as the document size is smaller than 16mb which is BSON largest size allowed.

2.3.2.2 Normalized data model

As its own name shows, this kind of data model is normal and common. Applications can resolve these references to access the related data. References are added from one document and linked to other to present the relationship between data. Related data then can be accessed by resolving references [19.].



```
{
  _id: <ObjectId1>,
  username: "123xyz"
}
```

```
{
  _id: <ObjectId2>,
  user_id: <ObjectId1>,
  phone: "123-456-7890",
  email: "xyz@example.com"
}
```

```
{
  _id: <ObjectId3>,
  user_id: <ObjectId1>,
  level: 5,
  group: "dev"
}
```

Figure 7. References between related data

As can be seen from figure 7, both contact document and access document have reference linked to the user document.

Normalized data models should be used in these following cases:

- data duplication happens when embedding but performance advantages are not enough to outperform the duplication.
- complicated many-to-many relationships exist.
- big hierarchical data exist [20.].

2.3.3 MongoDB Atlas

MongoDB Atlas, which announced in 2016 by MongoDB creator team, is the cloud service for storing data globally. It offers everything MongoDB provide without further requirements when building applications, allowing developers to fully focus on what they do best [21.]. With Atlas, developers do not have to worry about paying for unnecessary things as they follow a pay-as-you-go standard.

MongoDB Atlas introduces a simple interface to get started and running. Basically, by choosing instance size, region and any customized features needed, Atlas brings out the suitable instance and includes it with the following:

- Built-in Replication: Atlas ensures constant data availability by providing multiple servers, even when the primary server is down.
- Backups and Point-in-time Recovery: Atlas puts a lot of efforts to prevent data corruption.
- Automated Update and One-Click Upgrade: users take advantage of the latest and best features as soon as they are released due to Atlas automated patching.
- Various options for additional tools: users can freely decide on which regions, cloud providers and billing options they prefer to use, making them feel like customizing their own instances.
- Fine-Grained Monitoring: users are kept up with a diversity of organized information, to let them know the right time to advance things to the next level.

MongoDB Atlas is practical and reliable thanks to its integrated automation mechanisms. With Atlas, it is unnecessary to concern about operational tasks as following:

- Supply and Configuration: Atlas gives clear instruction step by step to go through the setup process, so developers do not have to think about what aspect to choose even if they are beginners.
- Patching and Upgrades: Atlas is integrated with automatic upgrade and patching, ensures user can reach latest features when they are released as patching process takes just some minutes with no downtime.
- Monitoring and Alerts: database and hardware metrics are always visible so users can foresee and prepare for any performance and user experience problems [22.].

2.3.4 Mongoose

Mongoose is an Object Data Modeling (ODM) JavaScript-based library used to connect MongoDB with Node.js. Mongoose provides a straight-forward, schema-based solution to create your application data template. It handles data relationships, provides methods to validate schema, and is used to render and represent between objects in MongoDB [23.].

Mongoose schema is covered inside a mongoose model, and a specific schema creates model. While schema and model are slightly equivalent, there is a primary difference: schema determines the document formation, default values, validator, etc. while model is responsible for document-related operation like creating, querying, updating and deleting. A schema definition is simple, and its structure is usually based on application requirements. Schemas are reusable and can include multiple child-schemas. Schema applies a standard structure to all the documents in a collection. Moreover, Mongoose provides additional features like query helper functions and business logic in the data. For example, Mongoose can help connect database with the server and perform typical database operations for reading, writing, updating and deleting data. Mongoose removes the need of writing complicated data validations by providing schema validation rules to allow only acceptable data to be saved in MongoDB [24.].

2.4 React.js

React is an open-source front-end JavaScript-based library that specializes in building user interfaces. It was originally created by a Facebook software engineer and first implemented in newsfeed feature of Facebook in 2011 and followed by Instagram a year later. Due to the minimal understanding requirement of HTML and JavaScript, React is easy to learn and thanks to the support by Facebook and strong community behind it, React expands its popularity and becomes one of the most used JavaScript library [25.].

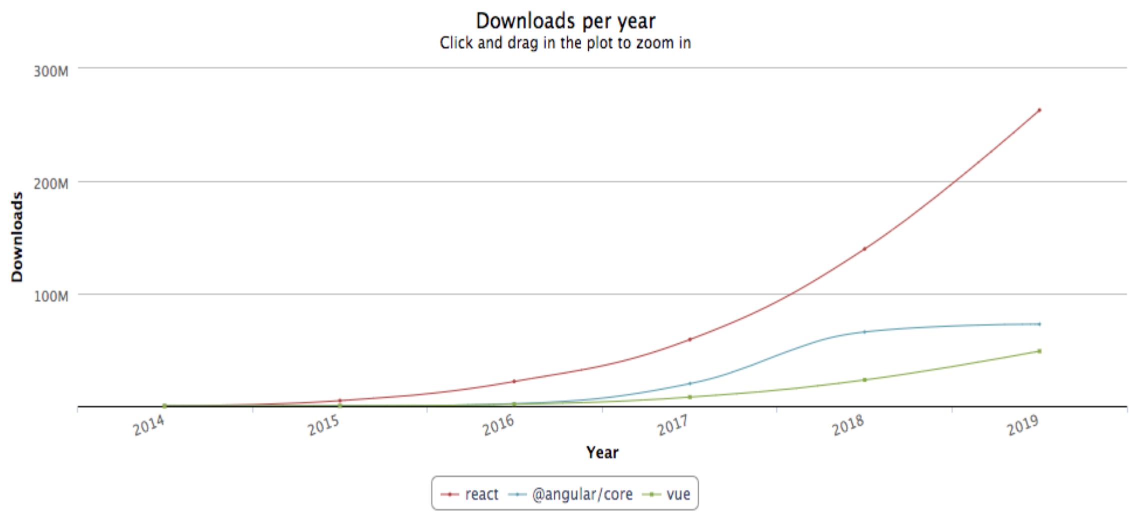


Figure 8. Number of package downloads with NPM per year of React, Angular and Vue

Figure 8 compares the number of package downloads with NPM among React and two other popular frameworks - Angular and Vue. As can be seen, the number of React has increased dramatically in popularity in the past few years and definitely has proven its preference [26.].

React works only on user interfaces of web and mobile applications. This equivalent to the view layer of MVC template. ReactJS allows developers to create reusable UI components as well as to create scalable web applications that can change data without reloading the page. In addition to providing reusable component code, which means reducing development time and lessening the risk of bugs and errors, React released some key features that add to its appeal for developers [27.]:

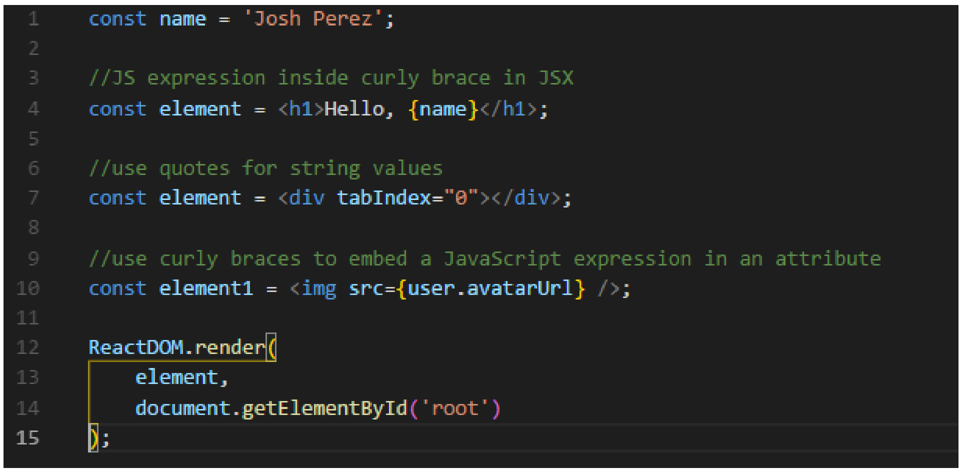
- JSX (JavaScript Syntax extension)
- Virtual Dom
- Component

2.4.1 JSX

The beginning foundation of any basic website is made by HTML files. Web browsers read and display them as web pages. During this process, browsers create a Document Object Model which is a representational tree of the page structure. Dynamic content can be added by modifying the DOM with JavaScript [28]. JSX is XML/HTML-like syntax used to make it easier to modify the DOM by using simple HTML-like code [29]. Literally, JSX makes it possible to write brief HTML-like structures in the same file with JavaScript code, then transpiler such as Babel will convert these expressions to standard JavaScript code. Contrary to the past when JavaScript is put into HTML, now JSX allows HTML to be mixed in JavaScript.

React takes advantage of JSX to handle templating and writing React element. It is not compulsory to use JSX, but following are some benefits that should be considered:

- Time efficiency due to performing optimization while compiling code to JavaScript.
- Type-safe due to the ability to find out most of the errors during compilation.
- Faster in templating, if developers are familiar with HTML.



```
1   const name = 'Josh Perez';
2
3   //JS expression inside curly brace in JSX
4   const element = <h1>Hello, {name}</h1>;
5
6   //use quotes for string values
7   const element = <div tabIndex="0"></div>;
8
9   //use curly braces to embed a JavaScript expression in an attribute
10  const element1 = <img src={user.avatarUrl} />;
11
12  ReactDOM.render(
13      element,
14      document.getElementById('root')
15  );
```

Figure 9. Some examples of JSX

As can be seen in figure 9 line 4, variable ‘name’ is called inside JSX by wrapping it in curly braces. In general, all valid JavaScript expression need to be inside curly braces in order to be used in JSX. Line 7 and 10 indicate that in case of an attribute, either quotes or curly braces should be used properly depend on specific situations.

2.4.2 Virtual DOM

Considered as the next important breakthrough in web development after AJAX, the virtual DOM (Document Object Model) is the main reason why React is able to create fast and scalable web application.

Normally without react, the web application uses HTML to update its DOM. This works well for uncomplicated and static sites, but it can be a huge performance issue for dynamic websites especially the one that involve high user interaction and view update because the whole DOM needs to reload every time the user triggers a page refresh [30]. Despite of JavaScript engines nowadays which are fast enough to carry out such complicated applications, DOM manipulations are still not that advanced. Another factor is that DOM is tree-structured so that even a change in a layer can cause extreme changes. Updating DOM is always the shortcoming when it comes to performance. React optimized this by introducing Virtual DOM.

Virtual DOM is a representation of the DOM object, where it executes all updates required before rendering the final page to the browser. Whenever a user action happens or by any means, there is a change to the DOM, React will generate a copy of the Virtual DOM. At that point, a diff algorithm compares the previous and current states of the Virtual DOM and figures out the optimal way with the least amounts of updates needed to apply these changes. If there are any differences, React updates that single element only rather than update a tons of elements, while if there is no change, React make browser render nothing [31.]. As a result, this behavior spends less computing power and less loading time, leading to better user experience and performance.

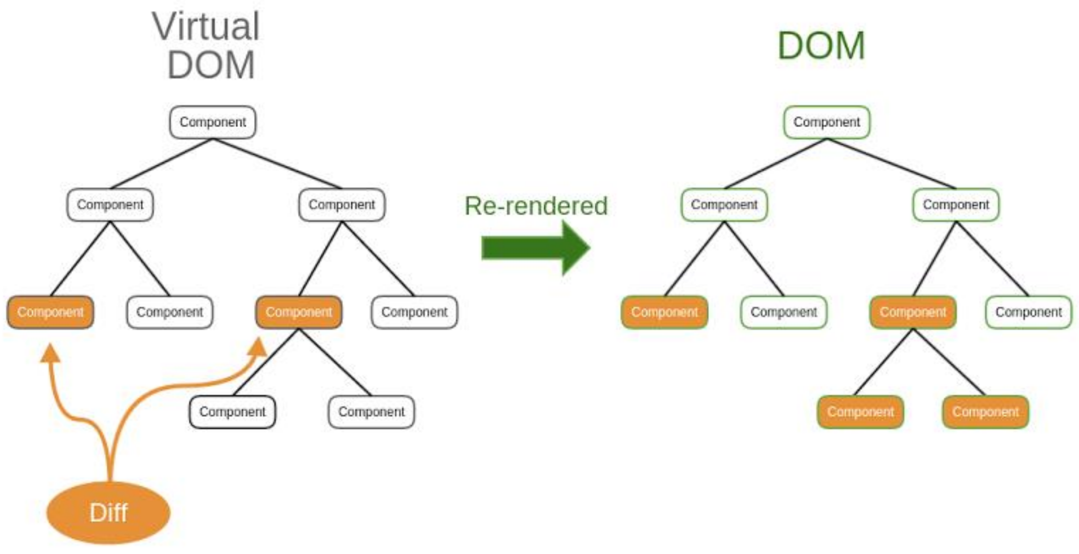


Figure 10. A picture of React Virtual DOM

Figure 10 indicates how Virtual DOM works, only the specific changes are updated and re-rendered to the real DOM. This is the core reason behind React high performance.

2.4.3 Component

React is all about component, which reflects the primary unit of every application. React allow developers to divide the user interface into simple, independent and reusable components. A developer can start with common tiny components that can be used repeatedly on several pages like navigation bar, button, input form etc. This is what reusability means, which is a perfect way to reduce development time, so that developers can concentrate on more crucial features and business logic. Then comes the turn of wrapper components that include children components with internal logic. Each component determines its own way how it should be rendered. A component can also be combined with other components or nested inside higher order components. The development process keeps going on like that until it reaches the root component which is also the application. As a result, this approach guarantees the application consistency and uniformity which make it easier for maintenance as well as further codebase growth.

There are 2 types of components, functional component and class component.

2.4.3.1 Functional components

Functional components are completely presentational and basically are written under the form of a JavaScript function that can receive some props (properties) as argument and return a React element. Thanks to their predictability and straightforwardness, functional components always make the same result given the same props. Therefore, developers tend to pick functional components whenever possible. Stateless component or dumb component is all functional component’s name as it comes from the natural fact that functional components do not manage any state and their task is simply output user interface elements [32.].

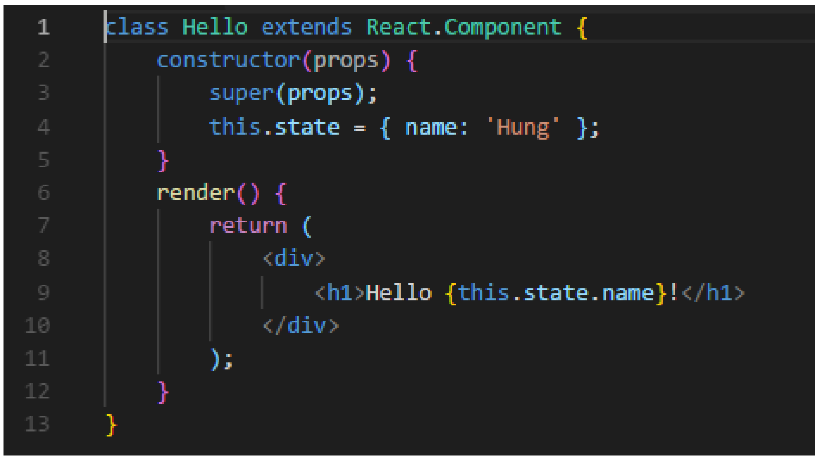
```
Function Hello (props) {
     Return <h1>Hello {props.name} </h1>;
}
```

Listing 5. A functional component

Listing 5 illustrates an example of a functional component which takes ‘name’ as a props and return a JSX.

2.4.3.2 Class components

ECMAScript6 class syntax are utilized to write class-based components, the one which not only can return JSX but also can dispatch action, fetch data, handle events and have local state. Class components offer more functionalities by inheriting from React.Component class. They can access all additional lifecycle methods from their parent class and manipulate code at particularly moment during the process [33]. While functional components are dumb and stateless, class components are said to be smart and stateful thanks to being a container of the local state, internal logic and other children components. Therefore, a class component should be considered in case if there is a need for local state management or lifecycle method as well as some logic. Otherwise, a functional component is more suitable.



```
class Hello extends React.Component {
    constructor(props) {
        super(props);
        this.state = { name: 'Hung' };
    }
    render() {
        return (
            <div>
                <h1>Hello {this.state.name}!</h1>
            </div>
        );
    }
}
```

Figure 11. A class component

As figure 11 summarizes, all React.Component subclasses have to define render function. A constructor function is implemented here because there is initial state and inside constructor, super(props) should be called first out of all statements. If not, this can lead to errors because of undefined props [34].

3 Application Implementation

A prototype version of the e-commerce application was created to apply the study of MERN stack as well as to understand how they contribute to the whole entity in web development.

3.1 Application requirements

Typically, a (business to customer) B2C e-commerce web application has two types of users, which are admin and user. Admins are responsible for some specific management tasks such as creating, updating and removing the products from the database as well as managing user orders. A user is able to browse and read product's information displayed in the application. He can also add the product to the shopping cart and perform the payment for that product. While some resources and web routes are public, the others can only be accessed by an admin or a signed in user.

By interviewing and researching some normal customers and business owners, the author figured out what different type of user want from the application, what features they think are necessary for an e-commerce web application. Based on that, a list of user stories is shown below to illustrate some of the required functionalities for this application:

- As a user, user want to create an account for himself
- As a user, user want to update his profile
- As a user, user want to surf through all the products
- As a user, user want to see product information such as category, price, name, review, picture, etc.
- As a user, user want to add many products to the shopping cart and is able to view the cart
- As a user, user want to delete products from the cart
- As a user, user want to modify the quantity of products inside the cart
- As a user, user want to pay for the products in the cart
- As an admin, admin want to add product to the database
- As an admin, admin want to remove product from the database
- As an admin, admin want to update product to the database

- As an admin, admin want to add category to the database
- As an admin, admin want to manage user orders

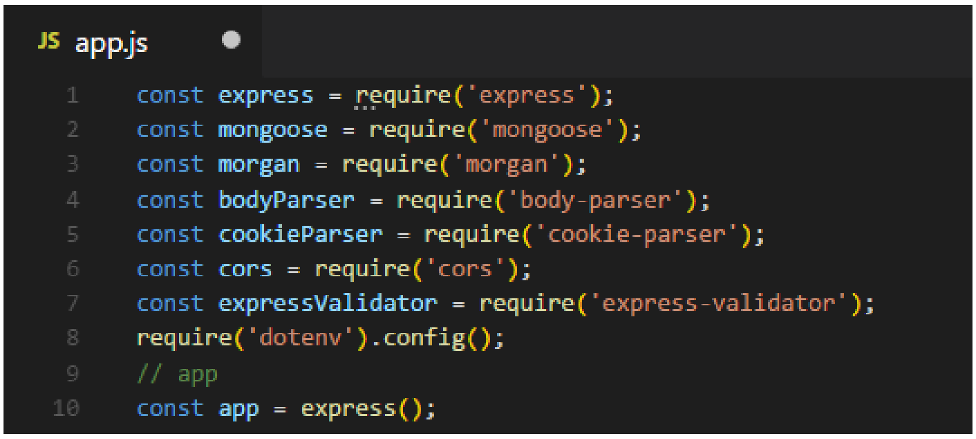
3.2 Application development

This section is dedicated to demonstrate the functionalities development process from back-end to front-end of the e-commerce application. Due to the limited scope of this thesis, it is not able to mention all the files or describe every step in the project into details, but it aims to discuss precisely about all fundamental and important parts that needed to implement the MERN application. Basic concepts of any third-party libraries or module are also explained along the way. The project structure is divided into 2 folder, ecommerce and ecommerce-front which contain the source code of back-end and front-end respectively.

3.2.1 Back-end development

3.2.1.1 Basic setup

The very first thing to do is to set up an Express application by creating an app.js file, which is the entrance file of the project, where some of the necessary middlewares and node packages are stored. Express instance is defined under app variable.



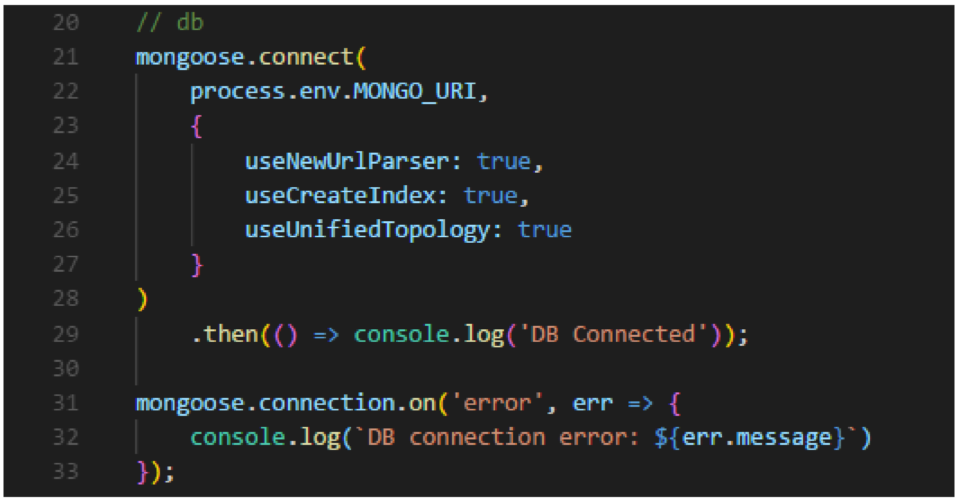
```
const express = require('express');
const mongoose = require('mongoose');
const morgan = require('morgan');
const bodyParser = require('body-parser');
const cookieParser = require('cookie-parser');
const cors = require('cors');
const expressValidator = require('express-validator');
require('dotenv').config();
// app
const app = express();
```

Figure 12. A screenshot of app.js file from the e-commerce application

The purpose of those middlewares in figure 12 are explained as below:

- Mongoose is discussed in chapter 2.3.4
- Morgan logs the request details
- bodyParser unzips the whole body part of an incoming request and makes it available on req.body object [35].
- cookieParser deconstructs cookie header and populates all the cookie in req object under property named cookies.
- dotenv let developers use environment variable by accessing .env file

The following step is setting up database connection. MongoDB atlas is used due to various advantages it brings in for the project as chapter 2.3.3 summarizes above. Since Atlas is an online database service, no installation is required. By accessing MongoDB Atlas official site and following instruction there, a cluster is created with the author's personal choice of cloud provider and region followed by a connection string which is saved as MONGO_URI variable in the environment file. It is then used by mongoose to connect to the database. When the connection is successful, 'DB Connected' is displayed in the terminal. Otherwise, a message telling the connection error is printed out as Figure 13 below explains.



```
// db
mongoose.connect(
    process.env.MONGO_URI,
    {
        useNewUrlParser: true,
        useCreateIndex: true,
        useUnifiedTopology: true
    }
)
    .then(() => console.log('DB Connected'));

mongoose.connection.on('error', err => {
    console.log(`DB connection error: ${err.message}`)
});
```

Figure 13. A code snippet of how to connect to the database.

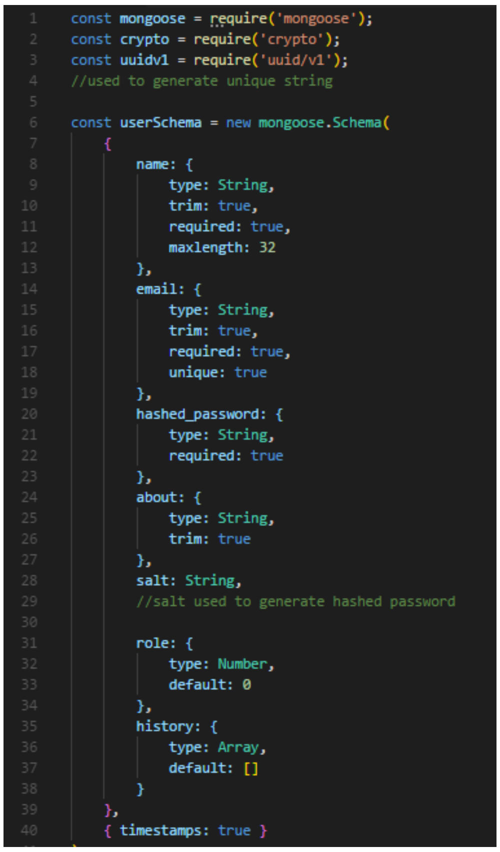
The back-end folder is structured by 3 main sub-folders: models, routes and controllers. While models contain all the mongoose schemas that are based on application requirements, routes define all the API routes and controllers comprise of the logic that needed to be execute after each incoming request match with the corresponding route.

3.2.1.2 Mongoose Schema Creation

There is a total of 4 schemas in this application: category, order, product and user. Each mongoose schema represents for a document structure User schema is written first because user model is needed to handle authentication and authorization.

User schema

As can be seen from figure 14 below, a user schema has 3 required properties called name, email and password. Role property is set to 0 by default as it means this is a normal user. By manually changing the role value to other (in this application: 1) the user becomes an admin. The user model only accepts defined properties in the schema to be added to the database. While history shows an array of purchases that user used to make, timestamps displays the time of creation and modification of a user object.

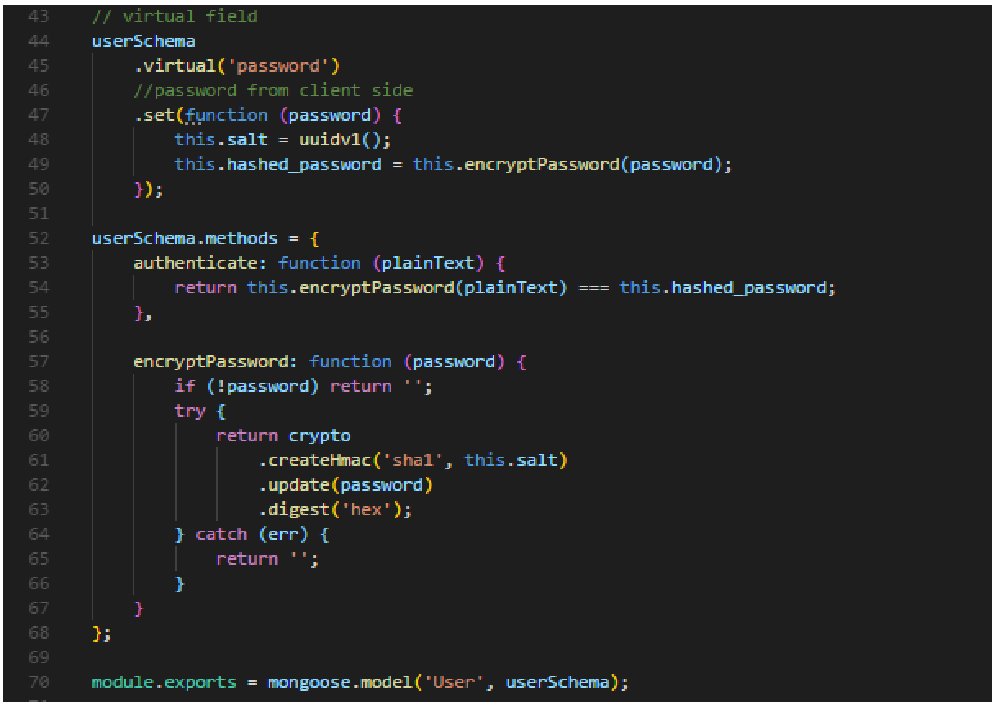


```
const mongoose = require('mongoose');
const crypto = require('crypto');
const uuidv1 = require('uuid/v1');
//used to generate unique string

const userSchema = new mongoose.Schema(
    {
        name: {
            type: String,
            trim: true,
            required: true,
            maxlength: 32
        },
        email: {
            type: String,
            trim: true,
            required: true,
            unique: true
        },
        hashed_password: {
            type: String,
            required: true
        },
        about: {
            type: String,
            trim: true
        },
        salt: String,
        //salt used to generate hashed password

        role: {
            type: Number,
            default: 0
        },
        history: {
            type: Array,
            default: []
        }
    },
    { timestamps: true }
```

Figure 14. A screenshot of User schema

For security reasons, real password is not saved in the database but an encrypted one, therefore the author used Crypto, which is a Node module to hash the password while combined with a tool called mongoose virtual.

A Mongoose Virtual is a property that is not stored in MongoDB. Mongoose Virtuals, which has getter and setter methods are great option for computing properties.



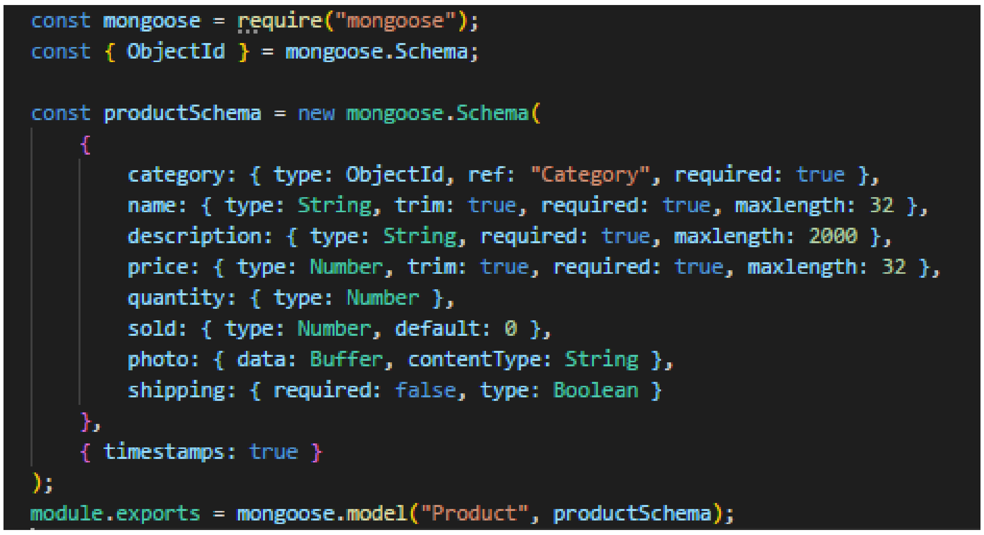
```javascript
// virtual field
userSchema
    .virtual('password')
    //password from client side
    .set(function (password) {
        this.salt = uuidv1();
        this.hashed_password = this.encryptPassword(password);
    });

userSchema.methods = {
    authenticate: function (plainText) {
        return this.encryptPassword(plainText) === this.hashed_password;
    },

    encryptPassword: function (password) {
        if (!password) return '';
        try {
            return crypto
                .createHmac('sha1', this.salt)
                .update(password)
                .digest('hex');
        } catch (err) {
            return '';
        }
    }
};

module.exports = mongoose.model('User', userSchema);
```

Figure 15. Usage of Mongoose Virtual in the application

Figure 15 demonstrates how ‘hashed_password’ is created based on Mongoose Virtual. Firstly, Virtual creates a property named password for user object. When a new user is signed up, the value of ‘password’ property from the req.body is set to the virtual property and is passed to setter function as an argument. Then ‘password’ is encrypted and set to ‘hashed_password’ property. A function is also assigned to userSchema method object to create an authenticate method which compare the encrypted input password with the hashed one to verify the user.

Product schema

A product schema is structured as figure 16 below. It has all the properties that any e-commerce product may need, like name, description, price, quantity, category, etc. Sold field is set to 0 as default value and is incremented after each user purchase. One different with the user schema above is that category field has a type of ObjectId while the 'ref' option indicates which model to refer to during population (in this case category model). This illustrates the relationship between product model and category model and by using populate method, category data is no longer its original _id but replaced with mongoose document retrieved from the database.



```
const mongoose = require("mongoose");
const { ObjectId } = mongoose.Schema;

const productSchema = new mongoose.Schema(
    {
        category: { type: ObjectId, ref: "Category", required: true },
        name: { type: String, trim: true, required: true, maxlength: 32 },
        description: { type: String, required: true, maxlength: 2000 },
        price: { type: Number, trim: true, required: true, maxlength: 32 },
        quantity: { type: Number },
        sold: { type: Number, default: 0 },
        photo: { data: Buffer, contentType: String },
        shipping: { required: false, type: Boolean }
    },
    { timestamps: true }
);
module.exports = mongoose.model("Product", productSchema);
```

Figure 16. ProductSchema structure

While user schema and product schema look complex, category schema is pretty simple and straightforward with only name and timestamps field.

3.2.1.3 Authentication with JWT

JSON Web Token (JWT) is a standard that defines a compact and self-contained way to transmit data securely between client and server as a JSON object. Tokens can be transferred through an URL or a HTTP request header easily thanks to its compact size while self-contained feature let JWT comprise all the necessary user information. Data inside a JWT is verified and reliable because it is signed with a secret key or a public private key pair. Moreover, the signature also confirms that only the party holding the private key have signed it.

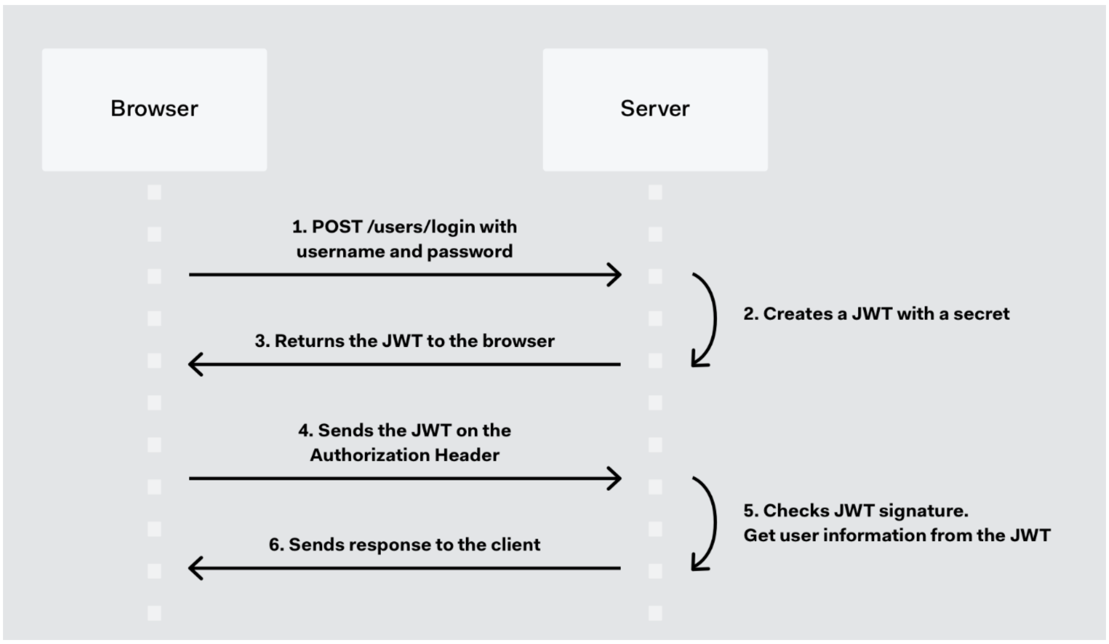
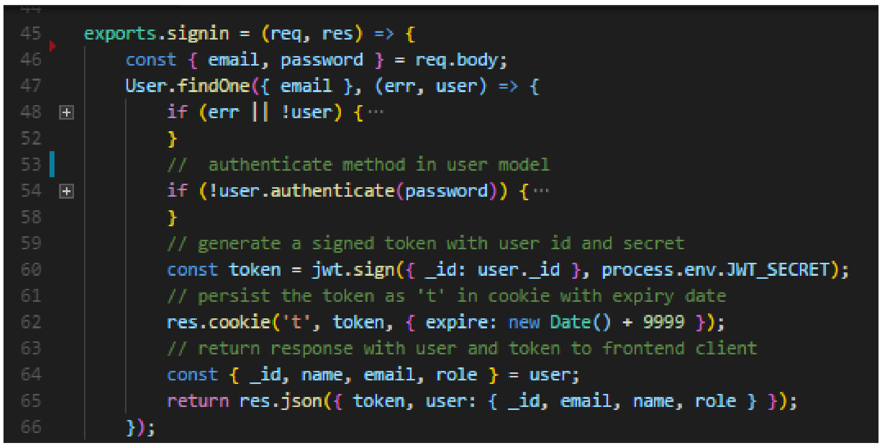

Browser
Server
1. POST /users/login with username and password
2. Creates a JWT with a secret
3. Returns the JWT to the browser
4. Sends the JWT on the Authorization Header
5. Checks JWT signature. Get user information from the JWT
6. Sends response to the client

Figure 17. How JWT works in authorization

Authentication is the most popular use case of JWT. After a user signs in, the authorization is granted and a JWT is created by the application and sent back to the user. By that time, all following requests made by user will contain the token in the authorization header with Bearer schema. The server will check for a valid token, and if it is available, the user is allowed to access protected routes, services and resources that require that token. As JWT is self-contained, all needed data stay there, leading to less works toward the database [36.]. This whole process is analyzed in figure 17 above



```
exports.signin = (req, res) => {
  const { email, password } = req.body;
  User.findOne({ email }, (err, user) => {
    if (err || !user) {⋯
    }
    //  authenticate method in user model
    if (!user.authenticate(password)) {⋯
    }
    // generate a signed token with user id and secret
    const token = jwt.sign({ _id: user._id }, process.env.JWT_SECRET);
    // persist the token as 't' in cookie with expiry date
    res.cookie('t', token, { expire: new Date() + 9999 });
    // return response with user and token to frontend client
    const { _id, name, email, role } = user;
    return res.json({ token, user: { _id, email, name, role } });
  });
```

Figure 18. Usage of JWT in E-commerce application to sign in user

Figure 18 demonstrates how JWT is implemented in the 'signin' controller method. This method is executed when there is a POST request to the route '/api/signin'. Firstly, user credentials are retrieved from the request body and set to the corresponding variable. Then database looks for the user with that email and checks if the password is matched with hashed password. If yes, a signed token is generated with user ID and a secret random string which is saved in environment file. This secret string key is needed for security reasons since tokens are user credentials. Then the token is attached in cookie with an expiry time and is returned with user data as json format to the client.

3.2.1.4 Routing and API Documentations

Data distribution and sharing between two or more systems has always been an essential aspect of software development. Taking into account a case when a user search for some books of a specific category, an API is called and the request is sent to the server. The server analyzes that request, performs necessary actions and finally, user gets a list of books as a response from the server. This is the way how REST API works. An API stands for Application Programming Interface, which is a set of rules that allows two applications or programs to interact with each other [37].

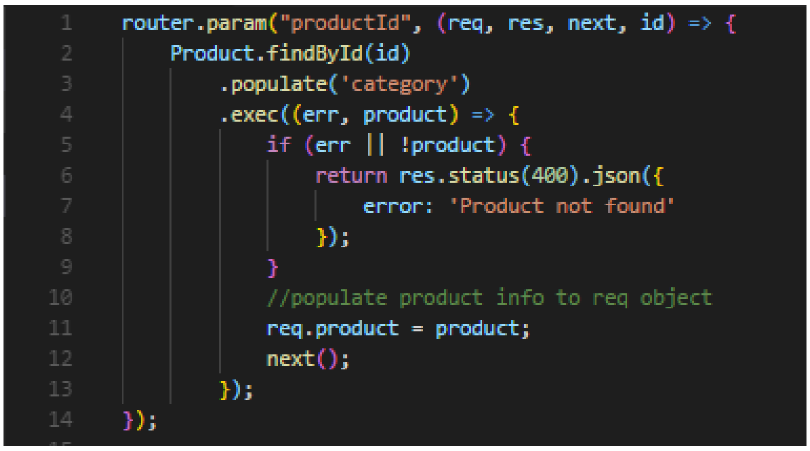
REST determines how the API looks like. It stands for “Representational State Transfer” -an abstract definition of the most popular web service technology. REST is a way for two computer systems to communicate over HTTP in a similar way to web browsers and servers. It is a set of rules that developers follow when they create their API.

Table 2. Product related API

Method	Route path	Description
GET	api/product/:productId	Return a product with the given ID under json format
POST	api/product/create/:userId	Create a new product and save it to database, return a json object of that product. Required to be admin and be authenticated
DELETE	api/product/:productId/:userId	Remove a product with the given ID and return a json message object. Required to be admin and be authenticated
PUT	api/product/:productId/:userId	Update a product with the given ID and return updated product under json object. Required to be admin and be authenticated

GET	api/products	Return a list of products under json format
GET	api/products/search	Return a list of products based on search query under json format
GET	api/products/related/:productId	Return all the products with the same category as the given ID product

Table 2 above illustrates all the product related API routes with corresponding method and description in brief. As can be seen, only user with admin role can perform operation like creating, deleting and updating to a product. Other public routes can be accessed wherever and by whatever kind of user even without a signed account.



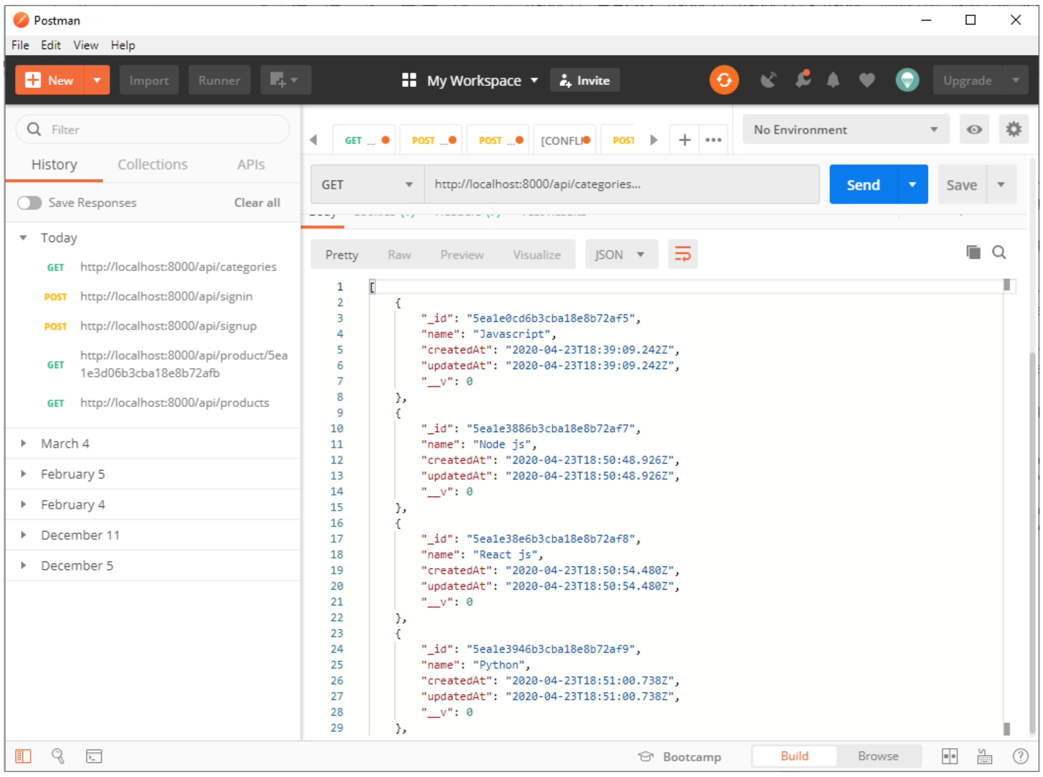
```
router.param("productId", (req, res, next, id) => {
    Product.findById(id)
        .populate('category')
        .exec((err, product) => {
            if (err || !product) {
                return res.status(400).json({
                    error: 'Product not found'
                });
            }
            //populate product info to req object
            req.product = product;
            next();
        });
});
```

Figure 19. Usage of router.param method

The author also makes use of router.param method as most of the product API routes above have a parameter (productid, userId) inside. Router.param finds the product with that ID and populate its information to request object under product property as figure 19 summarizes. This is also applied to other routes which have userId, categoryId and orderId as well since it facilitates the logic implementation.

3.2.1.5 API Testing with Postman

At this moment of the development process, the front-end is not available yet so a third-party tool called Postman is used to handle API testing.


Postman
File Edit View Help
New
Import
Runner
My Workspace
Invite
Upgrade
No Environment
Filter
History
Collections
APIs
Save Responses
Clear all
Today
GET http://localhost:8000/api/categories
POST http://localhost:8000/api/signin
POST http://localhost:8000/api/signup
GET http://localhost:8000/api/product/5ea1e3d06b3cba18e8b72afb
GET http://localhost:8000/api/products
March 4
February 5
February 4
December 11
December 5
GET
http://localhost:8000/api/categories...
Send
Save
Pretty
Raw
Preview
Visualize
JSON
Bootcamp
Build
Browse

```
[
    {
        "_id": "5ea1e0cd6b3cba18e8b72af5",
        "name": "Javascript",
        "createdAt": "2020-04-23T18:39:09.242Z",
        "updatedAt": "2020-04-23T18:39:09.242Z",
        "__v": 0
    },
    {
        "_id": "5ea1e3886b3cba18e8b72af7",
        "name": "Node js",
        "createdAt": "2020-04-23T18:50:48.926Z",
        "updatedAt": "2020-04-23T18:50:48.926Z",
        "__v": 0
    },
    {
        "_id": "5ea1e38e6b3cba18e8b72af8",
        "name": "React js",
        "createdAt": "2020-04-23T18:50:54.480Z",
        "updatedAt": "2020-04-23T18:50:54.480Z",
        "__v": 0
    },
    {
        "_id": "5ea1e3946b3cba18e8b72af9",
        "name": "Python",
        "createdAt": "2020-04-23T18:51:00.738Z",
        "updatedAt": "2020-04-23T18:51:00.738Z",
        "__v": 0
    },
```

Figure 20. A screenshot of Testing with Postman

As can be seen from figure 20, a GET request has been called to the route ‘api/categories’ and been successfully handled. Since this is a public route and categories is not protected resource, no authorization token in the header is needed. As a result, an array of json object containing all the categories is returned. Each category object includes all the properties defined in Mongoose schema like name, timestamps and auto generated ID.

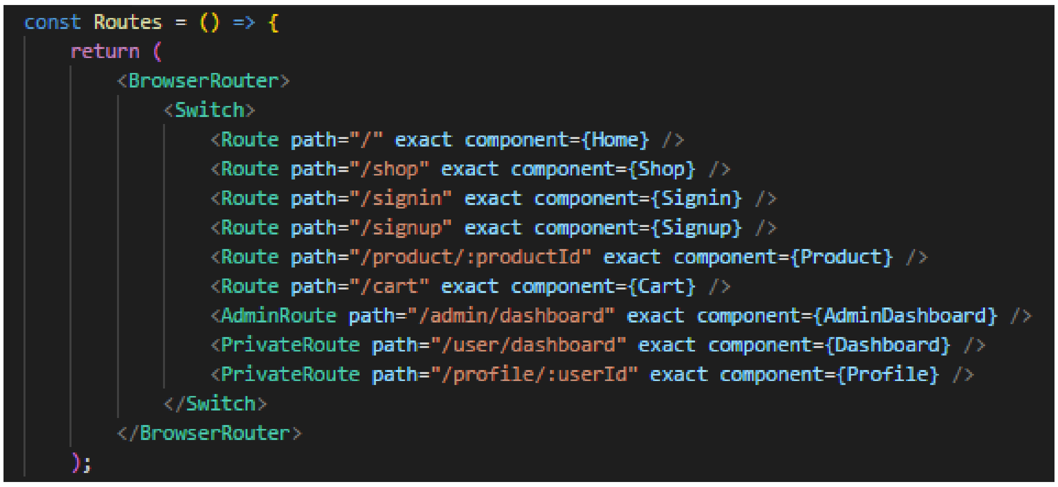
3.2.2 Front-end development

3.2.2.1 Basic setup and Routing

Unlike back-end is performed with multiple technologies, front-end development is handled by only React.js. It is not impossible to set up a React application from scratch, but this process includes of many intimidating and time-consuming steps, such as setting up Babel to convert JSX to compatible JavaScript that old browser can understand and configuring Webpack to bundle all the modules. Fortunately, Facebook has developed Create React App node module for quickly scaffolding a React template, which saves developers from all those complicated configurations. Create React App not only generates a boilerplate with core structure for a React application but also takes care of some build script and development server.

After running command ‘npx create-react-app’ to generate a template, bootstrap – the most popular CSS framework is added to minimize styling tasks from scratch since the author want to focus on the development part using MERN stack.

Then Routes.js file is created with the sole purpose of including all the route paths with their corresponding components by using a package called react-router-dom. Route component is then rendered by ReactDom as the root component of the application.



```
const Routes = () => {
    return (
        <BrowserRouter>
            <Switch>
                <Route path="/" exact component={Home} />
                <Route path="/shop" exact component={Shop} />
                <Route path="/signin" exact component={Signin} />
                <Route path="/signup" exact component={Signup} />
                <Route path="/product/:productId" exact component={Product} />
                <Route path="/cart" exact component={Cart} />
                <AdminRoute path="/admin/dashboard" exact component={AdminDashboard} />
                <PrivateRoute path="/user/dashboard" exact component={Dashboard} />
                <PrivateRoute path="/profile/:userId" exact component={Profile} />
            </Switch>
        </BrowserRouter>
    );
```

Figure 21. A screenshot of Routes.js file, with BrowserRouter wraps around Switch and Route

Figure 21 summarizes all the route paths and the component to be render when that route is accessed. For example, any kind of user can go to public route like '/shop' to access Shop component, but only authenticated user can see Dashboard or Profile component as they are protected routes.

There is a total of three main types of components in React Router:

- routers, like <BrowserRouter> and <HashRouter>
- route matchers, like <Route> and <Switch>
- navigation, like <Link>, <NavLink>, and <Redirect>

Router component is the wrapper of React Router application. BrowserRouter is mainly used for web-based projects. Router component must be rendered as the root element.

Switch and Route are route matchers. When a <Switch> is rendered, it finds the <Route> element whose path is similar to the current URL. When a <Route> is found, it renders that <Route> and ignores the rest. This means <Route> with more specific (usually longer) paths should be written before less-specific ones [38.].

One essential thing to consider when setting up Route is that a Route path matches the beginning of the URL, not the whole URL. Therefore a <Route path="/"> will match every URL. That is why <Route> should be located last in the <Switch>, otherwise <Route exact path="/"> can be used to match the whole URL.

3.2.2.2 User Authentication

Sign up Component

Although some main pages of this application like Home page, Shop page do not require the user to sign up in order to enhance user experience, if users want to make a purchase, they have to sign up and log in to their account first. Below is a simple user interface to sign up new users.

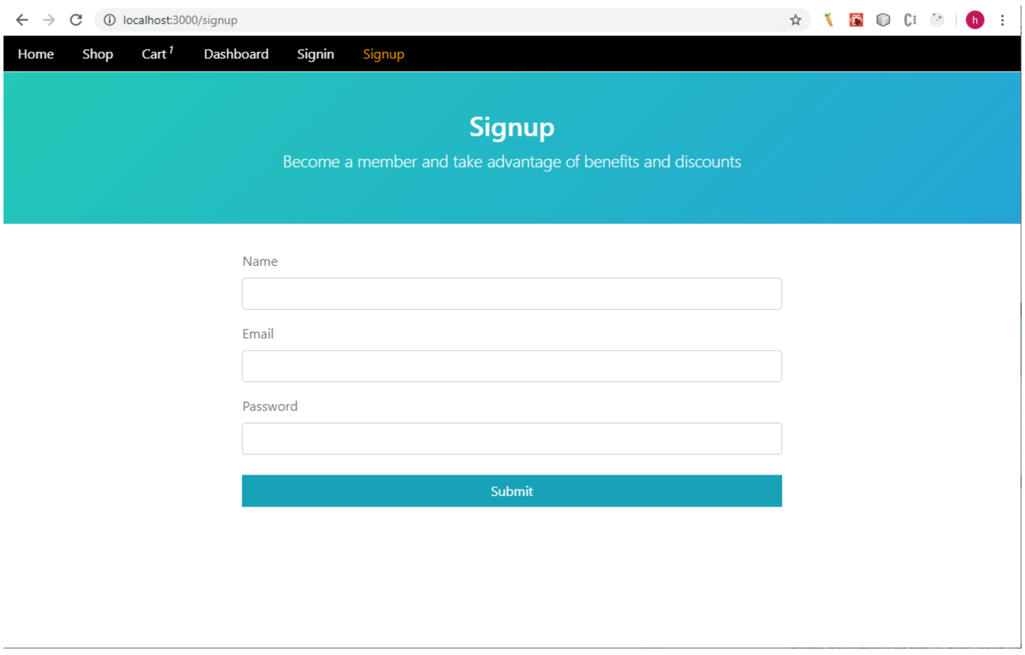


Figure 22. A screenshot of the Signup page

Figure 22 displays a web page with shared navigation bar and layout. Right below is the signup form which includes some inputs for name, email and password with a submit button. Bootstrap class 'form-group' is applied to facilitate these styling tasks. In this component, beside the state of each input field there are error and success state which determine if some alerts should be shown up when user fail or succeed to sign up.

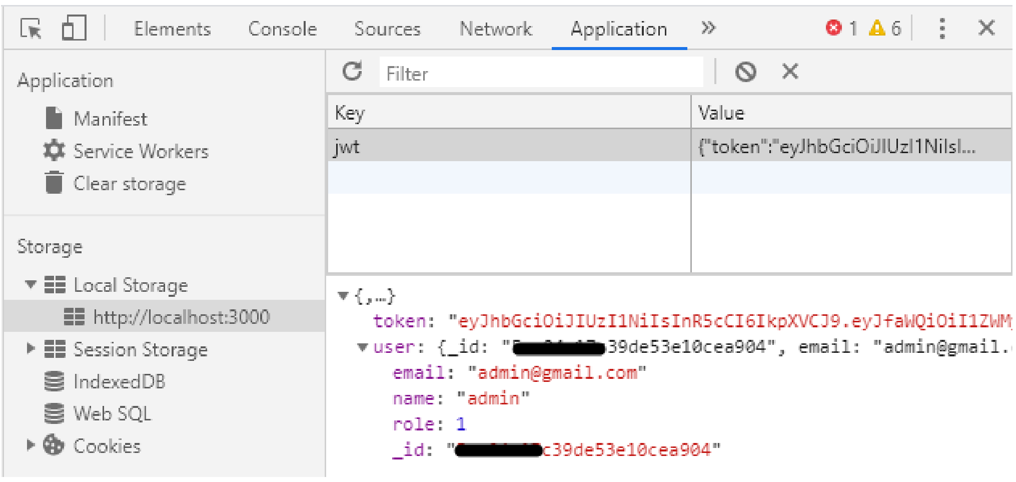
Given the user put in correct data and press submit, fetch method is used to send a POST request with user data under json format in the body to the back-end API 'api/sig-nup'. After validation process, a new instance of user model is created based on req.body and is saved into the database. The server then returns a json file containing user data without hashed password back to the client. Finally, a success alert is shown up and is redirecting the user to the sign in page.

Sign in Component

The sign in component is quite similar to the sign up one except the data flow when the user press submit button. As summarized in chapter 3.2.1.3, after the server handled the POST request from the client, a token is signed and sent back to the client along with user information. Those data then are passed to authenticate function and stored in the local storage as jwt.

```
export const authenticate = (data, next) => {
    //check if we have window obj
    if (typeof window !== undefined) {
        localStorage.setItem('jwt', JSON.stringify(data))
        next();
    }
};

export const isAuthenticated = () => {
    if (typeof window == undefined) {
        return false;
    }
    if (localStorage.getItem('jwt')) {
        return JSON.parse(localStorage.getItem('jwt'));
    } else {
        return false;
    }
};
```

Listing 6.   A snippet code to store user information in local storage.



Key	Value
jwt	{"token":"eyJhbGciOiJIUzI1NiIsI...

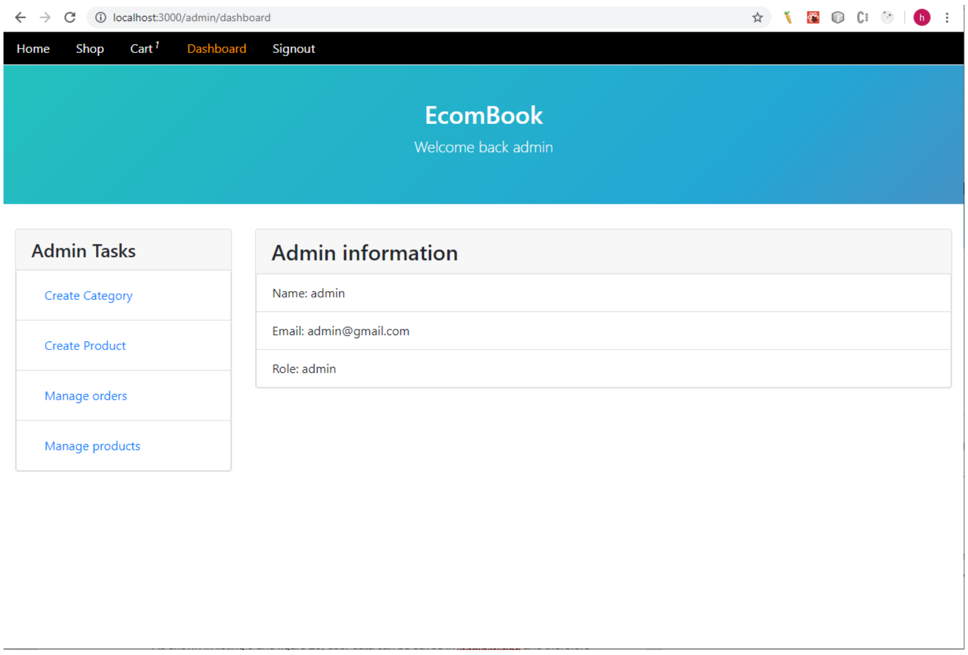
```
▼{,…}
  token: "eyJhbGciOiJIUzI1NiIsInR5cCI6IkpXVCJ9.eyJfaWQiOiI1ZWM
 ▼user: {_id: "[redacted]39de53e10cea904", email: "admin@gmail.
    email: "admin@gmail.com"
    name: "admin"
    role: 1
    _id: "[redacted]c39de53e10cea904"
```

Figure 23. A screenshot of Local Storage

As shown in listing 6 and figure 23, user data can be saved in local storage and therefore can be retrieved from there. By using JSON.parse(), user data is converted from json string back to JavaScript object and can be used to find out the user role (user or admin). Based on that signing the user in to the corresponding dashboard.

3.2.2.3 Dashboard Component

Admin Dashboard



Name: admin

Email: admin@gmail.com

Role: admin

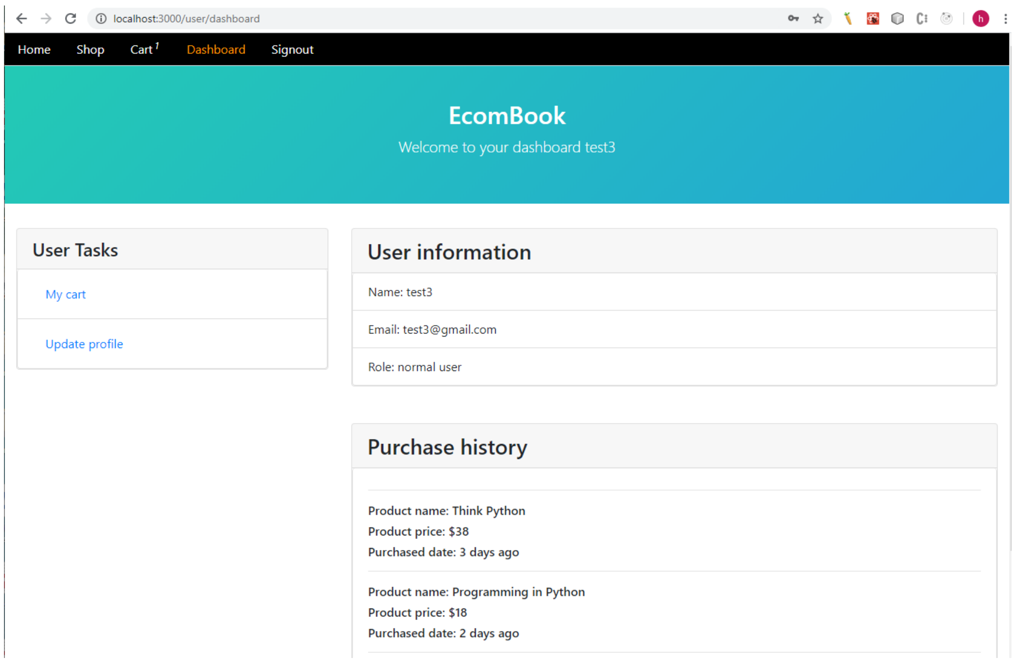
Figure 24. User interface of Admin Dashboard

Admin dashboard is accomplished with this component as can be seen in figure 24. It consists of 2 section elements which both applies Bootstrap class Card. All admin information is shown on the right side while some admin actions like creating category and product, viewing and managing order are on the left. By clicking on tasks link, admin will be navigated to the matching component where he/she can create a category or a product. The admin also has the ability to view orders and manage them, for example setting the order status from processing to shipped or delivered. Moreover, ManageProduct component enables the admin user to modify products or even delete them from the database.

User Dashboard

Generally, the user dashboard component is quite similar to the admin one. Since the user have less power than an admin, there is fewer actions for a user to perform.

Checking out in the Cart page or updating their profiles are the two only user's tasks, as visualized in figure 25.


localhost:3000/user/dashboard

Home Shop Cart 1 Dashboard Signout

EcomBook

Welcome to your dashboard test3

User Tasks

My cart

Update profile

User information

Name: test3

Email: test3@gmail.com

Role: normal user

Purchase history

Product name: Think Python
Product price: $38
Purchased date: 3 days ago

Product name: Programming in Python
Product price: $18
Purchased date: 2 days ago

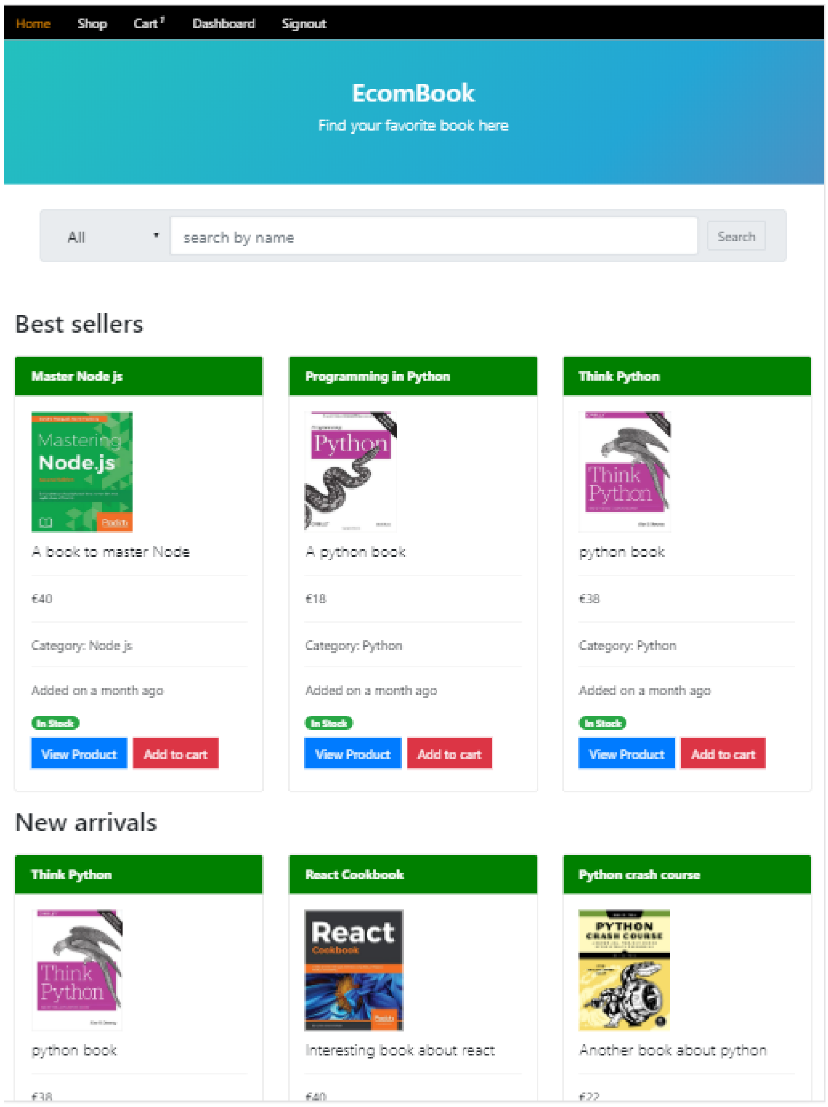
Figure 25. User interface of User Dashboard

Unlike admin dashboard, user's purchase history is presented under his/her personal information. This list provides a precise look of order history, such as product name, price and the time it was performed.

3.2.2.4 Home Component

UI Description

Home page, which is the main page of this application is demonstrated by Home component. This component is accessible through a public empty URL. It plays an important role in an e-commerce application.



Best sellers

Master Node js
A book to master Node
€40
Category: Node js
Added on a month ago
In Stock
View Product
Add to cart

Programming in Python
A python book
€18
Category: Python
Added on a month ago
In Stock
View Product
Add to cart

Think Python
python book
€38
Category: Python
Added on a month ago
In Stock
View Product
Add to cart

New arrivals

Think Python
python book
€38

React Cookbook
Interesting book about react
€40

Python crash course
Another book about python
€22

Figure 26. User interface of Home component

An overview of the Home page is described in figure 26. Some of the most fundamental functionalities of an e-commerce application are shown in this component. As can be seen, there are 2 lists of products. One is for best sellers, which are those products with highest sold property, the other is new arrivals, meaning that the createdAt property is closest to the current time. Each product is presented by a Card component which applies a Bootstrap class called ‘card’. The card header shows the product name while other information like product image, price, category, timestamps are set in the card body. In stock feature depends on the quantity property of each product. In the end comes 2 buttons for user to view each product in detail and to add to cart for payment and purchase. There is also a search engine rendered by the Search component on top of the page right below the shared layout. Here user can search product based on category and by text in name.

Logic and Data Flow

```
const Home = () => {
    const [productsBySell, setProductsBySell] = useState([]);
    const [productsByArrival, setProductsByArrival] = useState([]);
    const [error, setError] = useState(false);

    const loadProductsBySell = () => {
        getProducts('sold').then(data => {
            if (data.error) {
                setError(data.error)
            } else {
                setProductsBySell(data)
            }
        })
    }

    const loadProductsByArrival = () => {
        getProducts('createdAt').then(data => {
            if (data.error) {
                setError(data.error)
            } else {
                setProductsByArrival(data)
            }
        })
    }

    useEffect(() => {
        loadProductsByArrival()
        loadProductsBySell()
    }, [])
```

Listing 7. A snippet code of Home component

As can be seen in listing 7, when Home component is mounted Effect Hook is called to perform some side effects like fetching data, setting up a subscription or changing the DOM, in this case is fetching product data by running 2 functions loadProductsByArrival and loadProductsBySell. By default, Effect Hook runs after every render or update, even the first one. An empty array is passed as the second argument to tell React that this effect only needs to run once because it does not depend on any state or props. Then getProducts is executed with 2 different sorting method as parameter to send a GET request to the back-end API. Server returns all the best seller and new arrival products as json object to the client. Component local state is set by setState function after that and finally, array of products is looped through map function to render multiple Card components. Each Card takes a product as its props as listing 8 describes below:

```
<div className="row">
     {productsBySell.map((product, index) => (
          <div key={index} className="col-4 mb-3">
               <Card product={product} />
           </div>
      ))}
</div>
```

Listing 8. A snippet of code to render an array of Card components

With the search engine, user is required to type in a text string, otherwise pressing search button does not trigger anything. When user has provided valid input and clicked search button, an object containing search criteria is passed to query-string Node module to generate a text string query, followed by an API request with that query to the server. Query string is then analyzed and passed to database query function to look for appropriate products. The rest of the data flow is similar to Home component as the server response with those products and React render Card component based on them.

3.2.2.5 Shop Component

A shop page enables user to sort products based on category and price.

UI description

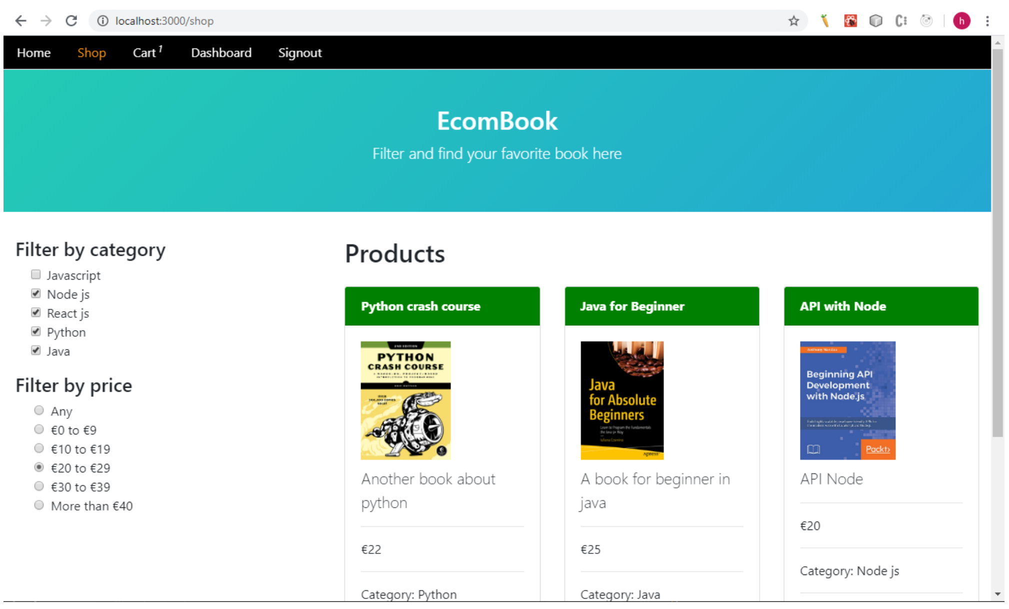


Figure 27. User interface of Shop component

Figure 27 illustrates the Shop component with shared layout and a navigation bar like other pages, followed by some filter features on the left side and filtered results on the right side of the page. Card component is again utilized to render products. Category filter is handled by checkbox component while price filter is presented by radio-box component.

Logic and Data Flow

Firstly, when a user selects an input from the checkbox, handleToggle method is triggered with an argument of that selected category ID. This function finds the index of that selected category in the state array (checked state) and checks if it is already there. If not, add that category to the array as the user is looking for that one. On the other hand, remove that category from the array as the user does not want that type of products. This Checked array which includes all selected category IDs is then updated and passed to the parent component-Shop component. Here is where an API request is called to the server with an object containing 2 array, category ID and price range values. Finally, client updates the user interface immediately when it receives the response from back-end server. Listing 9 in the following shows all steps before checked state is passed to Shop component.

```
const Checkbox = (props) => {
    const { categories, handleFilters } = props;
    const [checked, setChecked] = useState([]);
    const handleToggle = (catId) => () => {
        const indexOfCheckedCate = checked.indexOf(catId);
        //clone an array es6
        const ArrayOfCateId = [...checked];

        if (indexOfCheckedCate === -1) {
            ArrayOfCateId.push(catId)
        } else {
            ArrayOfCateId.splice(indexOfCheckedCate, 1)
        }
        setChecked(ArrayOfCateId);
        handleFilters(ArrayOfCateId);
    }
    return (
        <ul>
            {categories.map((cat, index) => (
                <li key={index} className='list-unstyled' >
                    <input
                        onChange={handleToggle(cat._id)}
                        type="checkbox"
                        className='form-check-input'
                    />
                    <label className='form-check-label'> {cat.name}</label>
                </li>
            ))}
        </ul>
    )
}
export default Checkbox;
```

Listing 9. Checkbox component

3.2.2.6 Cart Component and Payment Gateway

UI Description

Cart page is the last page users have to go through to get the purchase done. Beside some common shared components, there are a Card component which renders the product that users want to buy and a check-out component that demonstrates the total amount, delivery address and a form to fill in with payment information. This Card component inside Cart is slightly different than the one in Home or Shop component. It has a remove button to delete the product from the cart and an input field where users can increase or decrease the quantity of product in the end. Cart component is visualized clearly in figure 28 below

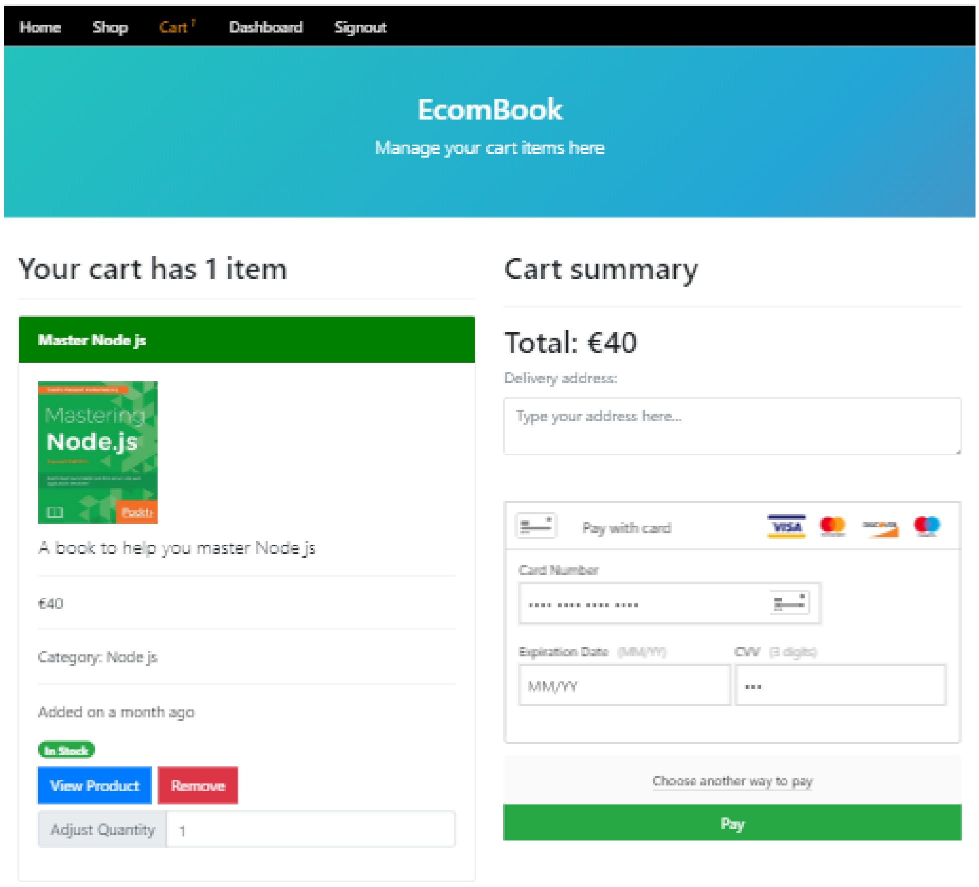


Figure 28. User interface of Cart component

Logic and Data Flow

When a user clicks Add to cart button on a specific product, that product item will be added to the local storage. Then the user is redirected to this Cart page. Local storage is utilized to store cart data so that the data will not be lost every time the user refresh the page. Cart data stays in local storage until it is removed or after the purchase is handled successfully.

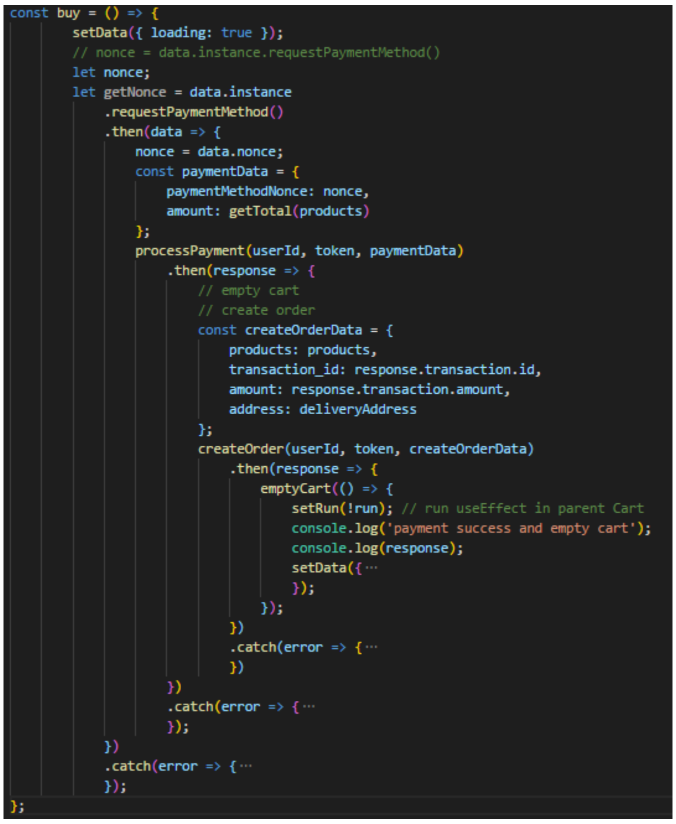
To implement and test payment gateway, a test environment which is almost equivalent to production environment – Braintree sandbox is installed. Braintree supports credit card and PayPal, two of the most popular and emerging payment methods. Firstly, Braintree module is installed in the back-end server so that it can generate a token which is necessary to perform Braintree in the client as described in listing 10.

```
exports.generateToken = (req, res) => {
    gateway.clientToken.generate({}, function (err, response) {
        if (err) {
            res.status(500).send(err);
        } else {
            res.send(response);
        }
    });
};
```

Listing 10. generateToken method is executed when calling API request to Braintree

As soon as Checkout component is mounted, Effect Hook initiate a function which send an API request to tell the server to create a token for the client. When the token is available with at least 1 product item in the cart, a payment method is shown based on Dropin, which is imported from the package ‘braintree-web-drop-in-react’.

After all input are filled with valid data, the user clicks pay button to complete the transaction and create an order in the database, followed by a removal of cart in the local storage and an alert informing successful payment as shown in figure 29.



```
const buy = () => {
        setData({ loading: true });
        // nonce = data.instance.requestPaymentMethod()
        let nonce;
        let getNonce = data.instance
            .requestPaymentMethod()
            .then(data => {
                nonce = data.nonce;
                const paymentData = {
                    paymentMethodNonce: nonce,
                    amount: getTotal(products)
                };
                processPayment(userId, token, paymentData)
                    .then(response => {
                        // empty cart
                        // create order
                        const createOrderData = {
                            products: products,
                            transaction_id: response.transaction.id,
                            amount: response.transaction.amount,
                            address: deliveryAddress
                        };
                        createOrder(userId, token, createOrderData)
                            .then(response => {
                                emptyCart(() => {
                                    setRun(!run); // run useEffect in parent Cart
                                    console.log('payment success and empty cart');
                                    console.log(response);
                                    setData({⋯
                                    });
                                });
                            })
                            .catch(error => {⋯
                            })
                    })
                    .catch(error => {⋯
                    });
            })
            .catch(error => {⋯
            });
};
```

Figure 29. A screenshot of buy function to perform transaction

4 Discussion

This section illustrates the evaluations of the e-commerce web application. There is also an in-depth discussion about possible improvements that can be done in the future.

4.1 Application Evaluation

In the end, a prototype version of the e-commerce application simulating an online bookstore was developed successfully with the aid of 4 main technologies in the MERN stack along with numerous other Node modules. This application is easy to use and user-friendly as it takes only a couple of clicks from the Home page to get the purchase done. Users can sign in, edit their profiles, check purchase history and the most important feature – to search for their favorite book and pay for it. This application offers 2 type of product filtering, the first one is based on a search engine which takes user input and the other one is dependent on category and price of the products. Admin users have all the same functionalities, added some more features such as creating product and managing orders. Payment gateways also works well as it is already tested in sandbox account.

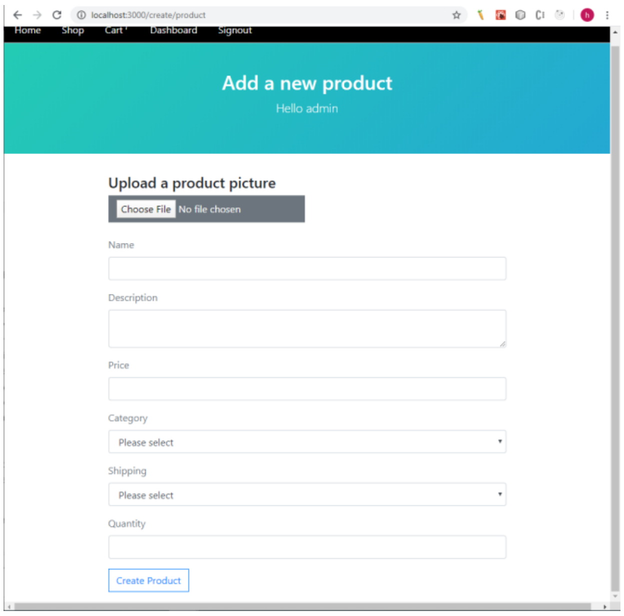
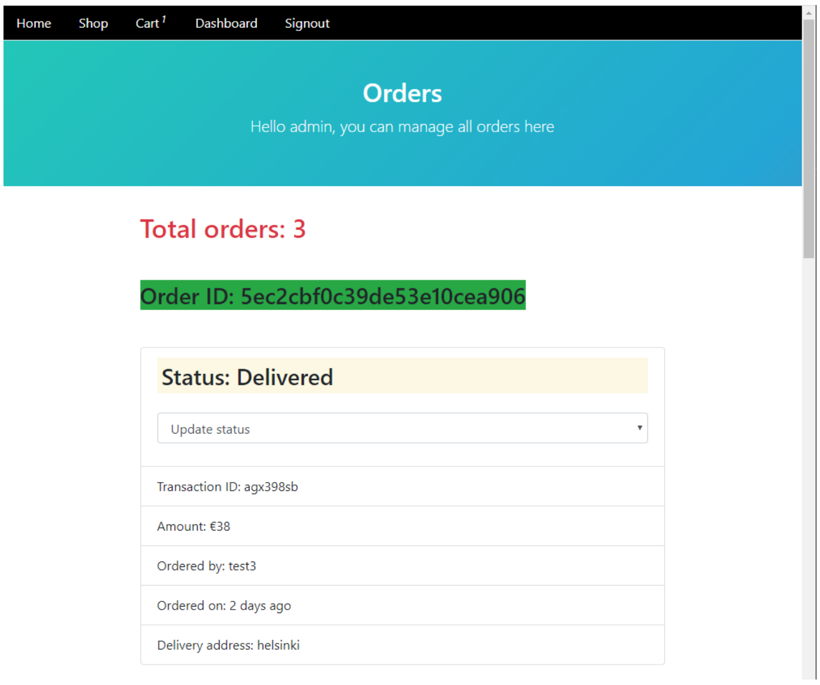


Figure 30. User Interface of Add-product component

Figure 30 provides a view of add-product page, which is only accessible by admin user. Beside text field, there have also 2 dropdowns option to choose category and shipping method and a form to upload a book picture.

User orders are saved in the database and are rendered as soon as the Order component mounted. Each order contains all the user information and its status can be updated by the admin as can be seen in figure 31.



Total orders: 3

Order ID: 5ec2cbf0c39de53e10cea906

Status: Delivered

Transaction ID: agx398sb

Amount: €38

Ordered by: test3

Ordered on: 2 days ago

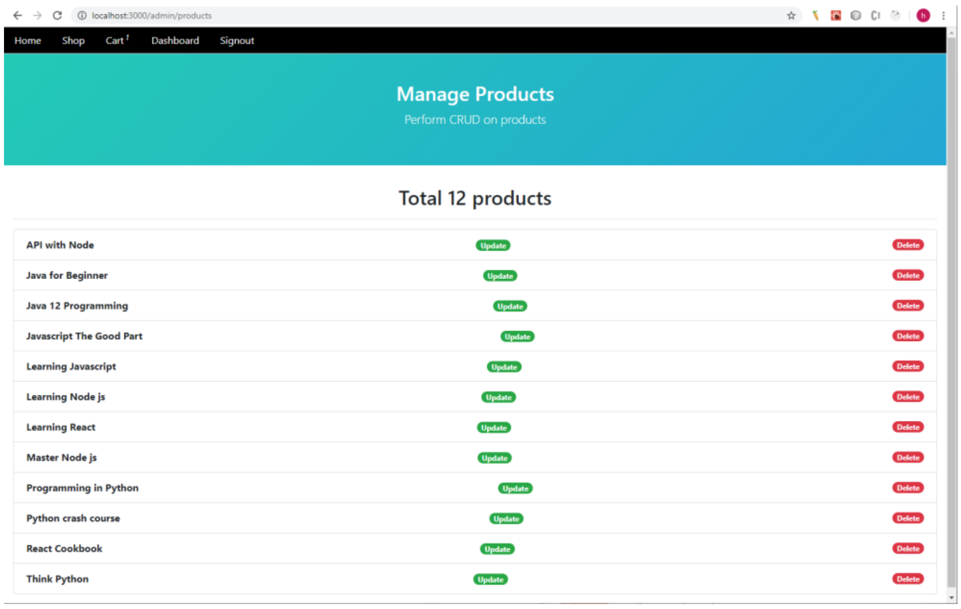
Delivery address: helsinki

Figure 31. User interface of Order component

Generally, the outcome application achieved all the requirements in case of functionality for an end-to-end e-commerce application which is visualized from the beginning and it aims to be suitable for small businesses such as an online bookstore.

4.2 Further Improvement

Although this application meets all the feature requirements as planned, there are still some aspects needed to improve. Concerning the Manage Product page in figure 32, the main improvement would be some CSS styling as the update button are in a mess. Color design should also be taken into account to enhance the user experience.



localhost:3000/admin/products

Home Shop Cart 1 Dashboard Signout

Manage Products

Perform CRUD on products

Total 12 products

API with Node	Update	Delete
Java for Beginner	Update	Delete
Java 12 Programming	Update	Delete
Javascript The Good Part	Update	Delete
Learning Javascript	Update	Delete
Learning Node js	Update	Delete
Learning React	Update	Delete
Master Node js	Update	Delete
Programming in Python	Update	Delete
Python crash course	Update	Delete
React Cookbook	Update	Delete
Think Python	Update	Delete

Figure 32. User interface of ManageProduct component, where admin can update or delete a product. It also shows the total number of products in the database.

Despite of all the fundamental and useful implemented functionalities in the application, these features in the following list can be considered for further development:

- User sign up using Gmail or Facebook
- Email notification after successful payment
- Each product has a review and rating section

Eventually, in order for this e-commerce application to switch from development mode to production mode, testing and deployment have to be handled appropriately as the development process may have some unseen bugs.

5 Conclusion

The goal of this thesis was to study different characteristic of each technology in the MERN stack and develop a full-stack e-commerce web application based on it. It took the author a considerable amount of time to research and study in-depth each modern technology in order to carry on the web application. All the technologies that comprises of the MERN stack were discussed precisely, from fundamental concepts to advanced features as well as their usage in the application to ensure the reader understand about this paper. The thesis also provided all the steps needed in the development process to implement an e-commerce application.

The application was successfully developed at the end. A fully functional end-to-end e-commerce application featuring an online bookstore was released and aimed to help the startup develop their business strategy in general. This application was meant to solve the problem that is mentioned in the first section of this thesis: to help the book retailer startup become more widely known and gain more potential customers. People and book lovers also have one more source to expand their knowledge.

Overall, the thesis can be used as a tutorial or documentation of the MERN stack in particular or full-stack web development in general. By researching and studying this paper, the author gained much more useful knowledge and understood why MERN stack is rising its popularity and plays a leading role in web development recently. Although the application still has some drawbacks and needs more further improvements, both in styling issue and new features, it is a combination of one of the most widely used web stack technology with one of the most emerging business ideas nowadays – ecommerce.

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