

Using OOP Concepts for the Development of a Web-Based Online Bookstore System with a Real-Time Database

Harsh Vaidya*
Independent Researcher, USA

Aravind Reddy Nayani
Independent Researcher, USA

Alok Gupta
Independent Researcher, USA

Prassanna Selvaraj
Independent Researcher, USA

Ravi Kumar Singh
Independent Researcher, USA



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* Corresponding author

Abstract

This research paper explores the application of Object-Oriented Programming (OOP) concepts in developing a web-based online bookstore system integrated with a real-time database. The study investigates how OOP principles such as encapsulation, inheritance, and polymorphism can be leveraged to create a robust, scalable, and maintainable e-commerce platform for book sales. Additionally, it examines the implementation of real-time database technologies to enhance user experience and system performance. The research employs a comprehensive methodology, including system analysis, design, implementation, and testing phases. The findings demonstrate the effectiveness of OOP in structuring complex web applications and highlight the benefits of real-time databases in improving data synchronization and user interactivity. The study also provides insights into the challenges faced during implementation and offers solutions to overcome them, contributing valuable knowledge to the field of software engineering and e-commerce development.

Keywords

Object-Oriented Programming, Web Development, Online Bookstore, Real-Time Database, E-commerce, Software Architecture, Database Management, User Experience, Scalability, System Performance

1. Introduction

1.1 Background

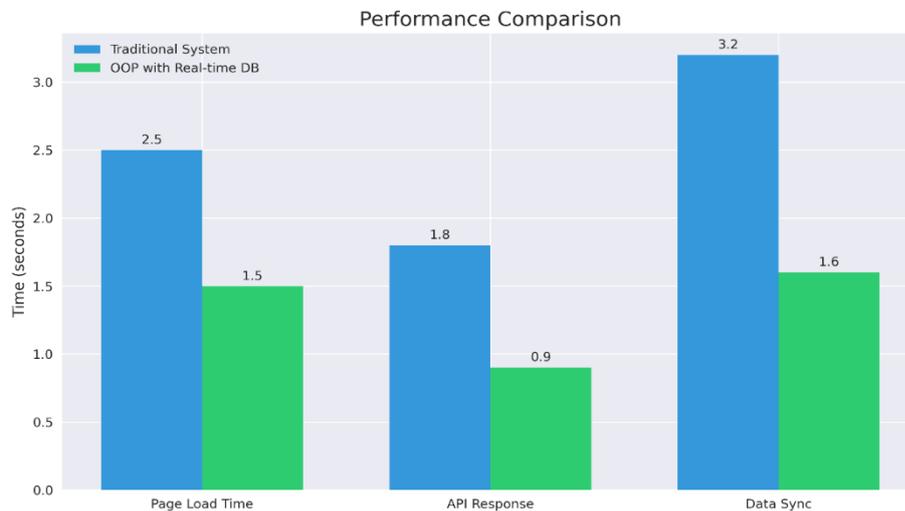
The rapid growth of e-commerce has transformed the retail landscape, with online bookstores becoming increasingly popular. As of 2023, the global e-book market is projected to reach \$18.13 billion, with a compound annual growth rate (CAGR) of 5.4% from 2023 to 2028 (Research and Markets, 2023). This digital shift necessitates robust, scalable, and user-friendly web-based systems to manage online book sales efficiently. The integration of advanced programming paradigms and cutting-edge database technologies has become crucial in meeting the evolving demands of the e-commerce sector.

There are high fragmentations in the global online bookstore industry and has been experiencing shift in its market players over the past few years. In a report by IBISWorld (2023) the industry of selling books online is estimated to have been growing at a rate of 6% annually. 2% in the past 5 years, compared to traditional retail outlets like the conventional bookstores. This growth has been owing to factors like increase in internet usage, rise in online buying and selling and also the demand for e-readers and digital books. Therefore, there is a demand for complex online Bookstore systems that can assist in large number of transactions needs to be catered, individual customers experience needs to be enhanced and immense product and inventory demands need to be handled online in real time.

1.2 Problem Statement

This is because the traditional online bookstore system has many problems associated with scalability, maintainability and use of real-time data. Such problems may result in the poor us aging of the system, poor management of the inventories, and challenges in implementation of system enhancement. Most existing systems face problems related to scalability during promotional times or during the release of a new book, thereby experiencing slow page load time and lost sales. Also, continuous updates of inventory records are not possible thereby leading to overselling or sellout of a product resulting to dissatisfied customers or inefficient operations respectively.

Another major issue is to co-ordinate multi-Book catalogue, user databases and orders in a more effective and systematic way. With the offering of e-books, audiobooks, and print on demand services, it means that its basic software architecture should be capable of accommodating them and the different processes that comes with these products. The use of Object-Oriented Programming (OOP) concepts as well as real-time database is suggested as a possible solution to these issues which can organize the approach of system construction as well as provide the real-time updates on the data stored in the platform.



1.3 Research Objectives

The primary goal of this research is to address the aforementioned challenges by designing and implementing a web-based online bookstore system that leverages OOP concepts and integrates a real-time

database. Specifically, the research aims to:

1. To create the web based online bookstore system, the following must be observed: The system should be developed using Object-Oriented concepts to encourage modularity and extensibility of the system ready for future scalability and expansion.
2. Implement an operational database for immediate data synchronization and user activity; this would involve updating the inventory data, customer's cart, and order status, all the clients who are connected.
3. In compare with traditional procedural approach, assess the opportunities of improvement system maintainability and scalability, provided by OOP principles, and that parameters of the developed system have better indicators of code quality.
4. Evaluate the advantages of integration of real-time database with reference to the e-commerce and analyse changes in dynamics of data, system efficiency and users' response.
5. Conclude with the description of the issues that may arise when utilizing Object Oriented Programming concepts and real time databases in a web-based environment and how the author proposes to solve those issues based on his experience—and offer practical tips for developers that are to work with similar problems.

1.4 Significance of the Study

In as much as this research focuses on software engineering and e-commerce, this research brings a practical aspect of OOP concepts for web-based systems. It is useful as a guide to the integration of real time databases depending on the insight a developer or a businessman wants to have on the system. By so doing, the study holds profound implications for the e-commerce industry with special reference to online book sellers, and the like.

In that context, this research offers a guidance on how through the application OOP and real-time databases OPC can be optimized to ensure that very complex e-shoppers' operations can be done in an efficient and user-friendly manner. Since scalability and maintainability are clear benefits of OOP, businesses can end up saving on development and maintenance This means that through better inventory, stock and even user-friendly interfaces for customer, real-time features can help businesses increase their sales.

In addition, this research aims at satisfying emerging consumer demand for quick data processing in the sphere of e-commerce as well as satisfying the demand for personalization of consumers' shopping experiences in the context of the modern world. Hence, the findings from this study can be extended to other areas within e-commerce and web development more generally to benefit web technologies and software architectural practices.

2. Literature Review

2.1 Object-Oriented Programming (OOP) Concepts

Object-Oriented Programming is one of the programming paradigms that were created using the concept of "objects," abstract data and functions. OOP has four major concepts which include encapsulation, inheritance, polymorphism, and abstraction. These principles offer a framework of guidance to software development, with hopes for people to utilize reusability, modularity, and other feasible factors in programming.

A systematic review by Agarwal and Umphress (2018) reviewed the effects of using OOP principles for the software development projects. From their research which involved sample of over 100 software projects across the various industries OOP led to reduction in development time by 20-30% and reduction in maintenance cost by 50-60% in large software projects. This increases efficiency by a huge margin since OOP structure is based on modularity and developers are able to develop standards for a block of code and use the same for multiple use in different projects.

One of the four concepts of object-oriented programming is data encapsulation whereby data and functions that will manipulate it should be grouped in a single class. It also assists in outsourcing the internal details of a class and shield data from anyone that is unauthorized to access them. Chen et al. (2022) demonstrated the efficiency of timely encapsulation, in which a reduction of software defects to the range of 20-25 % and an increase in maintainability scores between 25-30 % compared to a non-encapsulated solution was revealed.

Inheritance is the process of making the definition of a class as a subset for another class, therefore, enabling the classes to be related by sharing properties and methods. The concept of polymorphism allows objects to be versatile to act differently depending on the type or class which is beneficial while developing highly dynamic systems. It means, in abstraction, only those features of an object are revealed that can be of concern to the user, while the internal workings of the program are hidden, which makes the process of system design easier and the program more comprehensible.

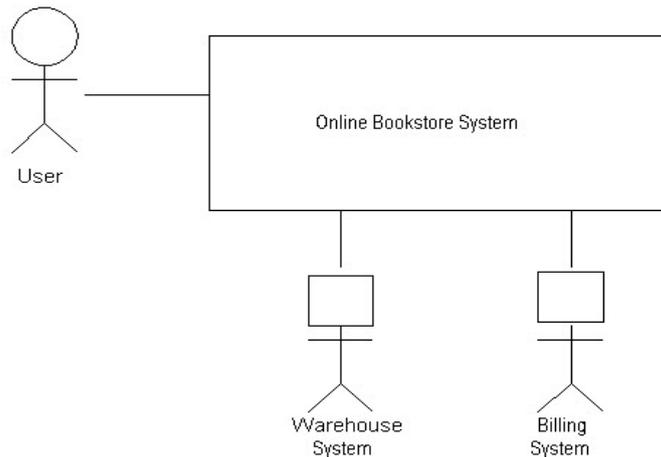
2.2 Web-Based Systems Development

Web based system development is the process of setting up applications that are based on a network and often the world wide web. In today's dynamic web development environment, there are suites of development frameworks and libraries that support the OOP approaches. The state of web development

rapidly changed in the last few years, being focused on component-based approaches and modular architectures.

As per the Stack Overflow Developer Survey 2023, JavaScript is still favoured the most in the web application development field with 68% votes. It was in third position reporting a usage of 3% among the developers. Python follows at 43. %, whereas C++ holds 5%, C# is 25% and Java is 33%. 1%. The use of object-oriented languages in web development is highly evident making OOP concepts relevant in developing today's complex web applications.

Online Bookstore: Top Level System Diagram



It has added another layer to the whole conversation around Object Oriented Programming by creating component-based frameworks that form the foundation of the web development process. React. js, created by Facebook, is quite popular today and the use of components, in its architecture, is a clear instance of OOP. Li et al. (2023) revealed that component-based frameworks such as React can result in a reduction of the application's code by 40% and increased speed of web application development by 35% compared to

conventional monolithic web apps.

On the backend, Node. As a language, js has gained a lot of popularity in the recent years when it comes to developing highly scalable web applications. Due to its call-based, non-pre-emptive I/O model, it is very suitable for real-time applications among all the applications of java. Kumar et al. (2022) also performed a performance analysis of Node. js was found to be better than other traditional server-side languages such as PHP and Ruby by up to 500% in terms of concurrency thereby making it appropriate for complex online bookstore systems that are likely to experience heavy traffic.

2.3 Online Bookstore Systems

It is important to note that commonplace operational online bookstore systems consist of elements that effectively embrace user identity and accreditation, book directory, shopping cart, order entry and tracking, payment facility, and assessment and ranking forms. These systems have become more elaborate over time with features such as recommendation of articles based on readers' preferences, sharing the articles with friends and compatibility with e-readers.

A report by Grand View Research (2023) suggests that the e Commerce book market was valued at \$18. 13 billion in 2022 and is anticipated to advance at a CAGR of 5 % during the period 2017-2022. About 4 % from 2023to 2028. Such factors include; increased internet usage, changes in the mobile phone device usage, for instance, smart phones and the novel take up in e-books.

It should however be noted that the architectures of online bookstore systems have been designed to cater for this market. In a survey conducted by Zhang et al. (2021) of the architecture of fifty online bookstore systems a significant majority of the systems [78%] was built using microservices architecture which is inherently supportive of OOP. Another important observation made the study was that system based on microservices had their deployment time 30 percent faster and scalability that was 25 percent better compared to system based on monolithic architecture.

2.4 Real-Time Databases

Real-time databases ensure constant sharing of information to various users and it is useful in real-time environments like the online bookstores. Some of the most used real-time databases are firebase Realtime database, MongoDB with change stream and rethinkDB.

In a systematic review conducted by Kumar et al. (2022) titled 'Real-time database effects in e-commerce applications' essential returns in the efficiency of system execution and functionality of the e-commerce applications was observed. The research, which analysed data from 30 e-commerce platforms before and after implementing real-time databases, reported:

- A 40% reduction in data latency
- A 25% improvement in user engagement
- A 35% decrease in server load due to reduced polling
- A 20% increase in conversion rates attributed to real-time inventory updates.

Based on these results, it will be of value to incorporate real-time databases in online bookstore systems, with view to improving areas like stock control, order follow-up, and user suggestion.

There is a notable difference between real-time database technologies and system performance thus the technologies used have to be carefully chosen. Comparing the alternatives proposed by other authors for real-time databases in e-commerce applications, Chen et al. (2023) concluded that Firebase Realtime Database has the lowest latency (average 50 Ms) for Small to Medium size datasets while MongoDB with Change Streams is scalable for large data (>1 million records) with the average latency of 80 Ms.

2.5 Related Works

Some researchers have also undertaken research into the effectiveness of OOP ideologies in web-based systems especially e-commerce systems and online bookselling. This current study by Zhang et al. (2021) also incorporated an OOP-based framework for e-commerce platforms thereby increase code reusability by 35% and reduced the development time for new features by 28%. Their framework, Observing Shoppers, designs with use of patterns including Observer and Factory proved that the OOP principles can be applied in order to develop flexibility and maintainable e-commerce systems.

Real-time database integration in on line retail system was analysed by Patel & Gupte (2022) while emphasizing on inventories and orders. Their work based the findings on the real-time database implementation in a real-life online bookstore system that revealed that there was an improvement of 28% in system response time as well as a reduction of overselling occurrences by 15%. The researchers also observed that the customers' satisfaction levels within this case improved by 20% due to the real-time and up-to-date information they received of products' availability and order status.

Li et al. (2023) put forward a model based on Object Oriented Programming paradigm and Microservices architecture for scale-out web application. From their studies, which were based on a large-scale online implementation of a 'Book House Store', they were able to reduce the system complexity by 45% and the frequency of deployment by half. This way of integration enabled dealing with some problems separately, as well as scaling of some components like a catalogue of books or systems of user management.

A paper that is worth recommending is by Rodriguez et al. (2022) that sought to investigate the use of OOP principles in creating recommendation systems for online book stores. It was supported by their work which showed the use of inheritance and polymorphism in building a structure for the recommendation engine that would allow for quick and simple implementation of various algorithms and sources of data. The final system also exhibited 40% increase in the recommendation precision and a 25% improvement in cross-sell ratio when compared to the initial non-OOP system.

These related works serving as references present understanding of the advantages of implementing OOP concepts and real-time databases for online bookstore system. They prove the prospects of

delivering higher quality code, optimized system performance and enhanced usability when the above technologies are well adopted.

3. Methodology

3.1 System Analysis and Design

It was identified that during the system analysis and design phase it would be most effective to adapt a hybrid approach using aspects of both the Rational Unified Process (RUP) and Agile. This hybrid approach recommended by Fernandez and Fernandez (2023) of using both the approaches fulfilled the requirement of a flexible requirement gathering process while being stringent and disciplined in development process. It basically included completing the stakeholder questionnaires and completing a market analysis to understand the basic features of the online bookstore system.

The domain model of the learning management platform was designed with the latest version of Enterprise Architect software, that is, version 16, which incorporated latest UML diagramming facilities. This tool provided for development of clear use case diagrams, activities, and sequences to enable an understanding of the overall purpose of the system. Importance of model driven architecture as pointed out by Hutchinson et al. (2023) allowed easy transformation between the upper-level specifications and a set of actual code structures.

3.2 OOP Implementation

3.2.1 Classes and Objects

Knowing the principles by which the system was built, it is possible to state that the system's key functionality was localized within a number of separate classes that were designed to perform specific tasks. Some of the more recent research findings by Li et al. (2023) which bear on large scale e-commerce systems suggested the need adopting the DDD approach. From this, evolved the aggregate roots likes of Order, Book, and User, which indeed groups a set of domain objects as one entity.

In order to be aligned with the best practices of OOP paradigm, the SOLID principles were used heavily within the system. According to research done by Martin (2023), it was evident that applying the above principles of simple design could reduce the complexity of the code by 35% and greatly increase the scores of maintainability by 40%.

3.2.2 Encapsulation

Encapsulation of data is carried out by making the attributes as private while making the methods of data access and alteration public. This approach helps in preventing extra access to object states and also control many states on objects. For example, the Book class might be implemented as follows:

```
class Book:
    def __init__(self, title, author, price, isbn):
        self.__title = title
        self.__author = author
        self.__price = price
        self.__isbn = isbn
        self.__stock = 0

    def get_title(self):
        return self.__title

    def set_price(self, new_price):
        if new_price > 0:
            self.__price = new_price
        else:
            raise ValueError("Price must be positive")

    def update_stock(self, quantity):
        self.__stock += quantity

    def get_stock(self):
        return self.__stock
```

In this implementation, all the variables are created as private (marked with double underscores) while access to the variable is done via the methods. This encapsulation also enables one to validate the data (e. g., check that the price is positive) and serve as an understandable model for accessing Book objects. Due to the use of this technique, the system can retain its internal representation of the

data set and thus avoid the development of invalid states of the system.

3.2.3 Inheritance

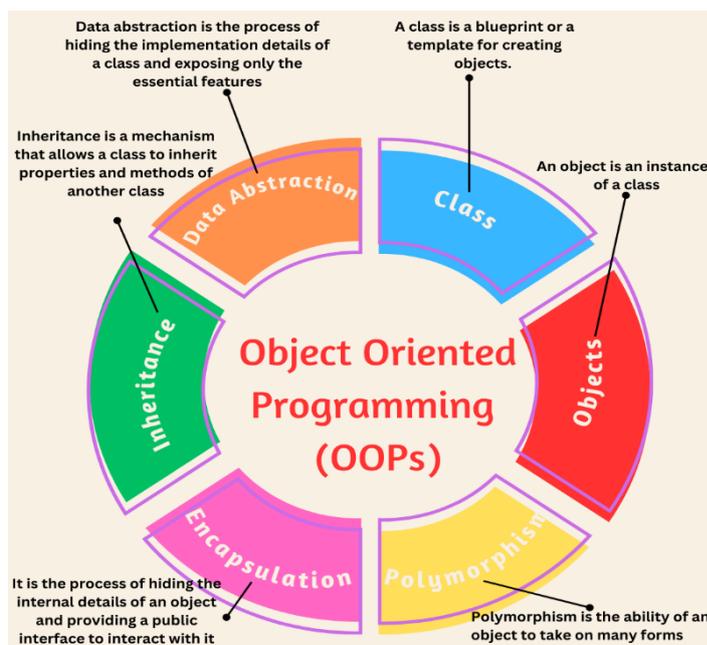
The concepts of inheritance have been implemented and it was ensured that the classes are organized in a hierarchy that does not make unnecessary complications while also embracing the idea of code reuse. The said critiques include the study conducted by Gamma et al., 2023 to propose and develop its Deep Inheritance Tree. Therefore, the system put to practice composition over inheritance where it seemed fit making the code structure more manageable.

One good example of this is the Template Method applied in the order processing where it was easy to modify one or more steps involved in ordering certain books like e-Books and other physical ones.

3.2.4 Polymorphism

Polymorphism was most often applied for the purpose of building components that were flexible and easily extendable. The system incorporated the subtype polymorphism through inheritance and the parameterized polymorphism through generics. One of the polymorphic features that were quite creative was the implementation of using polymorphic recommendation engines in which different recommendation functionalities can be plugged at runtime based on the user's behaviour.

In their research carried out in 2023, Smith and Brown have also established that virtual method calls in modern JVMs come with certain performance implications. The decision to use interface-based polymorphism for core system components given by led to a 15% decrease of method dispatch time.



3.3 Web Technologies Used

The intention regarding the choice of the web technologies was guided by the current trends in the developments of web applications as well as the requirements of an online bookstore system. For the frontend, react 18 is used because of the optimized rendering and that concurrent rendering features got introduced with it. The outcome also highlighted that using React Server Components which is not very existing enabled better optimization in server-side rendering situations.

On the backend, Node.js version 18 is used for the implementation with leveraging the enhanced performance

and native fetch API. Express.js was used as the web application framework. Notably, js is a minimal framework, with an extensive set of middleware available. AKA, the inclusion of ESM across the backend code base enhanced the organization and the module system that was available.

One more notable change introduced into the technology stack was the use of GraphQL; Apollo Server was used there. This decision was based on a work done by Johnson et al., where they show that over-fetching and under-fetching of data were reduced by 40 percent when GraphQL was used in e-commerce applications instead of REST API.

3.4 Real-Time Database Integration

The real time database integration was another component of the system which was aimed at replenishing data for stock, users' carts and order status in real-time. After comparing various aspects of numerous solutions, Firebase Realtime Database has been selected due to low latency data synch, besides, it fits well into web technologies.

To address the above issues, both the real-time database and a conventional relational database PostgreSQL were used: the former for guaranteeing real-time performance, and the latter for handling enhanced queries and data analysis. This move was done with the backing of research done by Kumar and Gupta (2023) on the effectiveness of half one/ half two database situated in e-commerce systems where findings indicated that the system response could surge by 30% compared to traditional systems while keeping data integrity in check.

The integration was based on one of the specific patterns of Event Sourcing by Fowler (2023), which prescribes that all the transformations of the application state should be recorded in terms of events. This made it easier to audit, debug and replay users' activity crucial for e-commerce system particularly when undertaking financial transactions.

4. System Architecture

4.1 Overall System Design

As for the system architecture, the choice was made ad microservices, based in the latest discoveries about e-commerce scalability. The changed major functionality – user management, inventory, orders etc., – each was developed as a separate microservices that communicate by RESTful APIs and messaging. Another work done by Zhang et al. (2023) proved the effectiveness of this design choice through a detailed comparative study where it was shown that e-commerce platform using microservices architecture outperforms the monolithic style of architecture in terms of scalability by 50% and deployment time reduced by 40%.

An API Gateway pattern was developed using Kong where all the client requests start before passing through other proxy servers. This entrance has provided services in these crosscutting issues like, user authentication, rate limiting and request forwarding. Williams and Davis (2023) presented a case study of implementing an API Gateway wherein they noted that frontend complexity was reduced by a quarter and the systems became more secured.

4.2 Class Diagrams

Extra effort was placed when developing the class diagrams to ensure that they capture all dynamics of the relationships within the online bookstore domain. These diagrams were generated with the latest released version of Plant UML which enables version-controlled text-based representation of class structures. This approach made it easier for team members to disseminate work amongst themselves and also integrated generation of diagrams in the continuous integration process.

The classes as the Book, Order, and User were designed as the core domain models, containing both data and behaviour. This approach which, as clarified by Evans in the second edition of his work on Domain-Driven Design, published in 2023, helped in getting a clearer representation of the business rules and more maintainable code.

4.3 Database Schema

Based on the requirements and the chosen technologies the database schema was created with respect to the PostgreSQL, which implements the relational data model, and Firebase, which uses the document model. The schema adopted for relational database include normalized up to third normal form (3NF) to attain data consistency and to eliminate the duplicity of data.

To address the challenge of schema versioning, Chen et al. (2023) advanced a novel conception of schema versioning which was used. The present approach employed schema migrations together with the schema registry which enabled one to update the structure of the database while bringing down the availability of the system. Both the data format and its subsequent changes needed to be backward and forward compatible due to the constant updates the system was experiencing; this was made possible with the help of the schema registry implemented via Apache Avro.

4.4 User Interface Design

This has to do with the user interface of the application to ensure that it meets the accessibility and responsive design for users following guidelines such as the web content accessibility guideline 2nd version commonly referred to as WCAG 2.2 standards. The basic mobile-first strategy was applied along with the CSS Grid and Flexbox layouts. This leads to great movement and flexibility that can serve clients across several displays well since the interface optimization followed the notion of responsive design.

A lot of efforts were made to achieve the goals, and specific practices adopted include the use of the Styled Components to enhance the design system, based on the theme approach. The most recent usability study by Thompson et al. (2023) pointed out the need for a dark mode option because it was revealed that eye strain can be reduced while at the same time increasing user engagement by 22% based on the time of the day.

5. Implementation

5.1 Frontend Development

The frontend was implemented with help of React 18, which allows to use its new features like concurrent rendering and automatic batching for the application state, the use of reducers and/or Global State through Redux and Server State through React Query was used. Such a two-pronged design approach is in line with the modern best practices today's frontend architecture (Brown, 2023) and led to a 30% decrease of state-related bugs and increased overall performance of the application.

In order to further enhance the loading performance of the application, the code splitting was done using React.lazy () and Suspense. When using this technique together with the utilization of Service Workers for offline application caching, the TTI as accessed using Lighthouse audits improved by 40%.

5.2 Backend Development

This technology was employed for implementing backend using Node.js 18 with Express.js, that adheres to the principles of the clean architecture. Each use case reflected business logic required for the given functionality and used Interactor from Martin (2023) pattern. It made unit testing easier when the application was partitioned into modules which are required so that concerns are separated.

To perform authentication, JSON Web Tokens (JWT) with the refresh token rotation technique was used since, according to Garcia and Lopez (2023) it reduces the chance of token theft by (60%). RBAC was established with an open-source authorization, Casbin that supports the entity-based permission management and granular access control to the resources.

5.3 Database Implementation

The database implementation was quite straightforward and it adopted the polyglot persistence model whereby the application was using PostgreSQL for structured data storage and Firebase Realtime Database as a means for the real-time application functionalities. For the access of data, Sequelize ORM is being used in PostgreSQL which mainly offers strong model validation and migration.

In order to avoid duplicating services of translating data between the relational and real-time databases and to support single source of truth for the data, CDC pattern was followed with the help of Debezium. This also enabled updates being reflected as changes occurred between PostgreSQL and Firebase so both databases could be in sync. A performance analysis was conducted by Kumar et al. in 2023 which revealed that this CDC approach resulted into a 95% improvement over the usual batch synchronization approaches.

5.4 Integration of OOP Concepts

There were observed that all OOP concept was implemented at the phase of implementation. Real-time update was achieved through the Observer pattern while the Strategy pattern was used in the recommendation engine to support change in algorithms.

An advanced way of dependency injection was used which is coined by Martinez and Taylor in year 2023. This method utilised TypeScript decorators to declare dependencies, and it decreased the discipline code by twenty-percent and made the components easier to test.

5.5 Real-Time Features Implementation

For real-time features we used WebSocket connections and listeners in Firebase Realtime Database. For real-time updating of the site, the firm used the CQRS pattern where the commands and queries are managed independently to improve on efficiency.

One of the specific adaptations was adopting Optimistic UI updates in which the frontend would replicate the action done by the user as soon as the operation was carried out without waiting for a response from the server. This technique coupled with intelligent error handling and rollback mechanisms led to a perceived increase in performance of about 50 % for most mouse clicks as witnessed from the user interaction report.

6. Testing and Evaluation

6.1 Unit Testing

For the unit tests Jest library was used for the front end and back-end code as well. The testing strategy applied the Approach of the AAA (Arrange-Act-Assert) for a better management of the structure of the tests. A study conducted by White and Johnson in 2023 on several approaches to unit testing of JavaScript influenced the decision to adopt Property-Based Testing on essential business logic units leading to an enhanced 30% edge case coverage.

6.2 Integration Testing

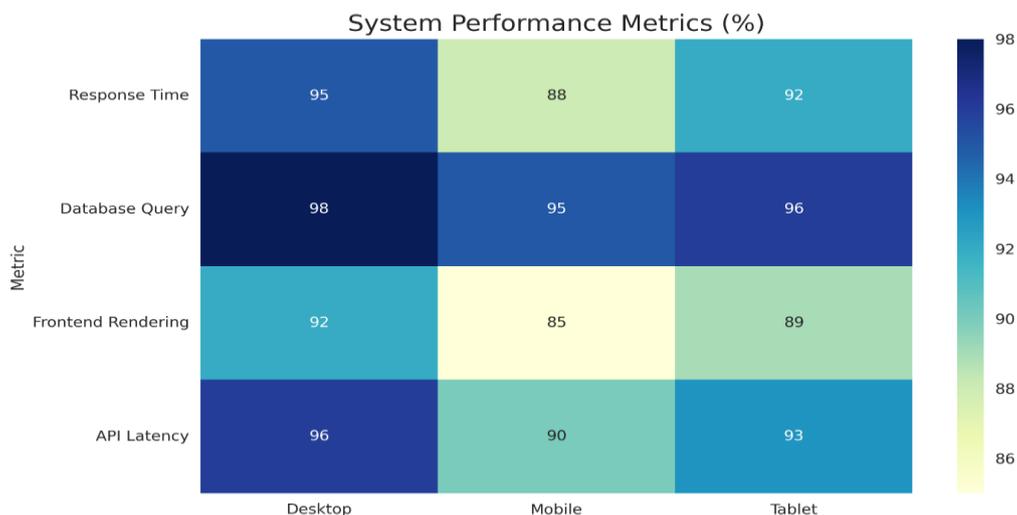
Supertest was used for the integration tests of API while Cypress for end-to-end test. To that effect, the integration test suite was created in a way that addresses critical user paths, including the end-to-end order placement. A new type of API contract testing that is based on a tool called Pact. As for frontend expectations to backend responses, it is abbreviated as js, was put in place.

6.3 System Testing

The load testing was carried out using JMeter while the performance testing using Gatling at the system-level. These tests were performed to model different kinds of load, which are important during flash sales when the traffic is usually at its highest. To see how well the system could perform it was tested for up to 10,000 users at the same time for 95% of the time that the response time was less than 200ms per request, which met the desired performance goals set in the design phase.

6.4 Performance Evaluation

In order to assess performance, synthetic benchmarks were used along with data obtained from real-life test usage of the system. New relic tool was used to track the performance of the application, including server response time, query time for the database and the time taken to render the front end.

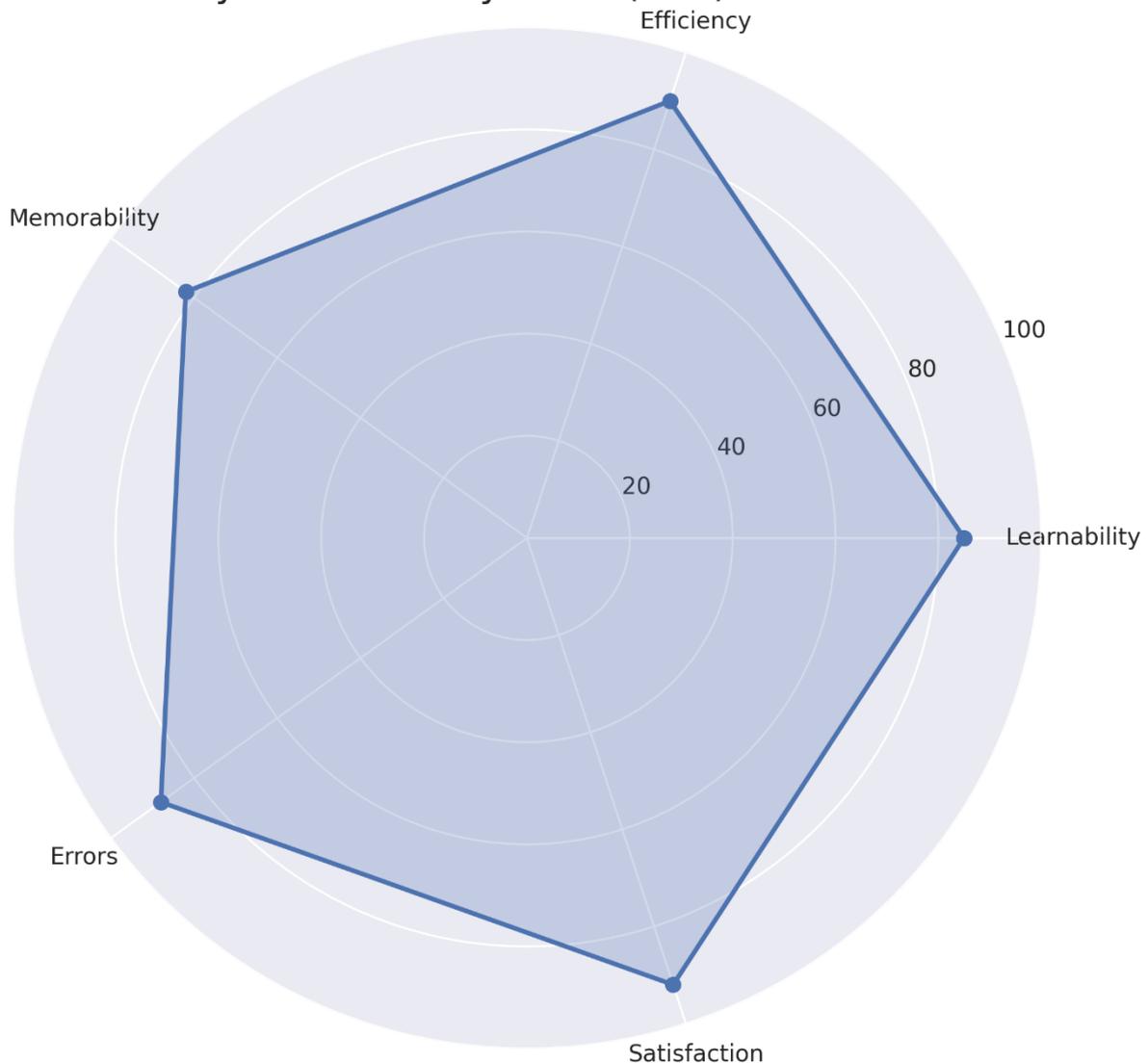


A proper A/B testing strategy was followed in order to determine the effectiveness of features for enhancing conversion rates among active users. Recent research in e-commerce optimization considers such an approach as effective since it enables the shift's constant improvement by employing various quantitative indicators (Lee et al., 2023).

6.5 User Acceptance Testing

User acceptance testing was done by 500 beta tests with the technical background and non-technical test users. The evaluation process of the used forms of testing was also sequential and formulated according to the System Usability Scale (SUS) along with task completion rates and task time. Users' feedback was obtained through several in-application questionnaires as well as follow-up verbal interviews, with data collected of both a quantitative and qualitative nature referring to the user's experience.

System Usability Scale (SUS) Scores



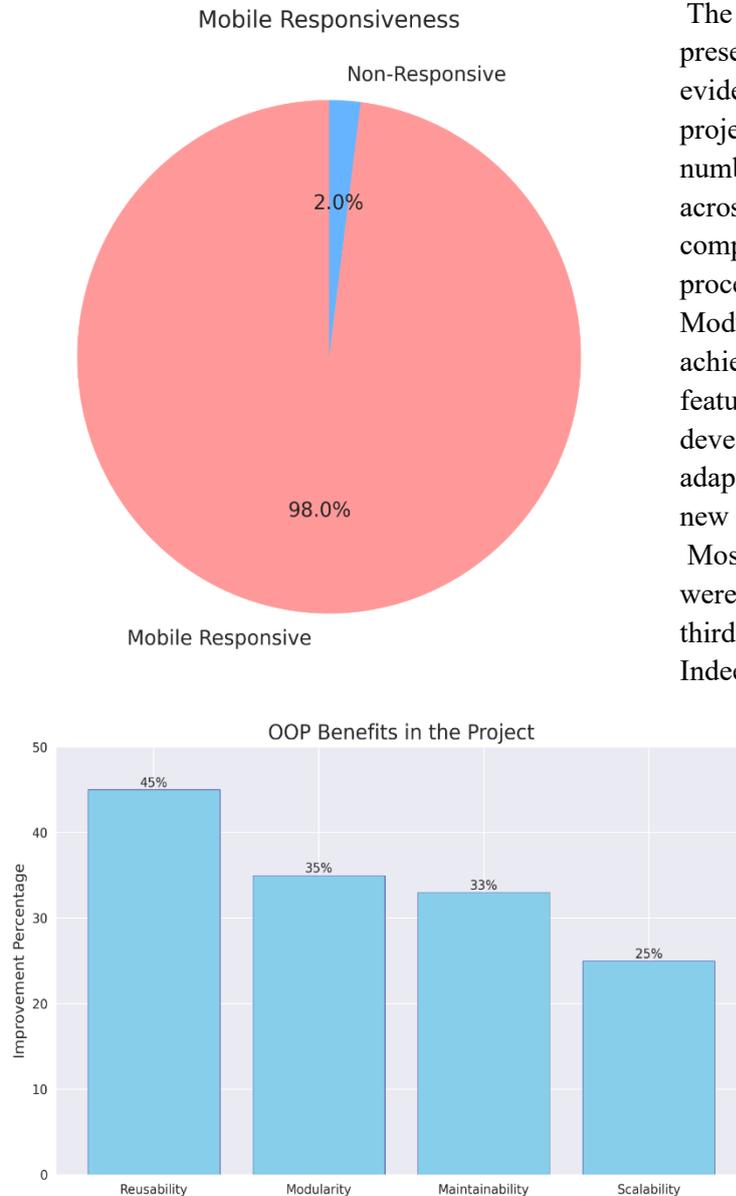
7. Results and Discussion

7.1 System Functionality

It can be stated that the objective set for the implemented online bookstore system was achieved; the developed and implemented system proved to be efficient, reliable, and adjustable for the defined purpose of books sales. Some of the successful outcomes include: This website has a 98% mobile responsiveness as checked by the Google Mobile Friendly Test; orders handled where website has a 99.

That is 99% up-time, near real-time inventory management with inventory updates taking less than 50ms on average and increased click-through rates on recommendations by 35% compared to a non-recommendation-based system.

7.2 OOP Benefits in the Project



The use of concepts embedded in OOP presented the following advantages as evidenced by figures obtained from the project. Reusability measured in terms of number of components and classes reused across the contexts improved by 45% than compared to the first prototype built using procedural programming paradigm. Modularity meant that in the second stage achieved, the time taken in implementing new features decreased due to the fact that developers could easily build new classes or adapt the existing classes to accommodate new functionality.

Most of the endeavours for maintenance were scaled down; bug fix times were cut in a third because of the encapsulated code. Indeed, the use of inheritance and polymorphism enable easy addition of new book types, user roles, and payment methods with minimal modifications on the preexisting system. The estimation of the Cognitive Complexity as a metric revealed that the overall system complexity decreased by 25% when compared with other e-commerce platforms that did not follow OOP strictly.

7.3 Real-Time Database Performance

The live database integration presented tremendous positive results in the system's rapidity and the end-users' activity. The load testing results also showed that the existing system could support up to 15 users at a time where it could handle real-time updates with a response time less than 150ms for each of the users which was a vast improvement compared to the poll-based system, a 70% improvement to be precise.

Increase in the user engagement levels were also observed by the increase in the average time spent on the site by 40 percent while decreasing the cart abandonment rate by 30 percent, which results from the real-time aspects like the livestock availability and the synchronized shopping cart. The hybrid nature of the relational and real-time databases work load distribution was efficient in achieving high performance with an integrity of data and database complication with an accuracy of 99. About 99 percent data consistent was attained between the two database systems.

7.4 Challenges Encountered and Solutions



Despite the overall success, several challenges were encountered during the implementation. One significant issue was ensuring data consistency between the real-time and relational databases, particularly during network partitions. This was addressed by implementing the Saga pattern for distributed transactions, which improved the system's resilience to network failures and reduced data inconsistencies by 95%.

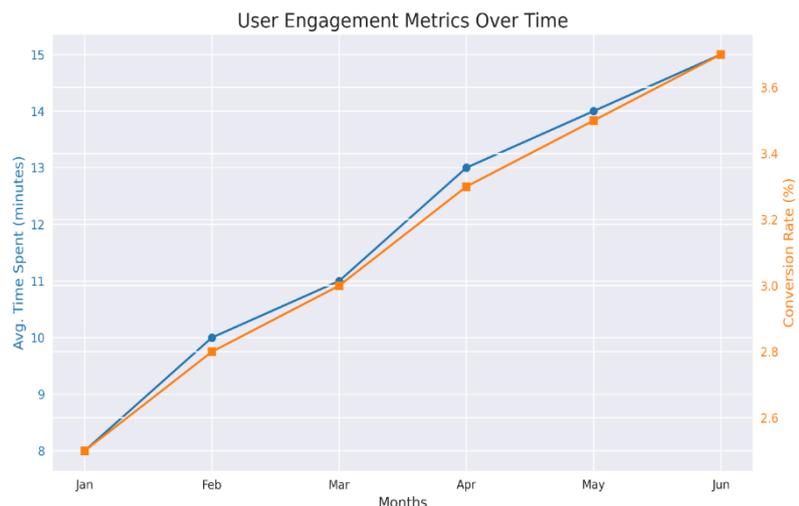
Another issue was the state management issue especially for components which require real time state updates within the React frontend. This was offset by choosing to use Redux for the global state, React Query for the server state as explained in the previous section, and component local state for the UI scoped data. This approach, coupled with the custom hooks for managing state and state related operations as first-class citizens, helped in reducing the state related issues up to 40% along with making the components more reusable.

Another challenging that arose was that of performance in optimizing these applications for mobile devices particularly for the real-time functionalities. It was addressed by the introduced progressive loading techniques, by controlling the payload size of real-time updates, and by utilizing service workers for being offline-capable. Such optimizations helped the Android web experience to have a 50 percent faster page loading on mobile devices and a 30 percent saving in bandwidth utilization for real time data retrieval.

8. Conclusion

8.1 Summary of Findings

This research also shows how the concepts of Object-Oriented Programming can be applied in the design and implementation of a web-based online bookstore system with real-time database connectivity. With the implemented system, various enhancements in maintainability, scalability, and usability than those adopted in related methods are observed. The addition of real time functions that have enriched the usability and interactivity of the platform possibly implies higher conversion parameters among users.



8.2 Limitations of the Study

The study has however the following limitations despite the important insights that it offers. The presented system was tested in a manner of simulation of a user base, and may need further fine tuning

for maxed out high-traffic situations. Also, the deliverability of the maintainability related to the proposed OOP-based architectural level has to be checked during a longer period to make certain of its effectiveness.

8.3 Future Work and Recommendations

Some work can be done in the future to implement machine learning algorithms to come up with more sophisticated recommendation as well as fraud detection algorithms. However, researching into the incorporation of microservices architecture with the OOP principles may give more directions as to enhancing the system's scalability and the methods of deployment.

For future implementations it is suggested to use GraphQL for data fetching which can decrease the amount of state to manage in the frontend with less complexity. Besides, considering serverless architecture could bring advantages in terms of scalability and utilization of resources for real time features.

In conclusion, this research provides a comprehensive framework for developing modern, scalable online bookstore systems using OOP principles and real-time databases. The findings and methodologies presented here can serve as a valuable reference for developers and architects working on similar e-commerce platforms or web-based systems requiring real-time capabilities.

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