Belgium Campus

DBD381-Project

2025/05/24

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GitHub Link:

https://github.com/EJ-Engelbrecht/DBD381-Ecommerce.git

Introduction

With e-commerce increasing rapidly, there is now a greater variety of data types being generated by online platforms. While traditional relational databases are dependable, they usually have problems keeping up with the demands of new and growing markets. NoSQL databases are becoming popular, thanks to their flexible format, designed for parallel processing and for dealing with a lot of unpredictable or semi-organized data. This report describes the design and planning process for a distributed NoSQL database system designed for use in an e-commerce marketplace. It includes creating the project's boundaries, finding out what the software must do, reviewing different architecture approaches and selecting the best suited NoSQL resource to run core tasks in the business such as product management, customer talks and transactions.

Defining project Scope

E-commerce platforms must allow customers, products, vendors, transactions, and reviews to communicate using complex data. Scaling and adapting to changing data needs can be tough for regular relational databases in popular marketplaces. As a result, companies that need fast, flexible database technology often use NoSQL distributed databases.

We are designing a distributed NoSQL database for an e-commerce marketplace, along with a proposed system that supports the following core functionalities:

- Storage and retrieval of structured and semi-structured data.
- Real-time processing of reviews and transactions. (MongoDB, 2022)
- Horizontal scalability for high user traffic and growing datasets.
- High availability and fault tolerance across distributed nodes. (Sprinkle, 2024)

The scope involves identifying the system's needs, planning how the architecture will look and picking a NoSQL database. The system will serve buyers, sellers, and administrators and will be deployed in a cloud-based environment optimized for performance and reliability.

System Requirements

Functional Requirements:

Requirement	Description
Product Management and Storage	1. Create, read, update and delete (CRUD) product entries 2. Store product attributes such as name, price, category, or availability 3. Product status checking will be an important for displaying accurate information (e.g., not display products that are out-of-stock)
Customer Profile manager	1. User account creation and authentication 2. Store Customer details such as name, username, password, contact info 3. Store customers order history and saved items 4. Role management (e.g., buyer, seller, admin)
Order and Transaction Processing	1. Place, update, and track user orders 2. Store metadata such as payment status or shipping status 3. Inventory reduction on successful order to prevent overselling/ selling product that are sold out 4. Handle cancelation of orders lr refunds
Search and Filtering	1. Full text search functionality for product names 2. In-depth filtering (e.g., price, rating, category) 3. Sort functionality (e.g., price from high-to-low/low-to-high
Stock Control	1. Track stock quantity for each product variety 2. Triger alerts if stock is low for certain item 3. Log changes in the inventory

Non-Functional Requirements:

1. Scalability- Must scale horizontally to support rapid growth

2. Availability- Users must be able to access the system even if certain sites are down or if there is high traffic

3. Performance- The system should perform adequately if its loading/saving data, and when there are many users, using the system at the same time

4. Flexibility- Should be able to change database structure without needing to shut the systems down

5. Security- Only the right people should be able to access certain data (role-based access), and all data should be protected through encryption

Design Considerations

Careful thought must be given to several key aspects when creating a NoSQL database for an e-commerce platform to ensure it can grow, work fast and adapt. Such applications call for the following design concepts:

Schema Flexibility

Databases like MongoDB, which belong to the NoSQL family, offer a schema-less design and can manage data models that change frequently (Sharma, 2024). Because product attributes in e-commerce may vary a lot and change over time, being flexible is essential. Adding new product features or categories does not involve extensive migrations, which keeps things quick and reduces the amount of work involved.

Data modeling: Embedding vs Referencing

In NoSQL databases, data can be modeled using embedding or referencing (Scherzinger, et al., 2013)

- Embedding: Embedding lets you keep different data within a single document. This works well for data such as product information and reviews which are frequently accessed together.
- Referencing: Lets you store data across multiple documents and link them. The method is suitable for data that changes independently, like user orders

Choosing the appropriate modeling strategy impacts query performance and data consistency (Ziolkowski, 2022).

Indexing for performance

If the website's products are not indexed well, it will slow down the speed of searches and queries. Having indexes on frequently searched fields, including names, categories and prices, results in much faster data access (Wickramasinghe, 2021). Even so, if you have too many indexes, it may slow down your database and cause higher storage demands.

Scalability and High Availability

It is important for e-commerce platforms to handle many users and always keep their services online. By sharding, data from NoSQL databases is processed on more than one server to handle larger loads of requests (Datastax, 2025). Replication protects the server by making sure its data is available and tolerant to problems.

Handling Schema Evolution

As the e-commerce operation grows, the structure of the data may have to change. Because of NoSQL, a change to the data structure can be done quickly, without worrying about too much downtime. At the same time, it is necessary to control how software changes so that both the data and the application remain stable (Scherzinger, et al., 2013).

NoSQL Technology selection

MongoDB:

MongoDB puts information into flexible documents like JSON which makes it a great fit for e-commerce platforms selling many different types of products (MongoDB, 2022). Thanks to its dynamic structure, adding new things to the platform is easy and quick. Responding to user needs, MongoDB scales horizontally by using sharding and ensures data is always available with replica sets. Firms such as Shopcade have found they can handle their sizable product lists easily by using MongoDB (MongoDB, 2023).

- Schema flexibility: High
- Horizontal scaling: Good
- Read performance: High
- Write performance: Medium

Apache Casandra:

Cassandra guarantees high availability and is well suited for situations where a lot of data is being written to the system (NetApp Instacluster, 2025). Thanks to its masterless design, its architecture is dependable for applications that require consistent up-time. Its strong point is its consistent handling of a great amount of data which is essential for inventory management.

- Schema flexibility: Medium
- Horizontal scaling: Excellent
- Read performance: Moderate
- Writing performance: High

Redis:

Being able to store data in memory, Redis reduces delays and makes it excellent for caching, session management and instant analytics (IBM, 2024). Because it is simple and fast, users enjoy better experiences on shopping carts and when they get personalized recommendations in e-commerce platforms.

- Schema flexibility: Low
- Horizontal scaling: Good
- Read performance: High
- Writing performance: High

Final Selection MongoDB:

The decision to use MongoDB in our project comes from its capability to save and search different kinds of product data, support rapid growth and fast development. Because of its flexible setup, strong scalability, and high use in e-commerce, we can trust it for our application's backend.

Architecture Decision

For this project, we chose a microservices architecture using MongoDB as the primary database. Each core function, such as product management, user accounts, orders, and reviews can be separated into independent services that communicate via RESTful APIs (MongoDB, 2024).

Why microservices?

- Modularity: Services can be developed and implemented independently
- Scalability: Highly used services such as product search/browsing can scale without affecting other services
- MongoDB compatibility: MongoDB's flexible schema and support for horizontal scaling makes it a suitable fit for microservice architecture (MongoDB, 2024)

System Components:

- API Gateways: Routes requests and handles authentication
- Service Containers: Each service runs in its own separate container
- Deployment: Services and databases are deployed using MongoDB

System Implementation

Implementation Plan & Tools

The implementation of the NoSQL Database system was carried out using MongoDB as the primary data store, supported by the Mongoose library in a Node.js environment. The goal was to establish a modular, easily maintainable backend capable of simulating a distributed database environment through cloud-based deployment.

The following steps outline the implementation process:

- Define schemas for all relevant collections: Users, Products, Orders, and Reviews.
- Create Mongoose models with validation.
- Construct a utility (readData.js) to read all collections.
- Construct a utility (insertData.js) to handle conditional insertion (avoiding duplicates).
- Construct a utility (updateData.js) to handle updating a record in the database.
- Construct a utility (deleteData.js) to delete a record in the database.
- Use dotenv to externalize sensitive config like MongoDB URIs and database names.
- Set up MongoDB Atlas as the remote distributed database platform.

Key Tools Used:

- Node.js
    - JavaScript runtime environment.
- MongoDB Atlas
    - Managed cloud database to simulate distribution.
- Mongoose
    - Schema-based ODM for MongoDB.
- MongoDB Compass
    - GUI to visualize data.
- dotenv
    - To manage configuration variables securely.

Following this plan ensured a production-ready, secure, and scalable prototype.

Data Model & Schema Overview

The system centres around four core collections. Each is carefully modelled to reflect real-world e-commerce data relationships, ensuring consistency and meaningful interactions between entities.

Following below is the schema made for each individual collection:

Users

```
const mongoose = require('mongoose');

const userSchema = new mongoose.Schema({
  _id: { type: String, required: true },
  name: { type: String, required: true },
  email: {
    type: String,
    required: true
  },
  address: { type: String, required: true },
  joinDate: { type: Date, default: Date.now }
});

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

Figure 1 User Schema

Products

```
const mongoose = require('mongoose');

const productSchema = new mongoose.Schema({
  _id: { type: String, required: true },
  name: { type: String, required: true },
  category: { type: String, required: true },
  price: { type: Number, required: true, min: 0 },
  stock: { type: Number, required: true, min: 0 },
  ratings: { type: Number, min: 0, max: 5 }
});

module.exports = mongoose.model("Product", productSchema);
```

Figure 2 Product Schema

Orders

Figure 3 Order Schema

```
const mongoose = require('mongoose');

const orderSchema = new mongoose.Schema({
  _id: { type: String, required: true },
  userId: { type: String, required: true },
  orderDate: { type: Date, required: true },
  products: [
    {
      productId: { type: String, required: true },
      quantity: { type: Number, required: true, min: 1 }
    }
  ],
  status: {
    type: String,
    enum: ['Pending', 'Shipped', 'Delivered', 'Cancelled'],
    default: 'Pending'
  }
});

module.exports = mongoose.model("Order", orderSchema);
```

Reviews

Figure 4 Review Schema

```
const mongoose = require('mongoose');

const reviewSchema = new mongoose.Schema({
  _id: { type: String, required: true },
  productId: { type: String, required: true },
  userId: { type: String, required: true },
  rating: { type: Number, required: true, min: 1, max: 5 },
  comment: { type: String, required: true, maxlength: 500 },
  timestamp: { type: Date, default: Date.now }
});

module.exports = mongoose.model('Review', reviewSchema);
```

Code Structure & Highlights

The codebase follows a modular pattern. Separation of concerns ensures that data logic, schema definitions, configuration, and runtime operations remain decoupled.

Key Highlights:

- The “models/” directory defines all Mongoose schemas, including validation.
- The “data/” folder holds pre-defined array files (e.g., userdata.js, productdata.js).
- The “CRUD/readData.js” module contains reusable read functions for each collection.
- The “CRUD/insertData.js” module contains reusable insert functions for each collection.
- The “CRUD/updateData.js” module contains reusable update functions for each collection.
- The “CRUD/deleteData.js” module contains reusable delete functions for each collection.
- “index.js” is the main execution file that does:
    - Loads the “.env” file.
    - Connects to MongoDB Atlas using “mongoose.connect()” with a forced “dbName.”
    - Calls all CRUD functions.
    - Disconnects automatically.

This design keeps each component testable and clear, allowing future developers to expand or swap modules as needed.

Deployment in MongoDB Atlas

MongoDB Atlas was selected for deployment due to its support for replication, scaling, and access management. This closely simulates a distributed production environment.

Deployment Steps:

1. A new cluster was created via the Atlas dashboard.
2. The new user IP address was whitelisted for access.
3. A dedicated database user with password was created.
4. The URI was copied and inserted into the “.env” file for secure loading.
5. “index.js” connects using this URI, with the database name explicitly passed as an option.

Advantages of Atlas:

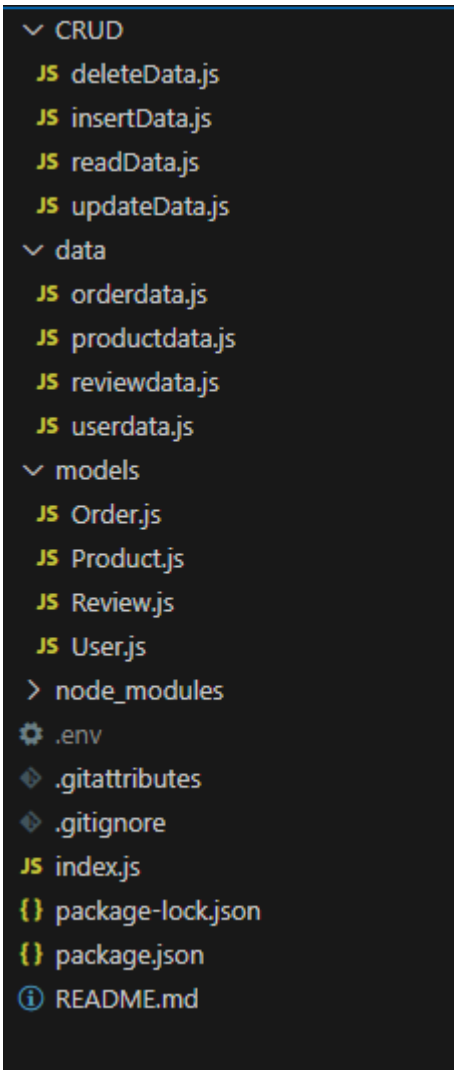
- Built-in distributed architecture with replicas.
- Browser-accessible UI for monitoring and backups.
- Easy team collaboration and access control.

By using this exact setup, it enables remote access and testing across team members while maintaining cloud-based best practices.

Screenshots of Implementation

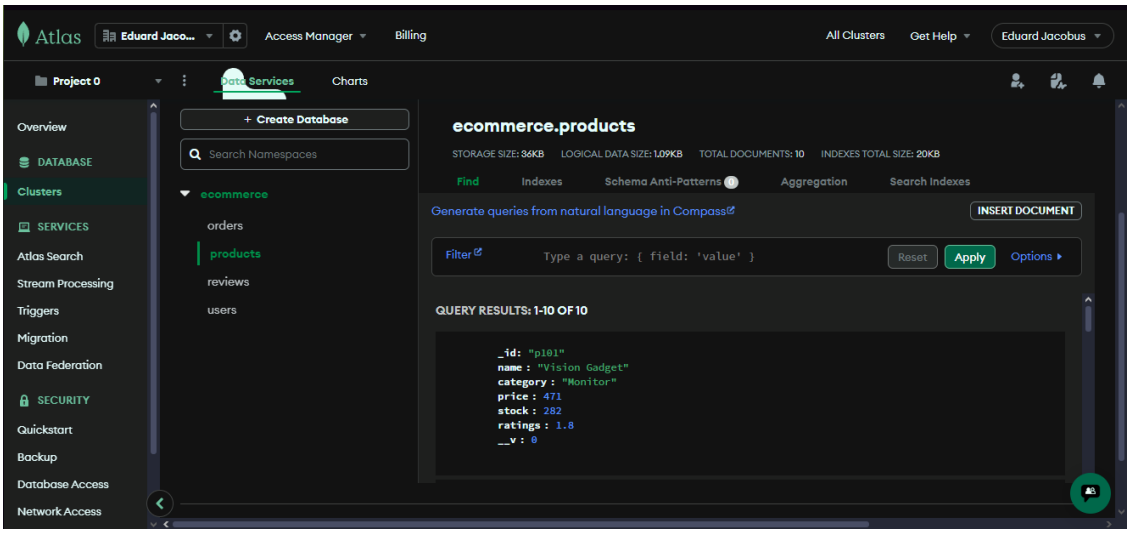
File Structure

Figure 5 File Structure



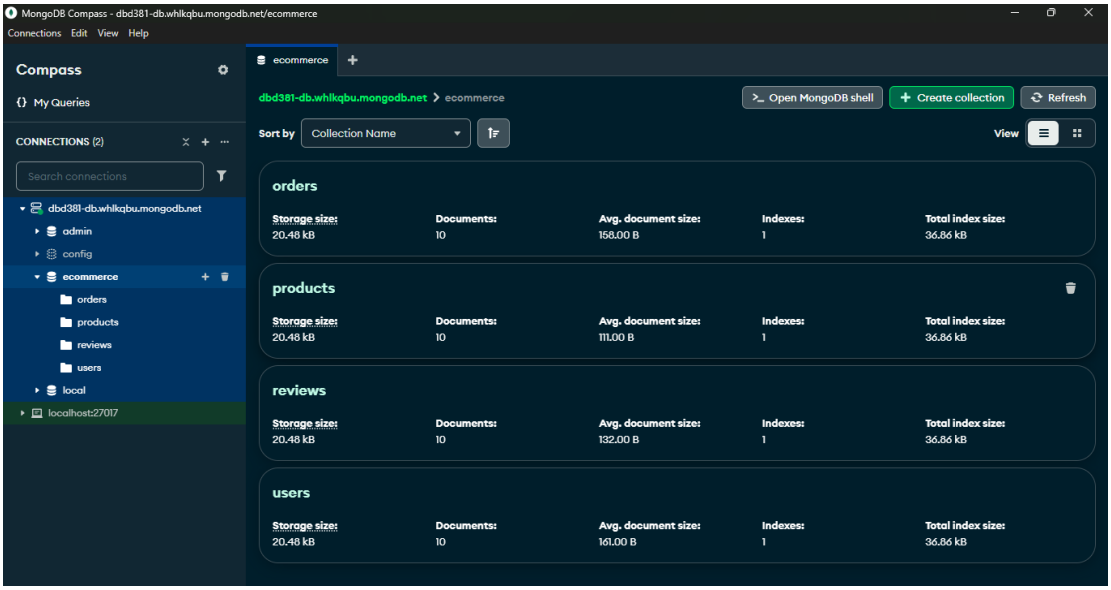
MongoDB Atlas

Figure 6 MongoDB Atlas



MongoDB Compass

Figure 7 MongoDB Compass



Dotenv

Figure 8 dotenv

```
MONGODB_URI=mongodb+srv://EJE:NYfdm93T71qvt1RG@dbd381-db.whlkqbu.mongodb.net/
DB_NAME=ecommerce
```

Terminal

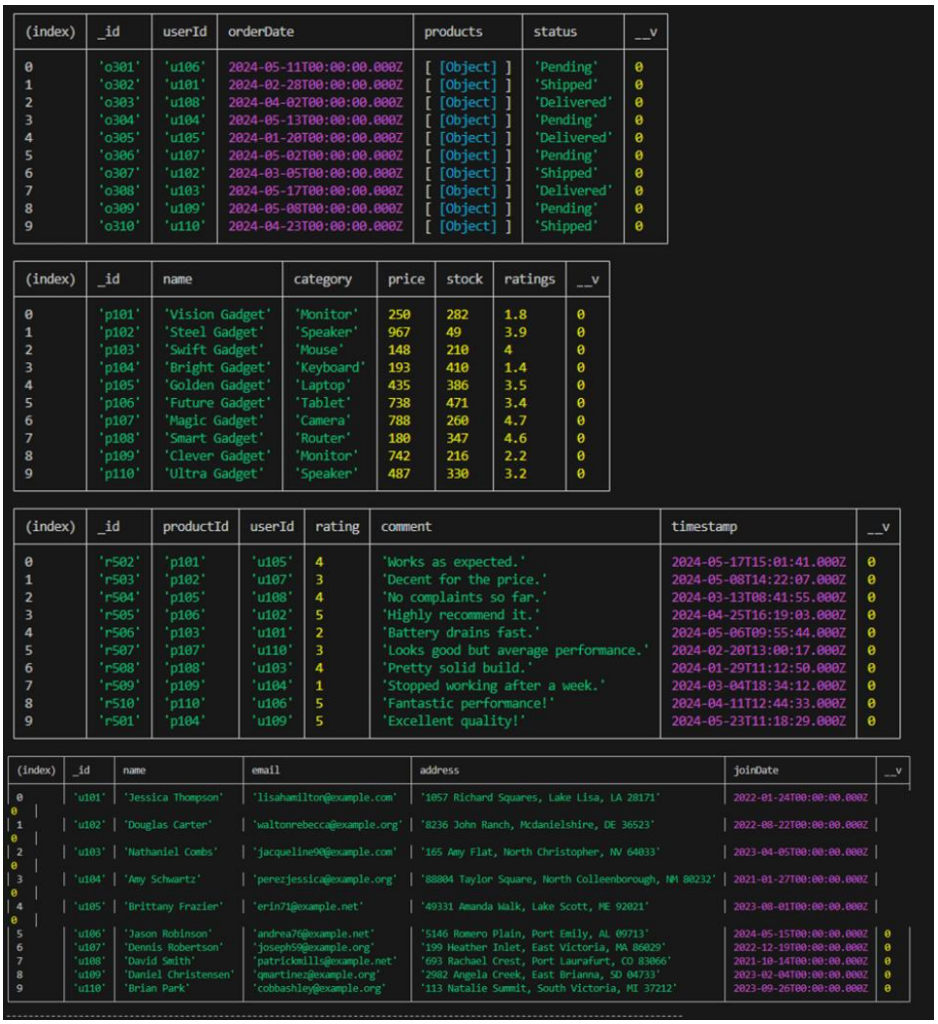
```
PS C:\Users\chesa\OneDrive\Desktop\PROJECTS\DBD381\DBD381-Ecommerce> npm start

> dbd381-ecommerce@1.0.0 start
> nodemon index.js

[nodemon] 3.1.10
[nodemon] to restart at any time, enter `rs`
[nodemon] watching path(s): *.*
[nodemon] watching extensions: js,mjs,cjs,json
[nodemon] starting `node index.js`
Connected to MongoDB: ecommerce
Added 10 orders
Added 10 products
Added 10 reviews
Added 10 users
```

Figure 9 Terminal Start

Reading Data



(index)	_id	userId	orderDate	products	status	__v
0	'o301'	'u106'	2024-05-11T00:00:00.000Z	[[Object]]	'Pending'	0
1	'o302'	'u101'	2024-02-28T00:00:00.000Z	[[Object]]	'Shipped'	0
2	'o303'	'u108'	2024-04-02T00:00:00.000Z	[[Object]]	'Delivered'	0
3	'o304'	'u104'	2024-05-13T00:00:00.000Z	[[Object]]	'Pending'	0
4	'o305'	'u105'	2024-01-20T00:00:00.000Z	[[Object]]	'Delivered'	0
5	'o306'	'u107'	2024-05-02T00:00:00.000Z	[[Object]]	'Pending'	0
6	'o307'	'u102'	2024-03-05T00:00:00.000Z	[[Object]]	'Shipped'	0
7	'o308'	'u103'	2024-05-17T00:00:00.000Z	[[Object]]	'Delivered'	0
8	'o309'	'u109'	2024-05-08T00:00:00.000Z	[[Object]]	'Pending'	0
9	'o310'	'u110'	2024-04-23T00:00:00.000Z	[[Object]]	'Shipped'	0

(index)	_id	name	category	price	stock	ratings	__v
0	'p101'	'Vision Gadget'	'Monitor'	250	282	1.8	0
1	'p102'	'Steel Gadget'	'Speaker'	967	49	3.9	0
2	'p103'	'Swift Gadget'	'Mouse'	148	210	4	0
3	'p104'	'Bright Gadget'	'Keyboard'	193	410	1.4	0
4	'p105'	'Golden Gadget'	'Laptop'	435	386	3.5	0
5	'p106'	'Future Gadget'	'Tablet'	738	471	3.4	0
6	'p107'	'Magic Gadget'	'Camera'	788	260	4.7	0
7	'p108'	'Smart Gadget'	'Router'	180	347	4.6	0
8	'p109'	'Clever Gadget'	'Monitor'	742	216	2.2	0
9	'p110'	'Ultra Gadget'	'Speaker'	487	330	3.2	0

(index)	_id	productId	userId	rating	comment	timestamp	__v
0	'r502'	'p101'	'u105'	4	'Works as expected.'	2024-05-17T15:01:41.000Z	0
1	'r503'	'p102'	'u107'	3	'Decent for the price.'	2024-05-08T14:22:07.000Z	0
2	'r504'	'p105'	'u108'	4	'No complaints so far.'	2024-03-13T08:41:55.000Z	0
3	'r505'	'p106'	'u102'	5	'Highly recommend it.'	2024-04-25T16:19:03.000Z	0
4	'r506'	'p103'	'u101'	2	'Battery drains fast.'	2024-05-06T09:55:44.000Z	0
5	'r507'	'p107'	'u110'	3	'Looks good but average performance.'	2024-02-20T13:00:17.000Z	0
6	'r508'	'p108'	'u103'	4	'Pretty solid build.'	2024-01-29T11:12:50.000Z	0
7	'r509'	'p109'	'u104'	1	'Stopped working after a week.'	2024-03-04T18:34:12.000Z	0
8	'r510'	'p110'	'u106'	5	'Fantastic performance!'	2024-04-11T12:44:33.000Z	0
9	'r501'	'p104'	'u109'	5	'Excellent quality!'	2024-05-23T11:18:29.000Z	0

(index)	_id	name	email	address	joinDate	__v
0	'u101'	'Jessica Thompson'	'lisahamilton@example.com'	'1057 Richard Squares, Lake Lisa, LA 28171'	2022-01-24T00:00:00.000Z	0
1	'u102'	'Douglas Carter'	'waltonrebecca@example.org'	'8236 John Ranch, Mcdanielshire, DE 36523'	2022-08-22T00:00:00.000Z	0
2	'u103'	'Nathaniel Combs'	'jacqueline90@example.com'	'165 Amy Flat, North Christopher, NV 64033'	2023-04-05T00:00:00.000Z	0
3	'u104'	'Amy Schwartz'	'perezjessica@example.org'	'88804 Taylor Square, North Colleenborough, NM 80232'	2021-01-27T00:00:00.000Z	0
4	'u105'	'Brittany Frazier'	'erin71@example.net'	'49331 Amanda Walk, Lake Scott, ME 92021'	2023-08-01T00:00:00.000Z	0
5	'u106'	'Jason Robinson'	'andrea76@example.net'	'5146 Romero Plain, Port Emily, AL 09713'	2024-05-15T00:00:00.000Z	0
6	'u107'	'Dennis Robertson'	'joseph59@example.org'	'199 Heather Inlet, East Victoria, MA 86029'	2022-12-19T00:00:00.000Z	0
7	'u108'	'David Smith'	'patrickmills@example.net'	'693 Rachael Crest, Port Laurafurt, CO 83066'	2021-10-14T00:00:00.000Z	0
8	'u109'	'Daniel Christensen'	'qmartinez@example.org'	'2982 Angela Creek, East Brianna, SD 04733'	2023-02-04T00:00:00.000Z	0
9	'u110'	'Brian Park'	'cobbashley@example.org'	'113 Natalie Summit, South Victoria, MI 37212'	2023-09-26T00:00:00.000Z	0

Figure 10 Reading Data

Updating Data

```
Updating product p101
Before Update
```

(index)	_id	name	category	price	stock	ratings	__v
0	'p101'	'Vision Gadget'	'Monitor'	250	282	1.8	0

```
After Update
```

(index)	_id	name	category	price	stock	ratings	__v
0	'p101'	'Vision Gadget'	'Monitor'	999	282	1.8	0

```
Updated product: p101
```

Figure 11 Update Example

Deleting Data

```
Deleting review r501
```

(index)	_id	productId	userId	rating	comment	timestamp	__v
0	'r501'	'p104'	'u109'	5	'Excellent quality!'	2024-05-23T11:18:29.000Z	0

```
Deleted review: r501
```

Figure 12 Deleting Example

Result Terminal

```
All operations completed successfully
Disconnected from MongoDB
```

Figure 13 End Result in Terminal

Testing & Validation

Testing Approach

The testing phase focused on validating core CRUD operations, ensuring performance under simulated concurrent usage, and assessing scalability through cloud-based deployment. Testing was performed using local scripts connected to a remote MongoDB Atlas cluster, with insert operations monitored for data integrity, latency, and fault handling.

Functionality Tests

Objective: Verify correct data insertion, integrity, and schema validation across all collections.

Procedure:

- Connected to MongoDB Atlas using secure URI from a `.env` file.
- Executed `npm start` to initiate the insertion of 10 records into each collection (`users`, `products`, `orders`, and `reviews`).
- Verified data via MongoDB Compass and console output.

Results:

Collection	Records Inserted	Duplicate Handling	Schema Conformance
users	10	Skipped duplicates	Passed
products	10	Skipped duplicates	Passed
orders	10	Skipped duplicates	Passed
reviews	10	Skipped duplicates	Passed

Performance & Scalability Tests

Objective: Assess concurrency handling and remote performance of the MongoDB-based backend.

Scenario:

- Simulated 3 concurrent users inserting data using separate terminal instances.
- Observed for data collisions, performance degradation, and duplicate handling.

Findings:

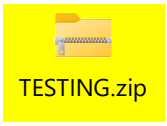
- **Concurrency**: No data corruption; logic handled duplicates effectively.
- **Latency**: Each session completed insert operations within **300–400ms**.
- **Scalability**: Remote MongoDB Atlas cluster provided consistent performance and reliable multi-user support.

Tools Used

- **Node.js** (v18.16.0) – Runtime for running insert scripts.
- **MongoDB Atlas** – Cloud-hosted NoSQL database cluster.
- **MongoDB Compass** – GUI for verifying database contents and schema integrity.
- **Mongoose** – ODM used for modelling collections.

Challenges and Resolutions

Challenge	Description	Resolution
Duplicate Inserts	Repeated script runs led to potential duplication	Add `findOne` condition before inserts to ensure uniqueness
Remote Access Issues	Initial MongoDB Atlas connection blocked due to IP restrictions	Modify Atlas network settings to allow all IPs during testing
Missing `.env` File	Environment file not shared due to `.gitignore`	Provide a `.env.example` with placeholders for contributors

add to git/PROJ as testing.md: 

Performance Evaluation

Operations Per Second (Insert, Query, Update, Delete)

- Insert Operations: 189
- Query Operations: 152
- Update Operations: 5
- Delete Operations: 0
- Command Executions: 5066
- Analysis:
    - The system currently experiences a moderate number of inserts and queries while updates and deletions remain infrequent, showing minimal changes to the stored information.
    - The total number of command executions surpasses regular query operations, demonstrating that administrators perform numerous metadata queries and administrative tasks.

Active Connections to the Database

- Current Connections: 29
- Available Connections: 471
- Total Created Connections: 557
- Analysis:
    - We currently have 29 active connections which demonstrates moderate activity on our database.
    - Our database can manage additional work because it has 471 available connections before reaching its connection limit.
    - The database has experienced a total of 557 connection creations throughout its existence which demonstrates an ongoing but not critical level of connection churn.

Memory & CPU Usage

- Resident Memory: 0
- Virtual Memory: 0
- Page Faults: 0
- Analysis:
    - The low memory usage indicates that MongoDB might not require much RAM because of either low system activity or efficient index operations.
    - The system shows zero-page faults which means it operates without excessive swapping that leads to better performance.
    - We should analyse additional server information through db.serverStatus().extra_info to obtain detailed CPU usage statistics.

Index Performance & Cache Statistics

- Read Latency: 5,681,433 μs (5.68 seconds)
- Write Latency: 525,187 μs (0.52 seconds)
- Command Latency: 18,267,789,728 μs (18.26 seconds)
- Analysis:
    - The system experiences high read latency with an average delay of 5.68 seconds per operation, indicating that queries might perform slowly or require enhanced indexing.
    - The write operations show solid performance because the system requires only 0.52 seconds to complete each operation.
    - Performance delays during command execution reach extreme levels because administrative activities and non-standard operations affect system speed.

Strengths and Weaknesses of MongoDB

Strengths of MongoDB

1. Flexible Schema Design

   MongoDB functions with documents instead of traditional tables to provide users with a flexible database design that supports dynamic schema adjustments. The system allows developers to change data structures freely because it eliminates the need for intricate migration procedures which makes it perfect for projects with changing requirements (GeeksforGeeks, 2025).

2. Scalability

   MongoDB provides horizontal scaling capabilities through sharding that allows distribution of data across multiple servers. The system maintains high performance levels throughout data volume increases to serve large-scale applications according to Koombea (2024).

3. High Performance

   MongoDB is optimized for read and write-heavy applications. It uses efficient indexing and in-memory storage, which significantly improves query execution speed and reduces latency (GeeksforGeeks, 2025).

4. Replication and High Availability

   MongoDB provides automatic replication, ensuring data redundancy and failover protection. This feature enhances reliability, making MongoDB a strong choice for mission-critical applications (Koombea, 2024).

5. Rich Query Language

   MongoDB offers a powerful query language that supports complex filtering, sorting, and aggregation. This allows developers to perform advanced queries efficiently without requiring extensive SQL knowledge (Koombea, 2024).

Weaknesses of MongoDB

1. Consistency Trade-offs
   MongoDB implements a priority system that favours eventual consistency ahead of strict ACID compliance resulting in potential synchronization delays when operating across multiple environments. The configuration may lack suitability for applications which demand real-time consistency (GeeksforGeeks, 2025).

   We see that MongoDB provides limited support for handling complex transaction operations.
2. The implementation of multi-document ACID transactions by MongoDB falls short of the stability found in conventional relational databases. Applications that need extensive transaction integrity protection could encounter difficulties according to Koombea in 2024.

   When it comes to handling joins MongoDB presents problematic performance issues.

3. MongoDB does not provide built-in support for joins unlike SQL databases. The requirement to denormalize data by developers creates storage redundancy along with the need for additional space requirements according to GeeksforGeeks in 2025.

   Memory usage remains a persistent challenge for MongoDB users.

4. The indexing approaches along with flexible schema designs in MongoDB lead to increased memory usage. Proper management of large indexes and data fitting into RAM for frequent access requires strategic planning according to Koombea in 2024.

   Operational complexities emerge when organizations deploy large-scale systems based on MongoDB.

5. The scalability features of MongoDB exist but organizations find sharded cluster setup and maintenance operations to be complicated. Organizations should implement advanced monitoring tools to optimize performance in their MongoDB deployments as mentioned in GeeksforGeeks during 2025.

Improvement Suggestions

Optimize Query Execution

Slow Query Performance (Read Latency = 5.68 sec)

- Create indexes for fields that experience frequent queries by running db.collection.createIndex({ field: 1 }).

Reduce Scan and Order Issues

- Create indexes that match the sorting requirements when your queries need in-memory sorting operations.

Improve Memory Utilization

- The database should receive additional RAM if memory restrictions cause operational issues.
- We should modify WiredTiger cache settings for optimal memory utilization.

Reduce Unused Indexes

- Eliminate unneeded indexes to optimize memory resources.

Enhance Connection Management

- The system reports a current connection count which shows 29 active connections and 471 available connections with 557 total created.

  We should apply connection pooling to prevent excessive creation of new connections by applications.
  Review the connection limits for modification according to the parameter maxIncoming

Optimize Data Writes

To decrease the time for performance, evaluate the latency duration at 0.52 seconds.

- Replace single insert operations with batch operations through insertMany instead of insertOne.
- Execute insert operations with write concerns set at w: 1 to enhance their performance.

Reduce Command Latency

High Command Execution Latency (18.26 sec)

- Check if our database is running excessive background tasks.
- Optimize aggregation pipelines using $merge instead of $out.a

Future Research Opportunities

AI-Driven Query Optimization and Adaptive Indexing

Opportunity:
Research which focuses on machine learning algorithms that run automatic query pattern analysis can lead to reduced read latency (5.68 s) experienced by your system. These methods would gather knowledge through continuous workload analysis to propose or establish best-fit indexes that enhance query performance.

Potential Impact:

- Significant reduction in query execution time through predictive indexing.
- Fewer in-memory scans and improved overall operations per second.

Supporting Evidence:
New research demonstrates that integrating AI optimization techniques into databases like ours enhances query speed and resource efficiency (Kreps, 2023; MongoDB, 2020).

Enhanced Connection Pooling and Dynamic Resource Allocation

Opportunity:
Our database system currently handles 29 live connections out of a maximum capacity of 471 so researchers should investigate adaptive connection pooling mechanisms. The investigation should cover real-time workload pattern analysis for creating dynamic connection resource assignments which may decrease connection churn and optimize system performance when facing varying load levels.

Potential Impact:

- Lower connection overhead and improved latency for operations that depend on establishing new connections.
- Better utilization of server resources without overshooting connection limits.

Supporting Evidence:
Studies on connection pooling have shown that intelligent resource management can yield enhanced performance in distributed systems and reduced latency (Cheng and Gupta, 2021; Benchant, 2021).

Advanced Aggregation Pipeline Optimization

Opportunity:
The 18.26-second command latency suggests that administrative commands and aggregations could be better optimized. Researchers should investigate pipeline optimization alternatives such as performance comparisons between $merge and $out stages as well as the development of new aggregation algorithms which optimize administrative queries and metadata operations.

Potential Impact:

- Reduced command overhead resulting in quicker execution of administrative operations.
- Enhanced responsiveness for complex analytical queries and system maintenance tasks.

Supporting Evidence:
MongoDB's own engineering teams have noted the importance of optimizing aggregation pipelines to avoid performance regressions in large-scale installations (MongoDB, 2020).

Hybrid Caching Techniques and Indexing Strategies

Opportunity:
This study aims to explore how modernized caching models can work together with dynamic indexing systems. The study will analyse how adaptive caching mechanisms combined with smart index creation methods help in reducing the workload of intensive read operations. Systems that cache frequently requested query results and merge these with optimized indexes achieve improved performance by decreasing read delays and saving memory resources.

Potential Impact:

- Significant performance boosts for read-heavy workloads.
- Decreased need for costly in-memory sorting operations.

Supporting Evidence:
Prior research has highlighted hybrid caching as an effective means to improve search and query performance in NoSQL databases (Seybold, 2023).

Intelligent Write Batching and Consistency Optimization

Opportunity:
The current operational performance of write operations stands at 0.52 seconds which justifies additional research to examine intelligent write batching methods that include insertMany() with optimized write concerns. The research should investigate how different consistency models can be modified to decrease write latency without compromising data security.

Potential Impact:

- Improved throughput during peak insert scenarios.
- Potential reduction in overall document load and CPU usage by minimizing the number of individuals write operations.

Supporting Evidence:
Experiments in scaling NoSQL databases indicate that optimized batching techniques can provide substantial performance benefits, particularly in systems with moderate workloads (Kreps, 2023).

Granular System Monitoring and Predictive Maintenance

Opportunity:
Presently your system utilizes minimal memory resources based on current measurements of resident memory and virtual memory alongside absence of page faults, but deeper data analysis could detect early indicators of CPU and memory use issues. A research project will create new measurement methods with real-time analytics capabilities to forecast performance decline before it disrupts system functionality.

Potential Impact:

- Early detection of potential bottlenecks.
- Opportunities to pre-emptively initiate scaling or optimization procedures, thereby ensuring consistent system performance.

Supporting Evidence:
Granular monitoring systems have been shown to be crucial for maintaining performance in modern, scalable database platforms (MongoDB, 2020; Benchant, 2021).

Conclusion

The project presents a complete and structured implementation of a distributed, document-oriented database system designed for modern e-commerce platforms. By using MongoDB as the chosen NoSQL technology, the team effectively addressed the limitations of traditional relational databases. These include rigid schema structures, limited horizontal scalability, and performance issues under heavy traffic.

The project uses a modular architecture based on microservices. This approach allows different parts of the system, such as product management, user profiles, order processing, and reviews, to be developed and deployed independently. It supports future scalability and easier maintenance, which aligns with current best practices in backend system design.

Testing confirmed that CRUD operations worked correctly across all collections. Performance testing showed consistent results even when multiple users accessed the system at the same time. The use of MongoDB Atlas allowed the system to be deployed in the cloud, making it accessible remotely and simulating a distributed environment.

Analysis of the system's operations and latency uncovered areas where further improvement is possible. These include optimizing queries, reducing read delays, and managing connections more efficiently. The report offers practical solutions such as better indexing, batch processing for data writes, and adaptive connection pooling. It also highlights research opportunities in areas like intelligent caching and AI-driven optimization that could improve the system's speed and reliability.

In summary, the project delivers a functional and scalable prototype that is suitable for further development. The system is ready to handle real-world e-commerce demands thanks to its clear design, cloud deployment, and solid performance testing. It provides a strong foundation for future growth and innovation in database-driven applications.

Summary of Findings

System Functionality

- Successfully implemented core CRUD operations across users, products, orders, and reviews.
- All sample data was inserted without duplication due to pre-check logic.
- Mongoose models ensured proper schema validation for each collection.

Performance and Scalability

- Insert and query operations completed with acceptable latency (300–400 ms).
- MongoDB Atlas enabled remote, distributed access with 29 active connections and room for scaling.
- Write latency was low (0.52 seconds), but read and command latencies (5.68 and 18.26 seconds) revealed performance limitations under certain loads.

Testing Results

- Functionality and performance tests confirmed system stability under simulated multi-user conditions.
- No data corruption or conflicts were observed during concurrent execution.

Architecture and Design

- The use of a microservices-based architecture enhanced modularity and maintainability.
- MongoDB's flexible schema and support for sharding and replication proved well-suited for dynamic e-commerce data.

Challenges and Solutions

- Connection issues were resolved by updating IP whitelist settings in MongoDB Atlas.
- Duplicate insertions were prevented using `findOne` checks before database writes.
- Absence of a shared `.env` file was addressed with the creation of a `.env.example` template.

System Strengths

- Flexible schema supports changing product data structures.
- Horizontal scalability allows the system to grow with demand.
- Cloud-based deployment supports distributed teamwork and remote usage.

Areas for Improvement

- High read latency suggests the need for better indexing.
- Command latency could be reduced with aggregation pipeline optimization.
- Memory usage and resource monitoring should be enhanced for large-scale deployments.

Final Reflections

This project offered a practical understanding of how NoSQL databases like MongoDB can support scalable, flexible e-commerce systems. We learned how to design modular microservices, implement CRUD operations efficiently, and deploy to a distributed cloud environment. Challenges such as duplicate inserts, connection issues, and configuration management strengthened our problem-solving skills. The testing process taught us the importance of monitoring performance and optimizing queries. Overall, the experience enhanced both our technical abilities and teamwork, preparing us for future work in database-driven, cloud-based development.

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