F25-314-D-CoWriteIA

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Chapter 1

Introduction

CoWriteIA is an AI-powered writing assistant designed to support creative writers, novelists, researchers, and content creators. Modern writing workflows require managing notes, drafts, characters, scenes, and references across several disconnected tools, which often breaks focus and reduces productivity. Writers struggle to maintain narrative consistency, track earlier ideas, and keep a coherent writing style when working on long projects. Existing tools offer only isolated features such as grammar correction or basic generation and do not provide project-level understanding or semantic memory [5, 8].

CoWriteIA addresses these issues by creating a unified, intelligent workspace where all project files are indexed, searchable, and semantically connected. By integrating project-level memory, context-aware writing, dialogue generation, character management, and research support, the system helps writers maintain consistency and improve their creative process. The platform is designed to reduce cognitive load, avoid fragmented workflows, and provide meaningful AI assistance throughout the writing journey. This chapter presents the background, existing solutions, problem statement, scope, project modules, and work division that form the foundation of this system.

1.1 Existing Solutions

Several writing and AI-assisted tools exist, but each focuses on limited aspects of the writing process. Grammarly offers grammar correction and style suggestions but lacks deep contextual awareness across long projects. Notion AI and Jasper AI provide generative assistance but do not maintain story-level continuity or user-specific writing style. Tools like Scrivener help with organization but have no semantic understanding or AI memory. As a result, writers must repeatedly switch between applications to manage notes, drafts, characters, and research, leading to inefficiency and inconsistent writing flow.

Table 1.1: Comparison of Existing Solutions

System Name	System Overview	System Limitations
Grammarly	Provides grammar correction, clarity improvements, and tone suggestions.	No project awareness, no memory of earlier chapters, no semantic search.
Notion AI	Offers AI-assisted content generation and note organization.	Cannot maintain narrative consistency; lacks dialogue and character support.
Scrivener	Strong organizational tool for large writing projects with chapter/scene structure.	No AI support, no semantic retrieval, no automated gap or style analysis.

1.2 Problem Statement

Writers working on long-form projects often lose track of earlier ideas, character traits, plot points, and stylistic decisions. This leads to inconsistencies, repeated ideas, and a break in narrative flow. Existing tools either provide isolated writing support or document organization but do not combine both with meaningful context. AI tools can generate text but fail to maintain project-level continuity, making the generated text feel disconnected from the writer's established style or storyline. Writers spend significant time searching through older drafts to recall information [3, 5].

CoWriteIA aims to solve these problems by offering an intelligent system that continuously indexes all project content, retrieves relevant context, and assists writers in generating text that aligns with their established narrative and writing style. By maintaining a unified knowledge base and supporting character consistency, scene management, dialogue generation, and semantic search, the system reduces cognitive overhead and improves creative flow.

1.3 Scope

The scope of **CoWriteIA** encompasses the development of an intelligent, AI-driven writing environment designed to support long-form creative and research-oriented projects. The system focuses on providing project-level understanding, semantic reasoning, and context-aware assistance to help writers maintain consistency, creativity, and workflow continuity.

In-Scope Features

- **Project Management and Indexing** — Upload, organize, and store documents across multiple writing projects.
- **Semantic Search and Retrieval** — Retrieve information using a vector-based se-

mantic memory instead of keyword matching [4, 8].

- **Context-Aware Writing Assistance** — Generate or refine text that aligns with prior chapters, scenes, tone, and writing style.
- **Dialogue and Narrative Support** — Produce character-consistent dialogues and maintain scene-level continuity.
- **Character and Knowledge Storage** — Maintain detailed character profiles, relationships, and narrative facts.
- **Research Integration** — Fetch, summarize, and integrate external factual information to support realistic writing.
- **Style Adaptation** — Adapt AI-generated content to match the user's writing voice across the project.

Out-of-Scope Features

- Plagiarism detection or originality scoring.
- Multimedia editing such as images, audio, or video.
- Complete publishing or formatting pipelines (e.g., EPUB, print layout).
- Full-fledged grammar-only tools or scriptwriting-specific toolkits.

Scope Summary

CoWriteIA is limited to enhancing the *writing process itself*: maintaining narrative consistency, providing intelligent context-aware support, and simplifying research-driven creative decision making. The system does not aim to replace editing, publishing, or multimedia tools, but instead acts as a unified, intelligent workspace to elevate author productivity and coherence throughout the creative workflow.

1.4 Modules

The project consists of several modules, each responsible for a unique part of the writing workflow.

1.4.1 Module 1: Project Indexing and Semantic Memory

This module extracts, embeds, and organizes all project content into a semantic database for context-aware retrieval [8].

1. Automatic project indexing and embedding generation.
2. Semantic search based on meaning instead of keywords.

1.4.2 Module 2: Context-Aware Writing Assistant

This module provides intelligent writing suggestions that match the user's tone and project context [5].

1. Generates coherent drafts aligned with past content.

2. Retrieves relevant information to maintain consistency.

1.4.3 Module 3: Character and Scene Management

This module stores and manages characters, scenes, and narrative details.

1. Character profiles with traits and relationships.
2. Scene storage and tracking.

1.4.4 Module 4: Dialogue Generation

Generates natural, character-consistent dialogue suggestions.

1. Dialogue generation based on personality and context.
2. Supports narrative flow within scenes.

1.4.5 Module 5: Research Integration

Fetches factual data from external sources for realistic writing.

1. Web-based research retrieval.
2. Insertable factual references.

1.4.6 Module 6: Project Query Interface

Allows users to ask natural-language questions about their own project.

1. Semantic question-answering.
2. Source-linked responses.

1.4.7 Module 7: Gap Analysis Module

Analyzes draft content to find missing or weak areas.

1. Identifies incomplete sections.
2. Suggests improvements for clarity and consistency.

1.5 Work Division

The work completed during FYP-1 was divided into two major iterations. A summary of responsibilities is presented in the tables below.

Iteration I Tasks

Table 1.2: Work Division for Iteration I

Task	Ayesha	Junaid	Aisha
SRS Document	✓	✓	✓
UML Diagrams	✓	✓	✓
UI Design		✓	✓
Database Connection		✓	✓
Frontend (Main Pages)	✓		
Project Indexing Agent	✓	✓	
Knowledge Retrieval Agent		✓	✓
ChatBot Support		✓	

Iteration II Tasks

Table 1.3: Work Division for Iteration II

Task	Ayesha	Junaid	Aisha
Inline Copilot Support	✓		
Context-Aware Writing Module	✓		
Gap Analysis Module			✓
Style Adaptation		✓	
Testing	✓	✓	✓
Documentation (All Sections)	✓	✓	✓

Project Timeline

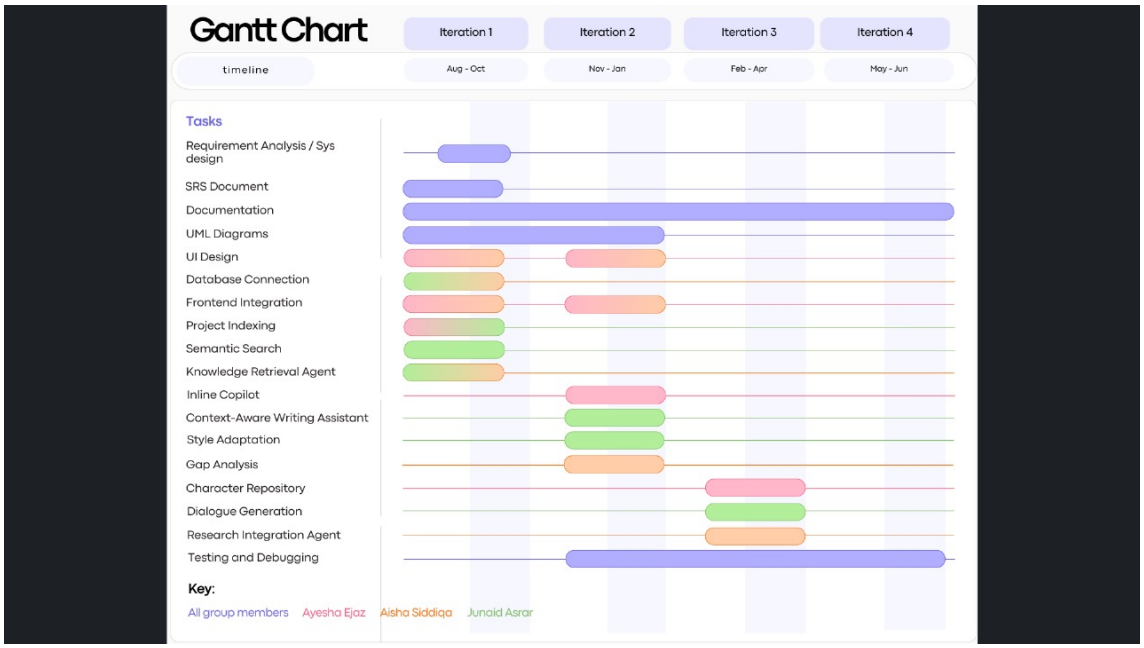


Figure 1.1: Gantt Chart - Project Timeline

Chapter 2

Project Requirements

This chapter defines the requirements essential for developing CoWriteIA. These requirements were derived from the FYP-1 Proposal, Mid Report, and the SRS document. They describe how the system should behave, how users will interact with it, and what constraints and quality standards must be followed. The requirements are divided into functional and non-functional categories, with additional details about expected user interactions.

2.1 Use-case

CoWriteIA provides writers with AI-assisted features such as project indexing, semantic retrieval, character management, context-aware writing, and dialogue generation. To clearly define how users interact with these features, system behavior is modeled through detailed use cases.

A use case describes the interaction between the primary actor (the writer) and the system to accomplish a specific task. Each use case outlines the trigger event, preconditions, main workflow steps, and system responses. These models help ensure that system functionality aligns with user expectations and guide the design of interactive features.

In addition to textual use cases, a visual representation in the form of a Use-Case Diagram provides an overview of the major user interactions with CoWriteIA. This includes actions such as uploading documents, retrieving semantic context, generating content with the writing assistant, managing characters, and initiating dialogue generation. Such diagrams help maintain clarity, consistency, and completeness throughout the system design.

A detailed use case example for the core functionality **Generate Context-Aware Writing (UC-01)** is provided in Appendix D. This detailed use case outlines the complete interaction flow including preconditions, main flow steps, alternate flows, exceptions, and postconditions. The use case demonstrates how the system retrieves semantic context, processes user requests through the AI model, and delivers generated content while han-

dling various edge cases such as missing embeddings or service unavailability.

2.2 Functional Requirements

The functional requirements describe the operations the CoWriteIA system must support. These requirements come directly from the system features identified in the Proposal and SRS.

2.2.1 Module 1: Project Indexing and Semantic Memory

This module handles ingestion, indexing, and semantic storage of project documents.

1. The system shall allow users to upload project files including text documents, chapters, notes, and research material.
2. The system shall extract, segment, and convert uploaded content into embeddings for semantic retrieval.
3. The system shall store embeddings in a vector database.
4. The system shall provide semantic search capabilities based on meaning rather than keyword matching.
5. The system shall return ranked search results with source references.

2.2.2 Module 2: Context-Aware Writing Assistant

This module generates content aligned with user writing style and project context.

1. The system shall analyze previous project content to understand tone, terminology, and style.
2. The system shall allow users to generate context-aware text suggestions based on previous chapters or notes.
3. The system shall retrieve relevant context automatically when generating new content.
4. The system shall maintain style consistency between newly generated and existing content.

2.2.3 Module 3: Character and Scene Management

This module manages characters, their traits, and related narrative structures.

1. The system shall allow users to create, edit, and store character profiles.
2. The system shall store attributes such as personality, relationships, behaviors, and backstory.
3. The system shall allow users to manage scenes and attach characters to scenes.
4. The system shall assist in retrieving character information when generating story text or dialogue.

2.2.4 Module 4: Dialogue Generation

This module generates consistent, character-matching dialogue.

1. The system shall generate dialogue aligned with character personality and tone.
2. The system shall allow users to request dialogue for specific characters or scenes.
3. The system shall ensure continuity between generated dialogue and existing narrative.

2.2.5 Module 5: Research Integration Module

This module retrieves factual information to support realistic writing.

1. The system shall allow users to search for factual references.
2. The system shall fetch external information from trusted research sources.
3. The system shall present research results with citations.

2.2.6 Module 6: Project Query Interface

This module allows users to ask natural-language questions about their project.

1. The system shall process user queries related to characters, scenes, chapters, or events.
2. The system shall fetch relevant information from the semantic memory.
3. The system shall provide answers with linked source passages.

2.2.7 Module 7: Gap Analysis Module

This module identifies missing or weak areas of the writer's draft.

1. The system shall analyze uploaded chapters for missing elements such as incomplete scenes or inconsistent character behavior.
2. The system shall highlight areas needing expansion or clarification.
3. The system shall provide suggestions to improve narrative flow and completeness.

2.3 Non-Functional Requirements

Non-functional requirements ensure that CoWriteIA performs reliably, efficiently, and securely.

2.3.1 Usability

1. The system shall provide a simple and intuitive interface accessible to writers with minimal technical expertise.
2. The system shall allow users to perform core actions such as uploading files, searching, and generating text within no more than three interactions.
3. The UI shall clearly present semantic search results with source references.

2.3.2 Performance

1. The system shall index uploaded documents within 5 seconds for an average chapter-length file.
2. Semantic search results shall appear within 2 seconds of a query.
3. Generated text responses shall be produced within 3–5 seconds depending on context length.

2.3.3 Security

1. User project data shall be stored securely using encrypted connections.
2. Only authenticated users shall access their own documents.
3. The system shall not use project data for training without user permission.

2.3.4 Reliability

1. The system shall maintain uptime of at least 99
2. The system shall recover gracefully from API or model failures by retrying or presenting fallback responses.

2.3.5 Maintainability

1. The codebase shall follow modular architecture to allow updates to individual agents.
2. The system shall support integration of new language models without requiring major structural changes.

2.3.6 Compatibility

1. The system shall run on modern browsers including Chrome, Edge, and Firefox.
2. The frontend shall be built using Next.js and shall be compatible with desktop and tablet interfaces.

2.3.7 Scalability

1. The vector database shall support scaling as the user creates larger projects.
2. The system shall handle multiple concurrent requests without significant performance degradation.

Chapter 3

System Overview

Introduction

This chapter provides a high-level description of the system's overall functionality, context, and architectural design. The aim is to present how the major parts of the system interact and why the system has been decomposed into specific modules and tiers.

System Overview

CoWriteIA is an AI-assisted writing platform designed to support writers through various stages of the creative process [2, 6, 7]. The system enables users to:

- Create and manage writing projects
- Upload and organize documents
- Manage character profiles and story elements
- Generate and refine written content using AI assistance

To efficiently support these features, the system separates concerns into distinct, coordinated components: user interaction, application logic, AI processing, and data management.

3.1 Architectural Design

The architecture of CoWriteIA follows a **multi-tier model**, combining **client–server** and **layered** principles. This structure organizes the system into four logical tiers, each with specific responsibilities to ensure maintainability, scalability, and clarity.

Architectural Tiers

Data Storage Components

- **Main Database**: Stores structured system data (users, projects, characters)
- **Vector Database**: Manages embeddings for semantic retrieval and search

Tier	Component	Responsibilities
Presentation	Frontend Application	User interaction, interface rendering, and user input handling
Application Logic	Backend (API Server)	Authentication, business workflows, and project/document/character management
AI Processing	Processing Worker	Embeddings generation, semantic retrieval, and AI text generation
Data	Storage Systems	Structured data, vector storage, and file management

Table 3.1: Architectural Tiers and Responsibilities

- **File Storage**: Handles uploaded documents and exported files

Architectural Diagram

A detailed architecture diagram illustrating the complete multi-tier structure of CoWriteIA is provided in Appendix C (Figure A.3).

Diagram Development Process

- **Initial Design Stage**: Create a *Box and Line Diagram* for simpler representation of systems
- **Finalization Stage**: After selecting the architecture style/pattern (MVC, Client-Server, Layered, Multi-tiered), create detailed mapping of modules/components to each part of the architecture

Design Principles

This architectural decomposition supports the system's functional requirements while ensuring:

- **Flexibility**: Components can be modified independently
- **Maintainability**: Clear separation of concerns simplifies updates and debugging
- **Scalability**: Each tier can be scaled independently based on demand
- **Security**: Controlled data flow between tiers with proper authentication

Key Architectural Decisions

- **Separation of AI Processing**: Intensive AI tasks are handled by dedicated workers to maintain API responsiveness
- **Multi-tier Structure**: Enables independent development, testing, and deployment of each tier

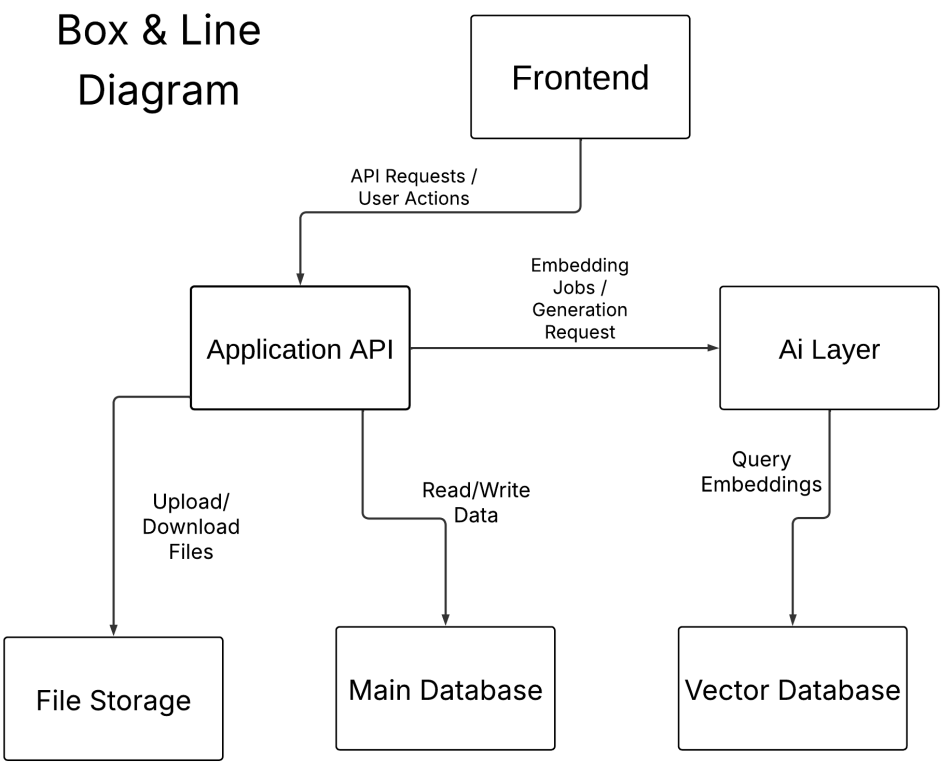


Figure 3.1: Box and Line Diagram

- **Modular Design**: Supports future enhancements and feature additions

3.2 Data Design

The data design of CoWriteIA transforms functional requirements into structured data models that support **project creation**, **AI-assisted writing**, **semantic search**, **character management**, and **dialogue modelling**.

Data Organization

The system organizes data into three primary categories:

- **Relational Data**: User accounts, projects, documents, characters, and chat sessions stored in a structured database with defined schemas and foreign key relationships
- **Vector Data**: High-dimensional embeddings generated from text content, enabling semantic similarity search and context retrieval
- **Binary Data**: Uploaded files and exported documents stored separately with metadata linkage

Data Flow and Transformation

Data flows through multiple transformation stages:

- **Input Processing**: User actions validate and create/update structured database records
- **Embedding Generation**: Text content is transformed into vector representations for AI operations
- **Retrieval Augmentation**: Semantic queries fetch relevant context from vector and relational stores
- **Output Generation**: AI responses and exports combine retrieved data with generated content

This design ensures **data integrity**, **efficient retrieval**, and **scalable processing**. Recent work on efficient local models such as Phi-3 highlights practical on-device capabilities for embedding and retrieval [1].

Figure 3.2 provides the Entity–Relationship Diagram showing database schema structure, while Figure 3.4 presents the conceptual domain model.

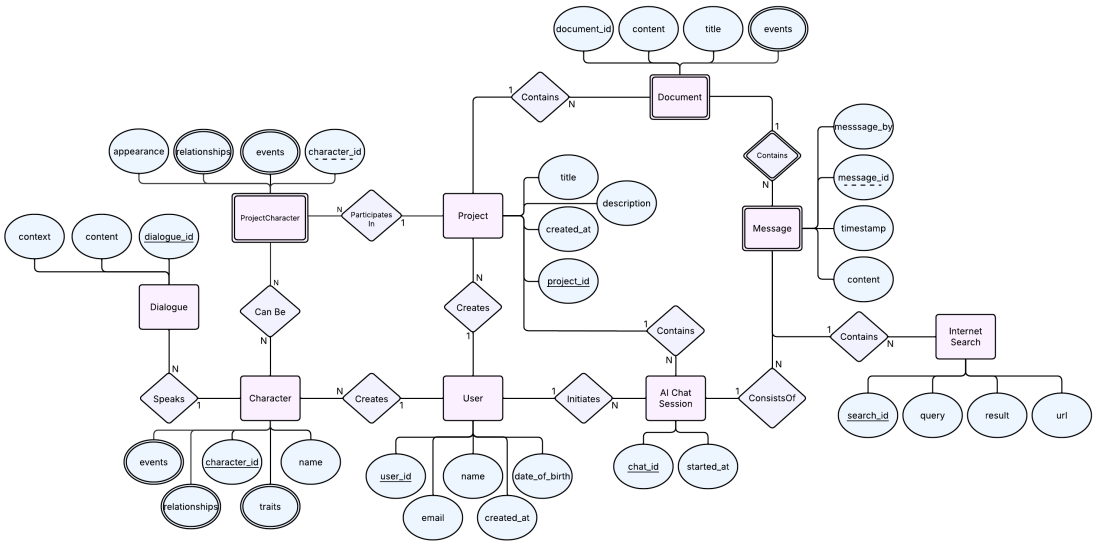


Figure 3.2: Entity–Relationship Diagram for CoWriteIA

3.2.1 Class Diagram

The class diagram represents the object-oriented view of the system and shows classes, attributes, and associations used by the application logic. It provides a structural foundation for backend implementation and helps ensure consistency between the conceptual design and the code-level architecture.

3.3 Domain Model

The domain model provides a conceptual view of the system's core entities and their relationships, bridging functional requirements and technical implementation. It describes

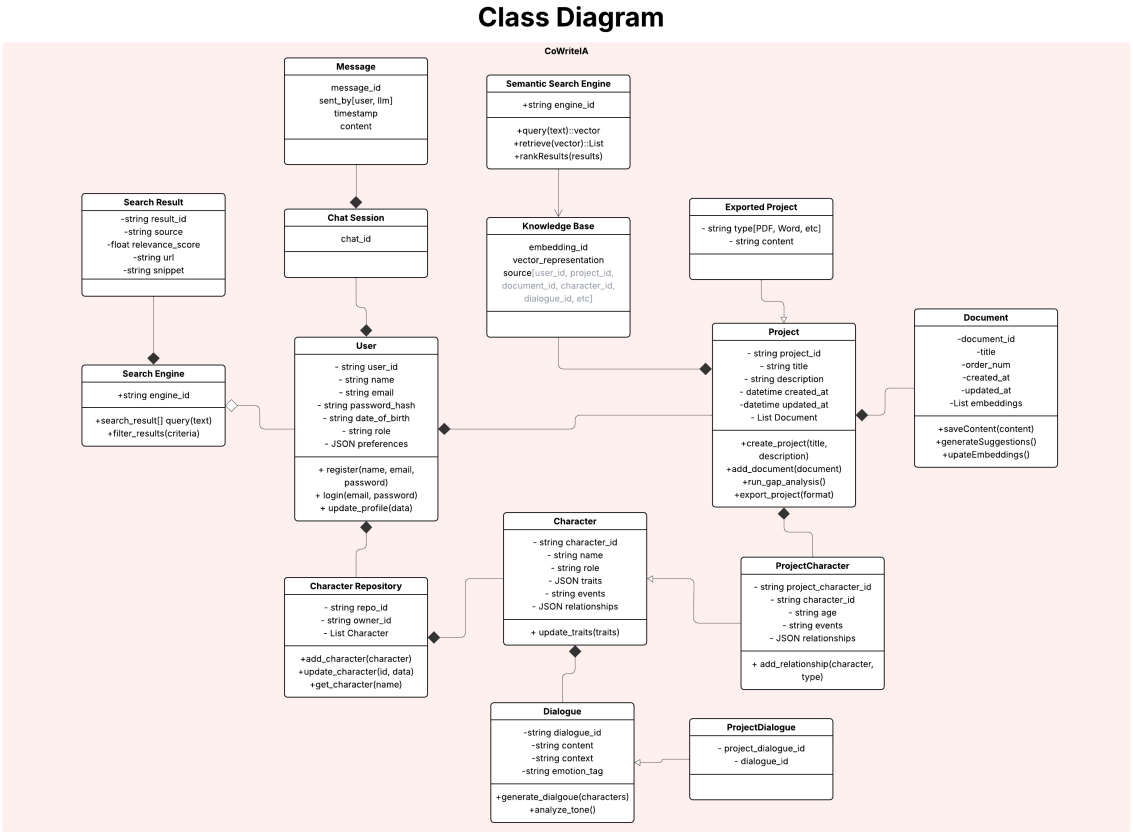


Figure 3.3: Class Diagram for CoWriteIA

the key business objects, their attributes, and how they interact within CoWriteIA.

Entities and Attributes

The major entities of the system include:

- **User**: Represents a system user who owns projects and interacts with the AI. Attributes include `user_id`, `name`, `email`, `date_of_birth`, `password_hash`, `role`, and `created_at`.
- **Project**: A workspace created by the user. Attributes include `project_id`, `title`, `created_at`, and `updated_at`.
- **Document**: Represents a chapter or section of a project. Attributes include `document_id`, `title`, `order_num`, `created_at`, and `updated_at`.
- **Character Repository**: A user-owned collection that groups all character profiles.
- **Character**: Represents a story character. Attributes include `character_id`, `name`, `traits`, `history`, `created_at`, and `updated_at`.
- **ProjectCharacter**: An association class linking characters with specific projects. Stores project-specific values such as `age` and `events`.
- **Dialogue**: Represents character dialogues. Attributes include `dialogue_id`, `content`, `context`, and `emotion_tag`.
- **ProjectDialogue**: A linking entity that associates dialogues with a project.
- **Chat Session**: Represents an AI chat interaction initiated by the user. Identified by `chat_id`.
- **Message**: Stores an individual message in a chat session. Attributes include `message_id`, `sent_by`, `timestamp`, and `content`.
- **Search Engine**: Represents the semantic search component.
- **Search Result**: Stores contextual search outputs. Attributes include `result_id`, `query`, and `content`.
- **Knowledge Base**: Stores vector embeddings and source references. Attributes include `embedding_id`, `vector_representation`, and `source_ids`.
- **Exported Project**: Represents generated output files such as PDF or Word exports.

3.3.1 Relationships and Associations

The domain model defines the relationships that structure how information flows across the system:

- A **User** owns multiple **Projects**.
- A **Project** contains multiple **Documents**.
- A **User** owns a **Character Repository**, which stores many **Characters**.
- A **Project** includes multiple **Characters** via **ProjectCharacter**.
- A **Character** speaks one or more **Dialogues**.
- A **Project** associates specific dialogues through **ProjectDialogue**.
- A **User** initiates a **Chat Session**.

- A **Chat Session** stores multiple **Messages**.
- The **LLM Chatbot** interacts with the **Semantic Search Engine** and **Knowledge Base** to generate responses.
- The **Search Engine** produces multiple **Search Results**, which may be injected into messages or documents.

These relationships ensure that writing, character creation, semantic search, and AI interactions remain consistent and interconnected across the system.

3.3.2 Domain Model Diagram

Figure 3.4 presents the complete domain model for CoWriteIA. It includes all major entities, attributes, and associations, including weak entities and conceptual relationships.

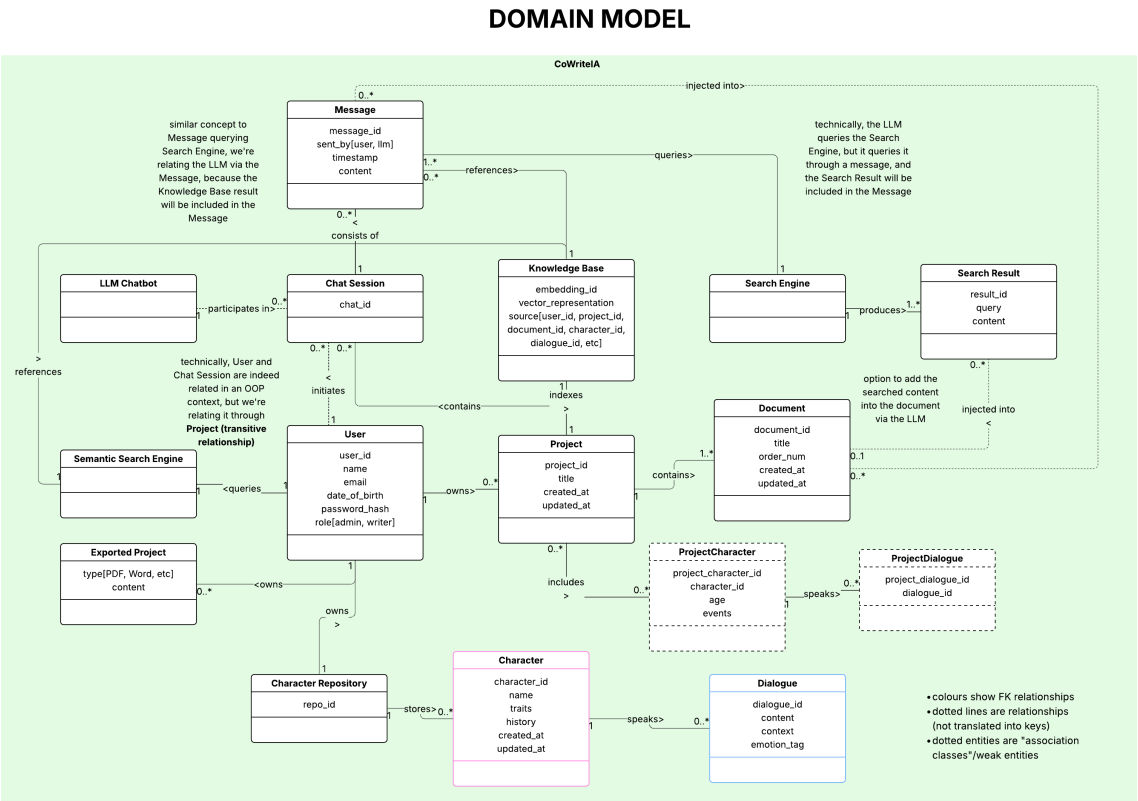


Figure 3.4: Domain Model Diagram for CoWriteIA

3.4 Design Models

3.4.1 Sequence Diagrams

This subsection presents sequence diagrams for the four main system flows, based on the implementation logic described in Chapter 4. Each diagram outlines the interactions between system components for a key workflow.

1. File Upload & Chunking

Actors: User, API Endpoint, TextExtractionService, TextChunkRepository

1. User uploads file via API endpoint.
2. API calls `TextExtractionService.extract_text_from_file`.
3. API calls `TextExtractionService.chunk_text` to split text into chunks.
4. Chunks are created and saved via `TextChunkRepository`.

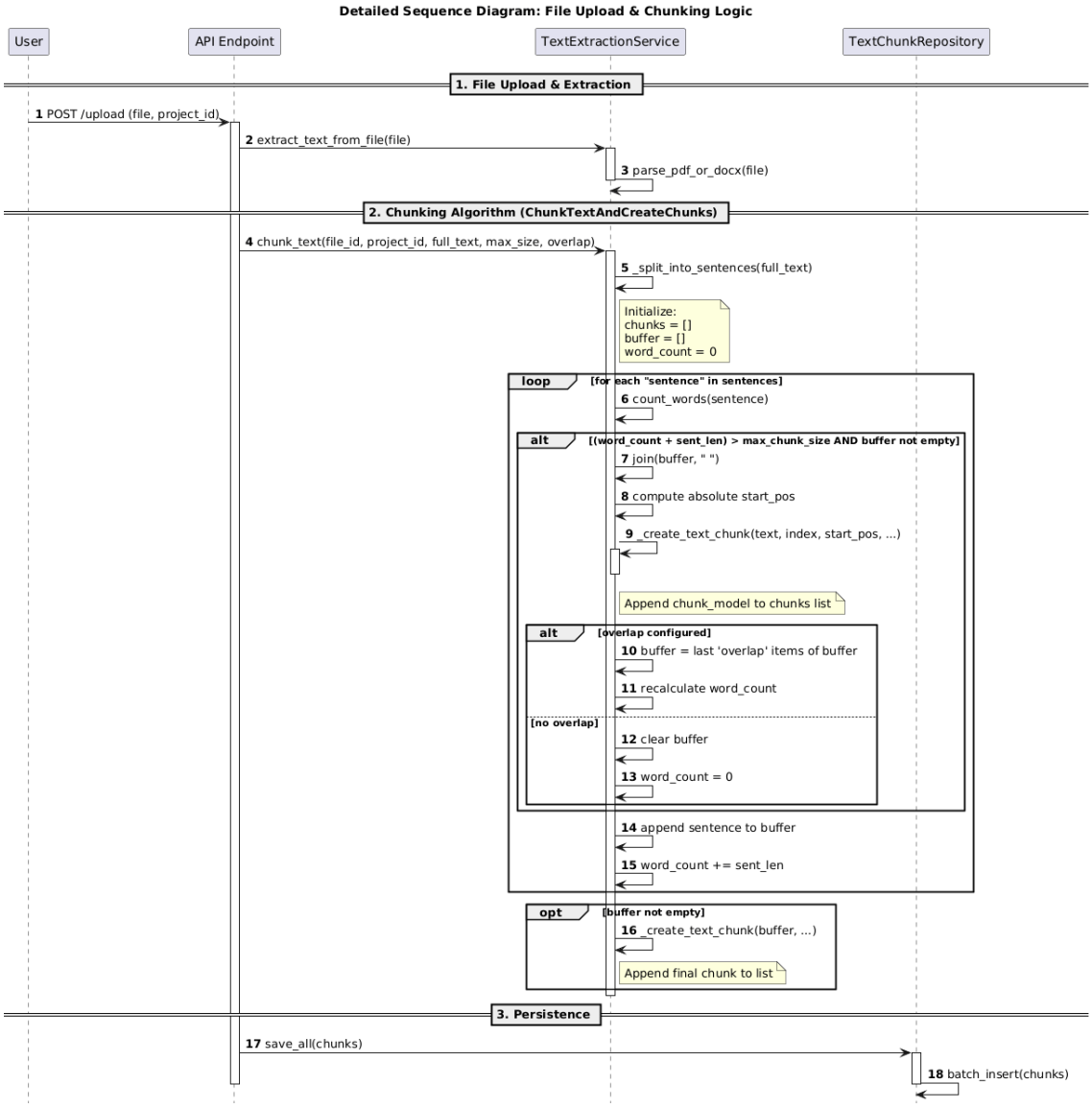


Figure 3.5: Sequence Diagram: File Upload & Chunking

2. Embedding Generation & Storage

Actors: API/Orchestrator, EmbeddingService, TextChunkRepository, ChromaService

1. **Batch Encoding:** The system extracts content strings from the chunks and calls

`EmbeddingService.generate_embeddings`. This runs a threadpool execution where the model loads lazily to convert text into dense vector representations.

2. **Metadata Persistence:** The system iterates through the original chunks and generated embeddings simultaneously. For each pair, a `TextChunk` model is built and saved to MongoDB via the `TextChunkRepository`.
3. **Vector Indexing:** If the `ChromaService` is configured and available:
   - The system maps the saved chunks to Chroma-compatible entries (ID, vector, and metadata).
   - It performs a bulk insert via `ChromaService.add_embeddings` to enable semantic search.
4. **Fallback:** If Chroma is unavailable, the embeddings remain stored solely within the MongoDB documents.

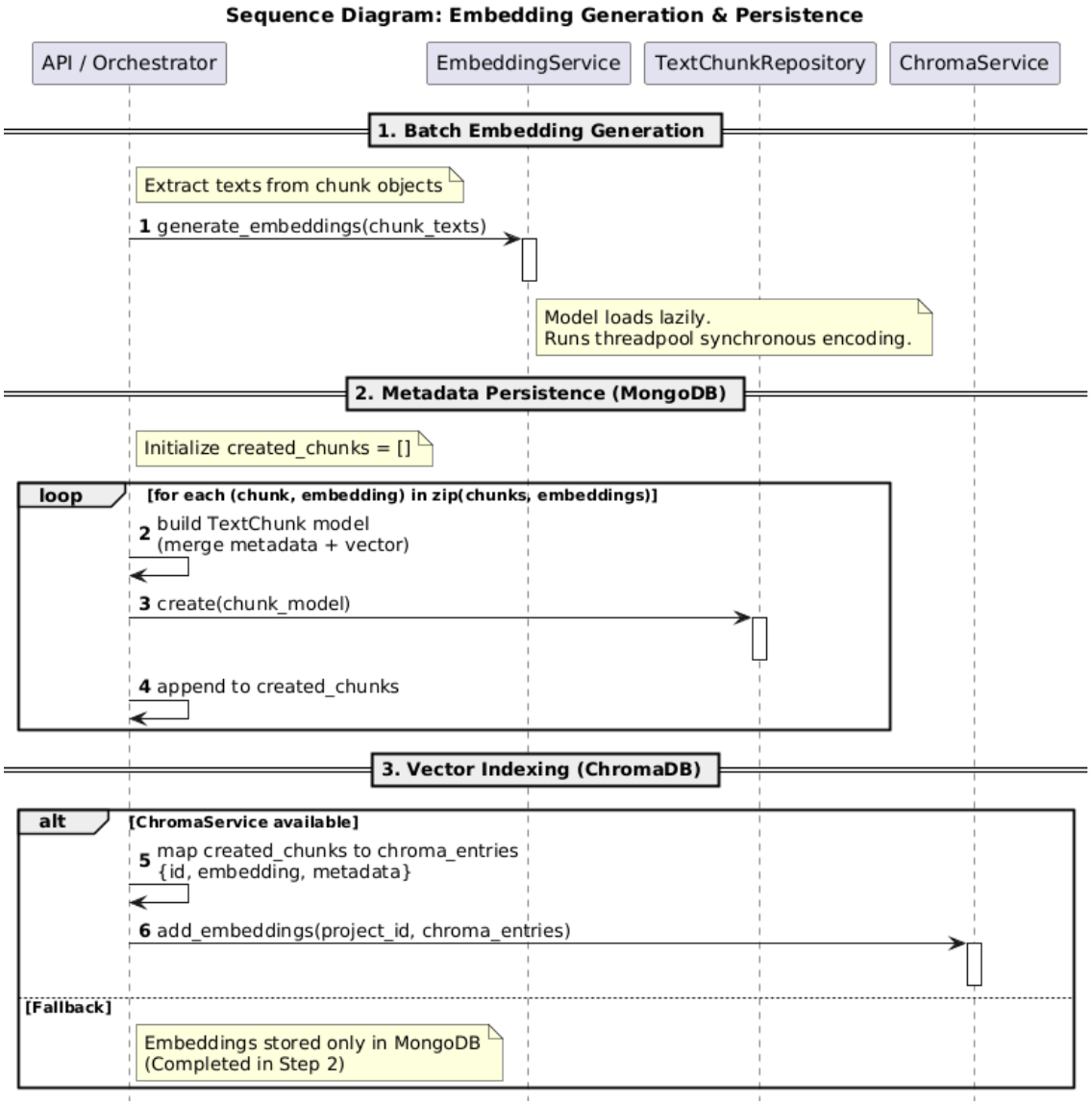


Figure 3.6: Sequence Diagram: Embedding Generation & Storage

3. Semantic Search / RAG Context Retrieval

Actors: User, API Endpoint, RAGContextService, ChromaService, SearchService, TextChunkRepository

1. User sends a search/query.
2. API calls `RAGContextService.assemble_context`.
3. RAGContextService generates query embedding.
4. ChromaService or TextChunkRepository performs vector search.
5. Top chunks and metadata are assembled and returned.

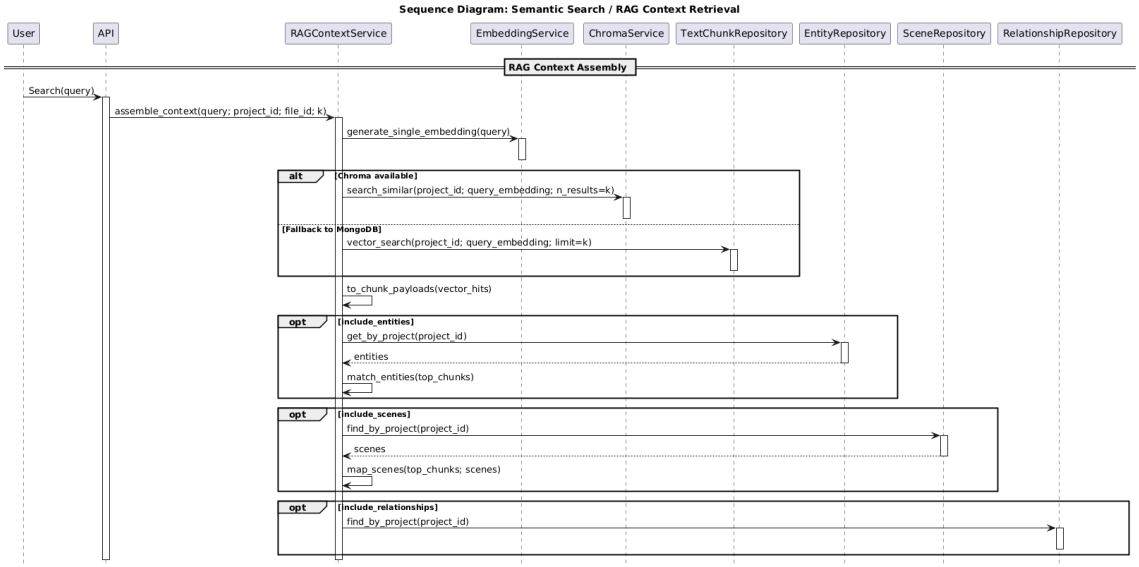


Figure 3.7: Sequence Diagram: Semantic Search / RAG Context Retrieval

4. AI Response Generation

Actors: User, API Endpoint, RAGContextService, AIChatService, GroqService, MessageRepository

1. User sends a message.
2. API calls `RAGContextService.assemble_context`.
3. Context is formatted for LLM.
4. AIChatService builds prompt and calls GroqService (LLM).
5. LLM response is cleaned and saved via MessageRepository.
6. Response returned to user.

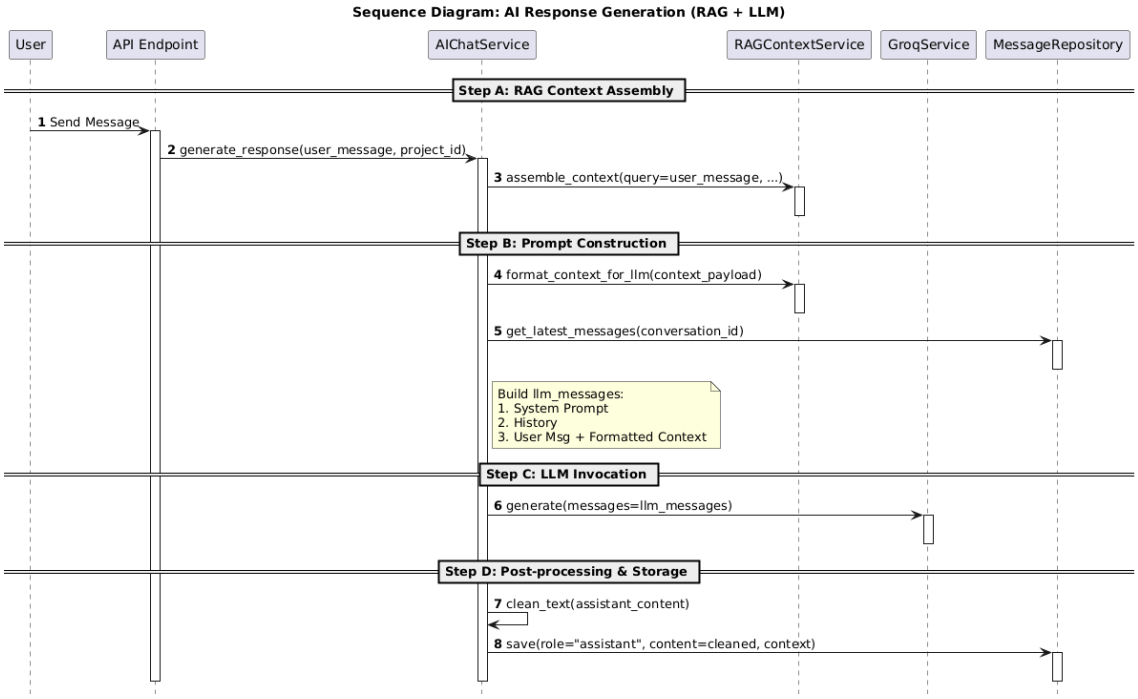


Figure 3.8: Sequence Diagram: AI Response Generation

5. Reprocessing & Incremental Update

Actors: User/Admin, TextChunkRepository, FileRepository, TextExtractionService, EmbeddingService

1. File is marked for reprocessing.
2. Existing chunks are deleted.
3. File is marked ready for processing.
4. Text is extracted and chunked again.
5. Chunks are inserted.
6. Embeddings are regenerated and stored.

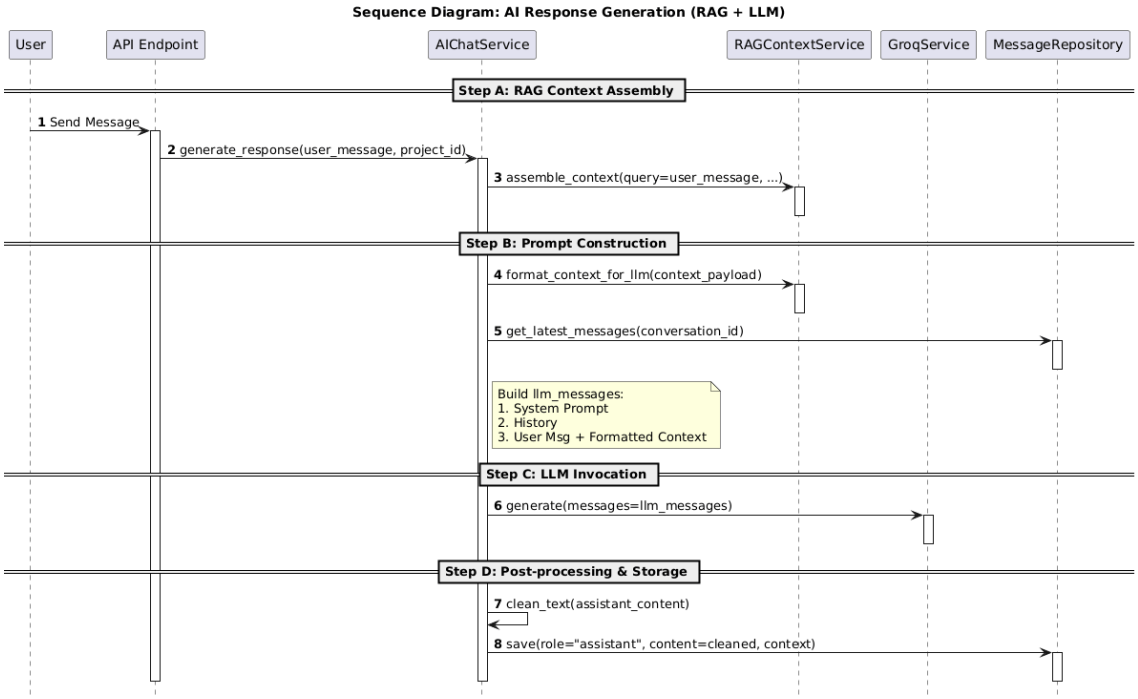


Figure 3.9: Sequence Diagram: Reprocessing & Incremental Update

3.4.2 State Transition Diagram

Figure 3.10 illustrates state transitions for key entities based on user actions and system events. The diagram shows how entities move between states:

- **Project**: Transitions from Draft → Active → Archived/Deleted based on user actions
- **Document**: Moves through Creating → Editing → Saved → Publishing → Published states
- **Chat Session**: Cycles between Idle → Processing → Waiting for User → Completed
- **Character**: Changes from Draft → Active → Archived as needed

These transitions ensure proper lifecycle management and data consistency throughout the system.

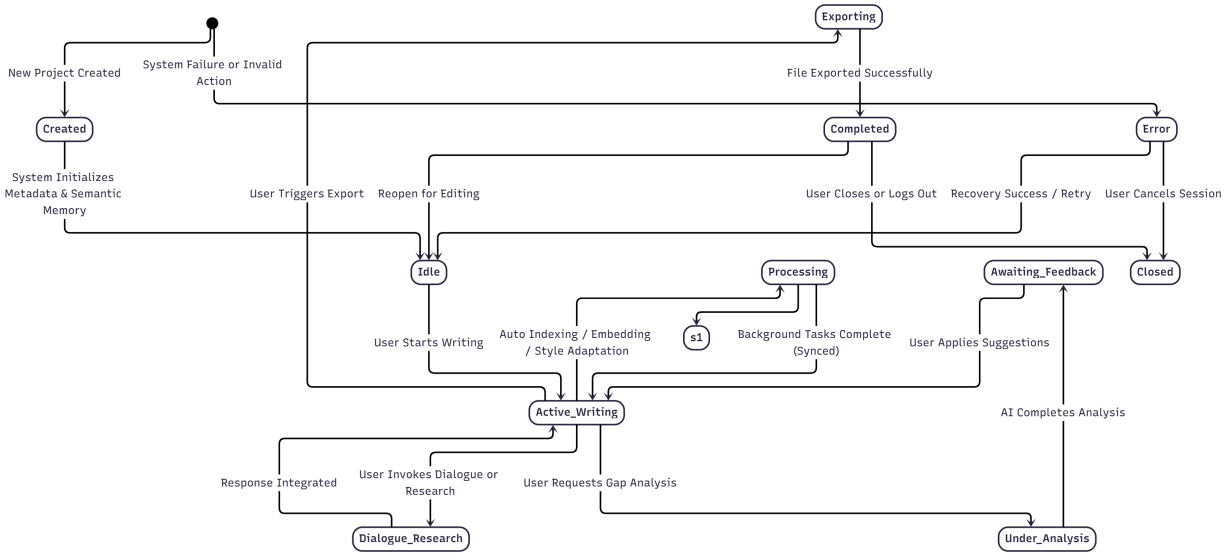


Figure 3.10: State Transition Diagram for CoWriteIA

Chapter 4

Implementation and Testing

This chapter describes the current implementation status of the CoWriteIA system and the testing strategies applied to validate its functionality. The focus of this phase was to implement the core backend services, major APIs, and conduct rigorous black box testing to ensure that all user-facing functionalities behave correctly according to the system requirements.

The implementation described in this chapter reflects the progress achieved up to the current iteration of the project.

4.1 Algorithm Design

The system implements a Retrieval-Augmented Generation (RAG) pipeline to enable intelligent document-based responses. The algorithm focuses only on the core functional requirements: document processing, semantic indexing, context retrieval, and AI response generation.

The CoWriteIA implementation in this repository realizes a semantic indexing + RAG (retrieval-augmented generation) pipeline. The implemented components (and their primary locations in the codebase) are:

- Document chunking and preprocessing
  - `backend/app/services/text_extraction_service.py :: TextExtractionService./ _create_text_chunk`
- Embedding generation and vector storage
  - `backend/app/services/embedding_service.py :: EmbeddingService.generate_si generate_embeddings, store_text_chunks_with_embeddings`
  - `backend/app/services/chroma_service.py :: ChromaService.add_embeddings, search_similar`
  - `backend/app/repositories/text_chunk_repository.py :: update_embedding, get_chunks_without_embeddings, vector_search / vector_search_chroma`

- Context retrieval (semantic similarity)
  - `backend/app/services/rag_context_service.py :: RAGContextService.assemble`
  - `backend/app/services/search_service.py :: SearchService.semantic_search, find_similar_content`
- AI response generation (RAG orchestration and assistant)
  - `backend/app/services/ai_chat_service.py :: AIChatService.chat`
  - `backend/app/services/copilot_service.py :: CopilotService.generate_sugges`

The following subsections contain concise algorithm descriptions derived from the actual implementation and precise pseudocode that maps to the repository functions.

4.1.1 High-level Flow

1. User uploads file via endpoints in `backend/app/api/v1/endpoints/files.py`.
2. File processing triggers text extraction and chunking:
   - `TextExtractionService.extract_text_from_file(...)` and `TextExtractionService`
   - Chunks are created as `TextChunk` models and persisted via `TextChunkRepository`.
3. Embeddings are generated for chunks:
   - `EmbeddingService.generate_embeddings(...)` / `generate_single_embedding(...)`
   - Embeddings saved both in chunk metadata (MongoDB) and in ChromaDB via `ChromaService` when available.
4. Semantic search / RAG:
   - `RAGContextService.assemble_context(...)` calls embedding/search services to retrieve top-k chunks.
   - `SearchService` handles hybrid/fallback logic (ChromaDB preferred, fallback to MongoDB vector search).
5. LLM generation:
   - `AIChatService.chat(...)` or `CopilotService.generate_suggestion(...)` build a prompt from the retrieved context and call the configured LLM (`GroqService` or other).
6. Results returned to the client; metadata and analytics stored as needed.

Example short sequence (mapping code → runtime)

1. User uploads file → API endpoint in `backend/app/api/v1/endpoints/files.py` triggers `process_uploaded_file`.
2. `process_uploaded_file` calls `TextExtractionService.chunk_text` to create chunks.
3. Indexing background task (or immediate synchronous call) calls `EmbeddingService.generate_emb` for chunks.
4. `EmbeddingService` stores embeddings via `TextChunkRepository` and `ChromaService`.
5. Later, user sends search/query → `RAGContextService.assemble_context` retrieves top chunks using `ChromaService` or `SearchService`.

6. `AIChatService.chat` builds prompt with context and calls `GroqService` (LLM); response persisted and returned.

4.1.2 Pseudocode: Document Chunking and Preprocessing

The system splits extracted text into sentence-aware chunks within a target size and optionally applies overlap. Each chunk is materialized using the implementation in `backend/app/services/`

Algorithm 1 ChunkTextAndCreateChunks

Require: *file_id*, *project_id*, *full_text*, *max_chunk_size*, *overlap* (optional), *start_chunk_index* (default 0)

Ensure: List of `TextChunk` models *chunks*

sentences ← `TextExtractionService._split_into_sentences`(full_text)
chunks ← [ ]
current_chunk_sentences ← [ ]; current_word_count ← 0; chunk_index ← start_chunk_index
for each sentence *s* in sentences **do**
    sentence_words ← `count_words`(*s*)
    if current_word_count + sentence_words > max_chunk_size **and** current_chunk_sentences not empty **then**
        chunk_text ← `join`(current_chunk_sentences, " ")
        start_pos ← compute absolute start in *full_text*
        chunk_model ← `TextExtractionService._create_text_chunk`(file_id, project_id, chunk_text, chunk_index, start_pos, current_word_count)
        append chunk_model to chunks
        chunk_index ← chunk_index + 1
        if overlap configured **then**
            current_chunk_sentences ← take last *overlap* words/sentences of current_chunk_sentences
            current_word_count ← `count_words`(current_chunk_sentences)
        else
            current_chunk_sentences ← [ ]; current_word_count ← 0
        end if
    end if
    append *s* to current_chunk_sentences; current_word_count ← current_word_count + sentence_words
end for
if current_chunk_sentences not empty **then**
    chunk_text ← `join`(current_chunk_sentences, " ")
    start_pos ← compute absolute start in *full_text*
    chunk_model ← `TextExtractionService._create_text_chunk`(file_id, project_id, chunk_text, chunk_index, start_pos, current_word_count)
    append chunk_model to chunks
end if
return chunks

Notes:

- Uses sentence-aware splitting and target size with optional overlap per `TextExtractionService`.

- Returns `TextChunk` Pydantic models; persistence occurs later (e.g., in `store_text_chunks_with_e`

4.1.3 Pseudocode: Embedding Generation and Storage

This stage encodes chunked text into dense vectors and persists both the metadata and vectors. It maps to `EmbeddingService` and `ChromaService` usage in the codebase.

Algorithm 2 GenerateAndPersistEmbeddings

Require: *project_id*, *file_id*, *list_of_chunks* (content strings)

Ensure: List of created/updated `TextChunk` records with embeddings

chunk_texts ← [`chunk.content` for *chunk* in *list_of_chunks*]
embeddings ← `EmbeddingService.generate_embeddings`(chunk_texts) ▷ Runs threadpool synchronous encoding; model loads lazily
created_chunks ← [ ]
for each $(chunk_info, embedding)$ in `zip`(list_of_chunks, embeddings) **do**
    chunk_model ← `build TextChunk`(file_id = file_id, project_id = project_id, content = chunk_info.content, start_position = …, end_position = …, chunk_index = chunk_info.chunk_index, word_count = …, embedding_vector = embedding)
    saved_chunk ← `TextChunkRepository.create`(chunk_model) ▷ Persist metadata in MongoDB
    append saved_chunk to created_chunks
end for
if `ChromaService` available **then**
    chroma_entries ← map *created_chunks* to {`id`, `embedding`, `metadata`}
    `ChromaService.add_embeddings`(project_id, chroma_entries)
else
    Optionally store embeddings only within MongoDB fields
end if
return created_chunks

Implementation highlights:

- **Embedding model:** `sentence-transformers/all-MiniLM-L6-v2` (see embedding service and verification scripts).
- **Dual storage:** Metadata in MongoDB `text_chunk` documents; vectors in ChromaDB via `backend/app/services/chroma_service.py`.
- **Batch background tasks:** Celery jobs generate missing embeddings in `backend/app/tasks/index` (`batch_generate_embeddings_task`).

4.1.4 Pseudocode: Context-aware Retrieval (RAG)

This step assembles a rich context from semantically similar chunks and optional entity/scene/relationship metadata.

Algorithm 3 AssembleRAGContext

Require: query Q, *project_id*, optional *file_id*, max_chunks k

Ensure: *context_payload*: list of chunks, entities, scenes, relationships

query_embedding ← `EmbeddingService.generate_single_embedding`(Q)
if `ChromaService` available **then**
    vector_hits ← `ChromaService.search_similar`(project_id, query_embedding, `n_results` = k)
else
    vector_hits ← `TextChunkRepository.vector_search`(project_id, query_embedding, `limit` = k)
end if
top_chunks ← convert *vector_hits* to chunk payloads (`id`, `content`, `score`, `file_id`, `positions`)
if include_entities **then**
    entities ← `EntityRepository.get_by_project`(project_id)
    entity_matches ← identify entities mentioned in *top_chunks* (`EntityExtractionService` or string matching)
end if
if include_scenes **then**
    scenes ← `SceneRepository.find_by_project`(project_id)
    mapped_scenes ← map chunks to scenes when positions overlap or proximity matches
end if
if include_relationships **then**
    relationships ← `RelationshipRepository.find_by_project`(project_id)
end if
context_payload ← {`"chunks"`: top_chunks, `"entities"`: entity_matches, `"scenes"`: mapped_scenes, `"relationships"`: relationships (filtered)}
return context_payload

Notes:

- `RAGContextService.assemble_context` collects chunk-level results, enriches them with entity and scene metadata, and returns a compact context mapping suitable for prompt building (see `backend/app/services/rag_context_service.py`).
- `SearchService` implements hybrid logic and fallback ordering (Chroma → Mon-

goDB `vectorSearch`).

4.1.5 Pseudocode: AI Response Generation (RAG + LLM Call)

This step orchestrates context assembly, prompt construction, LLM invocation, and persistence. It corresponds to `AIChatService.chat` and `CopilotService.generate_suggestion`.

Algorithm 4 GenerateAIResponseWithContext

Require: *user_message*, *project_id*, optional *file_id*, *user_id*, *max_context_chunks*

Ensure: *assistant_message*

Step A: Assemble RAG context
context ← `RAGContextService.assemble_context(query` = user_message, `project_id` = project_id, `file_id` = file_id, `max_chunks` = max_context_chunks)
Step B: Format context into LLM prompt
formatted_context ← `RAGContextService.format_context_for_llm`(context)
system_prompt ← `AIChatService.SYSTEM_PROMPT`
conversation_history ← `ConversationRepository.get_latest_messages`(conversation_id or new)
llm_messages ← `build_messages_list`(system_prompt, conversation_history, user_message, formatted_context) ▷ system message, recent assistant/user turns, current user message, appended context
Step C: Call LLM
assistant_content ← `GroqService.generate(messages` = llm_messages, `max_tokens` = ..., `model` = ...)
Step D: Postprocess and store
cleaned ← `clean_text`(assistant_content) ▷ e.g., `CopilotService._clean_suggestion`
`MessageRepository.save`(role = `assistant`, content = cleaned, context_used = context)
update conversation metadata (message count, token usage, timestamps)
return cleaned

Implementation notes:

- `AIChatService.chat` orchestrates assembling context, formatting prompts, invoking the LLM, and persisting messages.
- `CopilotService.generate_suggestion` targets inline assistance: it infers writing style from RAG results, calls the LLM, then returns a cleaned suggestion and the context used (see `backend/app/services/copilot_service.py`).

Complexity, Reliability, and Practical Concerns

- **Chunking complexity:** $O(n)$ in the number of sentences per document. Overlap increases effective storage but preserves local context for downstream retrieval.
- **Embedding generation:** Dominated by model inference cost per chunk. Batch generation reduces overhead (indexing background tasks `batch_generate_missing_embeddings`).
- **Vector search:** ChromaDB uses efficient ANN (HNSW) with sub-linear query cost; fallback MongoDB vector aggregation may be slower for large collections.
- **Fault tolerance:**
  - Embedding/model calls may fail due to transient network or provider issues; services use `try/catch` with sensible fallbacks (see embedding service and verify scripts).
  - RAG assembly respects available services and degrades gracefully (ChromaDB optional; code falls back to MongoDB vector search when unavailable).
- **Reindexing & incremental updates:** `TextExtractionService.reprocess_file` deletes existing chunks and marks the file ready for reprocessing; batch background tasks handle any missing embeddings.

Algorithm 5 ReprocessFileAndIncrementalUpdate

Require: *file_id*, *project_id*

Ensure: File is reindexed and embeddings regenerated as needed

1: `TextChunkRepository.delete_by_file`(file_id)
2: `FileRepository.mark_ready_for_processing`(file_id)
3: full_text ← `TextExtractionService.extract_text_from_file`(file_id)
4: chunks ← `TextExtractionService.chunk_text`(project_id, file_id, full_text, `max_chunk_size`, `overlap`)
5: `TextChunkRepository.bulk_insert`(chunks)
6: enqueue `batch_generate_missing_embeddings`(project_id, file_id)

Concrete File References (Key Implementation Points)

- **Text chunking and models**
  - `backend/app/services/text_extraction_service.py` :: `chunk_text()`, `_create_text_chunk()`, `_split_into_sentences()`
  - `backend/app/repositories/text_chunk_repository.py` :: `create()`, `get_by_file()`, `get_chunks_without_embeddings()`, `update_embedding()`
- **Embeddings and vector store**
  - `backend/app/services/embedding_service.py` :: `generate_single_embedding()`, `generate_embeddings()`, `store_text_chunks_with_embeddings()`, `find_similar_chu`
  - `backend/app/services/chroma_service.py` :: `get_or_create_collection()`,

`add_embeddings()`, `search_similar()`
  - `backend/app/tasks/indexing.py` :: `index_document_task()`, `batch_generate_embedd`
- **RAG and search**
  - `backend/app/services/rag_context_service.py` :: `assemble_context()`, `format_context_for_llm()`
  - `backend/app/services/search_service.py` :: `semantic_search()`, `find_similar_con` hybrid logic
- **LLM orchestration and assistants**
  - `backend/app/services/ai_chat_service.py` :: `chat()`
  - `backend/app/services/copilot_service.py` :: `generate_suggestion()`, `_gather_story_context()`

See Appendix A.5 for pseudo-API call signatures.

4.2 External APIs and SDKs

The system integrates multiple third-party APIs and SDKs to support AI capabilities, authentication, and data persistence.

API / SDK	Description	Purpose of Usage	Endpoint/ Function
OpenAI API (v1)	Large language model services	Text generation and embeddings	/v1/chat/completions
FastAPI	Python web framework	REST API backend	@app.get(), @app.post()
PostgreSQL	Relational database system	User and project data storage	psycopg2 driver
VectorDB (FAISS/Pinecone)	Vector similarity engine	Semantic search and retrieval	similarity_search()

Table 4.1: External APIs and SDKs Used

4.3 Testing Details

Testing played a critical role in validating the correctness, reliability, and stability of the implemented system. A combination of black box testing and unit testing strategies was adopted to ensure that the system meets its functional requirements.

4.3.1 Black Box Testing

Black box testing was used to validate the external behavior of the system without reference to internal implementation details. The focus was on verifying that system features produced correct outputs when interacting through public interfaces such as API end-

points.

4.3.1.1 Purpose of Black Box Testing

The objective of this testing was to ensure that system functionality aligned with the documented functional requirements by validating response codes, output structures, and observable system behavior.

4.3.1.2 Testing Environment

Testing was conducted using an isolated staging environment that included a running API server, a connected database, and a REST API testing client. All tests were executed externally without accessing source code.

4.3.1.3 Functional API Coverage

The following functional modules were tested as black box components:

- Authentication services (registration, login, token validation)
- Project management operations
- File handling operations
- Search and retrieval services
- Chat and conversational APIs

4.3.1.4 Workflow and Scenario Testing

End-to-end user workflows were validated through multi-step test scenarios, including project creation, file indexing, semantic search, and AI-assisted responses.

4.3.1.5 Negative and Security Testing

Invalid inputs, unauthorized requests, and forbidden access attempts were tested to verify that the system safely rejected improper usage without exposing internal errors.

4.3.1.6 Error and Edge Case Validation

Boundary conditions such as missing data, empty result sets, and invalid resource requests were evaluated to ensure stable system responses.

4.3.1.7 Black Box Test Evidence

All executed test cases were recorded and maintained as structured documentation.

	A	B	C	D	E	F	G	H	I	J
1	TC ID	Module	Test Case Name	Description	Test Type	Preconditions	Steps / Input	Expected Result	Priority	Tags / Req ID
2	TC-01	System Health	Root Endpoint до	Verify root endpo	Black Box	API server runnir	GET /	200 OK, valid res	High	health
3	TC-02	System Health	Health Check AP	Verify /health enc	Black Box	API server runnir	GET /health	200 OK, status =	High	health
4	TC-03	System Health	API Docs доступн	Verify API docs a	Black Box	API server runnir	GET /docs or /op	200 OK, docs av	Medium	docs
5	TC-04	Authentication	User Registration	Register user wit	Black Box	DB online, user r	POST /auth/regis	201 Created, use	High	REQ-auth-1
6	TC-05	Authentication	User Registration	Register with exi	Black Box	User already exis	POST /auth/regis	400/409 error me	High	negative
7	TC-06	Authentication	Login (Valid)	Login with correc	Black Box	Registered user	POST /auth/logir	200 OK, access	High	token
8	TC-07	Authentication	Login (Invalid)	Login with wrong	Black Box	User exists	POST /auth/logir	401 Unauthorize	High	negative
9	TC-08	Authentication	Get Current User	Retrieve user pro	Black Box	Valid access toke	GET /auth/me	200 OK, user dat	Medium	auth
10	TC-09	Authentication	Logout	Invalidate user se	Black Box	Logged in sessio	POST /auth/logo	200 OK, token in	Medium	auth
11	TC-10	Authentication	Refresh Token	Refresh expired	Black Box	Valid refresh toke	POST /auth/refre	200 OK, new acc	Medium	auth
12	TC-11	Projects	Create Project	Create new proje	Black Box	Authenticated us	POST /projects	201 Created, pro	High	REQ-proj-1
13	TC-12	Projects	List Projects	Retrieve projects	Black Box	Multiple projects	GET /projects?pa	200 OK, paginate	Medium	pagination
14	TC-13	Projects	Get Project Deta	Retrieve project I	Black Box	Project exists	GET /projects/{id	200 OK, correct	Medium	projects
15	TC-14	Projects	Update Project	Update project m	Black Box	Project exists, au	PUT/PATCH /pro	200 OK, updated	High	projects
16	TC-15	Projects	Delete Project	Delete project an	Black Box	Project exists	DELETE /project	200/204, project	High	cleanup
17	TC-16	Projects	Project Access C	Cross-user proje	Black Box	Multiple users/pr	Access other use	403 Forbidden	High	security
18	TC-17	Projects	Duplicate Project	Create project wi	Black Box	Project with sam	POST /projects (	400/409 validatic	Medium	validation
19	TC-18	Files	Upload File	Upload file to pro	Black Box	Project exists, au	POST /projects/{	201 Created, file	High	file-upload

Figure 4.1: BlackBox Tests fig:1

	A	B	C	D	E	F	G	H	I	J
30	TC-29	Search	Generate Embed	Generate vector	Black Box	Model available	POST /embeddir	200 OK, vector r	Medium	embeddings
31	TC-30	Search	Calculate Similar	Calculate similar	Black Box	Vectors exist	POST /similarity	200 OK, similarit	Low	utility
32	TC-31	Search	Find Similar Con	Retrieve similar c	Black Box	Indexed corpus	POST /similar	200 OK, similar c	Medium	search
33	TC-32	Search	Search with Filte	Filtered search	Black Box	Filterable data ex	POST /search (fi	200 OK, filtered I	Medium	filters
34	TC-33	Search	Search Paginatic	Paginated searcl	Black Box	Large dataset	POST /search (p	Paginated respor	Low	pagination
35	TC-34	Search	Search Without F	Missing project v	Black Box	Invalid/missing p	POST /search	400/422 validatic	High	negative
36	TC-35	Search	Embedding Stati	Retrieve embedc	Black Box	Embeddings stor	GET /embedding	200 OK, stats ret	Low	monitoring
37	TC-36	Search	Autocomplete	Suggest search t	Black Box	Index built	GET/POST /autc	200 OK, suggest	Low	UX
38	TC-37	Security	Unauthorized Ac	Protected API wi	Black Box	No/invalid token	Call secured end	401/403 Unautho	Critical	security
39	TC-38	Chat	Send Chat Mess	Send message to	Black Box	Chat service ava	POST /chat	200 OK, AI respc	Medium	chat
40	TC-39	Chat	Chat With Conte	Contextual conve	Black Box	Chat history exis	POST /chat (with	200 OK, contextu	Medium	context
41	TC-40	Chat	Get Chat History	Retrieve convers	Black Box	Conversation exi	GET /chat/{id}/his	200 OK, history I	Low	history
42	TC-41	E2E	Complete Projec	End-to-end proje	Black Box	All services runn	Full flow executic	Workflow succee	High	e2e
43	TC-42	E2E	File Update Worl	File update and r	Black Box	Existing file	Update file → rei	Updated content	High	e2e
44	TC-43	E2E	Multi-file Search	Cross-file search	Black Box	Multiple files inde	Run cross-file se	Correct cross-file	Medium	similarity
45	TC-44	Integration	Comprehensive I	Full indexing pipe	Black Box	NLP + vector DB	Run complete pi	Pipeline complet	Low	comprehensive
46	TC-45	Integration	Embedding Integ	Embedding + vec	Black Box	Embedding servi	Generate and sto	Vectors stored &	Medium	integration
47	TC-46	Integration	Async Indexing	Background asyr	Black Box	Worker queue ac	Trigger async tas	Tasks complete s	Medium	async
48	TC-47	Integration	Relationship Disc	Entity relationshi	Black Box	Extracted entities	Run relationship	Correct relations	Low	NLP

Figure 4.2: BlackBox Tests fig:2

TC ID	Module	Test Case Name	Description	Test Type	Preconditions	Steps / Input	Expected Result	Priority	Tags / Req ID
TC-09	Authentication	Logout	Invalidate user session/token	Black Box	Logged in session	POST /auth/logout	200 OK, token invalidated	Medium	auth
TC-10	Authentication	Refresh Token	Refresh expired token	Black Box	Valid refresh token	POST /auth/refresh	200 OK, new access token	Medium	auth
TC-11	Projects	Create Project	Create new project	Black Box	Authenticated user	POST /projects	201 Created, project created	High	REQ-proj-1
TC-12	Projects	List Projects	Retrieve projects list	Black Box	Multiple projects exist	GET /projects?page=1	200 OK, paginated list	Medium	pagination
TC-13	Projects	Get Project Details	Retrieve project by ID	Black Box	Project exists	GET /projects/{id}	200 OK, correct project data	Medium	projects
TC-14	Projects	Update Project	Update project metadata	Black Box	Project exists, authenticated	PUT/PATCH /projects/{id}	200 OK, updated values saved	High	projects
TC-15	Projects	Delete Project	Delete project and related data	Black Box	Project exists	DELETE /projects/{id}	200/204, project removed	High	cleanup
TC-16	Projects	Project Access Control	Cross-user project access restriction	Black Box	Multiple users/projects	Access other user project	403 Forbidden	High	security
TC-17	Projects	Duplicate Project Name	Create project with duplicate name	Black Box	Project with same name exists	POST /projects (duplicate name)	400/409 validation error	Medium	validation
TC-18	Files	Upload File	Upload file to project	Black Box	Project exists, authenticated	POST /projects/{id}/files	201 Created, file metadata	High	file-upload
TC-19	Files	List Project Files	Retrieve file list	Black Box	Files exist	GET /projects/{id}/files	200 OK, list returned	Medium	pagination
TC-20	Files	Get File Metadata	Fetch file metadata by ID	Black Box	File exists	GET /files/{id}/metadata	200 OK, metadata returned	Medium	files
TC-21	Files	Get File Content	Fetch file raw content	Black Box	File processed	GET /files/{id}/content	200 OK, content served	Medium	content
TC-22	Files	Update File Content	Modify existing file	Black Box	File exists	PUT /files/{id}/content	200 OK, updated content saved	High	files
TC-23	Files	Delete File	Delete file with cascade cleanup	Black Box	File exists	DELETE /files/{id}	200/204, file removed	High	cleanup

Figure 4.3: Black Box Test 1

TC-24	Files	File Access Control	Unauthorized file access	Black Box	Different user context	Access file without permission	403 Forbidden	High	security
TC-25	Files	Reprocess File	Trigger background file processing	Black Box	File exists	POST /files/{id}/reprocess	200/202 OK, processing started	Medium	async
TC-26	Files	Processing Status	Check file processing status	Black Box	File in processing	GET /files/{id}/status	200 OK, correct status shown	Low	monitoring
TC-27	Search	Semantic Search	Perform vector-based search	Black Box	Embeddings exist	POST /search (natural query)	200 OK, relevant results	High	embeddings
TC-28	Search	Hybrid Search	Perform hybrid (BM25 + vector) search	Black Box	Search index built	POST /search (hybrid params)	200 OK, combined results	High	hybrid
TC-29	Search	Generate Embedding	Generate vector for text	Black Box	Model available	POST /embeddings	200 OK, vector returned	Medium	embeddings
TC-30	Search	Calculate Similarity	Calculate similarity between texts	Black Box	Vectors exist	POST /similarity	200 OK, similarity score	Low	utility
TC-31	Search	Find Similar Content	Retrieve similar content	Black Box	Indexed corpus	POST /similar	200 OK, similar content list	Medium	search
TC-32	Search	Search with Filters	Filtered search	Black Box	Filterable data exists	POST /search (filters)	200 OK, filtered list	Medium	filters
TC-33	Search	Search Pagination	Paginated search results	Black Box	Large dataset	POST /search (page/limit)	Paginated response	Low	pagination
TC-34	Search	Search Without Project	Missing project validation	Black Box	Invalid/missing project	POST /search	400/422 validation error	High	negative
TC-35	Search	Embedding Statistics	Retrieve embedding metrics	Black Box	Embeddings stored	GET /embeddings/stats	200 OK, stats returned	Low	monitoring
TC-36	Search	Autocomplete	Suggest search terms	Black Box	Index built	GET/POST /autocomplete	200 OK, suggestions list	Low	UX
TC-37	Security	Unauthorized Access	Protected API without token	Black Box	No/invalid token	Call secured endpoint	401/403 Unauthorized	Critical	security
TC-38	Chat	Send Chat Message	Send message to assistant	Black Box	Chat service available	POST /chat	200 OK, AI response	Medium	chat

Figure 4.4: Black Box Test 2

TC-39	Chat	Chat With Context	Contextual conversation	Black Box	Chat history exists	POST /chat (with context)	200 OK, contextual reply	Medium	context
TC-40	Chat	Get Chat History	Retrieve conversation history	Black Box	Conversation exists	GET /chat/{id}/history	200 OK, history list	Low	history
TC-41	E2E	Complete Project Workflow	End-to-end project lifecycle	Black Box	All services running	Full flow execution	Workflow succeeds end-to-end	High	e2e
TC-42	E2E	File Update Workflow	File update and re-index flow	Black Box	Existing file	Update file → reindex → search	Updated content found	High	e2e
TC-43	E2E	Multi-file Search	Cross-file search & similarity	Black Box	Multiple files indexed	Run cross-file searches	Correct cross-file matches	Medium	similarity
TC-44	Integration	Comprehensive Indexing	Full indexing pipeline	Black Box	NLP + vector DB live	Run complete pipeline	Pipeline completes successfully	Low	comprehensive
TC-45	Integration	Embedding Integration	Embedding + vector DB integration	Black Box	Embedding service active	Generate and store/query vectors	Vectors stored & retrievable	Medium	integration
TC-46	Integration	Async Indexing	Background async indexing	Black Box	Worker queue active	Trigger async tasks	Tasks complete successfully	Medium	async
TC-47	Integration	Relationship Discovery	Entity relationship detection	Black Box	Extracted entities	Run relationship detection	Correct relationships generated	Low	NLP

Figure 4.5: Black Box Test 3

4.3.1.8 Black Box Testing Summary

The system demonstrated consistent and correct behavior for valid use cases and safely handled invalid or unauthorized operations.

4.3.2 Unit Testing

Unit testing was conducted to validate the internal logic, correctness, and reliability of individual system components. Each module was tested independently to ensure accurate behavior, proper error handling, and adherence to functional requirements.

4.3.2.1 Implemented Unit Test Coverage

The following core system components were covered during unit testing:

- Authentication services (registration, login, token handling)
- File processing and metadata management

- Search and autocomplete operations
- Text extraction, chunking, and incremental processing
- Embedding generation, statistics, and similarity scoring
- LLM interaction services (GroqService)
- Edit proposal generation and diff processing
- Copilot assistance (suggestions, style analysis, prompt building)
- RAG-based context assembly
- Entity extraction and validation
- Relationship discovery and contextual analysis

4.3.2.2 Testing Approach

Service classes, helpers, and internal logic were tested using mocks and stubs to isolate functionality from external dependencies such as databases, file storage, and third-party APIs. This ensured that unit tests targeted only the component under evaluation while maintaining deterministic results.

4.3.2.3 Failure and Boundary Validation

Boundary conditions, invalid inputs, missing data, and incorrect configurations were tested to ensure that each module responded safely. Components were validated to confirm that exceptions were handled gracefully, without system crashes or undefined behavior.

4.3.2.4 Authentication and File Services Unit Tests

ID	Component	Test Case	Expected Result	Actual Result	S
U-AUTH-01	AuthService	User registration (valid)	User created, 200/201	Passing	I
U-AUTH-02	AuthService	Token creation	Valid access/refresh tokens returned	Passing	I
U-AUTH-03	AuthService	Password hashing	Hash stored, verification correct	Passing	I
U-FILE-01	FileService	File metadata retrieval	Correct metadata returned	Passing	I
U-FILE-02	FileService	File deletion (incl. GridFS)	File + GridFS entries removed	Passing	I

Table 4.2: Unit Test Results — Authentication and File Services

ID	Component	Test Case	Expected Result	Actual Result	S
U-SEARCH-01	SearchService	Autocomplete suggestions	Relevant suggestions returned	Passing	
U-TEXT-01	TextExtractionService	Text extraction	Extracted text matches source	Passing	
U-TEXT-02	TextExtractionService	Text chunking	Semantic chunks generated	Passing	
U-TEXT-03	TextExtractionService	Empty text handling	Safe empty response	Passing	
U-TEXT-04	TextExtractionService	Incremental processing	Correct incremental output	Passing	
U-EMB-01	EmbeddingService	Similarity calculation	Correct similarity score	Passing	
U-EMB-02	EmbeddingService	Embedding statistics	Accurate statistics	Passing	
U-EMB-03	EmbeddingService	Embedding generation (mock)	Correct or mocked embedding	Partial	

Table 4.3: Unit Test Results — Search, Text Extraction, and Embedding Services

ID	Component	Test Case	Expected Result	Actual Result	S
U-GROQ-01..08	GroqService	Completion, formatting, errors, model listing	Correct structured responses	All passing	
U-EDIT-01..05	EditProposalService	Detection, proposal, parsing, diff, prompts	All edits and diffs accurate	Passing 12/12	
U-COP-01..05	CopilotService	Suggestions, style analysis, prompt building	Suggestions + context generated	6/8 passing	

Table 4.4: Unit Test Results — LLM Integration, Edit Proposals, and Copilot

4.3.2.5 Search, Text Extraction, and Embedding Unit Tests

4.3.2.6 LLM, Editing, and Copilot Unit Tests

4.3.2.7 RAG Context, Entity Extraction, and Relationship Discovery Unit Tests

4.3.2.8 Updated Unit Test Summary

ID	Component / Suite	Test case	Expected result	Actual result (as documented)	Status	Notes
U-AUTH-01	AuthService (unit)	User registration (valid)	New user created, 201/200, user object returned	Passing	PASS	One of 3 AuthService unit tests
U-AUTH-02	AuthService (unit)	Token creation (access & refresh)	Tokens returned and valid	Passing	PASS	
U-AUTH-03	AuthService (unit)	Password hashing	Stored password hashed; verify succeeds	Passing	PASS	
U-FILE-01	FileService (unit)	File metadata retrieval	Metadata returned correctly	Passing	PASS	
U-FILE-02	FileService (unit)	File deletion with GridFS cleanup	File removed and GridFS entries cleared	Passing	PASS	
U-SEARCH-01	SearchService (unit)	Autocomplete suggestions	Relevant suggestions returned	Passing	PASS	
U-TEXT-01	TextExtractionService (unit)	Text extraction from files	Extracted text matches source	Passing	PASS	
U-TEXT-02	TextExtractionService (unit)	Text chunking	Text split into semantic chunks	Passing	PASS	
U-TEXT-03	TextExtractionService (unit)	Empty text handling	No crash; appropriate empty response	Passing	PASS	
U-TEXT-04	TextExtractionService (unit)	Incremental file processing	Incremental results OK	Passing	PASS	
U-EMB-01	EmbeddingService (unit)	Similarity calculation	Correct similarity scores	Passing	PASS	1 of 3 embedding unit tests passed
U-EMB-02	EmbeddingService (unit)	Embedding statistics	Stats computed correctly	Passing	PASS	1 test had minor mocking issue (total 2/3 passing)
U-EMB-03	EmbeddingService (unit)	Embedding generation / other (mock)	Expected embedding produced or mocked	Partial / Mocking issue	FAIL (partial)	1 failing unit test due to mocking issue
U-GROQ-01	GroqService (unit)	Chat completion	Completion returned	Passing	PASS	GroqService 8/8 per docs
U-GROQ-02	GroqService (unit)	Response generation	Structured response	Passing	PASS	

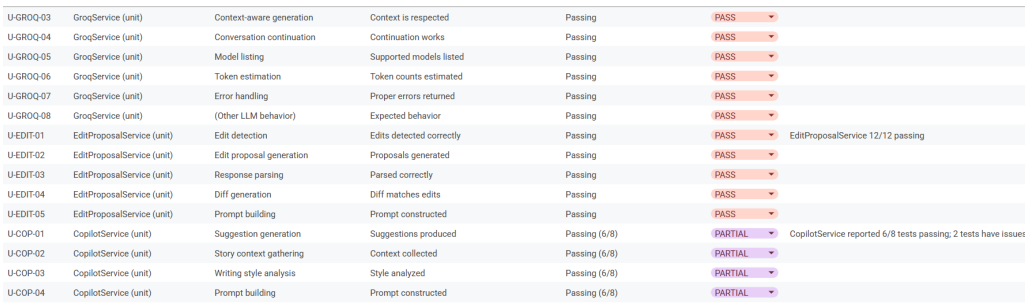
Figure 4.6: Unit Test Evidence 1

ID	Component	Test Case	Expected Result	Actual Result	S
U-RAG-01	RAGContextService	Context assembly	Assembled context correctly	2/5 passing	I
U-RAG-02	RAGContextService	LLM formatting	Proper formatting	2/5 passing	I
U-RAG-03	RAGContextService	Project overview	Should validate input	Validation issue	I
U-RAG-04	RAGContextService	Entity context	Should assemble entity data	Validation issue	I
U-RAG-05	RAGContextService	File filtering	Correct object filtering	ObjectId error	I
U-ENT-01..05	EntityExtractionService	Validation, NER, name detection	Accurate entity extraction	2/5 passing	I
U-REL-01..09	RelationshipDiscoveryService	Entity, context, classification	Relationship detection	7/9 passing	I

Table 4.5: Unit Test Results — RAG Context, Entity Extraction, and Relationship Discovery

Category	Count	Notes
Total Unit Tests Executed	70	Across all modules
Passing Tests	64	
Failed Tests	6	Require fixes/mocking updates
Overall Pass Rate	91%	Stable with minor issues

Table 4.6: Overall Unit Testing Summary



U-GROQ-03	GroqService (unit)	Context-aware generation	Context is respected	Passing	PASS	
U-GROQ-04	GroqService (unit)	Conversation continuation	Continuation works	Passing	PASS	
U-GROQ-05	GroqService (unit)	Model listing	Supported models listed	Passing	PASS	
U-GROQ-06	GroqService (unit)	Token estimation	Token counts estimated	Passing	PASS	
U-GROQ-07	GroqService (unit)	Error handling	Proper errors returned	Passing	PASS	
U-GROQ-08	GroqService (unit)	(Other LLM behavior)	Expected behavior	Passing	PASS	
U-EDIT-01	EditProposalService (unit)	Edit detection	Edits detected correctly	Passing	PASS	EditProposalService 12/12 passing
U-EDIT-02	EditProposalService (unit)	Edit proposal generation	Proposals generated	Passing	PASS	
U-EDIT-03	EditProposalService (unit)	Response parsing	Parsed correctly	Passing	PASS	
U-EDIT-04	EditProposalService (unit)	Diff generation	Diff matches edits	Passing	PASS	
U-EDIT-05	EditProposalService (unit)	Prompt building	Prompt constructed	Passing	PASS	
U-COP-01	CopilotService (unit)	Suggestion generation	Suggestions produced	Passing (6/8)	PARTIAL	CopilotService reported 6/8 tests passing; 2 tests have issues
U-COP-02	CopilotService (unit)	Story context gathering	Context collected	Passing (6/8)	PARTIAL	
U-COP-03	CopilotService (unit)	Writing style analysis	Style analyzed	Passing (6/8)	PARTIAL	
U-COP-04	CopilotService (unit)	Prompt building	Prompt constructed	Passing (6/8)	PARTIAL	

Figure 4.7: Unit Test Evidence 2

U-COP-05	CopilotService (unit)	Suggestion cleaning	Suggestions cleaned	Passing (6/8)	PARTIAL	
U-RAG-01	RAGContextService (unit)	Context assembly	Assembles context correctly	Passing (2/5)	PARTIAL	2/5 unit tests pass; remaining have validation/ObjectId issues
U-RAG-02	RAGContextService (unit)	LLM formatting	Formatting OK	Passing (2/5)	PARTIAL	
U-RAG-03	RAGContextService (unit)	Project overview	Validation issue	FAIL	FAIL	Validation issue reported in docs
U-RAG-04	RAGContextService (unit)	Entity context	Validation issue	FAIL	FAIL	
U-RAG-05	RAGContextService (unit)	File filtering	ObjectId issue	FAIL	FAIL	
U-ENT-01	EntityExtractionService (unit)	Character name validation	Validated	Passing (2/5)	PARTIAL	2/5 passing; some need spaCy or mocking
U-ENT-02	EntityExtractionService (unit)	Location name validation	Validated	Passing (2/5)	PARTIAL	
U-ENT-03	EntityExtractionService (unit)	Real location detection	Assertion issue	FAIL	FAIL	
U-ENT-04	EntityExtractionService (unit)	Entity extraction	Needs spaCy	FAIL	FAIL	
U-ENT-05	EntityExtractionService (unit)	Character extraction	Mock issue	FAIL	FAIL	
U-REL-01	RelationshipDiscoveryService (unit)	Entity finding	OK	Passing (7/9)	PARTIAL	7/9 passing; 2 have validation/minor issues
U-REL-02	RelationshipDiscoveryService (unit)	Context extraction	OK	Passing (7/9)	PARTIAL	
U-REL-03	RelationshipDiscoveryService (unit)	Relationship classification	OK	Passing (7/9)	PARTIAL	
U-REL-04	RelationshipDiscoveryService (unit)	Strength calculation	OK	Passing (7/9)	PARTIAL	

Figure 4.8: Unit Test Evidence 3

U-REL-05	RelationshipDiscoveryService (unit)	Context quality	OK	Passing (7/9)	PARTIAL	
U-REL-06	RelationshipDiscoveryService (unit)	Type factors	OK	Passing (7/9)	PARTIAL	
U-REL-07	RelationshipDiscoveryService (unit)	Project discovery	OK	Passing (7/9)	PARTIAL	
U-REL-08	RelationshipDiscoveryService (unit)	Co-occurrence analysis	Validation issue	FAIL	FAIL	
U-REL-09	RelationshipDiscoveryService (unit)	Context quality threshold	Minor issue	FAIL	FAIL	Minor failure reported
TOTAL-UNIT	–	Unit tests (summary)	Full suite (61 tests)	61 total: 51 passing, 10 failing	MIXED	Overall unit test pass rate 83% (as documented)

Figure 4.9: Unit Test Evidence 4

4.3.3 Test Evidence

Summary

121 tests took 00:04:32.

(Un)check the boxes to filter the results.

☐ 6 Failed, ☑ 115 Passed, ☑ 0 Skipped, ☑ 0 Expected failures, ☑ 0 Unexpected passes, ☑ 0 Errors, ☑ 0 Reruns

Result	Test
Passed	tests/test_auth_api.py::TestAuthenticationAPI::test_register_new_user
Passed	tests/test_auth_api.py::TestAuthenticationAPI::test_register_duplicate_email
Passed	tests/test_auth_api.py::TestAuthenticationAPI::test_register_invalid_password
Passed	tests/test_auth_api.py::TestAuthenticationAPI::test_register_password_mismatch
Passed	tests/test_auth_api.py::TestAuthenticationAPI::test_login_valid_credentials
Passed	tests/test_auth_api.py::TestAuthenticationAPI::test_login_invalid_credentials
Passed	tests/test_auth_api.py::TestAuthenticationAPI::test_login_nonexistent_user
Passed	tests/test_auth_api.py::TestAuthenticationAPI::test_get_current_user
Passed	tests/test_auth_api.py::TestAuthenticationAPI::test_get_current_user_unauthorized
Passed	tests/test_auth_api.py::TestAuthenticationAPI::test_get_current_user_invalid_token
Passed	tests/test_auth_api.py::TestAuthenticationAPI::test_logout
Passed	tests/test_auth_api.py::TestAuthenticationAPI::test_refresh_token
Passed	tests/test_chat_api.py::TestChatAPI::test_send_chat_message
Passed	tests/test_chat_api.py::TestChatAPI::test_chat_with_context
Passed	tests/test_chat_api.py::TestChatAPI::test_chat_conversation_history
Passed	tests/test_chat_api.py::TestChatAPI::test_chat_unauthorized

Figure 4.10: Test Execution Results

4.4 Test Summary

The testing results showed that the system successfully handled valid requests and appropriately rejected invalid or unauthorized access attempts. The core workflows such as project creation, file uploading, semantic search, and AI-assisted responses were verified to function as expected during the current iteration.

All critical defects identified during testing were resolved, and remaining enhancements will be addressed in the next development phase.

4.4.1 Integration Testing

4.4.1.1 Summary

Integration tests validated end-to-end behavior across API layers, databases, and services using the repository's pytest setup. The suite covers authentication, projects, files, search, chat, workflows, and health checks.

- **Total integration tests:** 60 (PHASE1 & TESTING_GUIDE) — reported as 100% passing in the repo docs.
- **Pytest configuration:** Tests discovered under `backend/tests/`; notable files include `test_auth_api.py`, `test_projects_api.py`, `test_files_api.py`, `test_search_api.py` `test_chat_api.py`, `test_integration_workflows.py`, and `test_health.py`.
- **Notes:** Built from testing documentation (`WHITEBOX_TESTING_COMPLETE.md`, `PHASE1_TESTING_SU` `TESTING_GUIDE.md`, `TEST_SUMMARY.md`) and concrete repo files (`conftest.py`, `pytest.ini`, run scripts). Exact counts may vary with updates.

ID	Component / Suite	Test case (category)	Expected result	Actual result (as documented)	Status	Notes
I-AUTH-01..12	Auth API (integration)	User registration/login/refresh/logout/get current	End-to-end authentication flows work	All cases documented; 12 tests	PASS	PHASE1 docs list 12 auth API tests
I-PROJ-01..11	Projects API (integration)	Create/list/get/update/delete/isolation	Project management flows work	11 tests	PASS	
I-FILE-01..14	Files API (integration)	Upload/list/get content/metadata/process/updat	File management flows	14 tests	PASS	
I-SEARCH-01..12	Search API (integration)	Semantic/hybrid search, filters, embeddings, simil	Search flows work	12 tests	PASS	
I-CHAT-01..05	Chat API (integration)	Send message, context, history, auth checks	Chat endpoints respond	5 tests	PASS / ACCEPTED CODES	Docs accept various status codes for chat (200, 4
I-WORKFLOWS-01..03	Integration workflows (E2E)	Full user workflow: register → create → upload →	End-to-end scenario success	3 tests	PASS	Docs report E2E workflows pass
I-HEALTH-01..03	System health (integration)	Root endpoint, /health, API docs	Available and healthy	3 tests	PASS	

Figure 4.11: Integration API Test Evidence

Chapter 5

Conclusions and Future Work

5.1 Conclusion

The first phase of this project focused on understanding the core challenges faced by long-form writers and designing a system capable of addressing those limitations. Through an analysis of existing tools and their gaps, we identified the need for a context-aware, memory-driven writing assistant. Based on these insights, we finalized the complete system architecture, data models, modules, and design decisions required for CoWriteIA.

During FYP-I, we also implemented the foundational components of the system, including project indexing, semantic memory, and the initial version of the writing assistant. This phase successfully established the technical direction and groundwork necessary for building a fully functional, intelligent writing platform in the next development stage.

5.2 Future Work

The next phase will focus on completing and integrating all remaining modules into a cohesive system. Key areas include enhancing the context-aware writing agent, completing dialogue generation and character management features, and improving the gap analysis module. Additional work will involve research integration, optimizing semantic search performance, refining the user interface, and conducting extensive testing across all modules.

By the end of the next phase, the goal is to deliver a robust, polished, and reliable AI-assisted writing platform that supports writers throughout their creative workflow.

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Appendix A

Appendices

A.1 Appendix A: System Diagrams

A.1.1 Use Case Diagram

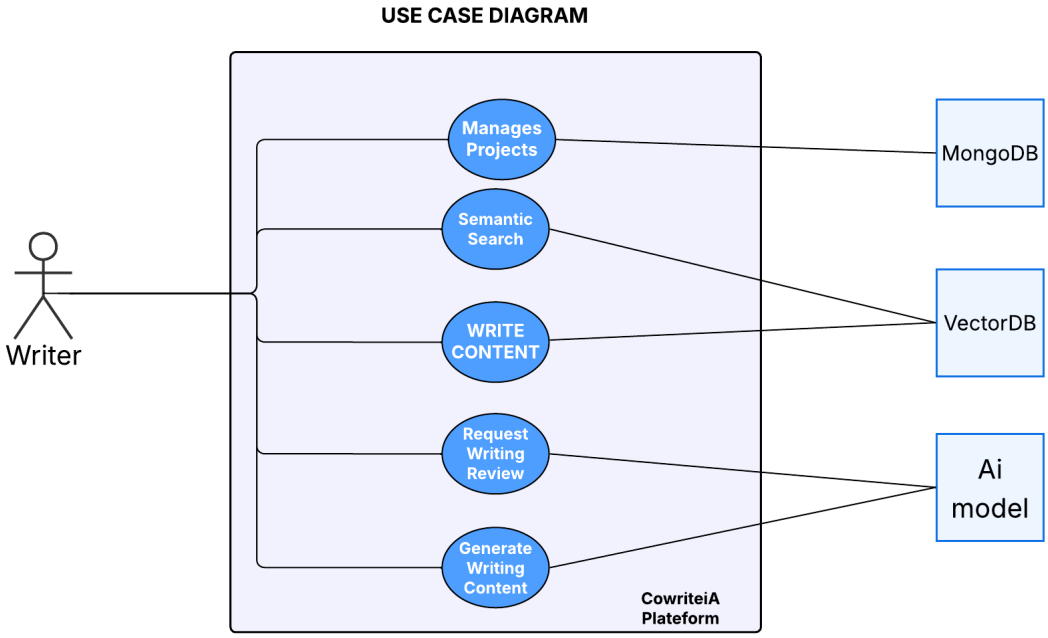

Figure A.1: Use Case Diagram CoWriteIA

A.1.2 Activity Diagram

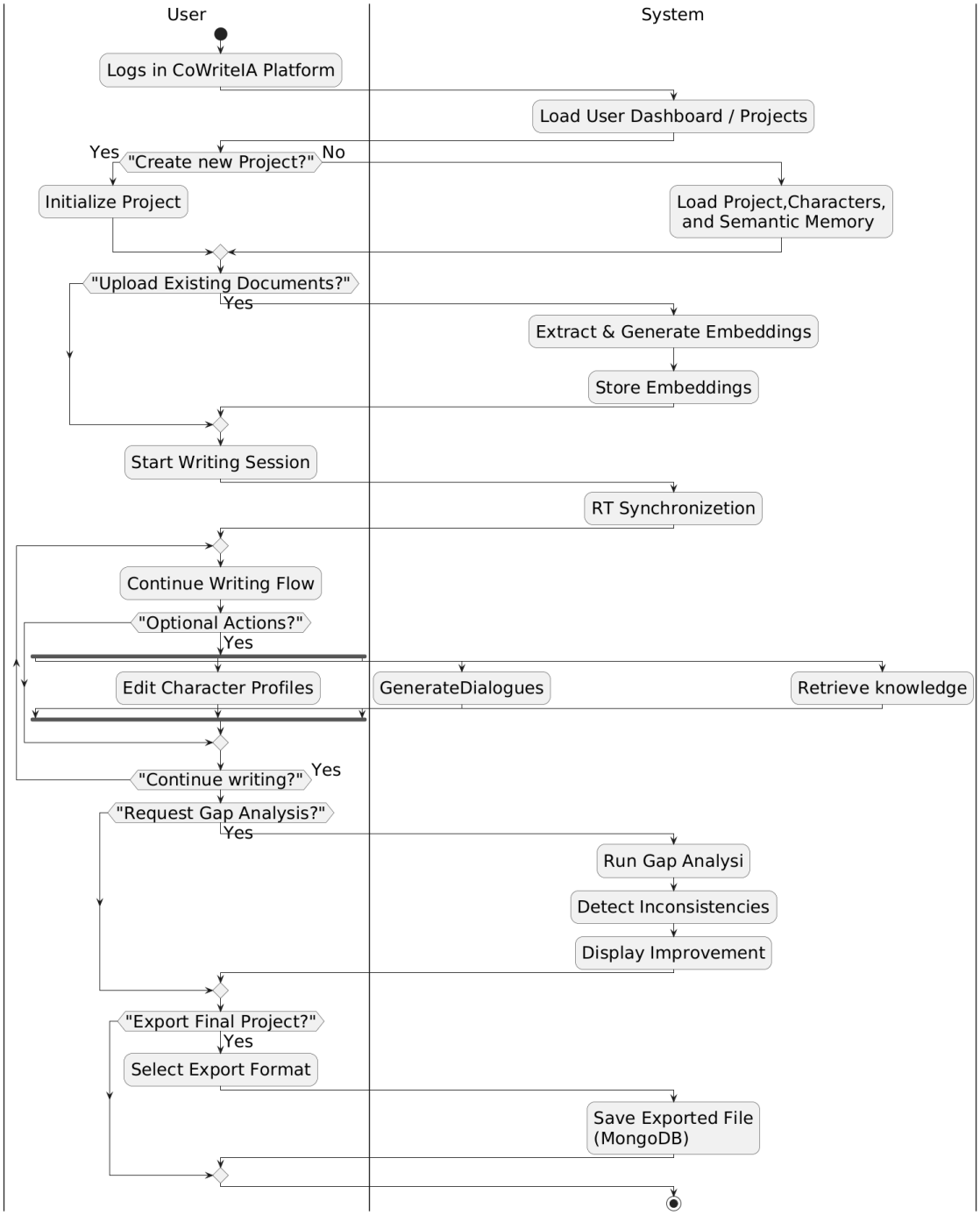

Figure A.2: Activity Diagram

A.2 Appendix B: Architecture Diagram

A.2.1 CoWriteIA Detailed Architecture Diagram

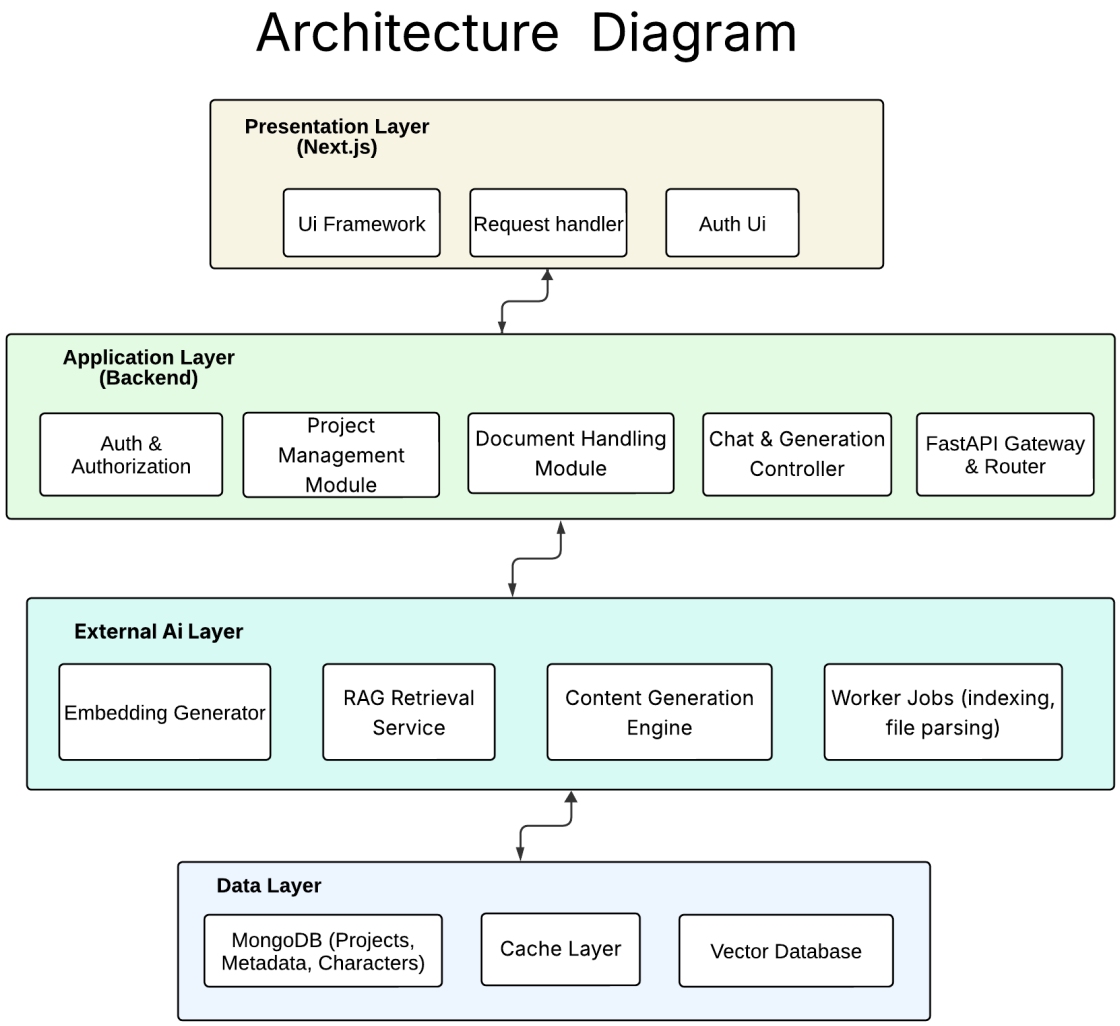

Figure A.3: CoWriteIA Multi-Tier Architecture Diagram

A.3 Appendix C: User Interface Screenshots

A.3.1 Dashboard Interface

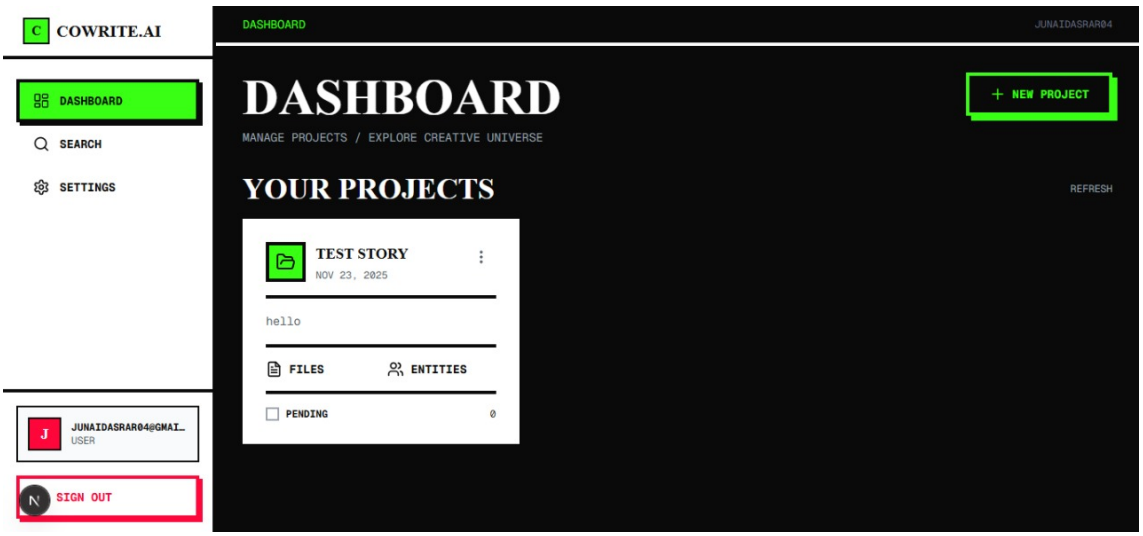

Figure A.4: CoWriteIA Dashboard Interface

A.3.2 Writing Environment Interface

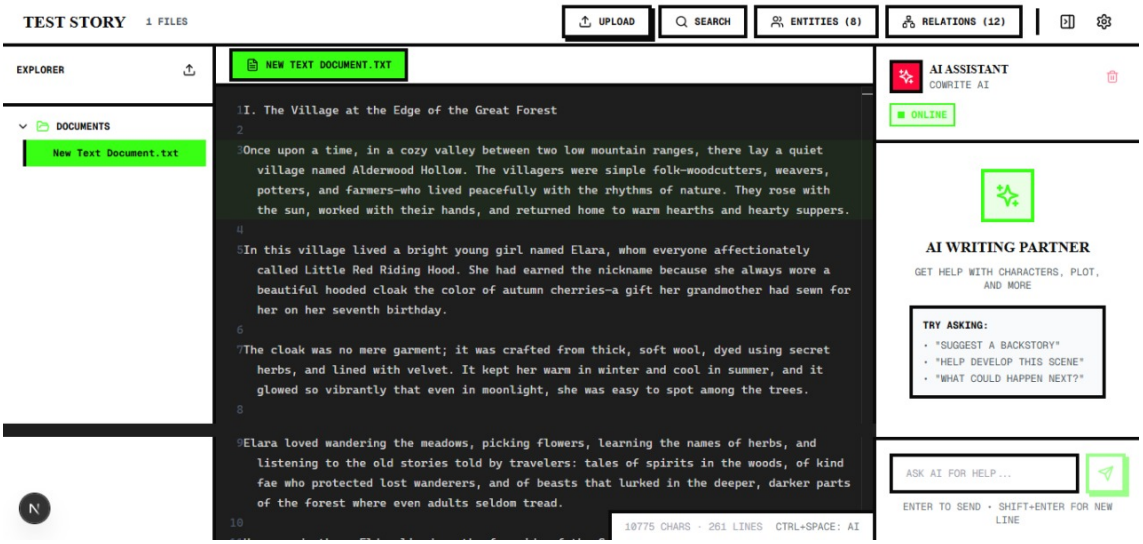

Figure A.5: Writing Environment Interface

A.3.3 Writing Assistant Interface

Figure A.6: Writing Assistant Interface

A.3.4 Login Interface

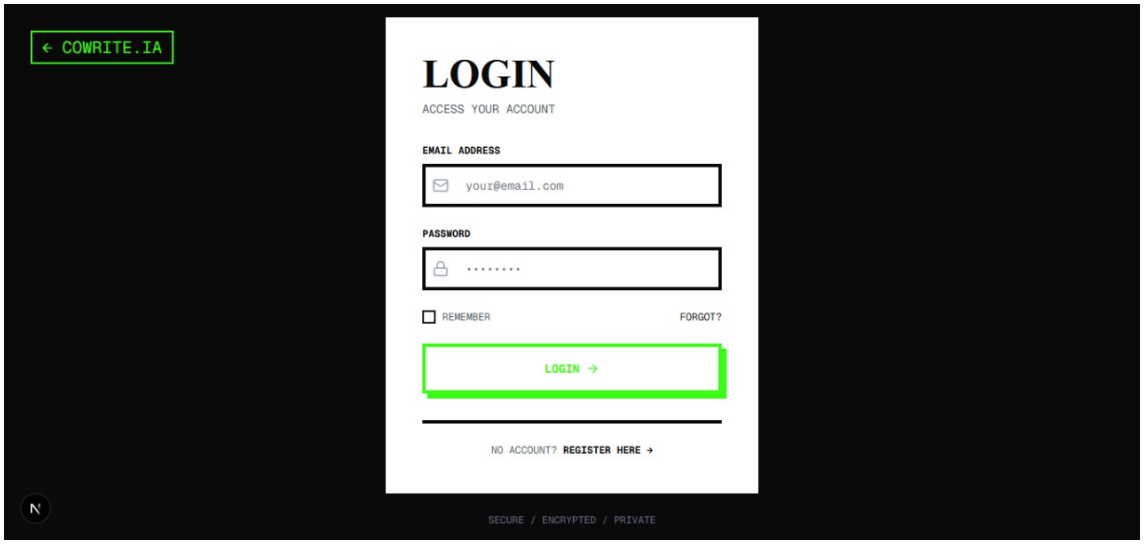

Figure A.7: Login Interface

A.4 Appendix D: Detailed Use Case Specification

A.4.1 UC-01: Generate Context-Aware Writing

Use Case ID	UC-01
Use Case Name	Generate Context-Aware Writing
Primary Actor	Writer (User)
Secondary Actors	AI Processing Engine, Semantic Retrieval Module
Preconditions	• User is authenticated and logged into the system. • A project exists with at least one uploaded or created document. • Project content has been indexed and embeddings are stored.
Postconditions	• AI-generated content is displayed to the user. • Generated text may be saved to the project document.
Trigger	User selects the "Generate Content" option within the writing interface.
Main Flow	1. User opens a project document in the writing environment. 2. User requests content generation (e.g., continue writing, rewrite, expand). 3. System retrieves relevant context using semantic search. 4. System sends the prompt + context to the AI model. 5. AI model generates new content. 6. System displays the generated text to the user. 7. User may choose to accept, edit, or regenerate the content.
Alternate Flow	AF-1 User requests generation with no specific prompt. (a) System uses recent document content as context. (b) AI generates a default continuation. AF-2 User modifies the context manually. (a) User provides custom text or notes. (b) System merges custom context with retrieved chunks.
Exceptions	E1 No embeddings found: System prompts user to index project files. E2 AI service unavailable: System displays fallback message and suggests retrying. E3 Empty or invalid user request: User is asked to refine or re-enter the prompt.
Priority	High
Frequency of Use	Very frequent (core functionality)

Table A.1: Detailed Use Case: Generate Context-Aware Writing

A.5 Appendix E: Pseudo-API Snippets (Call Signatures)

- `TextExtractionService.chunk_text(file_id: str, project_id: str, text: str, start_position: int = 0, start_chunk_index: int = 0) -> List[TextChunk]`
- `EmbeddingService.generate_single_embedding(text: str) -> List[float]`
- `EmbeddingService.generate_embeddings(texts: List[str]) -> List[List[float]]`
- `EmbeddingService.store_text_chunks_with_embeddings(file_id: str, project_id: str, chunk_data: List[Dict]) -> List[TextChunk]`
- `ChromaService.add_embeddings(project_id: str, entries: List[Dict]) -> None`
- `ChromaService.search_similar(project_id: str, query_embedding: List[float], n_results: int) -> List[Dict]`
- `RAGContextService.assemble_context(query: str, project_id: str, file_id: Optional[str] = None, max_chunks: int = 5) -> Dict`
- `AIChatService.chat(request: ChatRequest, user_id: str) -> ChatResponse`