# Module Guide for Chest Scan

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## 1 Revision History

| Date | Version | Notes |
|---|---|---|
| January 6, 2025 | 1.0 | Initial draft of the Module Guide (MG) document created. |
| January 8, 2025 | 1.1 | Added module descriptions and dependencies. Updated section on module interactions. |
| January 10, 2025 | 1.2 | Incorporated feedback from team review. Clarified module responsibilities and refined explanations. |
| January 12, 2025 | 1.3 | Improved formatting and consistency with the MIS document. Adjusted terminology for clarity. |
| January 14, 2025 | 1.4 | Revised diagrams and module relationships. Added missing assumptions and constraints. |
| January 16, 2025 | 1.5 | Finalized the document. Ensured alignment with project requirements and other documents (MIS, SRS). |

# 2 Reference Material

This section records information for easy reference.

## 2.1 Abbreviations and Acronyms

| **symbol** | **description** |
|---|---|
| AC | Anticipated Change |
| DAG | Directed Acyclic Graph |
| M | Module |
| MG | Module Guide |
| OS | Operating System |
| R | Requirement |
| SC | Scientific Computing |
| SRS | Software Requirements Specification |
| Chest Scan | Explanation of program name |
| UC | Unlikely Change |

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## 3 Introduction

In order to build large scale software systems, the intended software system must be decomposed into smaller logical modules. Ideally, these modules should be independent and thus reusable across the software system or in the event of a future software change or a change in demand. This allows the software system to become resilient to unanticipated changes and more easily maintainable.

Following this approach, in developing a diffusion model to generate chest x-ray images, we will decompose the individual parts into clear single-responsibility modules. This will enable the software to be more maintainable and thus easier to update in the future in the face of changing demand or issues.

It is important that the CXR image data generated by this project are of high-quality such that if the quality is less than ideal it is completely unusable, and more so can result in damaging effects such as if the poor data was later used to train future machine learning models used in medicine.

As a result of this building this project in modular clear single responsibility components will enable us to continue to improve the accuracy of our model to ensure it continues to be usable in the future, such as making it easy to tune the model in accordance to new research findings or updating the software at large. The purpose of this document is to explain how we've structured the system, why we made certain design choices, and how the parts of the system work together. It is intended to be useful for:

1. Onboarding engineers: To easily introduce new engineers to the architecture of the software system in a digestible fashion.
2. Future engineers: To enable future engineers to have clear documentation on how to proceed with their intended changes given the existing software architecture.
3. Requirements engineers: To analyse the existing software architecture to reach a conclusion if the software meets the intended specifications and requirements.

This design document aims to provide a structured and abstract explanation of the larger software architecture of this project. As a result, this document will include the large system design, single responsibility modules and the relationships between them. The object is to ensure that future stakeholders and engineers can easily digest the architecture presented such that they may become capable to contribute to the project if necessary.

## 4 Anticipated and Unlikely Changes

This section outlines possible changes that may impact the system. These changes are categorized based on their likelihood: anticipated changes, which are expected and should be designed for, and unlikely changes, which are considered rare and would require significant modification to implement.

## 4.1 Anticipated Changes

Anticipated changes are the areas of the system that are most likely to evolve and have been designed to accommodate future adjustments. Meaning that the software maintainability is built with this potential changes in mind. These changes are encapsulated within specific modules to ensure the system's flexibility.

- **AC1:** Model Architecture Updates: The architecture of the diffusion model may evolve as new research or improved techniques emerge. The system should support swapping or updating the model without significant rework.
- **AC2:** Chest X-ray Dataset Expansion: As more real-world chest X-ray datasets become available, the system should be able to integrate additional datasets for training or validation seamlessly.
- **AC3:** Synthetic Image Resolution: The resolution of the generated chest X-ray images may need to be increased or adjusted based on user requirements or advancements in computational resources.
- **AC4:** Evaluation Metrics: New evaluation metrics or benchmarks may be adopted to assess the quality of the generated images. The system should allow the addition of new evaluation pipelines.
- **AC5:** Export Formats for Generated Data: Users may require the generated chest X-rays in additional formats (e.g., DICOM, JPEG). The system should accommodate exporting in various formats.
- **AC6:** Integration with External Tools: The system may need to integrate with external tools, such as machine learning pipelines, medical imaging software, or hospital IT systems, to streamline usage.

## 4.2 Unlikely Changes

Unlikely changes are those that would require significant rework and are considered fixed for the foreseeable future. Designing for these changes would add unnecessary complexity to the system.

- **UC1:** Core Diffusion Model Methodology: A fundamental shift away from the diffusion model approach is considered highly unlikely, as it forms the core of the system's design.
- **UC2:** Removal of Synthetic Data Generation: Generating synthetic chest X-ray data is the primary purpose of the system. Removing this feature would negate the system's value.
- **UC3:** Elimination of GPU/TPU Acceleration: Hardware acceleration (e.g., GPUs or TPUs) is critical for training and generating high-quality images efficiently. Moving to CPU-only processing is not expected.

- **UC4:** Discontinuation of Medical Imaging Focus: The system is tailored for medical imaging, specifically chest X-rays. A shift to a completely different domain is not anticipated.
- **UC5:** Input Data Format Changes: The system is designed to process standardized chest X-ray input formats (e.g., DICOM). A fundamental change in these formats is unlikely in the short term.
- **UC6:** Standalone Usage Elimination: The software is intended to be a standalone tool for generating and exporting chest X-rays. Transitioning to a fully dependent cloud-based or third-party service is not planned.

## 5 Module Hierarchy

This section of the document describes the modules that make up the project and their related hierarchy. Table 1 categorizes the modules based on encapsulation, whereas Table 2 categorizes modules according to the MVC architecture. Each category can be identified as nodes in a tree, where each of the respective modules in each category are leaves of that node.

Total Module List:

- M1: DataPreprocessing Module
- M2: DiffusionModel Module
- M3: SyntheticImageGen Module
- M4: DatasetHandler Module
- M5: EvaluationMetrics Module
- M6: ImageExport Module
- M7: UserInterface Module
- M8: IntegrationModule (for external tools)
- M9: HardwareAcceleration Module
- M10: LoggingAndMonitoring Module
- M11: Login Module

Table 1: Encapsulation

| **Node** | **Leaf** |
|---|---|
| **Hardware Encapsulation** | HardwareAcceleration |
| **Behavior Encapsulation** | DataPreprocessing, SyntheticImageGen, DatasetHandler, EvaluationMetrics, LoggingAndMonitoring, Login |
| **Software Decision Encapsulation** | DiffusionModel, ImageExport, UserInterface, IntegrationModule |

Table 2: Model-View-Controller

| **Node** | **Leaf** |
|---|---|
| **Model Module** | DataPreprocessing, DatasetHandler, SyntheticImageGen, EvaluationMetrics, UserAuthMgmt |
| **View Module** | UserInterface, Login |
| **Controller Module** | DiffusionModel, ImageExport, IntegrationModule, LoggingAndMonitoring |

## 6 Connection Between Requirements and Design

Refer to Table 2

## 7 Module Decomposition

The structure of the system is based on the modular design principles outlined by David Parnas, which emphasize breaking down a system into independent components that hide their internal details. This ensures that changes made to one module do not unnecessarily affect others, leading to better maintainability and adaptability.

Each module encapsulates a specific ”secret,” or design decision, which represents the part of the system that is most likely to change. By isolating these secrets within modules, the software can more easily adapt to evolving requirements and unforeseen modifications. The Services field describes the functionality of the module at a high level, while the Implemented By field specifies the responsible implementation mechanism. Only the ”leaf” modules, those at the end of the hierarchy, are developed and implemented directly.

This modular approach allows for clear boundaries between components, ensuring that the overall system remains flexible and scalable. The following subsections detail each module's secrets, services, and implementation specifics.

## 7.1 Hardware Hiding Modules

Secrets: The data structure and algorithm used to implement virtual hardware acceleration for GPU/TPU computation.

Services: Provides an interface to GPU/TPU hardware for high-performance training and image generation.

Implemented By: OS

### 7.1.1 HardwareAcceleration Module (M9)

Secrets: The algorithms and optimizations used for efficient communication with GPU/TPU hardware.

Services: Optimizes computational tasks for the diffusion model, ensuring faster training and generation of synthetic chest X-ray images.

Implemented By: CUDA, TensorFlow, or PyTorch backends

Type of Module: Library

## 7.2 Behaviour-Hiding Module

Secrets: The specific behaviours required to meet the functional requirements outlined in the software requirements specification (SRS).

Services: Facilitates communication between hardware-hiding modules and software decision modules. Handles tasks like data preprocessing and model evaluation.

Implemented By: –

### 7.2.1 DataPreprocessing Module (M1)

Secrets: The data cleaning and augmentation techniques used to prepare the chest X-ray datasets.

Services: Reads raw chest X-ray images, applies transformations (e.g., normalization, resizing, and augmentation), and outputs clean data ready for model input.

Implemented By: preprocessing.py

Type of Module: Library

### 7.2.2 SyntheticImageGen Module (M3)

Secrets: Methods and parameters for generating high-quality synthetic chest X-ray images that mimic real-world data.

Services: Creates synthetic datasets to augment training data or simulate different imaging conditions for robust model evaluation.

Implemented By: `generate_images.py`

Type of Module: Library

#### 7.2.3 DatasetHandler Module (M4)

Secrets: Data organization and management techniques for maintaining large volumes of medical imaging data.

Services: Manages data storage, retrieval, and organization, ensuring compatibility with preprocessing and analysis pipelines.

Implemented By: Backend data management system.

Type of Module: Record

#### 7.2.4 EvaluationMetrics Module (M5)

Secrets: Metrics and evaluation techniques tailored to assess the quality of synthetic images and model performance.

Services: Computes quantitative evaluations, including accuracy, recall, and F1 scores, to monitor and validate the system's effectiveness.

Implemented By: `evaluation.py`

#### 7.2.5 LoggingAndMonitoring Module (M10)

Secrets: Internal mechanisms for tracking system performance, error handling, and usage patterns.

Services: Provides real-time monitoring, logs system activities, and tracks errors or anomalies to ensure reliability and maintainability.

Implemented By: Logging frameworks or custom logging implementations.

Type of Module: Abstract Object

#### 7.2.6 Login Module (M11)

Secrets: The data structure(s) and algorithm(s) used to show and make functional the login functionality for users.

Services: Displays login portal and authenticates user logins into this application. Implemented By: –

Type of Module: Library, Abstract Object

## 7.3 Software Decision Encapsulation

### 7.3.1 DiffusionModel Module (M2)

Secrets: The architecture and parameters of the diffusion model used for generating and enhancing chest X-ray images.

Services: Performs core image generation and refinement tasks, producing high-fidelity outputs for medical analysis.

Implemented By: `diffusion_model.py`

### 7.3.2 ImageExport Module (M6)

Secrets: Formatting and export configurations for rendering and saving images in required formats (e.g., DICOM, PNG).

Services: Exports generated or processed images in formats compatible with medical imaging standards and external tools.

Implemented By: `image_export.py`

### 7.3.3 UserInterface Module (M7)

Secrets: Design and implementation details of the graphical user interface for interacting with the system.

Services: Facilitates user interactions, allowing data input, viewing results, and managing system operations through a user-friendly interface.

Implemented By: Frontend frameworks or libraries (e.g., React, PyQt).

### 7.3.4 IntegrationModule (M8)

Secrets: Strategies and mechanisms for integrating with external tools, medical databases, and IT infrastructure.

Services: Provides APIs and connectors to enable seamless communication with external systems, ensuring interoperability.

Implemented By: Integration libraries or custom APIs.

# 8 Traceability Matrix

The Traceability Matrix provides a mapping between the software requirements, anticipated changes, and the modules outlined in the design document. This ensures that each requirement and anticipated change is addressed by specific modules, fostering consistency, maintainability, and scalability.

## 8.1 Traceability Between Requirements and Modules

The table below maps the functional requirements (FR) from the Software Requirements Specification (SRS) to the corresponding modules responsible for their implementation:

| **Requirement ID** | **Modules** |
|---|---|
| FR1 | M1 (DataPreprocessing), M4 (DatasetHandler) |
| FR2 | M2 (DiffusionModel), M3 (SyntheticImageGen) |
| FR3 | M3 (SyntheticImageGen), M5 (EvaluationMetrics) |
| FR4 | M6 (ImageExport), M5 (EvaluationMetrics) |
| FR5 | M7 (UserInterface), M6 (ImageExport) |
| FR6 | M7 (UserInterface), M8 (IntegrationModule) |
| FR7 | M4 (DatasetHandler), M10 (LoggingAndMonitoring) |
| FR8 | M11(Login) |

## 8.2 Traceability Between Anticipated Changes and Modules

The table below identifies how anticipated changes (AC) outlined in the SRS and design document are addressed by specific modules, ensuring that the design is resilient to future updates:

| **Anticipated Change ID** | **Modules** |
|---|---|
| AC1 | M2 (DiffusionModel), M9 (HardwareAcceleration) |
| AC2 | M1 (DataPreprocessing), M4 (DatasetHandler) |
| AC3 | M3 (SyntheticImageGen), M6 (ImageExport) |
| AC4 | M5 (EvaluationMetrics), M10 (LoggingAndMonitoring) |
| AC5 | M6 (ImageExport), M8 (IntegrationModule), M11(Login) |
| AC6 | M8 (IntegrationModule), M7 (UserInterface), M11(Login) |

### 8.2.1 Mapping Requirements to Modules

Each functional requirement is addressed by one or more modules:

- FR1: Handled by the DataPreprocessing and DatasetHandler modules to process and organize chest X-ray data.
- FR2: Managed by the DiffusionModel and SyntheticImageGen modules to generate disease signatures.
- FR3: Supported by SyntheticImageGen and EvaluationMetrics for disease classification and analysis.

- FR4: Managed by the ImageExport and EvaluationMetrics modules for diagnostic report generation.
- FR5: Delivered by UserInterface and ImageExport modules for displaying diagnostic findings.
- FR6: Facilitated by UserInterface and IntegrationModule to ensure accessibility and interaction with external tools.
- FR7: Supported by DatasetHandler and LoggingAndMonitoring modules for secure data management.

#### 8.2.2 Mapping Anticipated Changes to Modules

Anticipated changes are encapsulated in specific modules:

- AC1: DiffusionModel and HardwareAcceleration support updates in model architecture.
- AC2: DataPreprocessing and DatasetHandler enable seamless integration of new datasets.
- AC3: SyntheticImageGen and ImageExport accommodate resolution and format changes.
- AC4: EvaluationMetrics and LoggingAndMonitoring manage new evaluation metrics.
- AC5: IntegrationModule, ImageExport and login ensure compatibility with external tools.
- AC6: UserInterface, IntegrationModule and login facilitate GUI and external integration enhancements.

This traceability matrix ensures all requirements and anticipated changes are accounted for, aligning with the modular architecture specified in the design document.

# 9 Use Hierarchy Between Modules

The Use Hierarchy illustrates the dependency relationships between modules, following a top-down structure aligned with the Model-View-Controller (MVC) architecture. The modules are organized by their roles within the system, with each level of the hierarchy representing a distinct layer of responsibility.

## 9.1 Model Modules

Model modules encapsulate the data and business logic of the system, providing core functionalities.

| Module | Uses |
|---|---|
| M1 (DataPreprocessing) | M4 (DatasetHandler) |
| M4 (DatasetHandler) | M3 (SyntheticImageGen), M5 (EvaluationMetrics) |
| M3 (SyntheticImageGen) | M2 (DiffusionModel) |
| M5 (EvaluationMetrics) | M3 (SyntheticImageGen) |

## 9.2 View Modules

View modules are responsible for presenting information to the user and handling user interactions.

| Module | Uses |
|---|---|
| M7 (UserInterface) | M6 (ImageExport) |
| M11(Login) | M7(UserInterface) |

## 9.3 Controller Modules

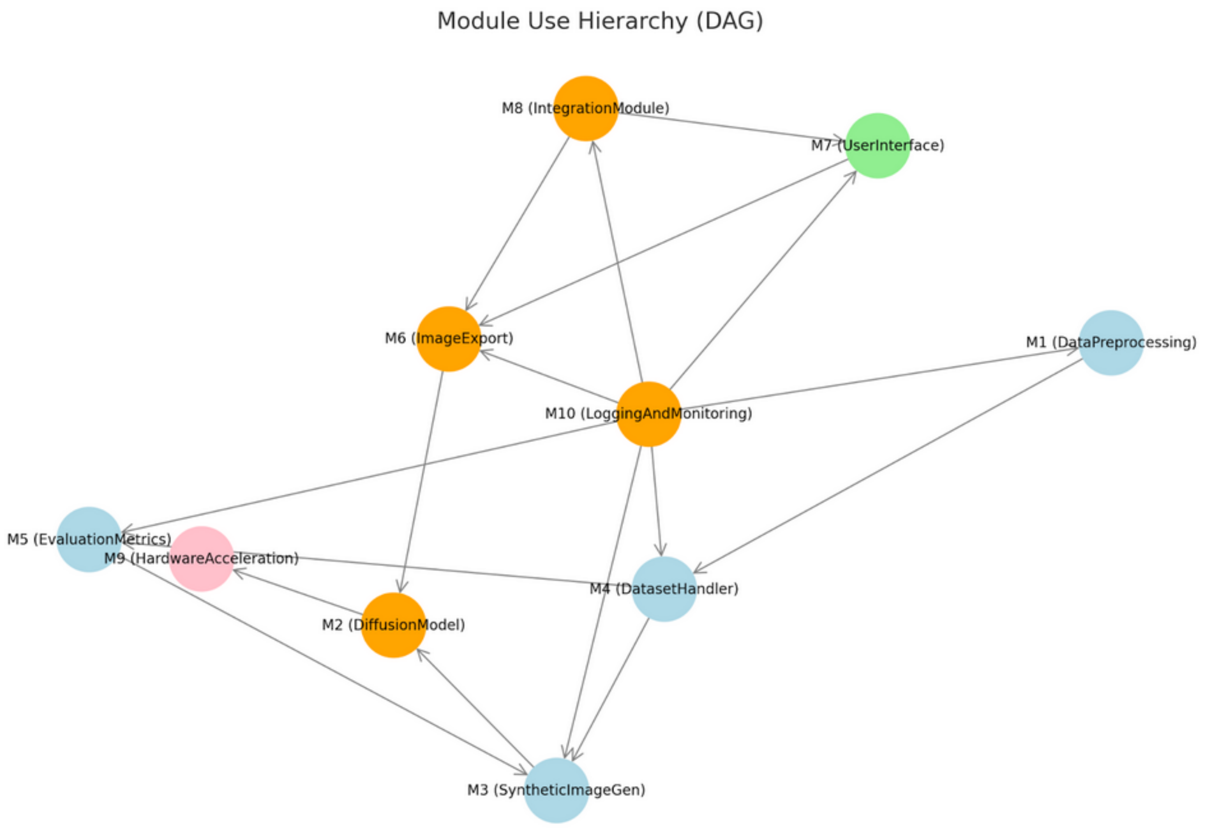
Controller modules manage the flow of data between the model and view layers and coordinate system behavior.

| Module | Uses |
|---|---|
| M2 (DiffusionModel) | M9 (HardwareAcceleration) |
| M6 (ImageExport) | M2 (DiffusionModel) |
| M8 (IntegrationModule) | M7 (UserInterface), M6 (ImageExport) |
| M10 (LoggingAndMonitoring) | All other modules |

## 9.4 Explanation of Use Hierarchy

- Top-Down Structure: The hierarchy begins with high-level controller modules, which coordinate operations and delegate tasks to the model and view modules.
- Layered Dependency: Modules depend on lower-level modules for specific services, following the principle of modularity. For instance, M2 (DiffusionModel) relies on M9 (HardwareAcceleration) for optimized computations.
- Cross-Layer Interactions: Controller modules like M8 (IntegrationModule) mediate interactions between views (M7) and models (M6), ensuring seamless system integration.

This hierarchy ensures a clear separation of concerns, making the system easier to maintain, test, and extend.



The Directed Acyclic Graph (DAG) above visualizes the Use Hierarchy Between Modules based on the Model-View-Controller architecture and the provided module dependencies. Each node represents a module, and edges indicate usage relationships. Colors distinguish categories:

- Light Blue: Model modules
- Light Green: View modules
- Orange: Controller modules
- Pink: Hardware modules

## 10 User Interfaces

Figma prototype includes login page, main page to prompt a generated image, a gallery page of the generated images, and a page to more clearly view the image and download it.

Figma design prototype:
https://www.figma.com/proto/O31J64KIWA8uFswM7JgFy4/Capstone-Design?node-id=0-1&t=JrT3K3FziVB66kCh-1

## 11 Timeline

Table 3: Schedule of Tasks and Responsibilities

| **Task** | **Responsible Team Member(s)** |
|---|---|
| Define system architecture and module design (MG and MIS) | Entire Team |
| Implement and train the diffusion model for image generation, including in-painting capabilities | Harrison, Hamza, Jared |
| Develop data preprocessing pipeline | Jared, Ahmad |
| Design and implement model evaluation using quantitative metrics | Ahmad, Gurnoor, Harrison |
| Develop and integrate bounding box detection for guiding synthetic image generation | Harrison, Jared |
| Develop and integrate the user interface | Hamza |
| Manage data storage, retrieval, and external system integration (DICOM compatibility, API connections) | Ahmad, Gurnoor |
| Conduct testing, debugging, and performance optimization for diffusion model, inpainting accuracy, and bounding box detection | Ahmad, Jared |
| Maintain documentation, version control, and deployment processes | Everyone |