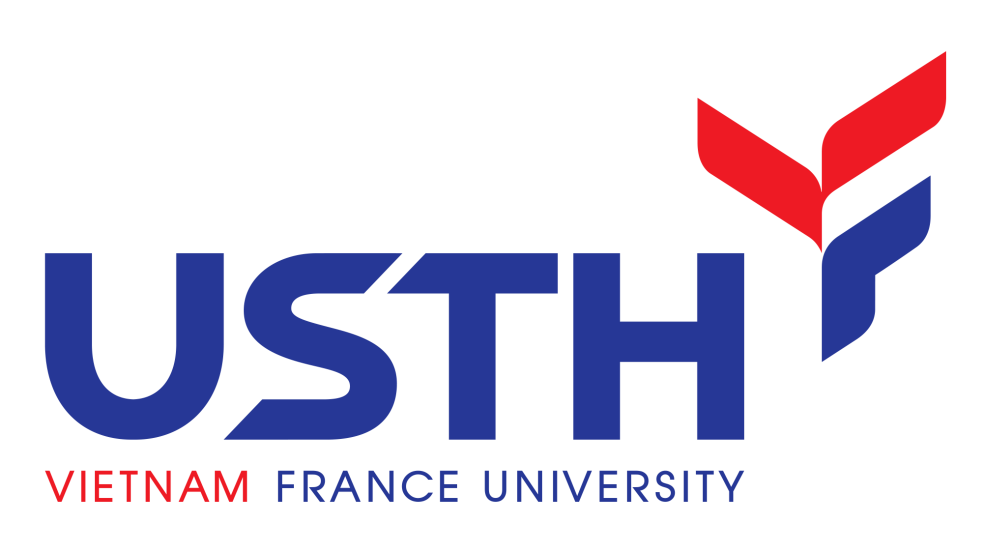
# DECLARATION

UNIVERSITY OF SCIENCE AND TECHNOLOGY OF HANOI

****

**MASTER 1 THESIS**

By

**DANG THAI SON (2440045)**

*Information and Communication Technology (ICT)*

Title

**ETL Microservice for Data Ingestion into a Data Lake**

------------------------------------------------------------------------------------------------------------------

Supervisor: **Assoc. Prof. Trần Giang Sơn**

*ICT Laboratory - USTH*

**Hanoi, August 2025**

I, hereby, Dang Thai Son, declare that all the work and result in this thesis are entirely my own and are not plagiarized from any source. This thesis was written based on my research which was carried out at the Information and Communication Technology laboratory at University of Science and Technology of Hanoi, under the guidance of Assoc. Prof. Tran Giang Son.

Any scientific result, method, comment, and statistics inherited during the research from other authors has been cited thoroughly. In case there is any plagiarism in my thesis, I understand that this work will not be evaluated and I will take full responsibility for penalties from the thesis defense committee and my university.

# ACKNOWLEDGEMENTS

I would like to express my gratitude to all those who offered me the chances to be capable of carrying out my project and then completing this thesis.

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# LIST OF ABBREVIATIONS

IDC International Data Corporation

AI Artificial Intelligence

ETL Extract, Transform, Load

GA4 Google Analytics 4

ICT Information and Communication Technology

CDSE Copernicus Data Space Ecosystem

I/O Input/Output

OAuth Open Authorization

REST Representational State Transfer

JSON JavaScript Object Notation

RDBMS Relational Database Management System

SQL Structured Query Language

GDAL Geospatial Data Abstraction Library

TIFF Tagged Image File Format

NASA National Aeronautics and Space Administration

USGS United States Geological Survey

ESA European Space Agency

ALOS Advanced Land Observing Satellite

JAXA Japan Aerospace Exploration Agency

MODIS Moderate Resolution Imaging Spectroradiometer

STAC SpatioTemporal Asset Catalog

SAR Synthetic Aperture Radar

UV Ultraviolet

S2-L2A Sentinel-2 Level-2A

NDVI Normalized Difference Vegetation Index

CI Continuous Integration

DAO Data Access Objects

DTO Data Transfer Objects

CSV Comma Separated Values

XLSX Excel Open XML Spreadsheet

HDFS Hadoop Distributed File System

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# ABSTRACT

**This should be written last.**

1. WHY: Context and Problem (1-2 sentences)
   1. Context: The importance of data lakes
   2. Specific problem the project solves: The challenge of ingesting complex, authenticated data
   3. Keywords: Data Lake, data ingestion, analytics, machine learning, diverse data sources, authentication, pre-processing.
2. WHAT: Aim and Objectives (1 sentence)
   1. What is set out to achieve?
   2. Example: "This thesis presents the design and development of a robust ETL microservice for..."
3. HOW: Methodology and Implementation (2-3 sentences)
   1. The technology stack (Reactive microservice, Quarkus)
   2. The data source and APIs (Copernicus Data Space Ecosystem, Sentinel Hub Catalog/Process APIs)
   3. The persistence layer (PostgreSQL for metadata)
   4. The overall process (Extract STAC metadata, download imagery, persist records)
4. SO WHAT: Results and Significance (1-2 sentences)
   1. What was the final outcome? What was successfully built?
   2. Significance of the work. Why does it matter? What contribution does it make?
   3. Keywords: Functional pipeline, improved data availability, data quality, robust solution, scalable architecture, blueprint for modern data services.

Data lakes are central repositories for storing vast amounts of raw data for analytics and machine learning applications. However, a significant challenge lies in the automated and reliable ingestion of data from diverse and complex sources, especially those requiring authentication and extensive pre-processing. This thesis addresses this challenge by presenting the design, development, and implementation of a robust ETL microservice for the automated ingestion of satellite imagery from the Copernicus Data Space Ecosystem into a data lake. The solution is architected as a reactive microservice using the Quarkus framework, leveraging the Sentinel Hub Catalog and Process APIs to extract STAC metadata and corresponding satellite imagery. The extracted metadata is transformed and loaded into a PostgreSQL database, creating a searchable catalog linked to the locally stored image files. The primary outcome is a fully functional, non-blocking ETL pipeline capable of handling API authentication, processing geospatial queries, and atomically persisting both the metadata and the image data. This work provides a practical and scalable blueprint for building modern data ingestion services, improving data availability and quality within the data lake ecosystem.

* Word Count: Aim for 150-300 words.
* .

**Keywords**: *..*.

# INTRODUCTION

## I/ Overview & Purpose

In today’s modern world, data grows exponentially and continuously in numerous domains. According to a report by International Data Corporation (IDC) and Seagate, the global datasphere which is the total amount of data created and duplicated all over the world is estimated to reach 163 zettabytes (1.63 × 1014 gigabytes) by 2025 [1]. This statistic is approximately ten times bigger than that of a decade ago. This data deluge results in a new terminology called “big data” which generally involves enormous, fast-moving, and diverse datasets. Thanks to it, various information-based applications have been developed to serve critical needs such as analytical models in agriculture, or forecast frameworks in weather and climate fields [2]. Some popular big data systems supporting scientific research include Copernicus Global Land Services, Sentinel-2, Landsat Program, ALOS World 3D, and ERA5 that provide valuable environmental information. However, coming with major advantages, big data has raised 3 V challenges (Volume, Variety, and Velocity) to traditional data systems, such as relational databases, which struggle with issues like scalability, handling unstructured formats, and real-time processing. Specifically, traditional systems may face performance bottlenecks and storage constraints when processing petabytes of data and managing the velocity of streaming inputs [3]. These limitations have urged for the development of new solutions, one of which is data lake.

In order to conveniently store, manage, and extract value from big data where sources are massive and complex, a new type of data storage architecture which is data lake has emerged. A data lake is defined as a highly scalable centralized repository that allows storing structured, semi-structured, and unstructured data in its raw format without the need to define a schema at the time of ingestion. In other words, this schema-on-read mechanism provides a flexible way to store and access heterogenous and high-volume data coming from sources like satellites, sensors, or user logs, without forcing early transformation. From an architectural viewpoint, data lakes can be broadly classified into two categories based on the deployment method: cloud-based and on-premises [4]. A cloud-based data lake leverages remote storage and services from public cloud providers, offering rapid scalability and minimal infrastructure management. In contrast, an on-premises data lake is hosted within the organization’s internal infrastructure where hardware, storage, and networking resources are controlled locally. Without such scalable storage architectures, traditional systems would face challenges when working with modern data streams, which would drastically reduce the ability to implement cutting-edge AI models or to fulfil analytical work. To seal that gap, several large-scale data lakes have been developed and widely adopted for either scientific or industrial use such as Amazon S3-based data lake, Google Cloud Storage, and Microsoft Azure data lake.

In the context of data lake, ETL process (Extract, Transform, and Load) is widely considered the backbone of the entire architecture since it performs the core operations needed to deliver up-to-date and consistent data for analysis and decision-making. As the name suggested, ETL is a sequential three-phase data integration procedure. Firstly, diverse raw data from multiple sources, for example structured databases, GA4 statistics, or user transaction logs, is extracted. Then using methods like format conversion, deduplication, and resizing, it is transformed into a clean and consistent format before being loaded into a destination system, here is the data lake, for analytical platforms or model training purposes [5]. Its importance lies in the fact that it not only automates data movement from source systems to target repositories but also ensures that data is clean, and compliant with business rules before it is stored. Without a properly implemented ETL process, organizations could have problems with data inconsistencies, schema mismatches, and loss of traceability, especially when working with high-volume or heterogeneous sources [6]. Take major data lake platforms, Amazon S3, Google Cloud, and Microsoft Azure, as examples, they all use ETL pipelines which are AWS Glue, Google Cloud Dataflow, and Azure Data Factory respectively for loading clean and structured data. Overall, ETL is indispensable for ensuring raw and unstructured data becomes reliable and usable for downstream applications.

In recent years, the acceleration of climate change and environmental degradation has boosted the global demand for reliable Earth observation and forecasting systems. To understand and respond to these needs, data scientists and analysts must work with high-resolution satellite imagery and geospatial datasets which are enormous, heterogenous, and frequently updated. These datasets which are considered as a big data source then need a scalable infrastructure to be ingested, stored, and processed effectively. As previously discussed, data lakes and ETL pipelines are fundamental for such workflow. At the ICT Lab, a centralized on-premises data lake infrastructure called ULake has been established, supporting ingestion pipelines for Kaggle and GitHub. However, there is currently no dedicated ETL process for ingesting satellite data into the lake, which limits the lab’s ability to fully integrate remote sensing data into its analytical workflows. Therefore, the goal of this project is to fulfil the need by developing an ETL microservice for data ingestion for the ULake that automates the end-to-end process of retrieving, transforming, and storing satellite data.

## II/ Objectives

The objective of this project is to design and implement a microservice-based ETL pipeline used for the ingestion of satellite imagery into the ULake data lake. The microservice supports interactions with a satellite data provider, here specifically is the Copernicus Data Space Ecosystem (CDSE), to extract relevant imagery and metadata. It then performs downsizing for full-band-color images as a preprocessing step before loading the data into appropriate storage locations within ULake. By doing so, this project will not only fill a current technical gap in the laboratory’s data infrastructure, but also enhance the efficiency and accessibility of downstream applications such as climate modeling and machine learning pipelines. On top of that, the ETL microservice will contribute to a streamlined, reusable, and scalable data ingestion job for Earth observation datasets in research and practical applications.

# MATERIALS AND METHODS

## I/ Tools

### 1. Quarkus framework

The microservice developed in this project was built using Quarkus, a modern full-stack Java framework optimized for building cloud-native, container-first, and reactive applications. Quarkus, which supports both imperative and reactive programming models, provides high performance and low memory footprint, making it well-suited for event-driven architectures and data-intensive workflows [7]. Therefore, one main reason why Quarkus was selected is its efficiency in handling data streams and non-blocking I/O operations, which is especially suitable when working with large volumes of satellite imagery and metadata from external APIs. Additionally, this choice ensured compatibility with the existing ULake ecosystem where other microservices were developed using Quarkus, which allows consistency in deployment and configuration across the data lake.

Several Quarkus extensions utilised to support the system’s functionality include: quarkus-oidc-client for secure OAuth2-based communication with external APIs, quarkus-hibernate-reactive-panache to simplify entity-repository mappings using reactive Hibernate, and quarkus-rest-jackson for handling RESTful endpoints and JSON serialization. The ETL pipeline was made following a modular structure comprising entity, model, proxy, repository, resource, and service packages with reactive programming principles which leverage Mutiny to ensure non-blocking behaviour across service layers.

### 2. PostgreSQL

In this project, PostgreSQL was used as a local relational database to store structured metadata extracted during the first phase of the ETL process. PostgreSQL is an open-source relational database management system (RDBMS) known for its stability, strong community support, and adherence to SQL standards [8]. It can handle structured tabular data which is an appropriate choice for storing metadata fields such as image identifiers, capture timestamps, source URLs, coordinates, and file paths related to downloaded satellite imagery. The primary reason for choosing PostgreSQL was to save metadata locally during the development and testing of the ETL microservice, which enabled intermediate storage between extraction and transformation phases, and supported data traceability and debugging. Without such tool, metadata shall need to be stored directly in flat files which are inconsistent, hard to query, and prone to loss if the system crashes.

### 3. GDAL translate utility

To support the transformation phase of the ETL process, this project took advantage of the gdal\_translate utility, which is a part of the Geospatial Data Abstraction Library (GDAL), a widely used open-source toolkit for reading, writing, and converting raster geospatial data formats. GDAL supports over 150 raster formats and capabilities for re-projection, resampling, and data compression. Specifically, gdal\_translate was employed in this project to downsize large multi-band satellite images by reducing their spatial resolution while preserving all spectral bands. This step is critical to ensure the data lake input file size remains below the upload threshold, allowing successful ingestion into ULake. Without this tool or any similar one in the preprocessing step, raw satellite imagery, especially full-band TIFF would exceed storage or transfer limitations set by the data lake’s ingestion interface, which may result in failure or performance degradation blocking the data ingestion workflow.

## II/ Dataset

### 1. Satellite imagery

Satellite imagery refers to images of Earth or other planets captured by satellites operated by governments or commercial providers. These images are typically obtained using onboard sensors that record electromagnetic radiation reflected or emitted from the Earth's surface. Depending on sensor specifications, satellite images can include multiple spectral bands, enabling advanced analysis of land cover, vegetation health, water bodies, and atmospheric conditions [8]. This type of data plays a vital role in a wide range of scientific and environmental applications, including climate monitoring, agricultural forecasting, and disaster management.

THÊM ẢNH VÍ DỤ VỀ CÁC DATASET

In this project, satellite imagery serves as the primary raw data source extracted and processed through the ETL pipeline. These images are essential for enabling downstream geospatial analysis and model training tasks. Without access to satellite data, there would be serious limitations in observing environmental patterns, particularly in regions lacking ground sensors. The ability to capture large-scale and repeatable observations makes satellite imagery irreplaceable for Earth observation and global-scale analysis.

Some of the most widely used open-access satellite data programs include the Landsat program operated by NASA and USGS which has provided continuous Earth observation since the 1970s, and the Sentinel constellation operated by European Space Agency (ESA) under the Copernicus program which offers high-resolution multispectral data. Other valuable sources include the ALOS World 3D dataset by JAXA and MODIS imagery by NASA.

### 2. Project dataset

Among popular satellite data programs, the CDSE was specifically chosen as the main data provider for this project. As mentioned previously, the CDSE is an open-access Earth observation platform developed under the Copernicus Program and operated by the ESA. It is designed to provide free, large-scale, and near real-time access to satellite imagery, primarily from the Sentinel imaging mission, along with modern features such as RESTful APIs and scalable interfaces for developers and researchers. Compared to other satellite data providers, this platform offers several key advantages including detailed API documents for efficient automation in data discovery and retrieval, no token limitation for programmatic use, and standardized metadata format following SpatioTemporal Asset Catalog (STAC) for simplified filtering. In terms of the platform’s features utilized in the ETL microservice, the data extraction process was driven mainly through two of its standardized APIs: Catalog API and Process API. While the former is used to search and filter metadata of available satellite scenes based on coordination and time range, the latter is for generating and retrieving imagery over a selected area of interest. Together, these APIs enable an efficient workflow to extract necessary data types for ingestion into the ULake environment for further analysis.

To be more specific about the data content, CDSE distributes big data from several Sentinel missions, which are a series of satellites developed as a part of the Copernicus Earth Observation Program. Each Sentinel satellite is designed for a specific purpose:

* Sentinel-1 provides Synthetic Aperture Radar (SAR) for land and ocean monitoring.
* Sentinel-2 supports high-resolution optical imagery for land use, vegetation, and agriculture.
* Sentinel-3 studies sea surface topography, ocean and land color and surface temperature.
* Sentienl-5P includes atmospheric composition like ozone and UV radiation.
* Sentinel-4, Sentinel-5, and Sentinel-6 are dedicated to atmospheric, air quality, and sea-level monitoring respectively.

Among these, CDSE currently offers access to Sentinel-1, Sentinel-2, Sentinel-3, and Sentinel-5P datasets. The Sentinel program plays a critical role in modern Earth observation due to its high-resolution, multi-spectral sensors and short global revisit capabilities, which provides consistent and reliable imagery essential for climate change tracking, deforestation monitoring, and disaster management applications [10]. Without open-access data sources like Sentinel, many global environmental analysis tasks and machine leaning models would rely heavily on commercial satellite data which is limited in coverage and accessibility.

In this project, Sentinel-2 Level-2A (S2-L2A) imagery was used as the primary dataset for stimulation and system testing. This product contains atmospherically corrected surface reflectance data, making it suitable for vegetation indices such as NDVI (Normalized Difference Vegetation Index) or agricultural monitoring applications. While only S2-L2A was applied in this implementation, the architecture is designed to support ingestion of other Sentinel data in the same ETL pipeline with just some small modifications.

Due to the vast size of satellite archives, instead of querying the entire globe, the system focuses on one target region only: the Red River Delta in Vietnam with bounding box *[105.5, 20.5, 106.2, 21.5].* This area is known for intensive rice cultivation and it has been used as an instance for NDVI tracking and crop phenology studies [11]. The extracted data can support downstream tasks like agricultural monitoring, model training, and vegetation pattern analysis.

## III/ Methods

### 1. Microservice Architecture

To ensure modularity and asynchronous processing, this project adopted a reactive microservice architecture as the backbone of the ETL system. To start with, a microservice is a lightweight architectural style in which an application is decomposed into small and independently deployable services, each of which is responsible for a specific business function. The microservice approach aims for parallel development, easier debugging, and more flexible deployment, which is crucial in big data workflows like ETL pipelines to ULake where different services may evolve at difference paces over time. Without microservices, developers could likely resort to a contrast approach which is the monolithic architecture that would bundle all ETL logic intro a single application. This may be easier to start but then becomes difficult to maintain, hard to scale, and more prone to system failure. For example, a bug in one function could crash the entire system, requiring full re-deployment for any change [12]. To be clearer about this, below are simple graphs to compare the deployment of the two approaches:

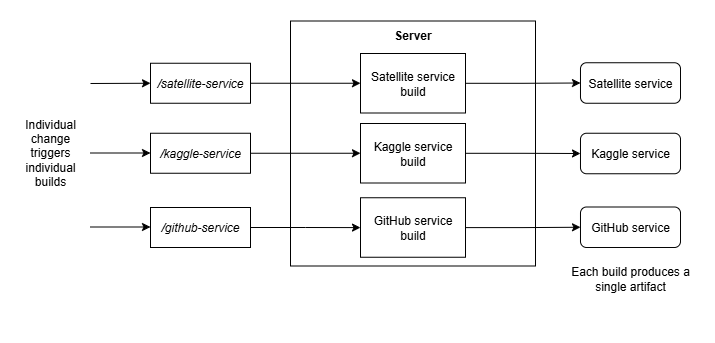


Figure 1. Microservice architecture with one source code repository and CI build per service [12].

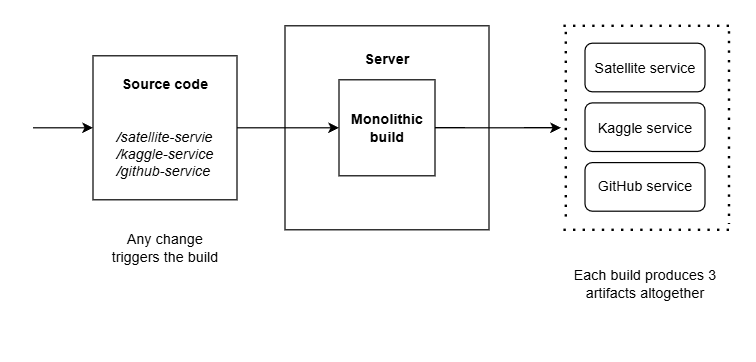


Figure 2. Monolithic architecture with a single source code repository and CI build for all services [12].

A reactive microservice further enhances the model by introducing non-blocking, event-driven, and backpressure-aware design patterns, aligning well with the demands of data stream ingestion and transformation. In this project, the reactive microservice was implemented using the Quarkus framework, leveraging its reactive core built on Mutiny and Vertx.

The project codebase was organized into separated functional packages under a root namespace *“usth.m1”* including:

* *entity*: Data Access Objects (DAO) contain data structures that map to PostgreSQL tables, particularly for storing satellite metadata.
* *model*: Data Transfer Objects (DTO) represents request/response bodies used in REST interactions.
* *proxy*: Defines REST client interfaces for external services such as the Copernicus APIs and ULake platform.
* *repository*: Manages database operations by utilizing Panache and PostgreSQL to store and query metadata records.
* *resource*: Acts as the REST entry point to the microservice, exposing API endpoints to trigger metadata extracting, image downloading, and data uploading.
* *service*: Business logic to chain catalog queries, process API calls, GDAL transformations, and file uploads to ULake.

This separation follows the single responsibility principle which makes the system easier to test, maintain, and scale within the boarder ULake platform.

In brief, using a reactive microservice structure not only improves the isolation, scalability but also ensures the system can ingest and process satellite imagery in a timely manner, aligning with the goals of the modern data lake environment [12].

### 2. Data Lake Architecture

As mentioned in the introduction, the ULake system, developed and maintained by the ICT Lab, is an example of an on-premises data lake designed to provide local, secure, and cost-efficient storage for high-volume scientific datasets. The primary motivation for adopting an on-premises architecture is to ensure data locality, access control, and integration with local compute infrastructure, which is often required in academic and governmental research environments where sensitive data workflows must be managed without depending on external networks.

The overall structure of the on-premises ULake used in this project follows a modular microservice-based architecture as illustrated in the diagram below:

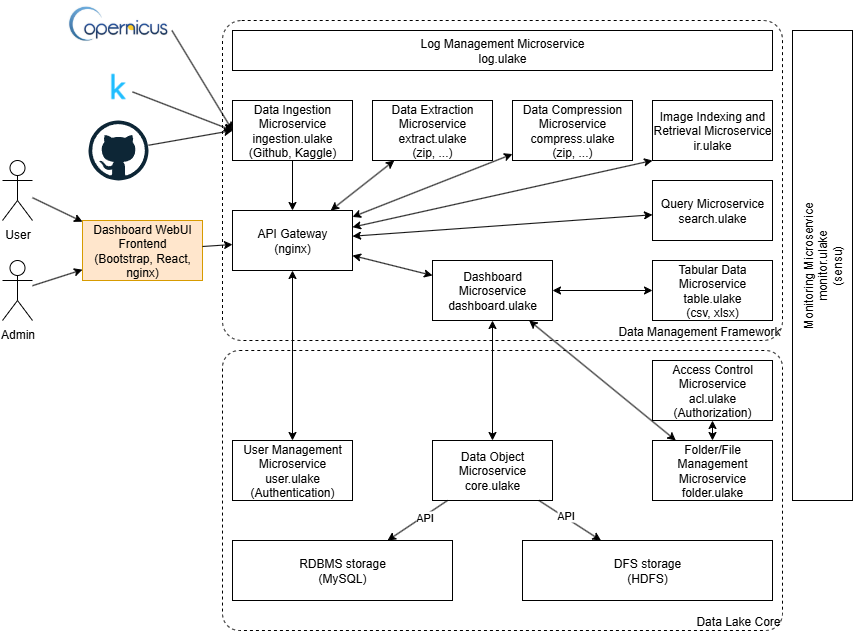


Figure 3. ULake architecture.

The system is composed of several interacting layers grouped into two primary blocks including Data Management Framework and Data Lake Core:

Data Management Framework contains:

* Log management microservice (package *log.ulake*) tracks the whole system logging details.
* Data ingestion microservice (package *ingestion.ulake*) connects to external data sources including Copernicus (the result from this project), Kaggle, and GitHub.
* Supporting data ingestion are data extraction (package *extract.ulake*) and data compression (package *compress.ulake*) microservices. These are responsible for data extraction and compression tasks respectively.
* Once data is ingested, it is further indexed and prepared for retrieval through the image indexing and retrieval microservice (package *ir.ulake*).
* The query microservice (package *search.ulake*) is used to search data after processing.
* All tabular data is handled via the tabular data microservice (package *table.ulake*) including CSV and XLSX files.
* The API gateway (based on nginx) acts as the central access point through which both users and admins interact with the system, typically via a dashboard interface served by package *dashboard.ulake*.

Data Lake Core includes:

* User management microservice (package *user.ulake*) manages account authentication to the ULake.
* Data object microservice (package *core.ulake*) connects directly to the underlying storage systems: MySQL for structured RDBMS storage and HDFS for distributed file system storage.
* Folder/File management microservice (package *folder.ulake*) used to manage the logical structure of folders and files is closely attached with access control microservice (package *acl.ulake*) which is in charge of enforcing user permission within the ULake.

Lastly, overall system health is handled by the monitoring microservice (package *monitor.ulake*).

This layered and modular design not only enables cleat separation of responsibilities across services but also ensures extensibility, making the architecture highly adaptable to evolving data needs. This creates a strong foundation for extending the platform through specialized components. One such extension is the focus of this project: an ETL microservice for data ingestion into the data lake which adds a mean of support for satellite image processing and ingestion from CDSE, significantly enhancing ULake’s ability to serve scientific and analytical work.

### 3. ETL microservice flow

#### a) Use-case diagram

Generally, the ETL microservice pipeline developed in this project consists of three main functional components: data extraction, data transformation, and data loading, which operates on satellite imagery provided by the CDSE aggregating data from multiple Sentinel missions namely Sentinel-1, Sentinel-2, Sentinel-3, and Sentinel-5P. The process begins with data extraction which includes two sub-processes: source authentication to acquire access tokens for interacting with CDSE APIs, and local save used to download metadata and images. The extracted data is then moved to the data transformation phase where preprocessing steps are applied. Finally, data loading is responsible for ingesting the processed data into the ULake. This last phase includes data lake authentication obtaining tokens to access to the ULake. Below is the use-case diagram which the project based on:

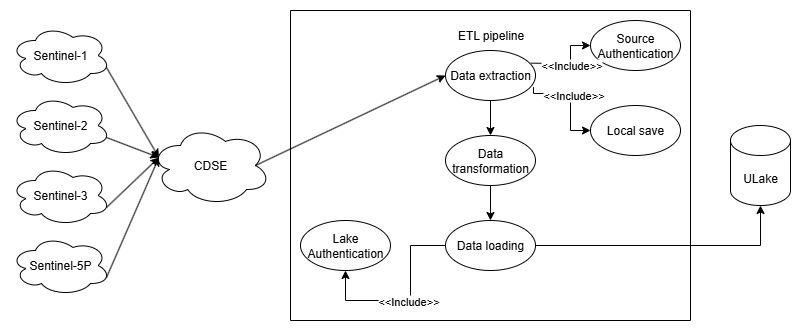


Figure 4. ETL use-case diagram

To be more specific about each component of the graphs, five sequence diagrams along with detailed description are shown thoroughly in the next part.

#### b) Authentication process

In order to secure the communication between the data source and any external application, CDSE and ULake both require authentication for mostly all request. Therefore, proper authentication processes must be implemented. In general, when a user or a scheduled process initiates an access request to the AuthResource component which is a REST API endpoint, the request is forwarded to AuthService and then AuthProxy

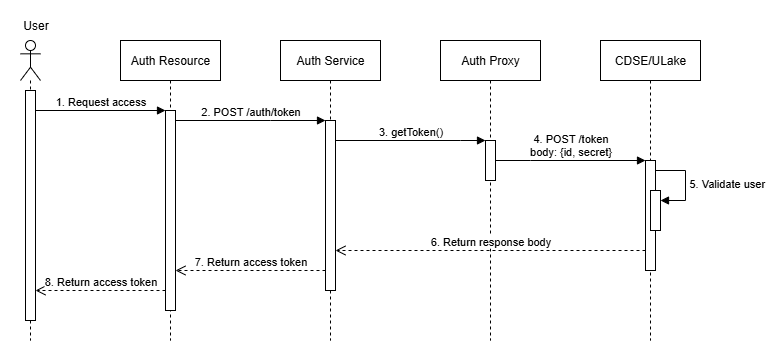


Figure 5. Authentication process

#### c) Extract process

- Extract (pull process)

- Setup token cho mỗi lần request

- Dữ liệu extract: ảnh true-color, ảnh full band, (STAC) metadata

- Khi lưu local: ảnh theo folder, metadata vào postgresql + time info + directory info

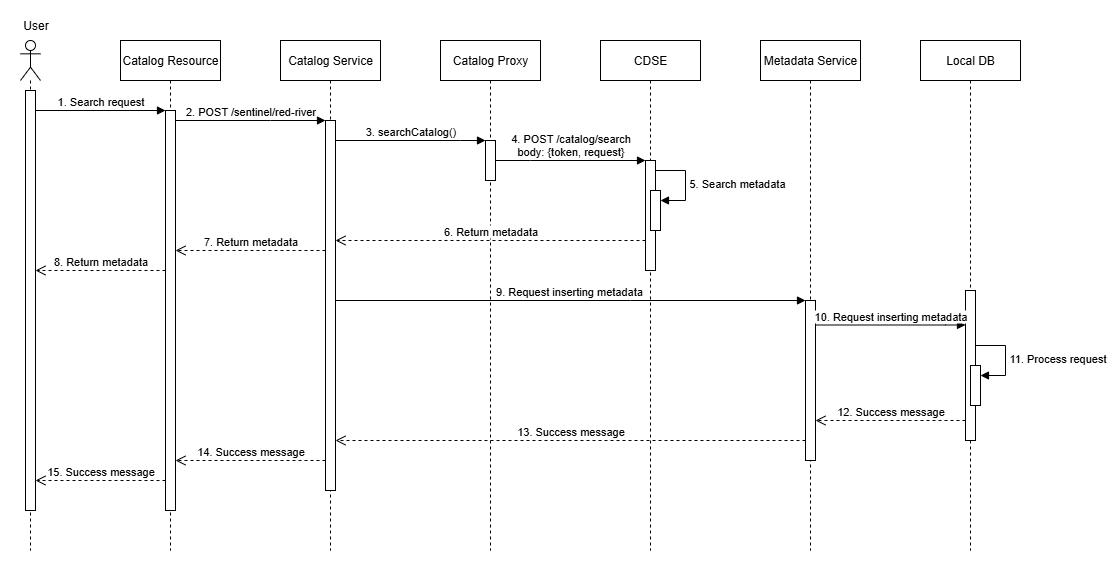


Figure 6. Extract process for Catalog APIs

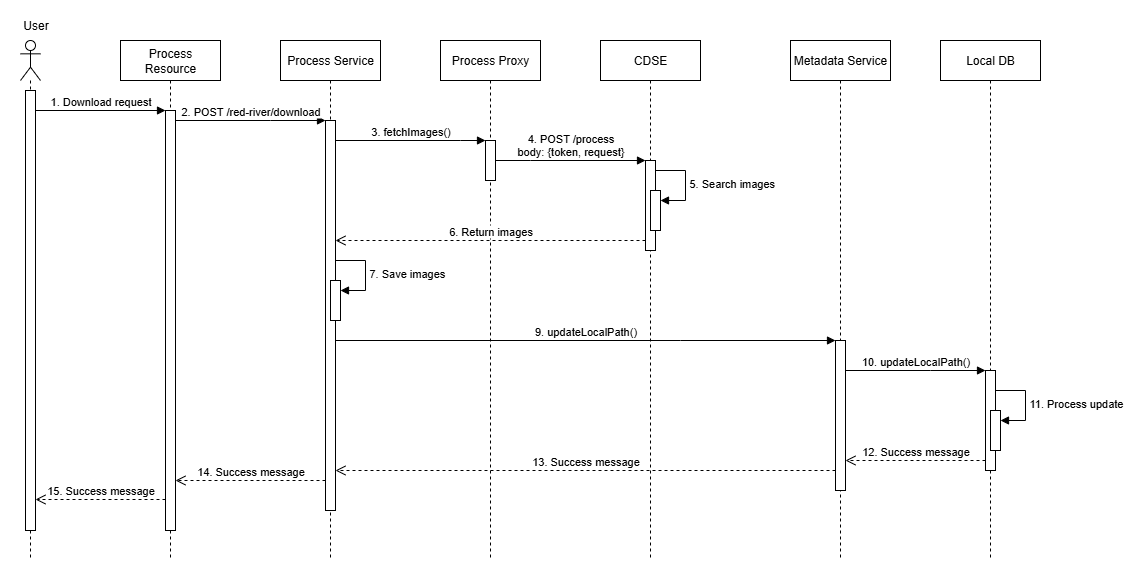


Figure 7. Extract process for Process APIs

#### d) Transform process

- Transform (preprocess: downsize image)

- Problem: raw images can be very large => need a downsize technique to be able to upload

- Nếu ko có thì quy trình sẽ phức tạp hơn: lưu ảnh ở cloud và chỉ save link ở lake

- Explain algorithm used

#### e) Load process

- Load (upload to lake)

- Retrieve token cho mỗi lần call

- Dùng file/folder microservice (nhắc về bất lợi Ulake nên ko dùng đc Object)

- Thông tin lưu: ảnh kèm 1 số thông tin cơ bản (nhắc về bất lợi Ulake nên ko upload đc metadata)

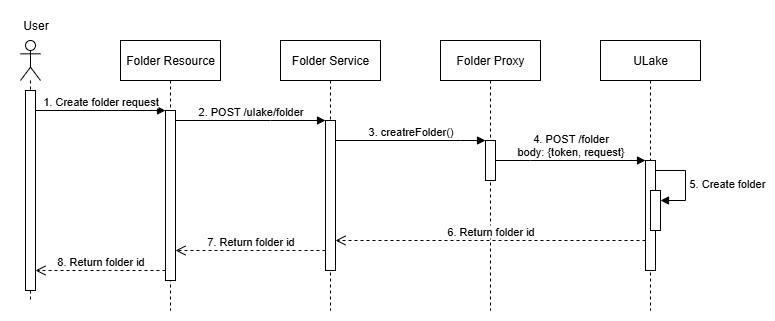


Figure 8. Load process for creating ULake folders

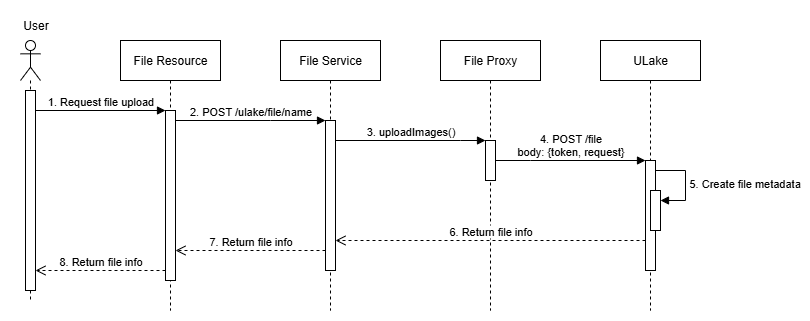


Figure 9. Load process for uploading files

# RESULT AND DISCUSSIONS

### 1. Result

- Hoạt động nnao?

- Extract đc loại dữ liệu gì

- Dữ liệu preprocess thành công ko? Kết quả đầu ra preprocess nnao?

- Upload dữ liệu vào datalake đc ko? Du lieu gi?

### 2. Discussion

Magento is a complex framework due to its dense design patterns and programming techniques. If considering only the functions of this project, it may seem simple and minor. However, to finish the module without being familiar with Magento is impossible. Actually, according to the timeline, two thirds of the internship is spent to understand just the most fundamental parts of the platform. Therefore, as a whole, this project is not straightforward at all. Even when I was able to implement all use cases, there are still some bugs that I could not manage to fix including failure to deal with complex products and to show correct price form in the search area. I did not have enough time to remove those flaws, but I was suggested to improve the controller for the former and to develop a new data binding for the latter in the future.

# CONCLUSION

- Overview: Paraphrase lại intro

- Future works

- Tạo log để theo dõi quá trình ETL

- Tạo cronjob chạy hàng ngày cho ETL để theo dõi 1 vài khu vực nhất định phục vụ nghiên cứu

- Thêm các bước preprocess để đảm bảo dữ liệu sạch: deduplication, avoid các ảnh trống (thường các ảnh này sẽ chỉ toàn màu đen. Dẫn chứng 1 ảnh).

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