# QUESTION A(i) Explain the IaaS, PaaS, and SaaS concepts using real-world examples from existing cloud providers and the literature in the context of your design

**Concepts of IaaS, PaaS, and SaaS**

The development of a cloud-native medical imaging application leverages the foundational models of cloud computing: Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS). These models provide the necessary scalability, security, and efficiency to manage sensitive medical data effectively. Below are definitions and practical examples relevant to the proposed application.

1. **Infrastructure as a Service (IaaS)**

IaaS is the bedrock for the application as it grants developers granular control over virtualized computing resources such as servers, networking, and storage such that they can manage and scale applications without owning physical hardware *Faridi et al. (2024*). A good example of such a resource is the AWS Elastic Compute Cloud (EC2).

* + **AWS EC2:** With its different instance types, including those equipped with powerful GPUs *Ascentient (2024)*, this resource can serve as the powerhouse for computationally intensive tasks. In this case, the medical imaging application runs on EC2 instances to process diagnostic images and manage requests for metadata and patient details. Also, EC2 instances are auto-scaled to handle peak workloads during high data inflow.

1. **Platform as a Service (PaaS):**

In essence, PaaS abstracts away the complexities of infrastructure management, allowing developers to focus on crafting innovative applications. This streamlined approach is the brains behind rapid development cycles and seamless scalability in modern healthcare technology *Covetus (2019)*.

* + **AWS Elastic Beanstalk:** Elastic Beanstalk is a PaaS offering strictly focused on helping developers to deploy applications without worrying about the underlying infrastructure. In the context of the proposed design, Elastic Beanstalk could be used to host the web service backend of the application, automatically managing deployment, scaling, and updates.

1. **Software as a Service (SaaS): Delivering a User-Centric Experience**

SaaS provides ready-to-use applications accessible via the internet, where users do not need to manage the underlying infrastructure or application code *Vola (2023)*.

* + The medical imaging application functions as a SaaS-like web service for radiologists and doctors, enabling them to securely upload, search, and retrieve patient data and imaging files. While not a prebuilt SaaS offering, it delivers SaaS-level convenience and accessibility to its users through a secure web interface hosted on **Amazon CloudFront**

**QUESTION A(ii)**

# Describe your design and how you plan to integrate different AWS products for this web service, considering cloud-related characteristics, such as storage, scalability, and security

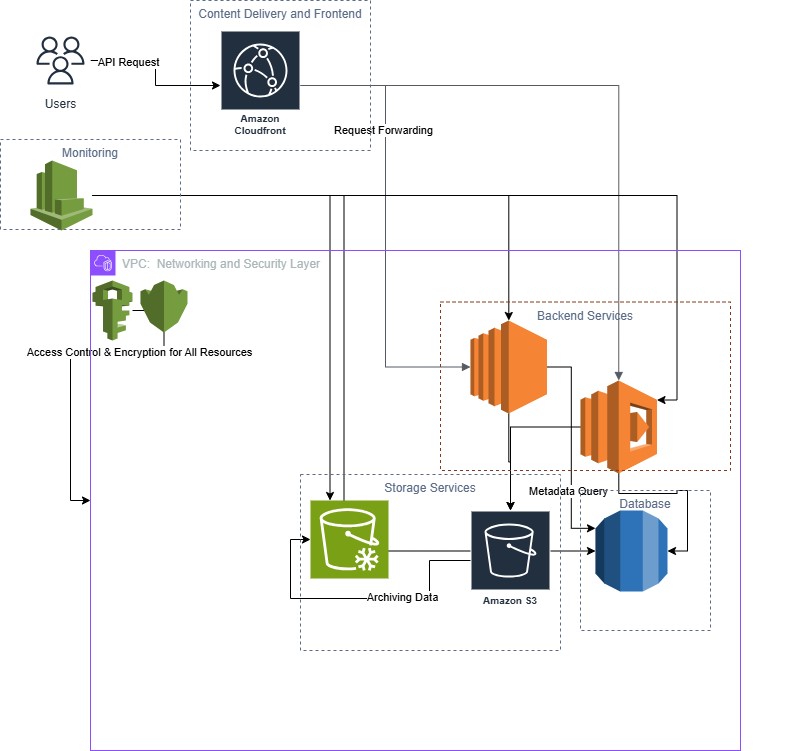
The proposed design of the medical imaging application integrates a range of AWS services to ensure scalability, security, and efficiency. Each service plays a critical role in achieving the desired outcomes of scalability, security, and efficient data handling, all of which align with the foundational principles taught within the AWS Academy Cloud Foundations course.

1. **Compute:**
   * **Integration:**
     + **Amazon EC2:** It serves as the backbone of backend infrastructure *Ascentient (2024)*, managing core operations such as processing user requests, running diagnostic workflows, and performing computationally demanding activities like rendering medical images and supporting AI-based analyses.
     + **AWS Lambda:** This handles event-driven tasks efficiently, including extracting metadata from uploaded images, updating the database, and sending notifications. This resource helps in optimizing resource utilization and minimizing operational costs.
2. **Storage:**
   * **Integration:**
     + **Amazon S3:** Serves as the primary storage repository for all diagnostic images and associated metadata, ensuring high availability, durability, and seamless data retrieval *Azeus Convene (2024)*.
     + **Amazon S3 Glacier :** Complements S3 by providing a low-cost option for archiving older or seldom-accessed data, preserving data integrity while reducing storage costs.
3. **Database:**
   * **Integration:**
     + **Amazon RDS:** Offers a reliable and scalable relational database solution for storing structured data such as, patient demographics, diagnostic outcomes, and metadata *Techvify Software (2023)*. Its Multi-AZ deployments ensure high availability and data resilience, making it suitable for healthcare-critical environments.

RDS helps healthcare professionals to quickly query and retrieve critical patient information alongside associated imaging data, that ultimately support quicker decision-making and quality patient care.

1. **Networking and Content Delivery:**
   * **Integration:**
     + **Amazon CloudFront:** Delivers images, reports, and other data to users by reducing latency *Healthcare IT News (2013)* and enhancing transfer speeds, providing a smooth user experience regardless of their location.
     + **Amazon VPC:** Creates a secure and isolated network for backend resources, protecting sensitive patient data and enhancing the overall security posture of the application.
2. **Security:**
   * **Integration:**
     + **AWS IAM:** Implements detailed access control, allowing only authorized personnel to access and modify patient data, *The App Solution*s (2023).
     + **AWS KMS:** Encrypts data both at rest (within S3) and in transit, protecting sensitive information and ensuring compliance with stringent healthcare regulations such as HIPAA.
3. **Monitoring:**
   * **Integration:**
     + **AWS CloudWatch:** Continuously monitors the performance and health of all critical components, including EC2 instances, S3 buckets, RDS databases, and Lambda functions *Carmatec (2024)*. It also aggregates and analyzes logs, which give useful insight into application performance and identifying potential issues.

# QUESTION A(iii) Provide an overview diagram of your design



**Example Workflow:**

1. A radiologist accesses the frontend application (hosted on CloudFront) and uploads a diagnostic image.
2. The image is uploaded to Amazon S3.
3. An AWS Lambda function is triggered, which extracts the key metadata from the image and stores it securely in the Amazon RDS database.
4. Lifecycle policies automatically archive older images to Amazon S3 Glacier for cost-effective long-term storage.
5. AWS CloudWatch monitors resource utilization, logs events, and provides alerts to notify administrators of any potential issues.
6. AWS IAM and AWS KMS ensure that all data access and interactions are secure and compliant with preset and relevant regulations.

# QUESTION A(iv) Describe your web service design and its REST interface for different access and search options

**Web Service Design**

The web service is designed as a **cloud-native application** with the following objectives:

1. **Accessibility**: Medical professionals can access patient data, diagnostic results, related images, and metadata through a secure web interface.
2. **Search and Filter Capabilities**: The service allows users to search and filter records based on patient IDs, diagnosis types, upload dates, and other metadata *Techvify Software (2023)*.
3. **Efficiency**: Implements a RESTful architecture to facilitate smooth interactions between the frontend (via **Amazon CloudFront**) and backend services hosted on **Amazon EC2** and **AWS Lambda** *WJAETS (2024)*.
4. **Scalability and Security**:
   * **Amazon S3** is used for scalable storage of images. o **Amazon RDS** serves as the relational database for structured metadata storage.
   * **AWS IAM** and **AWS KMS** manage access control and encryption.

**Search and Access Options**

1. **Filters**:
   * The /searchImages endpoint allows doctors to filter records by:

▪ **Diagnosis Type**: e.g., "Cancer."

▪ **Image Type**: e.g., "MRI," "X-ray."

▪ **Upload Date**: e.g., "2024-12-25."

1. **Direct Access**:
   * The /getPatientDetails endpoint provides direct access to all records for a specific patient.
2. **Metadata-Driven Retrieval**:
   * Metadata stored in **Amazon RDS** is used to refine searches and connect diagnostic images (from S3) with patient records.

**Security in REST API**

1. **Authentication**:
   * All endpoints require **JWT (JSON Web Tokens)** for secure user authentication.
   * Example header:

Authorization: Bearer <jwt\_token>

1. **Encryption**:
   * Data is encrypted at rest using **AWS KMS** and in transit using **HTTPS**.
   * Sensitive data such as patient records and imaging files are secured with strict access policies in **AWS IAM**.
2. **Access Control**:
   * Role-based access ensures that only authorized users (e.g., radiologists, doctors) can interact with specific endpoints.

**(B) Describe and evaluate the bioinformatics application**

# QUESTION B(i)

**Describe your source and output files and folders and how they should be used.**

The developed application is designed to analyze bacterial organisms based on their features using Gene Ontology (GO) annotations provided in .gaf files. The focus of the analysis is on the identification of organisms that exhibit the "competence" feature, a physiological state associated with the ability to take up exogenous genetic material. This feature is indicated by the GO term GO:0030420 and its subterms.

The application processes input .gaf files, which contain tab-separated data describing proteins and their functions *Ashburner et al. (2000)*. Specifically, the second column contains protein identifiers, and the fifth column includes associated GO terms. By analyzing occurrences of GO:0030420 and its subterms in the fifth column, the application determines the likelihood of each organism exhibiting competence.

The .gaf files used as input were:

* *Escherichia\_coli\_K-12\_ecocyc\_83333.gaf*
* *Bacillus\_subtilis\_168-224308.gaf*
* *Bacillus\_amyloliquefaciens\_FZB42-326423.gaf*
* *Bacillus\_licheniformis\_ATCC\_14580-279010.gaf*
* *Bacillus\_megaterium\_DSM\_319-592022.gaf*
* *Geobacillus\_kaustophilus\_HTA426-235909.gaf*
* *Geobacillus\_thermodenitrificans\_NG80\_2-420246.gaf*

For each organism, the application generates an output file summarizing the count of "competence" and its associated subterms, providing insights into the potential for DNA uptake within each bacterial species.

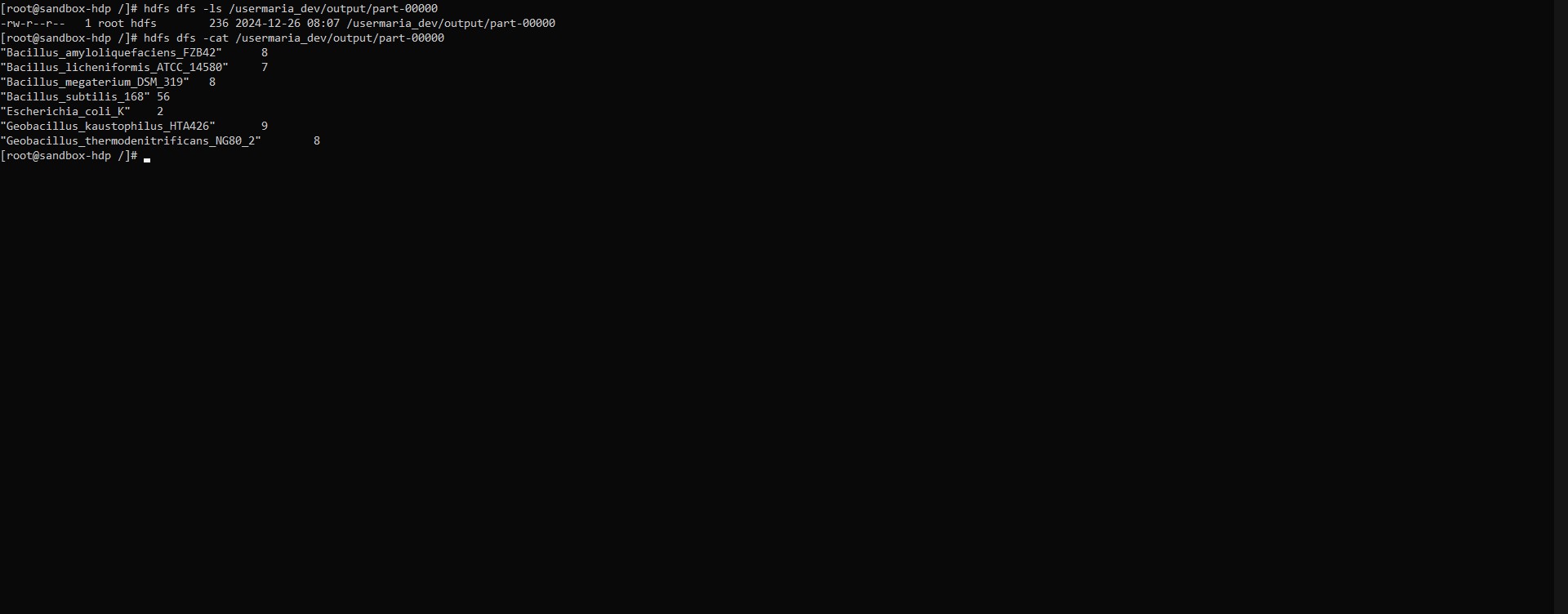
# Input

The .gaf files used in the application contain 17 fields, with the following relevant fields:

* **Column 2**: Protein Identifier
* **Column 5**: GO Term (e.g., GO:0030420)

These files were uploaded to Hadoop's HDFS for processing.

# Output



The output lists the count of GO:0030420 and its subterms for each organism, as shown below:

"Bacillus\_amyloliquefaciens\_FZB42" 8

"Bacillus\_licheniformis\_ATCC\_14580" 7

"Bacillus\_megaterium\_DSM\_319" 8

"Bacillus\_subtilis\_168" 56

"Escherichia\_coli\_K" 2

"Geobacillus\_kaustophilus\_HTA426" 9

"Geobacillus\_thermodenitrificans\_NG80\_2" 8

These results indicate the frequency of competence-related terms in the GO annotations for each organism.

**QUESTION B(ii)**

**Critically evaluate design aspects and findings related to your solution**

# Technology Stack

The application was developed using the following technologies:

* **Hadoop**: For distributed storage and computation.
* **MapReduce**: To process large .gaf files in a scalable manner.
* **Python**: Specifically, the mrjob library for writing the MapReduce job *Taylor (2010).*

# Implementation Logic

* **Mapper**: Extracts the organism name (from the file name) and counts occurrences of

GO:0030420 and its subterms in the fifth column of the .gaf files.

* **Reducer**: Aggregates the counts for each organism to produce a total count of competence-related terms.

**QUESTION B(iii)**

# Findings and Evaluation

## Findings

* Bacillus subtilis 168 exhibited the highest occurrence of competence-related GO terms (56 occurrences), indicating it is the most likely to display the competence feature.
* Bacillus amyloliquefaciens FZB42 and Geobacillus kaustophilus HTA426 showed moderate occurrences (8 and 9, respectively), suggesting a lower likelihood of competence compared to Bacillus subtilis
* *Escherichia\_coli\_K-12* had the lowest count (2 occurrences), indicating a lower likelihood of exhibiting competence.

## Evaluation

1. **Scalability**:
   1. The use of Hadoop and MapReduce demonstrated the potential for scalability. Adding more organisms or larger .gaf files would not significantly impact performance.
2. **Accuracy**:
   1. The application successfully identified and counted the relevant GO terms (GO:0030420 and its subterms) as per the task requirements.
3. **Limitations**:
   1. The results depend entirely on the annotations provided in the .gaf files. Missing or incomplete data in these files could affect the analysis.

○ The application employs simple pattern matching for GO subterms and does not currently perform hierarchical analysis that considers deeper relationships within the GO ontology structure.

1. **Improvements**:
   1. Future iterations could make use of an enhanced parser for .gaf files to handle unexpected formats or missing fields gracefully.

## References

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# Appendix

## A. Source Code

# competence\_feature\_count.py from mrjob.job import MRJob

class GAFCompetenceCount(MRJob): def mapper(self, \_, line): fields = line.split('\t') if len(fields) > 4 and "GO:0030420" in fields[4]:

filename = self.options.input\_file.split('/')[-1] organism = filename.split('-')[0] yield organism, 1

def reducer(self, organism, counts): yield organism, sum(counts)

if \_\_name\_\_ == "\_\_main\_\_":

GAFCompetenceCount.run()

## B. Output File Content

"Bacillus\_amyloliquefaciens\_FZB42" 8

"Bacillus\_licheniformis\_ATCC\_14580" 7

"Bacillus\_megaterium\_DSM\_319" 8

"Bacillus\_subtilis\_168" 56

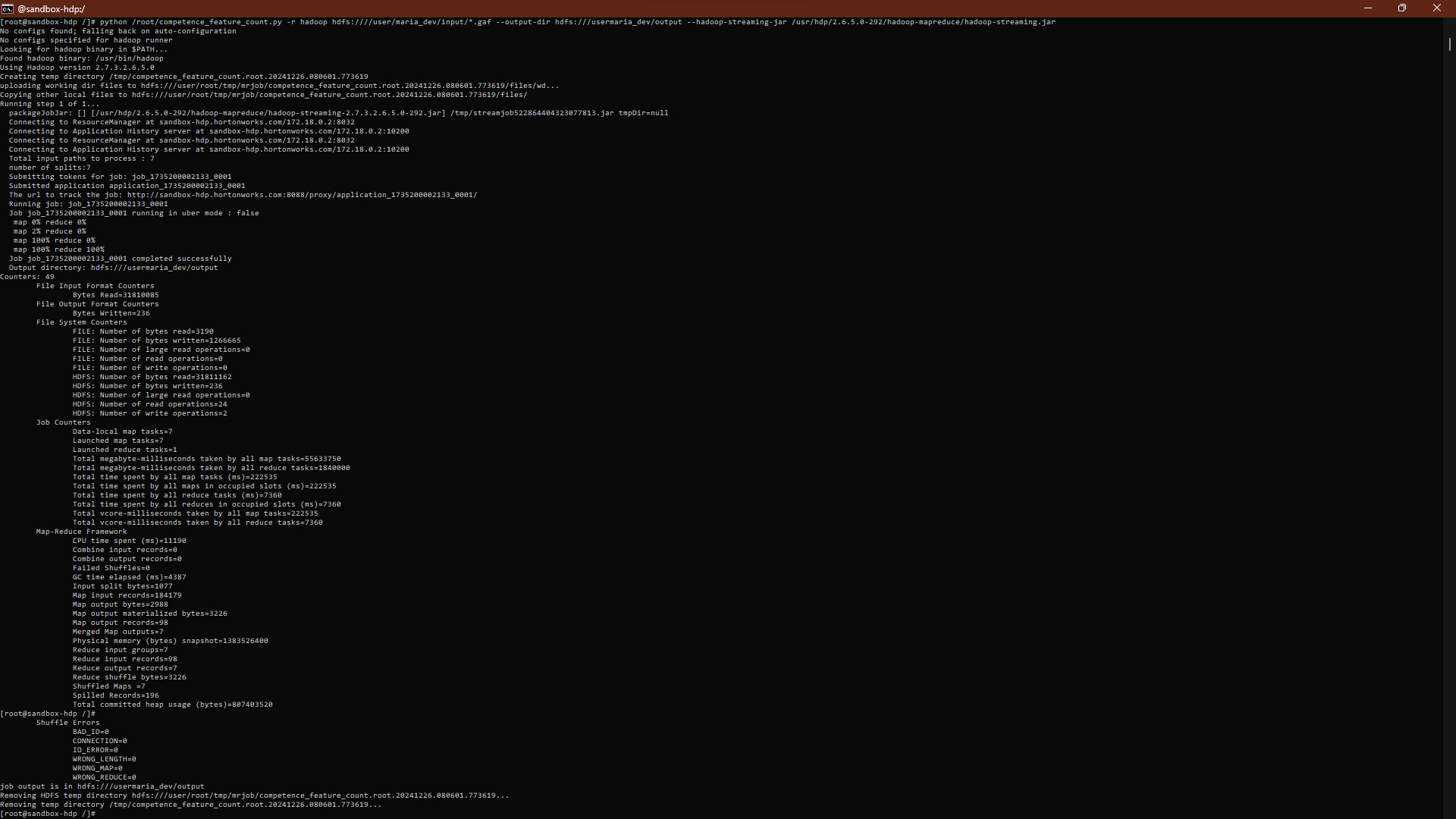
"Escherichia\_coli\_K" 2

"Geobacillus\_kaustophilus\_HTA426" 9

"Geobacillus\_thermodenitrificans\_NG80\_2" 8

## C. Commands Executed

1. Upload input files: hdfs dfs -put /root/input\_files/\*.gaf /user/maria\_dev/input
2. Run the MapReduce job:



python /root/competence\_feature\_count.py -r hadoop hdfs:///user/maria\_dev/input/\*.gaf \

--output-dir hdfs:///usermaria\_dev/output \

--hadoop-streaming-jar

/usr/hdp/2.6.5.0-292/hadoop-mapreduce/hadoop-streaming.jar

1. View results: hdfs dfs -cat /usermaria\_dev/output/part-00000