REDUCING HEALTHCARE COSTS THROUGH PATIENT ENCOUNTER ANALYSIS

MSDS436: Analytics Systems Engineering

Megan Bohan

Ferdynand Hebal

Andrew Lee

EXECUTIVE SUMMARY

Objectives: Reduce costs for a nationwide hospital system by identifying groups of patients who are predicted to have high costs and developing cost reduction programs.

Results: The bulk of the predicted costs come from patients aged 65-90. Patients with chronic conditions have higher median predicted costs than patients who do not have those chronic conditions. Patients with heart disease, diabetes, heart failure, and kidney disease are predicted to have a high sum of costs when taking patient volumes into consideration.

Conclusion: The hospital system should develop preventative health and monitoring programs for patients with risk factors for or already diagnosed with heart disease, diabetes, heart failure, and kidney disease. These programs should be prioritized for patients between ages 65-90, and states with high volumes of patients.

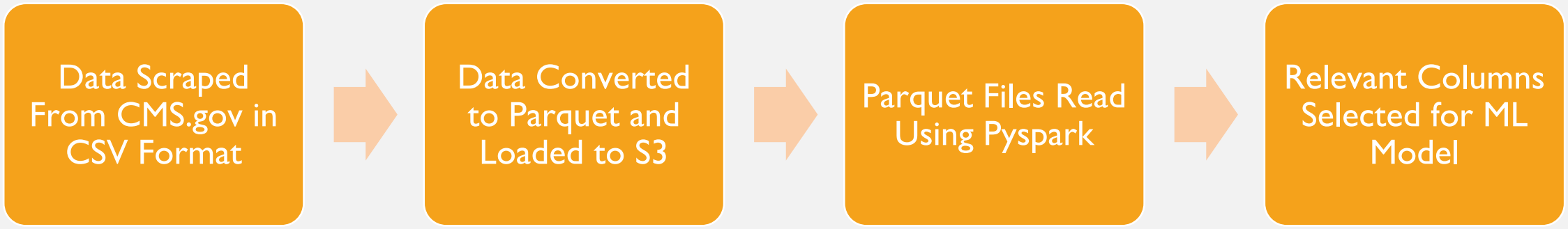
RESEARCH OBJECTIVES

- A nation wide hospital system is faced with increasing costs and is looking for help to decrease costs without negatively impacting patient care. **They are looking to identify groups of patients who are at risk of being high cost and develop programs that will reduce the overall cost.**
- Research has shown that patients with chronic conditions are high cost, and that the top 5% of high cost patients contribute to 55% of healthcare costs each year (van der Wees et al., 2018). Research has also shown that socio-economic factors contribute to overall health outcomes (Magnan, 2019).
- The Centers for Medicare & Medicaid's Synthetic Public Use data set contains both diagnosis and demographic data related to patient encounters. This data will be used to create a machine learning model that will predict the risk of a patient being high cost.
- The cost prediction information can be used to identify patient populations to proactively engage in health programs to reduce their overall cost to the healthcare system.

DATA SETS AND DATA PREPARATION

CMS Synthetic Public Use File (CMS.gov, 2019):

- Beneficiary Summary
- Inpatient Claims
- **Outpatient Claims
- **Prescription Drug Events



** Data was scraped and formatted but not used in analysis

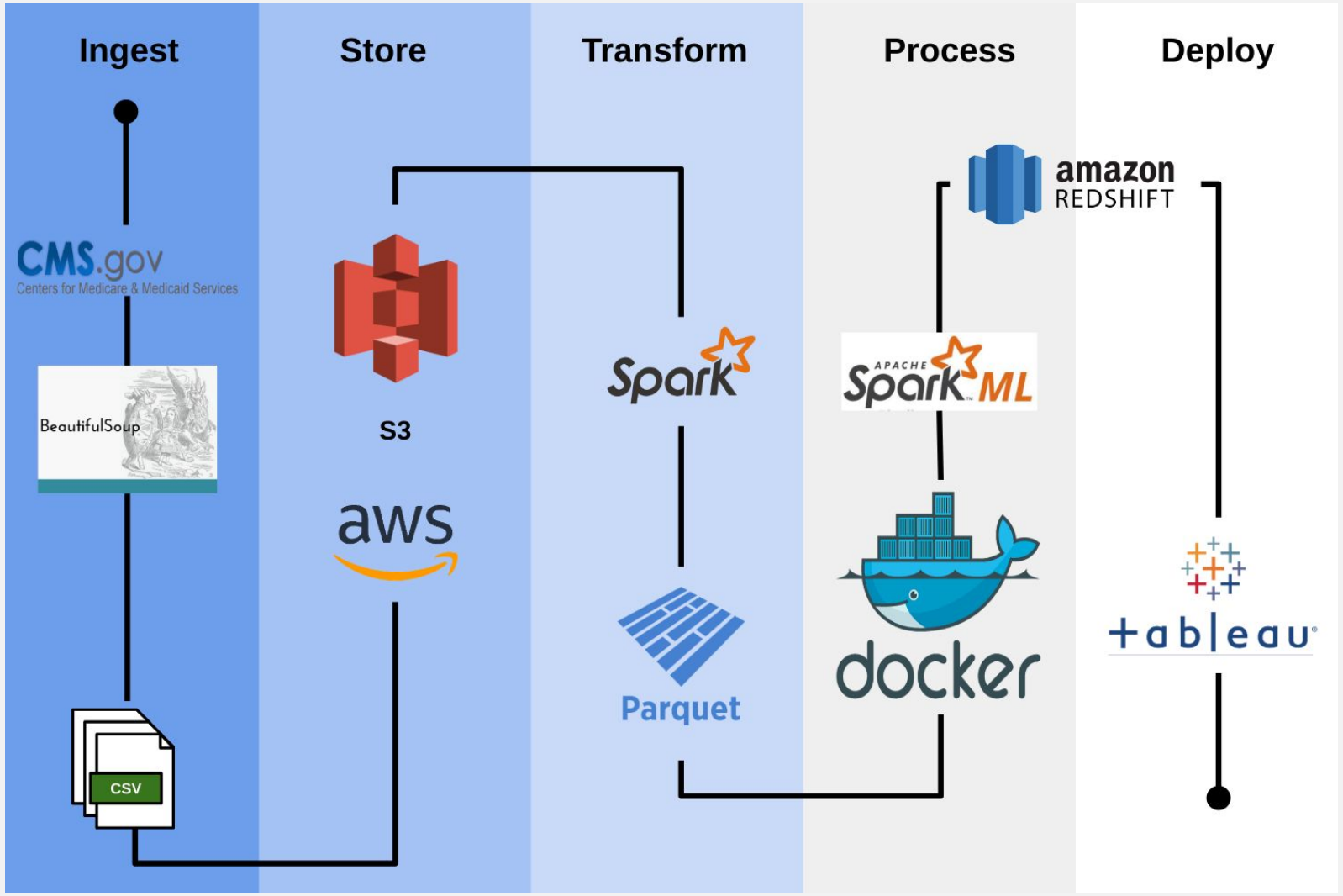
DATA INGESTION, ANALYSIS, PREPARATION

- CMS data was scraped using Python and Beautiful Soup
- All files including 5 table schemas and 135,666,373 patient records ingested
- Amazon S3 was the first stopping point for ingested data
- CSV files converted to Parquet files to compress size and speed up read
- Webscraping, data ingestion, and transformation script was containerized using Docker and deployed in Amazon EC2 instance
- PySpark jobs aggregated data and applied transformations
- ML script was built in Jupyter and reduced to a scalable Python script
- ML script was containerized using Docker and deployed in Amazon EC2 instance
- Feature engineering, model training and evaluation conducted in container scripts
- Analysis results output to Parquet file in Amazon Redshift

METHODOLOGY AND TOOLS USED

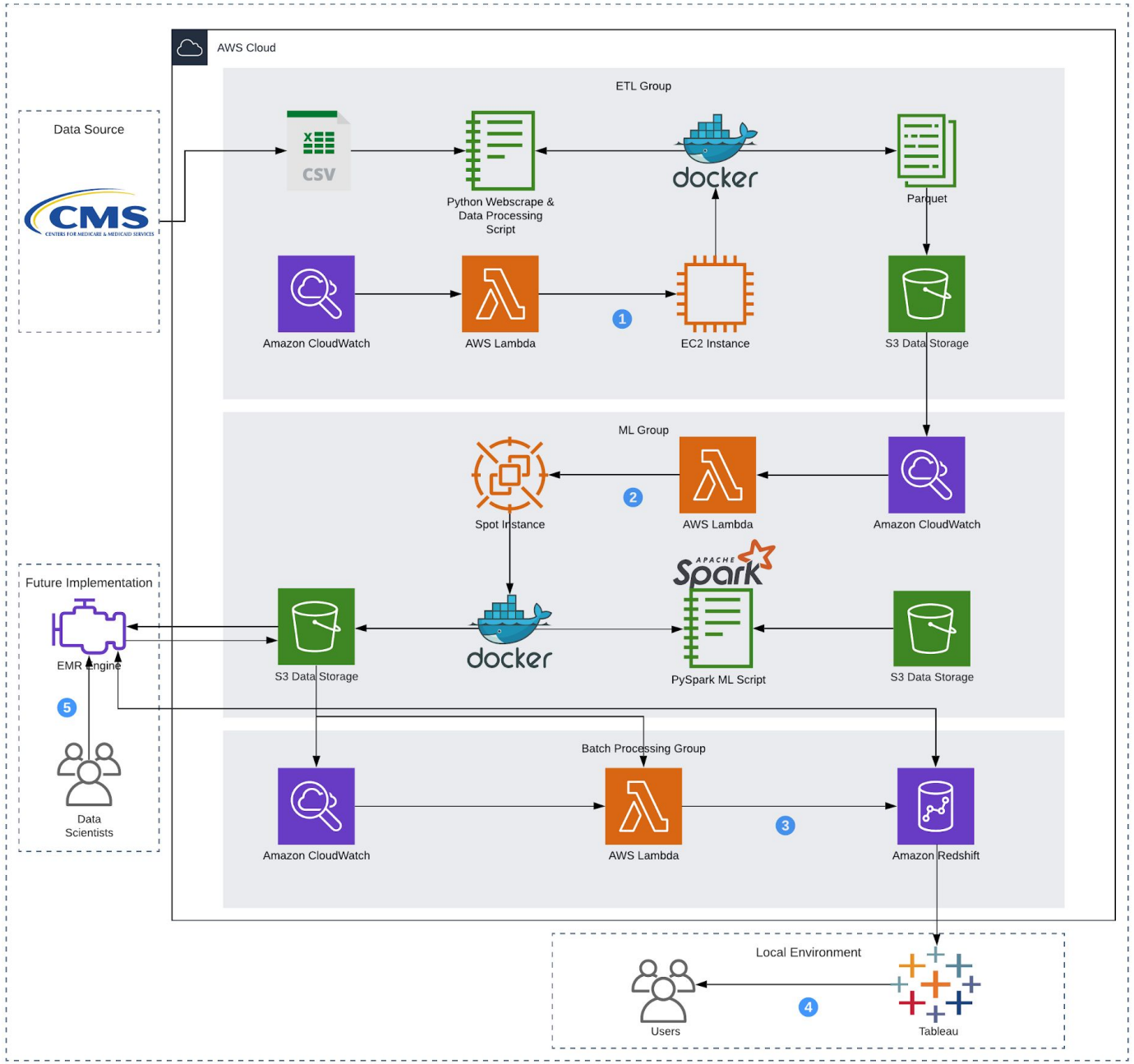
- Python & Beautiful Soup - Web Scraping
- PySpark - Data Ingestion and Transformation
- Boto3 - Interface with Amazon APIs
- AWS API
- Amazon CLI
- AWS Lambda - Automation/Scheduling Scripts and Batch Processing
- Paramiko - SSHv2 Protocol to Connect to EC2, Open Shell, and Run Docker Image
- AWS S3 - Storage
- Spark ML - Linear Regression
- Docker - Containerization of ETL Process, Feature Engineering, Model Training, and Deploy
- Node.js - Load Data into Redshift
- Redshift - Data Warehouse and Insight Result Storage for Deployment to Tableau
- Tableau - Data Visualization and Insight Reporting

SYSTEM ARCHITECTURE



SYSTEM ARCHITECTURE

- End to end pipeline is fully automated with a near serverless architecture.
- Automation is implemented with a series of Amazon Lambda functions that starts with an initial function that is scheduled on regular intervals within Amazon CloudWatch.
- Each script is containerized within Docker images where each VM instance is started and stopped through triggers for cost efficiency.



System Elements

1 *Using Amazon CloudWatch, a scheduled event triggers a Lambda function that starts an Amazon EC2 instance that contains a Docker image. Once the instance is started another function is triggered to connect to the instance via SSH through a virtual environment setup in Lambda. A shell is started that runs a Python script within the Docker image that scrapes CSV files from the CMS website, transforms and converts the data into Parquet files, and uploads them to Amazon S3. After processing, an event is logged triggering another Lambda function that stops the instance.*

2 *The event that is logged after processing triggers another Lambda function that starts an EC2 Spot Instance. Once the instance is started a Lambda function is triggered that connects to the Spot Instance via SSH through a virtual environment, and starts a shell that runs a machine learning script within a Docker image. Using PySpark, data is read from the files in S3 and a linear regression model is trained. Once trained, predictions are made and processed into a Parquet file that is uploaded into S3. The processing is logged and a Lambda function is triggered to set the Spot Instance to hibernate.*

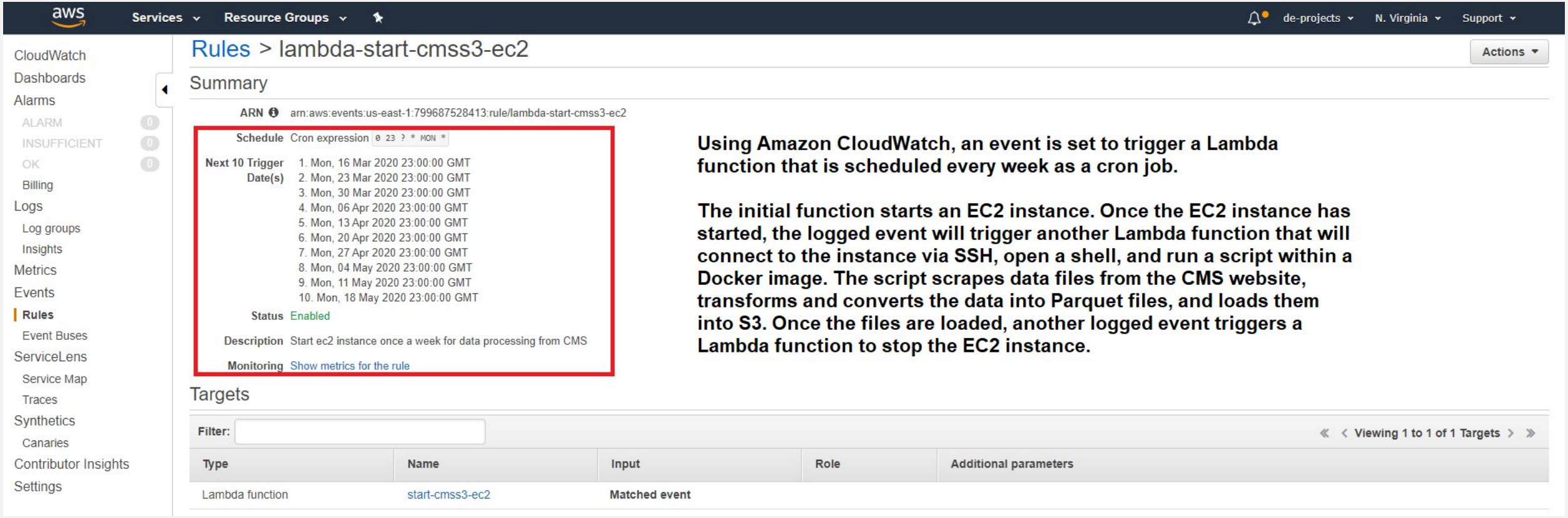
3 *Through CloudWatch logs, the processed event triggers multiple Lambda functions that contains files and scripts written in Node.js that loads the Parquet files from the folders in S3 to Amazon Redshift. Each Lambda function that loads Parquet files from an S3 folder into their respective table is set to trigger sequentially. That is, once a folder is loaded, an event is sent to CloudWatch logs. and the next Lambda function is triggered, which loads the next folder.*

4 *Once files are processed into Redshift, updated data is available for manipulation, analysis, and visualization either through direct queries in the Redshift query editor or a BI and visualization tool such as Tableau. Users are able to directly access data from Redshift when connected to the cluster using software like Tableau.*

5 *It is recommended that a future iteration implements an EMR cluster(s) for direct access by Data Scientists for more robust modeling and predictive analytics. The EMR cluster(s) can directly access S3 or Redshift and can be used to transform and move data in and out of storage or databases/datawarehouse.*

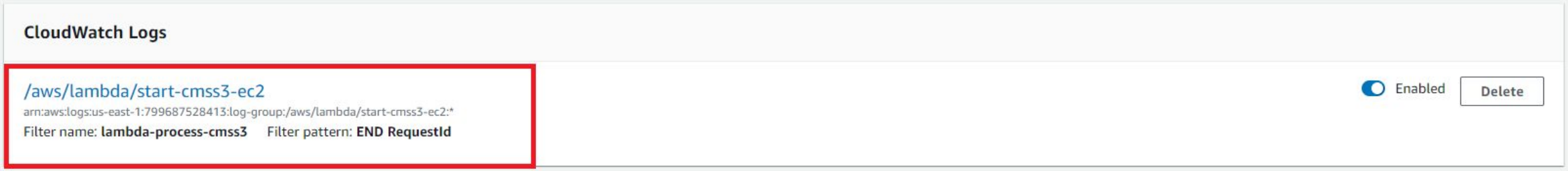
SYSTEM ARCHITECTURE AUTOMATION

Amazon Cloudwatch



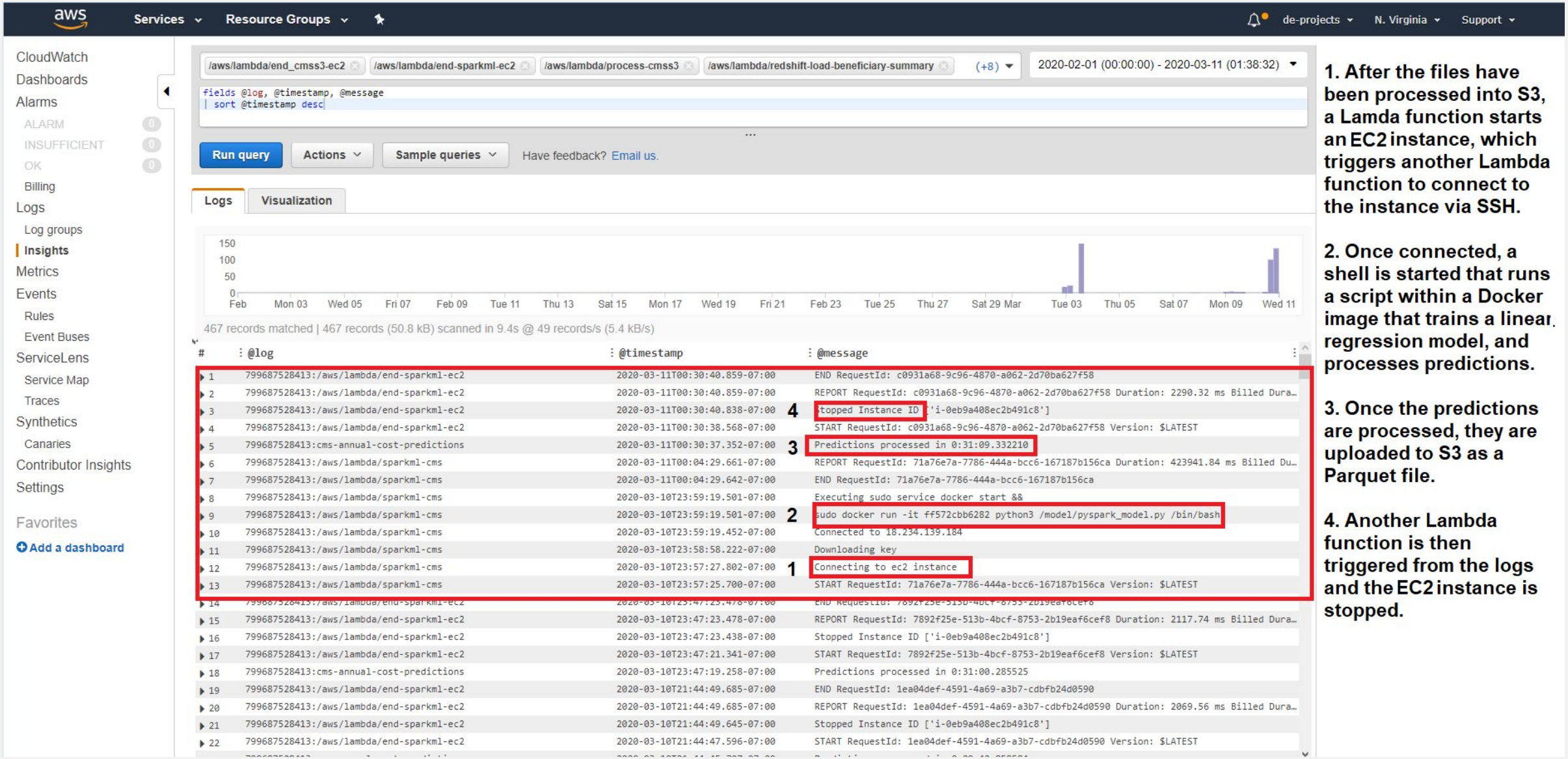
Using Amazon CloudWatch, an event is set to trigger a Lambda function that is scheduled every week as a cron job.

The initial function starts an EC2 instance. Once the EC2 instance has started, the logged event will trigger another Lambda function that will connect to the instance via SSH, open a shell, and run a script within a Docker image. The script scrapes data files from the CMS website, transforms and converts the data into Parquet files, and loads them into S3. Once the files are loaded, another logged event triggers a Lambda function to stop the EC2 instance.



SYSTEM ARCHITECTURE AUTOMATION

Amazon Cloudwatch



1. After the files have been processed into S3, a Lamda function starts an EC2 instance, which triggers another Lambda function to connect to the instance via SSH.

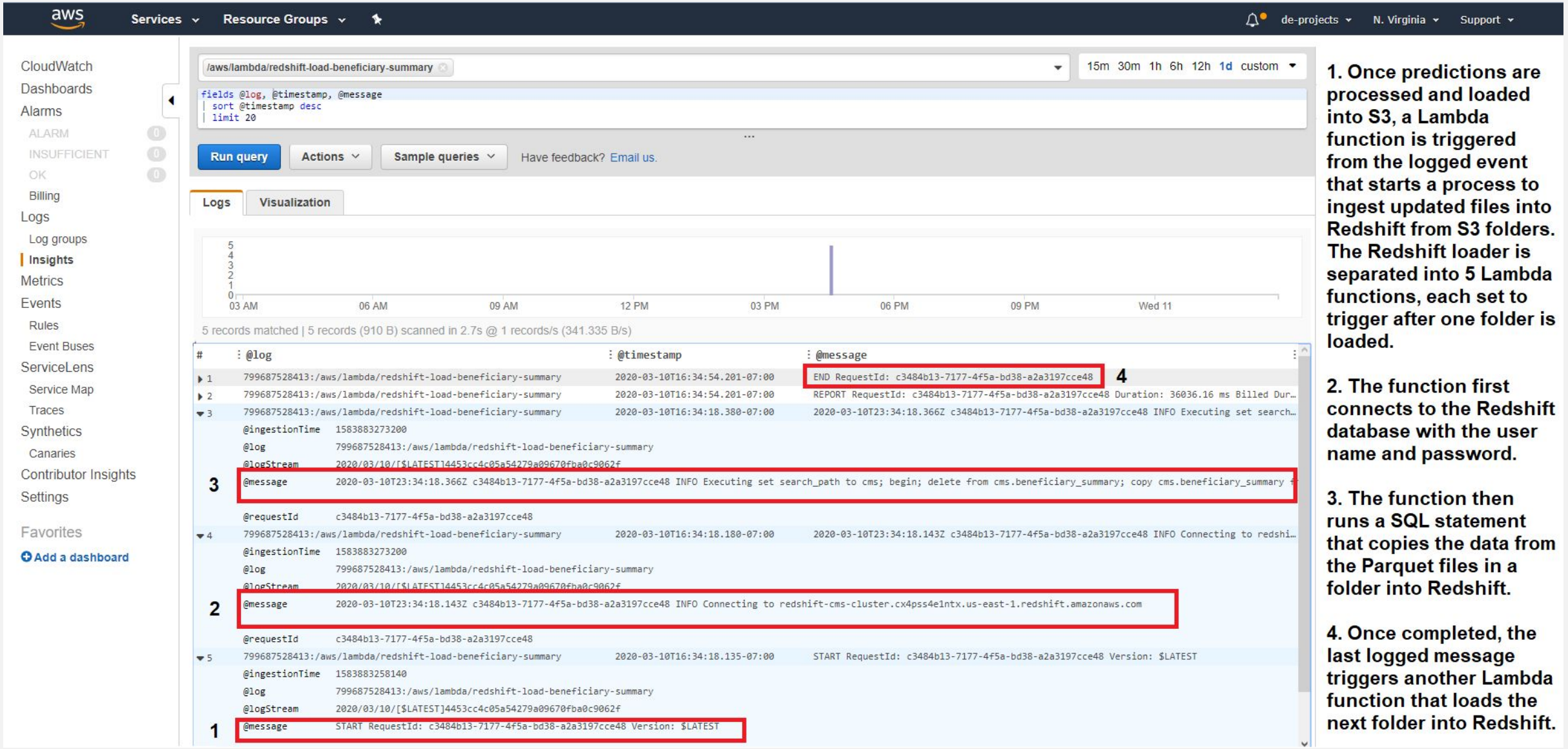
2. Once connected, a shell is started that runs a script within a Docker image that trains a linear regression model, and processes predictions.

3. Once the predictions are processed, they are uploaded to S3 as a Parquet file.

4. Another Lambda function is then triggered from the logs and the EC2 instance is stopped.

SYSTEM ARCHITECTURE AUTOMATION

Amazon Cloudwatch



1. Once predictions are processed and loaded into S3, a Lambda function is triggered from the logged event that starts a process to ingest updated files into Redshift from S3 folders. The Redshift loader is separated into 5 Lambda functions, each set to trigger after one folder is loaded.

2. The function first connects to the Redshift database with the user name and password.

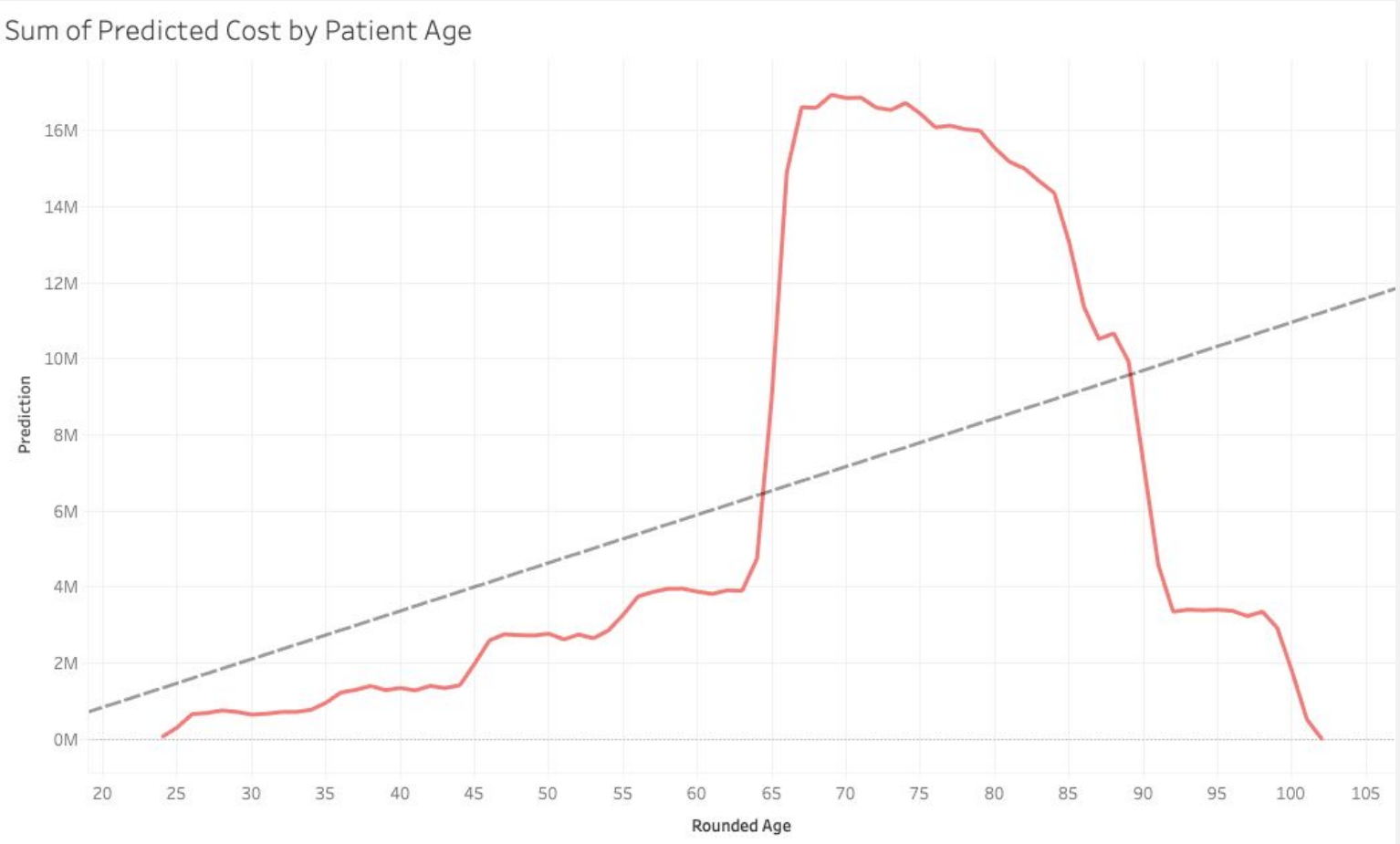
3. The function then runs a SQL statement that copies the data from the Parquet files in a folder into Redshift.

4. Once completed, the last logged message triggers another Lambda function that loads the next folder into Redshift.

MACHINE LEARNING MODEL
DEPLOYING ML MODELS TO PRODUCTION

- Parquet files read to spark dataframes and processed with PySpark pipeline functions to transform to appropriate format and data types for ML
- Transformed data random split 0.70. and 0.30 to train and test data sets
- Linear Regression model generated using patient's age, gender, race, and state with the encounter diagnosis code, procedure code, and common procedure code to predict annual cost.
- Predictions merged with patient chronic condition data and output into a Parquet file for evaluation.
- Machine learning script was containerized with Docker and image pushed to Dockerhub.

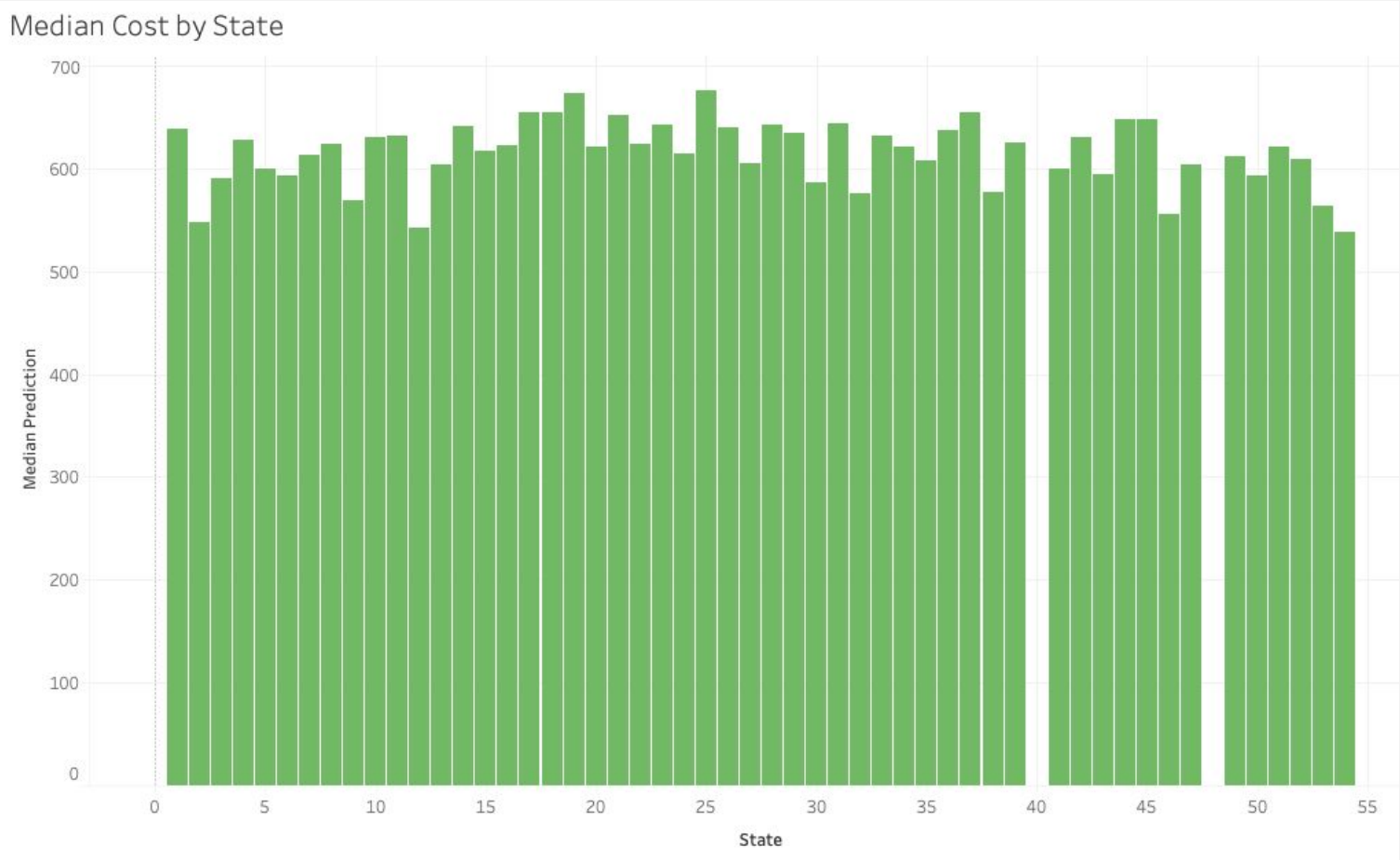
REPORTING



The sum of the predicted costs increases with age, with the bulk of the predicted costs are coming from patients aged 65-90.

tableau

REPORTING

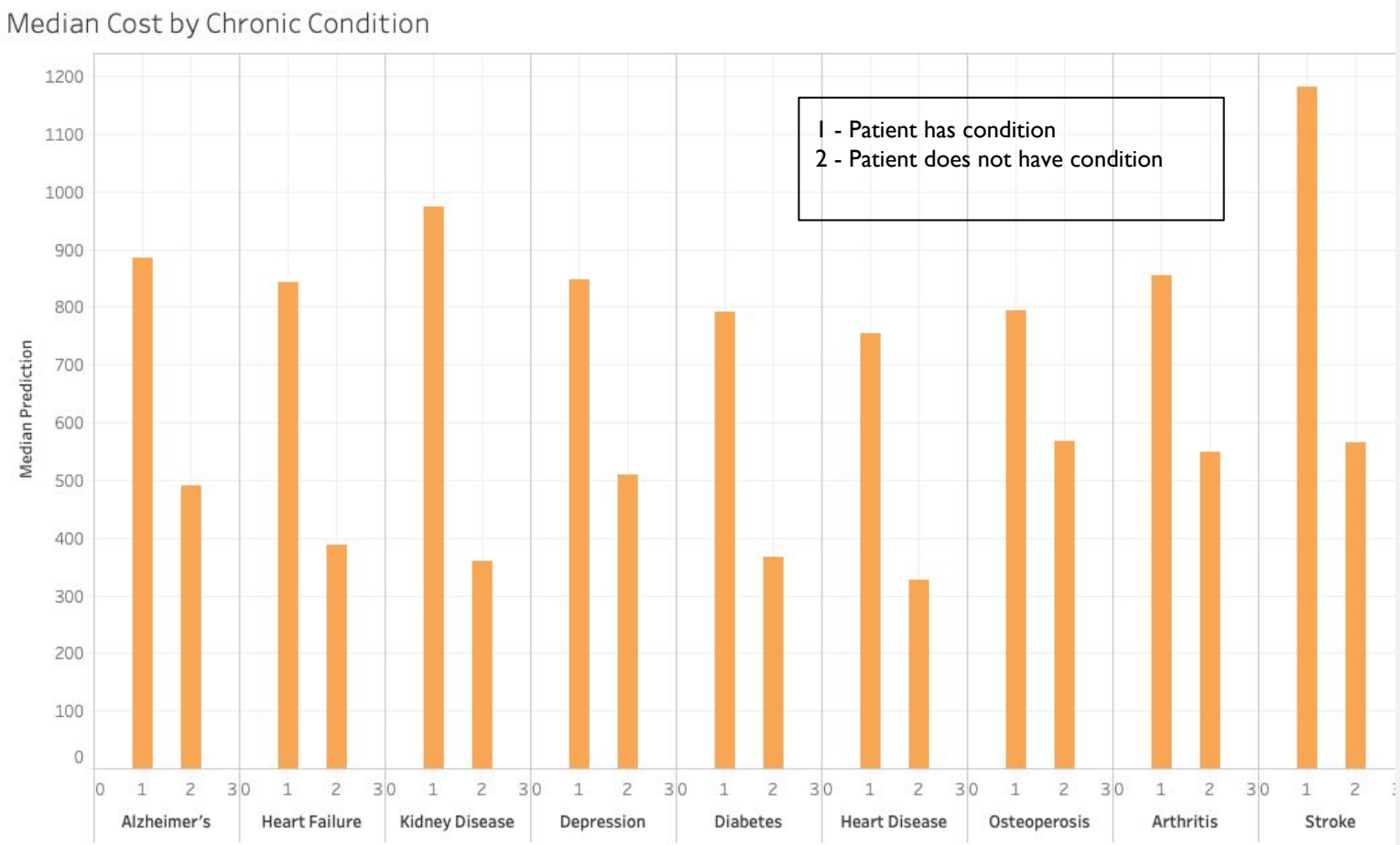


There is not a large difference in median predicted cost by state. This suggests that states with higher volumes of patients will incur higher costs.

* States have been given an ID number to protect patient confidentiality.

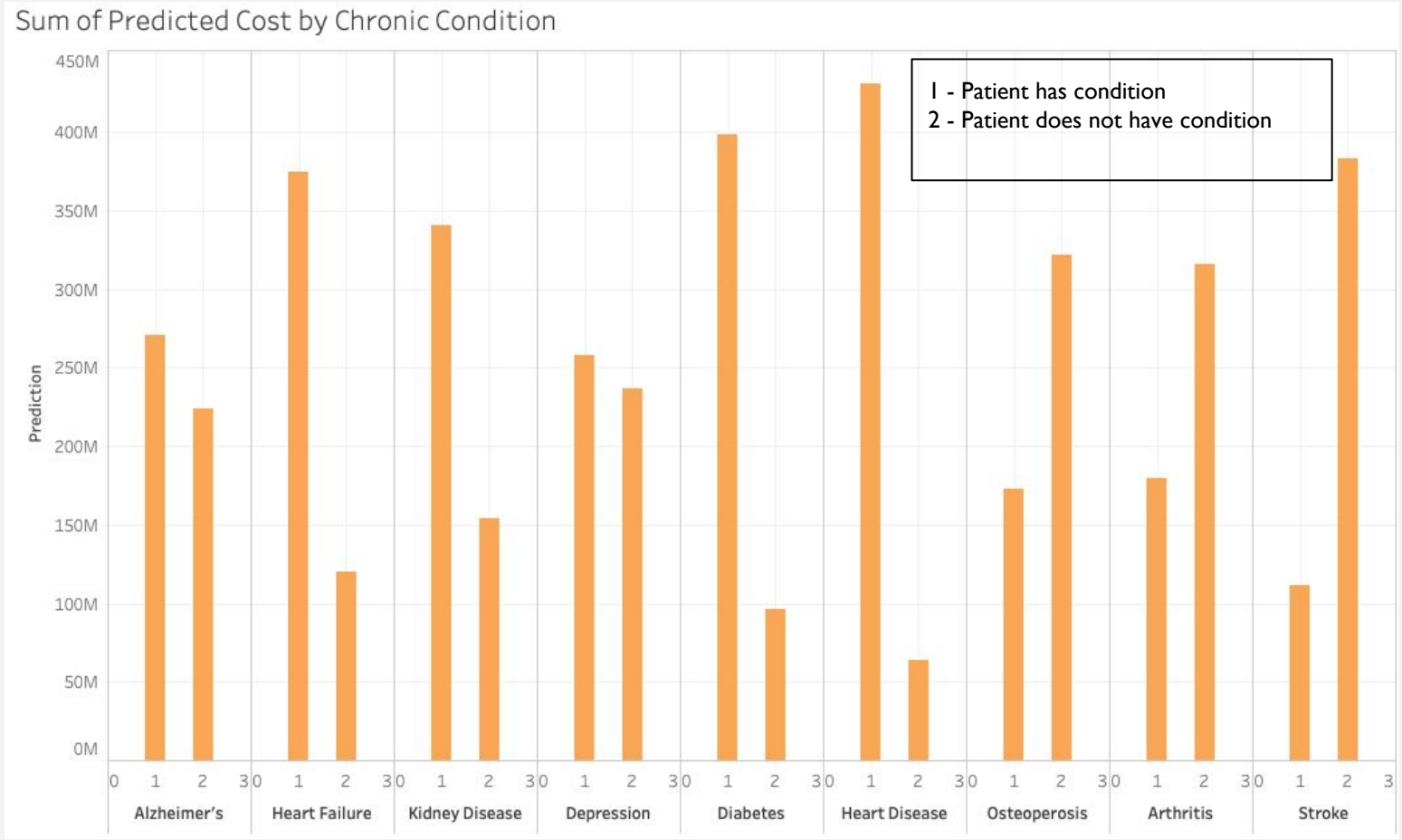
tableau

REPORTING



There is an increase in costs for patients who have chronic conditions vs patients who do not.

REPORTING



The sum of predicted costs by chronic condition takes patient volumes into account.

This view shows that patients with heart disease, diabetes, heart failure, and kidney disease are predicted to have high overall costs.

tableau

RECOMMENDATIONS

- The hospital system should develop preventative health programs for patients with risk factors for heart disease, diabetes, heart failure, and kidney disease.
- The hospital system should monitor patients already diagnosed with these conditions closely to ensure they are following treatment plans.
- The hospital system should prioritize preventative health programs and patient monitoring for patients between 65 and 90, and in states with high patient volumes.

LESSONS LEARNED

Technical

- Data ingestion, processing, transformation, and machine learning could have been accomplished in a completely serverless process.
- Automation process would have been better implemented and organized using AWS Step Functions.
- Amazon EMR was not utilized, and would have been a valuable feature to add.
- Utilizing Amazon ECS for Docker images would have been a great addition to the system architecture.
- Staging tables for Amazon Redshift would have been the ideal setup for data loading rather than copy and deletion.
- Instead of Lambda Functions for batch processing to Amazon Redshift, Amazon Kinesis Firehose would have been a better direction to reliably load data while adding stream processing to the architecture for efficiency.

LESSONS LEARNED

Technical (Continued)

- Rather than waterfall, an iterative methodology should have been utilized for better development.
- Parquet files are significantly smaller than CSV files (12 GB vs 3 GB for the CMS data) and are an efficient and cost effective way of processing data for analysis and transformation.

Analysis

- Test and evaluate other machine learning modeling methods. This was not accomplished due to limited time frame and focus was on building out a working Minimum Viable Product (MVP).
- Data on prescription drug events and outpatient claims were not included in the machine learning model. Though not necessary, they may have been useful in an additional model.

LESSONS LEARNED

Analysis (Continued)

- Predictions on annual cost were in line with the leading health problems affecting the total population in America today.

Team Process

- Weekly meetings and task overview was paramount in successfully deploying an MVP.
- Active peer review made a significant contribution in building out a functional system with fruitful insights and analysis.
- Separation of responsibilities and tasks helped to efficiently and effectively complete the project.
- Utilizing different skill sets and experiences ensured optimal efficiency and project development.

REFERENCES

- CMS 2008-2010 DATA ENTREPRENEURS' Synthetic public use FILE (DE-SYNPUF). (2019, November 22). Retrieved March 07, 2020, from https://www.cms.gov/Research-Statistics-Data-and-Systems/Downloadable-Public-Use-Files/SynPUFs/DE_Syn_PUF
- Magnan, S. (2019, June 18). Social determinants of Health 101 for health CARE: Five plus five. Retrieved March 07, 2020, from https://nam.edu/social-determinants-of-health-101-for-health-care-five-plus-five/
- Van der Wees, P., Tanke, M. A., Westert, G. P., Jeurissen, P. P., & Wammes, J. (2018, September 8). Systematic review of high-cost patients' characteristics and healthcare utilisation. Retrieved March 07, 2020, from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6129088/

APPENDIX
FILES

Processing and Machine Learning Files

- Data Ingest and Processing:
  cmss3.py
- Machine Learning:
  pyspark_model.py
- Docker:
  Dockerfile

Files for Amazon Lambda Functions

- Start and Stop EC2 Instances:
  start-cmss3-ec2.zip start-sparkml-ec2.zip
  end-cmss3-ec2.zip end-sparkml-ec2.zip
- SSH Connect and Run Docker Image:
  lambda-process-cmss3.zip
  lambda-sparkml.zip
- Redshift Loader:
  redshift-import.zip
  lambda-redshift-loader-commands.txt

APPENDIX
DATA SCHEMA

Annual Cost Predictions
Filename: synpuf_ml_output.parquet
Format: Parquet
Size: 660,075 records, 36.2 MB

```
root
 |-- ANNUAL_COST: double (nullable = true)
 |-- PATIENT_ID: string (nullable = true)
 |-- AGE_YRS: double (nullable = true)
 |-- GENDER: short (nullable = true)
 |-- RACE: short (nullable = true)
 |-- STATE: short (nullable = true)
 |-- DX: integer (nullable = true)
 |-- PX: integer (nullable = true)
 |-- HCPCS: integer (nullable = true)
 |-- SP_ALZHDMTA: short (nullable = true)
 |-- SP_CHF: short (nullable = true)
 |-- SP_CHRNKIDN: short (nullable = true)
 |-- SP_CNCR: short (nullable = true)
 |-- SP_COPD: short (nullable = true)
 |-- SP_DEPRESSN: short (nullable = true)
 |-- SP_DIABETES: short (nullable = true)
 |-- SP_ISCHMCHT: short (nullable = true)
 |-- SP_OSTEOPRS: short (nullable = true)
 |-- SP_RA_OA: short (nullable = true)
 |-- SP_STRKETIA: short (nullable = true)
 |-- GENDER_index: double (nullable = true)
 |-- RACE_index: double (nullable = true)
 |-- STATE_index: double (nullable = true)
 |-- SP_ALZHDMTA_index: double (nullable = true)
 |-- SP_CHF_index: double (nullable = true)
 |-- SP_CHRNKIDN_index: double (nullable = true)
 |-- SP_CNCR_index: double (nullable = true)
 |-- SP_COPD_index: double (nullable = true)
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 |-- SP_OSTEOPRS_index: double (nullable = true)
 |-- SP_RA_OA_index: double (nullable = true)
 |-- SP_STRKETIA_index: double (nullable = true)
 |-- features: string (nullable = true)
 |-- prediction: double (nullable = true)
```

APPENDIX
DATA SCHEMA

Beneficiary Summary
Filename: Multiple Files
Format: Parquet
Total Size: 6,760,520 records, 188.9 MB

```
root
 |-- DESYNPUF_ID: string (nullable = true)
 |-- BENE_BIRTH_DT: date (nullable = true)
 |-- BENE_DEATH_DT: date (nullable = true)
 |-- BENE_SEX_IDENT_CD: short (nullable = true)
 |-- BENE_RACE_CD: short (nullable = true)
 |-- BENE_ESRD_IND: string (nullable = true)
 |-- SP_STATE_CODE: short (nullable = true)
 |-- BENE_COUNTY_CD: short (nullable = true)
 |-- BENE_HI_CVRAGE_TOT_MONS: short (nullable = true)
 |-- BENE_SMI_CVRAGE_TOT_MONS: short (nullable = true)
 |-- BENE_HMO_CVRAGE_TOT_MONS: short (nullable = true)
 |-- PLAN_CVRG_MOS_NUM: short (nullable = true)
 |-- SP_ALZHDMTA: short (nullable = true)
 |-- SP_CHF: short (nullable = true)
 |-- SP_CHRNKIDN: short (nullable = true)
 |-- SP_CNCR: short (nullable = true)
 |-- SP_COPD: short (nullable = true)
 |-- SP_DEPRESSN: short (nullable = true)
 |-- SP_DIABETES: short (nullable = true)
 |-- SP_ISCHMCHT: short (nullable = true)
 |-- SP_OSTEOPRS: short (nullable = true)
 |-- SP_RA_OA: short (nullable = true)
 |-- SP_STRKETIA: short (nullable = true)
 |-- MEDREIMB_IP: double (nullable = true)
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 |-- PPPYMT_OP: double (nullable = true)
 |-- MEDREIMB_CAR: double (nullable = true)
 |-- BENRES_CAR: double (nullable = true)
 |-- PPPYMT_CAR: double (nullable = true)
```

APPENDIX
DATA SCHEMA

Inpatient Claims
Filename: Multiple Files
Format: Parquet
Size: 1,332,822 records, 75.3 MB

```
root
 |-- DESYNPUF_ID: string (nullable = true)
 |-- CLM_ID: long (nullable = true)
 |-- SEGMENT: short (nullable = true)
 |-- CLM_FROM_DT: date (nullable = true)
 |-- CLM_THRU_DT: date (nullable = true)
 |-- PRVDR_NUM: string (nullable = true)
 |-- CLM_PMT_AMT: double (nullable = true)
 |-- NCH_PRMRY_PYR_CLM_PD_AMT: double (nullable = true)
 |-- AT_PHYSN_NPI: string (nullable = true)
 |-- OP_PHYSN_NPI: string (nullable = true)
 |-- OT_PHYSN_NPI: string (nullable = true)
 |-- CLM_ADMSN_DT: date (nullable = true)
 |-- ADMTNG_ICD9_DGNS_CD: string (nullable = true)
 |-- CLM_PASS_THRU_PER_DIEM_AMT: double (nullable = true)
 |-- NCH_BENE_IP_DDCTBL_AMT: double (nullable = true)
 |-- NCH_BENE_PTA_COINSRNC_LBLTY_AM: double (nullable = true)
 |-- NCH_BENE_BLOOD_DDCTBL_LBLTY_AM: double (nullable = true)
 |-- CLM_UTLZTN_DAY_CNT: short (nullable = true)
 |-- NCH_BENE_DSCHRG_DT: date (nullable = true)
 |-- CLM_DRG_CD: string (nullable = true)
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```

APPENDIX
DATA SCHEMA

Outpatient Claims
Filename: Multiple Files
Format: Parquet
Size: 15,826,987 records, 667.6 MB

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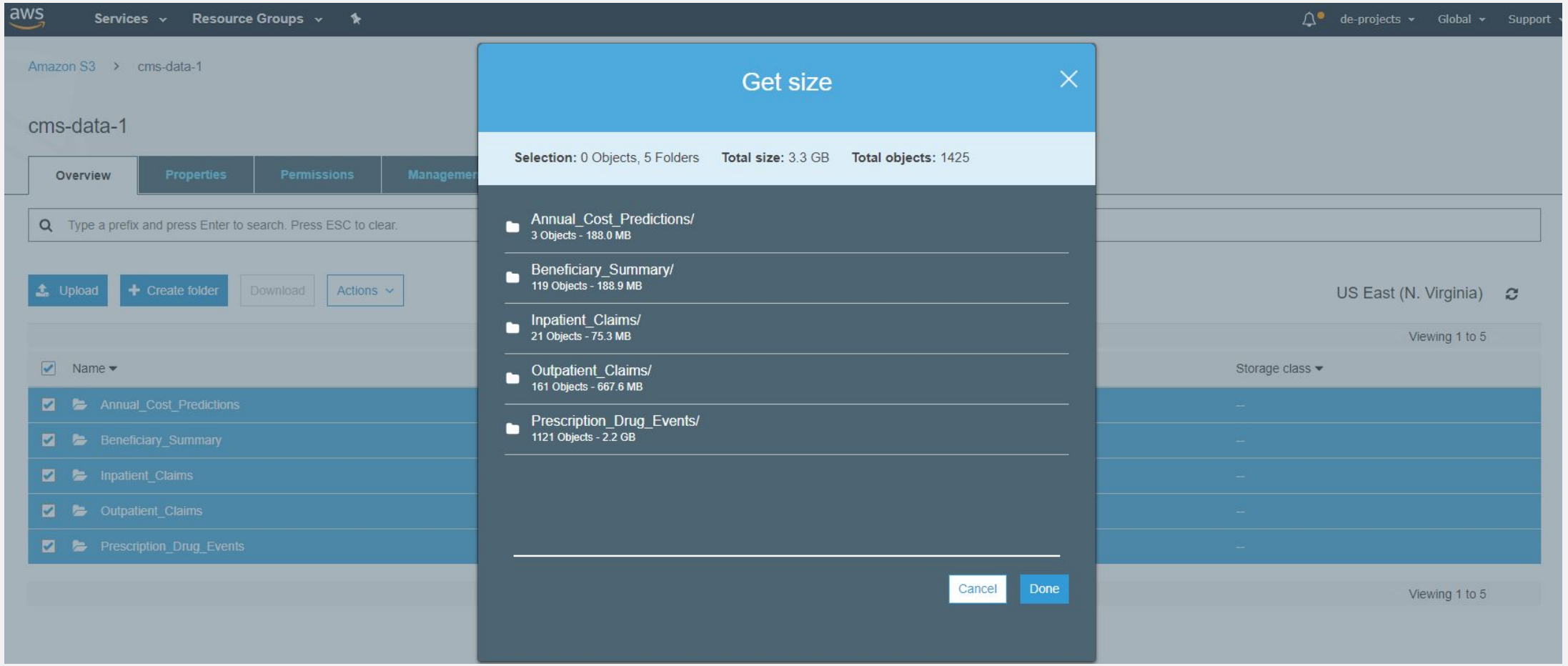
 |-- CLM_THRU_DT: date (nullable = true)
 |-- PRVDR_NUM: string (nullable = true)
 |-- CLM_PMT_AMT: double (nullable = true)
 |-- NCH_PRMRY_PYR_CLM_PD_AMT: double (nullable = true)
 |-- AT_PHYSN_NPI: string (nullable = true)
 |-- OP_PHYSN_NPI: string (nullable = true)
 |-- OT_PHYSN_NPI: string (nullable = true)
 |-- NCH_BENE_BLOOD_DDCTBL_LBLTY_AM: double (nullable = true)
 |-- ICD9_DGNS_CD_1: string (nullable = true)
 |-- ICD9_DGNS_CD_2: string (nullable = true)
 |-- ICD9_DGNS_CD_3: string (nullable = true)
 |-- ICD9_DGNS_CD_4: string (nullable = true)
 |-- ICD9_DGNS_CD_5: string (nullable = true)
 |-- ICD9_DGNS_CD_6: string (nullable = true)
 |-- ICD9_DGNS_CD_7: string (nullable = true)
 |-- ICD9_DGNS_CD_8: string (nullable = true)
 |-- ICD9_DGNS_CD_9: string (nullable = true)
 |-- ICD9_DGNS_CD_10: string (nullable = true)
 |-- ICD9_PRCDR_CD_1: string (nullable = true)
 |-- ICD9_PRCDR_CD_2: string (nullable = true)
 |-- ICD9_PRCDR_CD_3: string (nullable = true)
 |-- ICD9_PRCDR_CD_4: string (nullable = true)
 |-- ICD9_PRCDR_CD_5: string (nullable = true)
 |-- ICD9_PRCDR_CD_6: string (nullable = true)
 |-- NCH_BENE_PTB_DDCTBL_AMT: double (nullable = true)
 |-- NCH_BENE_PTB_COINSRNC_AMT: double (nullable = true)
 |-- ADMTNG_ICD9_DGNS_CD: string (nullable = true)
 |-- HCPCS_CD_1: string (nullable = true)
 |-- HCPCS_CD_2: string (nullable = true)
 |-- HCPCS_CD_3: string (nullable = true)
 |-- HCPCS_CD_4: string (nullable = true)
 |-- HCPCS_CD_5: string (nullable = true)
 |-- HCPCS_CD_6: string (nullable = true)
 |-- HCPCS_CD_7: string (nullable = true)
 |-- HCPCS_CD_8: string (nullable = true)
 |-- HCPCS_CD_9: string (nullable = true)
 |-- HCPCS_CD_10: string (nullable = true)
 |-- HCPCS_CD_11: string (nullable = true)
 |-- HCPCS_CD_12: string (nullable = true)
 |-- HCPCS_CD_13: string (nullable = true)
 |-- HCPCS_CD_14: string (nullable = true)
 |-- HCPCS_CD_15: string (nullable = true)
 |-- HCPCS_CD_16: string (nullable = true)
 |-- HCPCS_CD_17: string (nullable = true)
 |-- HCPCS_CD_18: string (nullable = true)
 |-- HCPCS_CD_19: string (nullable = true)
 |-- HCPCS_CD_20: string (nullable = true)
 |-- HCPCS_CD_21: string (nullable = true)
 |-- HCPCS_CD_22: string (nullable = true)
 |-- HCPCS_CD_23: string (nullable = true)
 |-- HCPCS_CD_24: string (nullable = true)
 |-- HCPCS_CD_25: string (nullable = true)
 |-- HCPCS_CD_26: string (nullable = true)
 |-- HCPCS_CD_27: string (nullable = true)
 |-- HCPCS_CD_28: string (nullable = true)
 |-- HCPCS_CD_29: string (nullable = true)
 |-- HCPCS_CD_30: string (nullable = true)
 |-- HCPCS_CD_31: string (nullable = true)
 |-- HCPCS_CD_32: string (nullable = true)
 |-- HCPCS_CD_33: string (nullable = true)
 |-- HCPCS_CD_34: string (nullable = true)
 |-- HCPCS_CD_35: string (nullable = true)
 |-- HCPCS_CD_36: string (nullable = true)
 |-- HCPCS_CD_37: string (nullable = true)
 |-- HCPCS_CD_38: string (nullable = true)
 |-- HCPCS_CD_39: string (nullable = true)
 |-- HCPCS_CD_40: string (nullable = true)
 |-- HCPCS_CD_41: string (nullable = true)
 |-- HCPCS_CD_42: string (nullable = true)
 |-- HCPCS_CD_43: string (nullable = true)
 |-- HCPCS_CD_44: string (nullable = true)
 |-- HCPCS_CD_45: string (nullable = true)
```

APPENDIX
DATA SCHEMA

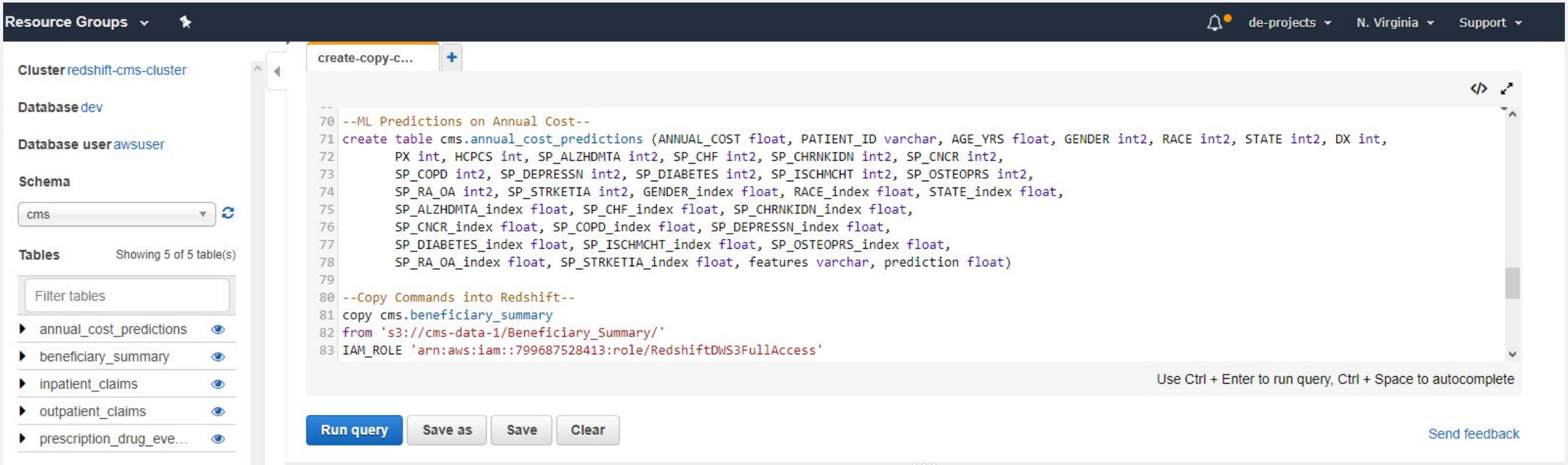
Prescription Drug Events
Filename: Multiple Files
Format: Parquet
Size: 111,085,969 records, 2.2 GB

```
root
 |-- DESYNPUF_ID: string (nullable = true)
 |-- PDE_ID: long (nullable = true)
 |-- SRVC_DT: date (nullable = true)
 |-- PROD_SRVC_ID: string (nullable = true)
 |-- QTY_DSPNSD_NUM: short (nullable = true)
 |-- DAYS_SUPLY_NUM: short (nullable = true)
 |-- PTNT_PAY_AMT: double (nullable = true)
 |-- TOT_RX_CST_AMT: double (nullable = true)
```

APPENDIX
S3 STORAGE



APPENDIX
REDSHIFT



APPENDIX
LAMBDA REDSHIFT LOAD

```
--Beneficiary Summary--
set search_path to cms;
begin;
delete from cms.beneficiary_summary;
copy cms.beneficiary_summary
from 's3://cms-data-1/Beneficiary_Summary/'
IAM_ROLE
'arn:aws:iam::799687528413:role/RedshiftDWS3FullAccess'
FORMAT AS PARQUET;
commit;
```