DataEng S24: Data Storage In-class Assignment

This week you'll gain experience with various ways to load data into a database.

Make a copy of this document and use it to record your results. Store a PDF copy of the document in your git repository along with any needed code before submitting for this week.

The data set for this week is US Census data from 2015. The United States conducts a full census of every household every 10 years (last one was in 2020), but much of the detailed census data comes during the intervening years when the Census Bureau conducts its detailed American Community Survey (ACS) of a randomly selected sample of approximately 3.5 million households each year. The resulting data gives a more detailed view of many factors of American life and the composition of households.

ACS Census Tract Data for 2015 (part 1)
ACS Census Tract Data for 2015 (part 2)

Your job is to load the 2015 data set (approximately 74000 rows divided into two parts). You'll configure a postgres DBMS on a new GCP virtual machine, and then load the two parts of the data using multiple loading methods, comparing the cost of each method. Load the two parts of the data separately so that you gain experience with the issues related to incremental loading of data.

Note that the goal here is not to achieve the fastest load times. Instead, your goal should be to observe and understand a variety of data loading methods. If you start to run out of time, then skip to part I (copy_from) to be sure to get experience with what is probably the fastest way to load bulk data into a Postgres server.

Please highlight your responses so that we can more easily see them

A. [MUST] Discussion Question (discuss as a group near the beginning of the week. Note your own response in this space):

Do you have any experience with ingesting bulk data into a DBMS? If yes, then describe your experience, especially what method was used to input the data into the database. If no, then describe how you might ingest daily incremental breadcrumb data for your class project.

Yes, I do have experience with ingesting bulk data into a DBMS. In the past, I worked on a project that involved importing a large dataset into a relational database. The method we used to input the data was through a combination of CSV file uploads and bulk insert operations. We prepared the data by organizing it into CSV files, ensuring that the data was clean and properly formatted. Then, we used database-specific tools to perform bulk imports, such as PostgreSQL's COPY command. This allowed us to efficiently load the data directly from the CSV files into the appropriate database tables.

For ingesting daily incremental breadcrumb data for a class project. The approach would involve:

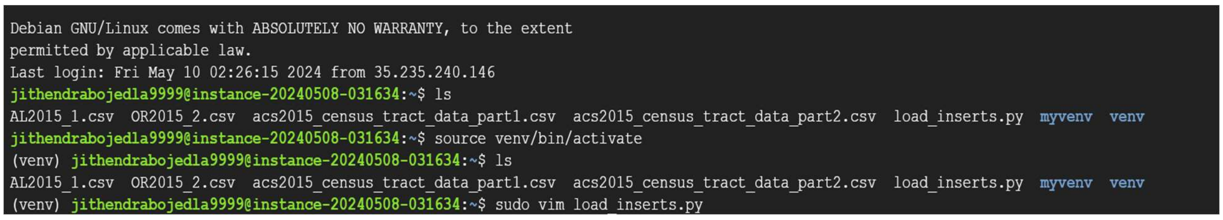
Data Extraction: Extract the daily breadcrumb data from the source.
Data Transformation: Clean, filter, and format the data as needed to match the schema of the target database. This step might involve removing duplicates, handling missing values, and ensuring data consistency.
Data Loading: Incrementally load the transformed data into the database.
Monitoring and Validation: Continuously monitor the data ingestion process for errors and validate the loaded data to confirm its accuracy and completeness.

Submit: submit your assignment by this Friday at 10pm

B. [MUST] Configure the Database

1. Create a new GCP virtual machine for this week's work (medium size or larger).
2. Follow the steps listed in the [Installing and Configuring a PostgreSQL server]() instructions. To keep your project work clean, use a new, different vm and delete the vm when finished with this assignment.
3. Also running the following commands on your VM will help to configure the python module "psycopg2" which you will use to connect to your postgres database:

```
sudo apt install python3 python3-dev python3-venv
sudo apt-get install python3-pip
pip3 install psycopg2-binary
```



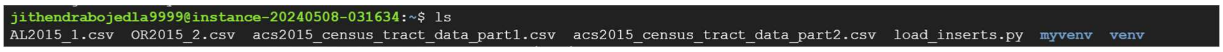
```
Debian GNU/Linux comes with ABSOLUTELY NO WARRANTY, to the extent
permitted by applicable law.
Last login: Fri May 10 02:26:15 2024 from 35.235.240.146
jithendrabojedla9999@instance-20240508-031634:~$ ls
AL2015_1.csv  OR2015_2.csv  acs2015_census_tract_data_part1.csv  acs2015_census_tract_data_part2.csv  load_inserts.py  myvenv  venv
jithendrabojedla9999@instance-20240508-031634:~$ source venv/bin/activate
(venv) jithendrabojedla9999@instance-20240508-031634:~$ ls
AL2015_1.csv  OR2015_2.csv  acs2015_census_tract_data_part1.csv  acs2015_census_tract_data_part2.csv  load_inserts.py  myvenv  venv
(venv) jithendrabojedla9999@instance-20240508-031634:~$ sudo vim load_inserts.py
```

C. [MUST] Prepare Data for Loading

1. Copy/upload both ACS Census Tract data files to your VM
2. Create a small test sample by running a linux command similar to the following. The small test sample will help you to quickly test any code that you write before running your code with the full dataset.

   ```
   head -1 acs2015_census_tract_data_part1.csv > AL2015_1.csv
   head -1 acs2015_census_tract_data_part2.csv > OR2015_2.csv
   grep Alabama acs2015_census_tract_data_part1.csv >> AL2015_1.csv
   grep Oregon acs2015_census_tract_data_part2.csv >> OR2015_2.csv
   ```

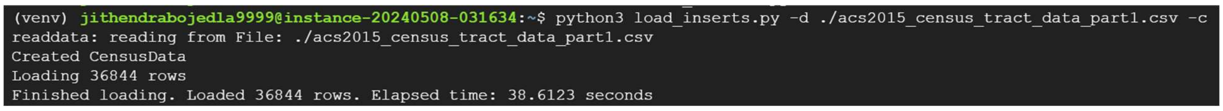
   The first two commands copy the headers to the sample files and the next command appends Alabama and Oregon 2015 data to the sample files. This should produce files with fewer than 1500 records per file. Use these sample files to save time during testing.

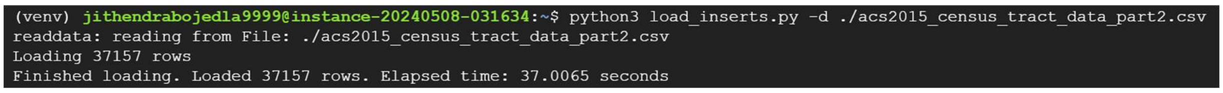
   ```
   jithendrabojedla9999@instance-20240508-031634:~$ ls
   AL2015_1.csv  OR2015_2.csv  acs2015_census_tract_data_part1.csv  acs2015_census_tract_data_part2.csv  load_inserts.py  myvenv  venv
   ```

3. Write a python program that connects to your postgres database and creates your main census data table. Start with this example code: load_inserts.py. For example:

   ```
   python3 load_inserts.py -d ./AL2015_1.csv -c
   python3 load_inserts.py -d ./OR2015_2.csv
   ```

   ```
   (venv) jithendrabojedla9999@instance-20240508-031634:~$ python3 load_inserts.py -d ./acs2015_census_tract_data_part1.csv -c
   readdata: reading from File: ./acs2015_census_tract_data_part1.csv
   Created CensusData
   Loading 36844 rows
   Finished loading. Loaded 36844 rows. Elapsed time: 38.6123 seconds
   ```

   ```
   (venv) jithendrabojedla9999@instance-20240508-031634:~$ python3 load_inserts.py -d ./acs2015_census_tract_data_part2.csv
   readdata: reading from File: ./acs2015_census_tract_data_part2.csv
   Loading 37157 rows
   Finished loading. Loaded 37157 rows. Elapsed time: 37.0065 seconds
   ```

D. [MUST] Baseline - Simple INSERT

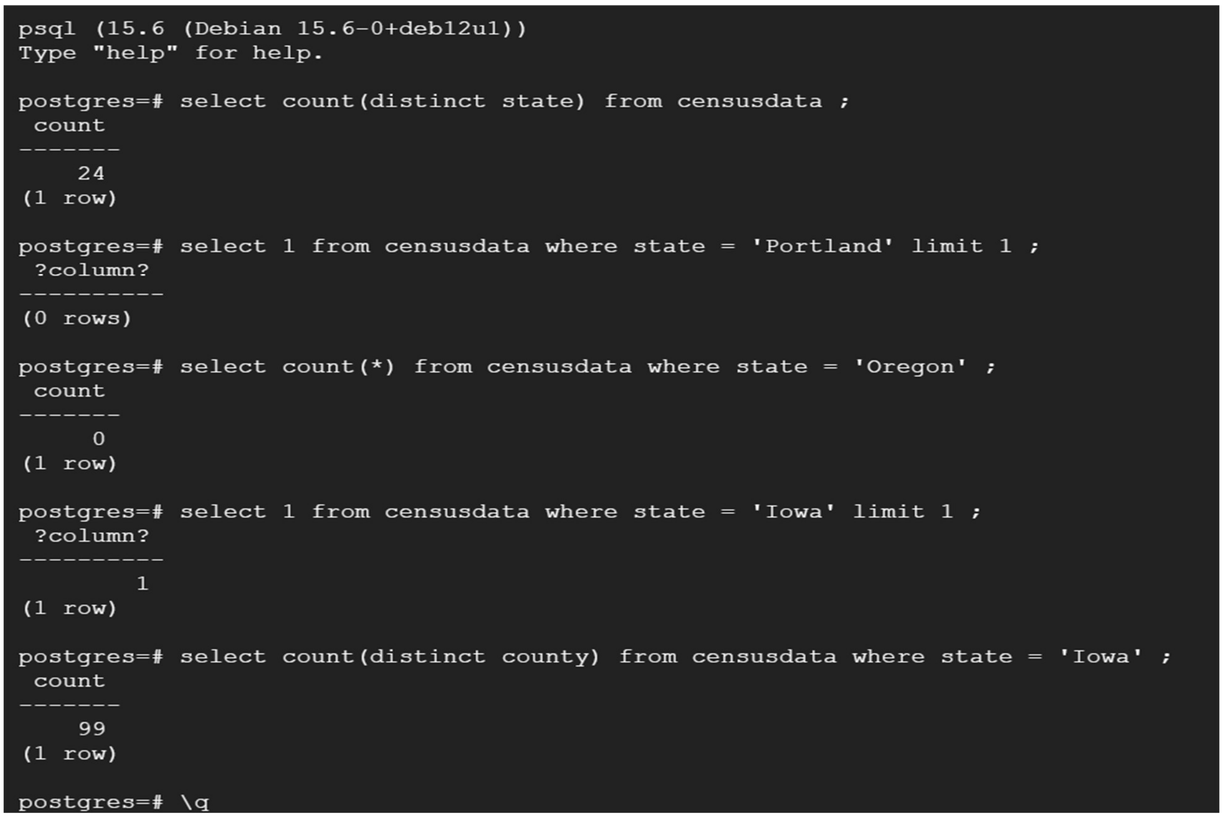
The tried and true SQL command INSERT INTO ... is the most basic way to insert data into a SQL database, and often it is the best choice for small amounts of data, production databases and other situations in which you need to maintain performance and ACID properties of the updated table.

The load_inserts.py program shows how to use simple INSERTs to load data into a database. It is possibly the slowest way to load large amounts of data. For me, it takes approximately 1 second for the Oregon sample and nearly 60 seconds to load each part of the acs data.

Take the program and try it with both of the test samples and both parts of the ACS data set. Fill in the appropriate information in the table below (see part J).

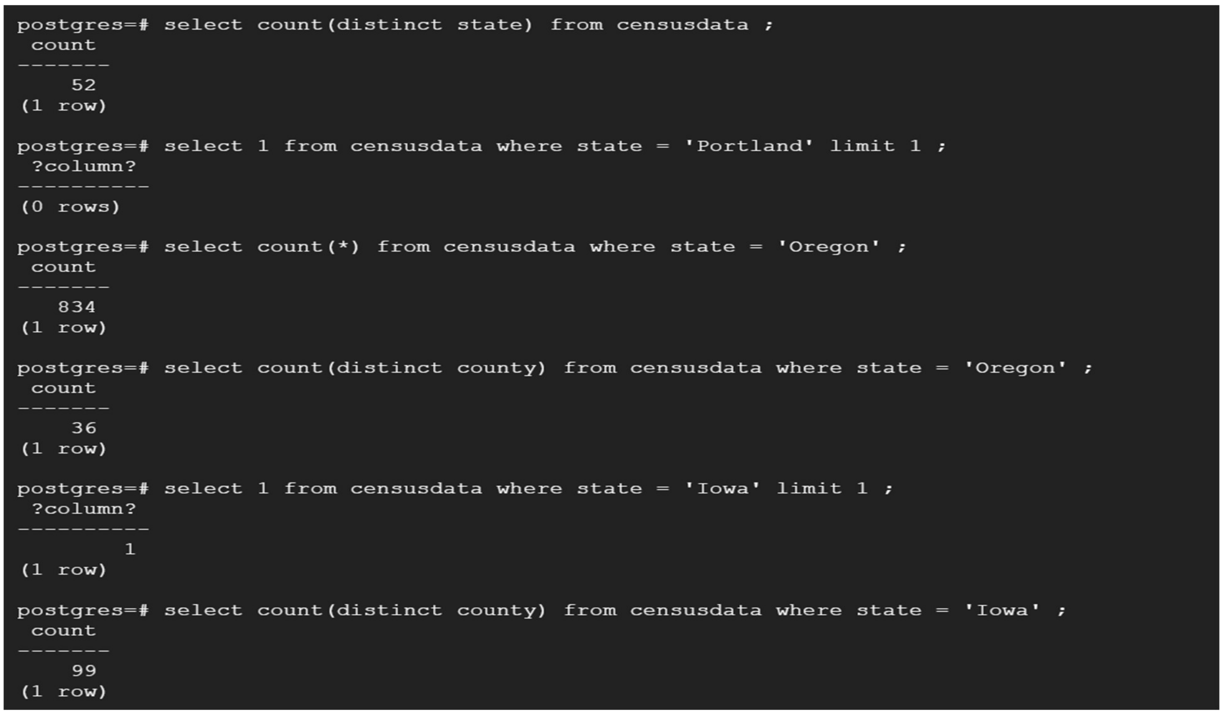
After loading each part of the ACS data, try out a few validations to check that the data is loaded correctly. Use the following SQL queries and/or create more of your own:

- After loading part1,
  - The number of states in the database should be 24
    - select count(distinct state) from censusdata ;
  - The state of Portland is not found in the database
    - select 1 from censusdata where state = 'Portland' limit 1 ;
  - The state of Oregon is not found in the database
    - select count(*) from censusdata where state = 'Oregon' ;
  - The state of Iowa is found in the database
    - select 1 from censusdata where state = 'Iowa' limit 1 ;
  - There are 99 counties in Iowa
    - select count(distinct county) from censusdata where state = 'Iowa' ;



```
psql (15.6 (Debian 15.6-0+deb12u1))
Type "help" for help.

postgres=# select count(distinct state) from censusdata ;
 count
-------
    24
(1 row)

postgres=# select 1 from censusdata where state = 'Portland' limit 1 ;
 ?column?
----------
(0 rows)

postgres=# select count(*) from censusdata where state = 'Oregon' ;
 count
-------
     0
(1 row)

postgres=# select 1 from censusdata where state = 'Iowa' limit 1 ;
 ?column?
----------
        1
(1 row)

postgres=# select count(distinct county) from censusdata where state = 'Iowa' ;
 count
-------
    99
(1 row)

postgres=# \q
```

- After loading part2,
    - The number of states in the database should be 52
        - select count(distinct state) from censusdata ;
    - The state of Portland is not found in the database
        - select 1 from censusdata where state = 'Portland' limit 1 ;
    - The state of Oregon is found in the database
        - select count(*) from censusdata where state = 'Oregon' ;
    - There are 36 counties in Oregon
        - select count(distinct county) from censusdata where state = ‘Oregon’ ;
    - The state of Iowa is found in the database
        - select 1 from censusdata where state = 'Iowa' limit 1 ;
    - There are 99 counties in Iowa
        - select count(distinct county) from censusdata where state = 'Iowa' ;

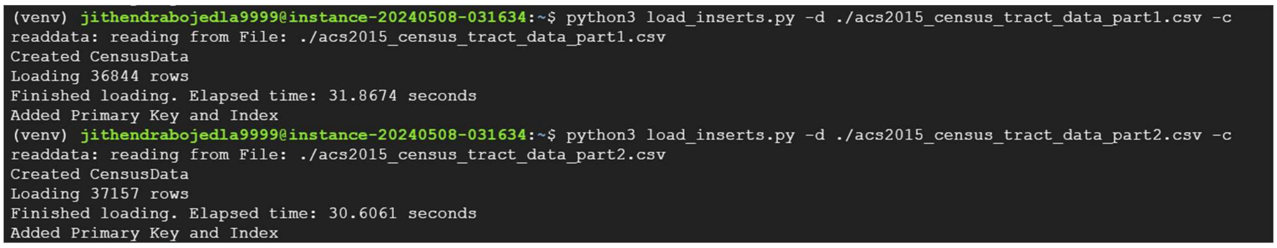


```
postgres=# select count(distinct state) from censusdata ;
 count
-------
    52
(1 row)

postgres=# select 1 from censusdata where state = 'Portland' limit 1 ;
 ?column?
----------
(0 rows)

postgres=# select count(*) from censusdata where state = 'Oregon' ;
 count
-------
   834
(1 row)

postgres=# select count(distinct county) from censusdata where state = 'Oregon' ;
 count
-------
    36
(1 row)

postgres=# select 1 from censusdata where state = 'Iowa' limit 1 ;
 ?column?
----------
        1
(1 row)

postgres=# select count(distinct county) from censusdata where state = 'Iowa' ;
 count
-------
    99
(1 row)
```

E. [MUST] Disabling Indexes and Constraints

You might notice that the CensusData table has a Primary Key constraint and an additional index on the state name column. Indexes and constraints are helpful for query performance but these features can slow down load performance.

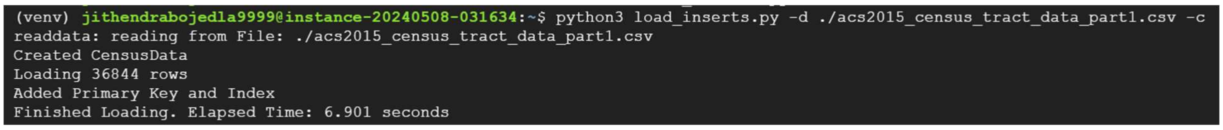
Modify your load_inserts.py program to delay creation of constraints/indexes until after the data set is loaded. Enter the resulting load time into the results table below. How much does this technique improve load performance?

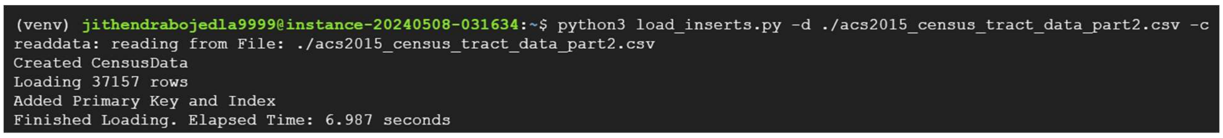

```
(venv) jithendrabojedla9999@instance-20240508-031634:~$ python3 load_inserts.py -d ./acs2015_census_tract_data_part1.csv -c
readdata: reading from File: ./acs2015_census_tract_data_part1.csv
Created CensusData
Loading 36844 rows
Finished loading. Elapsed time: 31.8674 seconds
Added Primary Key and Index
(venv) jithendrabojedla9999@instance-20240508-031634:~$ python3 load_inserts.py -d ./acs2015_census_tract_data_part2.csv -c
readdata: reading from File: ./acs2015_census_tract_data_part2.csv
Created CensusData
Loading 37157 rows
Finished loading. Elapsed time: 30.6061 seconds
Added Primary Key and Index
```

F. [SHOULD] Disabling Autocommit

You might have noticed that the load_inserts.py program sets autocommit=True on the database connection. This makes loaded data available to DB queries immediately after each insert. But it also triggers transaction-related overhead operations (e.g., write ahead logging). It also allows readers of the database to view an incomplete set of data during the load.

Modify your load_inserts.py program to avoid setting autocommit=True
Enter the resulting load time into the results table below.

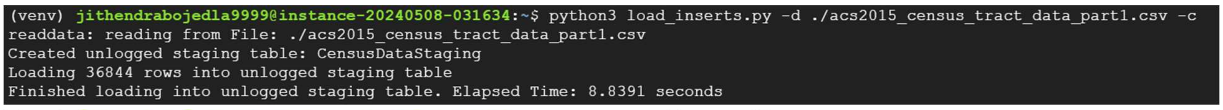

```
(venv) jithendrabojedla9999@instance-20240508-031634:~$ python3 load_inserts.py -d ./acs2015_census_tract_data_part1.csv -c
readdata: reading from File: ./acs2015_census_tract_data_part1.csv
Created CensusData
Loading 36844 rows
Added Primary Key and Index
Finished Loading. Elapsed Time: 6.901 seconds
```


```
(venv) jithendrabojedla9999@instance-20240508-031634:~$ python3 load_inserts.py -d ./acs2015_census_tract_data_part2.csv -c
readdata: reading from File: ./acs2015_census_tract_data_part2.csv
Created CensusData
Loading 37157 rows
Added Primary Key and Index
Finished Loading. Elapsed Time: 6.987 seconds
```

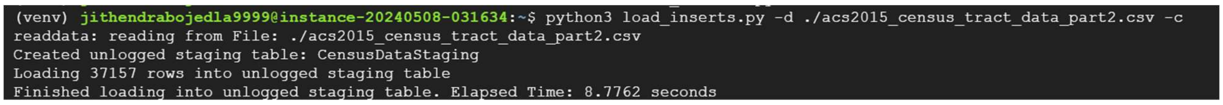
G. [SHOULD] UNLOGGED table

By default, RDBMS tables incur overheads of write-ahead logging (WAL) such that the database outputs extra metadata about each row insert to a log file known as the Transaction Recovery Log (sometimes just called the WAL or “Write-Ahead Log”). The RDBMS uses that WAL data to recover the contents of the table if/when the RDBMS crashes. Crash Recovery is a great feature but it can slow down load performance.

You can avoid this extra WAL overhead by [loading to an UNLOGGED table](). Modify your load_inserts.py program to load data to an UNLOGGED table. Then enhance load_inserts.py to use a SQL query to append the staging data to the main CensusData table. Then create the needed index and constraint.



```
(venv) jithendrabojedla9999@instance-20240508-031634:~$ python3 load_inserts.py -d ./acs2015_census_tract_data_part1.csv -c
readdata: reading from File: ./acs2015_census_tract_data_part1.csv
Created unlogged staging table: CensusDataStaging
Loading 36844 rows into unlogged staging table
Finished loading into unlogged staging table. Elapsed Time: 8.8391 seconds
```



```
(venv) jithendrabojedla9999@instance-20240508-031634:~$ python3 load_inserts.py -d ./acs2015_census_tract_data_part2.csv -c
readdata: reading from File: ./acs2015_census_tract_data_part2.csv
Created unlogged staging table: CensusDataStaging
Loading 37157 rows into unlogged staging table
Finished loading into unlogged staging table. Elapsed Time: 8.7762 seconds
```

H. [ASPIRE] Temp Tables and Memory Tuning

Next compare the above approach with loading the data to a temporary table (and copying from the temporary table to the CensusData table). Which approach works best for you?

The amount of memory used for temporary tables is default configured to only 8MB. Your VM has enough memory to allocate much more memory to temporary tables. Try allocating 256 MB (or more) to temporary tables. So update the temp_buffers parameter to allow the database to use more memory for your temporary table. Rerun your load experiments. Did it make a difference?

I. [MUST] Built In Facility (copy_from)

The number one rule of bulk loading is to pay attention to the native facilities provided by the DBMS system implementers. DBMS vendors often put great effort into providing purpose-built loading mechanisms that achieve high performance and scalability.

With a simple, one-server Postgres database, that facility is known as COPY, \copy, or for python programmers copy_from. See the last section of this blog post for an example.

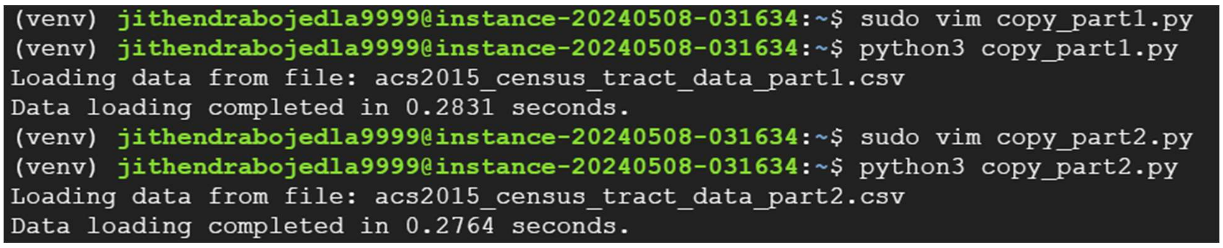
copy_part1:

```
import psycopg2
import time

# Define database connection parameters
DBname = "postgres"
DBuser = "postgres"
DBpwd = "165833"
TableName = "censusdatastaging"
Datafile = "acs2015_census_tract_data_part1.csv"
```

```
# Connect to the database
def dbconnect():
    connection = psycopg2.connect(
        host="localhost",
        database=DBname,
        user=DBuser,
        password=DBpwd,
    )
    return connection

# Load data using the copy_from function
def load_data_copy_from(conn, datafile):
    with conn.cursor() as cursor:
        print(f"Loading data from file: {datafile}")

        # Open the CSV file in read mode
        with open(datafile, 'r') as f:
            # Skip the header row if your CSV file contains headers
            next(f)

            start_time = time.time()

            # Use copy_from to load data from CSV file into the target table
            # Specify the null option to handle empty strings as NULL
            cursor.copy_from(f, TableName, sep=',', null='')
            # Calculate elapsed time
            elapsed_time = time.time() - start_time


        print("Data loading completed in {elapsed_time:.4f} seconds.")
        # Commit the changes to the database
        conn.commit()

# Main function
def main():
    # Establish a connection to the database
    conn = dbconnect()

    # Load data using copy_from
    load_data_copy_from(conn, Datafile)

    # Close the database connection
    conn.close()

if _name_ == "_main_":
    main()
```

copy_part2:

```
import psycopg2
import time

# Define database connection parameters
DBname = "postgres"
DBuser = "postgres"
DBpwd = "165833"
TableName = "censusdatastaging"
Datafile = "acs2015_census_tract_data_part1.csv"

# Connect to the database
def dbconnect():
    connection = psycopg2.connect(
        host="localhost",
        database=DBname,
        user=DBuser,
        password=DBpwd,
    )
    return connection

# Load data using the copy_from function
def load_data_copy_from(conn, datafile):
    with conn.cursor() as cursor:
        print(f"Loading data from file: {datafile}")

        # Open the CSV file in read mode
        with open(datafile, 'r') as f:
            # Skip the header row if your CSV file contains headers
            next(f)
            start_time = time.time()

            # Use copy_from to load data from CSV file into the target table
            # Specify the null option to handle empty strings as NULL
            cursor.copy_from(f, TableName, sep=',', null='')
            # Calculate elapsed time
            elapsed_time = time.time() - start_time


        print("Data loading completed in {elapsed_time:.4f} seconds.")
        # Commit the changes to the database
        conn.commit()

# Main function
def main():
    # Establish a connection to the database
    conn = dbconnect()

    # Load data using copy_from
    load_data_copy_from(conn, Datafile)

    # Close the database connection
    conn.close()

if _name_ == "_main_":
    main()
```



```
(venv) jithendrabojedla9999@instance-20240508-031634:~$ sudo vim copy_part1.py
(venv) jithendrabojedla9999@instance-20240508-031634:~$ python3 copy_part1.py
Loading data from file: acs2015_census_tract_data_part1.csv
Data loading completed in 0.2831 seconds.
(venv) jithendrabojedla9999@instance-20240508-031634:~$ sudo vim copy_part2.py
(venv) jithendrabojedla9999@instance-20240508-031634:~$ python3 copy_part2.py
Loading data from file: acs2015_census_tract_data_part2.csv
Data loading completed in 0.2764 seconds.
```

J. [MUST] Results

Use this table to present your results. List only the methods that you actually completed. List only load times for the full amount of Census data (not the small test sample of OR data created in part C). For each loading method, load both parts of the Census data and measure/report the load time for each part separately in the corresponding column of the table.

Method	**Time to load part1**	**Time to load part2**
D. Simple inserts	38.6123 seconds	37.0065 seconds
E. Drop Indexes and Constraints	31.8674 seconds	30.6061 seconds
F. Disable Autocommit	6.901 seconds	6.987 seconds
G. Use UNLOGGED table	8.8391 seconds	8.7762 seconds
H. Temp Table with memory tuning		
I. copy_from	0.2831 seconds	0.2764 seconds

K. [SHOULD] Observations

Use this section to record any observations about the various methods/techniques that you used for bulk loading of the USA Census data. Did you learn anything about why various loading approaches produce varying performance results?

Looking at the data loading results, it's clear that some methods work much faster than others. Here's a breakdown of the different approaches and why they perform so differently:

Simple Inserts:
Loading part 1 took about 39 seconds, and part 2 took about 37 seconds.
This method inserts each row one by one, which ends up being the slowest approach because it has to deal with each operation separately.
Dropping Indexes and Constraints:
Loading part 1 took about 32 seconds, and part 2 about 31 seconds.
Removing indexes and constraints during the loading process speeds things up because the database doesn't have to maintain those elements while inserting data. However, you need to re-create them afterward.
Disabling Autocommit:

Loading part 1 took about 7 seconds, and part 2 about 7 seconds as well.
Turning off autocommit means rows are inserted as part of a single transaction, reducing the overhead from repeated commits and making the process faster.

Using an Unlogged Table:

Loading part 1 took about 9 seconds, and part 2 about 9 seconds as well.
Loading data into an unlogged table is quicker since it skips writing to the database's log, but you risk losing data if the system crashes.

copy_from:

Loading part 1 took less than a second (0.2831 seconds), and part 2 about the same (0.2764 seconds).
This is by far the fastest method because it uses a direct database function to load data from a file in one go. It cuts out much of the usual overhead and speeds up the process significantly.

In short, methods that streamline the process and avoid unnecessary operations tend to be the quickest. Disabling autocommit and using specialized functions like copy_from lead to the most efficient data loading.