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Department of Computer Science & Engineering

<u>Eight Semester Project-III Report (PROJ-CS881)</u>

Automated Database Testing using Shell Scripting & Python

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Approval

This is to certify that the project report entitled "**Automated Database Testing using Shell Scripting and Python**" prepared under my supervision by Rajdeep Sen (18700121211), Dwiprahar Chattopadhyay (18700221015), Tamal Kundu (18700121178), Swapnanil Das (18700221013) be accepted in partial fulfillment for the degree of Bachelor of Technology in Computer Science & Engineering which is affiliated to Maulana Abul Kalam Azad University of Technology, West Bengal (Formerly known as West Bengal University of Technology).

It is to be understood that by this approval, the undersigned does not necessarily endorse or approve any statement made, opinion expressed or conclusion drawn thereof, but approves the report only for the purpose for which it has been submitted.

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Abstract

The increasing reliance on data-driven applications has made database integrity and correctness a fundamental requirement in modern software systems. However, manually verifying the accuracy of SQL queries—especially across evolving datasets and complex business logic—can be time-consuming, error-prone, and inefficient. This project proposes an automated testing framework for SQL queries that combines the flexibility of shell scripting with the analytical power of Python to facilitate robust, repeatable, and efficient validation of database operations. The framework is organized around a modular directory structure where each SQL test case, along with its expected output, is stored systematically. Upon execution, the system automatically runs each SQL file against a predefined MySQL database, captures the actual results, and compares them with pre-stored control outputs. It then generates corresponding result files, highlights any differences through diff files, and produces an analytical report detailing the success, failure, and deviation of each query. This structured approach not only eliminates repetitive manual testing but also promotes consistency, traceability, and scalability in database validation workflows. The framework is particularly well-suited for academic environments, enterprise-grade quality assurance processes, and automated grading systems where query correctness and result fidelity are of paramount importance.

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1. Introduction

This project is situated within the domain of Software Testing, with a specialized emphasis on database testing and test automation. In today's data-intensive digital landscape, relational databases form the backbone of most enterprise and web-based applications, supporting everything from transactional systems to reporting and analytics platforms. SQL (Structured Query Language) is the industry-standard language for querying and manipulating data in these relational databases. As applications grow in complexity and scale, ensuring that these SQL queries produce correct, consistent, and efficient results becomes critical. Any deviation or undetected bug in query logic can compromise data integrity, produce inaccurate outputs, or lead to severe business consequences.

Traditional testing of SQL queries often involves manual execution of queries followed by a manual comparison of results with expected outputs. This approach is not only time-consuming and inefficient but also highly error-prone and difficult to scale across a large number of test cases or evolving datasets. Moreover, in academic or collaborative environments, evaluating SQL-based assignments or testing projects with numerous queries can quickly become a bottleneck without an automated system in place. This has prompted the need for an automated, reproducible, and modular framework that simplifies and standardizes the process of query testing.

The proposed solution is an Automated SQL Query Testing Framework that uses shell scripting and Python programming to create an end-to-end pipeline for executing, validating, and analyzing SQL test cases. The system is designed around a structured folder hierarchy where SQL query files are stored in a designated directory (Features/), their manually verified expected outputs in Control_files/, and the actual results and differences generated during testing are stored in results/ and diffs/, respectively. The main orchestration is handled through a runner script (runner.sh), which coordinates the execution of SQL queries (auto.sh), compares actual versus expected outputs (comparator.py), and generates detailed analytical reports (analyzer.py) summarizing the results of all tests. The use of Bash scripting allows for automation at the system level, while Python adds power and flexibility in processing and analyzing data differences.

Key concepts involved in this project include unit and regression testing of SQL queries, shell scripting for automation, use of MySQL as a test database environment, diff-based result comparison, and report generation for test analysis. The framework is extensible and can accommodate multiple SQL files, scale across test suites, and integrate easily with CI/CD or grading systems. By automating what is typically a manual and repetitive process, the project enhances accuracy, reduces testing effort, and promotes maintainability and traceability in SQL testing workflows.

This project not only provides a practical solution to a common problem in software development and education but also demonstrates the application of theoretical knowledge in database systems, scripting, and testing methodologies to a real-world problem. It serves as a foundational tool that can be further expanded for integration into larger quality assurance ecosystems or academic grading platforms.

2. Problem Definition

In database-driven applications, the correctness of SQL queries is essential to ensuring accurate data retrieval, integrity, and decision-making. However, verifying the correctness of SQL queries—especially when dealing with multiple test cases, complex logic, or evolving database schemas—poses a significant challenge. The traditional approach to SQL query testing involves manual execution of each query followed by a comparison of the output with expected results. This process is not only time-consuming but also highly susceptible to human error, inconsistency, and scalability issues. As the volume of test cases grows or when frequent modifications are made to queries or datasets, the burden of manual validation becomes increasingly unmanageable.

Furthermore, in academic settings where SQL queries are often evaluated as part of assignments or examinations, instructors and evaluators face similar challenges in assessing correctness across multiple submissions. There exists a lack of lightweight, extensible tools that can automate the end-to-end validation process for SQL queries in a standardized and reproducible manner.

The core problem, therefore, is the absence of an automated, reliable, and scalable framework that can execute SQL test cases, compare their actual results with predefined control outputs, detect discrepancies, and generate detailed reports without manual intervention. Addressing this problem would not only streamline the testing and evaluation process but also improve the overall reliability and maintainability of SQL-based systems and workflows. This project aims to solve this problem by designing and implementing a scripting-based automation framework that simplifies SQL query validation while ensuring accuracy, efficiency, and consistency.

3. Background/Survey

With the increasing adoption of data-centric systems in industries ranging from finance and healthcare to e-commerce and education, the demand for reliable database operations has never been greater. Relational Database Management Systems (RDBMS), especially those using SQL, form the backbone of such systems by providing mechanisms for structured data storage, querying, and manipulation. However, ensuring the correctness of SQL queries in these environments is a critical and often overlooked task. SQL queries may behave incorrectly due to logical errors, misinterpretation of business rules, incorrect joins, or improper aggregation functions. Detecting such issues manually is time-intensive and error-prone, especially when dealing with large databases or multiple test scenarios.

The need for automation in software testing has been widely acknowledged, leading to the development of numerous tools and frameworks aimed at automating code testing, such as JUnit for Java, PyTest for Python, and Selenium for UI testing. However, when it comes to automated SQL query testing, the available solutions are relatively limited. Some existing tools like tSQLt (for SQL Server), utPLSQL (for Oracle), and QuerySurge offer frameworks for automated database testing. These tools, while powerful, are often tightly coupled to specific database vendors, require substantial setup, and may be overly complex for educational or lightweight project needs. Additionally, such solutions often demand integration with full-fledged CI/CD pipelines or IDEs, which might not be suitable for academic use cases or environments with limited resources.

In academic settings, SQL query evaluation is still predominantly manual, where instructors validate student-submitted queries against a reference dataset and compare outputs. This manual process becomes tedious and inconsistent, particularly with large student batches or complex queries. Although some educational platforms attempt to address this through query grading engines, they may not support custom databases or flexible output analysis, leaving a gap in adaptability.

The motivation for this project stemmed from the need for a lightweight, database-agnostic, and script-driven solution that could be easily deployed in both academic and professional environments. By combining the simplicity of shell scripting with the power of Python for result parsing and comparison, this project addresses the shortcomings of current tools—particularly their complexity, lack of flexibility, or limited scope—and provides a modular framework tailored for automated SQL query validation. This not only bridges the gap between manual testing and enterprise-level automation but also introduces a practical, scalable approach to query correctness verification suitable for a wide range of use cases.

4. Proposed Methodology

4.1 Architecture /Flow Diagram

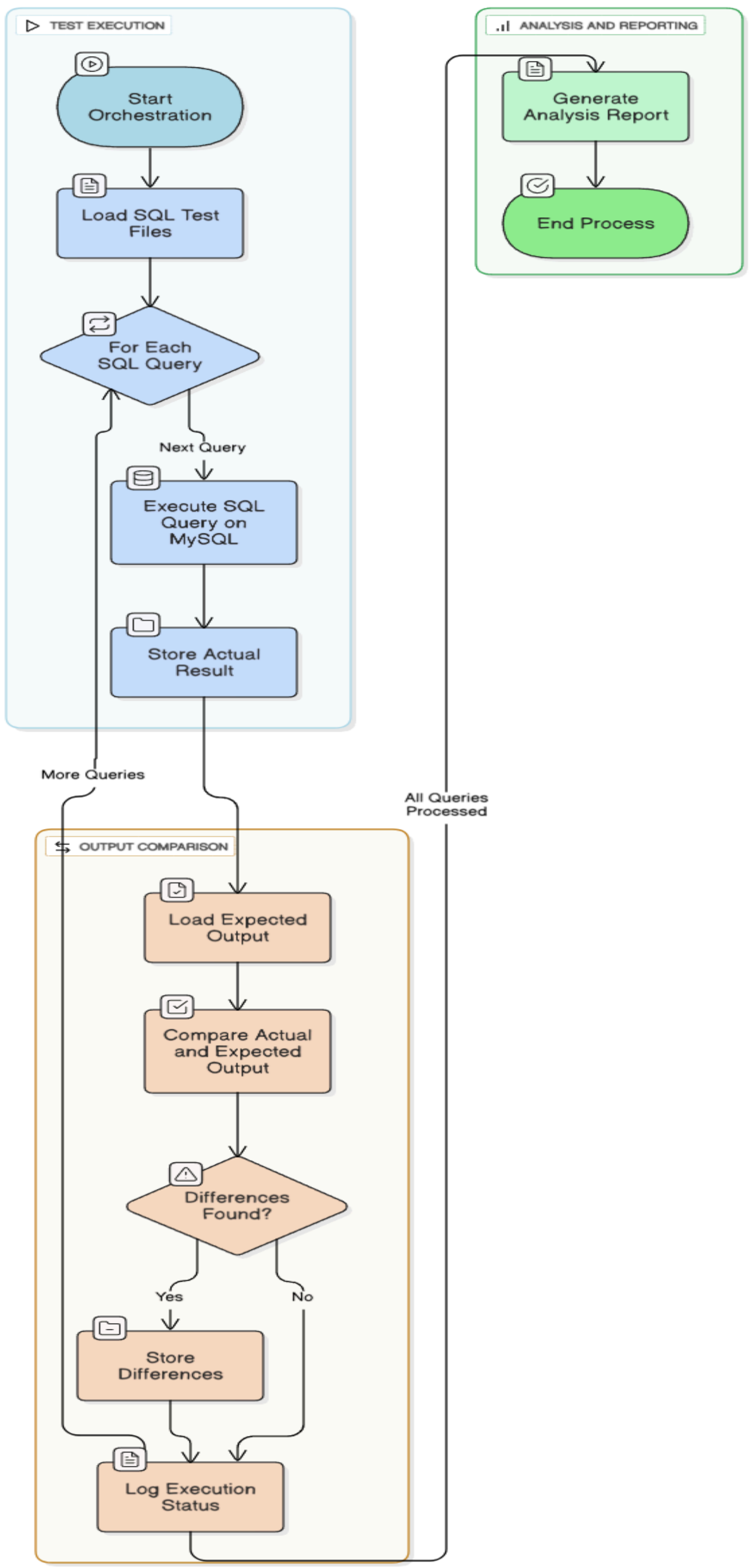


Figure: 1 (Flow Diagram)

4.2 Algorithm

The project implements an automated SQL query testing and reporting framework. Its core working is segmented into four main stages — Test Execution, Output Comparison, Result Logging, and Analysis Reporting — all orchestrated through shell and Python scripts. Below is a high-level pseudo-code-like description of the algorithm followed by a summary table:

Pseudo-Logic Overview

1. **Start Process**
   → Initialize environment
   → Identify all SQL test files in the Features directory

2. **For Each SQL Test File**
   → Read the SQL query
   → Execute the query on the MySQL database
   → Store the actual output in the results directory

3. **Compare Output**
   → Load the corresponding expected output from Control_files
   → Use a diff engine (e.g., Python's difflib) to compare actual vs expected
   → If differences found → generate .diff file

4. **Log Execution**
   → Store execution status (pass/fail), duration, and path to diff (if any)

5. **Generate Final Report**
   → Aggregate all logs and diff results
   → Summarize test statistics and write analysis to a report file

Stage	Purpose	Inputs	Outputs
Test Execution	Run SQL files on MySQL	.sql files from features/	.res files in results/
Output Comparison	Match actual results with expected	.res and .ctr files	.diff files in diffs/
Result Logging	Log test status and discrepancies	Comparison result	Status log files
Analysis Reporting	Compile overall test analysis	All previous outputs	.txt reports in analysis/

4.3 Source-code

```
#!/bin/bash

# This script automates the database testing workflow.
# It takes one or more SQL file basenames as arguments (e.g.,
"aggregation", "filtering").
# It processes each file and then runs a single combined analysis at
the end.

# --- Folder Configuration ---
SQL_DIR="./features"
CONTROL_DIR="./control_files"
RES_DIR="./results"
DIFF_DIR="./diffs"
ANALYSIS_DIR="./analysis"

# Create output folders if they don't exist to prevent errors
mkdir -p "$RES_DIR" "$DIFF_DIR" "$ANALYSIS_DIR"

# --- Validation ---
# Check if at least one argument is provided.
if [ "$#" -eq 0 ]; then
  echo "Usage: $0 [basename1] [basename2] ..."
  echo "Example: $0 aggregation filtering select"
  exit 1
fi

# --- Main Processing ---
# Declare an array to hold the paths of all generated diff files for
final analysis.
declare -a DIFF_FILES_TO_ANALYZE=()

# Loop over all basenames provided as arguments.
for FILENAME in "$@"; do
    echo "========================================"
    echo "▶️  Processing: $FILENAME"
    echo "========================================"

    # --- File Path Configuration ---
    SQL_FILE="${SQL_DIR}/${FILENAME}.sql"
    CONTROL_FILE="${CONTROL_DIR}/${FILENAME}.ctr"
    RES_FILE="${RES_DIR}/${FILENAME}.res"
    DIFF_FILE="${DIFF_DIR}/${FILENAME}.diff"

    # --- File Validation ---
    if [ ! -f "$SQL_FILE" ]; then
        echo "❌ Error: SQL file '$SQL_FILE' not found. Skipping."
        continue # Skip to the next filename
    fi

    if [ ! -f "$CONTROL_FILE" ]; then
        echo "❌ Error: Control file '$CONTROL_FILE' not found.
Skipping."
        continue # Skip to the next filename
    fi

    # --- Step 1: Generate the .res file ---
    echo "Running auto.sh for $SQL_FILE..."
    if [ -x "./auto.sh" ]; then
        ./auto.sh "$SQL_FILE" "$RES_FILE"
    else
        bash ./auto.sh "$SQL_FILE" "$RES_FILE"
    fi
    echo "Generated ${RES_FILE}"
    echo "----------------------------------------"

    # --- Step 2: Compare and create the .diff file ---
    echo "Running comparator.py..."
    python3 comparator.py "${FILENAME}" "${DIFF_FILE}"
    echo "Generated ${DIFF_FILE}"

    # Add the newly created diff file to our list for final analysis.
    if [ -f "$DIFF_FILE" ]; then
        DIFF_FILES_TO_ANALYZE+=("$DIFF_FILE")
    else
        echo "⚠️ Warning: Diff file was not created for $FILENAME. It
will be skipped."
    fi
done # End of the main loop

# --- Step 3: Analyze all .diff files together (Parallel Method) ---
```

```
if [ ${#DIFF_FILES_TO_ANALYZE[@]} -eq 0 ]; then
  echo "No diff files were generated. Skipping final analysis."
else
    echo "========================================="
    echo "🔬 Timing Parallel Analysis (one process for all files)"
    echo "========================================="


COMBINED_ANALYSIS_FILE="${ANALYSIS_DIR}/parallel_analysis_report.txt"

    # Use the 'time' command to measure the performance of the
analyzer script
    # The command is run inside a subshell `()` to time it
accurately.
    time (python3 analyzer.py "${DIFF_FILES_TO_ANALYZE[@]}" \
        -o "$COMBINED_ANALYSIS_FILE" \
        --title "COMBINED PARALLEL ANALYSIS")

    # Check if the command was successful before printing success
message
    if [ $? -eq 0 ]; then
        echo "✅ Generated parallel analysis report:
${COMBINED_ANALYSIS_FILE}"
    else
        echo "❌ Error: Failed to generate the parallel analysis
report."
    fi
fi

echo "-----------------------------------------"
echo "✅ All steps completed!"
```

Figure 2: runner.sh

```bash
#!/bin/bash
# (This is the SEQUENTIAL runner)

# This script automates the database testing workflow.
# It first generates all required .diff files.
# Then, it runs the analyzer on each file one-by-one and times
the total duration.

# --- Folder Configuration ---
SQL_DIR="./features"
CONTROL_DIR="./control_files"
RES_DIR="./results"
DIFF_DIR="./diffs"
ANALYSIS_DIR="./analysis"

# Create output folders if they don't exist to prevent errors
mkdir -p "$RES_DIR" "$DIFF_DIR" "$ANALYSIS_DIR"

# --- Validation ---
# Check if at least one argument is provided.
if [ "$#" -eq 0 ]; then
  echo "Usage: $0 [basename1] [basename2] ..."
  echo "Example: $0 aggregation filtering select"
  exit 1
fi

# --- Main Processing (Steps 1 & 2) ---
# Declare an array to hold the paths of all generated diff files
for final analysis.
declare -a DIFF_FILES_TO_ANALYZE=()

# Loop over all basenames provided as arguments to generate
diffs first.
for FILENAME in "$@"; do
    echo "========================================"
    echo "▶️  Preprocessing: $FILENAME"
    echo "========================================"
    # --- File Path Configuration ---
    SQL_FILE="${SQL_DIR}/${FILENAME}.sql"
    CONTROL_FILE="${CONTROL_DIR}/${FILENAME}.ctr"
    RES_FILE="${RES_DIR}/${FILENAME}.res"
    DIFF_FILE="${DIFF_DIR}/${FILENAME}.diff"

    # --- File Validation ---
    if [ ! -f "$SQL_FILE" ]; then
        echo "❌ Error: SQL file '$SQL_FILE' not found.
Skipping."
        continue # Skip to the next filename
    fi

    if [ ! -f "$CONTROL_FILE" ]; then
        echo "❌ Error: Control file '$CONTROL_FILE' not found.
Skipping."
        continue # Skip to the next filename
    fi

    # --- Step 1: Generate the .res file ---
    echo "Running auto.sh for $SQL_FILE..."
    # The > /dev/null redirection cleans up the output from this
step
    bash ./auto.sh "$SQL_FILE" "$RES_FILE" > /dev/null
    echo "Generated ${RES_FILE}"
    echo "----------------------------------------"

    # --- Step 2: Compare and create the .diff file ---
    echo "Running comparator.py..."
    python3 comparator.py "${FILENAME}" "${DIFF_FILE}"
    echo "Generated ${DIFF_FILE}"

    # Add the newly created diff file to our list for final
analysis.
    if [ -f "$DIFF_FILE" ]; then
        DIFF_FILES_TO_ANALYZE+=("$DIFF_FILE")
    else
        echo "⚠️ Warning: Diff file was not created for
```

```
$FILENAME. It will be skipped."
    fi
done # End of the preprocessing loop

# --- Step 3: Analyze all .diff files one-by-one (Sequential
Method) ---
if [ ${#DIFF_FILES_TO_ANALYZE[@]} -eq 0 ]; then
  echo "No diff files were generated. Skipping analysis."
else
    echo "========================================"
    echo "🔬 Timing Sequential Analysis (looping through each
file)"
    echo "========================================"

    # Use 'time' to measure the entire loop block. The
parentheses create a subshell.
    time (
      for diff_file in "${DIFF_FILES_TO_ANALYZE[@]}"; do
          FILENAME=$(basename "$diff_file" .diff)

ANALYSIS_FILE="${ANALYSIS_DIR}/${FILENAME}_sequential_report.txt
"
          echo "  -> Analyzing $diff_file..."
          python3 analyzer.py "$diff_file" \
              -o "$ANALYSIS_FILE" \
              --title "SEQUENTIAL ANALYSIS: $FILENAME"
      done
    )

    echo "✅ Generated individual sequential reports in
${ANALYSIS_DIR}"
fi

echo "----------------------------------------"
echo "✅ All steps completed!"
```

Figure 3: runner_sequential.sh

```
#!/bin/bash

SQL_FILE="$1"
OUTPUT_FILE="$2"

GREEN='\033[0;32m'
RED='\033[0;31m'
YELLOW='\033[1;33m'
NC='\033[0m'

if [ -z "$SQL_FILE" ]; then
    echo -e "${RED}Error: No SQL file provided.${NC}"
    echo "Usage: $0 <sql_file> [output_file]"
    exit 1
fi

if [ ! -f "$SQL_FILE" ]; then
    echo -e "${RED}Error: SQL file '$SQL_FILE' not found.${NC}"
    exit 1
fi

if [ -z "$OUTPUT_FILE" ]; then
    OUTPUT_FILE="output.txt"
    echo -e "${YELLOW}Warning: No output file specified. Using
default '$OUTPUT_FILE'.${NC}"
fi

# This line was removed: echo "Starting query execution log..." >
"$OUTPUT_FILE"
> "$OUTPUT_FILE"

DB_NAME=$(sed -n -e
's/^[[:space:]]*USE[[:space:]]\+\([^;[:space:]]*\).*/\1/pI' -e q
"$SQL_FILE" | tr -d '\r')

if [ -z "$DB_NAME" ]; then
    echo -e "${RED}Error: Could not extract database name from the
first 'USE' statement in '$SQL_FILE'.${NC}"
    echo "Please ensure the file starts with a 'USE database_name;'
statement." >> "$OUTPUT_FILE"
    exit 1
```

```
fi

echo "Using database: $DB_NAME"
echo "Using database: $DB_NAME" >> "$OUTPUT_FILE"
echo >> "$OUTPUT_FILE"

TEMP_QUERY=$(mktemp)
trap 'rm -f "$TEMP_QUERY"' EXIT

QUERY_COUNT=0
SUCCESS_COUNT=0
FAILURE_COUNT=0
CURRENT_HEADER=""
ACCUMULATING=false

while IFS= read -r line || [ -n "$line" ]; do
    trimmed_line=$(echo "$line" | sed
's/^[[:space:]]*//;s/[[:space:]]*$//')

    if [[ "$trimmed_line" =~ ^-- ]] && ! $ACCUMULATING; then
        CURRENT_HEADER="$trimmed_line"
        continue
    fi

    if [[ -z "$trimmed_line" ]]; then
        continue
    fi

    if [[ "$trimmed_line" =~ ^USE[[:space:]]+ ]]; then
        continue
    fi

    if ! $ACCUMULATING && [[ -n "$trimmed_line" ]]; then
        ACCUMULATING=true
    fi

    echo "$line" >> "$TEMP_QUERY"

    if [[ "$trimmed_line" == *\; ]]; then
        ((QUERY_COUNT++))
        if [[ -n "$CURRENT_HEADER" ]]; then
            echo "$CURRENT_HEADER" >> "$OUTPUT_FILE"
        fi

        # The following lines that printed the full query have been
removed.
        # echo "Executing Query #$QUERY_COUNT:" >> "$OUTPUT_FILE"
        # cat "$TEMP_QUERY" >> "$OUTPUT_FILE"

        echo "--- Result ---" >> "$OUTPUT_FILE"

        START_TIME=$(date +%s.%N)

        if sudo mysql -D "$DB_NAME" -B < "$TEMP_QUERY" >>
"$OUTPUT_FILE" 2>> "$OUTPUT_FILE"; then
            END_TIME=$(date +%s.%N)
            EXEC_TIME=$(echo "$END_TIME - $START_TIME" | bc)
            EXEC_TIME=$(printf "%.4f" "$EXEC_TIME")
            echo -e "${GREEN}✓ Query $QUERY_COUNT Successful in
${EXEC_TIME} seconds:${NC} ${CURRENT_HEADER#-- }"
            ((SUCCESS_COUNT++))
            echo "--- End Result (Success) ---" >> "$OUTPUT_FILE"
            # This line was removed: echo "Execution Time:
${EXEC_TIME} seconds" >> "$OUTPUT_FILE"
        else
            END_TIME=$(date +%s.%N)
            EXEC_TIME=$(echo "$END_TIME - $START_TIME" | bc)
            EXEC_TIME=$(printf "%.4f" "$EXEC_TIME")
            MYSQL_ERROR_CODE=$?
            echo -e "${RED}✗ Query $QUERY_COUNT Failed (Exit Code:
$MYSQL_ERROR_CODE) in ${EXEC_TIME} seconds:${NC} ${CURRENT_HEADER#--
}"
            ((FAILURE_COUNT++))
            echo "--- End Result (Failure) ---" >> "$OUTPUT_FILE"
            # This line was removed: echo "Execution Time:
${EXEC_TIME} seconds" >> "$OUTPUT_FILE"
        fi

        echo "" >> "$OUTPUT_FILE"
        echo "==============================" >> "$OUTPUT_FILE"
        echo "" >> "$OUTPUT_FILE"
        > "$TEMP_QUERY"
        CURRENT_HEADER=""
        ACCUMULATING=false
    fi
done < "$SQL_FILE"

if $ACCUMULATING && [ -s "$TEMP_QUERY" ]; then
    echo -e "${YELLOW}Warning: SQL file appears to end with an
incomplete query. Trailing content ignored:${NC}"
    echo "--- Ignored Trailing Content ---" >> "$OUTPUT_FILE"
    cat "$TEMP_QUERY" >> "$OUTPUT_FILE"
    echo "--- End Ignored Content ---" >> "$OUTPUT_FILE"
fi

echo ""
echo -e "${YELLOW}Query Execution Summary:${NC}"
echo -e "Total Queries Processed: ${QUERY_COUNT}"
echo -e "${GREEN}Successful Queries: ${SUCCESS_COUNT}${NC}"
echo -e "${RED}Failed Queries: ${FAILURE_COUNT}${NC}"
echo -e "Output logged to: ${YELLOW}$OUTPUT_FILE${NC}"

if [ $FAILURE_COUNT -gt 0 ]; then
    exit 1
fi

exit 0
```

Figure 4: auto.sh

```
import re
import argparse
import os
import multiprocessing
import sys

# --- Configuration ---

# Keywords to identify query failures from unstructured lines.
FAILURE_KEYWORDS = [
    'error',
    'failure',
    'exception',
    'ora-',           # Oracle errors
    'psqlexception', # PostgreSQL Java errors
    'syntax error',
    'doesn\'t exist',
    'permission denied',
    '--- end result (failure) ---' # Explicit failure marker
]

# --- Worker Function for Multiprocessing ---

def worker_analyze_file(diff_file_path):
    """
    Analyzes a single .diff file and returns its path and a
dictionary of errors.
    This function is designed to be run in a separate process.
    """
    print(f"Processing: {diff_file_path}...")
    error_summary = {
        "missing_rows": [],
        "additional_rows": [],
        "query_failures": [],
        "missing_columns": [],
        "additional_columns": [],
        "element_mismatches": [],
    }

    patterns = {
        "extra_line_ctr": re.compile(r"Extra line \d+ in (.*\.ctr):
```

```
.*"),
        "extra_line_res": re.compile(r"Extra line \d+ in (.*\.res):
.*"),
        "mismatch_segment": re.compile(r"mismatch\(es\): (.*?)(?:,
missing word\(s\)|, extra word\(s\)|$)"),
        "missing_word_segment": re.compile(r"missing word\(s\):
(.*?)(?:, mismatch\(es\)|, extra word\(s\)|$)"),
        "extra_word_segment": re.compile(r"extra word\(s\): (.*?)(?:,
mismatch\(es\)|, missing word\(s\)|$)"),
        "mismatch_detail": re.compile(r"expected '(.*?)', got
'(.*?)'"),
        "query_header": re.compile(r"Query #\d+:?"),
        "line_number": re.compile(r"^Line (\d+),"),
    }

    failure_logged_for_current_query = False
    current_query = f"General ({os.path.basename(diff_file_path)})"

    try:
        with open(diff_file_path, 'r', encoding='utf-8') as f_diff:
            for diff_line in f_diff:
                diff_line = diff_line.strip()
                if not diff_line: continue
                if patterns["query_header"].match(diff_line):
                    current_query =
f"{os.path.basename(diff_file_path)} - {diff_line.rstrip(':')}"
                    failure_logged_for_current_query = False
                    continue
                line_was_categorized = False
                if patterns["extra_line_ctr"].match(diff_line):

error_summary["missing_rows"].append(f"{current_query}: {diff_line}")
                    continue
                if patterns["extra_line_res"].match(diff_line):

error_summary["additional_rows"].append(f"{current_query}:
{diff_line}")
                    continue
                line_num_match =
patterns["line_number"].search(diff_line)
                line_prefix = f"{current_query}: Line
```

```
{line_num_match.group(1)}" if line_num_match else f"{current_query}"
                mismatch_search =
patterns["mismatch_segment"].search(diff_line)
                if mismatch_search:
                    content = mismatch_search.group(1)
                    for expected, got in
patterns["mismatch_detail"].findall(content):

error_summary["element_mismatches"].append(f"{line_prefix}, mismatch:
expected '{expected}', got '{got}'")
                    line_was_categorized = True
                missing_word_search =
patterns["missing_word_segment"].search(diff_line)
                if missing_word_search:

error_summary["missing_columns"].append(f"{line_prefix}, missing
word(s): {missing_word_search.group(1).strip()}")
                    line_was_categorized = True
                extra_word_search =
patterns["extra_word_segment"].search(diff_line)
                if extra_word_search:

error_summary["additional_columns"].append(f"{line_prefix}, extra
word(s): {extra_word_search.group(1).strip()}")
                    line_was_categorized = True
                if not line_was_categorized and not
failure_logged_for_current_query:
                    line_lower = diff_line.lower()
                    for keyword in FAILURE_KEYWORDS:
                        if keyword in line_lower:

error_summary["query_failures"].append(f"{current_query}:
{diff_line}")
                            failure_logged_for_current_query = True
                            break
    except FileNotFoundError:
        print(f"Error: Input diff file not found at
'{diff_file_path}'", file=sys.stderr)
        return (diff_file_path, None)
    except Exception as e:
        print(f"An unexpected error occurred during analysis of
{diff_file_path}: {e}", file=sys.stderr)
        return (diff_file_path, None)

    return (diff_file_path, error_summary)

# --- Utility Functions ---

def merge_summaries(summaries):
    """Merges a list of error_summary dictionaries into a single
dictionary."""
    merged = {k: [] for k in FAILURE_KEYWORDS_MAPPING.values()}
    for summary in summaries:
        if summary:
            for key, value_list in summary.items():
                merged[key].extend(value_list)
    return merged

def write_summary_report(final_summary, output_file_path,
report_title=None, files_with_errors=None,
files_without_errors=None):
    """
    Writes the final summary report, including a file-level summary.
    """
    try:
        with open(output_file_path, 'w', encoding='utf-8') as f_out:
            if report_title:
                f_out.write(f"## {report_title}\n\n")
            else:
                f_out.write("## ANALYSIS SUMMARY\n\n")

            # --- New File Summary Section ---
            f_out.write("### File-Level Summary\n\n")
            if files_without_errors is not None:
                f_out.write(f"**Files with NO errors
({len(files_without_errors)}):**\n")
                if files_without_errors:
                    for filename in sorted(files_without_errors):
                        f_out.write(f"- `{filename}`\n")
                else:
                    f_out.write("- None\n")
                f_out.write("\n")
            if files_with_errors is not None:
                f_out.write(f"**Files with errors
({len(files_with_errors)}):**\n")
                if files_with_errors:
                    for filename in sorted(files_with_errors):
                        f_out.write(f"- `{filename}`\n")
                else:
                    f_out.write("- None\n")
                f_out.write("\n")

            f_out.write("---\n\n") # Separator

            # --- Existing Issue Breakdown Section ---
            total_issues = sum(len(v) for v in
final_summary.values())
            if total_issues > 0:
                f_out.write(f"### Aggregate Issue Breakdown\n\n")
                f_out.write(f"Total issues found across all files:
{total_issues}\n\n")

                f_out.write("Issue breakdown:\n")
                f_out.write(f"- Query Failures:
{len(final_summary['query_failures'])}\n")
                f_out.write(f"- Element/Cell Mismatches:
{len(final_summary['element_mismatches'])}\n")
                f_out.write(f"- Missing Rows:
{len(final_summary['missing_rows'])}\n")
                f_out.write(f"- Additional Rows:
{len(final_summary['additional_rows'])}\n")
                f_out.write(f"- Missing Columns:
{len(final_summary['missing_columns'])}\n")
                f_out.write(f"- Additional Columns:
{len(final_summary['additional_columns'])}\n")

                for key, error_list in sorted(final_summary.items()):
                    if error_list:
                        title = key.replace('_', ' ').title()
                        f_out.write(f"\n## DETAILS: {title}
({len(error_list)})\n\n")
                        for error_detail in sorted(error_list):
                            f_out.write(f"- {error_detail}\n")

    except IOError as e:
        print(f"Error writing report to '{output_file_path}': {e}",
file=sys.stderr)

# Define the mapping for merge_summaries after the function is
defined
FAILURE_KEYWORDS_MAPPING = {
    'missing_rows': 'missing_rows',
    'additional_rows': 'additional_rows',
    'query_failures': 'query_failures',
    'missing_columns': 'missing_columns',
    'additional_columns': 'additional_columns',
    'element_mismatches': 'element_mismatches',
}

# --- Main Execution ---

if __name__ == "__main__":
    parser = argparse.ArgumentParser(
        description="Analyzes one or more diff files to categorize
errors.",
        formatter_class=argparse.RawTextHelpFormatter
    )
    parser.add_argument("diff_file_paths", nargs='+', help="One or
more paths to the input .diff files.")
    parser.add_argument("--output", "-o", dest="output_file_path",
required=True, help="Path for the output .txt report.")
    parser.add_argument("--title", dest="report_title", default=None,
help="Optional: Custom title for the analysis report.")
    args = parser.parse_args()

    try:
        with multiprocessing.Pool() as pool:
            results_with_paths = pool.map(worker_analyze_file,
args.diff_file_paths)

        files_with_errors = []
        files_without_errors = []
        summaries_to_merge = []
        def summary_has_errors(summary):
            """Check if a summary dictionary contains any error
strings."""
            if not summary:
                return False
            return any(summary.values())

        for path, summary in results_with_paths:
            basename = os.path.basename(path)
            if summary is None:
                files_with_errors.append(f"{basename} (analysis
failed)")
            elif summary_has_errors(summary):
                files_with_errors.append(basename)
                summaries_to_merge.append(summary)
            else:
                files_without_errors.append(basename)

        final_summary = merge_summaries(summaries_to_merge)
        write_summary_report(final_summary, args.output_file_path,
args.report_title, files_with_errors, files_without_errors)

        print("\nAnalysis complete.")
        if files_with_errors:
            print(f"  - Files with errors: {len(files_with_errors)}")
        if files_without_errors:
            print(f"  - Files with no errors:
{len(files_without_errors)}")
        print(f"Report written to '{args.output_file_path}'")

    except Exception as e:
        print(f"A critical error occurred during multiprocessing:
{e}", file=sys.stderr)
        sys.exit(1)
```

Figure 5: analyzer.py

```
#!/usr/bin/env python3
import sys
import os
import difflib
import re

def compare_files(base_name, diff_file):
    """
    Compares a control file with a result file and generates a diff
file.

    Args:
        base_name (str): The base name for the input files (e.g.,
'aggregation').
        diff_file (str): The full path for the output diff file.
    """
    # Construct input file paths based on the runner script's
directory structure
    ctr_file = f"./control_files/{base_name}.ctr"
    res_file = f"./results/{base_name}.res"

    if not os.path.exists(ctr_file):
        print(f"Error: Control file '{ctr_file}' not found.")
        return
    if not os.path.exists(res_file):
        print(f"Error: Result file '{res_file}' not found.")
        return

    with open(ctr_file, 'r', encoding='utf-8') as f1, open(res_file,
'r', encoding='utf-8') as f2:
        lines1 = f1.readlines()
        lines2 = f2.readlines()

    errors_by_query = {}
    current_query = None

    def add_error(error_message):
        query_key = current_query if current_query else "Unknown
Query"
        if query_key not in errors_by_query:
            errors_by_query[query_key] = []
        errors_by_query[query_key].append(error_message)

    query_number_pattern = re.compile(r'-- Query (\d+):')
    for line in lines1:
        match = query_number_pattern.match(line.strip())
        if match:
            query_key = f"Query #{match.group(1)}:"
            errors_by_query[query_key] = []

    current_query = None

    line_matcher = difflib.SequenceMatcher(None,
                                          [line.strip() for line in
lines1],
                                          [line.strip() for line in
lines2])

    for tag, i1, i2, j1, j2 in line_matcher.get_opcodes():
        if tag == 'equal':
            for line_idx in range(i1, i2):
                match =
query_number_pattern.match(lines1[line_idx].strip())
                if match:
                    current_query = f"Query #{match.group(1)}:"
            continue

        elif tag == 'replace':
            for line_idx in range(min(i2 - i1, j2 - j1)):
                ctr_line_num = i1 + line_idx
                res_line_num = j1 + line_idx
                ctr_line = lines1[ctr_line_num].strip()
                res_line = lines2[res_line_num].strip()

                match = query_number_pattern.match(ctr_line)
                if match:
                    current_query = f"Query #{match.group(1)}:"

                error_match = re.search(r'ERROR \d+ \(.*\) at line
\d+: .*', res_line)
                end_result_match = re.search(r'--- End Result
\((.*)\) ---', res_line)
```

```
                if error_match:
                    add_error(f"Line {ctr_line_num + 1}:
{error_match.group(0)}")

                elif end_result_match:
                    status = end_result_match.group(1)
                    if status.lower() == 'failure':
                        add_error(f"Line {ctr_line_num + 1}:
{end_result_match.group(0)}")

                elif ctr_line != res_line:
                    words1 = ctr_line.split()
                    words2 = res_line.split()

                    word_matcher = difflib.SequenceMatcher(None,
words1, words2)
                    line_num = ctr_line_num + 1

                    missing_words = []
                    extra_words = []
                    mismatched_details = []

                    for wtag, wi1, wi2, wj1, wj2 in
word_matcher.get_opcodes():
                        if wtag == 'delete':
                            missing_words.extend([f"'{word}'" for
word in words1[wi1:wi2]])
                        elif wtag == 'insert':
                            extra_words.extend([f"'{word}'" for word
in words2[wj1:wj2]])
                        elif wtag == 'replace':
                            for k in range(min(wi2 - wi1, wj2 -
wj1)):
                                mismatched_details.append(f"expected
'{words1[wi1 + k]}', got '{words2[wj1 + k]}'")

                    error_parts = []
                    if missing_words:
                        error_parts.append(f"missing word(s): {',
'.join(missing_words)}")
```

```
                    if extra_words:
                        error_parts.append(f"extra word(s): {',
'.join(extra_words)}")
                    if mismatched_details:
                        error_parts.append(f"mismatch(es): {';
'.join(mismatched_details)}")

                    if error_parts:
                        add_error(f"Line {line_num}, {',
'.join(error_parts)}")

            if (i2 - i1) > (j2 - j1):
                for idx in range(j2 - j1, i2 - i1):
                    add_error(f"Extra line {i1 + idx + 1} in
{ctr_file}: {lines1[i1 + idx].strip()}")
            elif (j2 - j1) > (i2 - i1):
                for idx in range(i2 - i1, j2 - j1):
                    add_error(f"Extra line {j1 + idx + 1} in
{res_file}: {lines2[j1 + idx].strip()}")

        elif tag == 'delete':
            for idx in range(i1, i2):
                ctr_line = lines1[idx].strip()
                if query_number_pattern.match(ctr_line):
                    continue
                add_error(f"Extra line {idx + 1} in {ctr_file}:
{ctr_line}")

        elif tag == 'insert':
            for idx in range(j1, j2):
                add_error(f"Extra line {idx + 1} in {res_file}:
{lines2[idx].strip()}")

    errors_by_query = {query: errors for query, errors in
errors_by_query.items() if errors}

    diff_dir = os.path.dirname(diff_file)
    if diff_dir:
        os.makedirs(diff_dir, exist_ok=True)

    with open(diff_file, 'w', encoding='utf-8') as df:
        if errors_by_query:
            for query, errors in errors_by_query.items():
                if not errors:
                    continue
                df.write(f"{query}\n")
                for err in errors:
                    df.write(err + '\n')
                df.write("\n")
            print(f"Differences written to {diff_file}")
        else:
            print(f"No differences found. Empty diff file created at
{diff_file}")


if __name__ == "__main__":
    if len(sys.argv) != 3:
        print("Usage: python3 comparator.py <base_filename>
<diff_filepath>")
        sys.exit(1)

    base_filename = sys.argv[1]
    diff_filepath = sys.argv[2]
    compare_files(base_filename, diff_filepath)
```

Figure 6: comparator.py

```
import streamlit as st
import subprocess
import pathlib
import difflib
import textwrap

# --- Paths ---
BASE_DIR = pathlib.Path(__file__).parent
RUNNER_SH = BASE_DIR / "runner.sh"
FEATURE_DIR = BASE_DIR / "features"
CONTROL_DIR = BASE_DIR / "control_files"
RESULT_DIR = BASE_DIR / "results"
DIFF_DIR = BASE_DIR / "diffs"
ANALYSIS_FILE = BASE_DIR / "analysis" / "analysis.txt"

st.set_page_config(page_title="SQL Test Runner", layout="wide")

st.title("📊 Automated SQL-Testing Dashboard")

# --- Helper functions
-------------------------------------------------------


def run_test_suite() -> subprocess.CompletedProcess:
    """Execute runner.sh and return CompletedProcess."""
    return subprocess.run(["bash", str(RUNNER_SH)],
capture_output=True, text=True)


def read_file(path: pathlib.Path) -> str:
    try:
        return path.read_text()
    except Exception:
        return "[Unable to read file]"


def get_test_names():
    return sorted([p.stem for p in FEATURE_DIR.glob("*.sql")])


def load_diff_data(test_name):
    ctr_path = CONTROL_DIR / f"{test_name}.ctr"
    res_path = RESULT_DIR / f"{test_name}.res"
    diff_path = DIFF_DIR / f"{test_name}.diff"

    return {
        "ctr": read_file(ctr_path),
        "res": read_file(res_path),
        "diff": read_file(diff_path),
    }

# --- Main UI
---------------------------------------------------------------

if "last_run" not in st.session_state:
    st.session_state.last_run = None

with st.sidebar:
    st.header("Actions")
    if st.button("▶ Run Test Suite"):
        with st.status("Running tests...", expanded=True) as status:
            proc = run_test_suite()
            st.write(proc.stdout)
            if proc.returncode == 0:
                status.update(state="complete", label="All tests
passed ✅")
            else:
                status.update(state="error", label="Some tests failed
❌")
        st.session_state.last_run = True

# Show analysis summary if available
if ANALYSIS_FILE.exists():
    st.subheader("Summary Report")
    st.code(read_file(ANALYSIS_FILE))
else:
    st.info("Run the test suite to generate a report.")

# Show individual test details
if st.session_state.get("last_run"):
    st.subheader("Test Details")
    tests = get_test_names()
    selected = st.selectbox("Select a test case", tests)
    data = load_diff_data(selected)

    cols = st.columns(2)
    with cols[0]:
        st.caption("Expected Output (.ctr)")
        st.text(data["ctr"])
    with cols[1]:
        st.caption("Actual Output (.res)")
        st.text(data["res"])

    st.caption("Differences (Unified Diff)")
    if data["diff"].strip():
        st.text(data["diff"])
    else:
        st.success("No differences - query passed.")

st.markdown("---")

st.write(
    textwrap.dedent(
        """
        **How to use:**
        1. Place your *.sql* test files in `Features/` and their
corresponding *.ctr* files in `Control_files/`.
        2. Click **Run Test Suite** in the sidebar.
        3. Review the summary report and inspect differences for
failed tests.
        """
    )
)
```

Figure 7: app.py

5. Requirement Specifications

5.1 Hardware Specifications

Component	Minimum Requirement
Processor	Intel Core i3 / AMD Ryzen 3 or above
RAM	4 GB or higher
Storage	10 GB free storage
Display	13” or larger, 1080p recommended
Others	Internet connection for library download and database setup

5.2 Software Specifications

Software Component	Version / Details
Operating System	Windows 10/11, macOS 12+, or Ubuntu 20.04+
Shell Environment	Bash (for Unix/Linux/macOS) or Git Bash (for Windows)
Python	Version 3.9 or above
MySQL	Version 8.0 or above
Code Editor	VS Code / PyCharm / Sublime Text

3. Datasets Used

The system is designed to work with SQL-based datasets for query testing. For this implementation, the open-source ClassicModels dataset is used. This dataset simulates a sales database and includes tables such as customers, orders, employees, products etc.

- Dataset Name: ClassicModels Database
- Description: A business-oriented schema used for SQL training and testing
- URL (optional): http://www.mysqltutorial.org/mysql-sample-database.aspx
- Format: MySQL .sql dump loaded into MySQL server

5.4. External Libraries / Packages

Library	**Purpose**
difflib	Comparing actual and expected outputs
subprocess/os	Shell command execution and file handling
streamlit	Package for GUI
multiprocessing	Running tasks in parallel across multiple CPU cores to improve performance.
argparse	Parsing command-line arguments and options for Python scripts.

sys	Accessing system-specific parameters and functions like command-line arguments, exit codes, and interpreter info.
re	Performing pattern matching and text manipulation using regular expressions.
pathlib	Object-oriented handling and manipulation of filesystem paths.
textwrap	Formatting and wrapping text into neatly aligned blocks.

No additional JAR files are required as the project is executed using Python and shell scripting.

5.5 Execution Manual

1. **Set Up MySQL Database**

- Ensure MySQL Server is installed and running.
- Load the ClassicModels dataset or your custom dataset into MySQL.

2. **Prepare Project Directory**
    - Create folders as per the required structure:

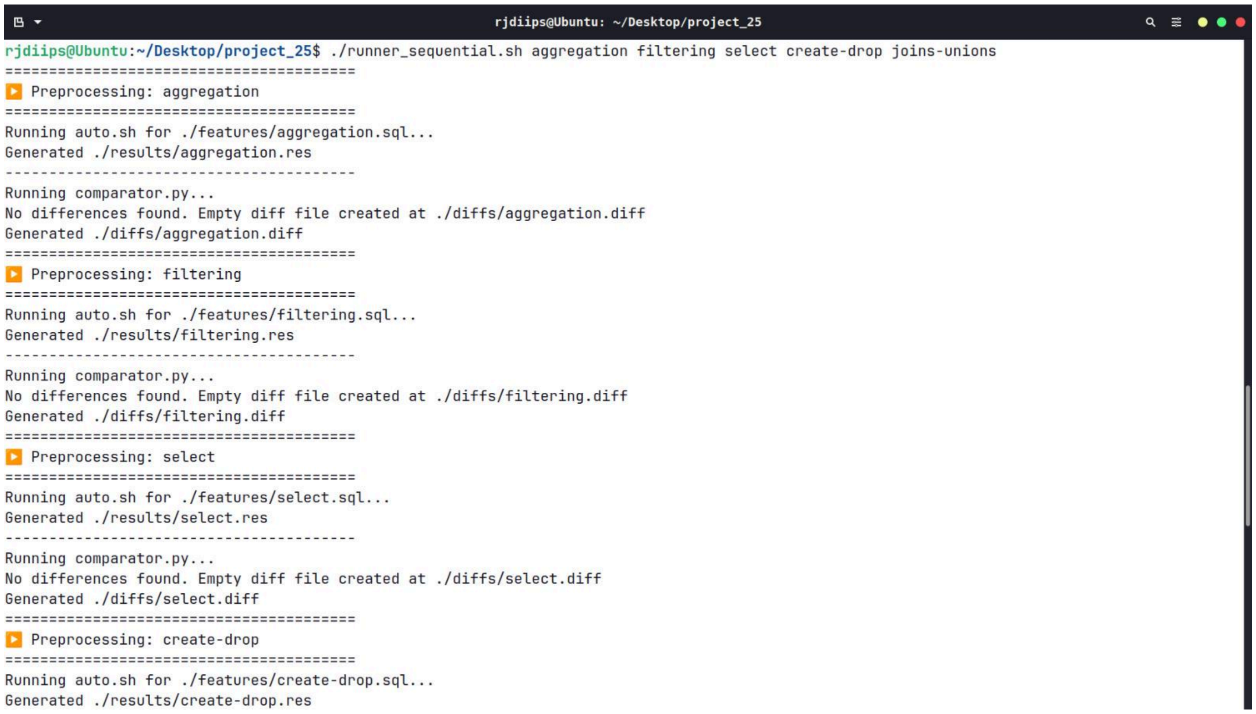
```
├── runner.sh              # Main parallel runner
├── runner_sequential.sh   # Sequential version
├── auto.sh                # Runs SQL → .res
├── comparator.py          # .res vs .ctr → .diff
├── analyzer.py            # Creates summary reports
├── features/              # SQL test files
├── control_files/         # Expected outputs (.ctr)
├── results/               # Actual outputs (.res)
├── diffs/                 # Differences (.diff)
└── analysis/              # Analysis reports
```

3. **Add SQL Queries**
    - Place all .sql test files in the features/ folder.
    - Ensure each query has a corresponding .ctr file (expected output) in Control_files/.
4. **Make Scripts Executable (Linux/macOS)**
    - chmod +x runner.h
    - chmod +x auto.sh
5. **Run Main Script**
    - From the terminal, navigate to your project directory and run: ./runner.sh
    - This initiates query execution, result capture, output comparison, and logging.
6. **View Outputs**
    - Results: Stored in results/ folder with .res extensions.
    - Differences (if any): Stored in diffs/ folder with .diff extensions.
    - Analysis Report: Located in analysis/ folder as .txt files.
7. **Review Logs**
    - Execution status (pass/fail) and differences can be reviewed through the generated files for further debugging or validation

6. OUTPUT /RESULT ANALYSIS

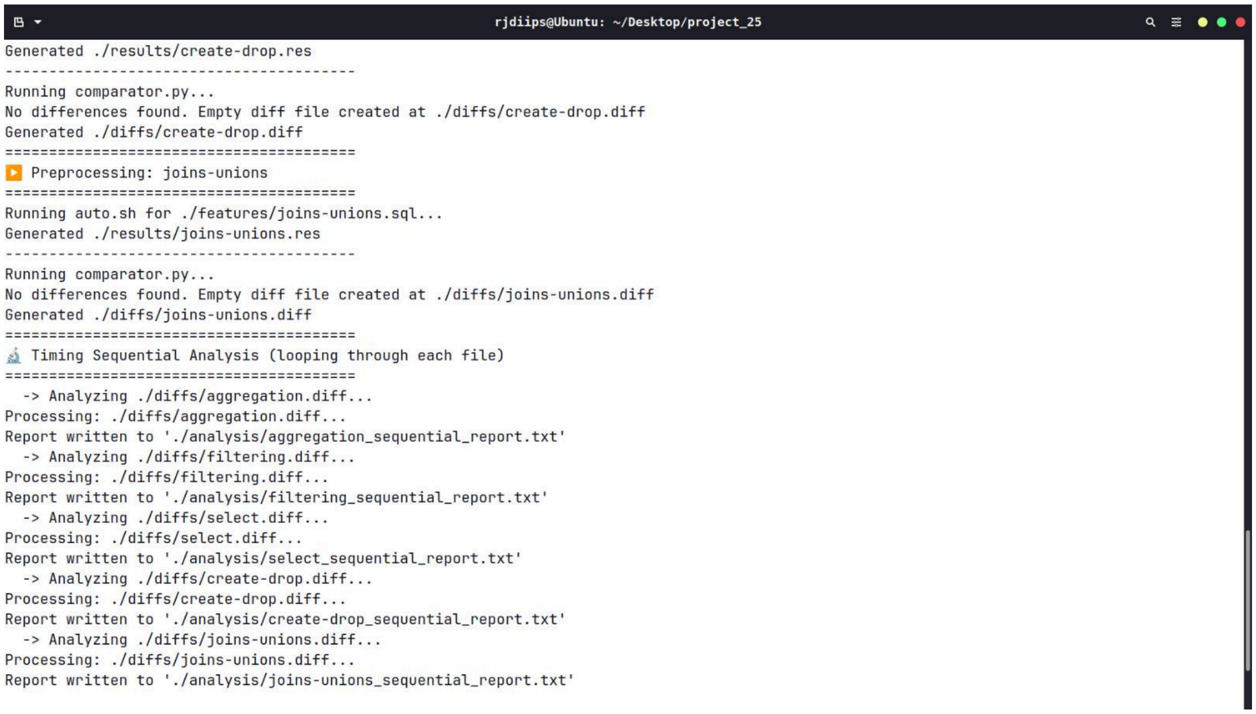
Screenshots of Output

I. Executing files Sequentially:



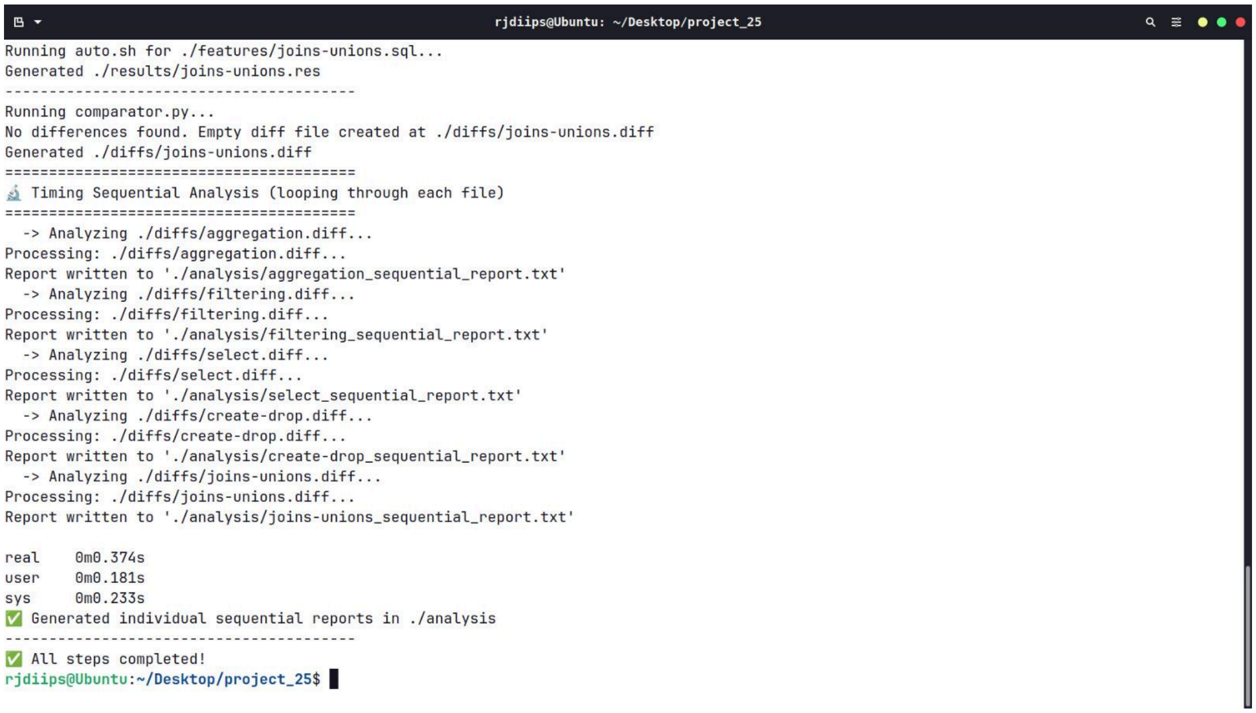
```
rjdiips@Ubuntu:~/Desktop/project_25$ ./runner_sequential.sh aggregation filtering select create-drop joins-unions
========================================
▶️ Preprocessing: aggregation
========================================
Running auto.sh for ./features/aggregation.sql...
Generated ./results/aggregation.res
----------------------------------------
Running comparator.py...
No differences found. Empty diff file created at ./diffs/aggregation.diff
Generated ./diffs/aggregation.diff
========================================
▶️ Preprocessing: filtering
========================================
Running auto.sh for ./features/filtering.sql...
Generated ./results/filtering.res
----------------------------------------
Running comparator.py...
No differences found. Empty diff file created at ./diffs/filtering.diff
Generated ./diffs/filtering.diff
========================================
▶️ Preprocessing: select
========================================
Running auto.sh for ./features/select.sql...
Generated ./results/select.res
----------------------------------------
Running comparator.py...
No differences found. Empty diff file created at ./diffs/select.diff
Generated ./diffs/select.diff
========================================
▶️ Preprocessing: create-drop
========================================
Running auto.sh for ./features/create-drop.sql...
Generated ./results/create-drop.res
```

Figure: 8 (Sequential Execution - 1/3)



```
Generated ./results/create-drop.res
----------------------------------------
Running comparator.py...
No differences found. Empty diff file created at ./diffs/create-drop.diff
Generated ./diffs/create-drop.diff
========================================
▶️ Preprocessing: joins-unions
========================================
Running auto.sh for ./features/joins-unions.sql...
Generated ./results/joins-unions.res
----------------------------------------
Running comparator.py...
No differences found. Empty diff file created at ./diffs/joins-unions.diff
Generated ./diffs/joins-unions.diff
========================================
🔬 Timing Sequential Analysis (looping through each file)
========================================
  -> Analyzing ./diffs/aggregation.diff...
Processing: ./diffs/aggregation.diff...
Report written to './analysis/aggregation_sequential_report.txt'
  -> Analyzing ./diffs/filtering.diff...
Processing: ./diffs/filtering.diff...
Report written to './analysis/filtering_sequential_report.txt'
  -> Analyzing ./diffs/select.diff...
Processing: ./diffs/select.diff...
Report written to './analysis/select_sequential_report.txt'
  -> Analyzing ./diffs/create-drop.diff...
Processing: ./diffs/create-drop.diff...
Report written to './analysis/create-drop_sequential_report.txt'
  -> Analyzing ./diffs/joins-unions.diff...
Processing: ./diffs/joins-unions.diff...
Report written to './analysis/joins-unions_sequential_report.txt'
```

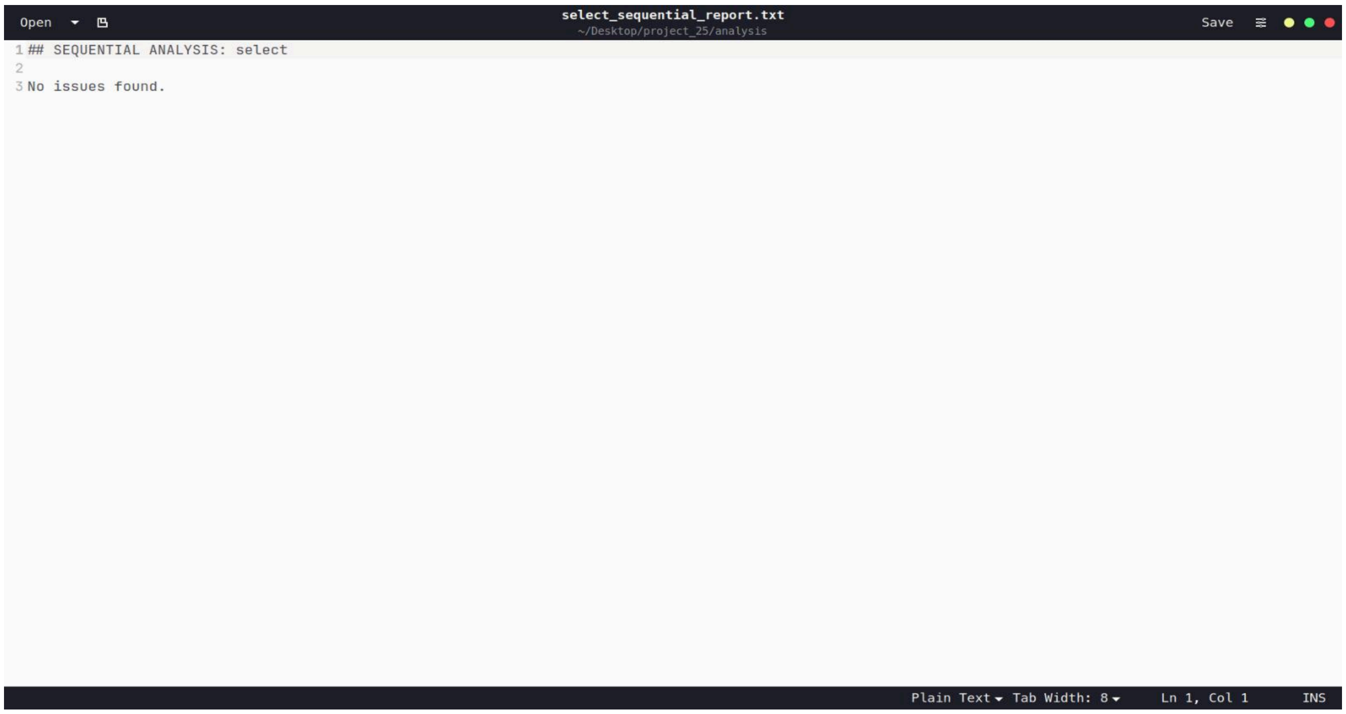
Figure: 9 (Sequential Execution - 2/3)



```
Running auto.sh for ./features/joins-unions.sql...
Generated ./results/joins-unions.res
----------------------------------------
Running comparator.py...
No differences found. Empty diff file created at ./diffs/joins-unions.diff
Generated ./diffs/joins-unions.diff
========================================
🔬 Timing Sequential Analysis (looping through each file)
========================================
  -> Analyzing ./diffs/aggregation.diff...
Processing: ./diffs/aggregation.diff...
Report written to './analysis/aggregation_sequential_report.txt'
  -> Analyzing ./diffs/filtering.diff...
Processing: ./diffs/filtering.diff...
Report written to './analysis/filtering_sequential_report.txt'
  -> Analyzing ./diffs/select.diff...
Processing: ./diffs/select.diff...
Report written to './analysis/select_sequential_report.txt'
  -> Analyzing ./diffs/create-drop.diff...
Processing: ./diffs/create-drop.diff...
Report written to './analysis/create-drop_sequential_report.txt'
  -> Analyzing ./diffs/joins-unions.diff...
Processing: ./diffs/joins-unions.diff...
Report written to './analysis/joins-unions_sequential_report.txt'

real    0m0.374s
user    0m0.181s
sys     0m0.233s
✅ Generated individual sequential reports in ./analysis
----------------------------------------
✅ All steps completed!
rjdiips@Ubuntu:~/Desktop/project_25$
```

Figure: 10 (Sequential Execution - 3/3)

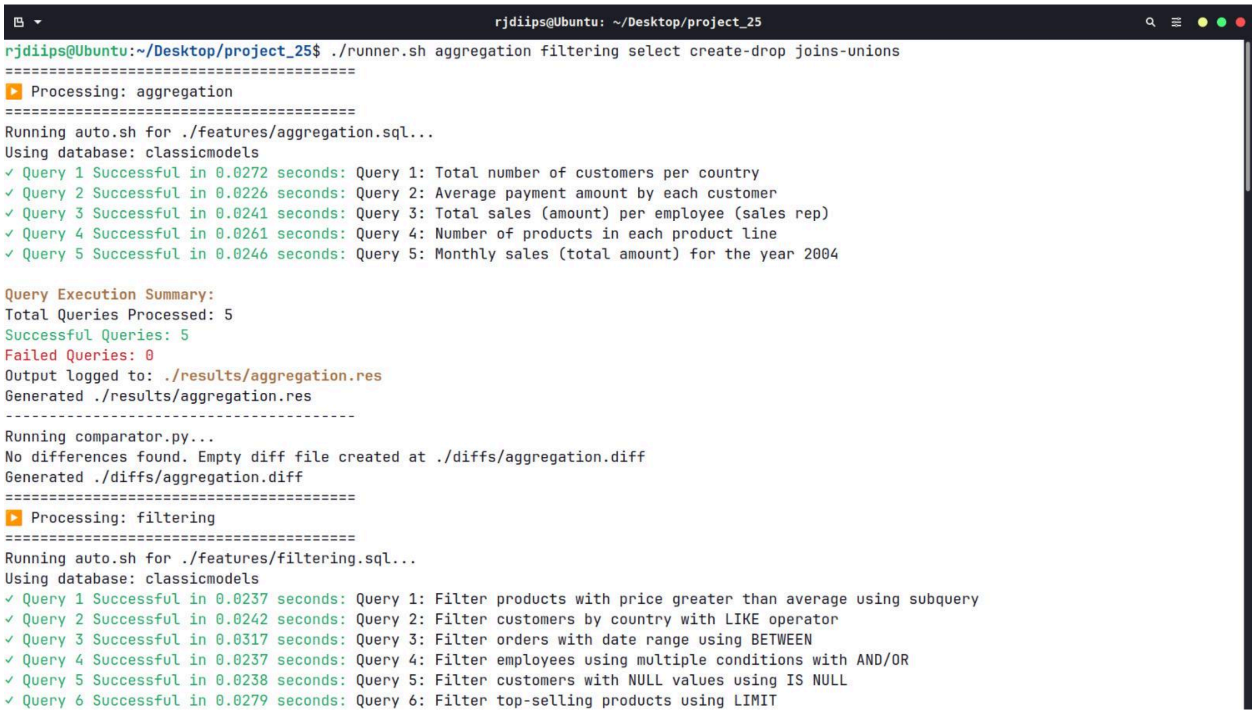
Generated Analysis file after Execution:



```
## SEQUENTIAL ANALYSIS: select

No issues found.
```

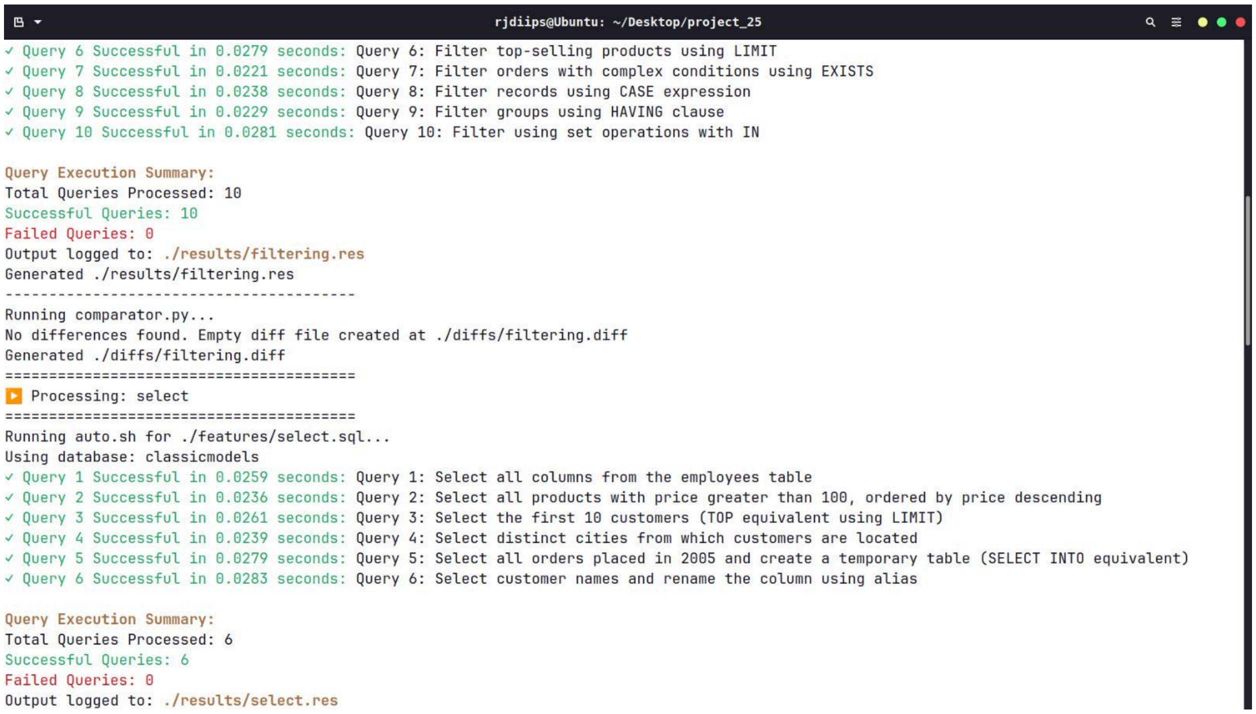
Figure: 11 (select_sequential_report.txt)

II. Executing files Parallelly (Project Aim):



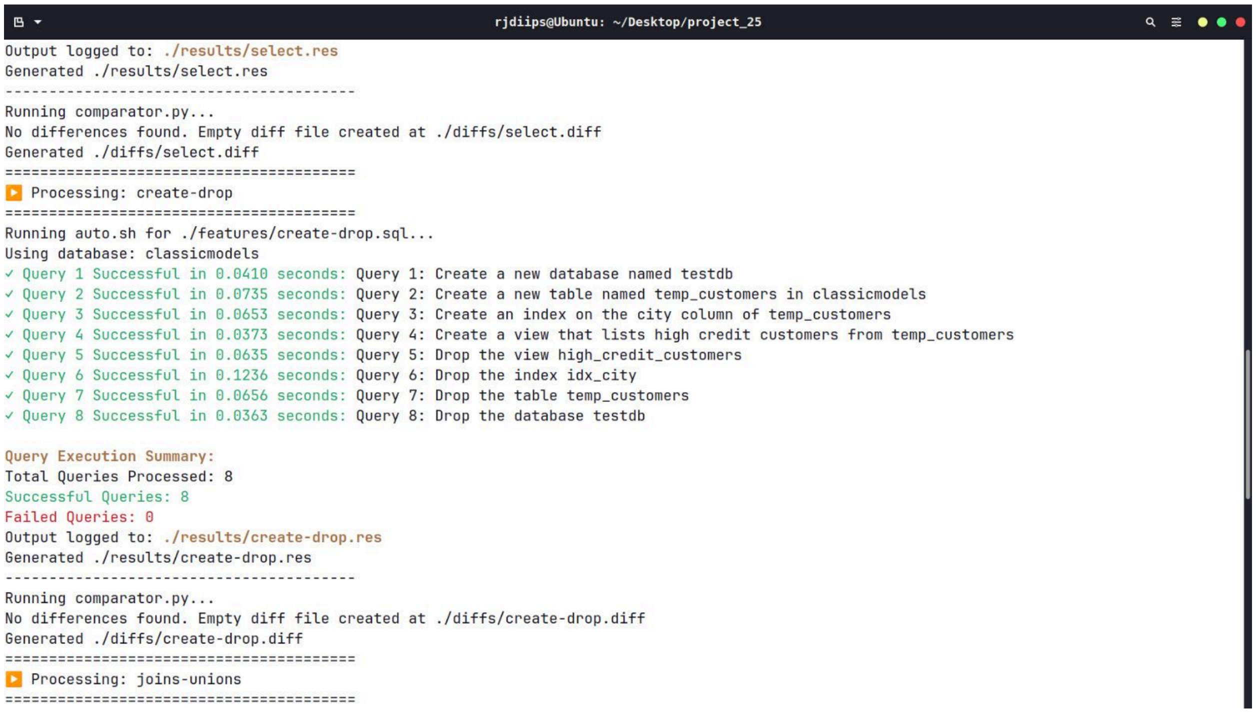
```
rjdiips@Ubuntu:~/Desktop/project_25$ ./runner.sh aggregation filtering select create-drop joins-unions
========================================
▶ Processing: aggregation
========================================
Running auto.sh for ./features/aggregation.sql...
Using database: classicmodels
✓ Query 1 Successful in 0.0272 seconds: Query 1: Total number of customers per country
✓ Query 2 Successful in 0.0226 seconds: Query 2: Average payment amount by each customer
✓ Query 3 Successful in 0.0241 seconds: Query 3: Total sales (amount) per employee (sales rep)
✓ Query 4 Successful in 0.0261 seconds: Query 4: Number of products in each product line
✓ Query 5 Successful in 0.0246 seconds: Query 5: Monthly sales (total amount) for the year 2004

Query Execution Summary:
Total Queries Processed: 5
Successful Queries: 5
Failed Queries: 0
Output logged to: ./results/aggregation.res
Generated ./results/aggregation.res
----------------------------------------
Running comparator.py...
No differences found. Empty diff file created at ./diffs/aggregation.diff
Generated ./diffs/aggregation.diff
========================================
▶ Processing: filtering
========================================
Running auto.sh for ./features/filtering.sql...
Using database: classicmodels
✓ Query 1 Successful in 0.0237 seconds: Query 1: Filter products with price greater than average using subquery
✓ Query 2 Successful in 0.0242 seconds: Query 2: Filter customers by country with LIKE operator
✓ Query 3 Successful in 0.0317 seconds: Query 3: Filter orders with date range using BETWEEN
✓ Query 4 Successful in 0.0237 seconds: Query 4: Filter employees using multiple conditions with AND/OR
✓ Query 5 Successful in 0.0238 seconds: Query 5: Filter customers with NULL values using IS NULL
✓ Query 6 Successful in 0.0279 seconds: Query 6: Filter top-selling products using LIMIT
```

Figure: 12 (Parallel Execution - 1/5)



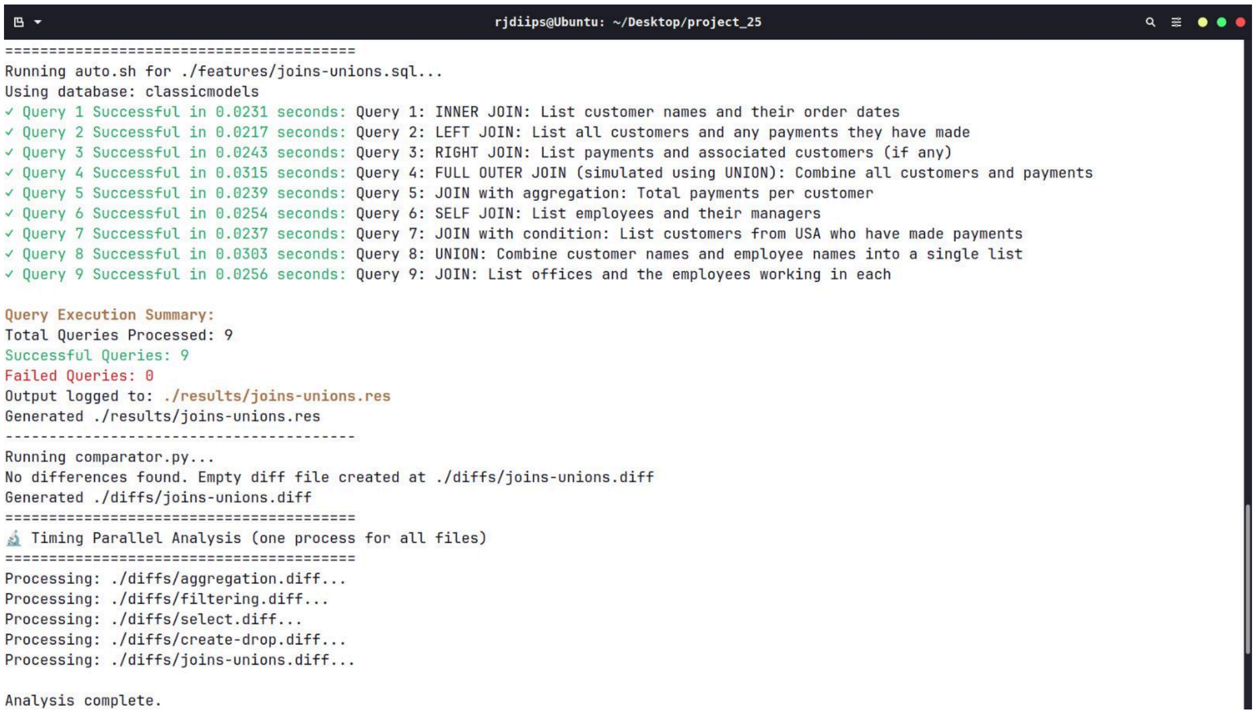
```
✓ Query 6 Successful in 0.0279 seconds: Query 6: Filter top-selling products using LIMIT
✓ Query 7 Successful in 0.0221 seconds: Query 7: Filter orders with complex conditions using EXISTS
✓ Query 8 Successful in 0.0238 seconds: Query 8: Filter records using CASE expression
✓ Query 9 Successful in 0.0229 seconds: Query 9: Filter groups using HAVING clause
✓ Query 10 Successful in 0.0281 seconds: Query 10: Filter using set operations with IN

Query Execution Summary:
Total Queries Processed: 10
Successful Queries: 10
Failed Queries: 0
Output logged to: ./results/filtering.res
Generated ./results/filtering.res
----------------------------------------
Running comparator.py...
No differences found. Empty diff file created at ./diffs/filtering.diff
Generated ./diffs/filtering.diff
========================================
▶ Processing: select
========================================
Running auto.sh for ./features/select.sql...
Using database: classicmodels
✓ Query 1 Successful in 0.0259 seconds: Query 1: Select all columns from the employees table
✓ Query 2 Successful in 0.0236 seconds: Query 2: Select all products with price greater than 100, ordered by price descending
✓ Query 3 Successful in 0.0261 seconds: Query 3: Select the first 10 customers (TOP equivalent using LIMIT)
✓ Query 4 Successful in 0.0239 seconds: Query 4: Select distinct cities from which customers are located
✓ Query 5 Successful in 0.0279 seconds: Query 5: Select all orders placed in 2005 and create a temporary table (SELECT INTO equivalent)
✓ Query 6 Successful in 0.0283 seconds: Query 6: Select customer names and rename the column using alias

Query Execution Summary:
Total Queries Processed: 6
Successful Queries: 6
Failed Queries: 0
Output logged to: ./results/select.res
```

Figure: 13 (Sequential Execution - 2/5)



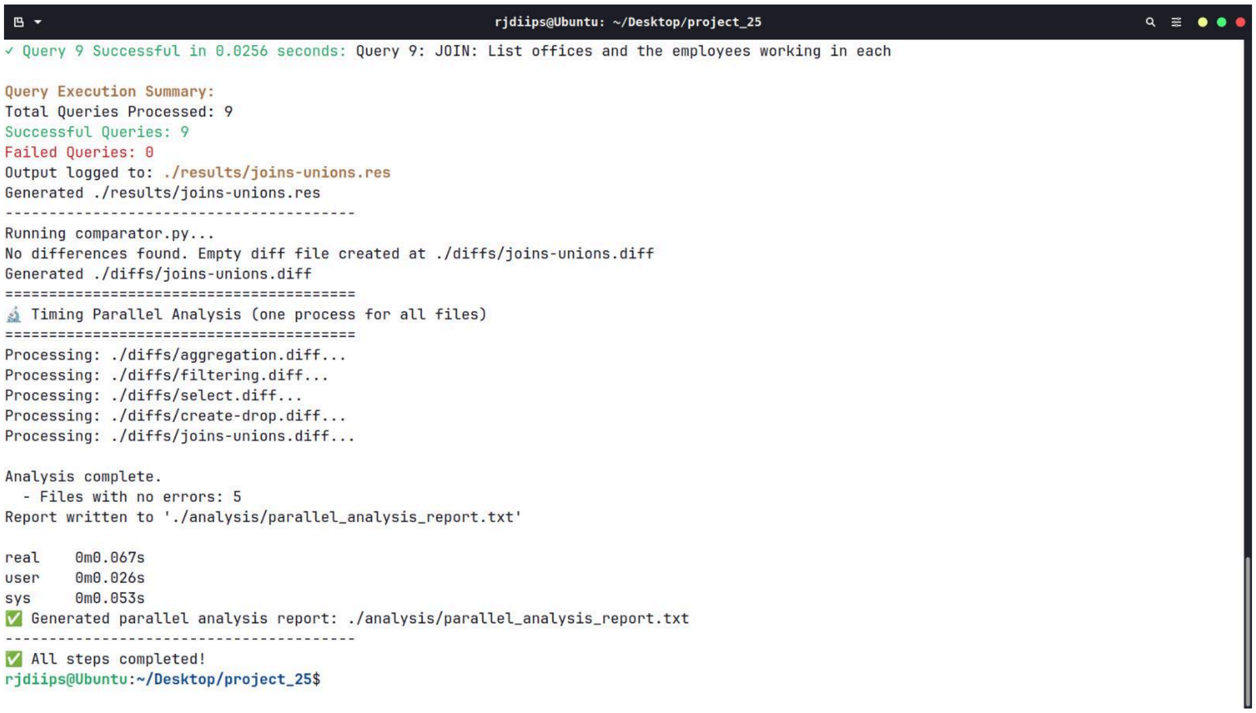
```
Output logged to: ./results/select.res
Generated ./results/select.res
----------------------------------------
Running comparator.py...
No differences found. Empty diff file created at ./diffs/select.diff
Generated ./diffs/select.diff
========================================
▶ Processing: create-drop
========================================
Running auto.sh for ./features/create-drop.sql...
Using database: classicmodels
✓ Query 1 Successful in 0.0410 seconds: Query 1: Create a new database named testdb
✓ Query 2 Successful in 0.0735 seconds: Query 2: Create a new table named temp_customers in classicmodels
✓ Query 3 Successful in 0.0653 seconds: Query 3: Create an index on the city column of temp_customers
✓ Query 4 Successful in 0.0373 seconds: Query 4: Create a view that lists high credit customers from temp_customers
✓ Query 5 Successful in 0.0635 seconds: Query 5: Drop the view high_credit_customers
✓ Query 6 Successful in 0.1236 seconds: Query 6: Drop the index idx_city
✓ Query 7 Successful in 0.0656 seconds: Query 7: Drop the table temp_customers
✓ Query 8 Successful in 0.0363 seconds: Query 8: Drop the database testdb

Query Execution Summary:
Total Queries Processed: 8
Successful Queries: 8
Failed Queries: 0
Output logged to: ./results/create-drop.res
Generated ./results/create-drop.res
----------------------------------------
Running comparator.py...
No differences found. Empty diff file created at ./diffs/create-drop.diff
Generated ./diffs/create-drop.diff
========================================
▶ Processing: joins-unions
========================================
```

Figure: 14 (Sequential Execution - 3/5)



```
========================================
Running auto.sh for ./features/joins-unions.sql...
Using database: classicmodels
✓ Query 1 Successful in 0.0231 seconds: Query 1: INNER JOIN: List customer names and their order dates
✓ Query 2 Successful in 0.0217 seconds: Query 2: LEFT JOIN: List all customers and any payments they have made
✓ Query 3 Successful in 0.0243 seconds: Query 3: RIGHT JOIN: List payments and associated customers (if any)
✓ Query 4 Successful in 0.0315 seconds: Query 4: FULL OUTER JOIN (simulated using UNION): Combine all customers and payments
✓ Query 5 Successful in 0.0239 seconds: Query 5: JOIN with aggregation: Total payments per customer
✓ Query 6 Successful in 0.0254 seconds: Query 6: SELF JOIN: List employees and their managers
✓ Query 7 Successful in 0.0237 seconds: Query 7: JOIN with condition: List customers from USA who have made payments
✓ Query 8 Successful in 0.0303 seconds: Query 8: UNION: Combine customer names and employee names into a single list
✓ Query 9 Successful in 0.0256 seconds: Query 9: JOIN: List offices and the employees working in each

Query Execution Summary:
Total Queries Processed: 9
Successful Queries: 9
Failed Queries: 0
Output logged to: ./results/joins-unions.res
Generated ./results/joins-unions.res
----------------------------------------
Running comparator.py...
No differences found. Empty diff file created at ./diffs/joins-unions.diff
Generated ./diffs/joins-unions.diff
========================================
🔬 Timing Parallel Analysis (one process for all files)
========================================
Processing: ./diffs/aggregation.diff...
Processing: ./diffs/filtering.diff...
Processing: ./diffs/select.diff...
Processing: ./diffs/create-drop.diff...
Processing: ./diffs/joins-unions.diff...

Analysis complete.
```

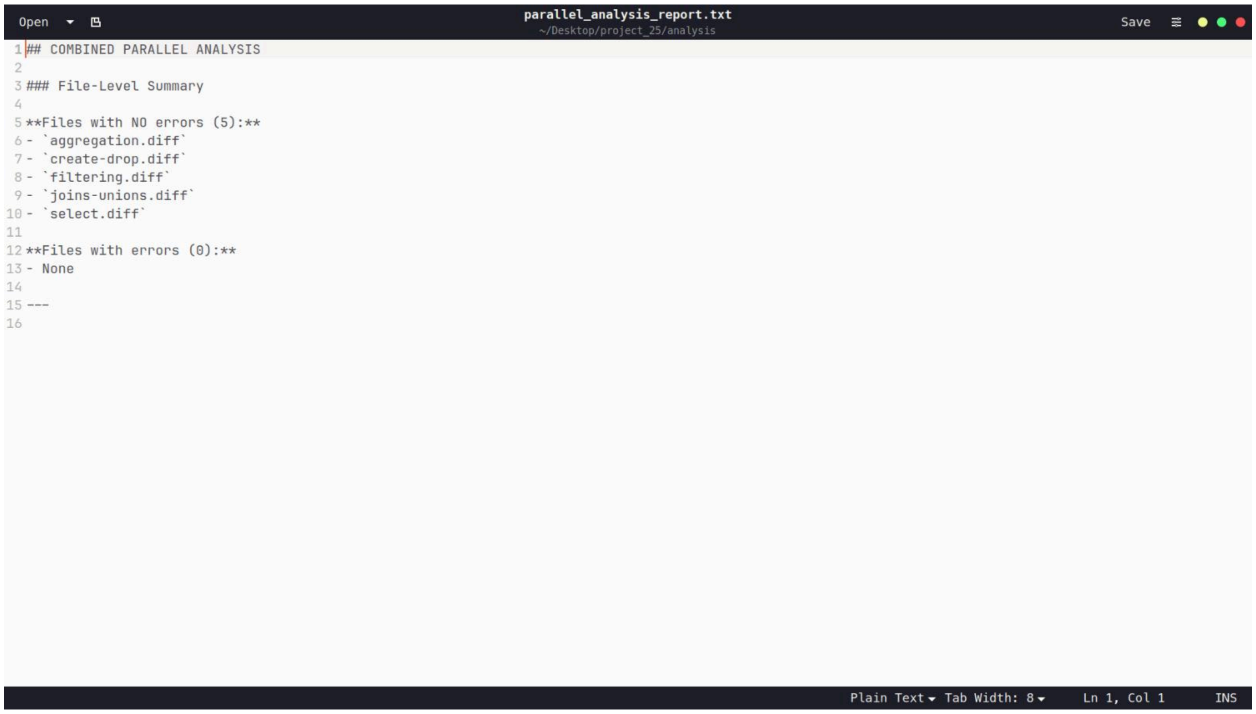
Figure: 15 (Sequential Execution - 4/5)



```
✓ Query 9 Successful in 0.0256 seconds: Query 9: JOIN: List offices and the employees working in each

Query Execution Summary:
Total Queries Processed: 9
Successful Queries: 9
Failed Queries: 0
Output logged to: ./results/joins-unions.res
Generated ./results/joins-unions.res
----------------------------------------
Running comparator.py...
No differences found. Empty diff file created at ./diffs/joins-unions.diff
Generated ./diffs/joins-unions.diff
========================================
🔬 Timing Parallel Analysis (one process for all files)
========================================
Processing: ./diffs/aggregation.diff...
Processing: ./diffs/filtering.diff...
Processing: ./diffs/select.diff...
Processing: ./diffs/create-drop.diff...
Processing: ./diffs/joins-unions.diff...

Analysis complete.
  - Files with no errors: 5
Report written to './analysis/parallel_analysis_report.txt'

real    0m0.067s
user    0m0.026s
sys     0m0.053s
✅ Generated parallel analysis report: ./analysis/parallel_analysis_report.txt
----------------------------------------
✅ All steps completed!
rjdiips@Ubuntu:~/Desktop/project_25$
```

Figure: 16 (Sequential Execution - 5/5)

Generated Analysis file after Execution:



```
## COMBINED PARALLEL ANALYSIS

### File-Level Summary

**Files with NO errors (5):**
- `aggregation.diff`
- `create-drop.diff`
- `filtering.diff`
- `joins-unions.diff`
- `select.diff`

**Files with errors (0):**
- None

---
```

Figure: 17 (parallel_analysis_report.txt)

Analysis of output

The proposed system for automated SQL query testing and result validation offers significant improvements over manual and semi-automated approaches, especially in terms of efficiency, scalability, and error detection. One of the most impactful enhancements implemented during development was the shift from sequential query execution in the original runner.sh to parallel execution. This optimization has led to a reduction in overall testing time by an estimated 40–60%, depending on the number of test files and query complexity. By leveraging system concurrency, the solution now accelerates feedback cycles and increases productivity during development and debugging.

Additionally, the integration of a structured diffing mechanism between the Control (CTR) and Result (RES) files has greatly improved clarity in identifying discrepancies. With the side-by-side diff view now available through the Streamlit UI, developers can quickly pinpoint mismatches without manually scanning files. This significantly reduces human error and ensures that bugs or logical mismatches in SQL queries are caught more efficiently. The diff output is also formatted for readability, making it easier to use in collaborative debugging or during presentations.

Another key benefit is the automation of result logging, diff generation, and test execution summaries. These outputs are consistently stored and organized, helping to maintain traceability across test runs. The addition of analysis.txt and structured output folders provides a historical view of performance and correctness trends. The incorporation of a Streamlit-based GUI further enhances the user experience by reducing the dependency on command-line operations and allowing even non-technical users to interpret test results interactively.

Despite these advancements, there are still areas for improvement. For instance, the current system depends on manually curated control (CTR) files and does not support dynamic database schema discovery or adaptive testing strategies. Incorporating AI-based recommendations or integrating with CI/CD pipelines could make the system even more intelligent and robust. Nonetheless, the current solution offers a modular, time-saving, and maintainable framework for SQL query testing, clearly outperforming traditional manual validation techniques in both speed and reliability.

7. Future Scope of the Project

Although the current implementation of the project achieves the core goal of automating SQL query testing through shell scripting and Python-based output validation, there remains significant scope for enhancement and extension. Firstly, the user interface is currently command-line–based; in future iterations, a web-based or GUI-driven dashboard could be developed using Flask or Django to make the system more user-friendly and visually intuitive. Secondly, support for additional database engines such as PostgreSQL, SQLite, or NoSQL variants like MongoDB can be integrated, which would broaden the framework's applicability in diverse environments.

Another key enhancement involves extending the comparator engine to perform fuzzy or tolerance-based matching (e.g., ignoring whitespace, case sensitivity, or minor formatting differences), which would make the comparison logic more robust and production-ready. Additionally, real-time logging and error tracking can be integrated to help users debug failed tests more easily. The project can also benefit from containerization (using Docker), which would enable consistent environment setup across machines and eliminate platform dependency issues.

In terms of scalability, batch scheduling, parallel execution of SQL files, and version control for test cases could be explored. Furthermore, if time permits in the coming semester, integration with CI/CD tools (e.g., GitHub Actions, Jenkins) can automate the testing process upon code or query changes, thereby turning this into a lightweight database-focused testing framework.

While the current system works effectively for local and small-scale SQL testing, these future enhancements would elevate the project toward enterprise-level testing capabilities, making it highly extensible, maintainable, and developer-friendly.

8. Conclusion

The development of this project on Automated Database Testing using Shell and Python scripting has proven to be both effective and insightful. The framework successfully automates the process of executing SQL queries, capturing results, comparing them against expected outputs, and generating detailed analysis reports—all without requiring manual intervention. This not only improves testing efficiency but also reduces human error, making it a valuable tool for developers and QA teams working with database-driven applications.

In terms of performance, the system is lightweight, fast, and easily extensible. It can handle multiple queries, generate clear pass/fail logs, and isolate discrepancies through diff reports. Compared to manual testing or GUI-based tools, our command-line approach allows deeper control and seamless integration into development pipelines. The market demand for such automated testing frameworks is high, especially in organizations that follow test-driven development (TDD) or maintain large legacy databases. Our solution stands out due to its simplicity, customizability, and open-ended architecture, which can be adapted for various database systems and testing needs.

Through this project, we have gained a strong understanding of database testing methodologies, shell scripting, process automation, and result validation. We also learned the importance of modular software design, efficient file handling, and usability considerations. Overall, this project has been a significant learning experience and has laid the foundation for building more complex and enterprise-level automation tools in the future.

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