Cover Paper: Distributed Hotel Database Project – PostgreSQL

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Project: Hotel Booking Management – Kigali & Rubavu Branches
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1. Project Objectives

- **Implement a distributed database across two branches (`kigali_hotel_db` and `rubavu_hotel_db`)**
- **Ensure data consistency, atomicity, and concurrency control**
- **Demonstrate parallel processing, ETL simulation, and performance optimization**
- **Evaluate distributed query optimization and benchmarking**

2. Tools & Methodology

- **Database: PostgreSQL (with dblink)**
- **Programming: SQL, PL/pgSQL**
- **Techniques:**
    - **Horizontal fragmentation**
    - **Two-Phase Commit (2PC)**
    - **Parallel queries & DML**
    - **Concurrency control**
    - **Distributed aggregation & joins**
- **Monitoring: EXPLAIN ANALYZE, pg_locks, pg_prepared_xacts**

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3. Key Tasks and Highlights

Task	Summary

Q1: Distributed Schema	**Split booking data across Kigali & Rubavu; created ER diagram and SQL schema.**
Q2: Database Links	**Created dblink for remote queries and distributed joins.**
Q3: Parallel Query Execution	**Used parallel aggregation on booking table; compared serial vs parallel performance.**
Q4: Two-Phase Commit	**Inserted bookings on both branches; verified atomicity using `pg_prepared_xacts`.**
Q5: Distributed Rollback & Recovery	**Simulated network failure; recovered transactions using `ROLLBACK PREPARED`.**
Q6: Concurrency Control	**Simulated lock conflicts between sessions; observed via `pg_locks`.**

Q7: Parallel Data Loading / ETL	**Loaded 1 million rows; performed parallel aggregation; runtime improved vs serial.**
Q8: Three-Tier Architecture	**Designed Presentation → Application → Database layers; highlighted dblink interaction.**
Q9: Query Optimization	**Used EXPLAIN ANALYZE to optimize distributed joins; reduced network data transfer.**
Q10: Performance Benchmark	**Compared centralized, parallel, and distributed queries; documented execution times and I/O.**

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4. Observations & Results

- **2PC ensures atomicity: either all branches commit or rollback.**
- **Locks prevent conflicts: distributed concurrency control works as expected.**

- **Parallel execution improves query performance significantly.**
- **Distributed queries require careful optimization to reduce network overhead.**
- **Branch-level aggregation enables better reporting and management.**

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5. Conclusion

The project demonstrates a robust distributed hotel management system using PostgreSQL.
It combines data fragmentation, database links, 2PC, parallel processing, and concurrency control.
Proper query optimization and parallel execution improve performance across branches.

🧩 Q1: Distributed Schema Design & Fragmentation (PostgreSQL Version)

🏨 Scenario

We have **two PostgreSQL databases**:

- `kigali_hotel_db` — branch A
- `rubavu_hotel_db` — branch B

Each branch stores its **own hotel data** (horizontal fragmentation).
That means:

- Guests, rooms, and bookings from Kigali go into `kigali_hotel_db`.
- Guests, rooms, and bookings from Rubavu go into `rubavu_hotel_db`.

🧠 Step 1: Fragmentation Plan

Table	Fragmentation Type	Distribution Rule
RoomType	Replicated	Same in both branches
Room	Horizontal	Kigali → Kigali DB, Rubavu → Rubavu DB
Guest	Horizontal	Guests by branch
Booking	Horizontal	Each branch stores its own bookings
Service	Horizontal	Related to branch bookings
Payment	Horizontal	Related to branch bookings

🧱 Step 2: Create Databases

In pgAdmin or psql terminal:

```
CREATE DATABASE kigali_hotel_db;
CREATE DATABASE rubavu_hotel_db;
```

Then connect to each one separately and execute the following scripts.

🧩 Step 3: Schema for KIGALI Branch

Connect to: `kigali_hotel_db`

```
-- Table 1: RoomType (replicated)
CREATE TABLE roomtype (
    roomtype_id SERIAL PRIMARY KEY,
    typename VARCHAR(50) NOT NULL,
    price_per_night NUMERIC(10,2) NOT NULL,
    capacity INT CHECK (capacity > 0)
);

-- Table 2: Room
CREATE TABLE room (
    room_id SERIAL PRIMARY KEY,
    roomtype_id INT REFERENCES roomtype(roomtype_id),
    status VARCHAR(20) CHECK (status IN ('Available', 'Occupied')),
    floor INT,
    description TEXT,
    branch VARCHAR(20) DEFAULT 'Kigali'
);

-- Table 3: Guest
CREATE TABLE guest (
    guest_id SERIAL PRIMARY KEY,
    fullname VARCHAR(100) NOT NULL,
    phone VARCHAR(20),
    email VARCHAR(50),
    nationalid VARCHAR(30),
    branch VARCHAR(20) DEFAULT 'Kigali'
);

-- Table 4: Booking
CREATE TABLE booking (
    booking_id SERIAL PRIMARY KEY,
    guest_id INT REFERENCES guest(guest_id) ON DELETE CASCADE,
    room_id INT REFERENCES room(room_id),
    checkin_date DATE,
    checkout_date DATE,
```

```
    status VARCHAR(20)
);

-- Table 5: Service
CREATE TABLE service (
    service_id SERIAL PRIMARY KEY,
    booking_id INT REFERENCES booking(booking_id) ON DELETE CASCADE,
    description TEXT,
    cost NUMERIC(10,2),
    staff_id INT
);

-- Table 6: Payment
CREATE TABLE payment (
    payment_id SERIAL PRIMARY KEY,
    booking_id INT REFERENCES booking(booking_id) ON DELETE CASCADE,
    amount NUMERIC(10,2),
    payment_date DATE,
    method VARCHAR(20)
);
```

✅ Optional Sample Data for Kigali

```
INSERT INTO roomtype (typename, price_per_night, capacity)
VALUES ('Deluxe', 60000, 2), ('Standard', 40000, 2);

INSERT INTO room (roomtype_id, status, floor, description)
VALUES (1, 'Available', 1, 'Lake view room'), (2, 'Available', 2,
'Standard comfort room');

INSERT INTO guest (fullname, phone, email, nationalid)
VALUES ('Jean Claude Harerimana', '0783000000',
'jeanclaude@example.com', '1199988888888888');

INSERT INTO booking (guest_id, room_id, checkin_date, checkout_date,
status)
VALUES (1, 1, '2025-10-25', '2025-10-27', 'Confirmed');
```

🧩 Step 4: Schema for RUBAVU Branch

Connect to: `rubavu_hotel_db`

```
-- Table 1: RoomType (replicated)
CREATE TABLE roomtype (
    roomtype_id SERIAL PRIMARY KEY,
    typename VARCHAR(50) NOT NULL,
    price_per_night NUMERIC(10,2) NOT NULL,
    capacity INT CHECK (capacity > 0)
);

-- Table 2: Room
CREATE TABLE room (
    room_id SERIAL PRIMARY KEY,
    roomtype_id INT REFERENCES roomtype(roomtype_id),
    status VARCHAR(20) CHECK (status IN ('Available', 'Occupied')),
    floor INT,
    description TEXT,
    branch VARCHAR(20) DEFAULT 'Rubavu'
);

-- Table 3: Guest
CREATE TABLE guest (
    guest_id SERIAL PRIMARY KEY,
    fullname VARCHAR(100) NOT NULL,
    phone VARCHAR(20),
    email VARCHAR(50),
    nationalid VARCHAR(30),
    branch VARCHAR(20) DEFAULT 'Rubavu'
);

-- Table 4: Booking
CREATE TABLE booking (
    booking_id SERIAL PRIMARY KEY,
    guest_id INT REFERENCES guest(guest_id) ON DELETE CASCADE,
    room_id INT REFERENCES room(room_id),
    checkin_date DATE,
    checkout_date DATE,
```

```sql
    status VARCHAR(20)
);

-- Table 5: Service
CREATE TABLE service (
    service_id SERIAL PRIMARY KEY,
    booking_id INT REFERENCES booking(booking_id) ON DELETE CASCADE,
    description TEXT,
    cost NUMERIC(10,2),
    staff_id INT
);

-- Table 6: Payment
CREATE TABLE payment (
    payment_id SERIAL PRIMARY KEY,
    booking_id INT REFERENCES booking(booking_id) ON DELETE CASCADE,
    amount NUMERIC(10,2),
    payment_date DATE,
    method VARCHAR(20)
);
```

✅ Optional Sample Data for Rubavu

```sql
INSERT INTO roomtype (typename, price_per_night, capacity)
VALUES ('Suite', 90000, 3), ('Standard', 40000, 2);

INSERT INTO room (roomtype_id, status, floor, description)
VALUES (1, 'Available', 1, 'Beachfront Suite'), (2, 'Available', 2,
'Comfort Standard');

INSERT INTO guest (fullname, phone, email, nationalid)
VALUES ('Umugwaneza Francine', '0783123456', 'francine@example.com',
'1200088888888888');

INSERT INTO booking (guest_id, room_id, checkin_date, checkout_date,
status)
VALUES (1, 1, '2025-10-26', '2025-10-29', 'Pending');
```

📘 How Fragmentation Looks

Branch	Tables	Example Record
`kigali_hotel_db`	Guest, Room, Booking, etc.	GuestID=1 → “Jean Claude Harerimana”
`rubavu_hotel_db`	Guest, Room, Booking, etc.	GuestID=1 → “Umugwaneza Francine”

✅ **You’ve Completed Question 1**
Your results:

- Two PostgreSQL databases (`kigali_hotel_db`, `rubavu_hotel_db`)
- Same structure (horizontal fragmentation)
- Each branch manages its own local data

🧩 Question 2 – Create and Use Database Links

Task Description

Create a database link between your two schemas (Kigali and Rubavu).
Demonstrate a successful **remote SELECT** and a **distributed JOIN** between local and remote tables.
Include scripts and query results.

🧠 Goal

We’ll connect the two branches:

- **Kigali_Hotel_DB** ↔ **Rubavu_Hotel_DB**
  and perform queries **across both** using the `dblink` extension.

⚙️ Step 1: Enable dblink Extension

We must enable `dblink` in both databases.

In Kigali_Hotel_DB

```
CREATE EXTENSION IF NOT EXISTS dblink;
```

In Rubavu_Hotel_DB

```
CREATE EXTENSION IF NOT EXISTS dblink;
```

🧩 Step 2: Create Database Link from Kigali → Rubavu

Since PostgreSQL doesn't have built-in "database links" like Oracle, we simulate it by defining connection parameters.

In Kigali_Hotel_DB, run:

```
-- Create connection from Kigali to Rubavu
-- Replace password with your actual postgres password if needed
SELECT dblink_connect(
    'rubavu_link',
    'host=127.0.0.1 user=postgres password=postgres
dbname=rubavu_hotel_db'
);
```

✅ If successful, you'll see:

```
dblink_connect
----------------
 OK
(1 row)
```

🧪 Step 3: Test Remote SELECT Query

Now, from **Kigali_Hotel_DB**, fetch data from the **Rubavu** branch:

```
-- Remote select from Rubavu's guest table
SELECT * FROM dblink('rubavu_link', 'SELECT guest_id, fullname, branch
FROM guest')
AS rubavu_guests(guest_id INT, fullname VARCHAR, branch VARCHAR);
```

✅ **Expected Output Example:**

guest_id	fullname	branch
1	Umugwaneza Francine	Rubavu

🔗 Step 4: Distributed JOIN (Local + Remote Data)

Now let's join **Kigali's local Guest table** with **Rubavu's Guest table** via `dblink`.

```
-- Distributed join: combine all guests from Kigali and Rubavu
SELECT g.fullname AS kigali_guest, r.fullname AS rubavu_guest
FROM guest g
JOIN dblink('rubavu_link', 'SELECT guest_id, fullname FROM guest')
AS r(guest_id INT, fullname VARCHAR)
ON g.guest_id = r.guest_id;
```

✅ **Interpretation:**

- You just joined a local table (`guest` in Kigali)
  with a remote table (`guest` in Rubavu) through `dblink`.
- This simulates **distributed query execution**.

🔄 Optional Step: Disconnect Link

When done, close the link:

```
SELECT dblink_disconnect('rubavu_link');
```

🧾 Deliverables for Task 2

Your lab report should include:

1. Screenshot of `CREATE EXTENSION dblink;`
2. Screenshot of successful connection (`OK`)
3. Output of remote SELECT from Rubavu
4. Output of distributed JOIN (Kigali + Rubavu)
5. A short explanation (below)

🗒️ Explanation

We enabled `dblink` to allow remote database communication between `kigali_hotel_db` and `rubavu_hotel_db`.
Using `dblink_connect`, we established a connection named `'rubavu_link'`.
A remote query was executed from Kigali to Rubavu, fetching data directly across databases.
Finally, we performed a **distributed JOIN**, proving data integration between the two branches.

⚙️ Question 3 – Parallel Query Execution

Task Description

Enable parallel query execution on a large table (e.g., `booking`, `payment`).
Use the **parallel query feature**, compare **serial vs. parallel performance**, and show the **EXPLAIN ANALYZE** results.

🧠 Goal

We'll test how PostgreSQL performs **parallel execution** vs **serial execution** using the `booking` table in the **Kigali_Hotel_DB**.

Parallelism in PostgreSQL depends on:

- Table size (larger tables → more parallel workers)
- Query complexity
- Server settings (e.g., `max_parallel_workers_per_gather`)

🧩 Step 1: Prepare Sample Data

We'll simulate a large dataset by inserting multiple booking records (to make PostgreSQL choose a parallel plan).

Run this in **Kigali_Hotel_DB**:

```
-- Generate large dataset (100,000 sample bookings)
INSERT INTO booking (guest_id, room_id, checkin_date, checkout_date,
status)
SELECT
    (RANDOM() * 10)::INT + 1,
    (RANDOM() * 10)::INT + 1,
    NOW() - (INTERVAL '1 day' * (RANDOM() * 365)::INT),
    NOW(),
    'Completed'
FROM generate_series(1, 100000);
```

✅ This creates 100,000 bookings to simulate a real workload.

🧩 Step 2: Enable Parallel Query Support

Ensure parallelism is enabled in your PostgreSQL settings:

```
SHOW max_parallel_workers_per_gather;
```

If it returns `0`, you can temporarily enable it:

```
SET max_parallel_workers_per_gather = 4;
```

This allows PostgreSQL to use **up to 4 workers** for parallel execution.

🧩 Step 3: Compare Serial vs. Parallel Execution

🔹 A. Serial Query

We'll force a **non-parallel execution** by setting parallel workers to 0.

```
SET max_parallel_workers_per_gather = 0;

EXPLAIN ANALYZE
SELECT COUNT(*)
FROM booking
WHERE status = 'Completed';
```

✅ **Expected Output (simplified):**

```
Aggregate  (cost=... rows=1 width=8)
  ->  Seq Scan on booking  (cost=... rows=100000 width=0)
Execution Time: 320 ms
```

🔹 B. Parallel Query

Now enable parallelism again.

```
SET max_parallel_workers_per_gather = 4;

EXPLAIN ANALYZE
SELECT COUNT(*)
FROM booking
```

```
WHERE status = 'Completed';
```

✅ **Expected Output (simplified):**

```
Finalize Aggregate  (cost=... width=8)
  ->  Gather  (cost=... width=8)
        Workers Planned: 4
        ->  Partial Aggregate
              ->  Parallel Seq Scan on booking
Execution Time: 120 ms
```

✅ **Interpretation:**

- The keyword **"Gather"** means parallelism is active.
- **Execution Time** is reduced — this is the performance gain.

📊 Step 4: Document the Comparison

Query Type	Parallel Workers	Execution Time (Example)
Serial Query	0	320 ms
Parallel Query	4	120 ms

🧾 Deliverables for Task 3

Your lab report should include:

1. Screenshot of `generate_series()` insertion
2. Screenshot of `EXPLAIN ANALYZE` for serial and parallel queries
3. A small table comparing times (like above)
4. Explanation paragraph

🗒️ Explanation

Parallel query execution allows PostgreSQL to use multiple CPU cores for data scanning and aggregation.
In this lab, the `booking` table was used with 100,000 rows.
The serial query performed a sequential scan on one process, taking longer.
The parallel query used four worker processes (`Gather` node visible in plan), significantly reducing total runtime.
This demonstrates PostgreSQL's ability to speed up analytical workloads using parallel execution.

⚙️ Question 4 – Two-Phase Commit Simulation (Oracle Version)

Task Description

Write a PL/SQL block performing inserts on both nodes and committing once.
Verify atomicity using `DBA_2PC_PENDING`.
Provide SQL code and explanation of results.

🧠 Concept Overview

A **Two-Phase Commit (2PC)** in Oracle works automatically when you perform a distributed transaction across **two databases linked with a database link**.

Oracle internally manages:

- **Phase 1:** Prepare (checks if both sides are ready to commit)
- **Phase 2:** Commit (executes on all nodes atomically)

If a failure occurs, you can check unresolved transactions in:

```
SELECT * FROM DBA_2PC_PENDING;
```

🧩 Step 1: Ensure Database Links Exist

Let's assume:

- You already have two databases:
  - `BRANCHDB_A` → **Kigali_Hotel**
  - `BRANCHDB_B` → **Rubavu_Hotel**
- Both are accessible via **database links**.

In **Kigali_Hotel**, create a link to Rubavu:

```
CREATE DATABASE LINK rubavu_link
CONNECT TO rubavu_user IDENTIFIED BY rubavu123
USING 'RUBAVU_PDB';
```

And in **Rubavu_Hotel**, you can (optionally) create a reverse link:

```
CREATE DATABASE LINK kigali_link
CONNECT TO kigali_user IDENTIFIED BY kigali123
USING 'KIGALI_PDB';
```

✅ Make sure both links test successfully:

```
SELECT * FROM dual@rubavu_link;
```

Should return:

```
DUMMY
-----
X
```

🧩 Step 2: Simulate the Two-Phase Commit

We'll use a **PL/SQL block** that inserts data into:

- `Booking` table in the **local (Kigali)** DB, and
- `Booking` table in the **remote (Rubavu)** DB using the link.

✅ PL/SQL Code

Run this block in **Kigali_Hotel**:

```
SET SERVEROUTPUT ON;

BEGIN
    -- Local insert (Kigali)
    INSERT INTO booking (bookingid, guestid, roomid, checkindate,
checkoutdate, status)
    VALUES (1001, 1, 1, DATE '2025-10-28', DATE '2025-10-30',
'Pending');

    -- Remote insert (Rubavu)
    INSERT INTO booking@rubavu_link (bookingid, guestid, roomid,
checkindate, checkoutdate, status)
    VALUES (2001, 1, 1, DATE '2025-10-28', DATE '2025-10-30',
'Pending');

    -- Commit both (Oracle performs 2PC automatically)
    COMMIT;
    DBMS_OUTPUT.PUT_LINE('Distributed transaction committed
successfully.');

EXCEPTION
    WHEN OTHERS THEN
        DBMS_OUTPUT.PUT_LINE('Error occurred, rolling back...');
        ROLLBACK;
END;
/
```

🔍 Step 3: Verify Commit and Atomicity

If all goes well:

```
SELECT * FROM booking;
SELECT * FROM booking@rubavu_link;
```

Both will show the inserted rows. ✅

If a failure occurs (e.g., Rubavu DB is offline):

- The Kigali transaction will be **pending** in the 2PC system view.

Check:

```
SELECT local_tran_id, global_tran_id, state
FROM dba_2pc_pending;
```

✅ **Expected output:**

LOCAL_TRAN_ID	GLOBAL_TRAN_ID	STATE
2.24.12345	gtid_9876@kigali	collecting

🧩 Step 4: Manual Recovery (if needed)

If the remote commit fails, you can:

Force a rollback:

```
ROLLBACK FORCE '2.24.12345';
```

-

Force a commit:

```
COMMIT FORCE '2.24.12345';
```

-

Then recheck:

```
SELECT * FROM dba_2pc_pending;
```

The entry should disappear (resolved).

🧾 Deliverables for Task 4

1. Screenshot of:
   - PL/SQL block execution
   - Query showing rows in both databases
2. Screenshot of `DBA_2PC_PENDING` showing pending transactions (if you simulate failure)
3. Explanation paragraph (below)

🗒️ Explanation

> This experiment demonstrates Oracle's built-in Two-Phase Commit (2PC) mechanism.
> The PL/SQL block inserted one record locally (Kigali) and another remotely (Rubavu) using a database link.
> Oracle automatically executed the **prepare** and **commit** phases across both databases.
> If one node fails, the transaction appears in `DBA_2PC_PENDING` and can later be resolved using `COMMIT FORCE` or `ROLLBACK FORCE`.
> This ensures **atomicity and consistency** in distributed database environments.

Question 6 – Distributed Concurrency Control (Full PostgreSQL Script)

Step 0: Verify dblink Connection

```
-- Connect from Kigali to Rubavu
SELECT dblink_connect(
    'rubavu_link',
    'host=127.0.0.1 user=postgres password=postgres
dbname=rubavu_hotel_db'
);
```

Step 1: Prepare Test Data

```
-- Kigali branch
INSERT INTO booking (guest_id, room_id, checkin_date, checkout_date,
status)
VALUES (100, 10, '2025-11-01', '2025-11-03', 'Pending');

-- Rubavu branch
SELECT dblink_exec('rubavu_link',
$$
INSERT INTO booking (guest_id, room_id, checkin_date, checkout_date,
status)
VALUES (100, 10, '2025-11-01', '2025-11-03', 'Pending');
$$);
```

✅ Now both branches have the same `guest_id` = 100 to simulate a **lock conflict**.

Step 2: Open Two Sessions

We simulate **Session 1** (local Kigali) and **Session 2** (remote Rubavu).

> Note: In practice, use **two database connections** in pgAdmin or psql.

Session 1 (Kigali)

```
-- Begin transaction
BEGIN;
```

```
-- Update the booking record
UPDATE booking
SET status = 'Confirmed'
WHERE guest_id = 100;

-- Do NOT commit yet; this holds a lock
```

Session 2 (Rubavu via dblink)

```
-- Attempt to update the same record remotely
SELECT dblink_exec('rubavu_link',
$$
BEGIN;
UPDATE booking
SET status = 'Confirmed'
WHERE guest_id = 100;
$$);
-- This will wait until Session 1 commits
```

Step 3: Observe Locks

Check locks in Kigali (local)

```
SELECT pid, relation::regclass, mode, granted
FROM pg_locks
JOIN pg_class ON pg_locks.relation = pg_class.oid;
```

Check locks in Rubavu (remote via dblink)

```
SELECT dblink_exec('rubavu_link',
'SELECT pid, relation::regclass, mode, granted
 FROM pg_locks
 JOIN pg_class ON pg_locks.relation = pg_class.oid;');
```

✅ You should see:

pid	relation	mode	granted
1234	booking	RowExclusiveLock	t
1235	booking	RowExclusiveLock	f

- `t` = lock is held
- `f` = session is waiting

Step 4: Commit or Rollback Session 1

```
-- Kigali Session 1
COMMIT;
```

> Session 2 in Rubavu will now **acquire the lock** and complete its update.

Step 5: Verify Updates

Check Kigali

```
SELECT * FROM booking WHERE guest_id = 100;
```

Check Rubavu

```
SELECT dblink_exec('rubavu_link',
'SELECT * FROM booking WHERE guest_id = 100;');
```

✅ Both branches should now show `status = 'Confirmed'`.

Step 6: Optional – Simulate Rollback Instead

If you want to test **rollback** instead of commit:

```
-- Kigali Session 1
ROLLBACK;

-- Session 2 will then acquire the lock and execute its update
```

Step 7: Explanation

This simulation demonstrates **distributed concurrency control**:

- Row-level locks prevent conflicts between two sessions updating the same record.
- PostgreSQL ensures **atomicity and isolation** across distributed nodes.
- Using `pg_locks` (local) and `dblink` (remote), you can monitor which session **holds or waits for locks**.

Question 7 – Parallel Data Loading / ETL Simulation

Task Description

Perform **parallel data aggregation or loading** using PostgreSQL's **parallel features**.
Compare runtime vs serial execution and document improvements.
Use large tables such as `booking` or `transactions`.

Step 0: Ensure PostgreSQL Allows Parallel Queries

Check current parallel settings:

```
SHOW max_parallel_workers_per_gather;
SHOW parallel_setup_cost;
SHOW parallel_tuple_cost;
```

If needed, increase parallelism:

```
-- Enable more parallel workers
ALTER SYSTEM SET max_parallel_workers_per_gather = 8;
SELECT pg_reload_conf();
```

✅ This ensures queries can run in parallel.

Step 1: Create a Large Test Table for ETL Simulation

We'll simulate **loading many bookings**:

```
-- Create staging table
CREATE TABLE booking_staging AS
SELECT *
FROM generate_series(1, 1000000) AS id
JOIN booking ON true;
```

- `booking_staging` now has **1 million rows** for parallel processing.

Step 2: Serial Aggregation Query

```
-- Serial execution
EXPLAIN ANALYZE
SELECT room_id, COUNT(*) AS total_bookings, AVG(checkout_date -
checkin_date) AS avg_stay
FROM booking_staging
GROUP BY room_id;
```

✅ Observe **execution time** and **cost**.

Step 3: Parallel Aggregation Query

```
-- Force parallel execution using parallel hint
EXPLAIN ANALYZE
SELECT /*+ PARALLEL(booking_staging, 8) */
       room_id,
       COUNT(*) AS total_bookings,
       AVG(checkout_date - checkin_date) AS avg_stay
FROM booking_staging
GROUP BY room_id;
```

> PostgreSQL automatically decides if parallel execution is feasible, but this forces it to **use 8 workers**.

✅ Observe **reduced runtime** compared to serial query.

Step 4: Parallel Data Loading (Optional)

If you want to simulate **ETL insert into another table**:

```
-- Create target table
CREATE TABLE booking_aggregated (
    room_id INT,
    total_bookings BIGINT,
    avg_stay INTERVAL
);

-- Parallel INSERT
INSERT INTO booking_aggregated
SELECT room_id,
       COUNT(*) AS total_bookings,
       AVG(checkout_date - checkin_date) AS avg_stay
FROM booking_staging
GROUP BY room_id;
```

> PostgreSQL may split the aggregation across workers to **speed up the insert**.

Step 5: Verify Results

```
SELECT * FROM booking_aggregated
ORDER BY room_id
LIMIT 10;
```

✅ Check that counts and averages match expectations.

Step 6: Compare Serial vs Parallel Performance

- Use `EXPLAIN ANALYZE` to compare **execution time**, **loops**, and **parallel workers**.
- Document the **improvement in runtime** — usually parallel execution is **faster for large tables**.

Step 7: Explanation

In this task, we simulated **parallel ETL and aggregation** in PostgreSQL:

- A large staging table is created to represent data loaded from multiple branches.
- Serial aggregation is compared to **parallel aggregation**, showing improved performance.
- This demonstrates **PostgreSQL parallel query capabilities** for distributed or large-scale data processing.

Question 8 – Three-Tier Client–Server Architecture

Task Description

Draw and explain a **three-tier architecture** for your project (Presentation, Application, Database).
Show **data flow** and **interaction with database links**.

Step 1: Identify the Three Tiers

1. **Presentation Tier (Client Layer)**
    - User interface — web browser, desktop app, or mobile app
    - Example: Staff booking system UI, manager dashboard
2. **Application Tier (Business Logic Layer)**
    - Handles **business rules**, validation, and distributed logic
    - Example: Python/Java server, Node.js backend, or PL/pgSQL procedures
    - Responsible for orchestrating **2PC**, concurrency control, and data aggregation
3. **Database Tier (Data Layer)**
    - Stores all hotel data in two databases:
        - `kigali_hotel_db` (Branch A)
        - `rubavu_hotel_db` (Branch B)
    - Handles **dblink connections**, parallel queries, and 2PC transactions

---

Step 2: Data Flow Description

1. **Client request:**
    - User submits a booking or retrieves reports from the UI
2. **Application processing:**

- Backend checks business logic (availability, validation)
- If distributed, initiates **2PC** via SQL + dblink
- Handles parallel aggregation for reports

3. **Database interaction:**
   - Queries local tables in Kigali or remote tables in Rubavu via dblink
   - Uses locks to maintain **concurrency control**
   - Commits or rollbacks transactions as needed
4. **Response back to client:**
   - Aggregated results, booking confirmation, or error messages

---

Step 3: Diagram (ASCII / Text Version)

```
+------------------------+
|   Presentation Tier    |
|  (Web / Desktop App)   |
+-----------+------------+
            |
            v
+------------------------+
|   Application Tier     |
|  (Backend Server)      |
| - Business Logic       |
| - 2PC Coordinator      |
| - Parallel ETL / Queries|
+-----------+------------+
            |
            v
+------------------------+       +------------------------+
| Database Tier          |       | Database Tier          |
| Kigali_Hotel_DB        |<----->| Rubavu_Hotel_DB       |
| - Local Booking Table  |       | - Remote Booking Table |
```

```
| - pg_prepared_xacts    |        | - pg_prepared_xacts    |
+------------------------+        +------------------------+
```

Legend:

- `<----->` = dblink connection between databases
- Application tier coordinates **distributed transactions** and handles **concurrency, 2PC, and parallel queries**

Step 4: Explanation

This architecture separates concerns:

- **Presentation tier**: interacts with users and displays data.
- **Application tier**: handles business logic, validation, and distributed coordination (2PC, ETL, concurrency).
- **Database tier**: manages persistent storage, local and remote transactions, and ensures **atomicity** and **consistency**.

Using **database links** allows the application to **query multiple branches as one logical system** while keeping data physically distributed.

Question 9 – Distributed Query Optimization

Task Description

Use **EXPLAIN PLAN** to analyze a **distributed join** between `kigali_hotel_db` and `rubavu_hotel_db`.
Discuss how the **optimizer strategy** works and how **data movement is minimized**.

Step 1: Set Up a Distributed Join Example

Suppose you want a **list of guests who have bookings in both branches**.

```
-- Kigali local table: booking
-- Rubavu remote table via dblink: booking

SELECT k.guest_id, k.room_id AS kigali_room, r.room_id AS rubavu_room
FROM booking k
JOIN dblink('rubavu_link',
            'SELECT guest_id, room_id FROM booking')
AS r(guest_id INT, room_id INT)
ON k.guest_id = r.guest_id;
```

✅ This is a **distributed join** between a local table (`booking`) and a remote table (`booking` via dblink).

Step 2: Analyze Query with EXPLAIN

```
EXPLAIN
SELECT k.guest_id, k.room_id AS kigali_room, r.room_id AS rubavu_room
FROM booking k
JOIN dblink('rubavu_link',
            'SELECT guest_id, room_id FROM booking')
AS r(guest_id INT, room_id INT)
ON k.guest_id = r.guest_id;
```

Optional with timing:

```
EXPLAIN ANALYZE
SELECT k.guest_id, k.room_id AS kigali_room, r.room_id AS rubavu_room
FROM booking k
JOIN dblink('rubavu_link',
            'SELECT guest_id, room_id FROM booking')
AS r(guest_id INT, room_id INT)
ON k.guest_id = r.guest_id;
```

✅ You'll see:

- `Foreign Scan` – fetching rows from Rubavu via dblink
- `Hash Join` or `Merge Join` – joining local and remote rows
- Estimated and actual rows, loops, and cost

Step 3: Optimizer Strategy

1. **Remote Filtering:**
    - Postgres can **push WHERE conditions to remote database** (via dblink query).
    - Minimizes rows transferred over the network.
2. **Join Method:**
    - **Hash Join** is typical for medium-sized datasets
    - **Merge Join** is better for sorted data
3. **Data Movement:**
    - Only required columns and rows are fetched via dblink
    - Avoids pulling entire tables unnecessarily

Step 4: Tips for Optimizing Distributed Queries

- Select only necessary **columns** (`SELECT guest_id, room_id`)
- Filter rows early (`WHERE status='Confirmed'`)
- Use **indexes** on join columns (`guest_id`)

- Consider **materialized views** if joins are repeated often
- Enable **parallel execution** for local aggregation after join

---

Step 5: Example of Optimized Distributed Query

```
EXPLAIN ANALYZE
SELECT k.guest_id, k.room_id AS kigali_room, r.room_id AS rubavu_room
FROM booking k
JOIN dblink('rubavu_link',
            'SELECT guest_id, room_id FROM booking WHERE status =
''Confirmed''')
AS r(guest_id INT, room_id INT)
ON k.guest_id = r.guest_id;
```

By **filtering remote rows first**, the optimizer **reduces network data transfer**, improving performance.

Step 6: Explanation

Distributed query optimization in PostgreSQL involves:

- **Minimizing network transfer** by filtering and selecting only necessary columns
- **Choosing efficient join methods** (hash, merge)
- Using **EXPLAIN ANALYZE** to measure actual runtime and costs
- Combining with **parallel execution** for large local tables

This ensures that queries across branches (Kigali ↔ Rubavu) are both **correct** and **efficient**.

Question 10 – Performance Benchmark and Report

Task Description

Run a **complex query** three ways:

1. Centralized (single branch)
2. Parallel query
3. Distributed (Kigali ↔ Rubavu via dblink)

Measure **execution time**, **I/O**, and **cost** using `EXPLAIN ANALYZE` or `AUTOTRACE`.
Summarize performance improvements.

Step 1: Prepare a Complex Query

Example: **Booking summary per room with guest count and average stay**

```
-- Centralized query on Kigali only
EXPLAIN ANALYZE
SELECT room_id,
       COUNT(*) AS total_bookings,
       AVG(checkout_date - checkin_date) AS avg_stay
FROM booking
GROUP BY room_id;
```

✅ This is your **baseline centralized execution**.

Step 2: Parallel Query (Local)

```
-- Parallel aggregation using multiple workers
EXPLAIN ANALYZE
SELECT /*+ PARALLEL(booking, 8) */
```

```
        room_id,
        COUNT(*) AS total_bookings,
        AVG(checkout_date - checkin_date) AS avg_stay
FROM booking
GROUP BY room_id;
```

✅ Observe **reduced execution time** and parallel workers in the plan.

Step 3: Distributed Query Across Branches

```
-- Distributed join/aggregation across Kigali and Rubavu
EXPLAIN ANALYZE
SELECT room_id, SUM(total_bookings) AS total_bookings, AVG(avg_stay)
AS avg_stay
FROM (
    -- Kigali
    SELECT room_id, COUNT(*) AS total_bookings, AVG(checkout_date -
checkin_date) AS avg_stay
    FROM booking
    GROUP BY room_id

    UNION ALL

    -- Rubavu via dblink
    SELECT room_id, COUNT(*) AS total_bookings, AVG(checkout_date -
checkin_date) AS avg_stay
    FROM dblink('rubavu_link',
                'SELECT room_id, checkin_date, checkout_date FROM
booking')
    AS r(room_id INT, checkin_date DATE, checkout_date DATE)
    GROUP BY room_id
) AS combined
GROUP BY room_id;
```

✅ This simulates **distributed aggregation** across both branches.

Step 4: Compare Execution

Execution Type	Notes / Observations
Centralized	Single branch, slower for large tables
Parallel	Multiple workers reduce CPU time and wall-clock time
Distributed	Adds network overhead, but scales across branches; optimizing with filters reduces data movement

Use **EXPLAIN ANALYZE** output to report:

- Total execution time
- Number of rows processed
- Loops and workers used

Step 5: Optional I/O Stats

If you want to capture **I/O**, enable **track_io_timing**:

```
-- Enable IO timing
SET track_io_timing = on;

-- Run query
EXPLAIN (ANALYZE, BUFFERS)
SELECT room_id, COUNT(*), AVG(checkout_date - checkin_date)
FROM booking
GROUP BY room_id;
```

Buffers and I/O info will show how many blocks were read/written, helping compare efficiency.

Step 6: Summary Report

1. **Centralized**: simplest, good for small tables, slower for large data.
2. **Parallel**: faster for large local datasets; uses multiple CPU workers.
3. **Distributed**: handles multiple branches; network transfer is key bottleneck; filters and projections reduce cost.

Recommendation: **use parallel for large local operations, distributed with proper filters for multi-branch operations**.

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