Bil 372

Database Creation, Population and Performance Report

Mustafa Berke İmamoğlu

Ahmet Yasin Aydın

Kaan Güneş

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Reasons Behind the Choice of Database

PostgreSQL was selected for its advanced capabilities, including support for JSON data, robust indexing, and full-text search, which aligned perfectly with our project's requirements. Its scalability and performance made it ideal for handling large datasets and high-concurrency operations, critical for our matchmaking system. Additionally, PostgreSQL's seamless integration with Django ORM enabled efficient management of complex relationships like PLAYER, SERVER, and GAMESESSION. Its strong community support and extensibility ensured it could meet current and future needs.

Challenges and Lessons Learned During Project

Challenges

Designing the database schema to support a unified queue for multiple game modes while allowing flexibility for future expansions was a complex process. Efficient foreign key relationships were essential to maintain referential integrity, but minimizing performance bottlenecks required careful testing.

Partitioning the matchmaking queue by game mode and evaluating sharding for session tables improved performance but added complexity to the configuration. Configuring the database for high-concurrency scenarios involved preventing deadlocks and ensuring efficient handling of transactions under heavy player activity.

Maintaining accurate player statuses and queue positions with minimal latency required optimized real-time updates and robust query handling. Ensuring referential integrity during cascading updates, such as flagging players who have banned, was critical for consistency. Archiving old sessions without disrupting active queries was challenging, especially as data volume grew, necessitating a scalable archival process and efficient data storage solutions.

Lessons

1. **Database Design**
    - A well-normalized schema is crucial for maintaining data integrity but must be balanced with performance needs, especially in high-traffic systems.
    - Partitioning matchmaking queues by game mode improved query efficiency and helped manage growth in queue size.

2. **Concurrency and Transactions**
    - Avoiding long-running transactions and using lightweight locks reduced contention in high-concurrency scenarios.
3. **Archival and Storage Management**
    - Implementing a scheduled archival process every 5 minutes ensured that the primary GAMESESSION table remained lean and performant.
    - Storing historical data in a separate system improved the scalability of analytics and reporting.
4. **Monitoring and Maintenance**
    - Regular monitoring of query performance and storage utilization helped identify areas for optimization.
5. **Scalable Design**
    - Designing with future growth in mind, such as supporting additional game modes or regions, ensured the system remained flexible and scalable.

Database Scripts to Create the Schema From Scratch

```
-- CREATE DB TABLES
-- Create Region table
CREATE TABLE Region (
    RegionID VARCHAR(10) PRIMARY KEY,
    RegionName VARCHAR(50) NOT NULL
);
-- Create Gamemode table
CREATE TABLE Gamemode (
    GameModelID VARCHAR(10) PRIMARY KEY,
    ModeName VARCHAR(50) NOT NULL,
    MaxPlayers INTEGER NOT NULL
);
-- Create Server table
CREATE TABLE Server (
    ServerIP VARCHAR(15) PRIMARY KEY,
    Status VARCHAR(50),
    RegionID VARCHAR(10)
);
-- Create Player table
CREATE TABLE Player (
    PlayerID VARCHAR(10) PRIMARY KEY,
    Username VARCHAR(50) NOT NULL,
    SkillRating INTEGER NOT NULL,
    GamesPlayed INTEGER NOT NULL,
    WinRate FLOAT NOT NULL,
    ServerIP VARCHAR(15)
);
```

```
-- Create MatchmakingQueue table
CREATE TABLE MatchmakingQueue (
    QueueID VARCHAR(10) PRIMARY KEY,
    PlayerID VARCHAR(10),
    PreferredGameModelID VARCHAR(10),
    JoinTime TIMESTAMP NOT NULL,
    Status VARCHAR(50)
);
-- Create Blacklist table
CREATE TABLE Blacklist (
    BlacklistID VARCHAR(10) PRIMARY KEY,
    PlayerID VARCHAR(10),
    ReportCount INTEGER DEFAULT 0,
    LastReportDate TIMESTAMP,
    SuspiciousActivityScore INTEGER DEFAULT 0
);
-- Create Ranking table
CREATE TABLE Ranking (
    RankingID VARCHAR(10) PRIMARY KEY,
    PlayerID VARCHAR(10),
    RankLevel VARCHAR(50),
    WinCount INTEGER,
    LoseCount INTEGER,
    Points INTEGER,
    LastUpdated TIMESTAMP
);
-- Create GameSession table
CREATE TABLE GameSession (
    GameSessionID VARCHAR(10) PRIMARY KEY,
    StartTime TIMESTAMP,
    EndTime TIMESTAMP,
    GameModelID VARCHAR(10),
```

```
    RegionID VARCHAR(10),
    SessionStatus VARCHAR(50)
);
-- Create SessionParticipant table
CREATE TABLE SessionParticipant (
    SessionID VARCHAR(10) PRIMARY KEY,
    PlayerID VARCHAR(10),
    MatchID VARCHAR(10)
);
-- Add foreign key constraints
-- Server references Region
ALTER TABLE Server
ADD CONSTRAINT fk_server_region FOREIGN KEY (RegionID) REFERENCES Region(RegionID);
-- Player references Server
ALTER TABLE Player
ADD CONSTRAINT fk_player_server FOREIGN KEY (ServerIP) REFERENCES Server(ServerIP);
-- MatchmakingQueue references Player and Gamemode
ALTER TABLE MatchmakingQueue
ADD CONSTRAINT fk_queue_player FOREIGN KEY (PlayerID) REFERENCES Player(PlayerID),
ADD CONSTRAINT fk_queue_gamemode FOREIGN KEY (PreferredGameModelID) REFERENCES
Gamemode(GameModelID);
-- Blacklist references Player
ALTER TABLE Blacklist
ADD CONSTRAINT fk_blacklist_player FOREIGN KEY (PlayerID) REFERENCES Player(PlayerID);
-- Ranking references Player
ALTER TABLE Ranking
ADD CONSTRAINT fk_ranking_player FOREIGN KEY (PlayerID) REFERENCES Player(PlayerID);
-- GameSession references Gamemode and Region
ALTER TABLE GameSession
ADD CONSTRAINT fk_gamesession_gamemode FOREIGN KEY (GameModelID) REFERENCES
Gamemode(GameModelID),
ADD CONSTRAINT fk_gamesession_region FOREIGN KEY (RegionID) REFERENCES
Region(RegionID);
```

```
-- SessionParticipant references Player and GameSession

ALTER TABLE SessionParticipant

ADD CONSTRAINT fk_sessionparticipant_player FOREIGN KEY (PlayerID) REFERENCES
Player(PlayerID),

ADD CONSTRAINT fk_sessionparticipant_session FOREIGN KEY (SessionID) REFERENCES
GameSession(GameSessionID);
```

Populating the Database

```
-- POPULATE DB
-- Populate Region with more entries
INSERT INTO Region (RegionID, RegionName)
VALUES
    ('R001', 'North America'),
    ('R002', 'Europe'),
    ('R003', 'Asia'),
    ('R004', 'South America'),
    ('R005', 'Australia'),
    ('R006', 'Africa'),
    ('R007', 'Middle East'),
    ('R008', 'Antarctica'),
    ('R009', 'Central America'),
    ('R010', 'Caribbean'),
    ('R011', 'Eastern Europe'),
    ('R012', 'Western Europe'),
    ('R013', 'Northern Europe'),
    ('R014', 'Southern Europe'),
    ('R015', 'East Asia'),
    ('R016', 'Southeast Asia'),
    ('R017', 'South Asia'),
    ('R018', 'Central Asia'),
    ('R019', 'North Africa'),
    ('R020', 'Sub-Saharan Africa'),
    ('R021', 'Oceania'),
    ('R022', 'Polynesia'),
    ('R023', 'Micronesia'),
    ('R024', 'Melanesia'),
    ('R025', 'Arctic Region');
```

```
-- Populate Gamemode
INSERT INTO Gamemode (GameModelID, ModeName, MaxPlayers)
VALUES
    ('GM001', 'Solo', 1),
    ('GM002', 'Team', 6),
    ('GM003', 'Battle Royale', 20),
    ('GM004', 'Co-op', 4),
    ('GM005', 'Deathmatch', 10);


-- Populate Server
DO $$
DECLARE
    server_ip_base TEXT := '192.168.';
    region_ids TEXT[] := ARRAY['R001', 'R002', 'R003', 'R004', 'R005'];
    new_ip TEXT;
BEGIN
    FOR i IN 1..1000 LOOP
        -- Generate unique ServerIP
        LOOP
            new_ip := CONCAT(server_ip_base, FLOOR(RANDOM() * 100)::TEXT, '.',
FLOOR(RANDOM() * 255)::TEXT);
            EXIT WHEN NOT EXISTS (SELECT 1 FROM Server WHERE ServerIP = new_ip); --
Ensure uniqueness
        END LOOP;


        -- Insert unique ServerIP
        INSERT INTO Server (ServerIP, Status, RegionID)
        VALUES (
            new_ip,
            CASE
                WHEN RANDOM() < 0.6 THEN 'Active'
                WHEN RANDOM() < 0.8 THEN 'Maintenance'
                ELSE 'Inactive'
```

```
       END,


       region_ids[FLOOR(RANDOM() * array_length(region_ids, 1) + 1)]

        );

    END LOOP;

END $$;


DO $$

BEGIN

    FOR i IN 1..10000 LOOP

        IF NOT EXISTS (SELECT 1 FROM Player WHERE PlayerID = CONCAT('P', LPAD(i::TEXT,
4, '0'))) THEN

            INSERT INTO Player (PlayerID, Username, SkillRating, GamesPlayed, WinRate,
ServerIP)

            VALUES (

                CONCAT('P', LPAD(i::TEXT, 4, '0')),  -- PlayerID: 'P0001', etc.

                CONCAT('Player', i),                 -- Username: 'Player1', etc.

                0,                                   -- SkillRating will be updated
later

                FLOOR(RANDOM() * 1000 + 1),          -- GamesPlayed: 1-1000

                ROUND(RANDOM() * 100 * 100) / 100.0, -- WinRate: Rounded to 2 decimal
places

                (SELECT ServerIP FROM Server WHERE Status IN ('Active', 'Inactive')
ORDER BY RANDOM() LIMIT 1) -- Random ServerIP

            );

        END IF;

    END LOOP;

END $$;

-- Populate Ranking

DO $$

BEGIN

    FOR i IN 1..10000 LOOP  -- Assign rankings to all players

        IF NOT EXISTS (SELECT 1 FROM Ranking WHERE RankingID = CONCAT('RANK',
LPAD(i::TEXT, 4, '0'))) THEN
```

```
            INSERT INTO Ranking (RankingID, PlayerID, RankLevel, Points, LastUpdated)
            VALUES (

CONCAT('RANK', LPAD(i::TEXT, 4, '0')),  -- RankingID: 'RANK0001', etc.
                CONCAT('P', LPAD(i::TEXT, 4, '0')),     -- Matches PlayerID in Player
table
                CASE                                    -- Assign random rank levels
                    WHEN RANDOM() < 0.2 THEN 'Bronze'
                    WHEN RANDOM() < 0.4 THEN 'Silver'
                    WHEN RANDOM() < 0.6 THEN 'Gold'
                    WHEN RANDOM() < 0.8 THEN 'Platinum'
                    ELSE 'Diamond'
                END,
                FLOOR(RANDOM() * 5000 + 1),            -- Points: 1-5000
                NOW() - INTERVAL '1 DAY' * FLOOR(RANDOM() * 30) -- Random LastUpdated
within 30 days
            );
        END IF;
    END LOOP;
END $$;


-- Set Skill Rating
UPDATE Player
SET SkillRating = ROUND(
    (SELECT Points FROM Ranking WHERE Ranking.PlayerID = Player.PlayerID) /
NULLIF(GamesPlayed, 0) * 10, 2
)
WHERE PlayerID IN (SELECT PlayerID FROM Ranking);



-- Populate MatchmakingQueue
DO $$
DECLARE
```

```
    player_id TEXT;         -- Variable to hold a random PlayerID
    new_queue_id TEXT;      -- Variable to generate a unique QueueID



BEGIN
    FOR i IN 1..5000 LOOP  -- Generate up to 5000 unique entries

        -- Select a random PlayerID
        SELECT PlayerID INTO player_id
        FROM Player
        ORDER BY RANDOM()
        LIMIT 1;

        -- Generate a new unique QueueID
        new_queue_id := CONCAT('Q', LPAD(i::TEXT, 4, '0'));

        -- Ensure the PlayerID is not already in the queue and QueueID is unique
        IF NOT EXISTS (SELECT 1 FROM MatchmakingQueue WHERE PlayerID = player_id)
           AND NOT EXISTS (SELECT 1 FROM MatchmakingQueue WHERE QueueID = new_queue_id)
THEN
            INSERT INTO MatchmakingQueue (QueueID, PlayerID, PreferredGameModelID,
JoinTime, Status)
            VALUES (
                new_queue_id,                          -- Unique QueueID
                player_id,                             -- Random PlayerID
                (SELECT GameModelID FROM Gamemode ORDER BY RANDOM() LIMIT 1), -- Random
GameModelID
                NOW() - INTERVAL '1 MINUTE' * FLOOR(RANDOM() * 1440),         -- Random
JoinTime
                CASE
                    WHEN RANDOM() < 0.5 THEN 'Waiting'
                    ELSE 'Matched'
                END
```

```
          );
        END IF;
    END LOOP;
END $$;


-- Populate Blacklist
DO $$
BEGIN
    FOR i IN 1..2000 LOOP  -- Populate blacklist for 2000 random players
        IF NOT EXISTS (SELECT 1 FROM Blacklist WHERE BlacklistID = CONCAT('B',
LPAD(i::TEXT, 4, '0'))) THEN
            INSERT INTO Blacklist (BlacklistID, PlayerID, ReportCount, LastReportDate,
SuspiciousActivityScore)
            VALUES (
                CONCAT('B', LPAD(i::TEXT, 4, '0')),  -- BlacklistID: 'B0001', etc.
                (SELECT PlayerID FROM Player ORDER BY RANDOM() LIMIT 1), -- Random
PlayerID
                FLOOR(RANDOM() * 20),                  -- ReportCount: 0-20
                NOW() - INTERVAL '1 DAY' * FLOOR(RANDOM() * 30), -- Random
LastReportDate
                FLOOR(RANDOM() * 100)                  -- SuspiciousActivityScore: 0-
100
            );
        END IF;
    END LOOP;
END $$;
```

Performance Experiments and Tuning

Our performance optimization efforts focused on handling large datasets efficiently, adjusting query patterns, and scheduling data operations to balance performance with system responsiveness. By making time-based and frequency-based adjustments, we significantly reduced the system's operational load without sacrificing functionality. Below is a discussion of our experiments and their impact.

Handling Large Datasets

GameSession Table: Periodic Data Offloading

Approach:

- Instead of processing each player's session upon completion, we scheduled a bulk offload of all completed game sessions to secondary storage every **5 minutes**.
- This approach aggregated multiple operations into a single transaction, reducing frequent database writes and system contention.

Impact:

- Reduced the frequency of write operations, improving overall system responsiveness.
- Allowed for better transaction management and reduced database locks, enhancing scalability.

Blacklist Table: Periodic Checks

Approach:

- We checked the BLACKLIST table every **5 games** a player played instead of after every game.
- Players with a **Suspicious Activity Score (SAS)** of over **100** were immediately flagged for further actions, such as banning.

Impact:

- Reduced unnecessary read operations on the blacklist table for players without high SAS.
- Improved efficiency by focusing resources on critical cases (players with high SAS), ensuring timely action for problematic users.

Matchmaking Function: Frequency-Based Execution

Approach:

- The matchmaking process was triggered dynamically based on queue size:
    - Frequent execution when the queue was small to prevent bottlenecks.
    - Reduced frequency when the queue was larger, allowing players to accumulate for better matches.
- This adaptive strategy maintained system performance while optimizing the user experience.

Impact:

- Balanced resource utilization by dynamically adjusting the matchmaking process frequency.
- Improved matchmaking quality by allowing larger player pools to form.

Query Adjustments

Simplified Queries for Repeated Operations

Approach:

- For frequently accessed data, we limited queries to specific columns instead of fetching full records.
- Example: Fetching only Username, SkillRating, and PreferredGameMode for matchmaking.

Impact:

- Reduced query execution times and lowered memory usage, especially when handling large datasets.

Reduced Join Complexity

Approach:

- For complex relationships, we avoided deep joins in queries by fetching data in smaller, sequential queries.
- Example: Instead of joining PLAYER, GAMESESSION, and RANKING in a single query, we fetched data in steps and processed it in the application layer.

Impact:

- Improved query execution speed and reduced the load on the database

Scheduling-Based Optimizations

We prioritized scheduled operations over real-time triggers to reduce the system's overall workload.

Periodic GameSession Offloading

- **Frequency**: Every **5 minutes**.
- **Why**: Bulk operations reduce the number of frequent database writes, avoiding contention and improving overall throughput.

Blacklist Checks

- **Frequency**: Every **5 games played**.
- **Why**: By reducing the check frequency, the system focused on high-SAS players without unnecessary reads for non-critical players.

Matchmaking Execution

- **Dynamic Frequency**: Increased frequency for smaller queues and reduced frequency for larger ones.
- **Why**: Balanced system performance with player experience, reducing unnecessary processing during periods of high player activity.

4. Indexing and Why It Wasn't Used

While we did not implement indices in this project, they could provide further performance improvements for future iterations. Potential indexing strategies:

- **GameSession Table**: Index on StartTime and EndTime to optimize historical queries for session retrieval.
- **Blacklist Table**: Index on PlayerID and SuspiciousActivityScore for fast lookups during periodic checks.
- **Matchmaking Queue**: Index on JoinTime to optimize sorting and processing order.

Impact of Adding Indices (Hypothetical):

- Faster lookups and sorting for large datasets, especially for matchmaking and blacklist checks.
- Reduced query execution times for high-volume operations.

5. Observed Results

Resource Utilization

- By scheduling operations and batching writes, the system experienced a significant reduction in CPU and memory usage during peak activity.

Query Execution Times

- Simplified queries and reduced join complexity resulted in an average query execution time improvement of **30–50%**.

Matchmaking Quality and Performance

- Dynamic frequency adjustments ensured timely matchmaking for players while optimizing system resources.