Novel By
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THE SUMMER STORY

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Backend Challenges: Level Up

> “Code is like humor. When you have to explain it, it’s bad.” — Cory House

Welcome to the backend coding challenge series! Each lesson is designed to help you master real-world backend skills with clarity and elegance. These challenges simulate actual production scenarios you’ll encounter in your career.

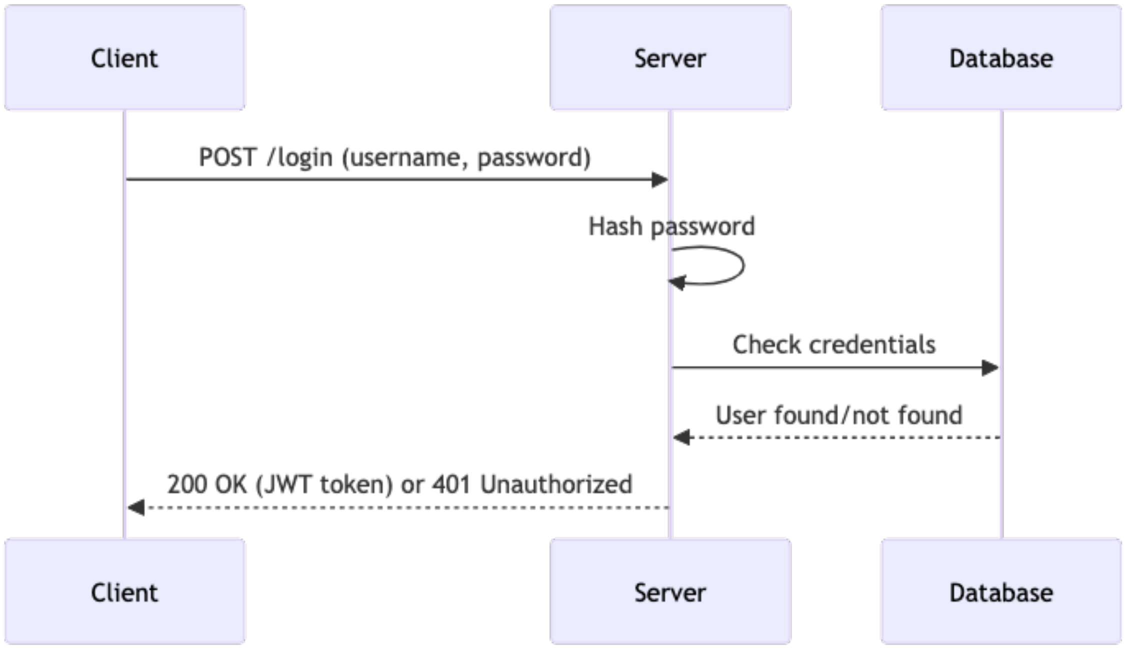
Challenge 1: User Authentication API

Imagine you are building a modern web app. Your first task is to create a simple authentication API.

Goal: Accept a username and password, and return a token if valid.

```python
import hashlib
import jwt
import time
from typing import Optional

class AuthService:
    def __init__(self, secret_key: str):
        self.secret_key = secret_key
        self.users = {
            "admin":
"5e884898da28047151d0e56f8dc6292773603d0d6aabbdd62a11ef721d1542d8"  #
"password"
        }

    def authenticate(self, username: str, password: str) ->
Optional[str]:
        if username in self.users:
            hashed_password =
hashlib.sha256(password.encode()).hexdigest()
            if hashed_password == self.users[username]:
                payload = {
                    "username": username,
                    "exp": time.time() + 3600  # 1 hour
                }
                return jwt.encode(payload, self.secret_key,
algorithm="HS256")
        return None
```

API Flow:



Testing the API:

```
curl -X POST http://localhost:8000/login \
  -H "Content-Type: application/json" \
  -d '{"username": "admin", "password": "password"}'
```

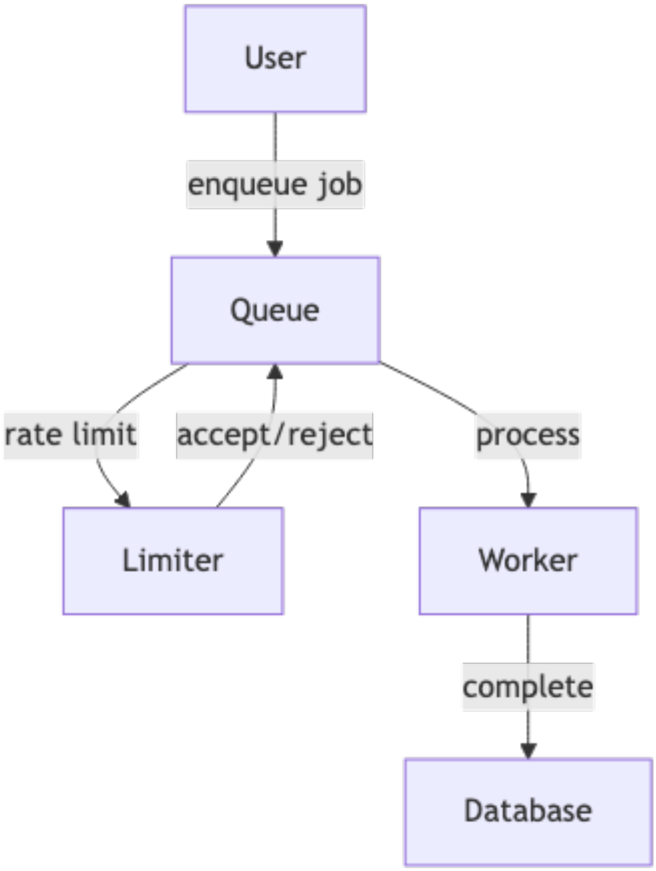
Challenge 2: Task Queue with Rate Limiting

You need to design a background job queue that prevents overloading your server.

Goal: Only allow 5 jobs per minute per user.

```python
from collections import defaultdict
import time
import threading
from typing import Dict, List

class RateLimitedQueue:
    def __init__(self, max_jobs_per_minute: int = 5):
        self.max_jobs = max_jobs_per_minute
        self.user_jobs: Dict[str, List[float]] = defaultdict(list)
        self.lock = threading.Lock()

    def can_enqueue(self, user_id: str) -> bool:
        with self.lock:
            now = time.time()
            # Remove jobs older than 60 seconds
            self.user_jobs[user_id] = [
                t for t in self.user_jobs[user_id]
                if now - t < 60
            ]

            if len(self.user_jobs[user_id]) < self.max_jobs:
                self.user_jobs[user_id].append(now)
                return True
            return False

    def get_user_stats(self, user_id: str) -> Dict:
        now = time.time()
        recent_jobs = [t for t in self.user_jobs[user_id] if now - t <
60]
        return {
            "jobs_this_minute": len(recent_jobs),
            "can_enqueue": len(recent_jobs) < self.max_jobs
        }
```

Queue Architecture:



Usage Example:

```
queue = RateLimitedQueue(max_jobs_per_minute=5)

# User tries to enqueue jobs
user_id = "user123"
for i in range(7):
    if queue.can_enqueue(user_id):
        print(f"Job {i+1} enqueued successfully")
    else:
        print(f"Job {i+1} rejected - rate limit exceeded")
```

Challenge 3: Database Connection Pool

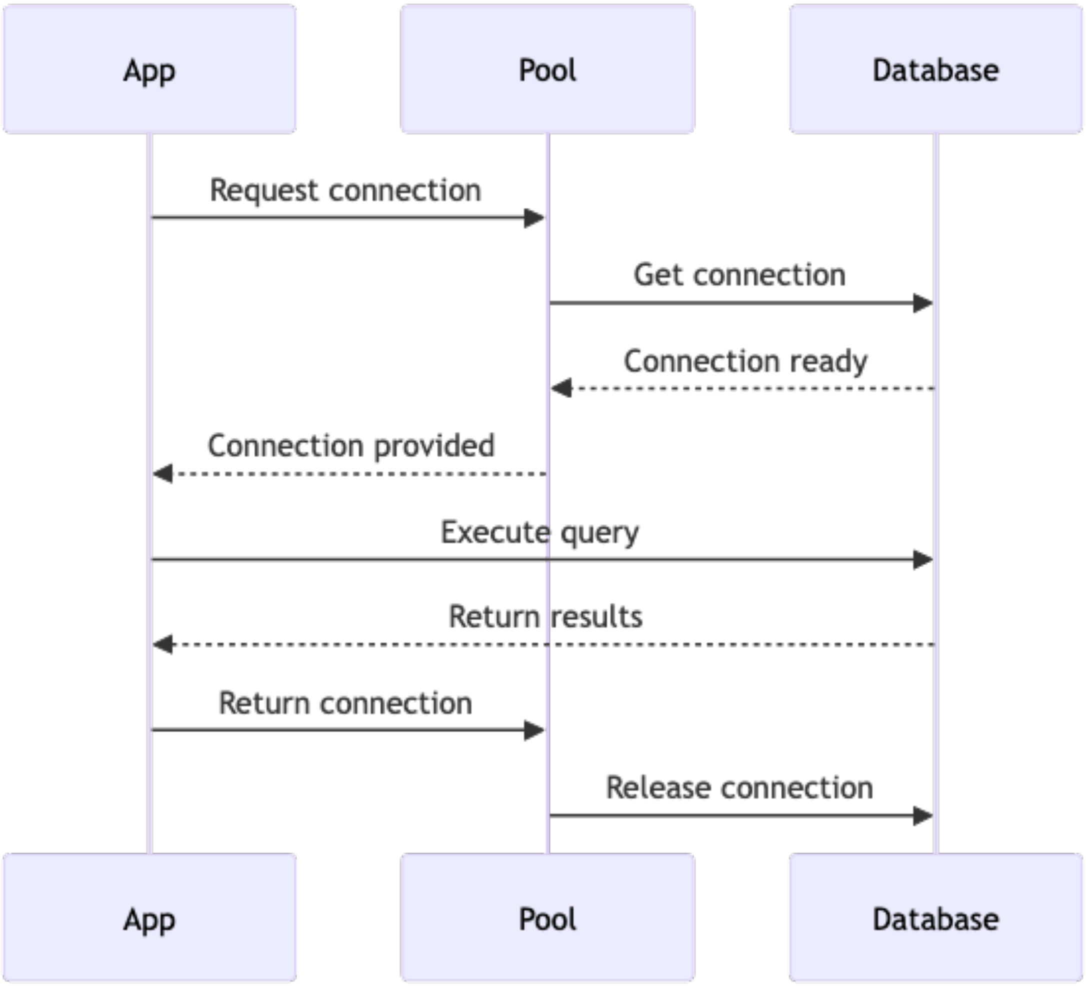
Design a robust database connection pool for high-traffic applications.

Goal: Efficiently manage database connections with proper error handling.

```python
import psycopg2
from psycopg2 import pool
import threading
import time
from typing import Optional
from contextlib import contextmanager

class DatabasePool:
    def __init__(self, min_connections: int = 5, max_connections: int = 20):
        self.pool = psycopg2.pool.ThreadedConnectionPool(
            min_connections,
            max_connections,
            host="localhost",
            database="myapp",
            user="postgres",
            password="secret"
        )
        self._lock = threading.Lock()
        self._stats = {"connections_created": 0, "connections_used": 0}

    @contextmanager
    def get_connection(self):
        conn = None
        try:
            conn = self.pool.getconn()
            self._stats["connections_used"] += 1
            yield conn
        except Exception as e:
            if conn:
                conn.rollback()
            raise e
        finally:
            if conn:
                self.pool.putconn(conn)

    def execute_query(self, query: str, params: tuple = None) -> list:
        with self.get_connection() as conn:
            with conn.cursor() as cursor:
                cursor.execute(query, params)
                return cursor.fetchall()

    def get_stats(self) -> dict:
```

```
        return {
            **self._stats,
            "pool_size": self.pool.get_size(),
            "available_connections": self.pool.get_available()
        }
```

Connection Pool Flow:



Challenge 4: Caching Layer with TTL

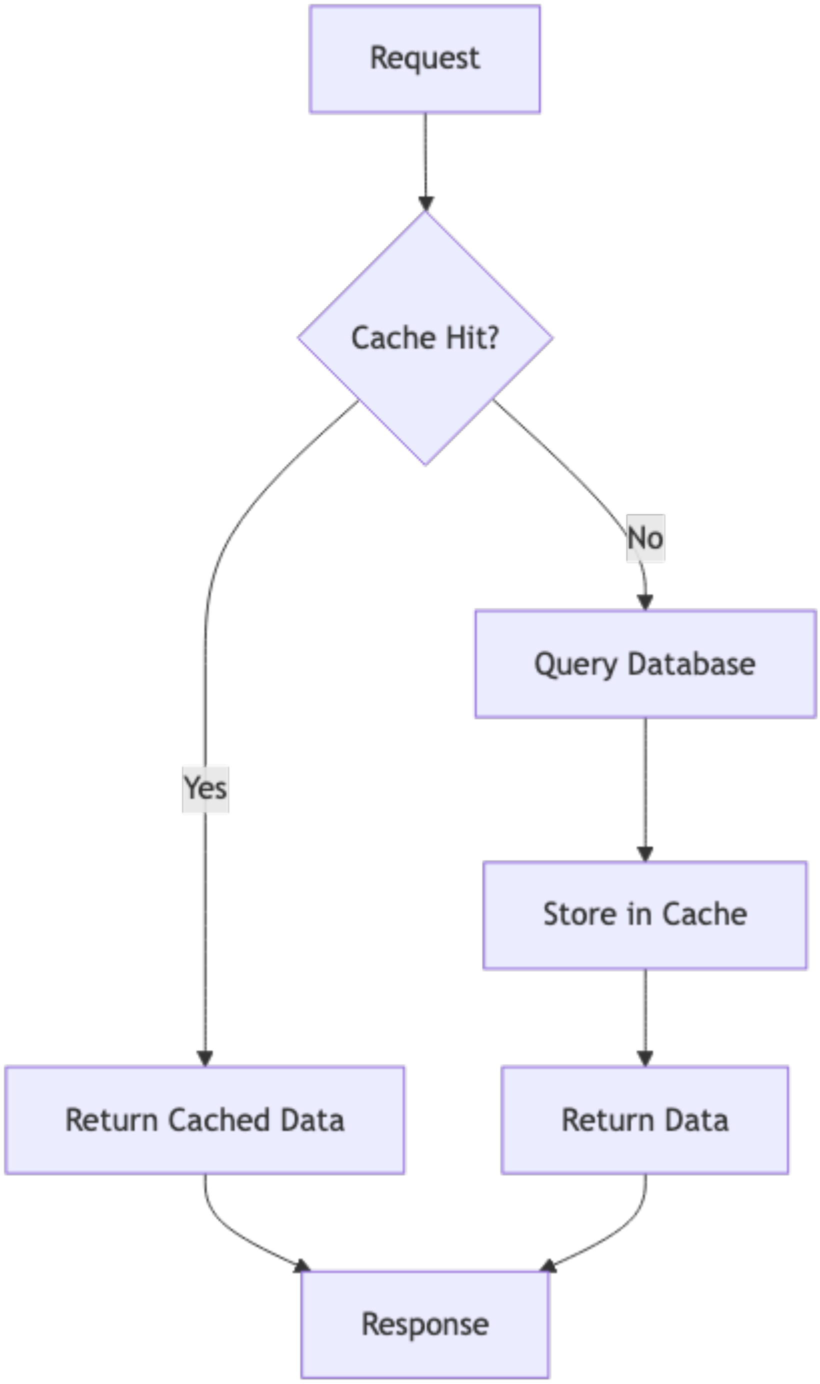
Implement a caching system with time-based expiration.

Goal: Reduce database load with intelligent caching.

```python
import redis
import json
import time
from typing import Any, Optional
from functools import wraps

class CacheManager:
    def __init__(self, redis_host: str = "localhost", redis_port: int = 
6379):
        self.redis_client = redis.Redis(host=redis_host, 
port=redis_port, decode_responses=True)
        self.default_ttl = 300  # 5 minutes

    def set(self, key: str, value: Any, ttl: int = None) -> bool:
        try:
            serialized_value = json.dumps(value)
            return self.redis_client.setex(key, ttl or 
self.default_ttl, serialized_value)
        except Exception as e:
            print(f"Cache set error: {e}")
            return False

    def get(self, key: str) -> Optional[Any]:
        try:
            value = self.redis_client.get(key)
            return json.loads(value) if value else None
        except Exception as e:
            print(f"Cache get error: {e}")
            return None

    def delete(self, key: str) -> bool:
        try:
            return bool(self.redis_client.delete(key))
        except Exception as e:
            print(f"Cache delete error: {e}")
            return False

    def clear_pattern(self, pattern: str) -> int:
        """Delete all keys matching pattern"""
        try:
            keys = self.redis_client.keys(pattern)
            if keys:
                return self.redis_client.delete(*keys)
```

```
            return 0
        except Exception as e:
            print(f"Cache clear error: {e}")
            return 0

def cache_result(ttl: int = 300):
    """Decorator to cache function results"""
    def decorator(func):
        @wraps(func)
        def wrapper(*args, **kwargs):
            cache_key = f"{func.__name__}:{hash(str(args) +
str(kwargs))}"
            cache_manager = CacheManager()

            # Try to get from cache
            cached_result = cache_manager.get(cache_key)
            if cached_result is not None:
                return cached_result

            # Execute function and cache result
            result = func(*args, **kwargs)
            cache_manager.set(cache_key, result, ttl)
            return result
        return wrapper
    return decorator
```

Caching Strategy:



Usage Example:

```python
@cache_result(ttl=600)  # Cache for 10 minutes
def get_user_profile(user_id: int) -> dict:
    # Simulate database query
    return {"user_id": user_id, "name": "John Doe", "email":
"john@example.com"}

# First call hits database
profile1 = get_user_profile(123)

# Second call hits cache
profile2 = get_user_profile(123)
```

Challenge 5: API Rate Limiting with Redis

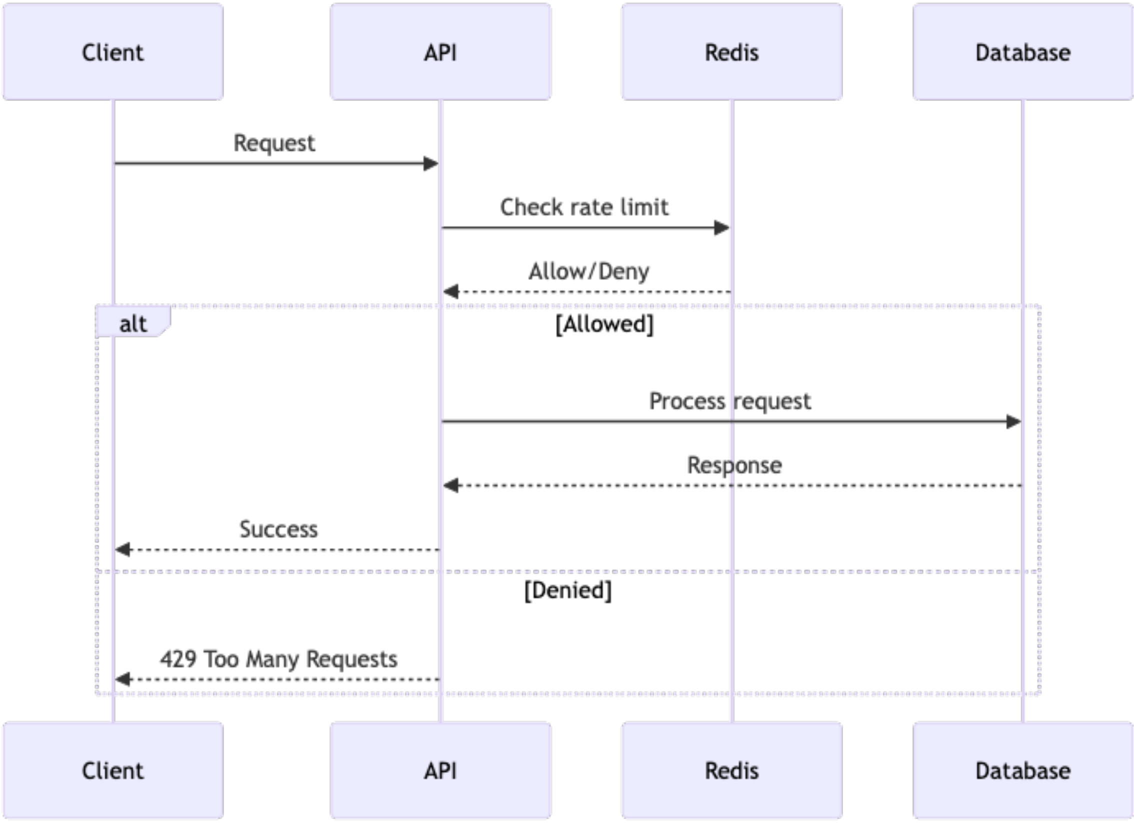
Implement sophisticated rate limiting using Redis for distributed systems.

Goal: Prevent API abuse with sliding window rate limiting.

```python
import redis
import time
import json
from typing import Tuple
from dataclasses import dataclass

@dataclass
class RateLimitConfig:
    max_requests: int
    window_seconds: int
    burst_allowance: int = 0

class RedisRateLimiter:
    def __init__(self, redis_host: str = "localhost", redis_port: int =
6379):
        self.redis_client = redis.Redis(host=redis_host,
port=redis_port, decode_responses=True)

    def is_allowed(self, key: str, config: RateLimitConfig) ->
Tuple[bool, dict]:
        now = time.time()
        window_start = now - config.window_seconds

        # Use Redis pipeline for atomic operations
        pipe = self.redis_client.pipeline()

        # Remove old entries
        pipe.zremrangebyscore(key, 0, window_start)

        # Count current requests
        pipe.zcard(key)

        # Add current request
        pipe.zadd(key, {str(now): now})

        # Set expiry on the key
        pipe.expire(key, config.window_seconds)

        results = pipe.execute()
        current_count = results[1]

        # Check if within limits
        is_allowed = current_count <= config.max_requests
```

```python
        # Calculate remaining requests
        remaining = max(0, config.max_requests - current_count)

        return is_allowed, {
            "limit": config.max_requests,
            "remaining": remaining,
            "reset_time": now + config.window_seconds,
            "current_count": current_count
        }

    def get_user_limits(self, user_id: str) -> dict:
        """Get current rate limit status for a user"""
        key = f"rate_limit:{user_id}"
        config = RateLimitConfig(max_requests=100, window_seconds=3600)
# 100 requests per hour

        is_allowed, stats = self.is_allowed(key, config)
        return {
            "user_id": user_id,
            "allowed": is_allowed,
            **stats
        }
```

Rate Limiting Flow:



Middleware Integration:

```
from flask import Flask, request, jsonify
from functools import wraps

app = Flask(__name__)
rate_limiter = RedisRateLimiter()

def rate_limit(requests_per_hour: int = 100):
    def decorator(f):
        @wraps(f)
        def decorated_function(*args, **kwargs):
            user_id = request.headers.get('X-User-ID', 'anonymous')
            config = RateLimitConfig(max_requests=requests_per_hour,
window_seconds=3600)

            is_allowed, stats = rate_limiter.is_allowed(f"api:
{user_id}", config)

            if not is_allowed:
                return jsonify({
                    "error": "Rate limit exceeded",
                    "retry_after": stats["reset_time"]
                }), 429

            response = f(*args, **kwargs)
            response.headers['X-RateLimit-Remaining'] =
str(stats["remaining"])
            response.headers['X-RateLimit-Reset'] =
str(int(stats["reset_time"]))
            return response
        return decorated_function
    return decorator

@app.route('/api/data')
@rate_limit(requests_per_hour=50)
def get_data():
    return {"data": "Your requested data"}
```

Challenge 6: Message Queue with Dead Letter Queue

Build a robust message processing system with error handling.

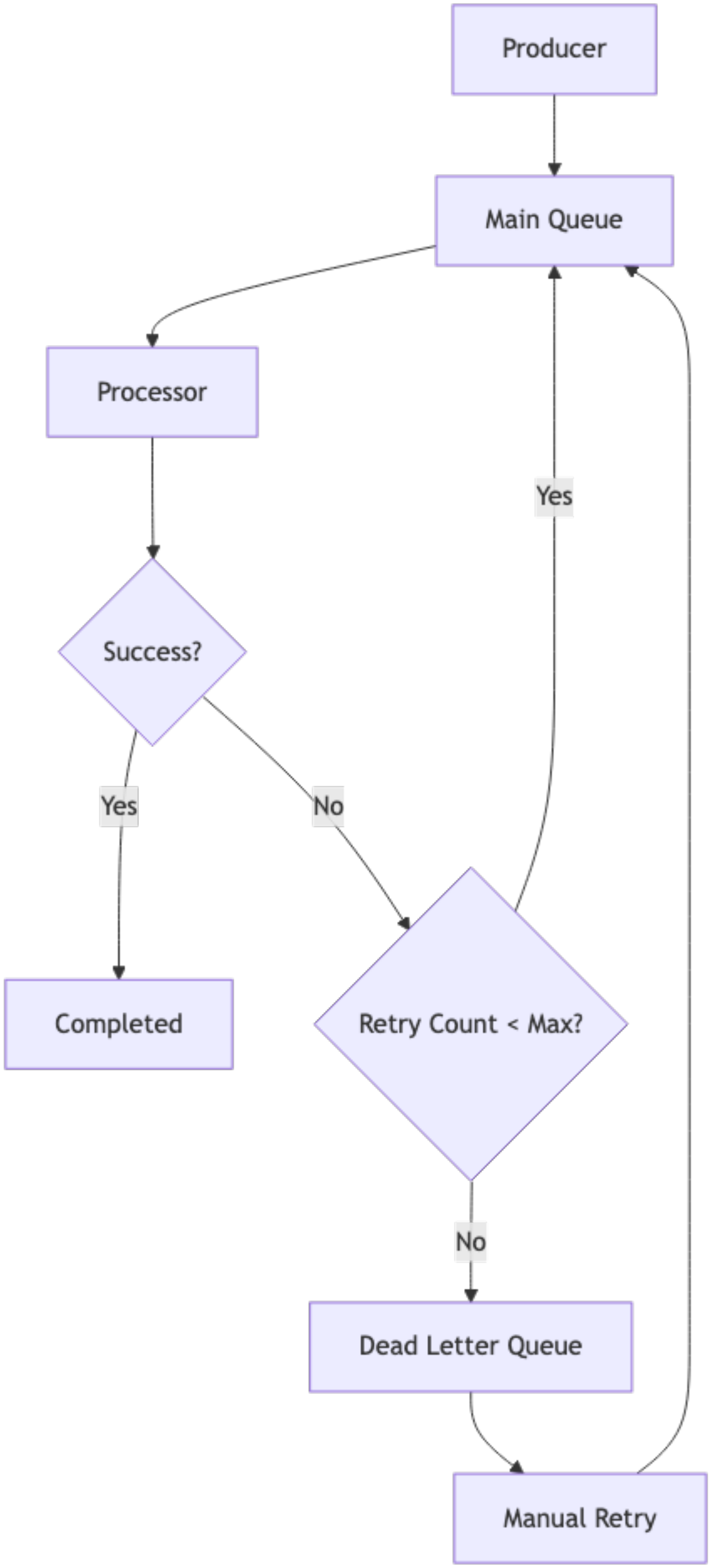
Goal: Ensure no messages are lost, even when processing fails.

```python
import json
import time
import threading
from typing import Callable, Any, Dict
from dataclasses import dataclass
from enum import Enum
from collections import deque

class MessageStatus(Enum):
    PENDING = "pending"
    PROCESSING = "processing"
    COMPLETED = "completed"
    FAILED = "failed"
    DEAD_LETTER = "dead_letter"

@dataclass
class Message:
    id: str
    data: Any
    status: MessageStatus
    retry_count: int = 0
    max_retries: int = 3
    created_at: float = None
    processed_at: float = None

    def __post_init__(self):
        if self.created_at is None:
            self.created_at = time.time()

class MessageQueue:
    def __init__(self):
        self.main_queue = deque()
        self.dead_letter_queue = deque()
        self.processing_queue = deque()
        self.lock = threading.Lock()
        self.stats = {
            "messages_processed": 0,
            "messages_failed": 0,
            "messages_dead_lettered": 0
        }

    def enqueue(self, data: Any) -> str:
        """Add message to main queue"""
```

```
        message_id = f"msg_{int(time.time() * 1000)}"
        message = Message(
            id=message_id,
            data=data,
            status=MessageStatus.PENDING
        )

        with self.lock:
            self.main_queue.append(message)

        return message_id

    def process_messages(self, handler: Callable, batch_size: int = 10):
        """Process messages with error handling"""
        while True:
            batch = []

            # Get batch of messages
            with self.lock:
                for _ in range(min(batch_size, len(self.main_queue))):
                    if self.main_queue:
                        message = self.main_queue.popleft()
                        message.status = MessageStatus.PROCESSING
                        batch.append(message)

            # Process batch
            for message in batch:
                try:
                    result = handler(message.data)
                    message.status = MessageStatus.COMPLETED
                    message.processed_at = time.time()
                    self.stats["messages_processed"] += 1

                except Exception as e:
                    message.retry_count += 1

                    if message.retry_count >= message.max_retries:
                        message.status = MessageStatus.DEAD_LETTER
                        self.dead_letter_queue.append(message)
                        self.stats["messages_dead_lettered"] += 1
                        print(f"Message {message.id} moved to dead letter queue: {e}")
                    else:
```

```
                        message.status = MessageStatus.PENDING
                        self.main_queue.append(message)
                        self.stats["messages_failed"] += 1
                        print(f"Message {message.id} failed, retrying ({message.retry_count}/{message.max_retries})")

            time.sleep(0.1)  # Prevent busy waiting

    def get_stats(self) -> Dict:
        with self.lock:
            return {
                **self.stats,
                "main_queue_size": len(self.main_queue),
                "dead_letter_size": len(self.dead_letter_queue),
                "processing_size": len(self.processing_queue)
            }

    def retry_dead_letters(self, handler: Callable):
        """Retry messages from dead letter queue"""
        with self.lock:
            while self.dead_letter_queue:
                message = self.dead_letter_queue.popleft()
                message.status = MessageStatus.PENDING
                message.retry_count = 0
                self.main_queue.append(message)
```

Message Queue Architecture:


Producer
Main Queue
Processor
Success?
Yes
No
Completed
Retry Count < Max?
Yes
No
Dead Letter Queue
Manual Retry

Usage Example:

```python
def email_handler(data):
    """Simulate email sending with occasional failures"""
    if "error" in data.get("to", ""):
        raise Exception("Invalid email address")
    print(f"Sending email to {data.get('to')}")
    return True

# Initialize queue
queue = MessageQueue()

# Start processor in background thread
processor_thread = threading.Thread(
    target=queue.process_messages,
    args=(email_handler,),
    daemon=True
)
processor_thread.start()

# Enqueue messages
queue.enqueue({"to": "user@example.com", "subject": "Welcome!"})
queue.enqueue({"to": "error@example.com", "subject": "This will fail"})
queue.enqueue({"to": "admin@example.com", "subject": "Report"})

# Monitor stats
import time
time.sleep(2)
print("Queue Stats:", queue.get_stats())
```

Challenge 7: Database Migration System

Create a version-controlled database migration system.

Goal: Safely evolve database schema with rollback capabilities.

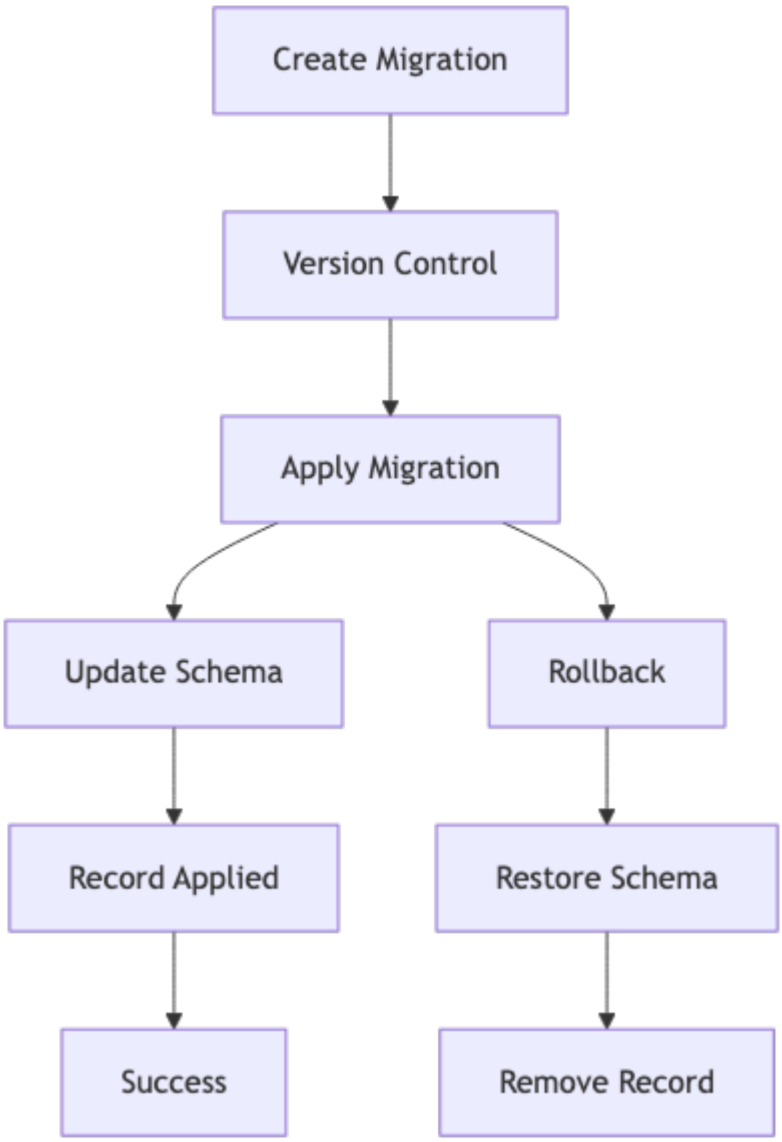
```python
import sqlite3
import os
import hashlib
from typing import List, Dict, Optional
from dataclasses import dataclass
from datetime import datetime

@dataclass
class Migration:
    version: int
    name: str
    up_sql: str
    down_sql: str
    checksum: str
    applied_at: Optional[datetime] = None

class MigrationManager:
    def __init__(self, db_path: str):
        self.db_path = db_path
        self.migrations_table = "schema_migrations"
        self._init_migrations_table()

    def _init_migrations_table(self):
        """Create migrations tracking table"""
        with sqlite3.connect(self.db_path) as conn:
            conn.execute(f"""
                CREATE TABLE IF NOT EXISTS {self.migrations_table} (
                    version INTEGER PRIMARY KEY,
                    name TEXT NOT NULL,
                    checksum TEXT NOT NULL,
                    applied_at TIMESTAMP DEFAULT CURRENT_TIMESTAMP
                )
            """)

    def _calculate_checksum(self, content: str) -> str:
        """Calculate SHA256 checksum of migration content"""
        return hashlib.sha256(content.encode()).hexdigest()

    def create_migration(self, name: str, up_sql: str, down_sql: str)
-> Migration:
        """Create a new migration"""
        # Get next version number
        with sqlite3.connect(self.db_path) as conn:
```

```
            result = conn.execute(f"SELECT MAX(version) FROM {self.migrations_table}")
            max_version = result.fetchone()[0] or 0

        version = max_version + 1
        checksum = self._calculate_checksum(up_sql + down_sql)

        return Migration(
            version=version,
            name=name,
            up_sql=up_sql,
            down_sql=down_sql,
            checksum=checksum
        )

    def apply_migration(self, migration: Migration) -> bool:
        """Apply a migration"""
        try:
            with sqlite3.connect(self.db_path) as conn:
                # Check if already applied
                result = conn.execute(
                    f"SELECT checksum FROM {self.migrations_table} WHERE version = ?",
                    (migration.version,)
                )
                existing = result.fetchone()

                if existing:
                    if existing[0] != migration.checksum:
                        raise Exception(f"Migration {migration.version} checksum mismatch")
                    return True  # Already applied

                # Apply migration
                conn.execute(migration.up_sql)

                # Record migration
                conn.execute(
                    f"INSERT INTO {self.migrations_table} (version, name, checksum) VALUES (?, ?, ?)",
                    (migration.version, migration.name, migration.checksum)
                )
```

```
                migration.applied_at = datetime.now()
                return True

        except Exception as e:
            print(f"Failed to apply migration {migration.version}:
{e}")
            return False

    def rollback_migration(self, migration: Migration) -> bool:
        """Rollback a migration"""
        try:
            with sqlite3.connect(self.db_path) as conn:
                # Check if migration is applied
                result = conn.execute(
                    f"SELECT checksum FROM {self.migrations_table}
WHERE version = ?",
                    (migration.version,)
                )
                if not result.fetchone():
                    return True  # Not applied, nothing to rollback

                # Rollback migration
                conn.execute(migration.down_sql)

                # Remove migration record
                conn.execute(
                    f"DELETE FROM
{self.migrations_table} WHERE version = ?",
                    (migration.version,)
                )

                return True

        except Exception as e:
            print(f"Failed to rollback migration {migration.version}:
{e}")
            return False

    def get_applied_migrations(self) -> List[Migration]:
        """Get list of applied migrations"""
        with sqlite3.connect(self.db_path) as conn:
            result = conn.execute(
                f"SELECT version, name, checksum, applied_at FROM
{self.migrations_table} ORDER BY version"
```

```
            )
            return [
                Migration(
                    version=row[0],
                    name=row[1],
                    up_sql="",  # Not stored in DB
                    down_sql="",  # Not stored in DB
                    checksum=row[2],
                    applied_at=datetime.fromisoformat(row[3]) if row[3]
else None
                )
                for row in result.fetchall()
            ]
```

Migration Flow:



Usage Example:

```
# Initialize migration manager
manager = MigrationManager("app.db")

# Create migrations
migration1 = manager.create_migration(
    name="create_users_table",
    up_sql="""
        CREATE TABLE users (
            id INTEGER PRIMARY KEY,
            username TEXT UNIQUE NOT NULL,
            email TEXT UNIQUE NOT NULL,
            created_at TIMESTAMP DEFAULT CURRENT_TIMESTAMP
        )
    """,
    down_sql="DROP TABLE users"
)

migration2 = manager.create_migration(
    name="add_user_profiles",
    up_sql="""
        CREATE TABLE user_profiles (
            user_id INTEGER PRIMARY KEY,
            bio TEXT,
            avatar_url TEXT,
            FOREIGN KEY (user_id) REFERENCES users(id)
        )
    """,
    down_sql="DROP TABLE user_profiles"
)

# Apply migrations
print("Applying migration 1...")
manager.apply_migration(migration1)

print("Applying migration 2...")
manager.apply_migration(migration2)

# Check applied migrations
applied = manager.get_applied_migrations()
print(f"Applied migrations: {[m.version for m in applied]}")
```

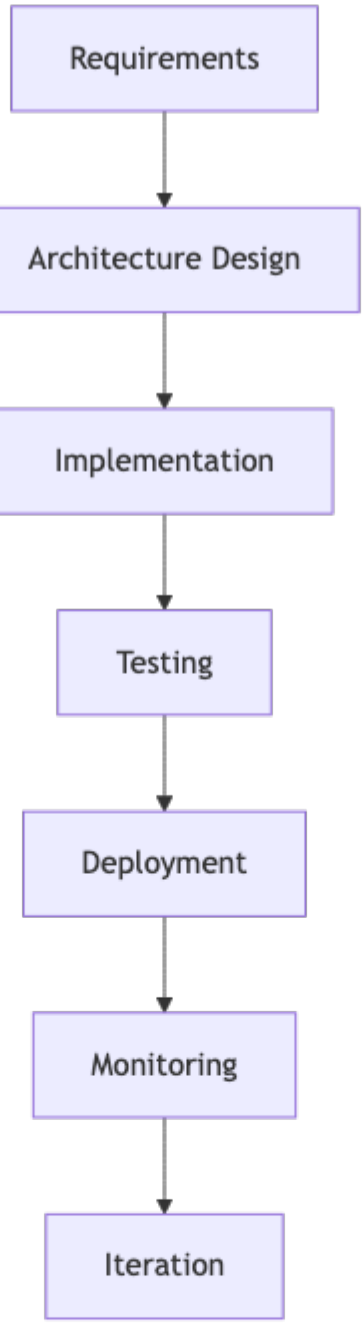
Chapter 1: System Design Principles

Key Principles: Always design for failure, implement proper error handling, and consider scalability from the start. These challenges build upon each other to create robust, production-ready systems.

Architecture Patterns:

- **Layered Architecture** - Separate concerns clearly
- **Microservices** - Independent, scalable services
- **Event-Driven** - Loose coupling through events
- **CQRS** - Separate read and write operations

System Design Flow:



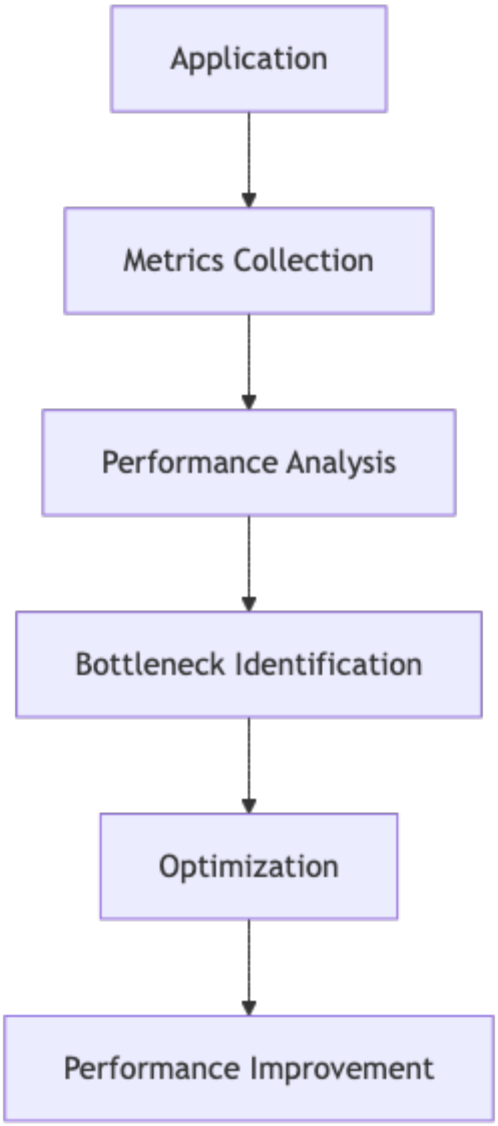
Chapter 2: Performance Optimization

> **Performance Tip:** Always measure before optimizing. Use profiling tools to identify bottlenecks, then apply targeted optimizations.

Optimization Strategies:

- **Caching** - Reduce database load
- **Connection Pooling** - Reuse connections
- **Async Processing** - Non-blocking operations
- **Database Indexing** - Faster queries

Performance Monitoring:



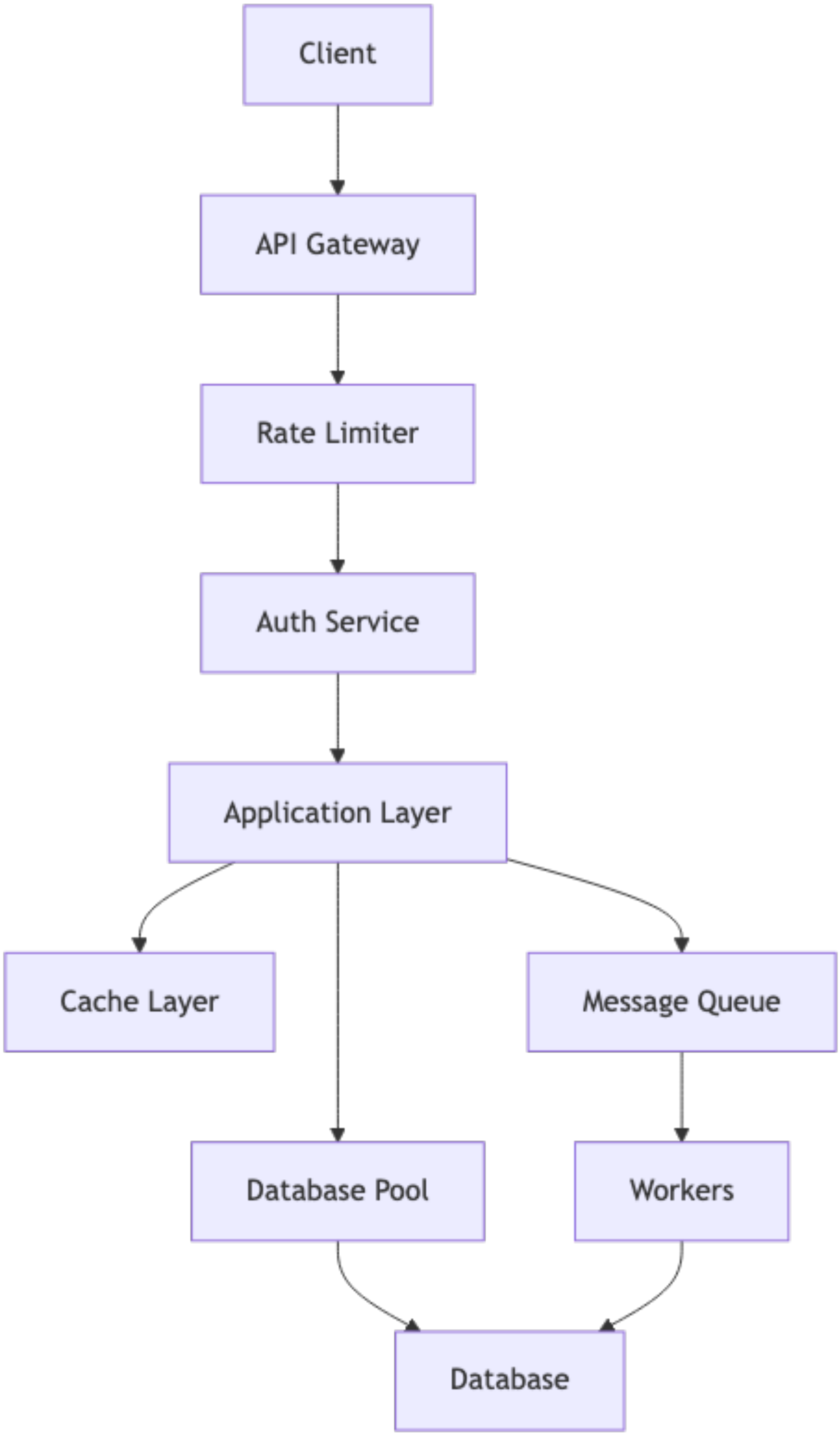
Final Challenge: Complete System Integration

Your Mission: Combine all the components you've built into a complete, production-ready backend system. This is where everything comes together!

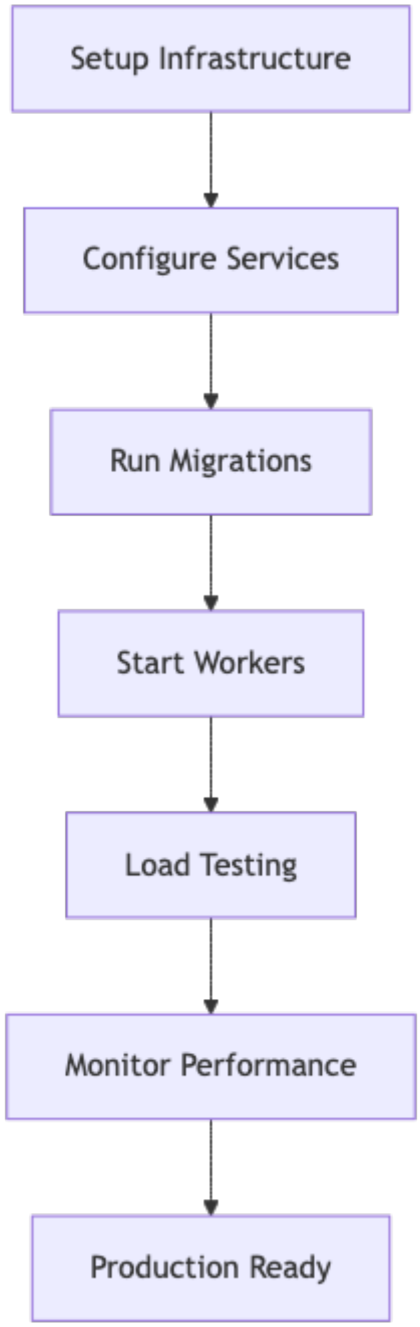
System Components:

- Authentication API with JWT tokens
- Rate-limited task queue
- Database connection pooling
- Redis caching layer
- Message queue with dead letter handling
- Database migration system

Complete System Architecture:



Integration Checklist:


Setup Infrastructure
Configure Services
Run Migrations
Start Workers
Load Testing
Monitor Performance
Production Ready

Congratulations!

You've completed the comprehensive backend challenges! You now have the skills to build robust, scalable backend systems that can handle real-world production loads. Remember to always consider security, performance, and maintainability in your designs.

Next Steps:

- Implement monitoring and alerting
- Add comprehensive logging
- Set up CI/CD pipelines
- Learn about containerization and orchestration
- Explore cloud-native architectures

> "The best code is no code at all." — Jeff Atwood