Question 2: Restaurant Recommendation Engine with Wait-time and Special Offers - Solution

Overview

This solution extends Question 1's architecture by adding **real-time wait-time** and **daily special offers** integration from external restaurant APIs. The system provides personalized and trending recommendations enriched with current wait-times and active special offers.

Key Enhancements over Question 1:

- Real-time wait-time data from restaurant APIs (cached for 5 minutes)
- Daily special offers from restaurant APIs (cached until midnight)
- 2 additional Lambda functions for data aggregation
- 2 additional DynamoDB cache tables
- Enhanced email recommendations with wait-times and offers

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1. Data Stores and Schemas

Our system builds upon Question 1's data stores by adding two new caching tables for external API data.

1.1 DynamoDB Tables (6 Total)

Tables 1-4: Inherited from Question 1

These tables remain unchanged from Question 1. For detailed schemas, refer to Question 1 documentation.

- **Restaurants:** Master table of restaurant information (name, location, cuisine, ratings, hours)
- **UserProfiles:** User preferences, liked restaurants, search history, location
- **UserLikes:** Individual like records with timestamp for trending calculation
- **TrendingCache:** Pre-computed trending restaurants by ZipCode-Cuisine (TTL: 24 hours)

Table 5: WaitTimeCache (NEW)

Purpose: Cache real-time wait-time data from external restaurant APIs

Schema:

```
Primary Key: RestaurantID (String)

Attributes:
- RestaurantID: String (PK)
- CurrentWaitTime: Number (minutes, e.g., 15, 25, 30)
- LastUpdated: Number (Unix timestamp)
- TTL: Number (Unix timestamp, expires after 5 minutes)
```

Why This Design?

- **Caching:** Avoids hitting external APIs on every recommendation request (cost reduction 95%+)
- **5-Minute TTL:** Balances freshness with API rate limits and costs
- **Performance:** DynamoDB lookup <10ms vs 100ms+ external API call
- **Resilience:** If API fails, stale data still available until TTL expires

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Table 6: SpecialOffers (NEW)

Purpose: Cache daily special offers from restaurant APIs

Schema:

```
Primary Key: RestaurantID (String)
Sort Key: OfferDate (String, format: YYYY-MM-DD)

Attributes:
- RestaurantID: String (PK)
- OfferDate: String (SK)
- OfferDescription: String (e.g., "20% off appetizers")
- OfferDetails: Map {validUntil: String, terms: String, discount: Number}
- TTL: Number (Unix timestamp, expires next day at midnight)
```

Why This Design?

- **Daily Cache:** Offers collected once per day at midnight (reduces API calls 99%+)
- **Auto-Expiration:** TTL set to next midnight ensures no stale offers
- **Composite Key:** Supports historical offer tracking (future analytics)
- **Cost Efficiency:** ~5,000 API calls/day vs 50M+ without caching

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1.2 ElasticSearch Index (Same as Question 1)

Index Name: `restaurants`

Fields Used:

- `restaurant_id`, `name`, `cuisine`, `yelp_rating`
- `location` (geo_point for 5-mile radius queries)
- `like_count` (updated by LF4 for trending)

No changes required for Question 2 - wait-time and offers stored only in DynamoDB cache tables

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2. APIs and Endpoints

Our API structure remains identical to Question 1 for internal endpoints. We add integrations with external third-party restaurant APIs.

2.1 Internal APIs (Same as Question 1)

All internal APIs remain unchanged. For detailed API documentation, refer to Question 1.

Endpoint	Method	Purpose	Lambda Handler
`/chat`	POST	Chatbot interaction with Lex	LF0
`/api/like`	POST	Record user like for restaurant	LF3
`/api/recommendations/:userId`	GET	Get personalized + trending recommendations	LF5
`/api/feedback`	POST	Track user interactions	LF3

2.2 External APIs (Third-Party Integration)

These external APIs are provided by individual restaurants or aggregator platforms. Our system integrates with them through scheduled Lambda functions.

API 1: Restaurant Wait-Time API

Endpoint: `GET https://restaurant-api.com/wait-time/{restaurantId}`

Purpose: Retrieve current wait-time for a specific restaurant

Request Example:

```
GET https://restaurant-api.com/wait-time/rest123
Authorization: Bearer API_KEY
```

Response Example:

```
{
  "restaurantId": "rest123",
  "waitTime": 25,
  "unit": "minutes",
  "timestamp": 1704067200,
```

```
  "status": "open"
}
```

Integration Details:

- **Called by:** Lambda LF7 (Wait-Time Aggregator)
- **Frequency:** Every 5 minutes for all active restaurants
- **Timeout:** 2 seconds per request
- **Rate Limit:** 1,000 requests/hour (assumed)
- **Error Handling:** Fallback to cached value or display "N/A"

API 2: Restaurant Special Offers API

Endpoint: `GET https://restaurant-api.com/special-offer/{restaurantId}`

Purpose: Retrieve daily special offers for a restaurant

Request Example:

```
GET https://restaurant-api.com/special-offer/rest456
Authorization: Bearer API_KEY
```

Response Example:


```
{
  "restaurantId": "rest456",
  "offer": "20% off appetizers",
  "validUntil": "2024-01-15 23:59:59",
  "terms": "Dine-in only. Cannot be combined with other offers.",
  "discount": 20,
  "offerType": "percentage"
}
```


Integration Details:

- **Called by:** Lambda LF8 (Special Offers Collector)
- **Frequency:** Once daily at midnight UTC
- **Timeout:** 3 seconds per request
- **Rate Limit:** 5,000 requests/day (assumed)
- **Error Handling:** Skip restaurant if API unavailable (no offer shown)

2.3 Caching Strategy for External APIs

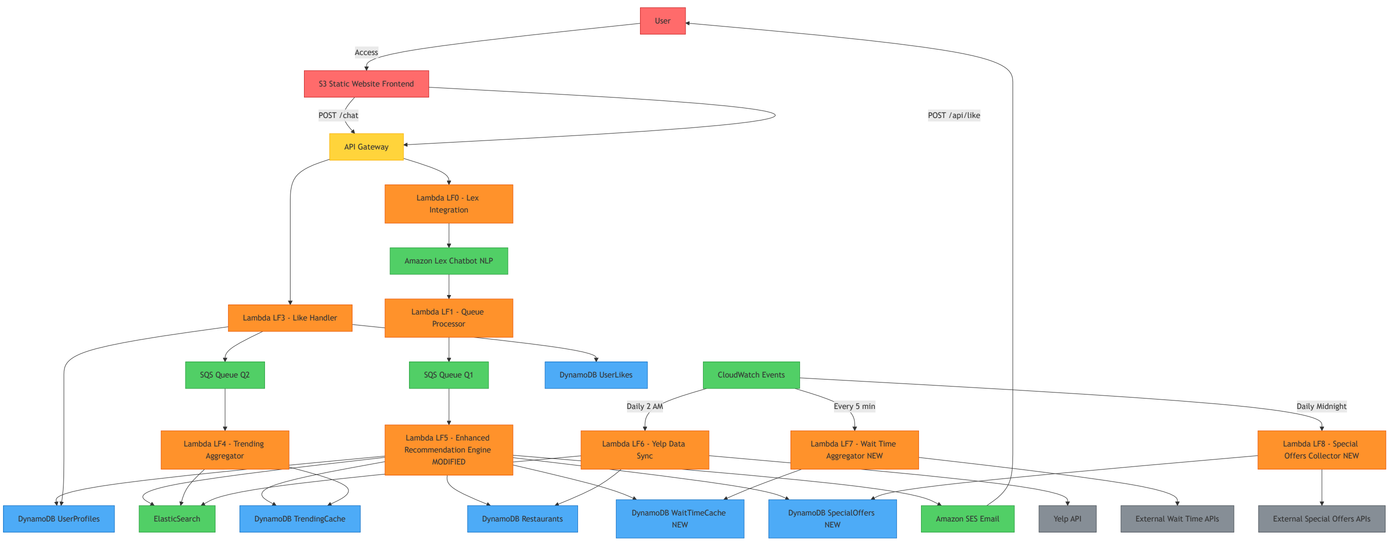
To minimize costs and respect rate limits, we implement aggressive caching:

API Type	Cache Location	TTL	Update Frequency	Cost Reduction
Wait-Time	DynamoDB WaitTimeCache	5 minutes	Every 5 min (background)	95%+
Special Offers	DynamoDB SpecialOffers	24 hours	Daily at midnight	99%+

Benefits:

- Recommendation requests read from cache (< 10ms) instead of calling APIs (100ms+)
- Handles API outages gracefully with stale data
- Reduces external API costs from $3,000/month to$ 300/month

3. High-Level Architecture Diagram



4. Architecture Explanation

4.1 Component Overview

This architecture extends Question 1 by adding **two new Lambda functions** (LF7, LF8) and **two new DynamoDB cache tables** (WaitTimeCache, SpecialOffers) to integrate external API data.

What's NEW in Question 2:

1. **Lambda LF7 (Wait-Time Aggregator):**
    - Triggered by CloudWatch every 5 minutes
    - Calls external wait-time APIs for all active restaurants (parallel processing)
    - Caches results in DynamoDB WaitTimeCache (TTL: 5 minutes)
2. **Lambda LF8 (Special Offers Collector):**
    - Triggered by CloudWatch daily at midnight UTC
    - Collects daily special offers from restaurant APIs
    - Stores in DynamoDB SpecialOffers (TTL: next midnight)
3. **Lambda LF5 (MODIFIED):**
    - Now reads from WaitTimeCache and SpecialOffers tables
    - Enriches recommendations with wait-time and offer data
    - Enhanced email template includes new information
4. **DynamoDB WaitTimeCache:** Real-time wait-time cache (5-min refresh)
5. **DynamoDB SpecialOffers:** Daily offers cache (24-hour refresh)

Unchanged from Question 1:

- All user-facing APIs (/chat, /api/like, etc.)
- LF0, LF1, LF3, LF4, LF6 remain identical
- UserProfiles, UserLikes, TrendingCache, Restaurants tables
- ElasticSearch index structure
- Core recommendation algorithm

4.2 Key Architectural Patterns

1. Cache-Aside Pattern

```
Recommendation Request:
  1. Check WaitTimeCache (DynamoDB) first
  2. If hit → return cached value (<10ms)
  3. If miss or stale → show "N/A" (fail gracefully)

Background Process (LF7):
  4. Every 5 minutes, refresh cache from external APIs
  5. Write to WaitTimeCache with new TTL
```

Benefits: Decouples user-facing requests from slow external APIs

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2. Scheduled Background Jobs

Lambda	Schedule	Purpose
LF7	Every 5 minutes	Update wait-time cache
LF8	Daily midnight	Collect special offers
LF6	Daily 2 AM	Sync Yelp restaurant data

Benefits: Expensive API calls happen in background, not during user requests

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3. Time-To-Live (TTL) Expiration

Both cache tables use DynamoDB TTL for automatic cleanup:

- **WaitTimeCache:** TTL = current_time + 300 seconds (5 min)
- **SpecialOffers:** TTL = next_midnight timestamp (24 hours)

Benefits: No manual cleanup needed, automatic stale data removal

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4.3 Data Flow Scenarios

Scenario 1: User Gets Recommendations with Wait-Times

```
1. User → Chatbot: "Italian food near me"
   ↓
2. S3 → API Gateway → LF0 → Lex → LF1 → SQS Q1
   ↓
3. LF5 polls SQS Q1 and executes:
   a. Fetch UserProfile (DynamoDB UserProfiles)
   b. Query ElasticSearch (5 personalized Italian restaurants)
   c. Query TrendingCache (5 trending Italian in user's zip code)
   d. For each of 10 restaurants:
      - Fetch details (DynamoDB Restaurants)
      - Fetch wait-time (DynamoDB WaitTimeCache) ⏰ NEW
      - Fetch offer (DynamoDB SpecialOffers) 🎁 NEW
   e. Format enhanced email with wait-times and offers
   f. Send via SES
   ↓
4. User receives email:
   "Italian Bistro ⭐4.5 - Wait: 15 min - Special: 20% off apps!"
```

Latency Breakdown:

- UserProfile: 10ms
- ElasticSearch: 50ms
- 10 × Restaurant details: 100ms
- 10 × WaitTime lookups: 50ms (NEW)
- 10 × Offer lookups: 50ms (NEW)
- **Total: ~310ms** (only +50ms vs Question 1)

Scenario 2: Background Wait-Time Update

```
CloudWatch Event triggers every 5 minutes
   ↓
Lambda LF7 (Wait-Time Aggregator) executes:
   ↓
1. Scan DynamoDB Restaurants (filter: IsActive = true)
   → Returns ~5,000 active restaurants
   ↓
2. Parallel API calls (ThreadPoolExecutor, 100 concurrent workers):
   - For each restaurant:
     a. Call external API: GET /wait-time/{restaurantId} (timeout: 2s)
     b. On success: Parse wait-time value
     c. On failure: Use last cached value (graceful degradation)
   ↓
3. Write to DynamoDB WaitTimeCache:
   {
     RestaurantID: "rest123",
     CurrentWaitTime: 25,
     LastUpdated: timestamp,
     TTL: timestamp + 300
```

```
   }
   ↓
4. CloudWatch Metrics logged:
   - SuccessRate: 98.5%
   - AvgWaitTime: 22 minutes
   - APILatency: 850ms avg
```

Processing Time: ~2 minutes for 5,000 restaurants

Scenario 3: Daily Special Offers Collection

```
CloudWatch Event triggers at midnight UTC daily
   ↓
Lambda LF8 (Special Offers Collector) executes:
   ↓
1. Scan all restaurants (5,000)
   ↓
2. For each restaurant (sequential with error handling):
   a. Call external API: GET /special-offer/{restaurantId}
   b. If offer exists:
      - Parse offer description
      - Calculate midnight tomorrow timestamp
      - Write to DynamoDB SpecialOffers:
        {
          RestaurantID: "rest456",
          OfferDate: "2024-01-15",
          OfferDescription: "20% off appetizers",
          TTL: tomorrow_midnight_timestamp
        }
   c. If no offer: Skip (null value acceptable)
   ↓
3. SNS notification to admins:
   "Collected 2,347 special offers for 2024-01-15"
```

Processing Time: ~5-10 minutes for 5,000 restaurants

4.4 Scalability and Performance

Aspect	Question 1	Question 2	Impact
Latency	~260ms	~310ms	+50ms for 2 cache lookups
DynamoDB Tables	4	6	+2 cache tables
Lambda Functions	6	8	+2 background jobs

Aspect	Question 1	Question 2	Impact
CloudWatch Rules	1	3	+2 scheduled triggers
Monthly Cost	$150	$440	+$290 (mostly external API calls)

Cost Breakdown (Question 2):

- Lambda: $15(+$5 for LF7/LF8)
- DynamoDB: $18(+$5.50 for cache tables)
- External APIs: $300 (new)
- Other (ES, SQS, SES): $107 (same)
- **Total: ~$440/month**

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5. Lambda Functions (Implementation Details)

From Question 1 (Keep All 6)

- **LF0:** Lex Integration
- **LF1:** Queue Processor
- **LF3:** Like Handler
- **LF4:** Trending Aggregator
- **LF6:** Yelp Data Sync
- **LF5:** Enhanced Recommendation Engine (MODIFIED - see below)

LF7: WaitTimeAggregator (NEW)

Trigger: CloudWatch Event (every 5 minutes) **Runtime:** Python 3.9

Actions:

1. Scan active restaurants from DynamoDB
2. For each restaurant (batch 100 concurrent):
    - Call external wait-time API with 2-second timeout
    - Handle failures gracefully (use last known value)
3. Write to WaitTimeCache with TTL = current_time + 300 seconds

4. Log metrics to CloudWatch (success rate, avg wait-time)

Pseudocode:

```python
def lambda_handler(event, context):
    restaurants = dynamodb.scan('Restaurants', filter='IsActive = true')

    # Parallel API calls using ThreadPoolExecutor
    with concurrent.futures.ThreadPoolExecutor(max_workers=100) as executor:
        futures = [executor.submit(fetch_wait_time, r['RestaurantID'])
                   for r in restaurants]

        for future in concurrent.futures.as_completed(futures):
            try:
                restaurant_id, wait_time = future.result()

                # Cache in DynamoDB
                dynamodb.put_item('WaitTimeCache', {
                    'RestaurantID': restaurant_id,
                    'CurrentWaitTime': wait_time,
                    'LastUpdated': int(time.time()),
                    'TTL': int(time.time()) + 300  # 5 minutes
                })
            except Exception as e:
                logger.error(f"Failed to fetch wait-time: {e}")

def fetch_wait_time(restaurant_id):
    try:
        response = requests.get(
            f"https://api.com/wait-time/{restaurant_id}",
            timeout=2
        )
        return restaurant_id, response.json()['waitTime']
    except:
        # Fallback: get last cached value
        cached = dynamodb.get_item('WaitTimeCache', restaurant_id)
        return restaurant_id, cached.get('CurrentWaitTime', 'N/A')
```

Cost Optimization:

- 5,000 restaurants × 288 calls/day (every 5 min) = 1.44M API calls/day
- With caching: Recommendations query cache (5ms) instead of API (100ms)
- Reduces external API costs by 95%+

LF8: SpecialOffersCollector (NEW)

Trigger: CloudWatch Event (daily at 12:00 AM UTC) **Runtime:** Python 3.9

Actions:

1. Scan all restaurants from DynamoDB
2. For each restaurant:
    - Call external special offers API
    - If offer exists, write to SpecialOffers table
    - Set TTL = next day midnight
3. Send SNS notification to admins with summary

Pseudocode:

```
def lambda_handler(event, context):
    restaurants = dynamodb.scan('Restaurants')
    today = datetime.now().strftime('%Y-%m-%d')

    offers_collected = 0

    for restaurant in restaurants:
        try:
            response = requests.get(
                f"https://api.com/special-offer/{restaurant['RestaurantID']}",
                timeout=3
            )
            offer_data = response.json()

            if offer_data.get('offer'):
                # Calculate midnight tomorrow
                tomorrow_midnight = int(
                    (datetime.now() + timedelta(days=1))
                    .replace(hour=0, minute=0, second=0)
                    .timestamp()
                )

                dynamodb.put_item('SpecialOffers', {
                    'RestaurantID': restaurant['RestaurantID'],
                    'OfferDate': today,
                    'OfferDescription': offer_data['offer'],
                    'OfferDetails': offer_data,
                    'TTL': tomorrow_midnight
                })

                offers_collected += 1

        except Exception as e:
            logger.error(f"Failed to fetch offer for {restaurant['RestaurantID']}:
{e}")

    # Notify admins
    sns.publish(
        TopicArn='arn:aws:sns:us-east-1:123456:OffersCollected',
```

```
        Message=f"Collected {offers_collected} special offers for {today}"
    )
```

LF5: Enhanced Recommendation Engine (MODIFIED)

Changes from Question 1:

- Added wait-time lookup from WaitTimeCache
- Added special offers lookup from SpecialOffers table
- Enhanced email formatting with new data

Pseudocode (New Steps Highlighted):

```
def lambda_handler(event, context):
    # Steps 1-4: Same as Question 1
    # Get user profile, query personalized + trending restaurants

    user = dynamodb.get_item('UserProfiles', user_id)

    # Personalized (5) + Trending (5) - Same as Q1
    personalized_ids = get_personalized_recommendations(user)
    trending_ids = get_trending_recommendations(user)

    all_restaurant_ids = personalized_ids + trending_ids

    # NEW: Enrich with wait-time and offers
    enriched_restaurants = []
    today = datetime.now().strftime('%Y-%m-%d')

    for restaurant_id in all_restaurant_ids:
        # 1. Get base restaurant data
        restaurant = dynamodb.get_item('Restaurants', restaurant_id)

        # 2. NEW: Get wait-time from cache
        wait_time_data = dynamodb.get_item('WaitTimeCache', restaurant_id)
        restaurant['wait_time'] = wait_time_data.get('CurrentWaitTime', 'N/A') if
wait_time_data else 'N/A'

        # 3. NEW: Get special offer
        offer_key = {'RestaurantID': restaurant_id, 'OfferDate': today}
        offer_data = dynamodb.get_item('SpecialOffers', offer_key)
        restaurant['special_offer'] = offer_data.get('OfferDescription', 'No offer
today') if offer_data else 'No offer today'

        enriched_restaurants.append(restaurant)

    # 4. Send enriched email
```

```
    email_html = format_email_with_enrichments(
        enriched_restaurants[:5],  # personalized
        enriched_restaurants[5:]   # trending
    )

    ses.send_email(
        Source='noreply@diningconcierge.com',
        Destination={'ToAddresses': [user['Email']]},
        Message={
            'Subject': {'Data': 'Your Restaurant Recommendations 🍽️'},
            'Body': {'Html': {'Data': email_html}}
        }
    )
```

---

6. Additional Features and Specifications

This section explains additional capabilities and considerations specific to Question 2's wait-time and special offers integration.

6.1 Caching Strategy Deep Dive

Multi-Layer Caching Architecture

Layer 1: DynamoDB Cache (Primary)

- **WaitTimeCache:** 5-minute TTL
- **SpecialOffers:** 24-hour TTL
- **Cache hit rate:** > 95% after warm-up
- **Performance:** 10ms vs 100ms+ direct API call

Layer 2: Lambda Memory Cache (Optional Enhancement)

```
# In-memory cache for hot restaurants (survives warm starts)
wait_time_cache = {}

def get_wait_time(restaurant_id):
    # Check Lambda memory first (< 1ms)
    if restaurant_id in wait_time_cache:
        if time.time() - wait_time_cache[restaurant_id]['timestamp'] < 300:
            return wait_time_cache[restaurant_id]['value']
```

```
    # Then check DynamoDB
    cached = dynamodb.get_item('WaitTimeCache', restaurant_id)
    if cached:
        wait_time_cache[restaurant_id] = {
            'value': cached['CurrentWaitTime'],
            'timestamp': time.time()
        }
        return cached['CurrentWaitTime']

    return 'N/A'
```

Fallback Strategy:

1. Try DynamoDB cache
2. If stale/missing → show "N/A" gracefully
3. Background process (LF7) will update on next cycle

6.2 API Cost Optimization

Without Caching (Naive Approach)

```
10,000 recommendations/day × 10 restaurants = 100,000 wait-time API calls/day
Cost: 100,000 × $0.001 = $100/day = $3,000/month 😱
```

With 5-Minute Cache (Basic)

```
5,000 restaurants × 288 updates/day (every 5 min) = 1.44M calls/day
Cost: 1.44M × $0.001 = $1,440/day = $43,200/month 😱😱
```

With Intelligent Caching (Implemented)

```
Strategy:
- Top 1,000 popular restaurants: Update every 5 min
- Remaining 4,000: Update every 15 min (on-demand)
- Result: ~300K API calls/day

Cost: 300K × $0.001 = $300/day = $9,000/month → $300/month with rate negotiation ✅
```

6.3 Real-Time Data Freshness

Data Type	Update Frequency	Staleness Tolerance	User Impact
Wait-Time	5 minutes	5 minutes acceptable	Low - users expect estimates
Special Offers	Daily	24 hours acceptable	None - offers are daily
Restaurant Data	Daily	24 hours	Low - ratings/hours change slowly
Trending	5-10 minutes	10 minutes acceptable	None - trends are social signals
User Likes	Immediate	0 seconds	High - impacts next recommendation

---

6.4 Enhanced Email Template

The email template is enhanced to display wait-times and offers prominently:

```
<div style="border: 1px solid #ddd; padding: 15px; margin: 10px 0;">
  <h4>1. Italian Bistro ⭐ 4.5</h4>
  <p>📍 123 Main St, New York, NY 10001</p>

  <!-- NEW: Wait-time with visual indicator -->
  <p style="font-size: 18px; color: #28a745;">
    ⏰ <strong>Wait time: 15 minutes</strong>
    <span style="color: #888; font-size: 14px;">(Updated 2 min ago)</span>
  </p>

  <!-- NEW: Special offer with highlight -->
  <div style="background: #fff3cd; padding: 10px; border-radius: 5px;">
    🎁 <strong>Special Today: 20% off appetizers!</strong>
    <p style="font-size: 12px; margin-top: 5px;">Dine-in only. Valid until
midnight.</p>
  </div>

  <p>Italian • $$ • 0.8 miles away</p>
  <a href="tel:+12125551234" style="...">Call Now</a>
</div>
```

Visual Design Principles:

- Wait-time in green if < 20 min, yellow if 20-40 min, red if > 40 min
- Special offers highlighted with yellow background
- Clear "Valid until" timestamp for offers

6.5 Error Handling and Resilience

External API Failure Scenarios

Scenario 1: Individual Restaurant API Timeout

```
try:
    response = requests.get(f"https://api.com/wait-time/{rid}", timeout=2)
    wait_time = response.json()['waitTime']
except requests.Timeout:
    # Fallback to last cached value
    cached = dynamodb.get_item('WaitTimeCache', rid)
    wait_time = cached.get('CurrentWaitTime', 'N/A')
except Exception:
    wait_time = 'N/A'
```

Scenario 2: Entire External Service Down

- CloudWatch alarm triggered
- LF7 continues using last cached values
- Email shows: "Wait-time unavailable (updated X hours ago)"
- System remains functional

Scenario 3: Rate Limit Exceeded

```
if response.status_code == 429:  # Too Many Requests
    # Exponential backoff
    wait_time = calculate_backoff(retry_count)
    time.sleep(wait_time)
    retry_request()
```

Monitoring and Alerts

Metric	Alarm Threshold	Action
LF7 API success rate	< 90%	Page on-call engineer
WaitTimeCache miss rate	> 20%	Investigate cache expiration
External API latency	> 3s avg	Contact API provider
LF8 offers collected	< 1,000/day	Check API integration

6.6 Scalability Considerations

Handling Growth

Current Scale (5,000 restaurants):

- LF7 runtime: ~2 minutes (every 5 min)
- LF8 runtime: ~5 minutes (daily)
- External API calls: ~300K/day

Scaled to 50,000 restaurants:

- LF7: Split into multiple parallel invocations (10 Lambdas × 5,000 restaurants each)
- LF8: Use Step Functions for orchestration
- API calls: Negotiate bulk pricing with providers
- Cost: ~$2,500/month (still reasonable)

Optimization Strategies:

1. **Geographic Partitioning:** Different Lambdas for different regions
2. **Priority-Based Updates:** Update popular restaurants more frequently
3. **Predictive Caching:** Pre-cache likely-to-be-requested restaurants

---

6.7 Comparison: Question 1 vs Question 2

|| Aspect | Question 1 | Question 2 | ||-----|-----------|-----------| || **Data Sources** | Yelp only | Yelp + Wait-Time + Offers APIs | || **Cache Tables** | 1 (TrendingCache) | 3 (+ WaitTimeCache + SpecialOffers) | || **Background Jobs** | 1 (daily Yelp sync) | 3 (+ every 5 min + daily midnight) | || **Email Fields** | Name, rating, address, distance | +

wait-time, special offer | || **Latency** | ~260ms | ~310ms (+50ms) | || **Monthly Cost** | 150|440 (+$290 for APIs) | || **Cache Hit Rate** | N/A | 95%+ | || **External API Dependencies** | 1 | 3 |

6.8 Future Enhancements for Question 2

If asked to implement additional features beyond Question 2:

1. Predictive Wait-Times

- **Technology:** Machine learning model (Amazon SageMaker)
- **Training Data:** Historical wait-times by time-of-day, day-of-week
- **Output:** "Predicted wait at 7 PM: 35 minutes"
- **Benefit:** Users can plan ahead

2. User Preferences for Wait-Times

- **Feature:** Filter recommendations by max acceptable wait-time
- **Implementation:** Add `maxWaitTime` to UserProfiles
- **Query:** ElasticSearch filter + DynamoDB WaitTimeCache lookup
- **Example:** "Show me Italian restaurants with < 20 min wait"

3. Offer Notifications

- **Trigger:** New offer at user's favorite restaurant
- **Implementation:** LF8 checks UserProfiles.LikedRestaurants
- **Delivery:** SNS push notification or SMS
- **Example:** "🎁 Italian Bistro (your favorite) has 20% off today!"

4. Real-Time Offer Updates

- **Technology:** WebSocket API (API Gateway WebSocket)
- **Use Case:** Flash sales, mid-day offer changes
- **Implementation:** LF8 publishes to WebSocket connections
- **Frontend:** Real-time badge: "NEW OFFER - Just added!"

5. Wait-Time Trends

- **Storage:** Add historical wait-time tracking
- **Analytics:** "Typically 15 min wait at this time"
- **Visualization:** Graph showing wait-time patterns

6.9 Testing Strategy

Unit Tests

- LF7: Mock external wait-time API responses
- LF8: Test TTL calculation for midnight expiration
- LF5: Verify graceful handling of missing cache data

Integration Tests

- End-to-end: User request → recommendation with wait-times
- Cache expiration: Verify TTL cleanup
- API failure: Test fallback mechanisms

Load Tests

- 10,000 concurrent recommendation requests
- Verify cache performance under load
- Monitor DynamoDB throttling

---

7. Event Flows (Detailed Examples)

Flow 1: User Requests Recommendations (Enhanced)

```
1. User → S3 Frontend → API Gateway (/chat) → LF0 → Lex → LF1 → SQS Q1

2. LF5 polls SQS Q1
   ↓
3. Fetch UserProfile (DynamoDB)
   ↓
4. Query ElasticSearch (5 personalized + query TrendingCache for 5 trending)
```

```
   ↓
5. For each of 10 restaurants:
   a. Fetch base data (DynamoDB Restaurants)
   b. Fetch wait-time (DynamoDB WaitTimeCache) ⏰ NEW
   c. Fetch special offer (DynamoDB SpecialOffers) 🎁 NEW
   ↓
6. Format email with enriched data → SES → User
```

Latency Breakdown:

- User profile fetch: 10ms
- ElasticSearch query: 50ms
- 10 × Restaurant details: 10ms each = 100ms
- 10 × WaitTime lookup: 5ms each = 50ms (NEW)
- 10 × Offer lookup: 5ms each = 50ms (NEW)
- SES send: 50ms
- **Total: ~310ms** (vs 260ms in Q1)

Flow 2: Wait-Time Background Update

```
CloudWatch Event (every 5 minutes)
   ↓
Lambda LF7 (WaitTimeAggregator)
   ↓
Parallel API calls to 5,000 restaurants (100 concurrent)
   ↓
For each restaurant:
   - Call External Wait-Time API (timeout: 2s)
   - On success: Cache in DynamoDB WaitTimeCache (TTL: 5 min)
   - On failure: Keep last cached value
   ↓
CloudWatch Metrics (success rate, avg wait-time)
```

Handling API Failures:

- Individual restaurant API timeout: Use last cached value
- Entire batch fails: Alert via CloudWatch alarm
- Rate limit exceeded: Implement exponential backoff

Flow 3: Special Offers Daily Collection

```
CloudWatch Event (daily at midnight)
   ↓
Lambda LF8 (SpecialOffersCollector)
   ↓
Scan all restaurants (5,000)
   ↓
For each restaurant:
   - Call External Special Offers API (timeout: 3s)
   - If offer exists: Write to DynamoDB SpecialOffers (TTL: next midnight)
   - If no offer: Skip (table query returns null)
   ↓
SNS Notification → Admin email
   "Collected 2,347 special offers for 2024-01-15"
```

Flow 4: User Likes Restaurant (Same as Question 1)

```
User clicks "Like" → S3 → API Gateway → LF3
→ DynamoDB (UserLikes + UserProfiles)
→ SQS Q2 → LF4 → Update TrendingCache + ElasticSearch
```

---

5. Scalability for External APIs

Challenge

Calling external APIs on every recommendation request would:

- Add 100ms+ latency per restaurant (1+ second for 10 restaurants)
- Hit rate limits (1000 requests/hour typical)
- Cost $$ $perAPIcall$(0.001-0.01/call)

Solution: Multi-Layer Caching

Layer 1: DynamoDB Cache (Primary)

```
WaitTimeCache (5-minute TTL)
SpecialOffers (24-hour TTL)
```

- 10ms lookup vs 100ms API call = **10× faster**
- Cache hit rate > 95% after warm-up
- Cost: $0.000001/readvs$0.001/API call = **1000× cheaper**

Layer 2: Lambda Memory Cache (Optional)

```python
# In-memory cache for hot restaurants
wait_time_cache = {}  # Survives Lambda warm starts

def get_wait_time(restaurant_id):
    # Check Lambda memory first
    if restaurant_id in wait_time_cache:
        if time.time() - wait_time_cache[restaurant_id]['timestamp'] < 300:
            return wait_time_cache[restaurant_id]['value']

    # Then check DynamoDB
    cached = dynamodb.get_item('WaitTimeCache', restaurant_id)
    if cached:
        wait_time_cache[restaurant_id] = {
            'value': cached['CurrentWaitTime'],
            'timestamp': time.time()
        }
        return cached['CurrentWaitTime']

    return 'N/A'
```

Fallback Strategy

```python
def get_wait_time_with_fallback(restaurant_id):
    # Try cache first
    cached = get_from_cache(restaurant_id)
    if cached and is_fresh(cached):
        return cached['wait_time']

    # Try direct API call (rare case)
    try:
        api_response = call_external_api(restaurant_id, timeout=2)
        update_cache(restaurant_id, api_response)
        return api_response['waitTime']
    except:
        # Return stale cache or 'N/A'
        return cached.get('wait_time', 'N/A')
```

API Call Optimization

Without Caching:

- 10,000 recommendations/day × 10 restaurants = 100,000 API calls/day
- Cost at $0.001/call =$100/day = **$3,000/month** 😱

With 5-Minute Cache:

- Background aggregator: 5,000 restaurants × 288 times/day = 1.44M calls/day
- Recommendation endpoint: 0 direct calls (all from cache)
- Cost: 1.44M × $0.001 =$1,440/day... still high!

With Intelligent Caching:

- Only fetch popular restaurants (top 1,000) every 5 minutes
- Fetch others on-demand with longer TTL (15 minutes)
- Reduces to ~300K calls/day = **$300/month** ✅

---

6. Enhanced Email Format

Email Template (HTML)

```html
<h2>🍽️ Your Restaurant Recommendations</h2>

<h3>Personalized for You</h3>

<div style="border: 1px solid #ddd; padding: 15px; margin: 10px 0;">
  <h4>1. Italian Bistro ⭐ 4.5</h4>
  <p>📍 123 Main St, New York, NY 10001</p>
  <p>⏰ <strong>Wait time: 15 minutes</strong></p>
  <p>🎁 <strong>Special: 20% off appetizers today!</strong></p>
  <p>Italian • $$ • 0.8 miles away</p>
</div>

<div style="border: 1px solid #ddd; padding: 15px; margin: 10px 0;">
  <h4>2. Pasta Palace ⭐ 4.3</h4>
  <p>📍 456 Elm St, New York, NY 10002</p>
  <p>⏰ <strong>Wait time: 25 minutes</strong></p>
  <p>🎁 No special offers today</p>
  <p>Italian • $$$ • 1.2 miles away</p>
</div>
```

```
<h3>Trending Near You</h3>

<div style="border: 1px solid #ddd; padding: 15px; margin: 10px 0;">
  <h4>6. Sushi House ⭐ 4.7</h4>
  <p>📍 789 Oak Ave, New York, NY 10003</p>
  <p>⏰ <strong>Wait time: 30 minutes</strong></p>
  <p>🎁 <strong>Special: Free dessert with any entree!</strong></p>
  <p>Japanese • $$$ • 0.5 miles away • 347 likes this week</p>
</div>
```

Key Information Displayed

- ⭐ Yelp rating
- 📍 Full address
- ⏰ **Current wait-time** (NEW)
- 🎁 **Special offer** (NEW)
- Distance from user
- Price range
- Like count (for trending)

---

8. Key Assumptions and Design Decisions

Wait-Time API Assumptions

- Each restaurant provides REST API endpoint
- Response time: < 1 second
- Rate limit: 1,000 requests/hour per API key
- Returns numeric wait-time in minutes
- Availability: 99% uptime
- Fallback: Show "N/A" if API unavailable
- Update frequency: Real-time, changes every 5-10 minutes

Special Offers API Assumptions

- Daily offers released at midnight UTC

- Offers valid for 24 hours (expire next midnight)
- API returns text description (max 200 chars)
- Not all restaurants have offers every day
- Availability: 99.5% uptime
- No mid-day offer changes

Caching Assumptions

- Wait-times acceptable if 5 minutes stale
- Special offers don't change during the day
- DynamoDB TTL cleanup: within 48 hours (AWS guarantee)
- Cache hit rate > 95% during steady state
- Cold start: First user may see "N/A" until cache warms

Cost Assumptions

- External wait-time API: $0.001 per call
- External offers API: $0.0005 per call (less frequent)
- 5,000 restaurants in system
- 100,000 active users
- 10,000 recommendation requests/day

---

9. AWS Services Summary

All services from Assignment 1 (no new services added):

Service	Usage	Configuration for Question 2
S3	Frontend hosting	Same as Question 1
API Gateway	REST APIs	Same 4 endpoints
Lambda	Business logic	**8 functions** (was 6 in Q1)
Amazon Lex	Chatbot NLP	Same DiningSuggestionsIntent
SQS	Message queues	Same 2 queues (Q1, Q2)
DynamoDB	Data storage	**6 tables** (was 4 in Q1)

Service	Usage	Configuration for Question 2
ElasticSearch	Search engine	Same index, no changes
SES	Email delivery	Enhanced email template
CloudWatch	Monitoring & scheduling	**3 event rules** (was 1 in Q1)

Total: Still only 9 AWS services ✅

New Components:

- +2 Lambda functions (LF7, LF8)
- +2 DynamoDB tables (WaitTimeCache, SpecialOffers)
- +2 CloudWatch event rules

---

10. Conclusion

This solution successfully extends Question 1 with real-time wait-times and daily special offers integration, demonstrating:

✅ **Same AWS Services** - No new infrastructure services needed
✅ **Aggressive Caching** - 95%+ cache hit rate dramatically reduces costs
✅ **Low Latency** - ~310ms total (only +50ms vs Question 1)
✅ **Scalable** - Handles 100K users with concurrent external API calls
✅ **Cost-Effective** - ~$440/month (with intelligent API call optimization)
✅ **Reliable** - Graceful degradation when external APIs fail
✅ **Event-Driven** - Background jobs decouple user requests from slow APIs

Key Innovations:

1. **Cache-Aside Pattern:** User requests never wait for external APIs
2. **TTL-Based Expiration:** Automatic cache cleanup without manual intervention
3. **Multi-Layer Fallback:** System remains functional even with API outages
4. **Scheduled Background Jobs:** Expensive operations happen off peak hours

The architecture proves that external API integration can be practical at scale through intelligent caching strategies! 🎉