E-commerce Platform Backend

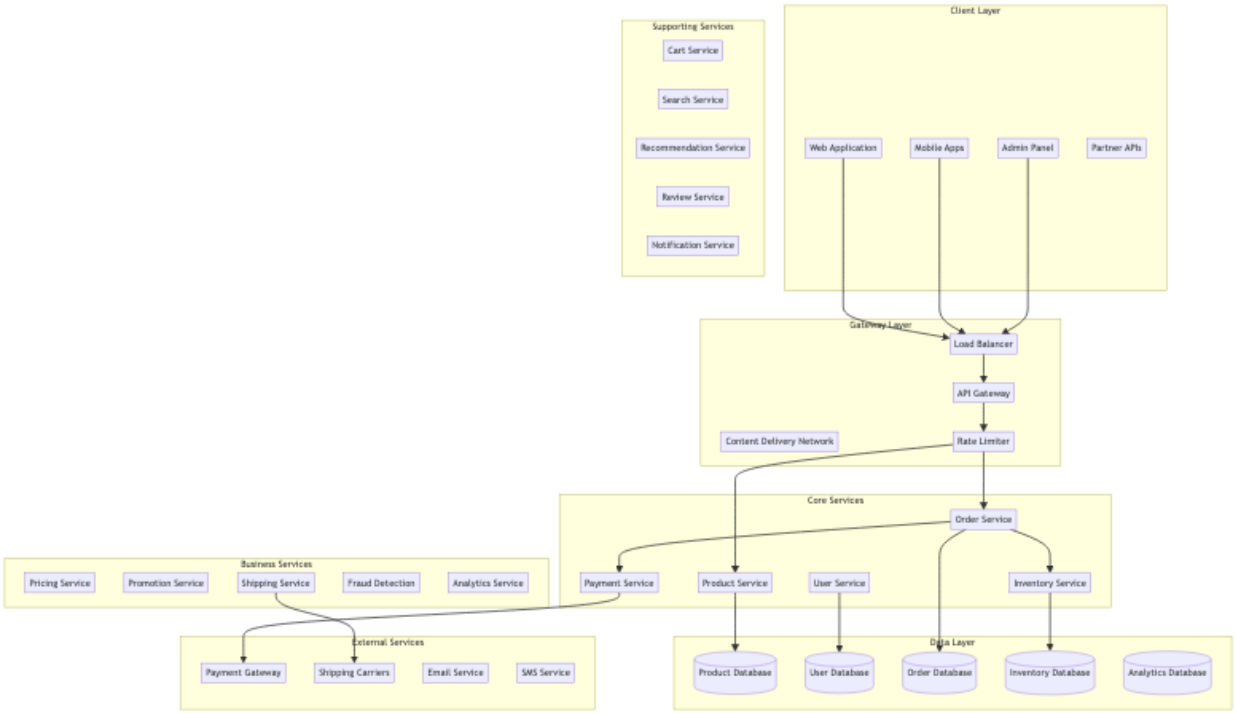
Table of Contents

High-Level Design (HLD)

Back to Top

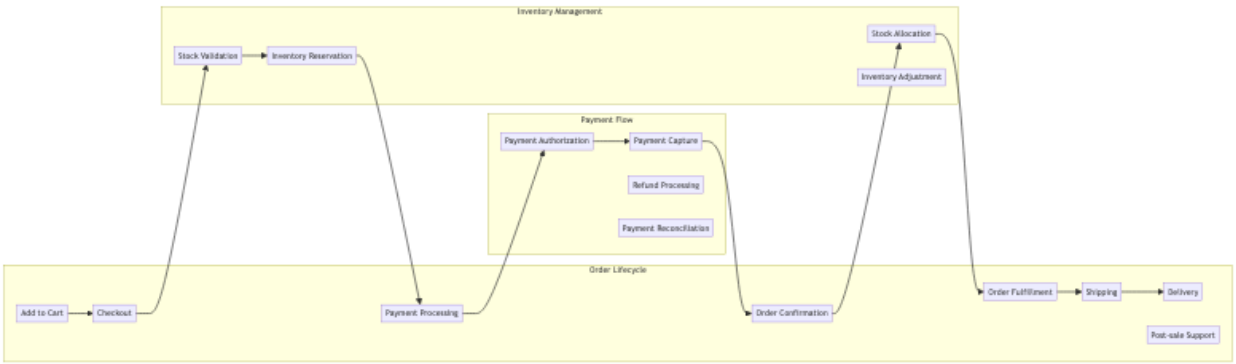
System Architecture Overview

Back to Top



Order Processing Flow

☐ Back to Top

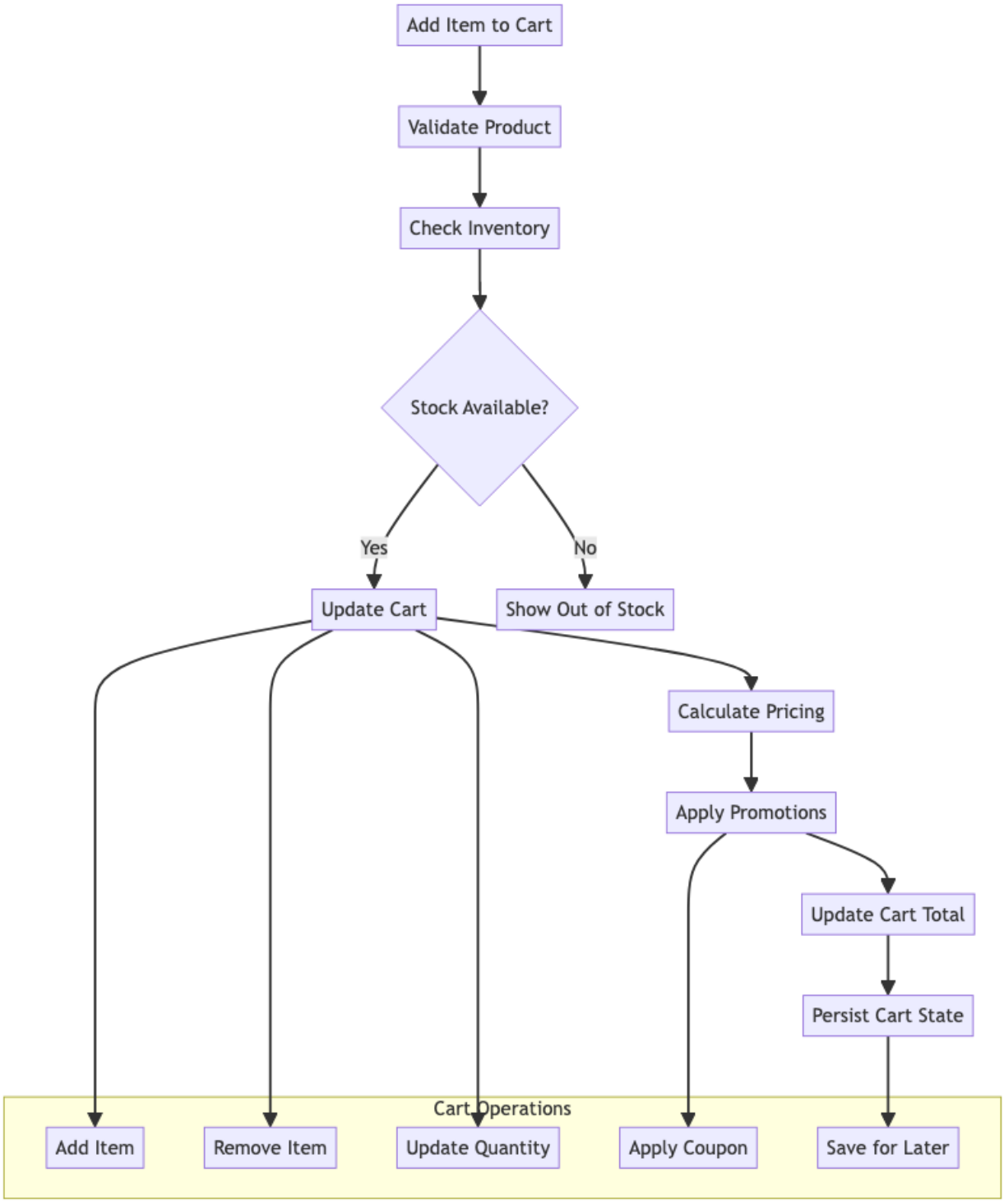


Low-Level Design (LLD)

☐ Back to Top

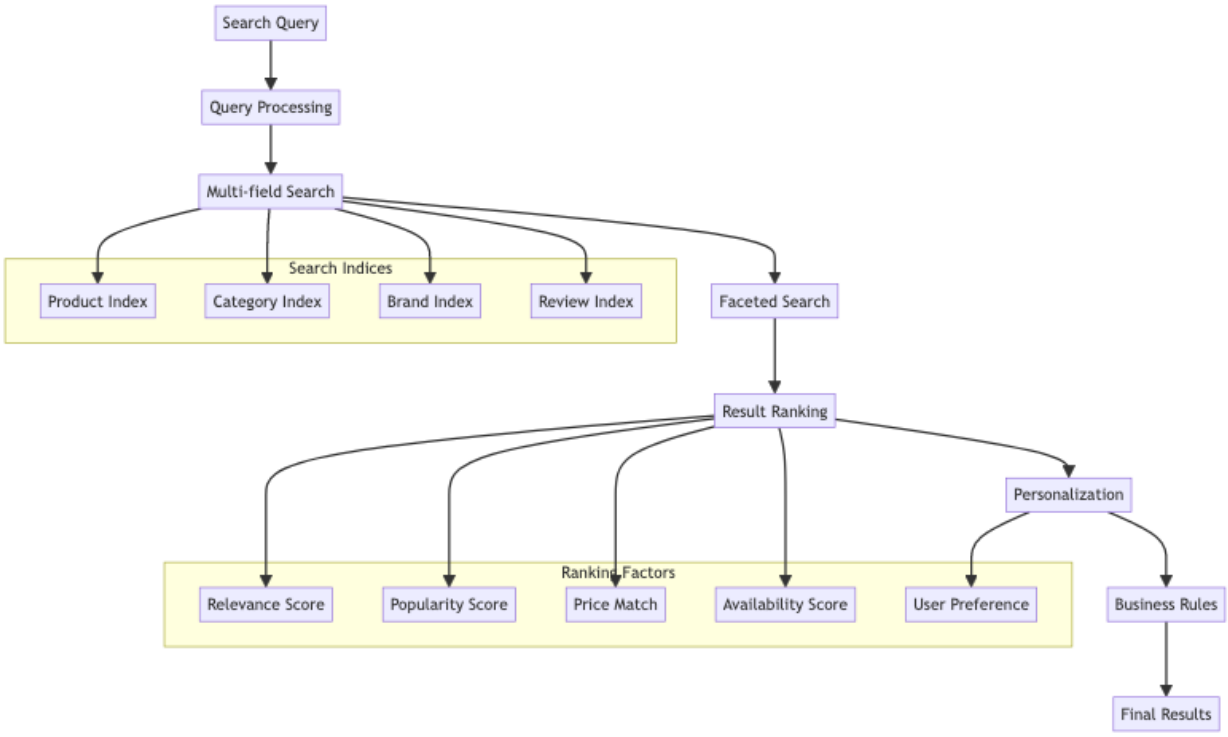
Shopping Cart Management

☐ Back to Top



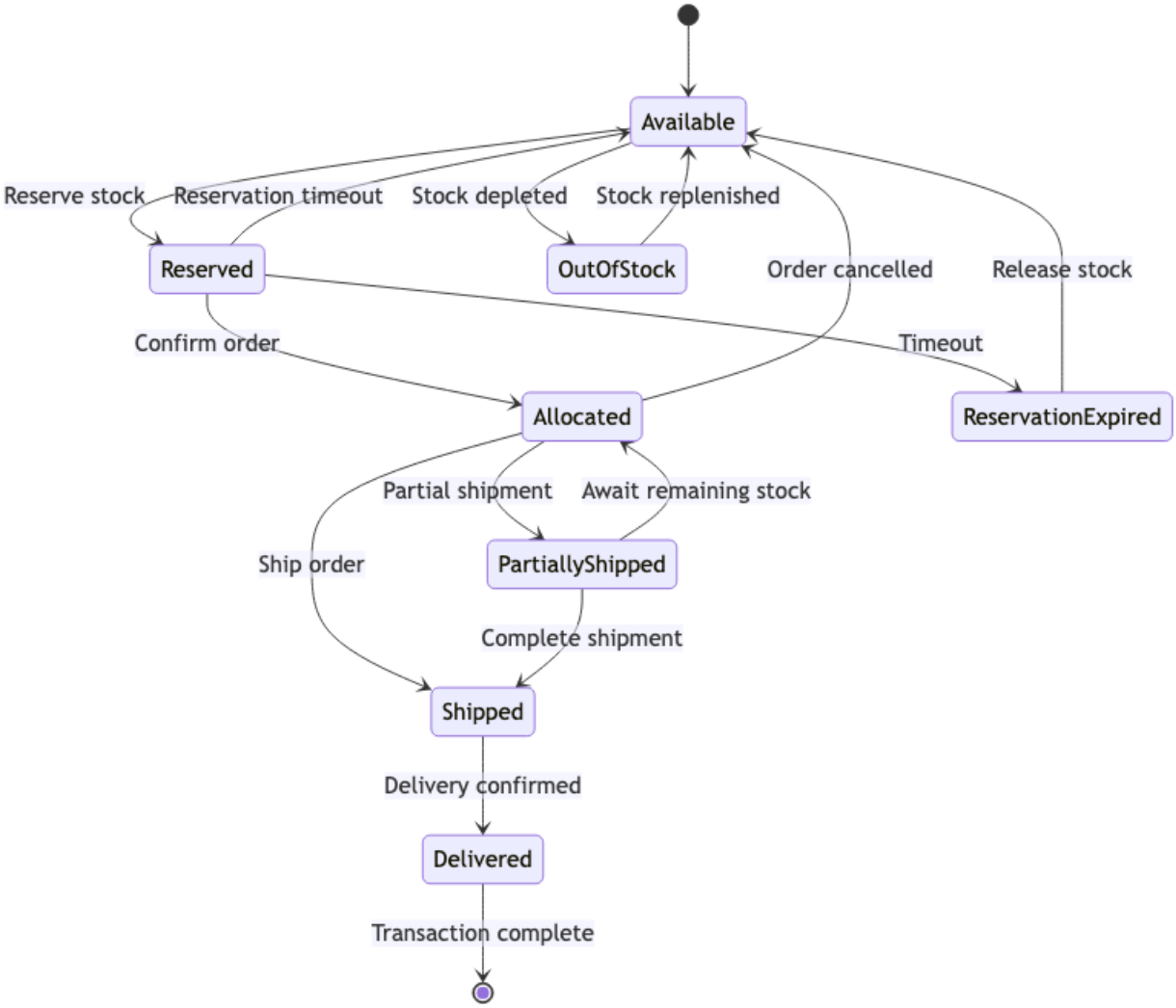
Product Search and Discovery

Back to Top



Inventory Management System

Back to Top



Core Algorithms

☐ Back to Top

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1. Dynamic Pricing Algorithm

☐ Back to Top

Purpose: Optimize product pricing based on demand, competition, and business objectives.

Price Optimization Factors:

```
PricingFactors = {
```

```
  demand: 0.30,           // Current demand level
  competition: 0.25,      // Competitor pricing
  inventory: 0.20,        // Stock levels
  seasonality: 0.15,      // Seasonal trends
  userSegment: 0.10       // Customer segment pricing
}

PricingConfig = {
  maxDiscountPercent: 30,    // Maximum discount allowed
  maxMarkupPercent: 50,      // Maximum markup allowed
  priceUpdateFrequency: 3600000,  // 1 hour
  competitorCheckFrequency: 86400000  // 24 hours
}

function calculateOptimalPrice(productId, context):
  product = getProduct(productId)
  basePrice = product.basePrice

  // Demand-based adjustment
  demandMultiplier = calculateDemandMultiplier(productId, context.timeWindow)

  // Competition-based adjustment
  competitionMultiplier = calculateCompetitionMultiplier(productId, context.region)

  // Inventory-based adjustment
  inventoryMultiplier = calculateInventoryMultiplier(productId)

  // Seasonal adjustment
  seasonalMultiplier = calculateSeasonalMultiplier(product.category, context.currentDate

  // User segment adjustment
  segmentMultiplier = calculateSegmentMultiplier(context.userId, product.category)

  // Calculate weighted price adjustment
  priceAdjustment = (
    demandMultiplier * PricingFactors.demand +
    competitionMultiplier * PricingFactors.competition +
    inventoryMultiplier * PricingFactors.inventory +
    seasonalMultiplier * PricingFactors.seasonality +
    segmentMultiplier * PricingFactors.userSegment
  )

  // Apply bounds
  adjustedPrice = basePrice * priceAdjustment
  maxPrice = basePrice * (1 + PricingConfig.maxMarkupPercent / 100)
```

```
  minPrice = basePrice * (1 - PricingConfig.maxDiscountPercent / 100)

  finalPrice = Math.max(minPrice, Math.min(adjustedPrice, maxPrice))

  return {
    price: finalPrice,
    originalPrice: basePrice,
    discountPercent: Math.max(0, (basePrice - finalPrice) / basePrice * 100),
    factors: {
      demand: demandMultiplier,
      competition: competitionMultiplier,
      inventory: inventoryMultiplier,
      seasonal: seasonalMultiplier,
      segment: segmentMultiplier
    }
  }
```

Demand Calculation Algorithm:

```
function calculateDemandMultiplier(productId, timeWindow = 86400000): // 24 hours
  currentTime = Date.now()
  timeStart = currentTime - timeWindow

  // Get recent activity metrics
  views = getProductViews(productId, timeStart, currentTime)
  cartAdds = getCartAdditions(productId, timeStart, currentTime)
  purchases = getPurchases(productId, timeStart, currentTime)
  wishlistAdds = getWishlistAdditions(productId, timeStart, currentTime)

  // Calculate conversion rates
  viewToCartRate = cartAdds / Math.max(views, 1)
  cartToPurchaseRate = purchases / Math.max(cartAdds, 1)

  // Calculate demand score
  demandScore = (
    views * 0.1 +
    cartAdds * 0.3 +
    purchases * 0.5 +
    wishlistAdds * 0.1
  )

  // Normalize demand score
  averageDemand = getAverageDemandForCategory(getProduct(productId).category)
  normalizedDemand = demandScore / Math.max(averageDemand, 1)

  // Convert to multiplier (range: 0.8 to 1.3)
```

```
  demandMultiplier = 0.8 + (normalizedDemand * 0.5)

  return Math.max(0.8, Math.min(demandMultiplier, 1.3))
```

2. Inventory Management Algorithm

Back to Top

Purpose: Maintain optimal stock levels while minimizing carrying costs and stockouts.

Inventory Optimization Model:

```
InventoryConfig = {
  reorderPointDays: 7,        // Days of safety stock
  leadTimeDays: 14,           // Supplier lead time
  reviewPeriodDays: 30,       // Inventory review frequency
  serviceLevel: 0.95,         // 95% service level target
  carryingCostPercent: 0.25   // 25% annual carrying cost
}

function calculateReorderPoint(productId):
  product = getProduct(productId)

  // Get historical demand data
  demandHistory = getDemandHistory(productId, timeWindow = 90 * 24 * 3600 * 1000) // 90

  // Calculate demand statistics
  averageDailyDemand = calculateAverageDailyDemand(demandHistory)
  demandStandardDeviation = calculateDemandStandardDeviation(demandHistory)

  // Calculate lead time demand
  leadTimeDemand = averageDailyDemand * InventoryConfig.leadTimeDays

  // Calculate safety stock
  serviceLevel = InventoryConfig.serviceLevel
  zScore = getZScoreForServiceLevel(serviceLevel)
  leadTimeVariability = Math.sqrt(InventoryConfig.leadTimeDays) * demandStandardDeviatio
  safetyStock = zScore * leadTimeVariability

  // Calculate reorder point
  reorderPoint = leadTimeDemand + safetyStock

  return Math.ceil(reorderPoint)

function calculateOptimalOrderQuantity(productId):
```

```
  product = getProduct(productId)

  // Get parameters for EOQ calculation
  annualDemand = getAnnualDemand(productId)
  orderingCost = getOrderingCost(product.supplierId)
  unitCost = product.cost
  carryingCost = unitCost * InventoryConfig.carryingCostPercent

  // Economic Order Quantity (EOQ) formula
  eoq = Math.sqrt((2 * annualDemand * orderingCost) / carryingCost)

  // Apply business constraints
  minOrderQuantity = product.minOrderQuantity || 1
  maxOrderQuantity = product.maxOrderQuantity || Infinity

  optimalQuantity = Math.max(minOrderQuantity, Math.min(eoq, maxOrderQuantity))

  return Math.ceil(optimalQuantity)
```

Stock Reservation System:

```
ReservationConfig = {
  reservationTimeout: 900000,    // 15 minutes
  maxReservationsPerUser: 10,
  reservationExtensionLimit: 2
}

function reserveInventory(productId, quantity, userId, cartId):
  currentTime = Date.now()

  // Check availability
  availableStock = getAvailableStock(productId)
  if availableStock < quantity:
    return { success: false, reason: 'insufficient_stock', available: availableStock }

  // Check user reservation limits
  userReservations = getUserActiveReservations(userId)
  if userReservations.length >= ReservationConfig.maxReservationsPerUser:
    return { success: false, reason: 'reservation_limit_exceeded' }

  // Create reservation
  reservation = {
    id: generateReservationId(),
    productId: productId,
    quantity: quantity,
    userId: userId,
```

```
    cartId: cartId,
    createdAt: currentTime,
    expiresAt: currentTime + ReservationConfig.reservationTimeout,
    status: 'active'
  }

  // Atomic operation: check and reserve
  reservationResult = atomicReserveStock(productId, quantity, reservation)

  if reservationResult.success:
    // Schedule expiration cleanup
    scheduleReservationExpiry(reservation.id, reservation.expiresAt)

    // Update inventory metrics
    updateInventoryMetrics(productId, -quantity, 'reserved')

    return {
      success: true,
      reservationId: reservation.id,
      expiresAt: reservation.expiresAt
    }
  else:
    return { success: false, reason: 'reservation_failed' }
```

3. Product Recommendation Engine

☐ Back to Top

Purpose: Provide personalized product recommendations to increase sales and user engagement.

Multi-Algorithm Recommendation System:

```
RecommendationModels = {
  collaborativeFiltering: {
    weight: 0.35,
    algorithm: 'matrix_factorization',
    factors: 50,
    regularization: 0.01
  },
  contentBased: {
    weight: 0.25,
    algorithm: 'cosine_similarity',
    features: ['category', 'brand', 'price_range', 'attributes']
  },
```

```
  behavioral: {
    weight: 0.20,
    algorithm: 'sequence_prediction',
    sessionLength: 10,
    decayFactor: 0.9
  },
  trending: {
    weight: 0.20,
    algorithm: 'popularity_boost',
    timeWindow: 24 * 3600 * 1000, // 24 hours
    trendingBoost: 1.5
  }
}

function generateRecommendations(userId, context, numRecommendations = 20):
  userProfile = getUserProfile(userId)
  browsedProducts = getRecentlyViewedProducts(userId, timeWindow = 7 * 24 * 3600 * 1000)

  recommendations = new Map()

  // Collaborative Filtering
  cfRecommendations = collaborativeFilteringModel.recommend(userId, numRecommendations *
  for rec in cfRecommendations:
    recommendations[rec.productId] = (recommendations[rec.productId] || 0) +
      rec.score * RecommendationModels.collaborativeFiltering.weight

  // Content-Based Filtering
  if browsedProducts.length > 0:
    cbRecommendations = contentBasedModel.recommend(browsedProducts, numRecommendations
    for rec in cbRecommendations:
      recommendations[rec.productId] = (recommendations[rec.productId] || 0) +
        rec.score * RecommendationModels.contentBased.weight

  // Behavioral Recommendations
  behavioralRecs = behavioralModel.recommend(userId, context.sessionId, numRecommendatic
  for rec in behavioralRecs:
    recommendations[rec.productId] = (recommendations[rec.productId] || 0) +
      rec.score * RecommendationModels.behavioral.weight

  // Trending Products
  trendingProducts = getTrendingProducts(context.category, numRecommendations)
  for product in trendingProducts:
    recommendations[product.id] = (recommendations[product.id] || 0) +
      product.trendingScore * RecommendationModels.trending.weight
```

```
  // Apply business rules and filters
  filteredRecommendations = applyBusinessFilters(recommendations, userProfile, context)

  // Sort and diversify
  sortedRecommendations = sortByScore(filteredRecommendations)
  diversifiedRecommendations = applyDiversification(sortedRecommendations, userProfile)

  return diversifiedRecommendations.slice(0, numRecommendations)
```

Real-time Behavioral Tracking:

```
function trackUserBehavior(userId, action, context):
  behaviorEvent = {
    userId: userId,
    sessionId: context.sessionId,
    action: action,
    productId: context.productId,
    category: context.category,
    timestamp: Date.now(),
    metadata: context.metadata
  }

  // Update real-time user session
  updateUserSession(userId, behaviorEvent)

  // Update user preferences
  updateUserPreferences(userId, behaviorEvent)

  // Trigger real-time recommendations if needed
  if shouldUpdateRecommendations(action):
    triggerRecommendationUpdate(userId, context)

  // Store for batch processing
  storeBehaviorEvent(behaviorEvent)

function updateUserPreferences(userId, behaviorEvent):
  preferences = getUserPreferences(userId)

  // Update category preferences
  if behaviorEvent.category:
    weight = getActionWeight(behaviorEvent.action)
    preferences.categories[behaviorEvent.category] =
      (preferences.categories[behaviorEvent.category] || 0) + weight

  // Update brand preferences
  if behaviorEvent.metadata.brand:
```

```
    preferences.brands[behaviorEvent.metadata.brand] =
      (preferences.brands[behaviorEvent.metadata.brand] || 0) + weight

  // Update price range preferences
  if behaviorEvent.metadata.price:
    updatePriceRangePreference(preferences, behaviorEvent.metadata.price, weight)

  // Normalize preferences
  normalizePreferences(preferences)

  // Store updated preferences
  saveUserPreferences(userId, preferences)
```

4. Order Processing and Fulfillment

☐ Back to Top

Purpose: Efficiently process orders from checkout to delivery with proper error handling.

Order State Machine:

```
OrderStates = {
  PENDING: 'pending',
  PAYMENT_PROCESSING: 'payment_processing',
  PAYMENT_CONFIRMED: 'payment_confirmed',
  INVENTORY_ALLOCATED: 'inventory_allocated',
  PREPARING: 'preparing',
  SHIPPED: 'shipped',
  DELIVERED: 'delivered',
  CANCELLED: 'cancelled',
  REFUNDED: 'refunded'
}

function processOrder(orderId):
  order = getOrder(orderId)

  try:
    // Validate order
    validation = validateOrder(order)
    if not validation.isValid:
      updateOrderStatus(orderId, OrderStates.CANCELLED, validation.reason)
      return { success: false, reason: validation.reason }

    // Process payment
    updateOrderStatus(orderId, OrderStates.PAYMENT_PROCESSING)
```

```
    paymentResult = processPayment(order.paymentDetails, order.total)

    if not paymentResult.success:
      updateOrderStatus(orderId, OrderStates.CANCELLED, 'payment_failed')
      return { success: false, reason: 'payment_failed' }

    updateOrderStatus(orderId, OrderStates.PAYMENT_CONFIRMED)

    // Allocate inventory
    allocationResult = allocateInventory(order.items)
    if not allocationResult.success:
      // Refund payment
      refundPayment(paymentResult.transactionId, order.total)
      updateOrderStatus(orderId, OrderStates.CANCELLED, 'inventory_unavailable')
      return { success: false, reason: 'inventory_unavailable' }

    updateOrderStatus(orderId, OrderStates.INVENTORY_ALLOCATED)

    // Create fulfillment tasks
    fulfillmentTasks = createFulfillmentTasks(order)
    for task in fulfillmentTasks:
      queueFulfillmentTask(task)

    updateOrderStatus(orderId, OrderStates.PREPARING)

    // Send confirmation
    sendOrderConfirmation(order.customerId, orderId)

    return { success: true, orderId: orderId, status: OrderStates.PREPARING }

  catch error:
    // Handle errors and cleanup
    handleOrderProcessingError(orderId, error)
    return { success: false, reason: 'processing_error', error: error.message }
```

Inventory Allocation Algorithm:

```
function allocateInventory(orderItems):
  allocations = []
  reservations = []

  // Sort items by priority (high-value items first)
  prioritizedItems = orderItems.sort((a, b) => b.unitPrice - a.unitPrice)

  for item in prioritizedItems:
    // Check available inventory across all warehouses
```

```
  warehouseInventory = getWarehouseInventory(item.productId)

  remainingQuantity = item.quantity
  itemAllocations = []

  // Allocate from warehouses (prefer closest to customer)
  for warehouse in warehouseInventory.sort((a, b) => a.distanceToCustomer - b.distance
    if remainingQuantity <= 0:
      break

    availableQuantity = warehouse.availableQuantity
    allocationQuantity = Math.min(remainingQuantity, availableQuantity)

    if allocationQuantity > 0:
      allocation = {
        productId: item.productId,
        warehouseId: warehouse.id,
        quantity: allocationQuantity,
        reservationId: generateReservationId()
      }

      // Reserve inventory
      reservationResult = reserveWarehouseInventory(
        warehouse.id,
        item.productId,
        allocationQuantity,
        allocation.reservationId
      )

      if reservationResult.success:
        itemAllocations.push(allocation)
        reservations.push(allocation.reservationId)
        remainingQuantity -= allocationQuantity
      else:
        // Warehouse inventory changed, continue to next warehouse
        continue

  if remainingQuantity > 0:
    // Cannot fulfill complete order, rollback all reservations
    rollbackReservations(reservations)
    return { success: false, reason: 'insufficient_inventory', shortfall: remainingQua

  allocations.push(...itemAllocations)

return { success: true, allocations: allocations }
```

5. Fraud Detection System

Back to Top

Purpose: Detect and prevent fraudulent transactions and activities.

Multi-layer Fraud Detection:

```
FraudDetectionRules = {
  velocityChecks: {
    maxOrdersPerHour: 5,
    maxOrderValuePerDay: 5000,
    maxFailedPaymentsPerHour: 3
  },
  patternAnalysis: {
    suspiciousLocationChanges: true,
    deviceFingerprintingEnabled: true,
    behavioralAnalysisEnabled: true
  },
  riskScoring: {
    highRiskThreshold: 0.8,
    mediumRiskThreshold: 0.5,
    autoBlockThreshold: 0.9
  }
}

function analyzeOrderForFraud(orderId):
  order = getOrder(orderId)
  customer = getCustomer(order.customerId)

  riskScore = 0
  riskFactors = []

  // Velocity checks
  velocityRisk = checkVelocityLimits(order.customerId, order)
  riskScore += velocityRisk.score * 0.3
  if velocityRisk.triggered:
    riskFactors.push(...velocityRisk.factors)

  // Payment analysis
  paymentRisk = analyzePaymentRisk(order.paymentDetails, customer)
  riskScore += paymentRisk.score * 0.25
  if paymentRisk.triggered:
    riskFactors.push(...paymentRisk.factors)
```

```
  // Geographic analysis
  geoRisk = analyzeGeographicRisk(order.shippingAddress, order.billingAddress, customer)
  riskScore += geoRisk.score * 0.2
  if geoRisk.triggered:
    riskFactors.push(...geoRisk.factors)

  // Behavioral analysis
  behavioralRisk = analyzeBehavioralRisk(order.customerId, order.sessionId)
  riskScore += behavioralRisk.score * 0.15
  if behavioralRisk.triggered:
    riskFactors.push(...behavioralRisk.factors)

  // Device fingerprinting
  deviceRisk = analyzeDeviceRisk(order.deviceFingerprint, customer)
  riskScore += deviceRisk.score * 0.1
  if deviceRisk.triggered:
    riskFactors.push(...deviceRisk.factors)

  // Determine risk level and actions
  riskLevel = categorizeRisk(riskScore)
  recommendedActions = getRecommendedActions(riskLevel, riskFactors)

  return {
    riskScore: riskScore,
    riskLevel: riskLevel,
    riskFactors: riskFactors,
    recommendedActions: recommendedActions
  }

function checkVelocityLimits(customerId, order):
  currentTime = Date.now()
  hourStart = currentTime - 3600000  // 1 hour
  dayStart = currentTime - 86400000  // 24 hours

  // Check orders per hour
  ordersLastHour = getOrderCount(customerId, hourStart, currentTime)
  if ordersLastHour > FraudDetectionRules.velocityChecks.maxOrdersPerHour:
    return {
      triggered: true,
      score: 0.8,
      factors: ['excessive_order_frequency']
    }

  // Check order value per day
  orderValueLastDay = getOrderValue(customerId, dayStart, currentTime)
```

```
  if orderValueLastDay + order.total > FraudDetectionRules.velocityChecks.maxOrderValueP
    return {
      triggered: true,
      score: 0.7,
      factors: ['excessive_order_value']
    }

  // Check failed payments
  failedPaymentsLastHour = getFailedPaymentCount(customerId, hourStart, currentTime)
  if failedPaymentsLastHour > FraudDetectionRules.velocityChecks.maxFailedPaymentsPerHou
    return {
      triggered: true,
      score: 0.9,
      factors: ['excessive_payment_failures']
    }

  return { triggered: false, score: 0, factors: [] }
```

Performance Optimizations

Back to Top

Database Optimization

Back to Top

Sharding Strategy: - Product catalog: Shard by category - User data: Shard by user ID - Orders: Shard by order date and region - Inventory: Shard by warehouse location

Caching Strategy: - Product data: Redis with 1-hour TTL - User sessions: Redis with session-based TTL - Search results: Elasticsearch with smart invalidation - Cart data: Redis with extended TTL

Search Performance

Back to Top

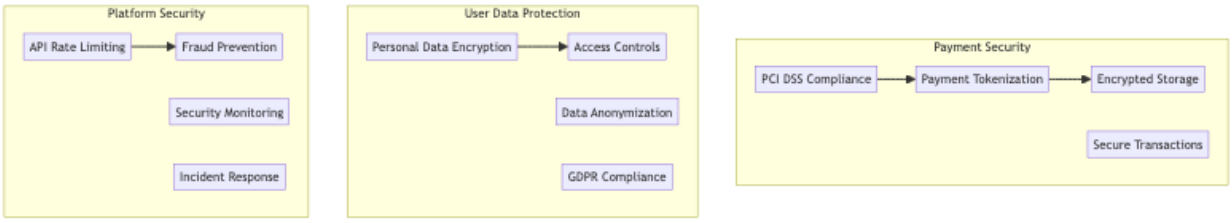
Elasticsearch Optimization: - Use appropriate analyzers for text fields - Implement search result caching - Optimize index structure for common queries - Use aggregations for faceted search

Security Considerations

Back to Top

Data Protection Framework

Back to Top



Testing Strategy

Back to Top

Load Testing Scenarios

Back to Top

High Traffic Events: - Flash sales and promotional events - Black Friday/Cyber Monday traffic - Product launch campaigns - Peak shopping season loads

Performance Benchmarks: - Product search response time < 200ms - Cart operations latency < 100ms - Order processing time < 5 seconds - Payment processing time < 3 seconds

Trade-offs and Considerations

Back to Top

Consistency vs Availability

Back to Top

- **Inventory updates**: Strong consistency vs high availability
- **Pricing updates**: Real-time pricing vs cached performance
- **Order processing**: ACID compliance vs processing speed
- **Search results**: Freshness vs query performance

Personalization vs Privacy

Back to Top

- **User tracking**: Recommendation accuracy vs privacy
- **Data collection**: Personalization vs data minimization
- **Behavioral analysis**: User insights vs anonymity
- **Location tracking**: Local offers vs location privacy

Scalability vs Cost

Back to Top

- **Global CDN**: Performance vs infrastructure cost
- **Real-time inventory**: Accuracy vs computational resources
- **Search capabilities**: Feature richness vs operational cost
- **Analytics granularity**: Business insights vs storage expenses

This e-commerce platform backend provides a comprehensive foundation for large-scale online retail with features like dynamic pricing, intelligent recommendations, robust fraud detection, and efficient order processing while maintaining high performance, security, and scalability standards.