Content Delivery Network (CDN) System

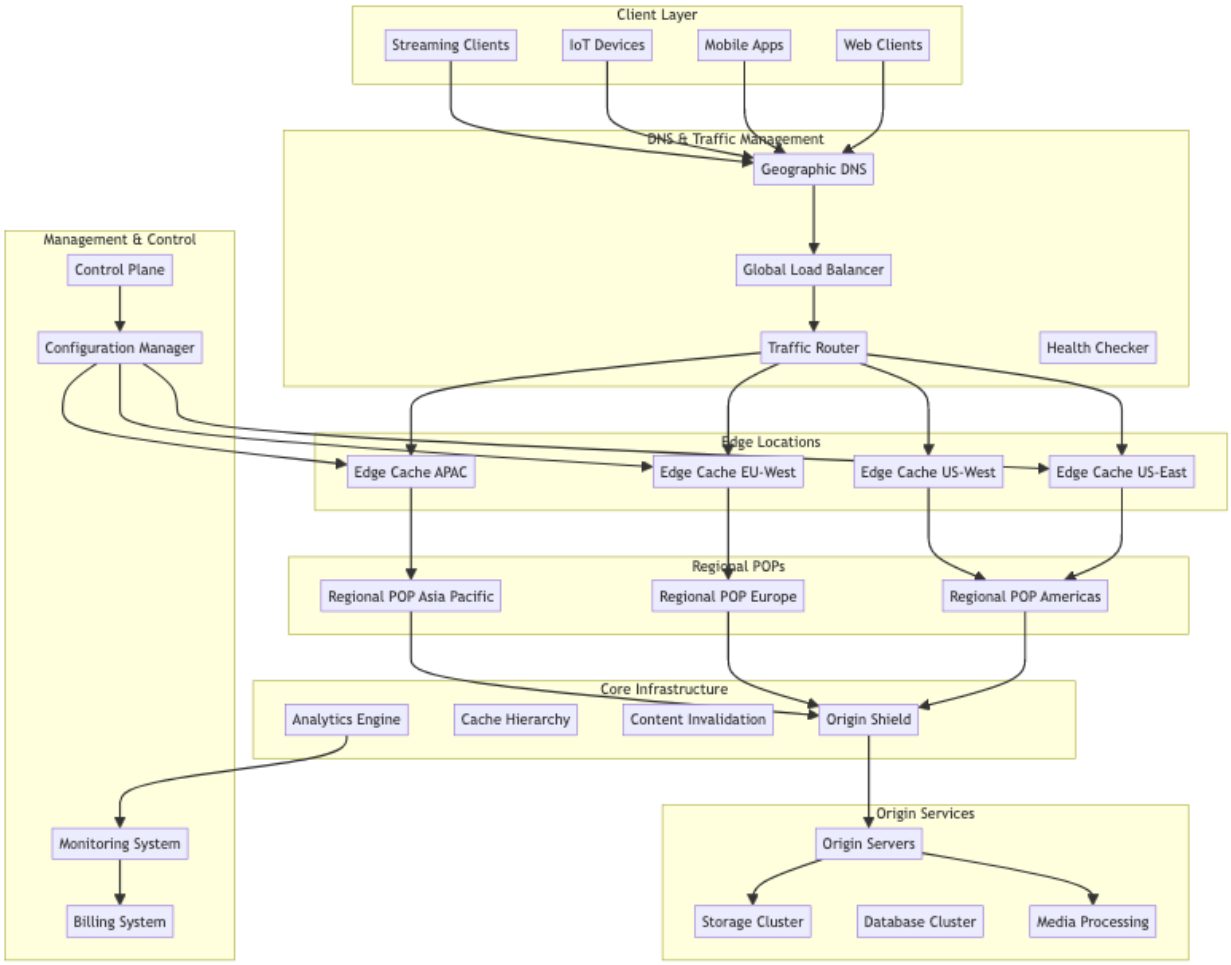
Table of Contents

High-Level Design (HLD)

Back to Top

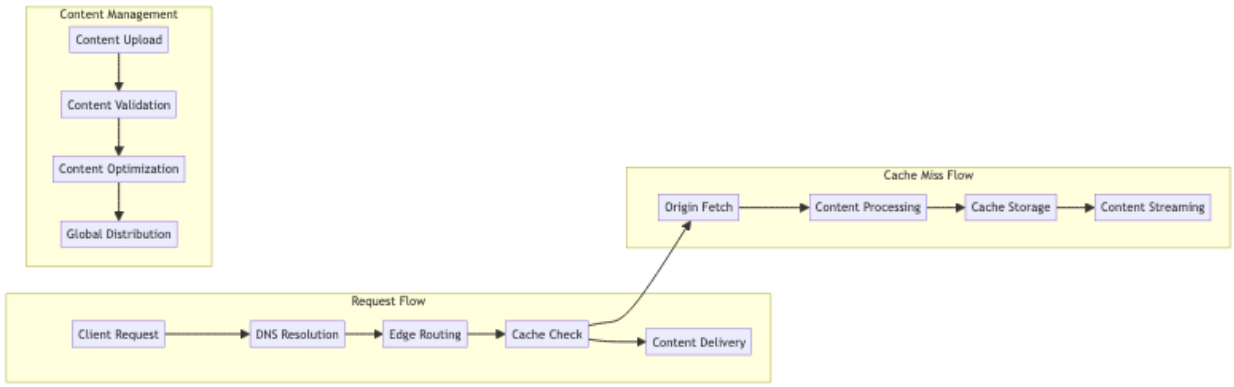
System Architecture Overview

Back to Top



Content Delivery Flow

☐ Back to Top

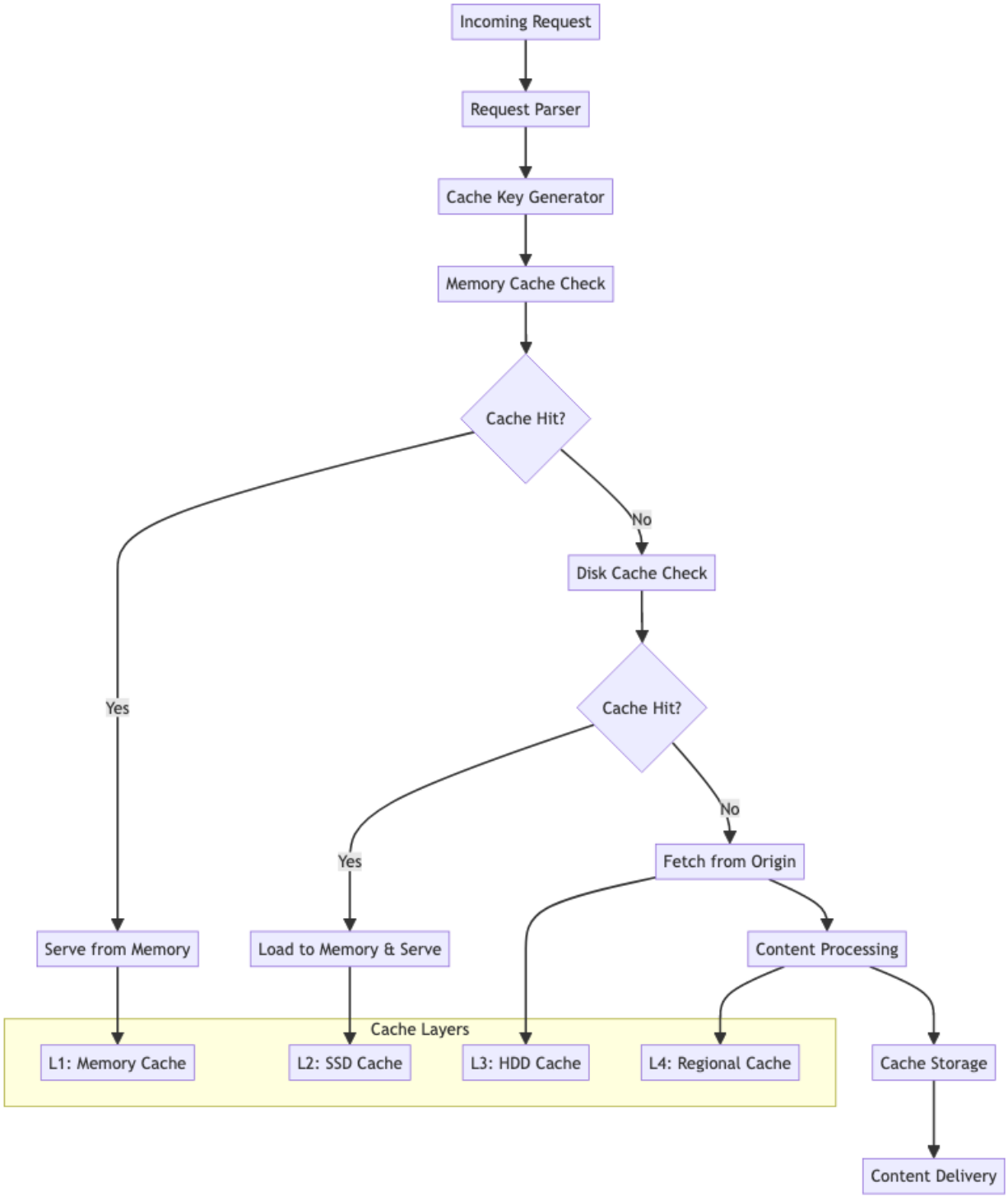


Low-Level Design (LLD)

Back to Top

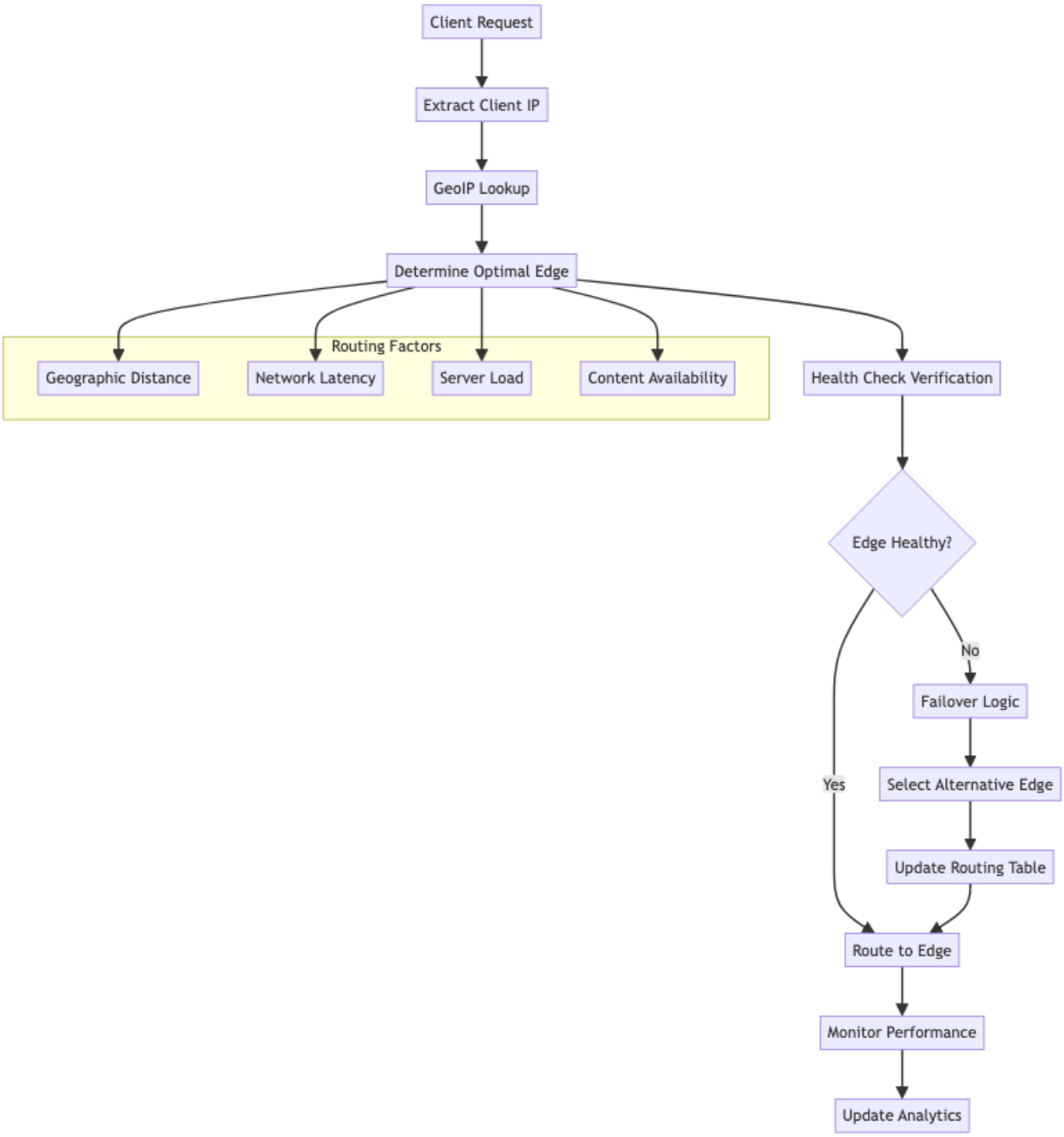
Cache Architecture

Back to Top



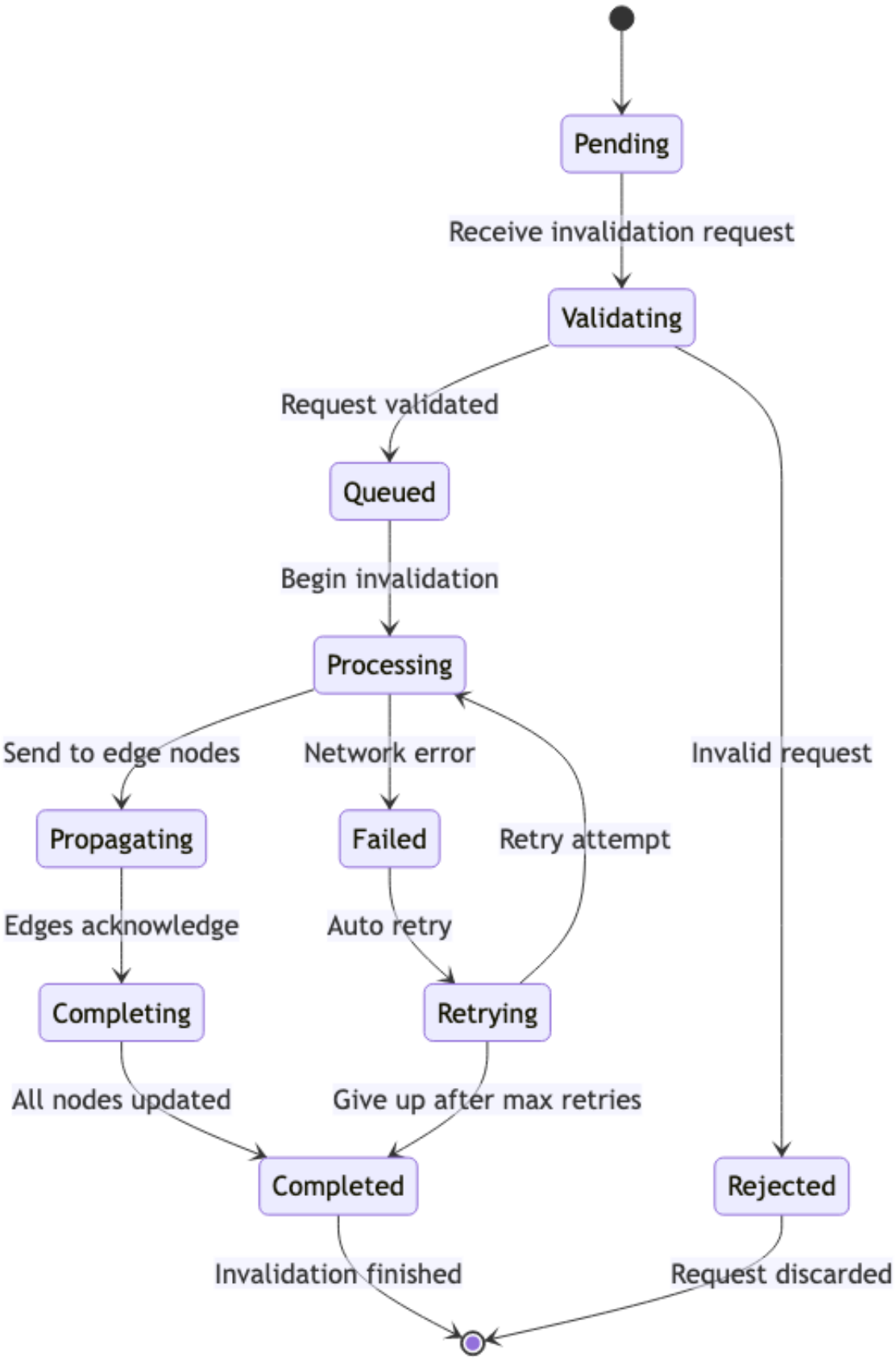
Geographic Routing Algorithm

Back to Top



Content Invalidation Flow

Back to Top


Pending
Receive invalidation request
Validating
Request validated
Queued
Begin invalidation
Processing
Send to edge nodes
Network error
Invalid request
Propagating
Failed
Retry attempt
Edges acknowledge
Auto retry
Completing
Retrying
All nodes updated
Give up after max retries
Completed
Rejected
Invalidation finished
Request discarded

Core Algorithms

Back to Top

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1. Intelligent Content Caching Algorithm

Back to Top

Purpose: Optimize cache hit rates by predicting content popularity and managing cache eviction based on multiple factors including geographic demand patterns.

Multi-Factor Cache Management:

```
CacheConfig = {
  caching: {
    levels: {
      memory: { size: '32GB', ttl: 3600000 },      # 1 hour
      ssd: { size: '1TB', ttl: 86400000 },         # 24 hours
      hdd: { size: '10TB', ttl: 604800000 }        # 7 days
    },

    evictionPolicy: 'adaptive_lru',                # 'lru', 'lfu', 'adaptive_lru'
    prefetchingEnabled: true,
    compressionEnabled: true,
    hotContentThreshold: 100                        # Requests per hour
  },

  prediction: {
    popularityWindow: 3600000,                     # 1 hour prediction window
    trendingThreshold: 5.0,                        # 5x increase in requests
    seasonalityDetection: true,
    geographicWeighting: true
  },

  optimization: {
    bandwidthThrottling: true,
    adaptiveQuality: true,
    contentCompression: true,
    imageOptimization: true
  }
}

class IntelligentCacheManager:
```

```
constructor(config):
  this.config = config
  this.memoryCache = new MemoryCache(config.caching.levels.memory)
  this.ssdCache = new SSDCache(config.caching.levels.ssd)
  this.hddCache = new HDDCache(config.caching.levels.hdd)
  this.popularityPredictor = new PopularityPredictor()
  this.geoAnalyzer = new GeographicAnalyzer()

function handleRequest(requestInfo):
  cacheKey = this.generateCacheKey(requestInfo)

  # Check cache hierarchy
  cacheResult = this.checkCacheHierarchy(cacheKey, requestInfo)

  if cacheResult.hit:
    # Update access patterns
    this.updateAccessPattern(cacheKey, requestInfo)
    return this.serveCachedContent(cacheResult)
  else:
    # Fetch from origin and cache
    return this.fetchAndCache(requestInfo, cacheKey)

function checkCacheHierarchy(cacheKey, requestInfo):
  # Level 1: Memory Cache
  memoryResult = this.memoryCache.get(cacheKey)
  if memoryResult:
    return {
      hit: true,
      level: 'memory',
      content: memoryResult.content,
      metadata: memoryResult.metadata,
      latency: 1 # ~1ms
    }

  # Level 2: SSD Cache
  ssdResult = this.ssdCache.get(cacheKey)
  if ssdResult:
    # Promote to memory cache if frequently accessed
    if this.shouldPromoteToMemory(cacheKey, requestInfo):
      this.memoryCache.set(cacheKey, ssdResult.content, ssdResult.metadata)

    return {
      hit: true,
      level: 'ssd',
      content: ssdResult.content,
```

```
      metadata: ssdResult.metadata,
      latency: 10 # ~10ms
    }

  # Level 3: HDD Cache
  hddResult = this.hddCache.get(cacheKey)
  if hddResult:
    # Promote to SSD cache if warranted
    if this.shouldPromoteToSSD(cacheKey, requestInfo):
      this.ssdCache.set(cacheKey, hddResult.content, hddResult.metadata)

    return {
      hit: true,
      level: 'hdd',
      content: hddResult.content,
      metadata: hddResult.metadata,
      latency: 50 # ~50ms
    }

  return { hit: false }

function fetchAndCache(requestInfo, cacheKey):
  fetchStart = Date.now()

  # Fetch from origin or upstream cache
  originResponse = this.fetchFromOrigin(requestInfo)

  if not originResponse.success:
    return this.handleOriginFailure(requestInfo)

  # Process and optimize content
  processedContent = this.processContent(originResponse.content, requestInfo)

  # Determine cache placement strategy
  cachePlacement = this.determineCachePlacement(cacheKey, processedContent, requestInf

  # Store in appropriate cache levels
  this.storeCachedContent(cacheKey, processedContent, cachePlacement)

  # Predict future demand and prefetch related content
  this.triggerPredictivePrefetch(cacheKey, requestInfo)

  return {
    content: processedContent.data,
    metadata: processedContent.metadata,
```

```
    cacheStatus: 'miss',
    origin: 'fetched',
    latency: Date.now() - fetchStart
  }

function determineCachePlacement(cacheKey, content, requestInfo):
  placement = {
    memory: false,
    ssd: false,
    hdd: false,
    priority: 'normal'
  }

  # Analyze content characteristics
  contentSize = content.size
  contentType = content.type

  # Analyze request patterns
  accessPattern = this.getAccessPattern(cacheKey)
  geographicDemand = this.geoAnalyzer.getGeographicDemand(cacheKey)

  # Predict popularity
  popularityScore = this.popularityPredictor.predict(cacheKey, requestInfo, accessPatt

  # Small, frequently accessed content goes to memory
  if contentSize < 10485760 and popularityScore > 0.8: # 10MB and high popularity
    placement.memory = true
    placement.priority = 'high'

  # Medium-sized popular content goes to SSD
  if contentSize < 104857600 and popularityScore > 0.5: # 100MB and medium popularity
    placement.ssd = true
    placement.priority = popularityScore > 0.7 ? 'high' : 'normal'

  # All content goes to HDD cache (cold storage)
  placement.hdd = true

  # Geographic considerations
  if geographicDemand.isRegionallyPopular:
    placement.priority = 'high'
    placement.replicationFactor = geographicDemand.regions.length

  return placement

function storeCachedContent(cacheKey, content, placement):
```

```
  metadata = {
    cacheKey: cacheKey,
    size: content.size,
    type: content.type,
    cachedAt: Date.now(),
    lastAccessed: Date.now(),
    accessCount: 1,
    etag: content.etag,
    expires: content.expires
  }

  # Store in appropriate cache levels
  if placement.hdd:
    this.hddCache.set(cacheKey, content, metadata, placement.priority)

  if placement.ssd:
    this.ssdCache.set(cacheKey, content, metadata, placement.priority)

  if placement.memory:
    this.memoryCache.set(cacheKey, content, metadata, placement.priority)

  # Log cache storage event
  this.logCacheEvent('store', cacheKey, metadata, placement)

function shouldPromoteToMemory(cacheKey, requestInfo):
  accessPattern = this.getAccessPattern(cacheKey)

  # Promote if content is frequently accessed
  if accessPattern.hourlyAccess > this.config.caching.hotContentThreshold:
    return true

  # Promote if content is trending
  if accessPattern.trendingScore > this.config.prediction.trendingThreshold:
    return true

  # Promote if geographically concentrated demand
  geoDemand = this.geoAnalyzer.getGeographicDemand(cacheKey)
  if geoDemand.concentration > 0.8:
    return true

  return false

function triggerPredictivePrefetch(cacheKey, requestInfo):
  # Analyze related content that might be requested
  relatedContent = this.identifyRelatedContent(cacheKey, requestInfo)
```

```
    for relatedItem in relatedContent:
      prefetchProbability = this.calculatePrefetchProbability(relatedItem, requestInfo)

      if prefetchProbability > 0.6: # 60% probability threshold
        this.schedulePrefetch(relatedItem, prefetchProbability)

  function calculatePrefetchProbability(contentItem, requestInfo):
    # Base probability from historical patterns
    baseProbability = this.getHistoricalPrefetchSuccess(contentItem.id)

    # User behavior patterns
    userBehaviorScore = this.analyzeUserBehavior(requestInfo.userAgent, requestInfo.clie

    # Content similarity
    similarityScore = this.calculateContentSimilarity(contentItem, requestInfo.requested

    # Time-based patterns
    temporalScore = this.getTemporalPrefetchScore(contentItem.id, Date.now())

    # Weighted combination
    probability = (
      baseProbability * 0.4 +
      userBehaviorScore * 0.3 +
      similarityScore * 0.2 +
      temporalScore * 0.1
    )

    return Math.min(1, Math.max(0, probability))
```

2. Global Traffic Routing Algorithm

☐ Back to Top

Purpose: Route client requests to optimal edge locations based on geographic proximity, server load, content availability, and network conditions.

Anycast Routing with Load Balancing:

```
RoutingConfig = {
  routing: {
    algorithm: 'weighted_round_robin',      # 'round_robin', 'least_connections', 'weigh
    healthCheckInterval: 30000,             # 30 seconds
    failoverThreshold: 3,                   # 3 consecutive failures
    latencyThreshold: 200,                  # 200ms maximum acceptable latency
```

```
    loadThreshold: 0.8                      # 80% load threshold
  },

  geographic: {
    regionPriority: true,
    continentFallback: true,
    crossOceanPenalty: 100,                 # Additional latency penalty for cross-ocean
    geoipAccuracy: 'city'                   # 'country', 'region', 'city'
  },

  optimization: {
    contentAwareRouting: true,
    networkConditionMonitoring: true,
    predictiveFailover: true,
    loadPrediction: true
  }
}

class GlobalTrafficRouter:
  constructor(config):
    this.config = config
    this.edgeLocations = new Map()
    this.geoipDatabase = new GeoIPDatabase()
    this.healthMonitor = new HealthMonitor()
    this.loadBalancer = new IntelligentLoadBalancer()
    this.networkMonitor = new NetworkConditionMonitor()

  function routeRequest(clientRequest):
    routingStart = Date.now()

    # Extract client information
    clientInfo = this.extractClientInfo(clientRequest)

    # Get available edge locations
    availableEdges = this.getAvailableEdgeLocations()

    # Score each edge location
    edgeScores = this.scoreEdgeLocations(availableEdges, clientInfo)

    # Select optimal edge
    selectedEdge = this.selectOptimalEdge(edgeScores, clientRequest)

    # Update routing metrics
    this.updateRoutingMetrics(selectedEdge, clientInfo, routingStart)
```

```
  return {
    edgeLocation: selectedEdge,
    routingDecision: this.getRoutingDecision(edgeScores, selectedEdge),
    estimatedLatency: selectedEdge.estimatedLatency,
    routingTime: Date.now() - routingStart
  }

function extractClientInfo(clientRequest):
  clientIP = this.extractClientIP(clientRequest)
  geoLocation = this.geoipDatabase.lookup(clientIP)

  return {
    ip: clientIP,
    country: geoLocation.country,
    region: geoLocation.region,
    city: geoLocation.city,
    latitude: geoLocation.latitude,
    longitude: geoLocation.longitude,
    isp: geoLocation.isp,
    asn: geoLocation.asn,
    userAgent: clientRequest.headers['user-agent'],
    acceptEncoding: clientRequest.headers['accept-encoding'],
    requestedContent: this.parseRequestedContent(clientRequest)
  }

function scoreEdgeLocations(edges, clientInfo):
  edgeScores = []

  for edge in edges:
    score = this.calculateEdgeScore(edge, clientInfo)
    edgeScores.push({
      edge: edge,
      score: score,
      factors: score.factors
    })

  # Sort by score (highest first)
  return edgeScores.sort((a, b) => b.score.total - a.score.total)

function calculateEdgeScore(edge, clientInfo):
  factors = {}

  # Geographic distance score
  factors.geographic = this.calculateGeographicScore(edge, clientInfo)
```

```
  # Network latency score
  factors.latency = this.calculateLatencyScore(edge, clientInfo)

  # Server load score
  factors.load = this.calculateLoadScore(edge)

  # Content availability score
  factors.content = this.calculateContentAvailabilityScore(edge, clientInfo.requestedC

  # Network condition score
  factors.network = this.calculateNetworkScore(edge, clientInfo)

  # Health score
  factors.health = this.calculateHealthScore(edge)

  # Calculate weighted total score
  totalScore = (
    factors.geographic * 0.25 +
    factors.latency * 0.20 +
    factors.load * 0.20 +
    factors.content * 0.15 +
    factors.network * 0.10 +
    factors.health * 0.10
  )

  return {
    total: totalScore,
    factors: factors
  }

function calculateGeographicScore(edge, clientInfo):
  # Calculate great circle distance
  distance = this.calculateDistance(
    clientInfo.latitude, clientInfo.longitude,
    edge.latitude, edge.longitude
  )

  # Base score inversely proportional to distance
  baseScore = Math.max(0, 1 - (distance / 20003931)) # Normalize by half Earth circumf

  # Regional bonus
  regionalBonus = 0
  if edge.country === clientInfo.country:
    regionalBonus = 0.3
  else if edge.continent === clientInfo.continent:
```

```
    regionalBonus = 0.1

  # Cross-ocean penalty
  crossOceanPenalty = 0
  if this.isCrossOceanRouting(edge, clientInfo):
    crossOceanPenalty = 0.2

  return Math.min(1, Math.max(0, baseScore + regionalBonus - crossOceanPenalty))

function calculateLatencyScore(edge, clientInfo):
  # Get measured latency or estimate
  measuredLatency = this.networkMonitor.getLatency(edge.id, clientInfo.asn)

  if not measuredLatency:
    # Estimate latency based on distance and network path
    estimatedLatency = this.estimateLatency(edge, clientInfo)
    measuredLatency = estimatedLatency

  # Score based on latency threshold
  if measuredLatency <= 50:
    return 1.0 # Excellent latency
  else if measuredLatency <= 100:
    return 0.8 # Good latency
  else if measuredLatency <= this.config.routing.latencyThreshold:
    return 0.6 # Acceptable latency
  else:
    return 0.2 # Poor latency

function calculateLoadScore(edge):
  currentLoad = edge.currentLoad

  # Score inversely proportional to load
  if currentLoad <= 0.5:
    return 1.0 # Low load
  else if currentLoad <= 0.7:
    return 0.8 # Medium load
  else if currentLoad <= this.config.routing.loadThreshold:
    return 0.5 # High load
  else:
    return 0.1 # Overloaded

function calculateContentAvailabilityScore(edge, requestedContent):
  if not this.config.optimization.contentAwareRouting:
    return 1.0
```

```
  # Check if content is already cached at edge
  contentCached = edge.hasCachedContent(requestedContent.url)

  if contentCached:
    return 1.0 # Content available locally

  # Check cache hierarchy for content
  hierarchyScore = this.calculateHierarchyAvailability(edge, requestedContent)

  return hierarchyScore

function selectOptimalEdge(edgeScores, clientRequest):
  if edgeScores.length === 0:
    throw new Error('No available edge locations')

  # Primary selection: highest scored edge
  primaryEdge = edgeScores[0]

  # Validate primary edge can handle request
  if this.canHandleRequest(primaryEdge.edge, clientRequest):
    return primaryEdge.edge

  # Fallback selection
  for i in range(1, edgeScores.length):
    candidateEdge = edgeScores[i]

    if this.canHandleRequest(candidateEdge.edge, clientRequest):
      return candidateEdge.edge

  # Last resort: any available edge
  throw new Error('No edge location can handle the request')

function canHandleRequest(edge, clientRequest):
  # Check basic capacity
  if edge.currentLoad >= 0.95:
    return false

  # Check health status
  if not edge.healthy:
    return false

  # Check request size limits
  if clientRequest.contentSize > edge.maxRequestSize:
    return false
```

```
  # Check supported content types
  if not edge.supportedContentTypes.includes(clientRequest.contentType):
    return false

  return true

function handleFailover(failedEdge, clientRequest):
  # Remove failed edge from available list temporarily
  this.markEdgeUnavailable(failedEdge.id)

  # Get alternative edges
  alternativeEdges = this.getAvailableEdgeLocations()
    .filter(edge => edge.id !== failedEdge.id)

  if alternativeEdges.length === 0:
    throw new Error('No alternative edge locations available')

  # Re-route to best alternative
  clientInfo = this.extractClientInfo(clientRequest)
  edgeScores = this.scoreEdgeLocations(alternativeEdges, clientInfo)

  selectedEdge = this.selectOptimalEdge(edgeScores, clientRequest)

  # Log failover event
  this.logFailoverEvent(failedEdge, selectedEdge, clientRequest)

  return selectedEdge

function updateRoutingMetrics(selectedEdge, clientInfo, routingStart):
  routingMetrics = {
    edgeId: selectedEdge.id,
    clientCountry: clientInfo.country,
    clientRegion: clientInfo.region,
    routingTime: Date.now() - routingStart,
    estimatedLatency: selectedEdge.estimatedLatency,
    timestamp: Date.now()
  }

  # Update edge load
  selectedEdge.requestCount++
  selectedEdge.currentLoad = this.calculateCurrentLoad(selectedEdge)

  # Update geographic routing statistics
  this.updateGeographicStats(selectedEdge.id, clientInfo)
```

```
    # Store metrics for analysis
    this.storeRoutingMetrics(routingMetrics)
```

3. Content Optimization Algorithm

Back to Top

Purpose: Optimize content delivery through compression, format conversion, image optimization, and adaptive quality selection based on client capabilities and network conditions.

Adaptive Content Optimization:

```
OptimizationConfig = {
  compression: {
    algorithms: ['gzip', 'brotli', 'zstd'],
    qualityLevels: [1, 6, 9],              # Compression levels
    minSizeThreshold: 1024,                # 1KB minimum for compression
    contentTypes: ['text/*', 'application/json', 'application/javascript']
  },

  images: {
    formats: ['webp', 'avif', 'jpeg', 'png'],
    qualityLevels: [50, 70, 85, 95],
    resolutions: [480, 720, 1080, 1440, 2160],
    enableAdaptive: true
  },

  video: {
    codecs: ['av1', 'h265', 'h264'],
    bitrates: [500, 1000, 2000, 4000, 8000], # kbps
    resolutions: ['480p', '720p', '1080p', '4k'],
    enableABR: true                         # Adaptive bitrate streaming
  }
}

class ContentOptimizationEngine:
  constructor(config):
    this.config = config
    this.imageProcessor = new ImageProcessor()
    this.videoProcessor = new VideoProcessor()
    this.compressionEngine = new CompressionEngine()
    this.formatConverter = new FormatConverter()
    this.qualityAnalyzer = new QualityAnalyzer()
```

```
function optimizeContent(content, clientInfo, networkConditions):
  optimizationStart = Date.now()

  # Analyze content characteristics
  contentAnalysis = this.analyzeContent(content)

  # Determine optimal transformations
  optimizations = this.planOptimizations(contentAnalysis, clientInfo, networkCondition

  # Apply optimizations
  optimizedContent = this.applyOptimizations(content, optimizations)

  # Validate optimization results
  validationResult = this.validateOptimization(content, optimizedContent, optimization

  return {
    originalContent: content,
    optimizedContent: optimizedContent,
    optimizations: optimizations,
    metrics: {
      originalSize: content.size,
      optimizedSize: optimizedContent.size,
      compressionRatio: content.size / optimizedContent.size,
      optimizationTime: Date.now() - optimizationStart,
      qualityScore: validationResult.qualityScore
    }
  }

function analyzeContent(content):
  analysis = {
    type: content.type,
    size: content.size,
    format: this.detectFormat(content),
    characteristics: {}
  }

  if content.type.startsWith('image/'):
    analysis.characteristics = this.analyzeImage(content)
  else if content.type.startsWith('video/'):
    analysis.characteristics = this.analyzeVideo(content)
  else if content.type.startsWith('text/') or content.type.includes('javascript') or c
    analysis.characteristics = this.analyzeText(content)

  return analysis
```

```
function planOptimizations(contentAnalysis, clientInfo, networkConditions):
  optimizations = []

  # Compression optimization
  compressionPlan = this.planCompression(contentAnalysis, clientInfo, networkCondition
  if compressionPlan:
    optimizations.push(compressionPlan)

  # Format optimization
  formatPlan = this.planFormatConversion(contentAnalysis, clientInfo)
  if formatPlan:
    optimizations.push(formatPlan)

  # Quality optimization
  qualityPlan = this.planQualityOptimization(contentAnalysis, clientInfo, networkCondi
  if qualityPlan:
    optimizations.push(qualityPlan)

  # Resolution optimization
  resolutionPlan = this.planResolutionOptimization(contentAnalysis, clientInfo, networ
  if resolutionPlan:
    optimizations.push(resolutionPlan)

  return optimizations

function planCompression(contentAnalysis, clientInfo, networkConditions):
  # Skip compression for already compressed content
  if this.isCompressed(contentAnalysis.format):
    return null

  # Skip compression for small files
  if contentAnalysis.size < this.config.compression.minSizeThreshold:
    return null

  # Check if content type supports compression
  supportedType = this.config.compression.contentTypes.some(type =>
    contentAnalysis.type.match(new RegExp(type.replace('*', '.*')))
  )

  if not supportedType:
    return null

  # Select compression algorithm based on client support
  algorithm = this.selectCompressionAlgorithm(clientInfo.acceptEncoding)
```

```
  # Select compression level based on network conditions
  compressionLevel = this.selectCompressionLevel(networkConditions)

  return {
    type: 'compression',
    algorithm: algorithm,
    level: compressionLevel,
    priority: this.calculateCompressionPriority(contentAnalysis, networkConditions)
  }

function planFormatConversion(contentAnalysis, clientInfo):
  if contentAnalysis.type.startsWith('image/'):
    return this.planImageFormatConversion(contentAnalysis, clientInfo)
  else if contentAnalysis.type.startsWith('video/'):
    return this.planVideoFormatConversion(contentAnalysis, clientInfo)

  return null

function planImageFormatConversion(contentAnalysis, clientInfo):
  currentFormat = contentAnalysis.format

  # Determine best format based on client support
  supportedFormats = this.getSupportedImageFormats(clientInfo.userAgent)

  # Prefer modern formats for better compression
  preferredFormats = ['avif', 'webp', 'jpeg', 'png']

  for format in preferredFormats:
    if supportedFormats.includes(format) and format !== currentFormat:
      # Check if conversion would be beneficial
      expectedSavings = this.estimateFormatSavings(contentAnalysis, format)

      if expectedSavings > 0.1: # At least 10% savings
        return {
          type: 'format_conversion',
          sourceFormat: currentFormat,
          targetFormat: format,
          expectedSavings: expectedSavings,
          priority: 'medium'
        }

  return null

function planQualityOptimization(contentAnalysis, clientInfo, networkConditions):
  if not (contentAnalysis.type.startsWith('image/') or contentAnalysis.type.startsWith
```

```
    return null

  # Determine optimal quality based on network conditions
  optimalQuality = this.calculateOptimalQuality(networkConditions, clientInfo)

  # Check if quality reduction is needed
  currentQuality = contentAnalysis.characteristics.quality || 85

  if optimalQuality < currentQuality:
    return {
      type: 'quality_optimization',
      currentQuality: currentQuality,
      targetQuality: optimalQuality,
      expectedSavings: this.estimateQualitySavings(currentQuality, optimalQuality),
      priority: 'high'
    }

  return null

function calculateOptimalQuality(networkConditions, clientInfo):
  baseQuality = 85 # Default quality

  # Adjust based on network speed
  if networkConditions.bandwidth < 1000000: # < 1 Mbps
    baseQuality = 60
  else if networkConditions.bandwidth < 5000000: # < 5 Mbps
    baseQuality = 70
  else if networkConditions.bandwidth > 25000000: # > 25 Mbps
    baseQuality = 95

  # Adjust based on device type
  if clientInfo.deviceType === 'mobile':
    baseQuality = Math.min(baseQuality, 80)
  else if clientInfo.deviceType === 'tablet':
    baseQuality = Math.min(baseQuality, 85)

  # Adjust based on screen resolution
  if clientInfo.screenResolution:
    if clientInfo.screenResolution.width <= 1920:
      baseQuality = Math.min(baseQuality, 85)

  return baseQuality

function applyOptimizations(content, optimizations):
  processedContent = { ...content }
```

```
  # Sort optimizations by priority
  sortedOptimizations = optimizations.sort((a, b) => {
    priorityOrder = { 'high': 3, 'medium': 2, 'low': 1 }
    return priorityOrder[b.priority] - priorityOrder[a.priority]
  })

  for optimization in sortedOptimizations:
    try:
      processedContent = this.applyOptimization(processedContent, optimization)
    catch error:
      this.logOptimizationError(optimization, error)
      continue

  return processedContent

function applyOptimization(content, optimization):
  switch optimization.type:
    case 'compression':
      return this.applyCompression(content, optimization)

    case 'format_conversion':
      return this.applyFormatConversion(content, optimization)

    case 'quality_optimization':
      return this.applyQualityOptimization(content, optimization)

    case 'resolution_optimization':
      return this.applyResolutionOptimization(content, optimization)

    default:
      return content

function applyCompression(content, optimization):
  switch optimization.algorithm:
    case 'gzip':
      return this.compressionEngine.gzipCompress(content, optimization.level)

    case 'brotli':
      return this.compressionEngine.brotliCompress(content, optimization.level)

    case 'zstd':
      return this.compressionEngine.zstdCompress(content, optimization.level)

    default:
```

```
      throw new Error(`Unsupported compression algorithm: ${optimization.algorithm}`)

function applyImageFormatConversion(content, optimization):
  conversionOptions = {
    sourceFormat: optimization.sourceFormat,
    targetFormat: optimization.targetFormat,
    quality: optimization.quality || 85,
    preserveMetadata: false # Remove EXIF data for privacy and size
  }

  return this.formatConverter.convertImage(content, conversionOptions)

function applyQualityOptimization(content, optimization):
  if content.type.startsWith('image/'):
    return this.imageProcessor.adjustQuality(content, optimization.targetQuality)
  else if content.type.startsWith('video/'):
    return this.videoProcessor.adjustQuality(content, optimization.targetQuality)

  return content

function validateOptimization(originalContent, optimizedContent, optimizations):
  validation = {
    qualityScore: 1.0,
    sizeReduction: (originalContent.size - optimizedContent.size) / originalContent.si
    errors: [],
    warnings: []
  }

  # Check file size reduction
  if optimizedContent.size >= originalContent.size:
    validation.warnings.push('Optimization did not reduce file size')

  # Check quality degradation for media files
  if originalContent.type.startsWith('image/') or originalContent.type.startsWith('vid
    qualityScore = this.calculateQualityScore(originalContent, optimizedContent)
    validation.qualityScore = qualityScore

    if qualityScore < 0.7:
      validation.warnings.push('Significant quality degradation detected')

  # Validate file integrity
  if not this.validateFileIntegrity(optimizedContent):
    validation.errors.push('Optimized content failed integrity check')

  return validation
```

```
function calculateQualityScore(originalContent, optimizedContent):
  if originalContent.type.startsWith('image/'):
    return this.calculateImageQualityScore(originalContent, optimizedContent)
  else if originalContent.type.startsWith('video/'):
    return this.calculateVideoQualityScore(originalContent, optimizedContent)

  return 1.0 # No quality metrics for non-media content

function generateAdaptiveVariants(content, clientProfiles):
  variants = []

  for profile in clientProfiles:
    try:
      # Generate optimized variant for this client profile
      optimizations = this.planOptimizations(
        this.analyzeContent(content),
        profile.clientInfo,
        profile.networkConditions
      )

      variant = this.applyOptimizations(content, optimizations)

      variants.push({
        profile: profile,
        content: variant,
        cacheKey: this.generateVariantCacheKey(content, profile),
        optimizations: optimizations
      })

    catch error:
      this.logVariantGenerationError(profile, error)
      continue

  return variants
```

4. Content Invalidation Algorithm

☐ Back to Top

Purpose: Efficiently propagate content invalidation requests across the global CDN network while maintaining consistency and minimizing performance impact.

Distributed Cache Invalidation:

```
InvalidationConfig = {
  propagation: {
    method: 'cascade',                    # 'broadcast', 'cascade', 'selective'
    batchSize: 1000,                      # URLs per invalidation batch
    maxRetries: 3,
    retryDelay: 5000,                     # 5 seconds
    timeout: 30000                        # 30 seconds per node
  },

  priority: {
    critical: { ttl: 0, timeout: 5000 },   # Immediate invalidation
    high: { ttl: 60000, timeout: 15000 },  # 1 minute TTL
    normal: { ttl: 300000, timeout: 30000 }, # 5 minutes TTL
    low: { ttl: 3600000, timeout: 60000 }   # 1 hour TTL
  },

  validation: {
    urlPatternValidation: true,
    authorizedSourceOnly: true,
    rateLimiting: { maxPerHour: 10000, maxPerMinute: 500 }
  }
}

class ContentInvalidationManager:
  constructor(config):
    this.config = config
    this.edgeNodes = new Map()
    this.invalidationQueue = new PriorityQueue()
    this.propagationTracker = new PropagationTracker()
    this.rateLimiter = new RateLimiter(config.validation.rateLimiting)

  function invalidateContent(invalidationRequest):
    invalidationStart = Date.now()

    # Validate invalidation request
    validation = this.validateInvalidationRequest(invalidationRequest)
    if not validation.isValid:
      return { success: false, errors: validation.errors }

    # Check rate limits
    rateLimitCheck = this.rateLimiter.checkLimit(invalidationRequest.source)
    if not rateLimitCheck.allowed:
      return { success: false, error: 'rate_limit_exceeded', retryAfter: rateLimitCheck.

    # Create invalidation job
```

```
  invalidationJob = this.createInvalidationJob(invalidationRequest)

  # Add to queue with appropriate priority
  this.invalidationQueue.enqueue(invalidationJob, invalidationJob.priority)

  # Process invalidation
  result = this.processInvalidation(invalidationJob)

  return {
    success: result.success,
    invalidationId: invalidationJob.id,
    affectedNodes: result.affectedNodes,
    propagationTime: Date.now() - invalidationStart,
    status: result.status
  }

function createInvalidationJob(request):
  return {
    id: this.generateInvalidationId(),
    urls: this.normalizeUrls(request.urls),
    priority: this.determinePriority(request),
    source: request.source,
    reason: request.reason || 'manual',
    createdAt: Date.now(),

    # Invalidation strategy
    method: request.method || this.config.propagation.method,
    batchSize: request.batchSize || this.config.propagation.batchSize,

    # Tracking
    status: 'pending',
    progress: 0,
    affectedNodes: [],
    errors: []
  }

function processInvalidation(invalidationJob):
  invalidationJob.status = 'processing'

  try:
    # Determine target nodes for invalidation
    targetNodes = this.selectTargetNodes(invalidationJob.urls)

    # Group URLs into batches
    urlBatches = this.createUrlBatches(invalidationJob.urls, invalidationJob.batchSize
```

```
    # Execute invalidation across nodes
    propagationResult = this.propagateInvalidation(targetNodes, urlBatches, invalidati

    # Update job status
    invalidationJob.status = propagationResult.success ? 'completed' : 'failed'
    invalidationJob.affectedNodes = propagationResult.affectedNodes
    invalidationJob.errors = propagationResult.errors

    return propagationResult

  catch error:
    invalidationJob.status = 'failed'
    invalidationJob.errors.push(error.message)

    return {
      success: false,
      error: error.message,
      affectedNodes: [],
      status: 'failed'
    }

function selectTargetNodes(urls):
  targetNodes = new Set()

  for url in urls:
    # Find nodes that potentially have this content cached
    nodesWithContent = this.findNodesWithContent(url)

    for node in nodesWithContent:
      targetNodes.add(node)

  # Also include all edge nodes for pattern-based invalidations
  if this.hasWildcardPatterns(urls):
    allEdgeNodes = this.getAllEdgeNodes()
    for node in allEdgeNodes:
      targetNodes.add(node)

  return Array.from(targetNodes)

function propagateInvalidation(targetNodes, urlBatches, invalidationJob):
  propagationResults = {
    success: true,
    affectedNodes: [],
    errors: [],
```

```
    totalRequests: 0,
    successfulRequests: 0
  }

  # Propagate to nodes in parallel
  propagationPromises = targetNodes.map(node =>
    this.invalidateNode(node, urlBatches, invalidationJob)
  )

  # Wait for all propagations to complete
  results = await Promise.allSettled(propagationPromises)

  for i, result in results.entries():
    node = targetNodes[i]

    if result.status === 'fulfilled':
      propagationResults.affectedNodes.push(node)
      propagationResults.successfulRequests += result.value.successfulBatches
      propagationResults.totalRequests += result.value.totalBatches
    else:
      propagationResults.errors.push({
        node: node,
        error: result.reason
      })
      propagationResults.success = false

  return propagationResults

function invalidateNode(node, urlBatches, invalidationJob):
  return new Promise((resolve, reject) => {
    nodeInvalidation = {
      nodeId: node.id,
      totalBatches: urlBatches.length,
      successfulBatches: 0,
      errors: []
    }

    # Process batches sequentially to avoid overwhelming the node
    this.processBatchesSequentially(node, urlBatches, nodeInvalidation)
      .then(result => {
        # Track propagation success
        this.propagationTracker.recordNodeSuccess(invalidationJob.id, node.id, result)
        resolve(nodeInvalidation)
      })
      .catch(error => {
```

```
        # Track propagation failure
        this.propagationTracker.recordNodeFailure(invalidationJob.id, node.id, error)
        reject(error)
      })
  })

function processBatchesSequentially(node, urlBatches, nodeInvalidation):
  return new Promise(async (resolve, reject) => {
    for batch in urlBatches:
      try:
        batchResult = await this.invalidateBatch(node, batch)

        if batchResult.success:
          nodeInvalidation.successfulBatches++
        else:
          nodeInvalidation.errors.push(batchResult.error)

        # Add delay between batches to prevent overwhelming
        if batch !== urlBatches[urlBatches.length - 1]:
          await this.delay(100) # 100ms delay

      catch error:
        nodeInvalidation.errors.push({
          batch: batch,
          error: error.message
        })

    resolve(nodeInvalidation)
  })

function invalidateBatch(node, urlBatch):
  return new Promise((resolve, reject) => {
    invalidationRequest = {
      type: 'cache_invalidation',
      urls: urlBatch,
      timestamp: Date.now(),
      requestId: this.generateRequestId()
    }

    # Set timeout for node response
    timeout = setTimeout(() => {
      reject(new Error(`Node ${node.id} invalidation timeout`))
    }, this.config.propagation.timeout)

    # Send invalidation request to node
```

```
    node.sendInvalidationRequest(invalidationRequest)
      .then(response => {
        clearTimeout(timeout)

        if response.success:
          resolve({
            success: true,
            invalidatedUrls: response.invalidatedUrls,
            responseTime: response.responseTime
          })
        else:
          reject(new Error(response.error))
      })
      .catch(error => {
        clearTimeout(timeout)
        reject(error)
      })
  })

function validateInvalidationRequest(request):
  errors = []

  # Check required fields
  if not request.urls or request.urls.length === 0:
    errors.push('URLs array is required and cannot be empty')

  if not request.source:
    errors.push('Source identifier is required')

  # Validate URL patterns
  if this.config.validation.urlPatternValidation:
    for url in request.urls:
      if not this.isValidUrlPattern(url):
        errors.push(`Invalid URL pattern: ${url}`)

  # Check authorization
  if this.config.validation.authorizedSourceOnly:
    if not this.isAuthorizedSource(request.source):
      errors.push('Unauthorized invalidation source')

  # Check URL count limits
  if request.urls.length > this.config.propagation.batchSize * 10:
    errors.push(`Too many URLs in single request. Maximum: ${this.config.propagation.b

  return {
```

```
    isValid: errors.length === 0,
    errors: errors
  }

function findNodesWithContent(url):
  nodesWithContent = []

  # Check cache directories for URL presence
  for [nodeId, node] in this.edgeNodes:
    if node.hasCachedContent(url):
      nodesWithContent.push(node)

  # For pattern-based URLs, check more broadly
  if this.isWildcardPattern(url):
    matchingNodes = this.findNodesWithPatternMatch(url)
    nodesWithContent.push(...matchingNodes)

  return nodesWithContent

function determinePriority(request):
  # Check for explicit priority
  if request.priority:
    return request.priority

  # Determine priority based on URL patterns
  for url in request.urls:
    if this.isCriticalContent(url):
      return 'critical'

    if this.isHighPriorityContent(url):
      return 'high'

  # Check invalidation reason
  if request.reason === 'security' or request.reason === 'emergency':
    return 'critical'

  if request.reason === 'content_update':
    return 'high'

  return 'normal'

function createUrlBatches(urls, batchSize):
  batches = []

  for i in range(0, urls.length, batchSize):
```

```
      batch = urls.slice(i, i + batchSize)
      batches.push(batch)

    return batches

  function getInvalidationStatus(invalidationId):
    # Get job from tracking system
    job = this.propagationTracker.getJob(invalidationId)

    if not job:
      return { status: 'not_found' }

    # Calculate progress
    totalNodes = job.targetNodes.length
    completedNodes = job.completedNodes.length
    progress = totalNodes > 0 ? (completedNodes / totalNodes) * 100 : 0

    return {
      invalidationId: invalidationId,
      status: job.status,
      progress: progress,
      createdAt: job.createdAt,
      completedAt: job.completedAt,
      affectedNodes: job.affectedNodes,
      errors: job.errors,

      # Statistics
      totalUrls: job.urls.length,
      totalNodes: totalNodes,
      successfulNodes: job.completedNodes.length,
      failedNodes: job.errors.length
    }
```

5. Performance Analytics Algorithm

☐ Back to Top

Purpose: Collect, analyze, and provide insights on CDN performance metrics including cache hit rates, latency, bandwidth usage, and content popularity.

Real-time Analytics Engine:

```
AnalyticsConfig = {
  collection: {
    samplingRate: 0.1,                    # 10% sampling for detailed analytics
```

```
    metricsRetention: 2592000000,          # 30 days retention
    realTimeWindow: 300000,                # 5 minutes real-time window
    aggregationIntervals: [60000, 300000, 3600000, 86400000] # 1min, 5min, 1hour, 1day
  },

  metrics: {
    performance: ['latency', 'throughput', 'cache_hit_rate', 'error_rate'],
    business: ['bandwidth_usage', 'request_count', 'unique_visitors', 'geographic_distri
    technical: ['origin_load', 'edge_utilization', 'storage_usage', 'network_quality']
  },

  alerting: {
    thresholds: {
      cache_hit_rate: { warning: 0.8, critical: 0.7 },
      latency_p95: { warning: 200, critical: 500 },
      error_rate: { warning: 0.01, critical: 0.05 }
    }
  }
}

class PerformanceAnalyticsEngine:
  constructor(config):
    this.config = config
    this.metricsCollector = new MetricsCollector()
    this.timeSeriesDB = new TimeSeriesDatabase()
    this.alertManager = new AlertManager()
    this.reportGenerator = new ReportGenerator()
    this.anomalyDetector = new AnomalyDetector()

  function collectRequestMetrics(requestInfo, responseInfo):
    # Sample request for detailed analytics
    if not this.shouldSampleRequest():
      return

    metrics = {
      timestamp: Date.now(),
      requestId: requestInfo.id,

      # Request characteristics
      url: requestInfo.url,
      method: requestInfo.method,
      contentType: requestInfo.contentType,
      contentSize: responseInfo.contentSize,

      # Client information
```

```
    clientIP: requestInfo.clientIP,
    userAgent: requestInfo.userAgent,
    country: requestInfo.country,
    region: requestInfo.region,

    # Performance metrics
    latency: responseInfo.latency,
    cacheStatus: responseInfo.cacheStatus, # hit, miss, stale
    edgeLocation: responseInfo.edgeLocation,

    # Network metrics
    bandwidth: responseInfo.bandwidth,
    transferTime: responseInfo.transferTime,

    # Error information
    statusCode: responseInfo.statusCode,
    errorType: responseInfo.errorType
  }

  # Store metrics
  this.storeMetrics(metrics)

  # Update real-time aggregations
  this.updateRealTimeMetrics(metrics)

  # Check for anomalies
  this.checkAnomalies(metrics)

function generatePerformanceReport(timeRange, granularity = 'hour'):
  reportStart = Date.now()

  # Collect metrics for time range
  rawMetrics = this.timeSeriesDB.query({
    timeRange: timeRange,
    granularity: granularity,
    metrics: this.config.metrics.performance
  })

  # Calculate performance statistics
  performanceStats = this.calculatePerformanceStats(rawMetrics)

  # Generate geographic analysis
  geographicAnalysis = this.analyzeGeographicPerformance(rawMetrics)

  # Calculate cache efficiency
```

```
  cacheEfficiency = this.analyzeCacheEfficiency(rawMetrics)

  # Identify top content
  topContent = this.analyzeContentPopularity(rawMetrics)

  # Detect performance trends
  trends = this.detectPerformanceTrends(rawMetrics)

  # Generate insights and recommendations
  insights = this.generateInsights(performanceStats, trends)

  return {
    reportId: this.generateReportId(),
    timeRange: timeRange,
    granularity: granularity,
    generatedAt: Date.now(),
    generationTime: Date.now() - reportStart,

    performanceStats: performanceStats,
    geographicAnalysis: geographicAnalysis,
    cacheEfficiency: cacheEfficiency,
    topContent: topContent,
    trends: trends,
    insights: insights
  }

function calculatePerformanceStats(rawMetrics):
  stats = {
    latency: this.calculateLatencyStats(rawMetrics),
    throughput: this.calculateThroughputStats(rawMetrics),
    cacheHitRate: this.calculateCacheHitRate(rawMetrics),
    errorRate: this.calculateErrorRate(rawMetrics),
    bandwidth: this.calculateBandwidthStats(rawMetrics)
  }

  return stats

function calculateLatencyStats(rawMetrics):
  latencyValues = rawMetrics
    .filter(m => m.latency != null)
    .map(m => m.latency)
    .sort((a, b) => a - b)

  if latencyValues.length === 0:
    return null
```

```
  return {
    min: latencyValues[0],
    max: latencyValues[latencyValues.length - 1],
    mean: latencyValues.reduce((sum, val) => sum + val, 0) / latencyValues.length,
    median: this.calculatePercentile(latencyValues, 50),
    p95: this.calculatePercentile(latencyValues, 95),
    p99: this.calculatePercentile(latencyValues, 99),
    count: latencyValues.length
  }

function calculateCacheHitRate(rawMetrics):
  cacheStatuses = rawMetrics.map(m => m.cacheStatus)

  hitCount = cacheStatuses.filter(status => status === 'hit').length
  missCount = cacheStatuses.filter(status => status === 'miss').length
  staleCount = cacheStatuses.filter(status => status === 'stale').length

  totalRequests = hitCount + missCount + staleCount

  if totalRequests === 0:
    return null

  return {
    hitRate: hitCount / totalRequests,
    missRate: missCount / totalRequests,
    staleRate: staleCount / totalRequests,
    totalRequests: totalRequests,
    breakdown: {
      hits: hitCount,
      misses: missCount,
      stale: staleCount
    }
  }

function analyzeGeographicPerformance(rawMetrics):
  # Group metrics by geographic region
  regionMetrics = new Map()

  for metric in rawMetrics:
    region = metric.region || 'unknown'

    if not regionMetrics.has(region):
      regionMetrics.set(region, [])
```

```
    regionMetrics.get(region).push(metric)

  # Calculate performance stats for each region
  regionPerformance = []

  for [region, metrics] in regionMetrics:
    regionStats = {
      region: region,
      requestCount: metrics.length,
      latency: this.calculateLatencyStats(metrics),
      cacheHitRate: this.calculateCacheHitRate(metrics),
      errorRate: this.calculateErrorRate(metrics),
      topEdgeLocations: this.getTopEdgeLocations(metrics)
    }

    regionPerformance.push(regionStats)

  # Sort by request count
  regionPerformance.sort((a, b) => b.requestCount - a.requestCount)

  return {
    regions: regionPerformance,
    totalRegions: regionPerformance.length,
    globalStats: this.calculatePerformanceStats(rawMetrics)
  }

function analyzeCacheEfficiency(rawMetrics):
  # Analyze cache performance by content type
  contentTypeAnalysis = this.analyzeCacheByContentType(rawMetrics)

  # Analyze cache performance by URL patterns
  urlPatternAnalysis = this.analyzeCacheByUrlPattern(rawMetrics)

  # Identify cache optimization opportunities
  optimizationOpportunities = this.identifyOptimizationOpportunities(rawMetrics)

  return {
    overall: this.calculateCacheHitRate(rawMetrics),
    byContentType: contentTypeAnalysis,
    byUrlPattern: urlPatternAnalysis,
    optimizationOpportunities: optimizationOpportunities
  }

function analyzeContentPopularity(rawMetrics):
  # Group requests by URL
```

```
  urlCounts = new Map()
  urlMetrics = new Map()

  for metric in rawMetrics:
    url = metric.url

    # Count requests
    urlCounts.set(url, (urlCounts.get(url) || 0) + 1)

    # Collect metrics
    if not urlMetrics.has(url):
      urlMetrics.set(url, [])
    urlMetrics.get(url).push(metric)

  # Calculate statistics for each URL
  urlStats = []

  for [url, count] in urlCounts:
    metrics = urlMetrics.get(url)

    urlStats.push({
      url: url,
      requestCount: count,
      contentType: metrics[0].contentType,
      averageSize: metrics.reduce((sum, m) => sum + (m.contentSize || 0), 0) / metrics
      cacheHitRate: this.calculateCacheHitRate(metrics).hitRate,
      averageLatency: this.calculateLatencyStats(metrics).mean,
      bandwidth: count * (metrics[0].contentSize || 0),
      uniqueClients: new Set(metrics.map(m => m.clientIP)).size
    })

  # Sort by request count
  urlStats.sort((a, b) => b.requestCount - a.requestCount)

  return {
    topUrls: urlStats.slice(0, 100),
    totalUrls: urlStats.length,
    topContentTypes: this.getTopContentTypes(urlStats)
  }

function detectPerformanceTrends(rawMetrics):
  # Group metrics by time intervals
  timeIntervals = this.groupByTimeInterval(rawMetrics, 3600000) # 1 hour intervals

  # Calculate trends for key metrics
```

```
  trends = {
    latency: this.calculateTrend(timeIntervals, 'latency'),
    cacheHitRate: this.calculateTrend(timeIntervals, 'cacheHitRate'),
    throughput: this.calculateTrend(timeIntervals, 'throughput'),
    errorRate: this.calculateTrend(timeIntervals, 'errorRate')
  }

  return trends

function calculateTrend(timeIntervals, metric):
  # Extract metric values over time
  dataPoints = timeIntervals.map(interval => ({
    timestamp: interval.timestamp,
    value: this.calculateIntervalMetric(interval.metrics, metric)
  }))

  if dataPoints.length < 2:
    return { trend: 'insufficient_data' }

  # Calculate linear regression
  regression = this.linearRegression(dataPoints)

  # Determine trend direction
  trendDirection = 'stable'
  if regression.slope > 0.05:
    trendDirection = 'increasing'
  else if regression.slope < -0.05:
    trendDirection = 'decreasing'

  return {
    trend: trendDirection,
    slope: regression.slope,
    correlation: regression.correlation,
    dataPoints: dataPoints,
    prediction: this.predictNextValue(regression, dataPoints)
  }

function generateInsights(performanceStats, trends):
  insights = []

  # Cache hit rate insights
  if performanceStats.cacheHitRate.hitRate < 0.8:
    insights.push({
      type: 'performance',
      severity: 'warning',
```

```
      title: 'Low Cache Hit Rate',
      description: `Cache hit rate is ${(performanceStats.cacheHitRate.hitRate * 100).
      recommendation: 'Review cache TTL settings and consider preloading popular conte
    })

  # Latency insights
  if performanceStats.latency.p95 > 200:
    insights.push({
      type: 'performance',
      severity: 'warning',
      title: 'High Latency',
      description: `95th percentile latency is ${performanceStats.latency.p95}ms, abov
      recommendation: 'Investigate edge location optimization and origin server perfor
    })

  # Trend insights
  if trends.errorRate.trend === 'increasing':
    insights.push({
      type: 'reliability',
      severity: 'critical',
      title: 'Increasing Error Rate',
      description: 'Error rate is trending upward, indicating potential system issues'
      recommendation: 'Investigate error sources and implement additional monitoring'
    })

  return insights

function checkAnomalies(metrics):
  # Check for latency anomalies
  if this.anomalyDetector.detectLatencyAnomaly(metrics.latency):
    this.alertManager.triggerAlert({
      type: 'performance_anomaly',
      severity: 'warning',
      metric: 'latency',
      value: metrics.latency,
      threshold: this.anomalyDetector.getLatencyThreshold(),
      edgeLocation: metrics.edgeLocation
    })

  # Check for cache hit rate anomalies
  currentHitRate = this.getCurrentCacheHitRate()
  if currentHitRate < this.config.alerting.thresholds.cache_hit_rate.critical:
    this.alertManager.triggerAlert({
      type: 'cache_performance',
      severity: 'critical',
```

```
        metric: 'cache_hit_rate',
        value: currentHitRate,
        threshold: this.config.alerting.thresholds.cache_hit_rate.critical
      })

    # Check for error rate spikes
    currentErrorRate = this.getCurrentErrorRate()
    if currentErrorRate > this.config.alerting.thresholds.error_rate.warning:
      this.alertManager.triggerAlert({
        type: 'error_rate_spike',
        severity: currentErrorRate > this.config.alerting.thresholds.error_rate.critical
        metric: 'error_rate',
        value: currentErrorRate,
        threshold: this.config.alerting.thresholds.error_rate.warning
      })
```

Performance Optimizations

☐ Back to Top

CDN Performance Strategies

☐ Back to Top

Multi-tier Optimization Framework:

```
PerformanceOptimization = {
  caching: {
    memoryTiers: ['L1', 'L2', 'L3'],
    compressionRatio: 0.7,
    prefetchingEnabled: true,
    hotDataPromotion: true
  },

  networking: {
    httpVersion: 'http2',
    connectionReuse: true,
    multiplexing: true,
    serverPush: true
  },

  content: {
```

```
    imageOptimization: true,
    videoAdaptiveStreaming: true,
    minification: true,
    bundling: true
  }
}
```

Global Infrastructure Optimization

Back to Top

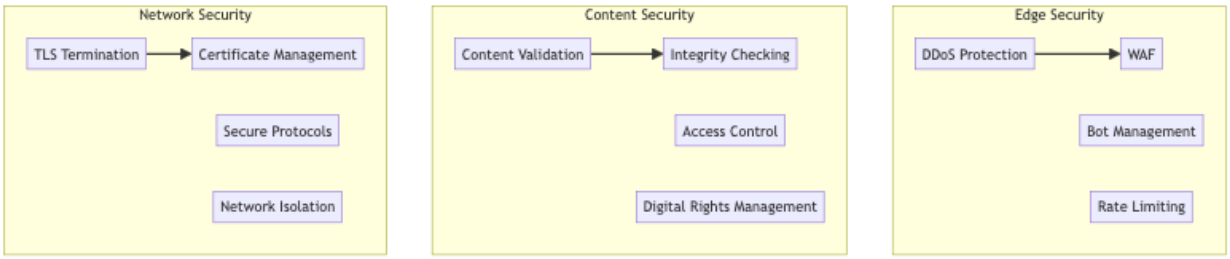
Edge Location Strategy: - Geographic distribution optimization - Network topology aware placement - Dynamic capacity scaling - Cross-region failover mechanisms

Security Considerations

Back to Top

CDN Security Framework

Back to Top



Testing Strategy

Back to Top

CDN Testing Framework

Back to Top

Comprehensive Testing Approach: - Performance testing under various load conditions - Geographic testing from multiple regions - Cache invalidation testing - Failover and disaster recovery testing - Security penetration testing

Load Testing

☐ Back to Top

Distributed Testing Environment: - Multi-region load generation - Realistic traffic pattern simulation - Cache behavior validation - Origin shielding effectiveness

Trade-offs and Considerations

☐ Back to Top

Performance vs Cost

☐ Back to Top

- **Edge location density**: Lower latency vs infrastructure cost
- **Cache storage**: Hit rate improvement vs storage expenses
- **Bandwidth**: Performance vs data transfer costs
- **Global reach**: Worldwide coverage vs operational complexity

Consistency vs Availability

☐ Back to Top

- **Cache invalidation**: Consistency vs propagation speed
- **Content updates**: Real-time updates vs cache efficiency
- **Geographic distribution**: Data consistency vs local performance
- **Failover mechanisms**: Availability vs potential inconsistency

Security vs Performance

☐ Back to Top

- **Content validation**: Security thoroughness vs processing speed
- **Access controls**: Security rigor vs user experience

- **DDoS protection**: Attack mitigation vs legitimate traffic impact
- **Encryption overhead**: Security vs performance impact

This content delivery network system provides a comprehensive foundation for global content distribution with features like intelligent caching, geographic routing, content optimization, cache invalidation, and performance analytics while maintaining high performance, security, and reliability standards.