

Cloud Test: Enterprise RAG System Architecture

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1. Assumptions

Document Volume & Characteristics

- **Total Documents:** Approximately 100,000 documents accumulated over 10+ years
- **Document Types:** 60% PDFs, 25% Word documents, 10% PowerPoint, 5% emails/other
- **Average Document Size:** 2-5 MB per document
- **Total Storage:** Approximately 300-500 GB of raw documents
- **Growth Rate:** Approximately 10,000 new documents per year (~800/month)

Update Frequency & Access Patterns

- **Batch Uploads:** Weekly bulk uploads of 50-200 documents
- **Real-time Indexing:** Required for newly added documents within 15 minutes
- **Query Volume:** Approximately 2,000-5,000 queries per day (average 3 queries/user/week)
- **Peak Usage:** Business hours (9 AM - 5 PM EST), 500 concurrent users during peaks
- **Query Distribution:** 70% simple lookups, 30% complex multi-document queries

User Access Patterns

- **Total Users:** 500 employees with authenticated access

- **Active Users:** Approximately 300 users querying monthly, approximately 80 users daily
- **Document Permissions:** 70% accessible to all, 20% department-restricted, 10% confidential
- **Mobile Access:** 30% of queries from mobile devices

Technology Stack Familiarity

- **Cloud Provider:** AWS (assumed based on enterprise adoption, US data residency)
 - **Development Team:** 3-5 engineers familiar with Python, React, cloud services
 - **Maintenance:** Preference for managed services over custom infrastructure
 - **Compliance:** SOC 2, basic data residency requirements (US-only)
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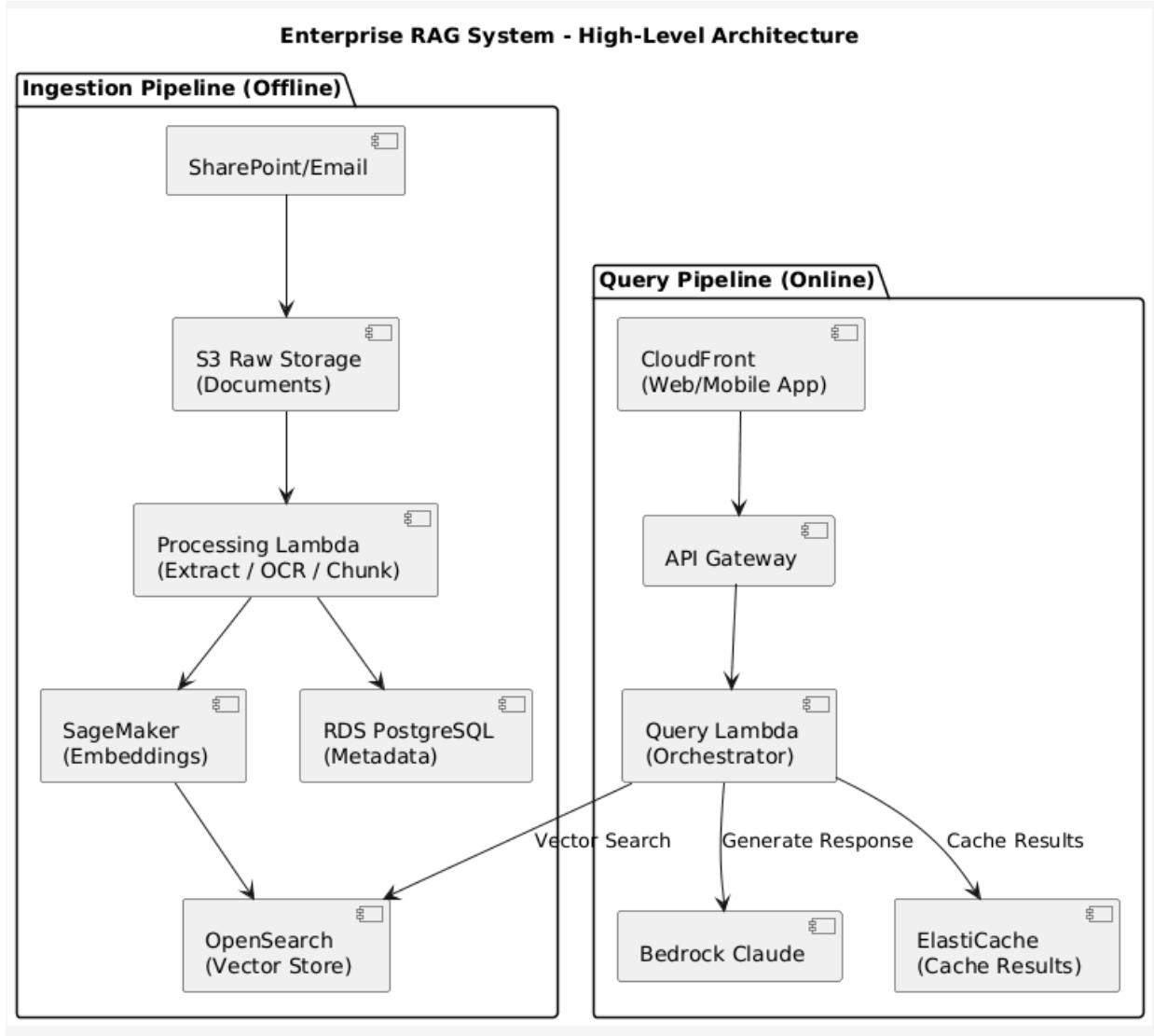
2. High-Level Architecture

System Overview

The RAG system follows a dual-pipeline architecture:

1. **Offline Ingestion Pipeline** for document processing and indexing
2. **Online Query Pipeline** for retrieval and generation

Architecture Diagram



Data Flow Summary

Ingestion Path:

Document Sources → S3 → Lambda (Extract/OCR/Chunk) →

SageMaker (Embeddings) → OpenSearch (Vector Store) + RDS (Metadata)

Query Path:

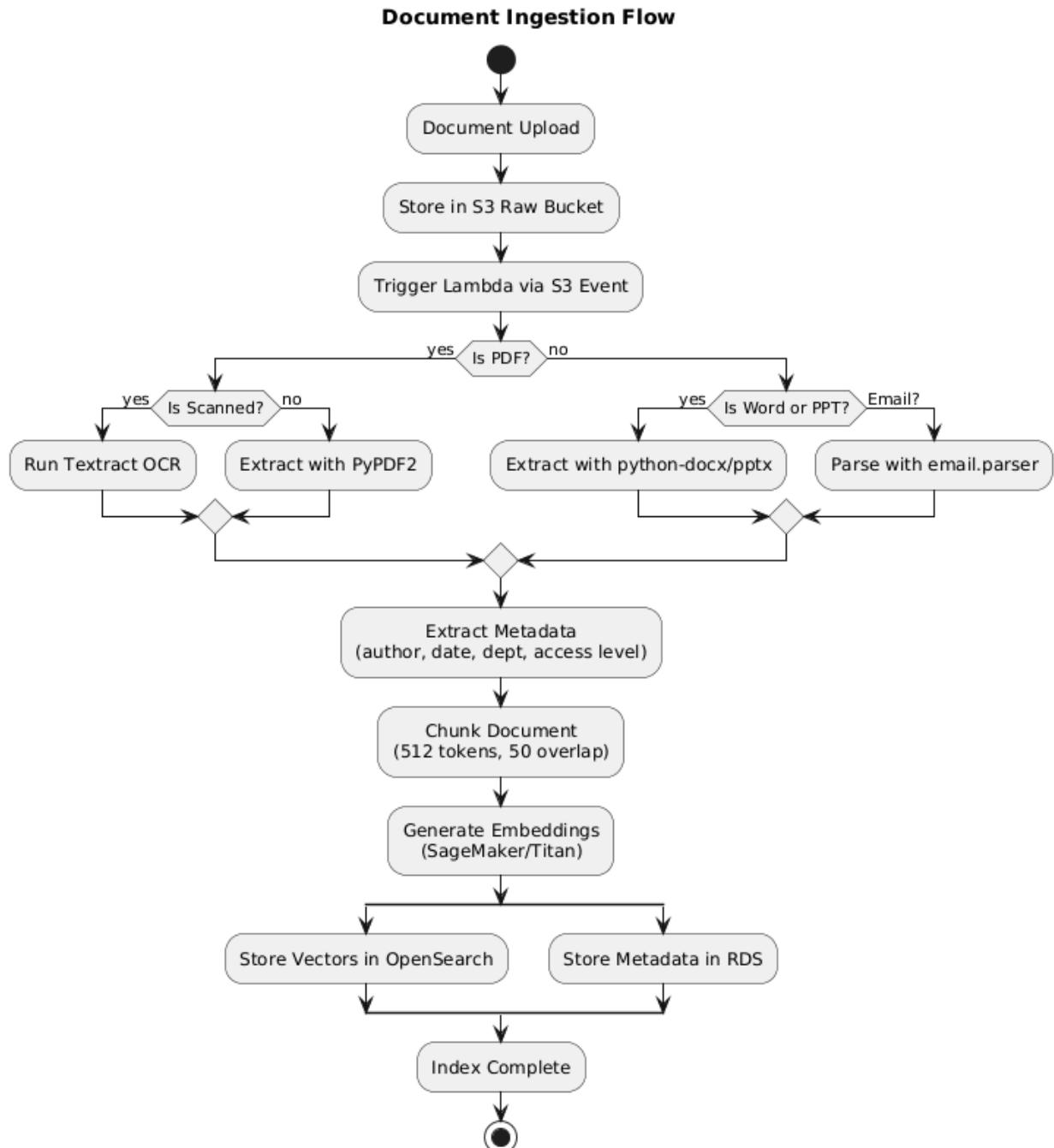
User Query → API Gateway → Lambda Orchestrator →

OpenSearch (Vector Search) → Re-rank → Bedrock Claude (Generate) →

ElastiCache (Cache) → User Response

3. Ingestion and Indexing Pipeline

Document Collection Flow



Source Integration

- Primary Sources:

- SharePoint/OneDrive API integration
- Email integration via Microsoft Graph API
- Web upload interface for ad-hoc documents
- **Implementation:**
 - AWS Lambda functions triggered by S3 events
 - Initial bulk migration: AWS DataSync or batch scripts
 - Ongoing sync: Daily scheduled Lambda pulling from SharePoint API

File Storage

- **Raw Document Storage:** S3 Standard tier
 - Bucket structure:
`s3://company-docs-raw/{year}/{department}/{document-id}`
 - Lifecycle policy: Move to S3 Glacier after 1 year
 - Versioning enabled for document updates

Document Preprocessing

Text Extraction Pipeline

- **PDF Processing:** PyPDF2 + Tesseract OCR for scanned documents
- **Word/PPT:** python-docx, python-pptx libraries
- **Email:** email.parser library for .eml files
- **Output:** Extracted plain text + metadata

Chunking Strategy

- **Chunk Size:** 512 tokens (~400 words) with 50-token overlap
- **Method:** Semantic chunking using LangChain's RecursiveCharacterTextSplitter
 - Split on paragraphs first, then sentences
 - Preserve section headers with chunks for context
- **Metadata Preservation:** Each chunk tagged with:
 - `document_id, chunk_index, source_file, page_number`
 - `department, created_date, author, access_level`
 - `document_type, project_id` (if applicable)

OCR Handling

- **Scanned PDFs:** Detected via PDF metadata or text extraction failure
- **OCR Engine:** Amazon Textract for production quality

- Cost optimization: Use async API for batch processing
- Fallback: Tesseract OCR for cost-sensitive scenarios

Embedding Generation

Model Selection

Amazon Titan Embeddings G1 or E5-large-v2

- **Reasoning:**
 - Titan: Fully managed, AWS-native, good cost/performance
 - E5-large: Higher quality, can self-host on SageMaker for cost control
- **Dimensions:** 1024 (Titan) or 768 (E5)
- **Batch Processing:** 100 chunks per API call via SageMaker batch transform

Vector Store Configuration

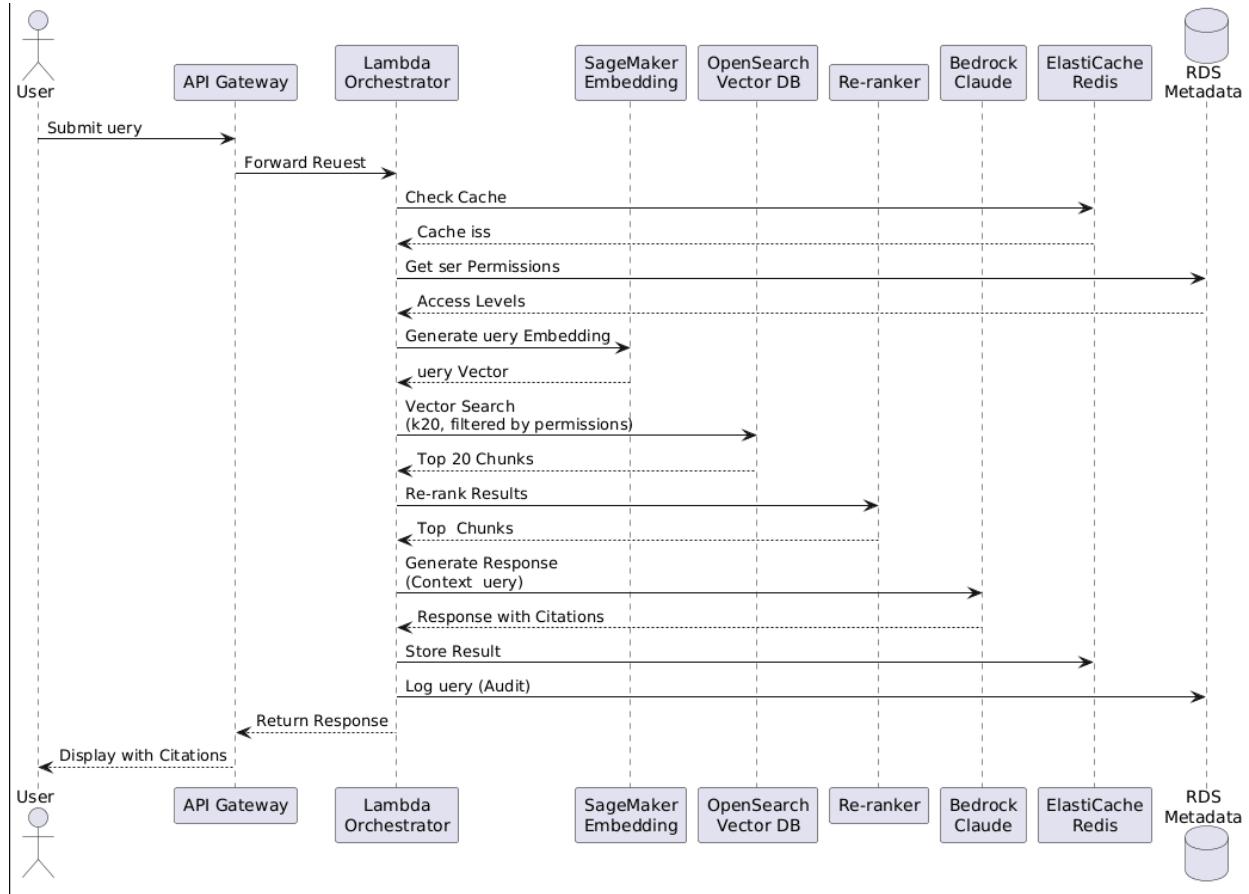
Amazon OpenSearch Serverless

- **Index Settings:**
 - Engine: k-NN with HNSW algorithm
 - Similarity: Cosine similarity
 - Dimensions: 1024
 - M (neighbors): 16, ef_construction: 512
- **Sharding:** Auto-scaled based on data volume
- **Replicas:** 2 for high availability

Alternative: Pinecone Serverless (if cost-effective at scale)

4. RAG Retrieval + Response Logic

Query Processing Flow



1. Query Embedding

- Same embedding model as documents (Titan/E5) for consistency
- Real-time inference via SageMaker endpoint (1-2 instances, auto-scaling)
- Latency target: <100ms for embedding generation

2. Vector Search Strategy

Initial Retrieval: k=20 documents

- Cosine similarity threshold: >0.7 (configurable)
- Metadata pre-filtering for access control

Hybrid Search (Optional Enhancement):

- Combine vector search (semantic) + BM25 (keyword) with 0.7:0.3 weighting

- Improves recall for specific terms (contract IDs, project names)

3. Re-ranking Strategy

Model: Cohere Rerank API or custom cross-encoder

- Input: Query + top 20 chunks
- Output: Rescored and sorted top 5-10 chunks
- Latency: ~200-500ms

Criteria:

- Semantic relevance to query
- Recency (boost documents from recent years)
- Document authority (boost official templates, final reports)

4. Context Assembly

Selected Chunks: Top 3-5 after re-ranking

- **Context Window:** ~3000 tokens for LLM (Claude 3 Sonnet: 200k context)

5. LLM Generation

Model: Amazon Bedrock - Claude 3.5 Sonnet

Reasoning:

- Best-in-class reasoning for complex queries
- Strong citation accuracy
- 200k context window handles large document sets
- AWS-native, simplified deployment

Inference Configuration:

- Temperature: 0.1 (low for factual accuracy)
- Max tokens: 1024

6. Citation Attachment

Post-processing:

- Parse LLM response for citation markers
- Validate citations against retrieved chunks
- Enrich with clickable links to original documents in S3

- Format: [Document Title, Page X](<https://link-to-doc>)

7. Response Caching

Cache Layer: Amazon ElastiCache (Redis)

- Key: Hash of (query + user_access_level)
 - TTL: 1 hour for frequently asked questions
 - Cache hit rate target: 20-30% (saves LLM costs)
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5. User Interface + Application Layer

Front-End Experience

Web Application (Primary)

Technology Stack:

- **Framework:** React 18 with TypeScript
- **UI Library:** Material-UI or Tailwind CSS
- **State Management:** React Query for API calls, Zustand for local state
- **Hosting:** AWS Amplify or S3 + CloudFront

Features:

- Clean chat interface (ChatGPT-like UX)
- Real-time typing indicators
- Inline citation cards with document previews
- Search history and saved queries
- Dark/light mode

Mobile Application

Progressive Web App (PWA):

- Same React app with responsive design
- PWA manifest for "Add to Home Screen"
- Offline support for recent queries (service workers)
- Touch-optimized interface

Document Preview

- Embedded PDF viewer (PDF.js) highlighting relevant sections

- Deep links to specific pages
- Download options (with audit logging)

Backend Services

API Gateway

AWS API Gateway (REST API):

- Rate limiting: 100 requests/minute per user
- Request validation and sanitization
- CORS configuration for web/mobile clients
- Custom domain: <https://api.knowledge.company.com>

Endpoints:

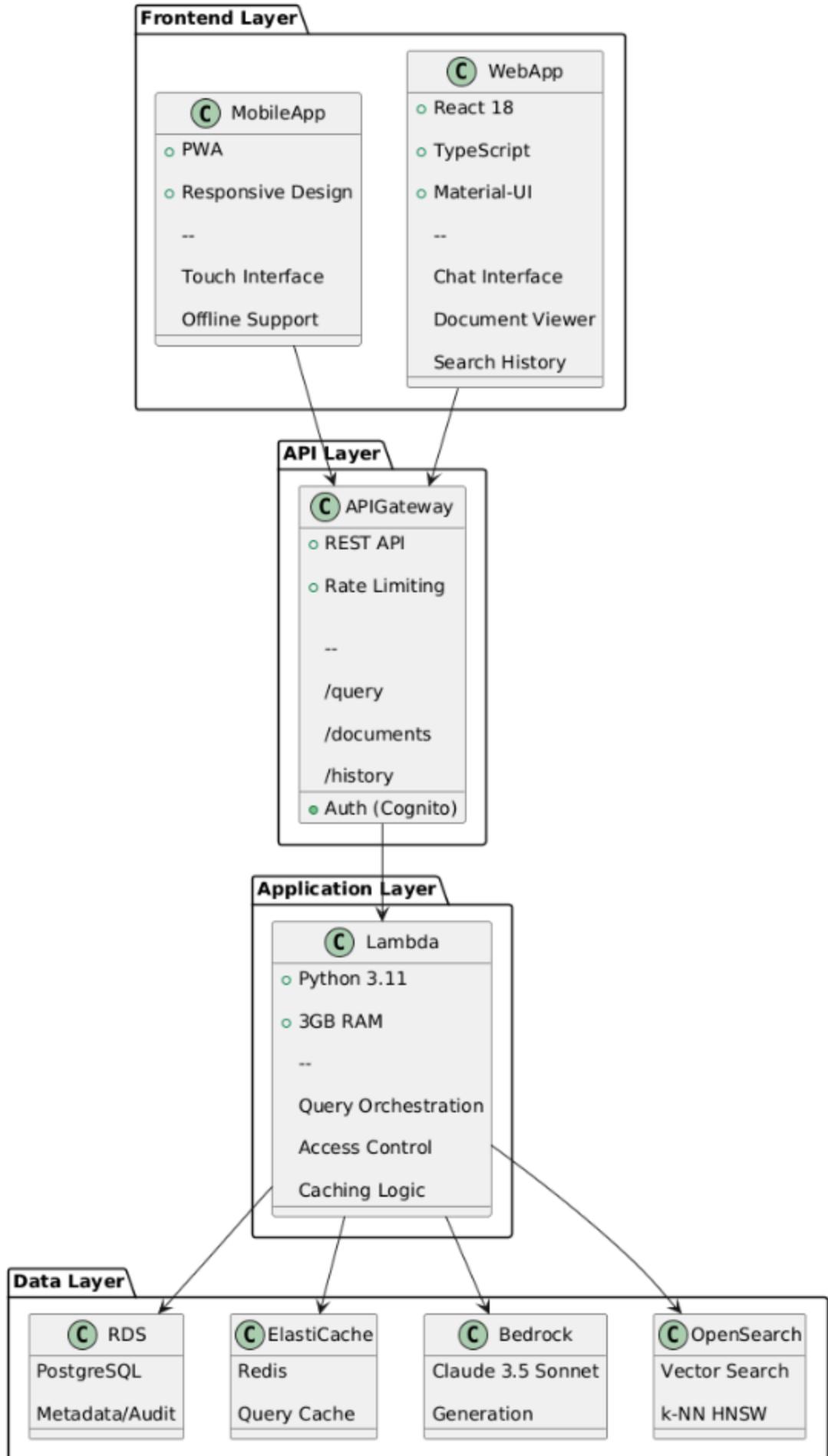
- `POST /query` - Main RAG query endpoint
- `GET /documents/{id}` - Document retrieval
- `GET /history` - User query history
- `POST /feedback` - Response quality feedback

Application Orchestrator

AWS Lambda (Recommended for cost):

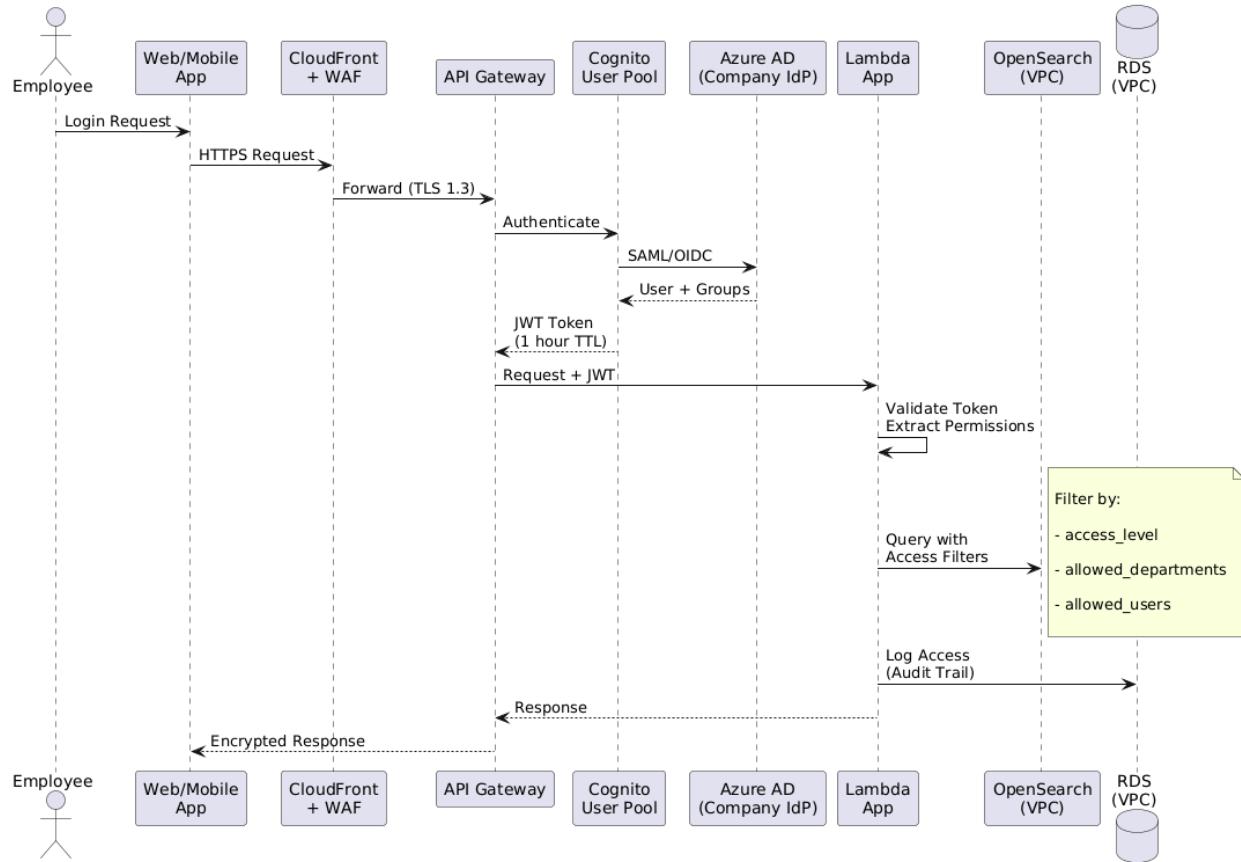
- Language: Python 3.11
- Memory: 3GB
- Timeout: 30 seconds
- Concurrency: 500 reserved (matches user count)

Component Architecture



6. Security Architecture

Authentication & Authorization Flow



Authentication: AWS Cognito

Configuration:

- **Integration:** SAML 2.0 with Azure AD/Okta (company IdP)
- **MFA:** Required for all users
- **Token Expiration:** 1 hour access tokens, 30-day refresh tokens
- **Groups:** Synced from company directory (Engineering, Sales, HR, etc.)

Document-Level Authorization

Access Control Model:

- Documents tagged with: `access_level`, `allowed_departments`, `allowed_users`
- Vector search includes metadata filters (OpenSearch query filters)
- Double-check: Post-retrieval validation before passing to LLM
- Audit: Log when access is denied

Encryption Strategy

Data at Rest:

- **S3**: SSE-S3 (AES-256) for raw documents
- **OpenSearch**: Encryption at rest enabled (AWS-managed keys)
- **RDS/DynamoDB**: Default encryption with KMS
- **KMS Key**: Customer-managed CMK for sensitive data rotation

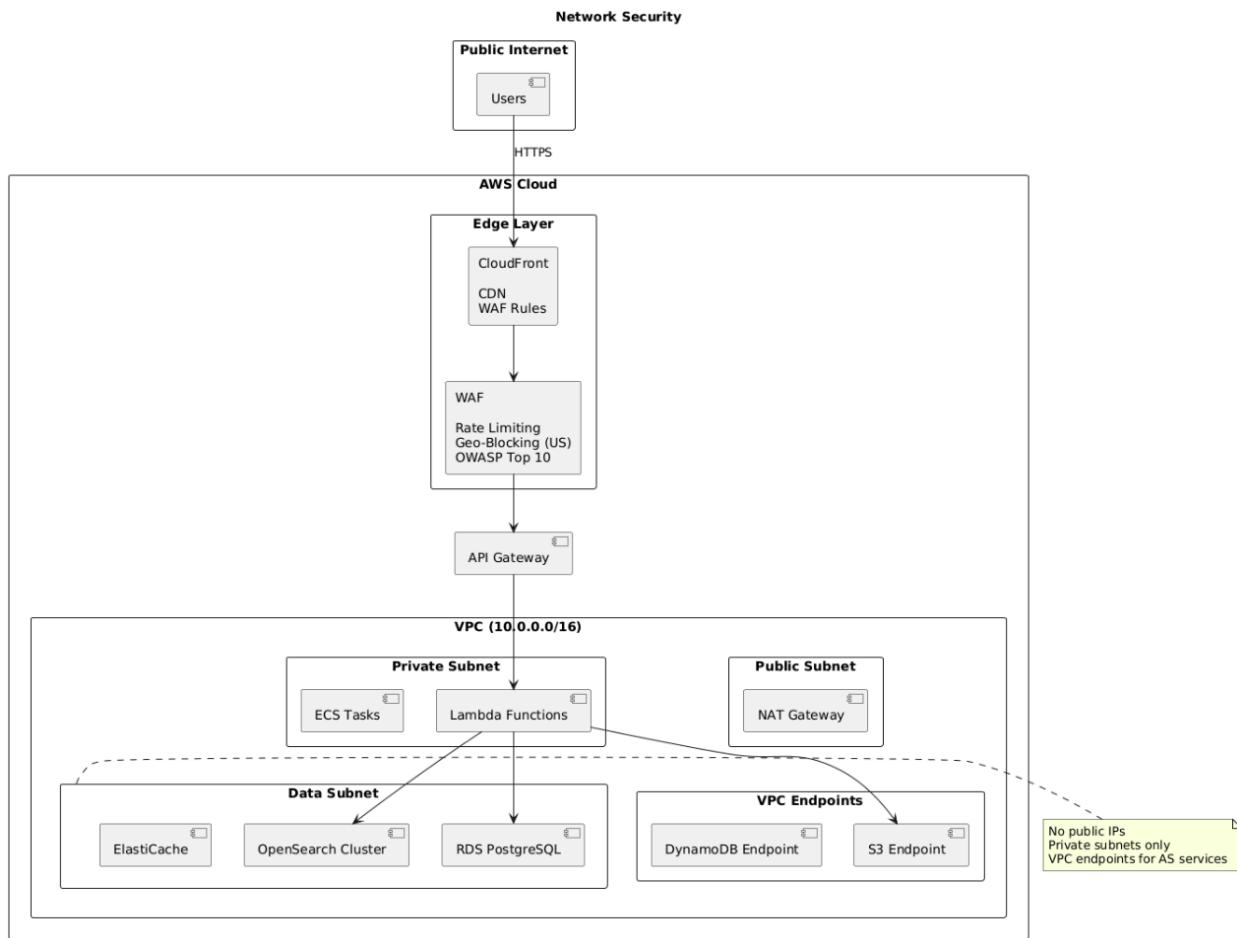
Data in Transit:

- **TLS 1.3**: All API communications
- **VPC PrivateLink**: Internal AWS service communication
- **Certificate Management**: AWS Certificate Manager (ACM)

Secrets Management:

- **AWS Secrets Manager**: API keys, database credentials
- **IAM Roles**: Preferred over long-lived credentials
- **Rotation**: Automatic 90-day rotation for DB passwords

Network Architecture



WAF Rules (AWS WAF)

- **Rate Limiting:** 2000 requests per 5 minutes per IP
- **Geo-Blocking:** US-only access (data residency requirement)
- **OWASP Top 10:** Managed rule groups for SQLi, XSS, etc.
- **IP Reputation:** AWS managed IP reputation lists

Audit Logging & Monitoring

CloudWatch Logs + S3 Archive:

- **Query Logs:** User ID, timestamp, query text, results returned, access denials
- **Document Access:** Who accessed which documents, when
- **Authentication Events:** Login attempts, MFA challenges, session expirations
- **Data Changes:** Document uploads, deletions, permission changes

Retention:

- CloudWatch: 90 days (hot access for investigations)
 - S3 Archive: 7 years (compliance requirement)
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7. Scaling Strategy

Document Volume Growth

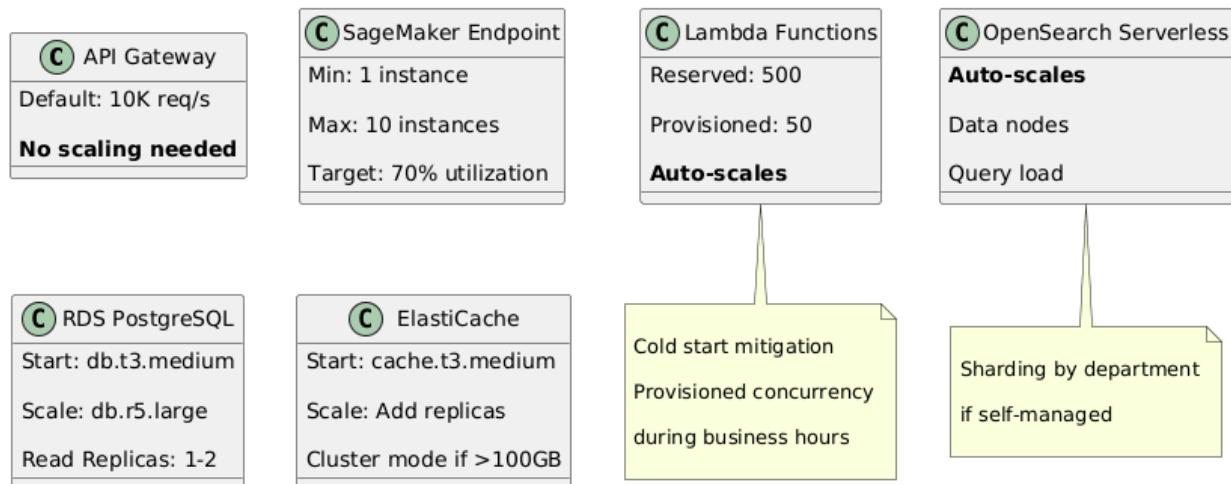
Current State (Year 1):

- Documents: 100,000
- Vectors: ~500,000 (5 chunks/document avg)
- Storage: 500 GB raw + 50 GB vectors

Projected Growth (Year 5):

- Documents: 150,000 (50% growth)
- Vectors: 750,000
- Storage: 750 GB raw + 75 GB vectors

Scaling Components



User Concurrency Scaling

Current Requirement:

- Peak Users: 500 concurrent
- Queries: ~5000/day (~350/hour during peaks)

Scaling Approach:

- **Lambda**: Reserved concurrency: 500, Provisioned: 50 (cold start elimination)
- **SageMaker**: Auto-scaling policy (70% target utilization, 2-10 instances)
- **Bedrock LLM**: Fully managed, no scaling configuration
- **ElastiCache**: Add read replicas (2-3 nodes) for read-heavy workloads

Performance Targets

Component	Target	Scaling Strategy
Query Embedding	<100ms	SageMaker auto-scaling
Vector Search	<200ms	OpenSearch compute scaling
Re-ranking	<300ms	Async processing if >500ms
LLM Generation	<3s	Use Bedrock on-demand
Total E2E	<5s	Cache frequent queries for <500ms

High Availability

Multi-AZ Deployment:

- **RDS**: Multi-AZ for automatic failover
- **OpenSearch**: 2 replicas across 3 AZs
- **ElastiCache**: Multi-AZ with automatic failover
- **Lambda**: Inherently multi-AZ

Disaster Recovery:

- **RTO**: 1 hour
- **RPO**: 15 minutes
- **Backup Strategy**:
 - S3: Versioning + cross-region replication
 - RDS: Automated backups (daily snapshots, 7-day retention)
 - OpenSearch: Automated snapshots to S3 (daily)

Uptime Target: 99.5% (allowed downtime: ~3.6 hours/month)

8. Cost Strategy

Monthly Cost Breakdown (Estimated)

Compute & Processing

Service	Configuration	Monthly Cost
Lambda (Query handling)	350K invocations, 3GB, 5s avg	\$250
Lambda (Document processing)	10K docs, 10GB, 5min avg	\$200
SageMaker Endpoint (Embeddings)	2x ml.m5.large, 50% utilization	\$500
Bedrock (Claude 3.5 Sonnet)	5M input tokens, 1M output	\$900
Subtotal		\$1,850

Storage

Service	Configuration	Monthly Cost
S3 (Raw documents)	500 GB Standard, 10 GB uploads	\$15
S3 (Processed data)	100 GB	\$3
OpenSearch Serverless	50 GB indexed, ~500K vectors	\$800
RDS PostgreSQL	db.t3.medium, 100 GB	\$120
Subtotal		\$938

Networking & Caching

Service	Configuration	Monthly Cost
CloudFront	100 GB transfer, 1M requests	\$20
API Gateway	350K requests	\$1.25
ElastiCache (Redis)	cache.t3.medium, 1 node	\$60
VPC Endpoints	3 endpoints	\$22

Service	Configuration	Monthly Cost
Data Transfer	50 GB out	\$5
Subtotal		\$108

Security & Monitoring

Service	Configuration	Monthly Cost
Cognito	500 MAU	\$14
WAF	2 rules, 350K requests	\$10
CloudWatch Logs	20 GB, 3-month retention	\$30
GuardDuty	500 GB logs	\$40
Secrets Manager	5 secrets	\$2
Subtotal		\$96

Additional Services

Service	Configuration	Monthly Cost
Step Functions	10K transitions	\$2.50
SQS	1M requests	\$0.40
Textract (OCR)	1,000 pages	\$15
EventBridge	10K events	\$0.10
Subtotal		\$18

TOTAL MONTHLY COST: ~\$3,010

Buffer for unexpected usage: ~\$500

Target Budget: \$8,000/month

Remaining Budget: ~\$4,500/month (56% under budget)

Cost Optimization Strategies

Reserved Capacity (20-40% savings):

- RDS Reserved Instance: 1-year saves ~\$40/month
- SageMaker Savings Plan: 1-year saves ~\$150/month
- ElastiCache Reserved Nodes: 1-year saves ~\$20/month
- **Total Savings:** ~\$210/month = \$2,520/year

Auto-Scaling & Right-Sizing:

- SageMaker: Scale to 1 instance during off-hours (saves ~\$150/month)
- Lambda Provisioned Concurrency: Only during business hours (saves ~\$300/month if used)

Managed vs. Self-Hosted Tradeoffs:

Option 1: Replace OpenSearch Serverless with Pinecone

- Pinecone Serverless: ~\$70/month for 500K vectors
- Savings: ~\$730/month
- Trade-off: Vendor lock-in, data egress costs

Option 2: Use Bedrock Claude 3 Haiku for simple queries

- Haiku: 80% cheaper
- Hybrid approach: Route simple queries to Haiku, complex to Sonnet
- Savings: ~\$500/month (if 60% queries can use Haiku)

Caching Strategy:

- ElastiCache Hit Rate: 30% → saves 30% of LLM API calls
 - LLM cost reduction: ~\$270/month
 - Cache cost: \$60/month
 - **Net Savings:** \$210/month
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9. Risks, Tradeoffs, and Alternatives

Design Optimizations

Primary Focus:

1. **Security & Compliance:** Document-level access control, audit logging, US data residency
2. **Cost-Effectiveness:** Under budget by 56%, managed services for lower maintenance

3. **Developer Velocity:** Familiar stack (AWS, Python, React), managed services reduce ops burden

Intentionally Deprioritized

1. Multi-Cloud Strategy

- **Why:** Adds complexity, increases costs
- **Risk:** Vendor lock-in to AWS
- **Mitigation:** Use portable abstractions (LangChain)

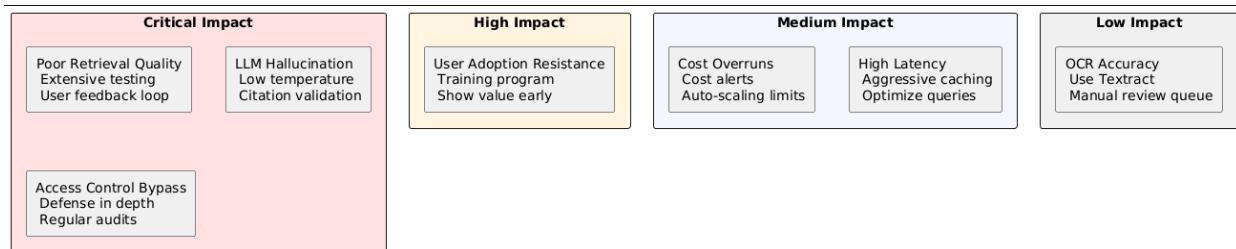
2. Advanced RAG Techniques

- **Not Implemented:** Multi-query generation, query decomposition, agentic workflows
- **Why:** Simple RAG meets 80% of use cases
- **Future:** Iterate based on user feedback

3. Real-Time Collaboration

- **Not Implemented:** Multi-user chat sessions, shared workspaces
- **Why:** Not in requirements
- **Future:** Phase 2 feature if demand exists

Key Risks & Mitigations



Risk	Impact	Probability	Mitigation
Poor retrieval quality	High	Medium	Extensive testing, A/B test chunking, feedback loop
LLM hallucination	High	Medium	Low temperature (0.1), citation validation
High latency (>10s)	Medium	Low	Aggressive caching, optimize vector search

Risk	Impact	Probability	Mitigation
OCR accuracy	Medium	Medium	Use Textract, flag low-confidence, manual review
Access control bypass	High	Low	Defense in depth, penetration testing
User adoption resistance	High	Medium	Training, gradual rollout, show value early
Cost overruns	Medium	Low	Cost alerts at 80%, auto-scaling limits

Alternative Architectures Considered

1. Self-Hosted LLM (Llama 3, Mistral)

- **Pros:** No per-token costs, full control
- **Cons:** High GPU costs (~\$2K+/month), ops burden, lower quality
- **Verdict:** Not cost-effective, revisit if query volume >50K/day

2. Hybrid Search (Vector + Traditional)

- **Pros:** Better recall for specific terms (project IDs)
- **Cons:** 2 indexes to maintain, minimal improvement for narrative queries
- **Verdict:** Consider as Phase 2 optimization

3. Fine-Tuned Embedding Model

- **Pros:** Domain-specific embeddings
- **Cons:** Requires labeled data, training costs, maintenance
- **Verdict:** Not justified for v1, revisit if retrieval quality is poor

4. GraphRAG (Knowledge Graphs)

- **Pros:** Better for relationship queries
- **Cons:** Complex to implement, minimal benefit for document-centric queries
- **Verdict:** Not suitable for this use case

Future Improvements

Phase 2 (Months 6-12):

- Multi-turn conversations with chat history

- Query suggestions based on popular queries
- Advanced filters (date range, document type, department)
- User feedback loop ("Helpful/Not Helpful" buttons)
- Analytics dashboard

Phase 3 (Year 2+):

- Proactive insights (weekly digests)
- Document summarization
- Hybrid search (vector + keyword)
- Multi-lingual support
- Fine-tuned models

Success Metrics

Technical KPIs:

- Retrieval Accuracy: >85% of queries return relevant documents
- Latency: 95th percentile <5 seconds
- Uptime: >99.5%
- Cache Hit Rate: >25%

Business KPIs:

- User Adoption: >60% of employees use system monthly within 6 months
- Query Volume: 5,000+ queries/month by month 3
- Time Savings: 30% reduction in document search time
- Cost Efficiency: Remain under \$4,000/month in Year 1

Quality KPIs:

- Citation Accuracy: >95% of citations point to correct sources
- User Satisfaction: >4.0/5.0 average rating
- False Positive Rate: <10% of responses marked "Not Helpful"

Conclusion

This RAG system architecture balances security, scalability, and cost-effectiveness for a mid-size consulting firm. By leveraging AWS managed services (Bedrock, OpenSearch Serverless, Cognito), we minimize operational overhead while maintaining enterprise-grade security controls.

The design prioritizes:

1. **Document-level access control** to protect confidential information
2. **Cost efficiency** (56% under budget with room to scale)
3. **Developer productivity** (familiar stack, managed services)
4. **Iterative improvement** (phased rollout, feedback loops)

With comprehensive monitoring, audit trails, and a clear scaling path, the system is production-ready and positioned for long-term success.

Total Estimated Cost: \$3,010/month (56% under \$8,000 budget)

Uptime Target: 99.5%

Concurrent Users: 500+

Query Latency: <5 seconds (95th percentile)