Quorus Comprehensive System Design

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Overview

Quorus is an enterprise-grade file transfer system designed for high reliability, scalability, and multi-tenant operation within corporate network environments. The system is optimized for internal corporate network transfers, providing both programmatic APIs and declarative YAML-based workflow definitions for complex file transfer orchestration with comprehensive multi-tenancy support.

Primary Use Cases

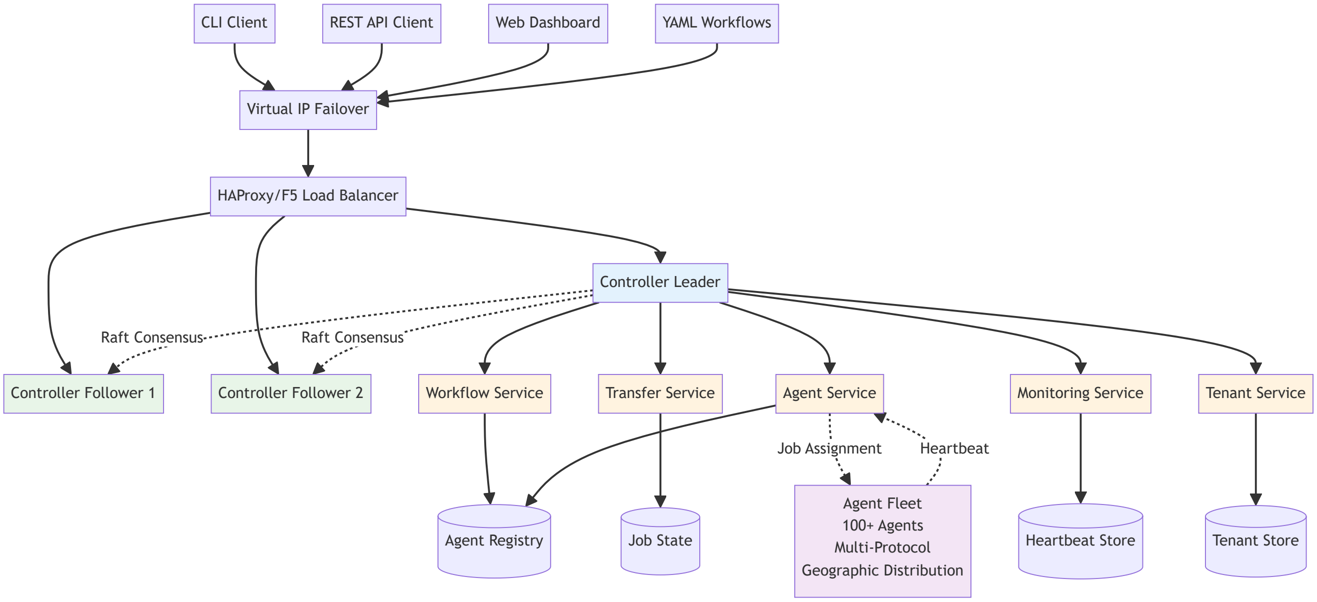
Quorus is designed primarily for **internal corporate network file transfers**, including:

- **Data center to data center** transfers within the same organization
- **Department to department** file sharing and data distribution
- **Application to application** data synchronization across internal systems
- **Backup and archival** operations within corporate infrastructure
- **ETL pipeline** data movement between internal databases and storage systems
- **Multi-tenant SaaS** file operations within controlled network environments
- **Hybrid cloud** transfers between on-premises and private cloud infrastructure

The system is architected to leverage the **high bandwidth, low latency, and trusted security** characteristics of internal corporate networks while providing enterprise-grade reliability, monitoring, and governance.

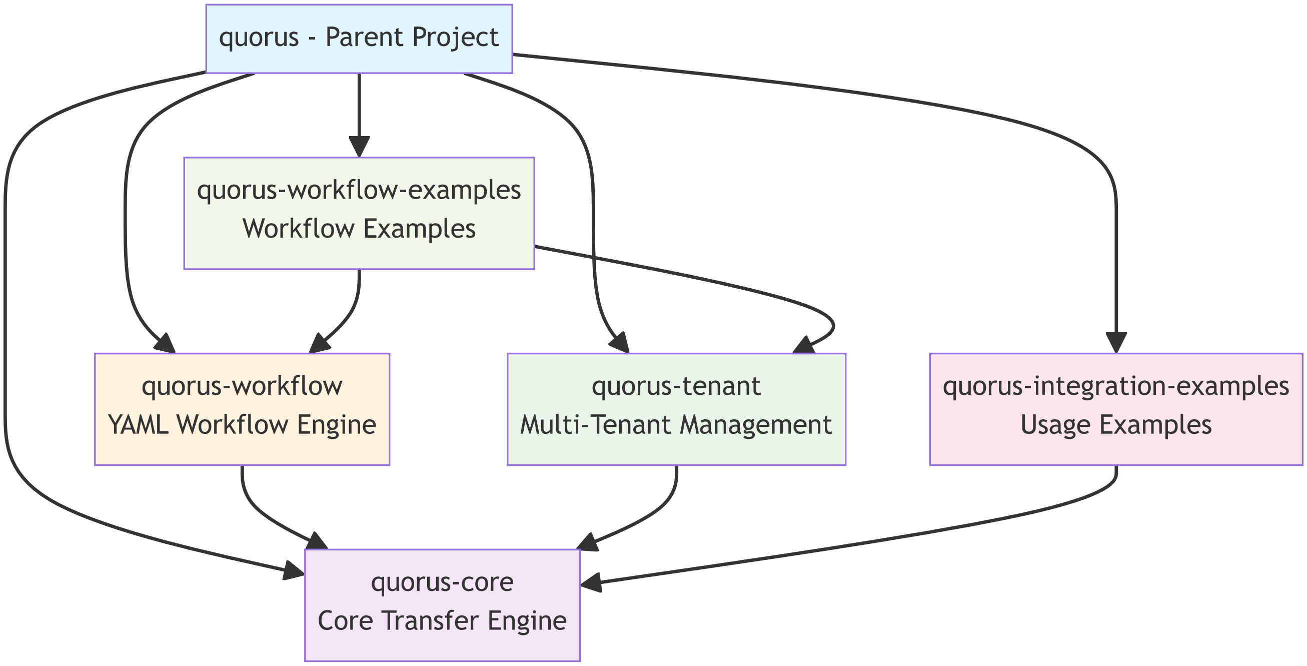
System Architecture

High-Level Distributed Architecture



Module Structure

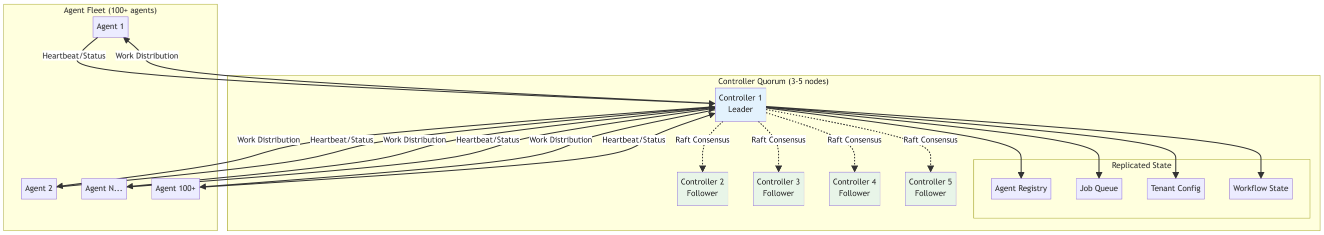
The system is organized into multiple Maven modules for clear separation of concerns:



Controller Quorum Architecture

Raft Consensus Implementation

The Quorus controller layer implements a distributed consensus system based on the Raft algorithm to ensure high availability, consistency, and fault tolerance across the controller cluster.



Key Features:

- **Leader Election**: Automatic leader election using Raft consensus algorithm
- **Log Replication**: All state changes replicated across quorum members
- **Fault Tolerance**: Tolerates (N-1)/2 failures in N-node cluster
- **Split-Brain Prevention**: Quorum-based decision making prevents split-brain scenarios
- **Consistent State**: Strong consistency guarantees for all cluster operations

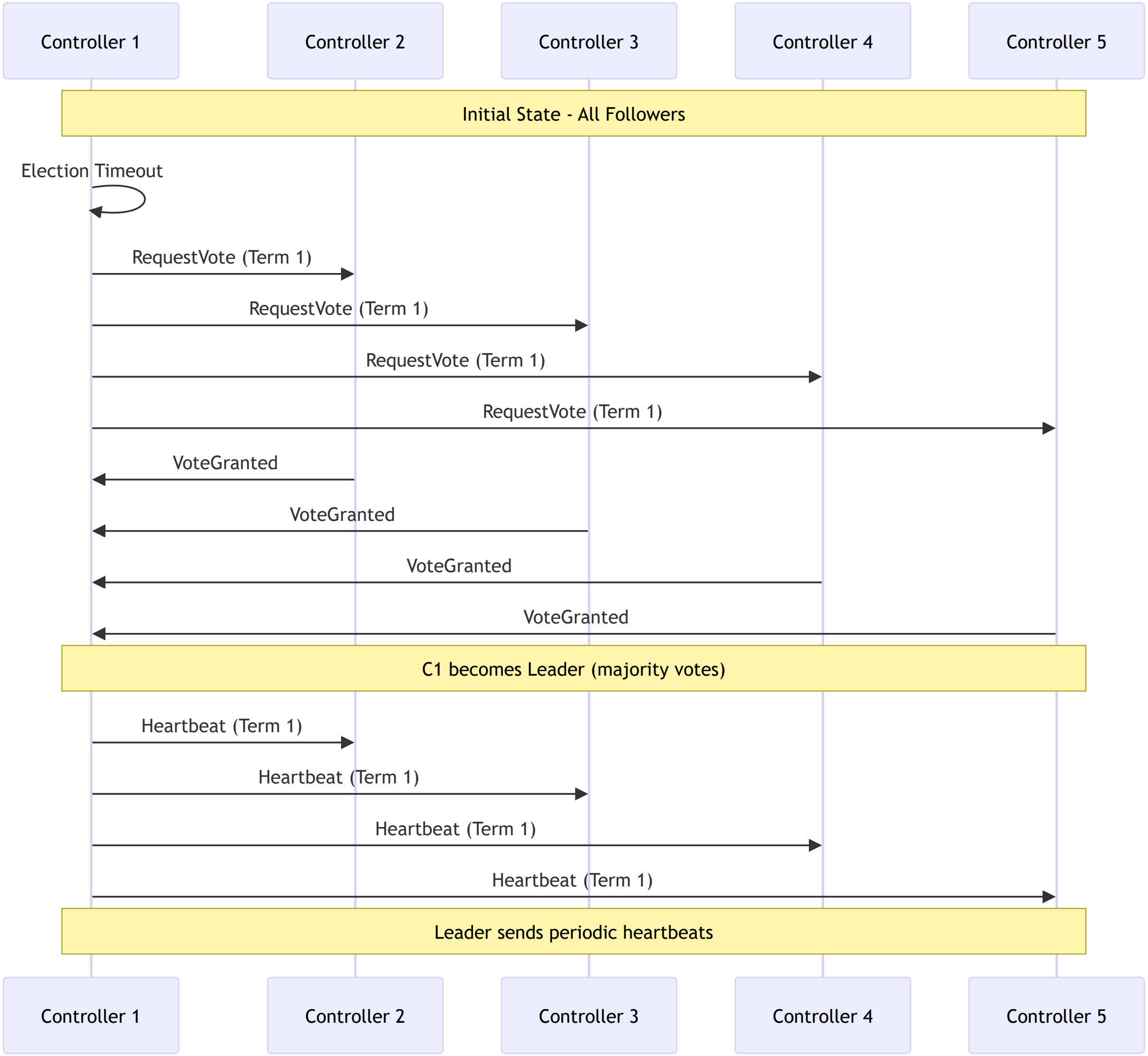
Quorum Configuration:

- **Minimum Nodes**: 3 controllers for basic HA (tolerates 1 failure)
- **Recommended**: 5 controllers for production environments (tolerates 2 failures)
- **Odd Numbers**: Always use odd number of controllers for proper quorum
- **Geographic Distribution**: Controllers distributed across availability zones
- **Network Partitioning**: Handles network partitions gracefully with majority rule

Controller Services:

- **Workflow Service**: YAML workflow parsing, validation, and orchestration
- **Transfer Service**: Transfer job management, scheduling, and lifecycle
- **Agent Service**: Agent registration, heartbeat processing, and lifecycle management
- **Monitoring Service**: System health monitoring, metrics collection, and alerting
- **Tenant Service**: Multi-tenant configuration management and isolation

Leader Election Process



Agent-Controller Communication Protocol

Agent Registration Protocol

Agents must register with the controller quorum before participating in transfer operations. The registration process establishes agent capabilities, resources, and location information.

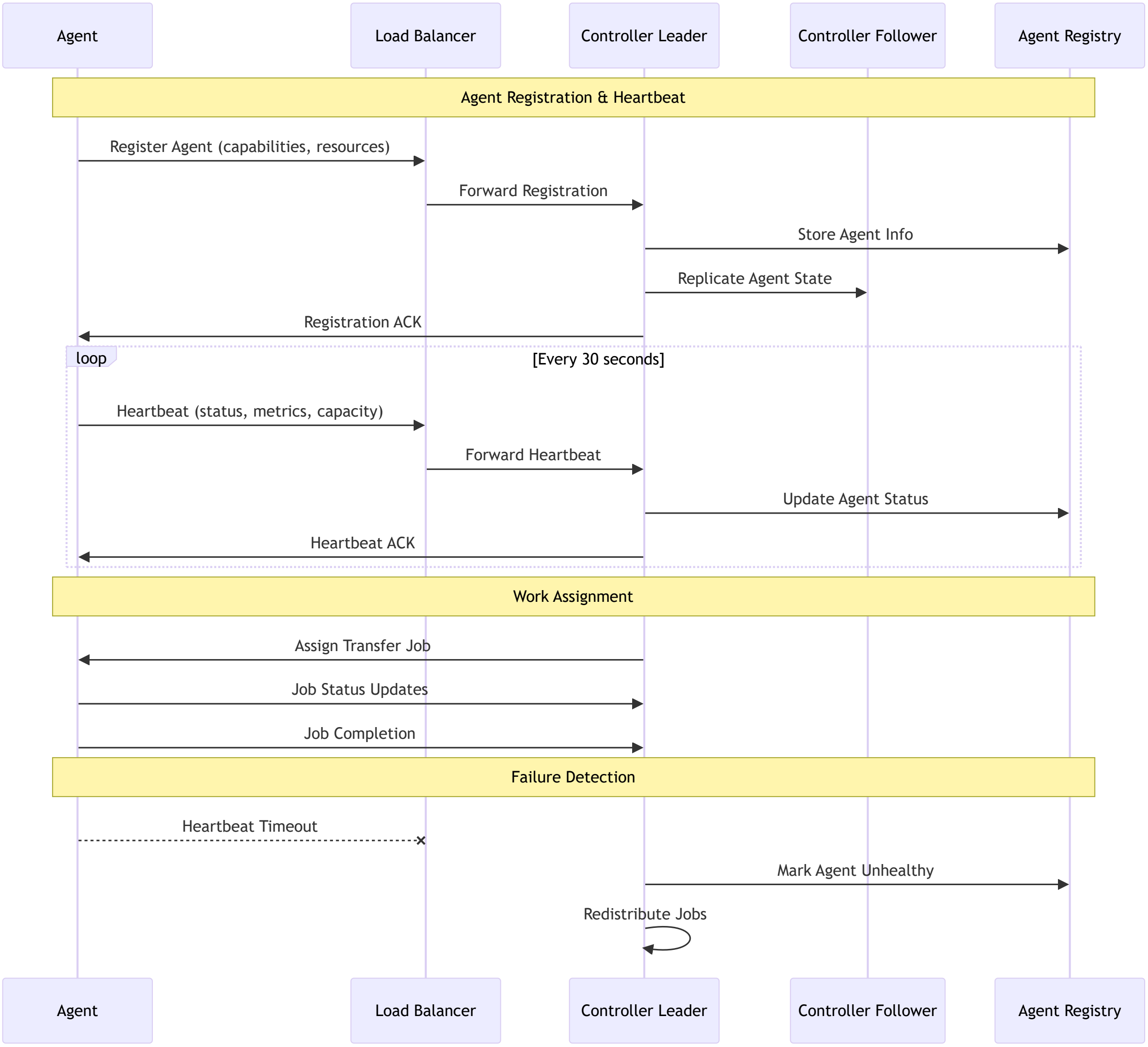
```
# Agent Registration Message
registration:
  agentId: "agent-001"
  hostname: "transfer-agent-001.corp.com"
  version: "1.0.0"
  capabilities:
    protocols: ["http", "https", "sftp", "smb", "ftp"]
    maxConcurrentTransfers: 10
    maxBandwidthMbps: 1000
    supportedFeatures: ["chunked-transfer", "resume", "compression"]
  resources:
    cpu:
      cores: 4
      architecture: "x86_64"
    memory:
      totalMB: 8192
      availableMB: 6144
    storage:
      totalGB: 1024
      availableGB: 512
    network:
      interfaces: ["eth0", "eth1"]
      totalBandwidthMbps: 1000
  location:
    datacenter: "dc-east-1"
    zone: "zone-a"
    region: "us-east"
    tags: ["production", "high-bandwidth"]
  security:
    certificateFingerprint: "sha256:abc123..."
    supportedAuthMethods: ["certificate", "token"]
```

Heartbeat Protocol

Agents send regular heartbeat messages to maintain their registration and report current status, capacity, and health metrics.

```
# Heartbeat Message (every 30 seconds)
heartbeat:
  agentId: "agent-001"
  timestamp: "2024-01-15T10:30:00Z"
  sequenceNumber: 12345
  status: "active"  # active, busy, draining, unhealthy
  currentJobs: 3
  availableCapacity: 7
  metrics:
    cpu:
      usage: 45.2
      loadAverage: [1.2, 1.5, 1.8]
    memory:
      usage: 62.1
      available: 3072
    network:
      utilization: 23.4
      bytesTransferred: 1073741824
    transfers:
      active: 3
      completed: 127
      failed: 2
  health:
    diskSpace: "healthy"
    networkConnectivity: "healthy"
    systemLoad: "normal"
  lastJobCompletion: "2024-01-15T10:28:45Z"
  nextMaintenanceWindow: "2024-01-16T02:00:00Z"
```

Communication Flow



Failure Detection and Recovery

Heartbeat Monitoring:

- **Heartbeat Interval**: 30 seconds
- **Timeout Threshold**: 90 seconds (3 missed heartbeats)
- **Grace Period**: 30 seconds for graceful shutdown
- **Health Checks**: Active health probes every 60 seconds

Failure Scenarios:

- **Agent Failure**: Jobs redistributed to healthy agents
- **Network Partition**: Agents continue current jobs, new jobs queued
- **Controller Failure**: Automatic leader election, minimal disruption
- **Partial Failure**: Degraded mode operation with reduced capacity

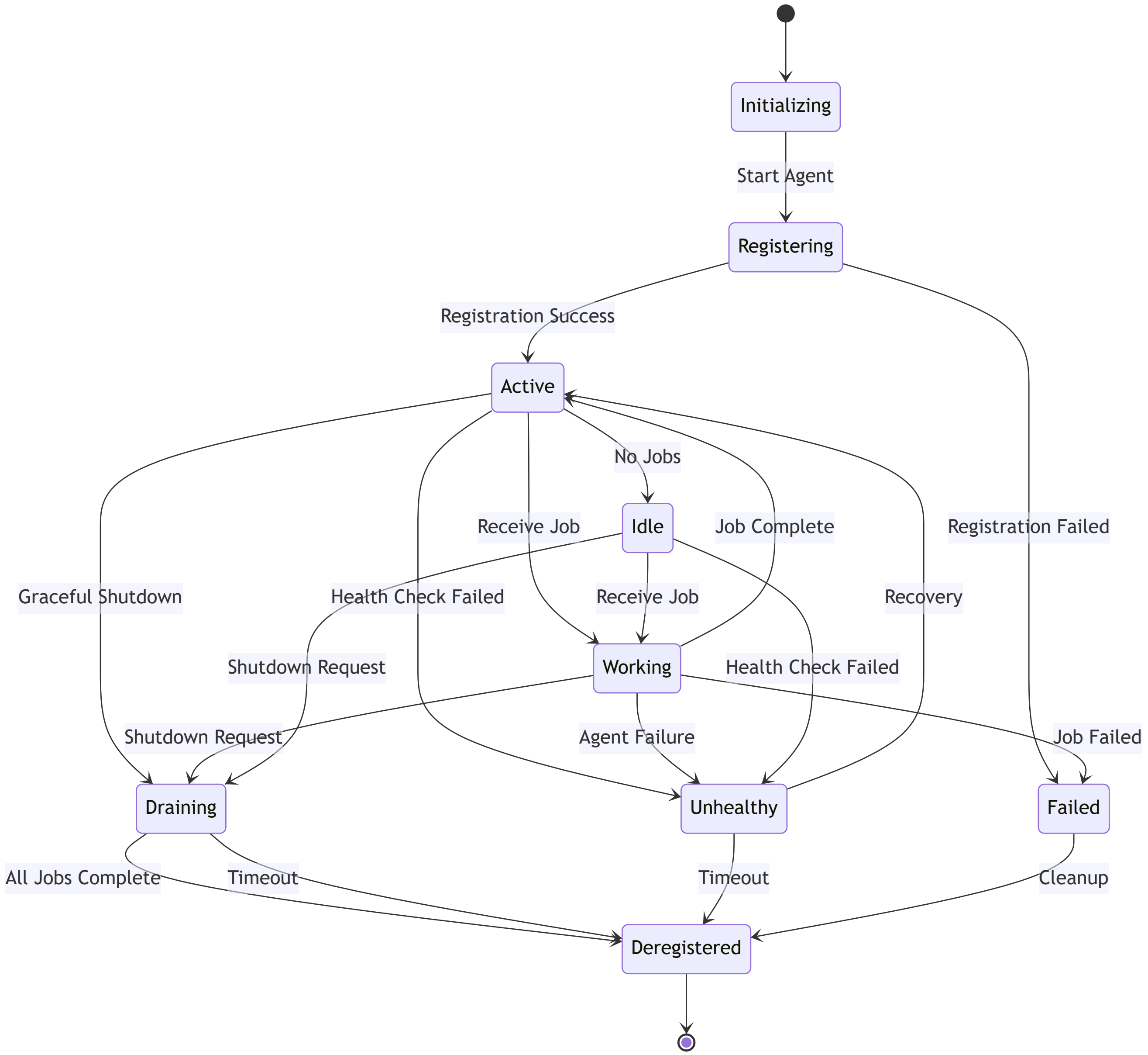
Recovery Mechanisms:

- **Automatic Recovery**: Failed jobs automatically redistributed

- **Graceful Shutdown**: 30-second drain period for active transfers
- **State Persistence**: Job state persisted for recovery after failures
- **Backpressure**: Automatic throttling when agents are overloaded

Agent Fleet Management

Agent Lifecycle Management



Agent States:

- **Initializing**: Agent starting up, loading configuration
- **Registering**: Attempting registration with controller quorum
- **Active**: Ready to receive and execute transfer jobs
- **Working**: Currently executing one or more transfer jobs
- **Idle**: No active jobs, available for new work

- **Draining**: Graceful shutdown in progress, completing current jobs
- **Unhealthy**: Failed health checks, not receiving new jobs
- **Deregistered**: Removed from agent registry

Dynamic Scaling and Load Balancing

Intelligent Work Distribution:

- **Capacity-Based**: Jobs assigned based on available agent capacity
- **Location-Aware**: Prefer agents closer to source/destination
- **Protocol-Specific**: Route jobs to agents with required protocol support
- **Load Balancing**: Even distribution across available agents
- **Affinity Rules**: Support for agent affinity and anti-affinity

Scaling Strategies:

- **Horizontal Scaling**: Add more agents to increase capacity
- **Vertical Scaling**: Upgrade agent resources (CPU, memory, bandwidth)
- **Geographic Scaling**: Deploy agents across multiple data centers
- **Protocol Scaling**: Specialized agents for specific protocols

Resource Optimization:

- **CPU Utilization**: Monitor and optimize CPU usage across agents
- **Memory Management**: Efficient memory allocation for concurrent transfers
- **Bandwidth Utilization**: Maximize network bandwidth usage
- **Storage Optimization**: Efficient temporary storage management

Scalability Architecture

Performance Targets

Agent Fleet Capacity:

- **Agent Support**: 100+ agents per controller quorum
- **Concurrent Transfers**: 10,000+ simultaneous transfers across fleet
- **Heartbeat Processing**: 1,000+ heartbeats/second
- **Job Throughput**: 100+ jobs/second assignment and completion
- **Geographic Distribution**: Multi-region deployment support

Controller Quorum Performance:

- **Request Throughput**: 10,000+ requests/second
- **State Replication**: Sub-100ms replication latency
- **Leader Election**: Sub-5 second failover time
- **Memory Usage**: Efficient in-memory state management
- **Disk I/O**: Optimized persistent storage for logs

Horizontal Scaling Strategies

Controller Scaling:

- **Quorum Expansion**: Add controllers to increase availability
- **Read Replicas**: Read-only replicas for query load distribution
- **Sharding**: Partition agents across multiple controller quorums
- **Federation**: Multiple quorums for different regions/tenants

Agent Scaling:

- **Linear Scaling**: Add agents to linearly increase transfer capacity
- **Auto-Scaling**: Automatic agent provisioning based on demand
- **Elastic Scaling**: Dynamic scaling up/down based on workload
- **Burst Capacity**: Temporary capacity increases for peak loads

Storage Scaling:

- **Distributed Storage**: Scale storage independently of compute
- **Replication**: Multi-replica storage for high availability
- **Partitioning**: Partition data across multiple storage nodes
- **Caching**: Intelligent caching for frequently accessed data

Network Architecture

High Availability Networking:

- **Load Balancers**: Multiple load balancers with failover
- **Network Redundancy**: Multiple network paths between components
- **Bandwidth Aggregation**: Combine multiple network interfaces
- **Quality of Service**: Network QoS for transfer prioritization

Security and Isolation:

- **Network Segmentation**: Isolated networks for different tenants
- **Encryption**: End-to-end encryption for all communications
- **Authentication**: Mutual TLS authentication between components
- **Authorization**: Fine-grained access control and permissions

Core Components

1. Transfer Engine (quorus-core)

The foundation of the system providing basic file transfer capabilities.

Key Components:

- `TransferEngine` : Main interface for transfer operations
- `TransferProtocol` : Pluggable protocol implementations
- `ProgressTracker` : Real-time progress monitoring
- `ChecksumCalculator` : File integrity verification

Features:

- **Internal network protocols** (HTTP/HTTPS, SMB/CIFS, NFS, FTP/SFTP)

- **High-throughput transfers** optimized for corporate network bandwidth
- **Concurrent transfer management** with intelligent scheduling
- **Retry mechanisms** with exponential backoff for network resilience
- **Progress tracking** with rate calculation and bandwidth utilization
- **SHA-256 integrity verification** for data consistency
- **Thread-safe operations** for multi-tenant environments
- **Network-aware routing** for optimal internal path selection

2. Multi-Tenant Management (quorus-tenant)

Enterprise-grade multi-tenancy with isolation and resource management.

Key Components:

- `TenantService` : Tenant lifecycle management
- `ResourceManagementService` : Quota and usage tracking
- `TenantSecurityService` : Authentication and authorization
- `TenantAwareStorageService` : Storage isolation

Features:

- Hierarchical tenant structure
- Resource quotas and limits
- Data isolation strategies
- Cross-tenant security controls
- Compliance and governance

3. YAML Workflow Engine (quorus-workflow)

Declarative workflow definition and execution system.

Key Components:

- `WorkflowDefinitionParser` : YAML parsing and validation
- `WorkflowEngine` : Workflow execution orchestration
- `DependencyResolver` : Dependency analysis and planning
- `VariableResolver` : Variable substitution and templating

Features:

- Declarative YAML definitions
- Complex dependency management
- Conditional execution
- Dry run and virtual run modes
- Variable substitution and templating

Multi-Tenancy Architecture

Core Multi-Tenancy Concepts

1. Tenant

A logical isolation boundary representing an organization, department, or business unit with its own:

- Configuration and policies
- Resource quotas and limits
- Security boundaries
- Workflow definitions
- Execution history and metrics

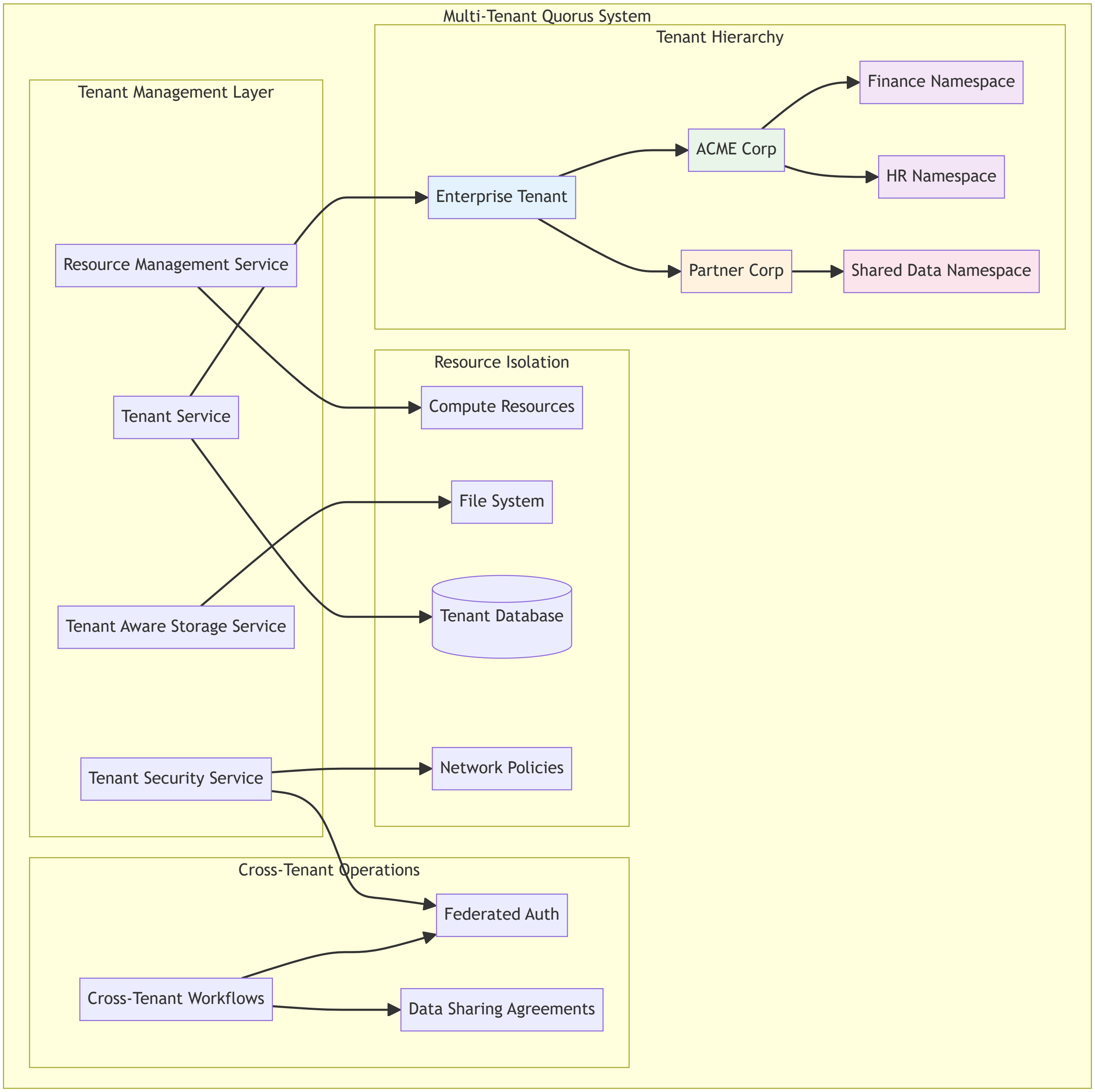
2. Tenant Hierarchy

Support for nested tenants (e.g., Company → Department → Team) with inheritance of policies and quotas.

3. Tenant Isolation Levels

- **Logical Isolation**: Shared infrastructure with data separation
- **Physical Isolation**: Dedicated resources per tenant
- **Hybrid Isolation**: Mix of shared and dedicated resources

Multi-Tenant System Architecture



1. Tenant Management Service

```
// New package: dev.mars.quorus.tenant
public interface TenantService {
    // Tenant lifecycle
    Tenant createTenant(TenantConfiguration config);
    Tenant updateTenant(String tenantId, TenantConfiguration config);
    void deleteTenant(String tenantId);

    // Tenant discovery
    Tenant getTenant(String tenantId);
    List<Tenant> getChildTenants(String parentTenantId);
    TenantHierarchy getTenantHierarchy(String tenantId);

    // Resource management
    ResourceQuota getResourceQuota(String tenantId);
    ResourceUsage getResourceUsage(String tenantId);
    boolean checkResourceLimit(String tenantId, ResourceType type, long amount);
}
```

2. Multi-Tenant Workflow Engine

```
public interface MultiTenantWorkflowEngine extends WorkflowEngine {
    // Tenant-aware execution
    WorkflowExecution execute(WorkflowDefinition definition, TenantContext context);

    // Cross-tenant operations
    WorkflowExecution executeCrossTenant(WorkflowDefinition definition,
                                       List<TenantContext> tenants);

    // Tenant isolation
    List<WorkflowExecution> getExecutions(String tenantId);
    WorkflowMetrics getMetrics(String tenantId, TimeRange range);
}
```

3. Tenant-Aware Security Service

```
public interface TenantSecurityService {
    // Authentication
    TenantPrincipal authenticate(String tenantId, AuthenticationToken token);

    // Authorization
    boolean authorize(TenantPrincipal principal, String resource, String action);

    // Data protection
    EncryptionKey getTenantEncryptionKey(String tenantId);
    String encryptForTenant(String tenantId, String data);
    String decryptForTenant(String tenantId, String encryptedData);

    // Cross-tenant security
    boolean isCrossTenantAllowed(String sourceTenant, String targetTenant);
    DataSharingAgreement getDataSharingAgreement(String tenant1, String tenant2);
}
```

4. Resource Management Service

```
public interface ResourceManagementService {
    // Quota management
    boolean reserveResources(String tenantId, ResourceRequest request);
    void releaseResources(String tenantId, ResourceRequest request);

    // Usage tracking
    void recordUsage(String tenantId, ResourceUsage usage);
    ResourceMetrics getUsageMetrics(String tenantId, TimeRange range);

    // Billing and cost allocation
    CostReport generateCostReport(String tenantId, TimeRange range);
    void allocateCosts(String tenantId, TransferExecution execution);
}
```

YAML Workflow System

Core Concepts

1. Transfer Definition

A single file transfer operation with source, destination, and metadata.

2. Transfer Group

A collection of related transfers that can be executed with dependencies, sequencing, and shared configuration.

3. Transfer Workflow

A higher-level orchestration of transfer groups with complex dependency trees, triggers, and conditional execution.

4. Transfer Plan

The resolved execution plan after dependency analysis and validation.

YAML Schema Design

Single Transfer Definition

```yaml
# transfer-internal-data.yaml
apiVersion: quorus.dev/v1
kind: Transfer
metadata:
  name: internal-data-sync
  description: "Sync customer data from CRM to data warehouse"
  tenant: acme-corp              # Tenant identifier
  namespace: finance             # Sub-tenant/namespace
  labels:
    environment: production
    priority: high
    team: data-ops
    dataClassification: confidential
    costCenter: "CC-12345"
    networkZone: "internal-dmz"
  annotations:
    created-by: "john.doe@company.com"
    ticket: "JIRA-12345"

spec:
  source:
    # Internal corporate API endpoint
    uri: "https://crm-internal.acme-corp.local/api/customers/export"
    protocol: https
    authentication:
      type: service-account      # Internal service account
      serviceAccount: "quorus-data-sync"
    headers:
      X-Internal-Service: "quorus"
      X-Data-Classification: "${metadata.labels.dataClassification}"
      X-Network-Zone: "${metadata.labels.networkZone}"
    timeout: 300s
    # Internal network optimization
    networkOptimization:
      useInternalRouting: true
      preferredDataCenter: "dc-east-1"

  destination:
    # Internal corporate storage path
    path: "/corporate-storage/data-warehouse/customers/customers-${date:yyyy-MM-dd}.json"
    protocol: nfs                # Internal NFS mount
    createDirectories: true
    permissions: "640"           # Corporate security standard
    # Corporate encryption standards
    encryption:
      enabled: true
      algorithm: "AES-256-GCM"
      keySource: "corporate-kms"
      keyId: "${tenant.security.keyManagement.keyId}"

  validation:
    expectedSize:
      min: 10MB                  # Larger internal datasets
      max: 5GB
    checksum:
      algorithm: "SHA-256"
      required: true
    # Internal data quality checks
    dataQuality:
      validateSchema: true
      schemaVersion: "v2.1"
      rejectOnValidationFailure: true

  retry:
    maxAttempts: 5               # More retries for internal reliability
    backoff: exponential
    initialDelay: 500ms          # Faster retry for internal network
    maxDelay: 10s

  # Corporate monitoring integration
  monitoring:
    enabled: true
    progressReporting: true
    metricsEnabled: true
    alertOnFailure: true
    # Corporate monitoring systems
    integrations:
      splunk: true
      datadog: true
      corporateSOC: true
    tags:
      tenant: "${tenant.id}"
      namespace: "${metadata.namespace}"
      costCenter: "${metadata.labels.costCenter}"
      networkZone: "${metadata.labels.networkZone}"
      dataClassification: "${metadata.labels.dataClassification}"
```

Transfer Group Definition

```
# backup-workflow.yaml
apiVersion: quorus.dev/v1
kind: TransferGroup
metadata:
  name: daily-backup-workflow
  description: "Daily backup workflow for critical data"
  tenant: acme-corp
  namespace: finance
  labels:
    schedule: daily
    criticality: high

spec:
```

```yaml
# Execution strategy
execution:
  strategy: sequential  # sequential, parallel, mixed
  maxConcurrency: 3
  timeout: 3600s
  continueOnError: false

# Shared configuration
defaults:
  retry:
    maxAttempts: 3
    backoff: exponential
  monitoring:
    progressReporting: true

# Variable definitions
variables:
  BACKUP_DATE: "${date:yyyy-MM-dd}"
  BACKUP_ROOT: "${tenant.storage.root}/backup/${BACKUP_DATE}"
  AUTH_TOKEN: "${env:API_TOKEN}"

# Transfer definitions
transfers:
  - name: user-data
    source:
      uri: "https://api.company.com/users/export"
      headers:
        Authorization: "${AUTH_TOKEN}"
    destination:
      path: "${BACKUP_ROOT}/users.json"
    dependsOn: []

  - name: order-data
    source:
      uri: "https://api.company.com/orders/export"
      headers:
        Authorization: "${AUTH_TOKEN}"
    destination:
      path: "${BACKUP_ROOT}/orders.json"
    dependsOn: ["user-data"]  # Wait for user-data to complete

  - name: analytics-data
    source:
      uri: "https://analytics.company.com/export"
    destination:
      path: "${BACKUP_ROOT}/analytics.json"
    dependsOn: ["user-data", "order-data"]
    condition: "${user-data.success} && ${order-data.success}"

# Post-execution actions
onSuccess:
  - action: notify
    target: "slack://data-ops-channel"
    message: "Daily backup completed successfully"
  - action: cleanup
    target: "/backup"
    retentionDays: 30

onFailure:
  - action: notify
    target: "email://ops-team@company.com"
    message: "Daily backup failed: ${error.message}"
  - action: rollback
    strategy: deletePartial
```

Multi-Tenant Workflow Definition

```yaml
# multi-tenant-workflow.yaml
apiVersion: quorus.dev/v1
kind: TransferWorkflow
metadata:
  name: cross-tenant-data-sync
  tenant: enterprise            # Parent tenant

spec:
  # Multi-tenant execution
  tenants:
    - name: acme-corp
      namespace: finance
      role: source              # source, destination, both

    - name: partner-corp
      namespace: shared-data
      role: destination

  # Tenant-specific execution policies
  execution:
    isolation: logical          # logical, physical, hybrid
    crossTenantAllowed: true
    approvalRequired: true
    dryRun: false
    virtualRun: false
    parallelism: 5
    timeout: 7200s

  # Cross-tenant security
  security:
    # Data sharing agreements
    dataSharing:
      agreements: ["DSA-2024-001"]
      dataClassification: "internal"
      retentionPolicy: "30d"

    # Cross-tenant authentication
    authentication:
      federatedAuth: true
      trustedTenants: ["partner-corp"]

  # Environment-specific variables
  environments:
    production:
      SOURCE_DB: "prod-db.company.com"
      TARGET_STORAGE: "s3://prod-backup"
    staging:
      SOURCE_DB: "staging-db.company.com"
      TARGET_STORAGE: "s3://staging-backup"

  groups:
    - name: extract-acme-data
      tenant: acme-corp
      namespace: finance
      transferGroup:
        spec:
          transfers:
            - name: customer-export
              source:
                uri: "${acme-corp.api.endpoint}/customers"
                authentication:
                  type: tenant-oauth2
              destination:
                path: "${shared.storage}/acme-customers.json"

    - name: sync-to-partner
      tenant: partner-corp
      namespace: shared-data
      dependsOn: ["extract-acme-data"]
      condition: "${acme-corp.dataSharing.approved}"
      transferGroup:
        spec:
          transfers:
            - name: partner-import
              source:
                path: "${shared.storage}/acme-customers.json"
              destination:
                uri: "${partner-corp.api.endpoint}/import"
                authentication:
                  type: tenant-oauth2

  # Workflow triggers
  triggers:
    - name: schedule
      type: cron
      schedule: "0 2 * * *"  # Daily at 2 AM
      timezone: "UTC"

    - name: file-watcher
      type: fileSystem
      path: "/incoming/trigger.flag"
      action: create

  # Validation rules
  validation:
    - name: source-connectivity
      type: connectivity
      targets: ["${SOURCE_DB}"]

    - name: storage-capacity
      type: diskSpace
      path: "/staging"
      required: 10GB

    - name: dependency-check
      type: yamlDependencies
      recursive: true
```

Tenant Configuration

```yaml
# tenant-config.yaml
apiVersion: quorus.dev/v1
kind: TenantConfiguration
metadata:
  name: acme-corp
  namespace: enterprise
  labels:
    tier: premium
    region: us-east-1
    industry: finance

spec:
  # Tenant hierarchy
  hierarchy:
    parent: null  # Root tenant
    children: ["acme-corp-finance", "acme-corp-hr", "acme-corp-it"]
```

```yaml
# Resource quotas and limits
resources:
  quotas:
    # Transfer limits
    maxConcurrentTransfers: 50
    maxDailyTransfers: 1000
    maxMonthlyDataTransfer: 10TB
    maxFileSize: 5GB

    # Storage limits
    maxStorageUsage: 1TB
    maxRetentionDays: 365

    # Compute limits
    maxCpuCores: 16
    maxMemoryGB: 64
    maxBandwidthMbps: 1000

  # Resource allocation strategy
  allocation:
    strategy: shared  # shared, dedicated, hybrid
    priority: high    # low, medium, high, critical

# Security policies
security:
  # Network access controls
  networking:
    allowedSourceCIDRs: ["10.0.0.0/8", "192.168.0.0/16"]
    allowedDestinations: ["s3://acme-corp-*", "/data/acme-corp/*"]
    requireVPN: true
    allowCrossRegion: false

  # Authentication and authorization
  authentication:
    provider: "oauth2"  # oauth2, saml, ldap, api-key
    endpoint: "https://auth.acme-corp.com"

  authorization:
    rbac:
      enabled: true
      defaultRole: "transfer-user"
      adminRole: "transfer-admin"

  # Data protection
  dataProtection:
    encryptionAtRest: true
    encryptionInTransit: true
    encryptionAlgorithm: "AES-256"
    keyManagement: "aws-kms"  # aws-kms, azure-kv, vault

# Compliance and governance
governance:
  # Data classification
  dataClassification:
    defaultLevel: "internal"
    allowedLevels: ["public", "internal", "confidential"]

  # Audit and compliance
  audit:
    enabled: true
    retentionDays: 2555  # 7 years
    exportFormat: "json"

  compliance:
    frameworks: ["SOX", "GDPR", "HIPAA"]
```

```
      dataResidency: "us-east-1"
      crossBorderTransfer: false

  # Monitoring and alerting
  monitoring:
    # Metrics collection
    metrics:
      enabled: true
      granularity: "1m"
      retention: "90d"

    # Alerting configuration
    alerting:
      channels:
        - type: "slack"
          webhook: "https://hooks.slack.com/acme-corp"
        - type: "email"
          recipients: ["ops@acme-corp.com"]
        - type: "webhook"
          endpoint: "https://monitoring.acme-corp.com/alerts"

      thresholds:
        errorRate: 5%
        quotaUsage: 80%
        transferLatency: 30s

  # Workflow defaults
  defaults:
    # Default retry policy
    retry:
      maxAttempts: 3
      backoff: exponential
      initialDelay: 1s

    # Default validation
    validation:
      checksumRequired: true
      sizeValidation: true

    # Default monitoring
    monitoring:
      progressReporting: true
      metricsEnabled: true
```

Workflow Engine Architecture

Core Components

1. YAML Parser & Validator

```
// New package: dev.mars.quorus.workflow
public interface WorkflowDefinitionParser {
    WorkflowDefinition parse(Path yamlFile) throws WorkflowParseException;
    ValidationResult validate(WorkflowDefinition definition);
    DependencyGraph buildDependencyGraph(List<WorkflowDefinition> definitions);
}
```

2. Workflow Engine

```java
public interface WorkflowEngine {
    WorkflowExecution execute(WorkflowDefinition definition, ExecutionContext context);
    WorkflowExecution dryRun(WorkflowDefinition definition, ExecutionContext context);
    WorkflowExecution virtualRun(WorkflowDefinition definition, ExecutionContext context);

    // Monitoring and control
    WorkflowStatus getStatus(String executionId);
    boolean pause(String executionId);
    boolean resume(String executionId);
    boolean cancel(String executionId);
}
```

3. Dependency Resolver

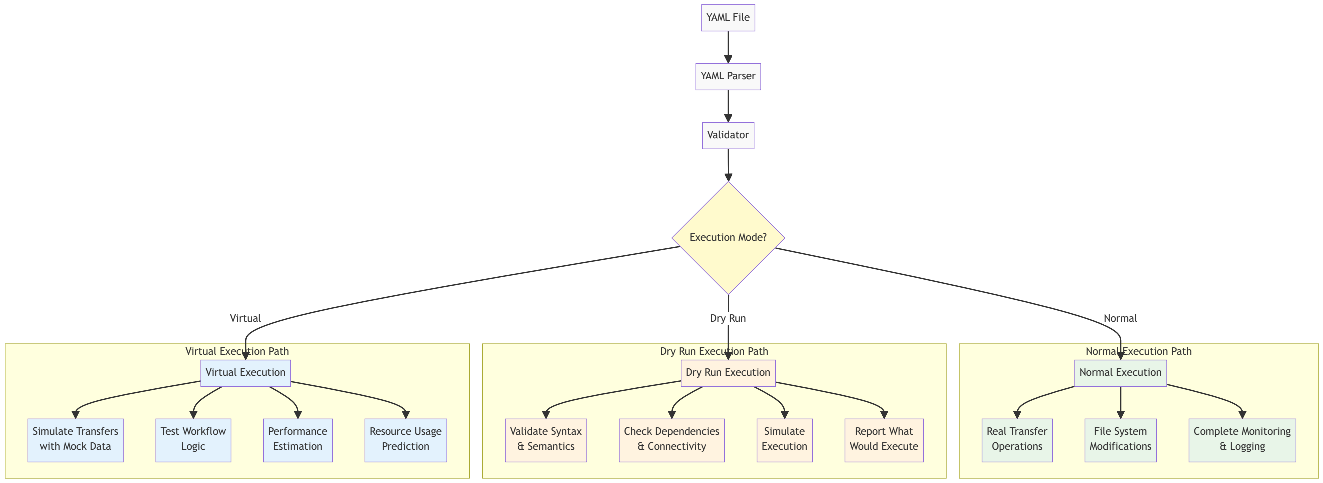
```java
public interface DependencyResolver {
    ExecutionPlan resolve(List<WorkflowDefinition> definitions);
    ValidationResult validateDependencies(DependencyGraph graph);
    List<WorkflowDefinition> getExecutionOrder(DependencyGraph graph);
}
```

4. Variable Resolver

```java
public interface VariableResolver {
    String resolve(String expression, ExecutionContext context);
    Map<String, String> resolveAll(Map<String, String> variables, ExecutionContext context);

    // Built-in functions
    // ${date:yyyy-MM-dd} -> current date
    // ${env:VAR_NAME} -> environment variable
    // ${file:path/to/file} -> file content
    // ${transfer.result.checksum} -> result from previous transfer
}
```

Execution Modes



1. Normal Execution

- Full transfer execution with real network operations

- File system modifications
- Complete monitoring and logging

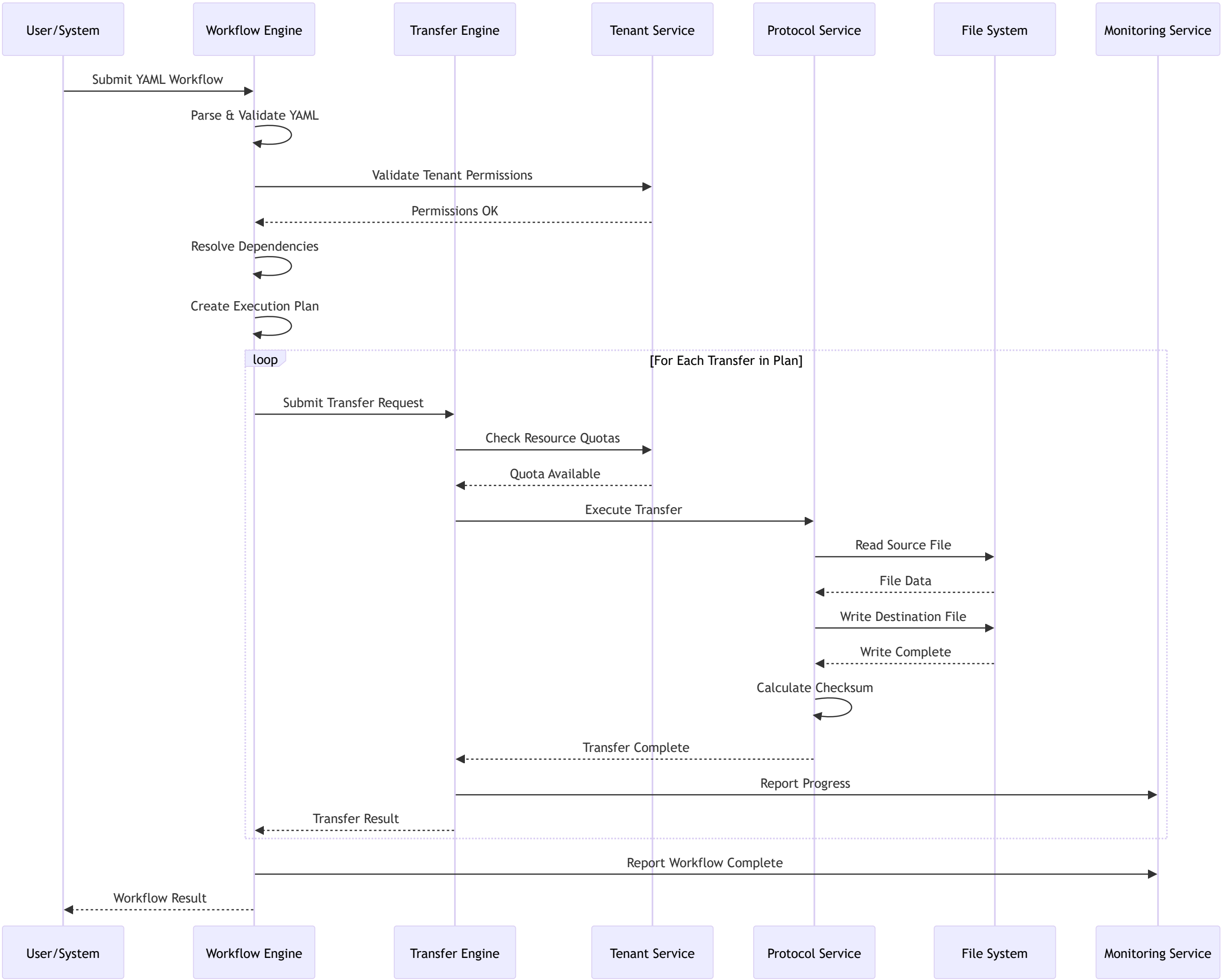
2. Dry Run

- Validate YAML syntax and semantics
- Check dependencies and connectivity
- Simulate execution without actual transfers
- Report what would be executed

3. Virtual Run

- Simulate transfers with mock data
- Test workflow logic and dependencies
- Performance estimation
- Resource usage prediction

Transfer Process Flow



Data Models

Core Domain Models

Transfer Request

```
public class TransferRequest {
    private String requestId;
    private URI sourceUri;
    private Path destinationPath;
    private String protocol;
    private String tenantId;
    private String namespace;
    private Map<String, String> metadata;
    private long expectedSize;
    private String expectedChecksum;
    // ... other fields
}
```

Transfer Job

```
public class TransferJob {
    private String jobId;
    private TransferRequest request;
    private TransferStatus status;
    private long bytesTransferred;
    private long totalBytes;
    private Instant startTime;
    private String actualChecksum;
    private String tenantId;
    // ... other fields
}
```

Multi-Tenant Models

Tenant Configuration

```
public class TenantConfiguration {
    private String tenantId;
    private String parentTenantId;
    private ResourceQuota resourceQuota;
    private SecurityPolicy securityPolicy;
    private ComplianceSettings compliance;
    private Map<String, String> variables;
    // ... other fields
}
```

Workflow Models

Workflow Definition

```
public class WorkflowDefinition {
    private String name;
    private String tenantId;
    private String namespace;
    private ExecutionStrategy execution;
    private List<TransferGroupDefinition> groups;
    private Map<String, String> variables;
    private List<TenantContext> tenants;
    // ... other fields
}
```

Data Isolation Strategies

1. Database-Level Isolation

```sql
-- Tenant-aware schema design
CREATE TABLE transfers (
    id UUID PRIMARY KEY,
    tenant_id VARCHAR(255) NOT NULL,
    namespace VARCHAR(255),
    request_data JSONB,
    status VARCHAR(50),
    created_at TIMESTAMP DEFAULT NOW(),

    -- Tenant isolation constraints
    CONSTRAINT fk_tenant FOREIGN KEY (tenant_id) REFERENCES tenants(id),
    INDEX idx_tenant_namespace (tenant_id, namespace)
);

-- Row-level security
CREATE POLICY tenant_isolation ON transfers
    FOR ALL TO application_role
    USING (tenant_id = current_setting('app.current_tenant'));
```

2. Storage Isolation

```java
public class TenantAwareStorageService {
    private final String getTenantStorageRoot(String tenantId) {
        return String.format("/data/tenants/%s", tenantId);
    }

    private final void validateTenantAccess(String tenantId, Path path) {
        String tenantRoot = getTenantStorageRoot(tenantId);
        if (!path.startsWith(tenantRoot)) {
            throw new SecurityException("Cross-tenant storage access denied");
        }
    }
}
```

3. Network Isolation

```yaml
# Kubernetes NetworkPolicy example
apiVersion: networking.k8s.io/v1
kind: NetworkPolicy
metadata:
  name: tenant-isolation
spec:
  podSelector:
    matchLabels:
      tenant: acme-corp
  policyTypes:
```

```
  - Ingress
  - Egress
  ingress:
  - from:
    - podSelector:
        matchLabels:
          tenant: acme-corp
  egress:
  - to:
    - podSelector:
        matchLabels:
          tenant: acme-corp
```

Enterprise Features

1. Governance & Compliance

```
governance:
  approvals:
    required: true
    approvers: ["data-ops-lead", "security-team"]

  compliance:
    dataClassification: confidential
    retentionPolicy: 7years
    encryptionRequired: true
    auditLogging: true

  security:
    allowedSources: ["*.company.com", "trusted-partner.com"]
    allowedDestinations: ["s3://company-*", "/backup/*"]
    requiresVPN: true
```

2. Resource Management

```
resources:
  limits:
    maxConcurrentTransfers: 10
    maxBandwidth: 100MB/s
    maxDiskUsage: 1TB

  quotas:
    dailyTransferLimit: 1TB
    monthlyTransferLimit: 30TB

  scheduling:
    priority: high
    preferredHours: "02:00-06:00"
    blackoutWindows: ["12:00-13:00"]
```

3. Monitoring & Alerting

```
monitoring:
  metrics:
    - transferRate
    - errorRate
    - queueDepth
    - resourceUtilization

  alerts:
    - name: transfer-failure
      condition: "errorRate > 5%"
      severity: critical
      channels: ["slack", "email", "pagerduty"]

    - name: slow-transfer
      condition: "transferRate < 1MB/s"
      severity: warning
      channels: ["slack"]
```

Security Architecture

Authentication

- **Enterprise directory integration** (Active Directory, LDAP)
- **Single Sign-On (SSO)** with corporate identity providers (SAML, OAuth2)
- **Service account authentication** for automated internal systems
- **Certificate-based authentication** for high-security internal transfers
- **Tenant-specific authentication** configuration for multi-tenant deployments

Authorization

- **Role-based access control (RBAC)** integrated with corporate directory
- **Department and team-based** access controls
- **Data classification-aware** permissions (confidential, internal, public)
- **Network segment-based** access controls for internal zones
- **Fine-grained resource access** controls for sensitive data

Data Protection

- **Encryption at rest** using corporate key management systems
- **TLS encryption** optimized for internal network performance
- **Data classification** and handling policies for corporate data
- **Network-level encryption** for high-security internal transfers
- **Tenant-specific encryption** keys for multi-tenant isolation

Internal Network Security

- **Network segmentation** awareness and routing
- **Corporate firewall** integration and rule management
- **VPN and private network** support for remote sites
- **Internal certificate authority** integration
- **Network monitoring** and intrusion detection integration

Audit & Compliance

- **Corporate audit system** integration

- **Compliance framework** support (SOX, GDPR, HIPAA, PCI-DSS)
- **Data lineage tracking** for internal data movement
- **Regulatory reporting** for internal data governance
- **Tenant-isolated audit trails** for multi-tenant compliance

Configuration Management

Hierarchical Configuration

```yaml
# Global defaults (system-level)
global:
  defaults:
    retry:
      maxAttempts: 3
    security:
      encryptionRequired: true

# Tenant-level overrides
tenant:
  acme-corp:
    defaults:
      retry:
        maxAttempts: 5  # Override global
      security:
        encryptionAlgorithm: "AES-256-GCM"  # Add tenant-specific

    # Namespace-level overrides
    namespaces:
      finance:
        defaults:
          retry:
            maxAttempts: 7  # Override tenant
          validation:
            checksumRequired: true  # Add namespace-specific
```

Variable Resolution with Tenancy

```yaml
variables:
  # System variables
  system:
    version: "1.0.0"
    region: "us-east-1"

  # Tenant variables
  tenant:
    id: "acme-corp"
    name: "ACME Corporation"
    storage:
      root: "/data/tenants/acme-corp"
      backup: "s3://acme-corp-backup"
    api:
      endpoint: "https://api.acme-corp.com"

  # Namespace variables
  namespace:
    name: "finance"
    costCenter: "CC-12345"
    approver: "finance-lead@acme-corp.com"
```

Deployment Architecture

Corporate Network Deployment with Controller Quorum

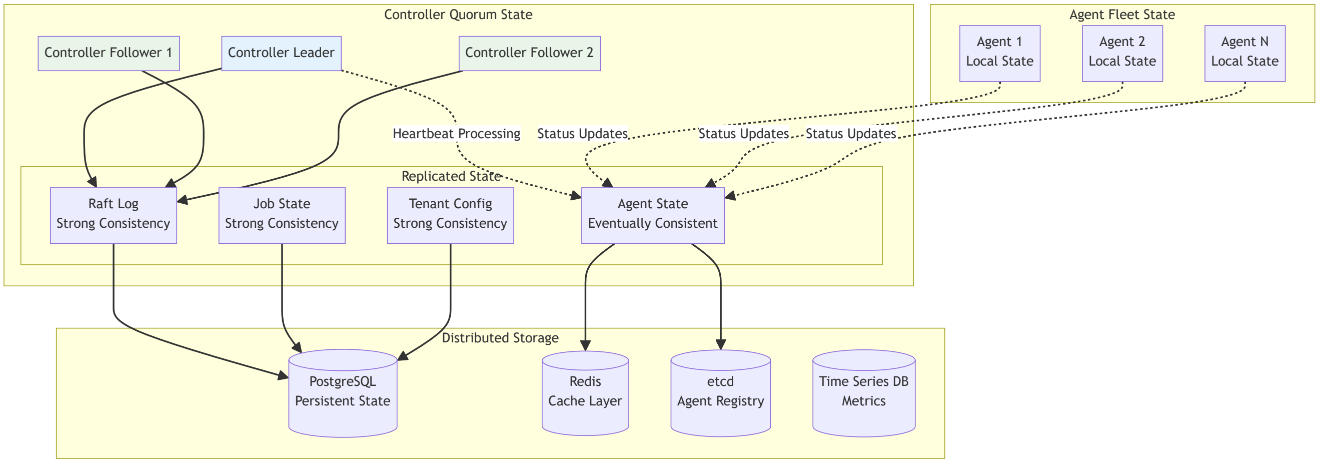
```
Parse error on line 112:
...Sensitive Data]    end    style CORP f
----------------------^
Expecting 'SEMI', 'NEWLINE', 'SPACE', 'EOF', 'subgraph', 'acc_title', 'acc_descr', 'acc_descr_multiline_value', 'AMP',
'COLON', 'STYLE', 'LINKSTYLE', 'CLASSDEF', 'CLASS', 'CLICK', 'DOWN', 'DEFAULT', 'NUM', 'COMMA', 'NODE_STRING', 'BRKT',
'MINUS', 'MULT', 'UNICODE_TEXT', 'direction_tb', 'direction_bt', 'direction_rl', 'direction_lr', got 'end'
```

```yaml
# Kubernetes deployment example
apiVersion: apps/v1
kind: Deployment
metadata:
  name: quorus-engine
spec:
  replicas: 3
  selector:
    matchLabels:
      app: quorus-engine
  template:
    metadata:
      labels:
        app: quorus-engine
    spec:
      containers:
      - name: quorus-engine
        image: quorus/engine:latest
        resources:
          requests:
            memory: "512Mi"
            cpu: "500m"
          limits:
            memory: "1Gi"
            cpu: "1000m"
        env:
        - name: QUORUS_TENANT_ID
          valueFrom:
            fieldRef:
              fieldPath: metadata.labels['tenant']
```

Distributed State Management

The enhanced Quorus architecture implements distributed state management to ensure consistency, availability, and partition tolerance across the controller quorum and agent fleet.

State Distribution Strategy



State Categories:

1. **Strongly Consistent State** (Raft Consensus):
   - Job assignments and status
   - Tenant configurations
   - Workflow definitions
   - System configuration
2. **Eventually Consistent State** (Gossip/Cache):
   - Agent heartbeats and status
   - Performance metrics
   - Capacity information
   - Health status
3. **Local State** (Agent-specific):
   - Active transfer progress
   - Local resource utilization
   - Temporary file state
   - Protocol-specific state

High Availability Configuration

Controller Quorum:

- **Minimum**: 3 controllers (tolerates 1 failure)
- **Recommended**: 5 controllers (tolerates 2 failures)
- **Geographic Distribution**: Controllers across availability zones
- **Network Partitioning**: Majority quorum required for operations

Data Persistence:

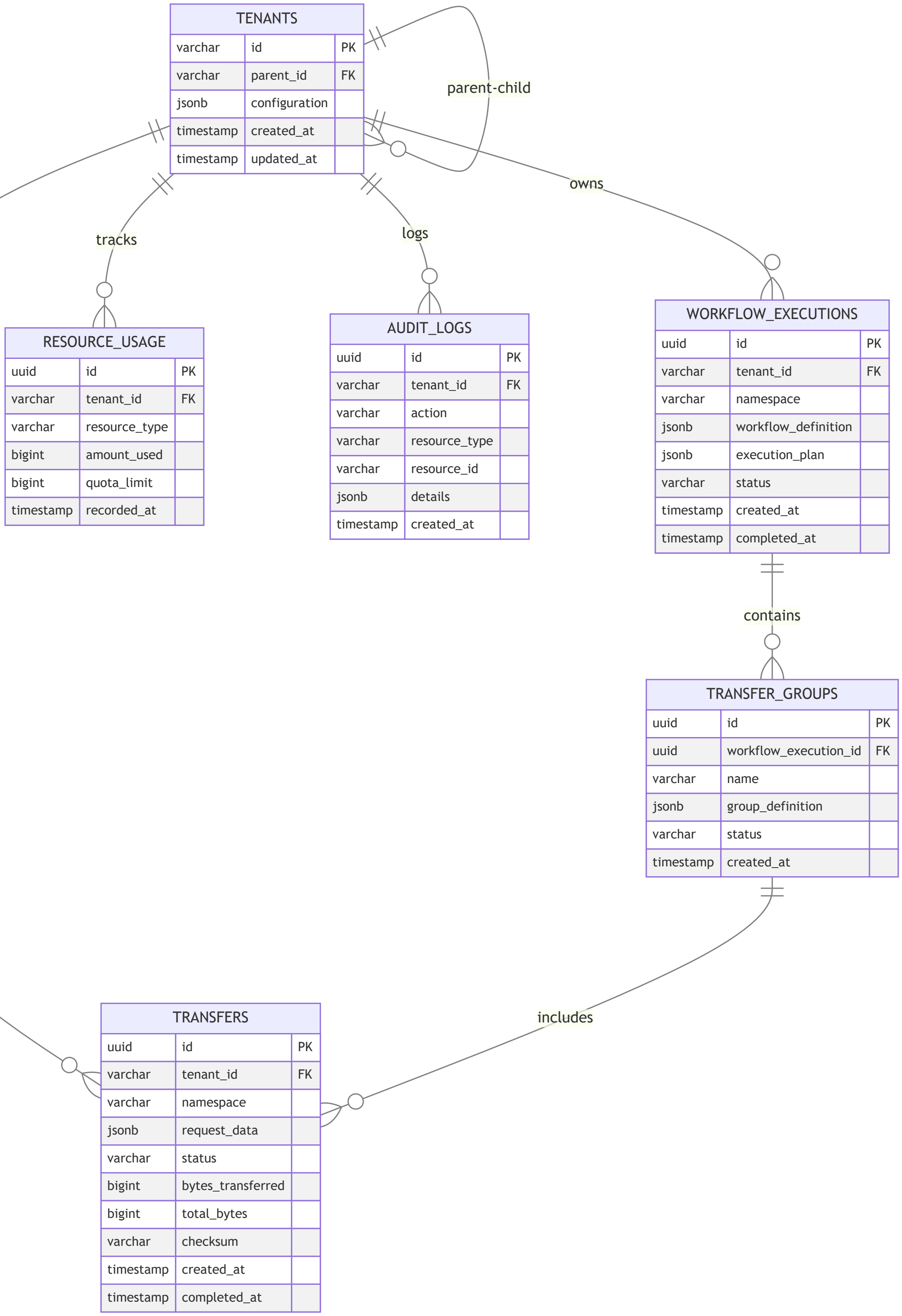
- **PostgreSQL Cluster**: Primary + 2 synchronous replicas
- **Redis Cluster**: 6 nodes (3 masters + 3 replicas)
- **etcd Cluster**: 3-5 nodes for agent registry
- **Backup Strategy**: Automated backups with point-in-time recovery

Failure Scenarios:

- **Single Controller Failure**: Automatic leader election, <5s downtime

- **Database Failure**: Automatic failover to replica, <30s downtime
- **Network Partition**: Majority partition continues operation
- **Agent Failure**: Jobs redistributed, no data loss

Database Schema



TENANTS

varchar	id	PK
varchar	parent_id	FK
jsonb	configuration	
timestamp	created_at	
timestamp	updated_at	

RESOURCE_USAGE

uuid	id	PK
varchar	tenant_id	FK
varchar	resource_type	
bigint	amount_used	
bigint	quota_limit	
timestamp	recorded_at	

AUDIT_LOGS

uuid	id	PK
varchar	tenant_id	FK
varchar	action	
varchar	resource_type	
varchar	resource_id	
jsonb	details	
timestamp	created_at	

WORKFLOW_EXECUTIONS

uuid	id	PK
varchar	tenant_id	FK
varchar	namespace	
jsonb	workflow_definition	
jsonb	execution_plan	
varchar	status	
timestamp	created_at	
timestamp	completed_at	

TRANSFER_GROUPS

uuid	id	PK
uuid	workflow_execution_id	FK
varchar	name	
jsonb	group_definition	
varchar	status	
timestamp	created_at	

TRANSFERS

uuid	id	PK
varchar	tenant_id	FK
varchar	namespace	
jsonb	request_data	
varchar	status	
bigint	bytes_transferred	
bigint	total_bytes	
varchar	checksum	
timestamp	created_at	
timestamp	completed_at	

```sql
-- Core tables
CREATE TABLE tenants (
    id VARCHAR(255) PRIMARY KEY,
    parent_id VARCHAR(255),
    configuration JSONB,
    created_at TIMESTAMP DEFAULT NOW(),
    updated_at TIMESTAMP DEFAULT NOW(),
    FOREIGN KEY (parent_id) REFERENCES tenants(id)
);

CREATE TABLE transfers (
    id UUID PRIMARY KEY,
    tenant_id VARCHAR(255) NOT NULL,
    namespace VARCHAR(255),
    request_data JSONB,
    status VARCHAR(50),
    bytes_transferred BIGINT DEFAULT 0,
    total_bytes BIGINT,
    checksum VARCHAR(255),
    created_at TIMESTAMP DEFAULT NOW(),
    completed_at TIMESTAMP,
    FOREIGN KEY (tenant_id) REFERENCES tenants(id)
);

CREATE TABLE workflow_executions (
    id UUID PRIMARY KEY,
    tenant_id VARCHAR(255) NOT NULL,
    namespace VARCHAR(255),
    workflow_definition JSONB,
    execution_plan JSONB,
    status VARCHAR(50),
    created_at TIMESTAMP DEFAULT NOW(),
    completed_at TIMESTAMP,
    FOREIGN KEY (tenant_id) REFERENCES tenants(id)
);

CREATE TABLE transfer_groups (
    id UUID PRIMARY KEY,
    workflow_execution_id UUID NOT NULL,
    name VARCHAR(255),
    group_definition JSONB,
    status VARCHAR(50),
    created_at TIMESTAMP DEFAULT NOW(),
    FOREIGN KEY (workflow_execution_id) REFERENCES workflow_executions(id)
);

CREATE TABLE resource_usage (
    id UUID PRIMARY KEY,
    tenant_id VARCHAR(255) NOT NULL,
    resource_type VARCHAR(100),
    amount_used BIGINT,
    quota_limit BIGINT,
    recorded_at TIMESTAMP DEFAULT NOW(),
    FOREIGN KEY (tenant_id) REFERENCES tenants(id)
);

CREATE TABLE audit_logs (
    id UUID PRIMARY KEY,
    tenant_id VARCHAR(255) NOT NULL,
    action VARCHAR(100),
    resource_type VARCHAR(100),
    resource_id VARCHAR(255),
    details JSONB,
    created_at TIMESTAMP DEFAULT NOW(),
    FOREIGN KEY (tenant_id) REFERENCES tenants(id)
);
```

Design Principles

1. Internal Network Optimization

- **High-throughput transfers** leveraging corporate network bandwidth
- **Protocol selection** optimized for internal network characteristics
- **Network-aware routing** for optimal internal path selection
- **Corporate infrastructure integration** (AD, PKI, monitoring)

2. Modularity

- Clear separation between core engine and enterprise features
- Pluggable architecture for protocols and storage
- Independent module development and testing
- **Corporate system integration** modules

3. Multi-Tenancy for Corporate Structure

- **Department and team-based** tenant isolation
- **Corporate hierarchy** alignment with organizational structure
- **Resource quotas** based on business unit allocations
- **Cost center integration** for chargeback and reporting

4. Declarative Configuration

- **YAML-based workflow definitions** for corporate data operations
- **Infrastructure-as-code** approach for corporate governance
- **Version-controlled** transfer configurations in corporate repositories
- **Corporate approval workflows** for configuration changes

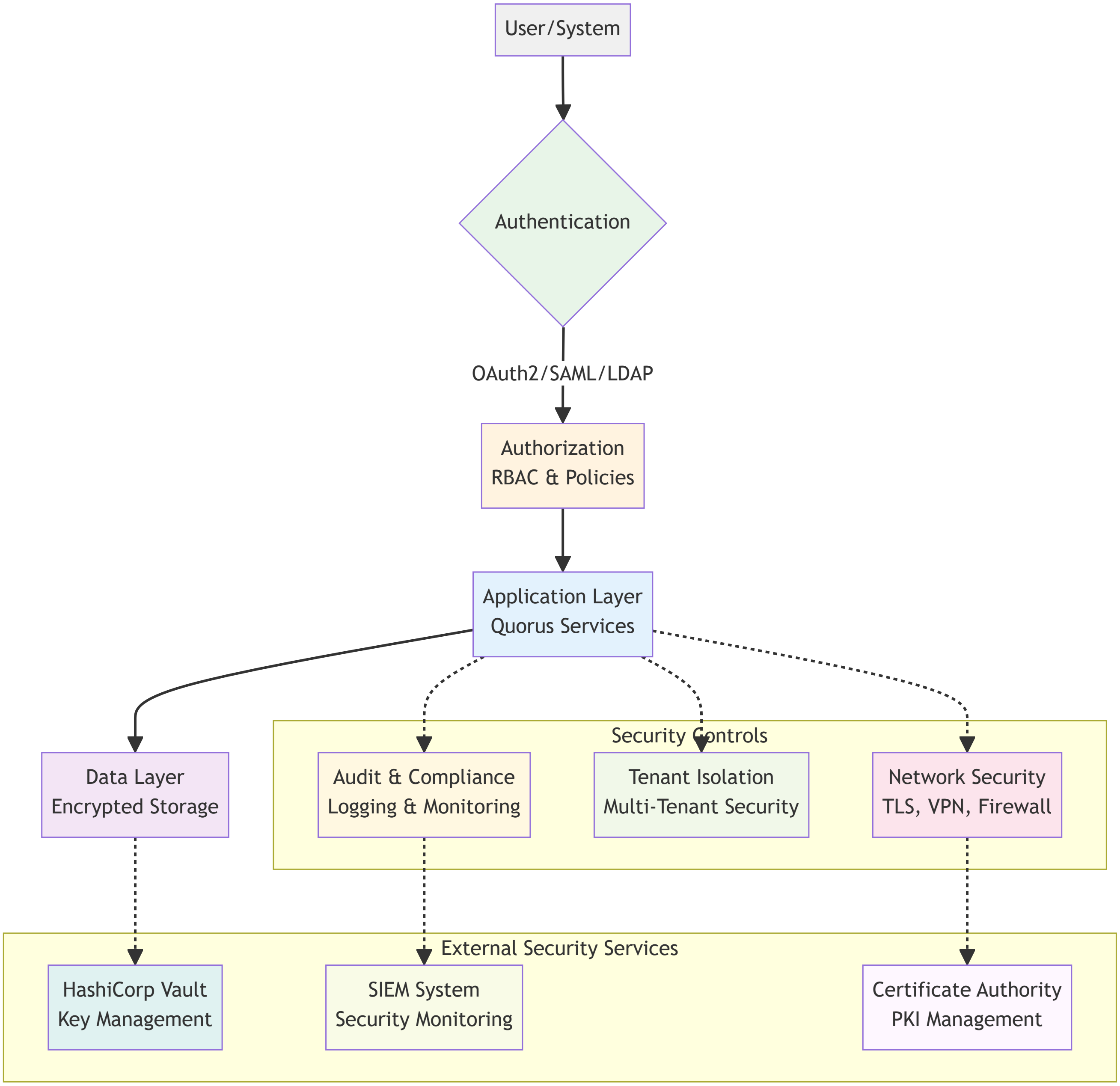
5. Enterprise-Grade Security

- **Corporate directory integration** (Active Directory, LDAP)
- **Certificate-based authentication** using corporate PKI
- **Network-level security** through corporate firewalls and VLANs
- **Data classification** and handling for corporate data governance
- **Audit logging** integrated with corporate SIEM systems

6. Corporate Observability

- **Corporate monitoring system** integration (Splunk, DataDog, etc.)
- **Real-time progress tracking** with corporate dashboard integration
- **Alerting** through corporate notification systems (Exchange, Teams)
- **Compliance reporting** for corporate audit requirements

Security Architecture



Security Layer Details

Authentication Layer

- **OAuth2 Provider** - Modern token-based authentication
- **SAML Provider** - Enterprise SSO integration
- **LDAP Provider** - Directory service authentication
- **API Key Authentication** - Service-to-service authentication

Authorization Layer

- **Role-Based Access Control (RBAC)** - User role management
- **Attribute-Based Access Control (ABAC)** - Fine-grained permissions
- **Policy Engine** - Centralized policy management
- **Permission Manager** - Access control enforcement

Data Protection Layer

- **Encryption at Rest** - Database and file encryption
- **Encryption in Transit** - TLS/mTLS for all communications
- **Key Management Service** - Centralized key management
- **Hardware Security Module** - Secure key storage

Network Security Layer

- **TLS/mTLS** - Secure communication protocols
- **VPN Gateway** - Secure network access
- **Firewall Rules** - Network traffic filtering
- **Network Policies** - Kubernetes network isolation

Audit & Compliance Layer

- **Audit Logging** - Comprehensive activity logging
- **Compliance Monitor** - Regulatory compliance tracking
- **Data Residency** - Geographic data controls
- **Retention Policies** - Data lifecycle management

Tenant Isolation Layer

- **Tenant Isolation** - Multi-tenant data separation
- **Row Level Security** - Database-level isolation
- **Namespace Isolation** - Kubernetes namespace separation
- **Quota Management** - Resource usage controls

Internal Network Optimizations

Corporate Network Characteristics

Quorus is designed to leverage the unique characteristics of internal corporate networks:

High Bandwidth Availability

- **Gigabit/10Gb Ethernet** standard in corporate environments
- **Dedicated network segments** for data transfer operations
- **Quality of Service (QoS)** policies for prioritizing transfer traffic
- **Network bandwidth reservation** for critical transfer operations

Low Latency Communications

- **Sub-millisecond latency** within data centers
- **Predictable network paths** through corporate routing
- **Optimized TCP window sizing** for internal network characteristics
- **Connection pooling** for frequently accessed internal services

Trusted Network Environment

- **Reduced encryption overhead** where appropriate within secure zones
- **Certificate-based authentication** for internal service-to-service communication
- **Network-level security** through corporate firewalls and VLANs

- **Simplified authentication** using corporate directory services

Internal Protocol Optimizations

SMB/CIFS Protocol Support

```yaml
source:
  uri: "smb://fileserver.corp.local/shares/data/export.csv"
  protocol: smb
  authentication:
    type: kerberos
    domain: "CORP"
  options:
    smbVersion: "3.1.1"
    directIO: true
    largeBuffers: true
```

NFS Protocol Support

```yaml
source:
  uri: "nfs://storage.corp.local/exports/data"
  protocol: nfs
  options:
    nfsVersion: "4.1"
    rsize: 1048576      # 1MB read buffer
    wsize: 1048576      # 1MB write buffer
    tcp: true
```

Internal HTTP Optimizations

```yaml
source:
  uri: "http://internal-api.corp.local/data/export"
  protocol: http
  options:
    keepAlive: true
    connectionPoolSize: 50
    tcpNoDelay: true
    bufferSize: 65536
    compressionEnabled: false  # Skip compression on fast internal networks
```

Corporate Integration Features

Active Directory Integration

- **Seamless authentication** using corporate credentials
- **Group-based authorization** aligned with corporate structure
- **Service account management** for automated transfers
- **Audit trail integration** with corporate security systems

Corporate Storage Integration

- **SAN/NAS connectivity** for high-performance storage access
- **Storage tiering** awareness for optimal placement
- **Backup integration** with corporate backup systems

- **Disaster recovery** coordination with corporate DR plans

Network Monitoring Integration

- **SNMP integration** with corporate network monitoring
- **Bandwidth utilization** reporting to network operations
- **Network path optimization** based on corporate topology
- **Traffic shaping** coordination with network QoS policies

Scalability & Performance

Horizontal Scaling

- Stateless service design
- Load balancing across instances
- Distributed execution coordination

Resource Management

- Configurable concurrency limits
- Resource quotas per tenant
- Dynamic resource allocation

Performance Optimization

- Efficient buffer management
- Connection pooling
- Asynchronous I/O operations

Monitoring & Observability

Metrics

- Transfer performance metrics
- Resource utilization tracking
- Error rates and latency measurements

Logging

- Structured logging with correlation IDs
- Tenant-scoped log aggregation
- Configurable log levels

Alerting

- Threshold-based alerting
- Tenant-specific notification channels
- Integration with external monitoring systems

Error Handling & Recovery

Retry Mechanisms

- Exponential backoff strategies
- Configurable retry limits
- Circuit breaker patterns

Failure Recovery

- Graceful degradation
- Automatic failover
- Manual recovery procedures

Error Reporting

- Structured error messages
- Error categorization and classification
- Integration with monitoring systems

Future Enhancements

Phase 2 Implementation (Moved from Future to Active Development)

The following features have been moved from future enhancements to **Phase 2: Service Architecture & REST API** implementation:

✅ **Distributed Controller Architecture** - Now part of Phase 2.1

- Controller quorum with Raft consensus *(previously listed as "Distributed coordination with Raft consensus")*
- Agent-based transfer execution with fleet management
- Horizontal scaling capabilities with intelligent load balancing
- Multi-region deployment support with geographic distribution
- Advanced load balancing and failover mechanisms *(previously listed as "Global load balancing")*

✅ **Agent Fleet Management** - Now part of Phase 2.2

- Agent registration and heartbeat system
- Dynamic scaling and capacity management *(previously listed as "Advanced clustering capabilities")*
- Failure detection and automatic recovery
- Geographic and resource-aware job scheduling
- Agent lifecycle management with graceful shutdown

✅ **Enterprise Scalability** - Now part of Phase 2.3

- Support for 100+ agents per controller quorum
- 10,000+ concurrent transfers across fleet
- High-throughput heartbeat processing (1000+ heartbeats/second)
- Distributed state management with strong consistency
- Enterprise-grade monitoring and alerting integration

Phase 3+ Future Features

Advanced Protocol Support:

- Additional protocols (S3, Azure Blob, Google Cloud Storage) *(expanded from "FTP, SFTP, S3")*
- Protocol-specific optimizations and features
- Custom protocol plugin architecture *(expanded from "Custom protocol development SDK")*
- Protocol conversion and transformation

Advanced Workflow Features:

- Conditional execution and loops in workflows *(expanded from "loops, conditions")*
- Dynamic workflow generation and templating
- Workflow versioning and rollback capabilities
- Advanced dependency management with complex conditions
- Real-time workflow modification and updates

Machine Learning and AI:

- Transfer optimization using machine learning *(expanded from "Machine learning for optimization")*
- Predictive failure detection and prevention
- Intelligent routing and path selection
- Bandwidth optimization algorithms
- Performance prediction and capacity planning

Advanced Security and Governance:

- End-to-end encryption with key rotation
- Advanced audit trails and compliance reporting *(expanded from "Advanced governance and compliance")*
- Integration with enterprise identity systems *(expanded from "Integration with enterprise systems")*
- Zero-trust security model implementation
- Advanced threat detection and response

Performance Optimizations:

- Transfer acceleration techniques (compression, deduplication)
- Intelligent caching and prefetching strategies
- Advanced bandwidth management and QoS
- Multi-path transfer optimization
- Real-time streaming transfers with low latency *(expanded from "Real-time streaming transfers")*

Cloud-Native Features:

- Kubernetes operator for automated deployment
- Service mesh integration (Istio, Linkerd)
- Cloud provider native integrations
- Serverless transfer execution options
- Container-based agent deployment

Implementation Roadmap Update

Phase 2: Service Architecture & REST API (Updated)

The implementation plan has been updated to include the distributed architecture enhancements:

Milestone 2.1: Distributed Controller Architecture (Weeks 17-19)

- Implement Raft consensus algorithm for controller quorum
- Agent registration and heartbeat system
- Distributed agent registry with failure detection
- Load balancer integration for high availability
- Controller leader election and failover mechanisms

Milestone 2.2: Agent Fleet Management (Weeks 20-22)

- Agent lifecycle management (register, heartbeat, deregister)
- Intelligent work distribution and load balancing
- Geographic and resource-aware job scheduling
- Agent health monitoring and automatic recovery
- Graceful shutdown and drain procedures

Milestone 2.3: REST API & Client Integration (Weeks 23-24)

- REST API for all controller operations
- Client SDKs and CLI tools
- Web dashboard for monitoring and management
- API documentation and OpenAPI specifications
- Integration testing with distributed architecture

Success Criteria for Phase 2

Scalability Targets:

- Support 100+ agents per controller quorum
- Handle 10,000+ concurrent transfers across fleet
- Process 1,000+ heartbeats/second
- Achieve 100+ jobs/second assignment and completion
- Maintain <5 second failover time for controller failures

Reliability Targets:

- 99.9% uptime for controller quorum
- <30 second recovery time for agent failures
- Zero data loss during controller failover
- Automatic job redistribution on agent failure
- Graceful handling of network partitions

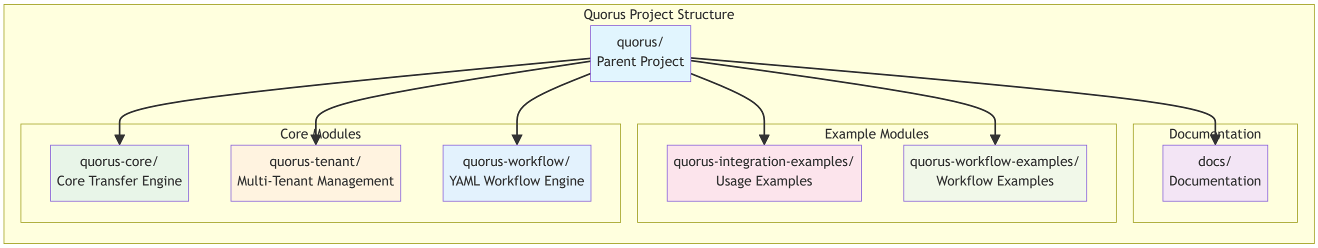
Performance Targets:

- <100ms latency for job assignment
- <1 second for agent registration
- <5 seconds for failure detection
- <10 seconds for job redistribution

- Linear scaling with agent additions

File Organization

Project Structure Overview



Module Details

Core Modules

```
quorus-core/                    # Core transfer engine
├── src/main/java/dev/mars/quorus/
│   ├── core/                   # Domain models
│   ├── transfer/               # Transfer engine
│   ├── protocol/               # Protocol handlers
│   ├── storage/                # File management
│   └── config/                 # Configuration
└── src/test/java/              # Unit tests

quorus-tenant/                  # Multi-tenant management
├── src/main/java/dev/mars/quorus/tenant/
│   ├── model/                  # Tenant models
│   ├── service/                # Tenant services
│   ├── security/               # Multi-tenant security
│   └── resource/               # Resource management
└── src/test/java/              # Unit tests

quorus-workflow/                # YAML workflow engine
├── src/main/java/dev/mars/quorus/workflow/
│   ├── definition/             # YAML models
│   ├── parser/                 # YAML parsing
│   ├── engine/                 # Workflow engine
│   └── resolver/               # Dependency resolution
└── src/test/java/              # Unit tests
```

Example Modules

```
quorus-integration-examples/    # Usage examples
├── src/main/java/dev/mars/quorus/examples/
│   └── BasicTransferExample.java
└── README.md

quorus-workflow-examples/       # Workflow examples
├── basic/                      # Simple examples
├── enterprise/                 # Complex workflows
```

```
  └── templates/                  # Reusable templates
```

Documentation

```
docs/                           # Documentation
├── quorus-comprehensive-system-design.md
├── quorus-implementation-plan.md
└── README.md
```

Related Documents

- **Implementation Plan** - Detailed 52-week development roadmap with Gantt chart timeline, milestones, and deliverables
- **API Documentation** - REST API specifications (future)

Conclusion

The Quorus comprehensive system design provides a solid foundation for enterprise-grade file transfer operations with:

- **Multi-tenant architecture** supporting complex organizational structures
- **Declarative YAML workflows** for infrastructure-as-code approach
- **Robust security framework** with authentication, authorization, and compliance
- **Scalable architecture** supporting horizontal scaling and high availability
- **Enterprise features** including governance, monitoring, and resource management

The modular design ensures maintainability and extensibility while meeting the demanding requirements of enterprise environments. The system is designed to grow from simple single-tenant deployments to complex multi-tenant enterprise scenarios with thousands of users and petabytes of data transfer.