```
CREATE POLICY journal_entries_tenant_isolation ON journal_entries
FOR ALL TO authenticated_users
USING (tenant_id = current_setting('app.current_tenant_id')::uuid);

-- Функция для установки контекста тенанта
CREATE OR REPLACE FUNCTION set_tenant_context(tenant_uuid UUID)
RETURNS void AS $
BEGIN
PERFORM set_config('app.current_tenant_id', tenant_uuid::text, false);
END;
$ LANGUAGE plpgsql;
```

Результаты Фазы 4:
- ✅ Cloud-native deployment в GCP/AWS
- ✅ ML-powered fraud detection
- ✅ Real-time analytics с ClickHouse
- ✅ BI dashboard с Plotly
- ✅ Multi-tenant архитектура
- ✅ 95% покрытие тестами всей системы

🎯 Фаза 5: Оптимизация и Go-Live (Месяцы 19-24)

Цели:
- Performance tuning
- Load testing
- Security audit
- User training
- Production deployment

5.1 Performance Optimization (Месяцы 19-20)

Database optimization
```sql
-- performance_optimization.sql

-- Партиционирование крупных таблиц по времени
CREATE TABLE journal_entries_optimized (
    LIKE journal_entries INCLUDING ALL
) PARTITION BY RANGE (transaction_date);

-- Создание партиций на 2 года вперед
DO $
DECLARE
    start_date DATE := '2025-01-01';
    end_date DATE;
    partition_name TEXT;
BEGIN
    FOR i IN 0..23 LOOP
        end_date := start_date + INTERVAL '1 month';
        partition_name := 'journal_entries_' || to_char(start_date, 'YYYY_MM');

        EXECUTE format('CREATE TABLE %I PARTITION OF journal_entries_optimized
```

```
                FOR VALUES FROM (%L) TO (%L)',
                partition_name, start_date, end_date);

        -- Индексы для каждой партиции
        EXECUTE format('CREATE INDEX %I ON %I (tenant_id, account_id, transaction_date)',
                'idx_' || partition_name || '_lookup', partition_name);

        start_date := end_date;
    END LOOP;
END $;

-- Материализованные представления для быстрых агрегаций
CREATE MATERIALIZED VIEW account_balances_daily AS
SELECT
    tenant_id,
    account_id,
    transaction_date,
    sum(debit - credit) OVER (
        PARTITION BY tenant_id, account_id
        ORDER BY transaction_date
        ROWS UNBOUNDED PRECEDING
    ) as running_balance,
    sum(debit - credit) as daily_change
FROM journal_entries_optimized
WHERE transaction_date >= CURRENT_DATE - INTERVAL '2 years'
GROUP BY tenant_id, account_id, transaction_date, debit, credit;

CREATE UNIQUE INDEX idx_account_balances_daily_unique
ON account_balances_daily (tenant_id, account_id, transaction_date);

-- Автоматическое обновление материализованных представлений
CREATE OR REPLACE FUNCTION refresh_daily_balances()
RETURNS void AS $
BEGIN
    REFRESH MATERIALIZED VIEW CONCURRENTLY account_balances_daily;
END;
$ LANGUAGE plpgsql;

-- Планировщик для обновления представлений
SELECT cron.schedule('refresh-daily-balances', '0 1 * * *', 'SELECT refresh_daily_balances();');
```

Caching strategy

python

```python
# caching/redis_cache.py
from functools import wraps
import redis.asyncio as redis
import json
import hashlib
from typing import Any, Optional, Callable
import asyncio

class DistributedCache:
    def __init__(self, redis_url: str = "redis://redis:6379"):
        self.redis = redis.from_url(redis_url, decode_responses=True)
        self.default_ttl = 3600  # 1 час

    def cache_key(self, prefix: str, *args, **kwargs) -> str:
        """Генерация ключа кэша на основе аргументов"""
        key_data = f"{prefix}:{args}:{sorted(kwargs.items())}"
        return hashlib.md5(key_data.encode()).hexdigest()

    async def get(self, key: str) -> Optional[Any]:
        """Получить значение из кэша"""
        try:
            value = await self.redis.get(key)
            if value:
                return json.loads(value)
        except Exception as e:
            logger.error(f"Cache get error: {e}")
        return None

    async def set(self, key: str, value: Any, ttl: Optional[int] = None) -> bool:
        """Установить значение в кэш"""
        try:
            ttl = ttl or self.default_ttl
            serialized = json.dumps(value, default=str)
            return await self.redis.setex(key, ttl, serialized)
        except Exception as e:
            logger.error(f"Cache set error: {e}")
            return False

    async def delete(self, pattern: str) -> int:
        """Удалить ключи по шаблону"""
        try:
            keys = await self.redis.keys(pattern)
            if keys:
```

```
            return await self.redis.delete(*keys)
        return 0
    except Exception as e:
        logger.error(f"Cache delete error: {e}")
        return 0

def cached(self, ttl: Optional[int] = None, key_prefix: str = "cache"):
    """Декоратор для кэширования результатов функций"""
    def decorator(func: Callable) -> Callable:
        @wraps(func)
        async def wrapper(*args, **kwargs):
            # Исключить self из аргументов для ключа кэша
            cache_args = args[1:] if args and hasattr(args[0], '__class__') else args
            cache_key = self.cache_key(f"{key_prefix}:{func.__name__}", *cache_args, **kwargs)

            # Попытаться получить из кэша
            cached_result = await self.get(cache_key)
            if cached_result is not None:
                return cached_result

            # Вычислить результат
            result = await func(*args, **kwargs)

            # Сохранить в кэш
            await self.set(cache_key, result, ttl)
            return result

        return wrapper
    return decorator

class SmartCache:
    """Умное кэширование с invalidation по тэгам"""

    def __init__(self, cache: DistributedCache):
        self.cache = cache
        self.tag_prefix = "tags:"

    async def set_with_tags(self, key: str, value: Any, tags: list, ttl: Optional[int] = None):
        """Установить значение с тэгами для invalidation"""
        # Сохранить основное значение
        await self.cache.set(key, value, ttl)

        # Связать с тэгами
        for tag in tags:
```

```
            tag_key = f"{self.tag_prefix}{tag}"
            await self.cache.redis.sadd(tag_key, key)
            if ttl:
                await self.cache.redis.expire(tag_key, ttl + 86400)  # TTL + 1 день для тэгов

    async def invalidate_by_tag(self, tag: str):
        """Инвалидировать все ключи с определенным тэгом"""
        tag_key = f"{self.tag_prefix}{tag}"
        keys = await self.cache.redis.smembers(tag_key)

        if keys:
            # Удалить основные ключи
            await self.cache.redis.delete(*keys)
            # Удалить тэг
            await self.cache.redis.delete(tag_key)

        return len(keys)

# Использование в сервисах
class AccountService:
    def __init__(self):
        self.cache = DistributedCache()
        self.smart_cache = SmartCache(self.cache)
        self.repository = AccountRepository()

    @cache.cached(ttl=1800, key_prefix="accounts")
    async def get_account_by_id(self, tenant_id: str, account_id: str) -> Optional[Account]:
        """Получить счет по ID с кэшированием"""
        with TenantContext(tenant_id):
            return await self.repository.get_by_id(account_id)

    async def create_account(self, tenant_id: str, account_data: AccountCreate) -> Account:
        """Создать счет с инвалидацией кэша"""
        with TenantContext(tenant_id):
            account = await self.repository.create(account_data)

            # Инвалидировать кэш
            await self.smart_cache.invalidate_by_tag(f"tenant:{tenant_id}:accounts")

            return account

    @smart_cache.cached(ttl=300, tags_func=lambda tenant_id: [f"tenant:{tenant_id}:balances"])
    async def get_account_balance(self, tenant_id: str, account_id: str, as_of_date: Optional[date] = None) -> Decimal:
        """Получить баланс счета с кэшированием по тэгам"""
```

```
    with TenantContext(tenant_id):
        return await self.repository.get_balance(account_id, as_of_date)
```

5.2 Load Testing (Месяц 21)

Load testing с Locust

python

```python
# load_testing/locustfile.py
from locust import HttpUser, task, between
import json
import uuid
from datetime import datetime, date
import random

class AccountingSystemUser(HttpUser):
    wait_time = between(1, 3)

    def on_start(self):
        """Авторизация перед началом тестов"""
        self.login()
        self.tenant_id = "test-tenant-001"
        self.auth_headers = {
            "Authorization": f"Bearer {self.access_token}",
            "X-Tenant-ID": self.tenant_id,
            "Content-Type": "application/json"
        }

    def login(self):
        """Авторизация в системе"""
        login_data = {
            "username": f"testuser_{random.randint(1, 100)}",
            "password": "testpass123"
        }
        response = self.client.post("/api/v1/auth/login", json=login_data)
        if response.status_code == 200:
            self.access_token = response.json()["access_token"]
        else:
            self.access_token = "dummy-token"

    @task(3)
    def get_accounts(self):
        """Получение списка счетов (частый запрос)"""
        self.client.get("/api/v1/accounts", headers=self.auth_headers)

    @task(2)
    def get_account_balance(self):
        """Получение баланса счета"""
        account_id = str(uuid.uuid4())  # В реальности должен быть существующий ID
        self.client.get(
            f"/api/v1/accounts/{account_id}/balance",
```

```
            headers=self.auth_headers
        )

    @task(5)
    def create_transaction(self):
        """Создание транзакции (основная нагрузка)"""
        transaction_data = {
            "transaction_date": date.today().isoformat(),
            "description": f"Test transaction {random.randint(1, 10000)}",
            "entries": [
                {
                    "account_id": str(uuid.uuid4()),
                    "debit": random.uniform(100, 10000),
                    "credit": 0,
                    "description": "Test debit entry"
                },
                {
                    "account_id": str(uuid.uuid4()),
                    "debit": 0,
                    "credit": random.uniform(100, 10000),
                    "description": "Test credit entry"
                }
            ]
        }

        # Убедиться что дебет = кредит
        transaction_data["entries"][1]["credit"] = transaction_data["entries"][0]["debit"]

        self.client.post(
            "/api/v1/transactions",
            json=transaction_data,
            headers=self.auth_headers
        )

    @task(1)
    def get_financial_report(self):
        """Генерация финансового отчета (тяжелый запрос)"""
        params = {
            "start_date": "2025-01-01",
            "end_date": date.today().isoformat(),
            "report_type": "balance_sheet"
        }

        self.client.get(
```

```
            "/api/v1/reports/financial",
            params=params,
            headers=self.auth_headers
        )

    @task(1)
    def calculate_vat(self):
        """Расчет НДС"""
        vat_data = {
            "net_amount": random.uniform(1000, 50000),
            "is_exempt": random.choice([True, False])
        }

        self.client.post(
            "/api/v1/tax/vat/calculate",
            json=vat_data,
            headers=self.auth_headers
        )

class HighLoadUser(HttpUser):
    """Пользователь с высокой нагрузкой для стресс-тестов"""
    wait_time = between(0.1, 0.5)  # Более агрессивная нагрузка
    weight = 1

    @task
    def rapid_balance_checks(self):
        """Частые проверки балансов"""
        for _ in range(10):
            account_id = random.choice([
                "550e8400-e29b-41d4-a716-446655440001",
                "550e8400-e29b-41d4-a716-446655440002",
                "550e8400-e29b-41d4-a716-446655440003"
            ])
            self.client.get(f"/api/v1/accounts/{account_id}/balance")

# Конфигурация для различных сценариев нагрузки
class LoadTestConfig:
    scenarios = {
        "normal_load": {
            "users": 100,
            "spawn_rate": 5,
            "duration": "10m"
        },
        "peak_load": {
```

```
        "users": 500,
        "spawn_rate": 25,
        "duration": "15m"
    },
    "stress_test": {
        "users": 1000,
        "spawn_rate": 50,
        "duration": "30m"
    },
    "endurance_test": {
        "users": 200,
        "spawn_rate": 10,
        "duration": "2h"
    }
}
```

Performance monitoring

python

```python
# monitoring/performance_monitor.py
import asyncio
import psutil
import time
from datetime import datetime
from dataclasses import dataclass
from typing import Dict, List
import aiohttp

@dataclass
class PerformanceMetrics:
    timestamp: datetime
    cpu_usage: float
    memory_usage: float
    disk_io: Dict[str, float]
    network_io: Dict[str, float]
    response_times: Dict[str, float]
    error_rates: Dict[str, float]
    active_connections: int

class PerformanceMonitor:
    def __init__(self):
        self.metrics_history: List[PerformanceMetrics] = []
        self.thresholds = {
            "cpu_usage": 80.0,
            "memory_usage": 85.0,
            "avg_response_time": 2.0,
            "error_rate": 5.0
        }
        self.alerts_sent = set()

    async def collect_system_metrics(self) -> Dict:
        """Сбор системных метрик"""
        cpu_percent = psutil.cpu_percent(interval=1)
        memory = psutil.virtual_memory()
        disk_io = psutil.disk_io_counters()
        network_io = psutil.net_io_counters()

        return {
            "cpu_usage": cpu_percent,
            "memory_usage": memory.percent,
            "disk_io": {
                "read_bytes": disk_io.read_bytes,
```

```
            "write_bytes": disk_io.write_bytes
        },
        "network_io": {
            "bytes_sent": network_io.bytes_sent,
            "bytes_recv": network_io.bytes_recv
        }
    }

async def collect_application_metrics(self) -> Dict:
    """Сбор метрик приложения"""
    # Запросы к Prometheus metrics endpoint
    async with aiohttp.ClientSession() as session:
        async with session.get("http://localhost:8000/metrics") as response:
            metrics_text = await response.text()

    # Парсинг метрик (упрощенно)
    response_times = {}
    error_rates = {}
    active_connections = 0

    for line in metrics_text.split('\n'):
        if 'http_request_duration_seconds' in line and 'quantile="0.95"' in line:
            # Извлечь значение 95-го перцентиля времени ответа
            value = float(line.split()[-1])
            endpoint = self._extract_endpoint(line)
            response_times[endpoint] = value

        elif 'http_requests_total' in line and 'status="5' in line:
            # Подсчет ошибок 5xx
            value = float(line.split()[-1])
            endpoint = self._extract_endpoint(line)
            error_rates[endpoint] = value

    return {
        "response_times": response_times,
        "error_rates": error_rates,
        "active_connections": active_connections
    }

async def check_thresholds(self, metrics: PerformanceMetrics):
    """Проверка пороговых значений и отправка алертов"""
    alerts = []

    if metrics.cpu_usage > self.thresholds["cpu_usage"]:
```

```
            alerts.append(f"High CPU usage: {metrics.cpu_usage:.1f}%")

        if metrics.memory_usage > self.thresholds["memory_usage"]:
            alerts.append(f"High memory usage: {metrics.memory_usage:.1f}%")

        avg_response_time = sum(metrics.response_times.values()) / len(metrics.response_times) if metrics.response_times
        if avg_response_time > self.thresholds["avg_response_time"]:
            alerts.append(f"High average response time: {avg_response_time:.2f}s")

        for alert in alerts:
            alert_hash = hash(alert)
            if alert_hash not in self.alerts_sent:
                await self.send_alert(alert)
                self.alerts_sent.add(alert_hash)

                # Удалить старые алерты
                if len(self.alerts_sent) > 100:
                    self.alerts_sent.clear()

    async def send_alert(self, message: str):
        """Отправка алерта"""
        alert_data = {
            "severity": "warning",
            "message": message,
            "timestamp": datetime.utcnow().isoformat(),
            "service": "accounting-system"
        }

        # Отправка в Slack/Teams/Email
        async with aiohttp.ClientSession() as session:
            await session.post(
                "https://hooks.slack.com/services/YOUR/SLACK/WEBHOOK",
                json={"text": f" Performance Alert: {message}"}
            )

    async def run_monitoring(self):
        """Основной цикл мониторинга"""
        while True:
            try:
                system_metrics = await self.collect_system_metrics()
                app_metrics = await self.collect_application_metrics()

                metrics = PerformanceMetrics(
                    timestamp=datetime.utcnow(),
```

```
            **system_metrics,
            **app_metrics
        )

        self.metrics_history.append(metrics)

        # Оставляем только последние 1000 записей
        if len(self.metrics_history) > 1000:
            self.metrics_history = self.metrics_history[-1000:]

        await self.check_thresholds(metrics)

    except Exception as e:
        logger.error(f"Performance monitoring error: {e}")

    await asyncio.sleep(30)  # Сбор метрик каждые 30 секунд
```

5.3 Security Audit (Месяц 22)

Security checklist

python

```python
# security/audit_checklist.py
from dataclasses import dataclass
from typing import List, Dict
import asyncio
import re

@dataclass
class SecurityCheck:
    name: str
    description: str
    status: str  # pass, fail, warning
    details: str
    recommendation: str

class SecurityAuditor:
    def __init__(self):
        self.checks: List[SecurityCheck] = []

    async def run_full_audit(self) -> List[SecurityCheck]:
        """Выполнить полный аудит безопасности"""
        await asyncio.gather(
            self.check_authentication(),
            self.check_authorization(),
            self.check_input_validation(),
            self.check_data_encryption(),
            self.check_database_security(),
            self.check_api_security(),
            self.check_logging_and_monitoring(),
            self.check_dependency_vulnerabilities()
        )

        return self.checks

    async def check_authentication(self):
        """Проверка системы аутентификации"""
        checks = [
            # JWT токены
            await self.verify_jwt_security(),
            # Пароли
            await self.check_password_policy(),
            # MFA
            await self.check_mfa_implementation(),
            # Session management
```

```
            await self.check_session_security()
        ]
        self.checks.extend(checks)

    async def verify_jwt_security(self) -> SecurityCheck:
        """Проверка безопасности JWT токенов"""
        # Проверить алгоритм подписи
        jwt_algorithm = "HS256"  # Получить из конфигурации

        if jwt_algorithm in ["none", "HS256"]:
            return SecurityCheck(
                name="JWT Algorithm",
                description="JWT signing algorithm verification",
                status="warning" if jwt_algorithm == "HS256" else "fail",
                details=f"Current algorithm: {jwt_algorithm}",
                recommendation="Consider using RS256 for better security"
            )

        return SecurityCheck(
            name="JWT Algorithm",
            description="JWT signing algorithm verification",
            status="pass",
            details=f"Secure algorithm in use: {jwt_algorithm}",
            recommendation=""
        )

    async def check_password_policy(self) -> SecurityCheck:
        """Проверка политики паролей"""
        password_policy = {
            "min_length": 8,
            "require_uppercase": True,
            "require_lowercase": True,
            "require_numbers": True,
            "require_special": True,
            "max_age_days": 90
        }

        if password_policy["min_length"] < 12:
            return SecurityCheck(
                name="Password Policy",
                description="Password strength requirements",
                status="warning",
                details=f"Minimum length: {password_policy['min_length']} characters",
                recommendation="Increase minimum password length to 12+ characters"
```

```
        )

    return SecurityCheck(
        name="Password Policy",
        description="Password strength requirements",
        status="pass",
        details="Strong password policy enforced",
        recommendation=""
    )

async def check_input_validation(self):
    """Проверка валидации входных данных"""
    # SQL Injection protection
    sql_injection_check = await self.check_sql_injection_protection()
    self.checks.append(sql_injection_check)

    # XSS protection
    xss_check = await self.check_xss_protection()
    self.checks.append(xss_check)

    # CSRF protection
    csrf_check = await self.check_csrf_protection()
    self.checks.append(csrf_check)

async def check_sql_injection_protection(self) -> SecurityCheck:
    """Проверка защиты от SQL инъекций"""
    # Сканирование кода на использование параметризованных запросов
    vulnerable_patterns = [
        r'execute\(.*\+.*\)',  # Конкатенация в SQL
        r'f".*{.*}.*".*execute',  # f-строки в SQL
        r'%.*%.*execute'  # Старый стиль форматирования в SQL
    ]

    # В реальности нужно сканировать файлы кода
    vulnerability_found = False

    if vulnerability_found:
        return SecurityCheck(
            name="SQL Injection Protection",
            description="Protection against SQL injection attacks",
            status="fail",
            details="Potentially vulnerable code patterns found",
            recommendation="Use only parameterized queries and ORM methods"
        )
```

```
        return SecurityCheck(
            name="SQL Injection Protection",
            description="Protection against SQL injection attacks",
            status="pass",
            details="All database queries use parameterized statements",
            recommendation=""
        )

    async def check_data_encryption(self):
        """Проверка шифрования данных"""
        # Encryption at rest
        encryption_at_rest = SecurityCheck(
            name="Data Encryption at Rest",
            description="Sensitive data encryption in database",
            status="pass",  # Проверить реальную конфигурацию
            details="Database encryption enabled",
            recommendation=""
        )
        self.checks.append(encryption_at_rest)

        # Encryption in transit
        encryption_in_transit = SecurityCheck(
            name="Data Encryption in Transit",
            description="TLS/SSL for all communications",
            status="pass",
            details="TLS 1.3 enforced for all connections",
            recommendation=""
        )
        self.checks.append(encryption_in_transit)

        # PII data handling
        pii_handling = await self.check_pii_handling()
        self.checks.append(pii_handling)

    async def check_pii_handling(self) -> SecurityCheck:
        """Проверка обработки персональных данных"""
        # Проверить соответствие Georgian Data Protection Law
        gdpr_compliance = True  # Проверить реальную реализацию

        if not gdpr_compliance:
            return SecurityCheck(
                name="PII Data Handling",
                description="Personal data protection compliance",
```

```
                status="fail",
                details="Georgian Data Protection Law compliance issues found",
                recommendation="Implement proper consent management and data retention policies"
            )

        return SecurityCheck(
            name="PII Data Handling",
            description="Personal data protection compliance",
            status="pass",
            details="Compliant with Georgian Data Protection Law",
            recommendation=""
        )

    async def generate_security_report(self) -> str:
        """Генерация отчета по безопасности"""
        total_checks = len(self.checks)
        passed = len([c for c in self.checks if c.status == "pass"])
        warnings = len([c for c in self.checks if c.status == "warning"])
        failed = len([c for c in self.checks if c.status == "fail"])

        report = f"""
# Security Audit Report
Generated: {datetime.utcnow().isoformat()}

## Summary
- Total Checks: {total_checks}
- ✅ Passed: {passed}
- ⚠️ Warnings: {warnings}
- ❌ Failed: {failed}

## Security Score: {(passed / total_checks) * 100:.1f}%

## Detailed Results
"""

        for check in self.checks:
            status_emoji = {"pass": "✅", "warning": "⚠️", "fail": "❌"}
            report += f"""
### {status_emoji[check.status]} {check.name}
**Description:** {check.description}
**Status:** {check.status.upper()}
**Details:** {check.details}
"""
            if check.recommendation:
```

```
            report += f"**Recommendation:** {check.recommendation}\n"

    return report
```

5.4 User Training Program (Месяц 23)

Training materials

```python
```

```python
# training/training_program.py
from dataclasses import dataclass
from typing import List, Dict
from datetime import datetime, timedelta

@dataclass
class TrainingModule:
    id: str
    title: str
    description: str
    duration_minutes: int
    prerequisites: List[str]
    learning_objectives: List[str]
    materials: List[str]
    assessment: Dict

class GeorgianAccountingTrainingProgram:
    def __init__(self):
        self.modules = self.create_training_modules()
        self.user_progress = {}

    def create_training_modules(self) -> List[TrainingModule]:
        """Создать модули обучения"""
        return [
            TrainingModule(
                id="basics-001",
                title="Основы системы: Навигация и интерфейс",
                description="Изучение основного интерфейса и навигации в системе",
                duration_minutes=30,
                prerequisites=[],
                learning_objectives=[
                    "Освоить основную навигацию в системе",
                    "Понять структуру меню и разделов",
                    "Научиться настраивать пользовательский интерфейс"
                ],
                materials=[
                    "video: interface_overview.mp4",
                    "pdf: user_interface_guide.pdf",
                    "interactive: navigation_tour"
                ],
                assessment={
                    "type": "interactive_quiz",
                    "passing_score": 80,
```

```
        "questions": 10
    }
),

TrainingModule(
    id="accounting-001",
    title="План счетов и двойная запись",
    description="Работа с планом счетов и принципы двойной записи",
    duration_minutes=60,
    prerequisites=["basics-001"],
    learning_objectives=[
        "Понять структуру грузинского плана счетов",
        "Освоить принципы двойной записи",
        "Научиться создавать и редактировать счета"
    ],
    materials=[
        "video: chart_of_accounts_georgian.mp4",
        "pdf: georgian_accounting_standards.pdf",
        "interactive: double_entry_simulator",
        "template: standard_chart_of_accounts.xlsx"
    ],
    assessment={
        "type": "practical_exercise",
        "passing_score": 85,
        "task": "Create chart of accounts for small Georgian business"
    }
),

TrainingModule(
    id="transactions-001",
    title="Создание и обработка транзакций",
    description="Полный цикл работы с бухгалтерскими транзакциями",
    duration_minutes=90,
    prerequisites=["accounting-001"],
    learning_objectives=[
        "Создавать различные типы транзакций",
        "Понять workflow утверждения и проведения",
        "Освоить работу с многовалютными операциями"
    ],
    materials=[
        "video: transaction_lifecycle.mp4",
        "pdf: transaction_types_guide.pdf",
        "interactive: transaction_creation_wizard",
        "case_study: multi_currency_transactions.pdf"
```

```
    ],
    assessment={
        "type": "scenario_based",
        "passing_score": 80,
        "scenarios": [
            "Process supplier invoice with VAT",
            "Record salary payments with taxes",
            "Handle foreign currency purchase"
        ]
    }
),

TrainingModule(
    id="georgian-tax-001",
    title="Грузинская налоговая система",
    description="Работа с НДС, подоходным налогом и отчетностью в RS.ge",
    duration_minutes=120,
    prerequisites=["transactions-001"],
    learning_objectives=[
        "Освоить расчет НДС 18%",
        "Понять малый статус (до 100,000 лари)",
        "Научиться подавать декларации в RS.ge",
        "Работать с реверс-чарж НДС"
    ],
    materials=[
        "video: georgian_vat_system.mp4",
        "pdf: tax_code_summary_2025.pdf",
        "interactive: vat_calculator_simulator",
        "webinar: rs_ge_integration_demo.mp4",
        "template: monthly_vat_declaration.xlsx"
    ],
    assessment={
        "type": "certification_exam",
        "passing_score": 90,
        "duration_minutes": 60,
        "topics": ["VAT calculation", "Tax deadlines", "RS.ge procedures"]
    }
),

TrainingModule(
    id="payroll-001",
    title="Расчет зарплаты и пенсионная система 2+2+2",
    description="Полный цикл расчета зарплаты с грузинскими налогами",
    duration_minutes=75,
```

```
        prerequisites=["georgian-tax-001"],
        learning_objectives=[
            "Рассчитать зарплату с подоходным налогом 20%",
            "Работать с системой 2+2+2 пенсионных взносов",
            "Генерировать зарплатные ведомости",
            "Подавать отчеты в пенсионное агентство"
        ],
        materials=[
            "video: georgian_payroll_system.mp4",
            "pdf: pension_system_guide.pdf",
            "calculator: salary_tax_calculator",
            "template: payroll_register.xlsx"
        ],
        assessment={
            "type": "practical_calculation",
            "passing_score": 85,
            "task": "Calculate monthly payroll for 10 employees"
        }
    ),

    TrainingModule(
        id="reporting-001",
        title="Финансовая отчетность по IFRS",
        description="Создание финансовых отчетов в соответствии с IFRS",
        duration_minutes=90,
        prerequisites=["payroll-001"],
        learning_objectives=[
            "Генерировать баланс по IFRS",
            "Создавать отчет о прибылях и убытках",
            "Формировать отчет о движении денежных средств",
            "Понять требования к раскрытию информации"
        ],
        materials=[
            "video: ifrs_reporting_overview.mp4",
            "pdf: ifrs_requirements_2025.pdf",
            "template: ifrs_financial_statements.xlsx",
            "case_study: annual_reporting_example.pdf"
        ],
        assessment={
            "type": "report_generation",
            "passing_score": 85,
            "task": "Generate full IFRS financial statements"
        }
    ),
```

```
        TrainingModule(
            id="advanced-001",
            title="Продвинутые функции и интеграции",
            description="Работа с API, автоматизацией и внешними системами",
            duration_minutes=60,
            prerequisites=["reporting-001"],
            learning_objectives=[
                "Настроить автоматические проводки",
                "Использовать API для интеграций",
                "Работать с банковскими выписками",
                "Настроить уведомления и алерты"
            ],
            materials=[
                "video: automation_features.mp4",
                "pdf: api_integration_guide.pdf",
                "hands_on: bank_statement_import",
                "tutorial: workflow_automation_setup"
            ],
            assessment={
                "type": "practical_setup",
                "passing_score": 80,
                "task": "Configure automated monthly closing process"
            }
        )
    ]

def create_training_schedule(self, user_role: str, available_hours_per_week: int = 5) -> Dict:
    """Создать индивидуальный план обучения"""
    role_modules = {
        "accountant": ["basics-001", "accounting-001", "transactions-001", "georgian-tax-001"],
        "chief_accountant": ["basics-001", "accounting-001", "transactions-001", "georgian-tax-001", "payroll-001", "repo
        "tax_specialist": ["basics-001", "accounting-001", "georgian-tax-001", "reporting-001"],
        "payroll_officer": ["basics-001", "accounting-001", "payroll-001"],
        "auditor": ["basics-001", "accounting-001", "transactions-001", "reporting-001"]
    }

    required_modules = role_modules.get(user_role, ["basics-001"])

    schedule = []
    current_date = datetime.now()
    weekly_minutes = available_hours_per_week * 60

    for module_id in required_modules:
```

```
        module = next((m for m in self.modules if m.id == module_id), None)
        if module:
            # Рассчитать время на изучение (с учетом практики)
            total_time = module.duration_minutes * 1.5  # +50% на практику

            # Распределить по неделям
            weeks_needed = max(1, int(total_time / weekly_minutes))

            schedule.append({
                "module": module,
                "start_date": current_date,
                "end_date": current_date + timedelta(weeks=weeks_needed),
                "estimated_hours": total_time / 60
            })

            current_date += timedelta(weeks=weeks_needed)

    return {
        "user_role": user_role,
        "total_duration_weeks": (current_date - datetime.now()).days // 7,
        "schedule": schedule
    }

def generate_training_materials(self, module_id: str) -> Dict:
    """Генерировать учебные материалы для модуля"""
    module = next((m for m in self.modules if m.id == module_id), None)
    if not module:
        return {}

    # Специфичные материалы для грузинской системы
    georgian_materials = {
        "georgian-tax-001": {
            "vat_examples": [
                {
                    "scenario": "Продажа товаров на 1000 лари",
                    "calculation": "НДС = 1000 * 18% = 180 лари",
                    "total": "1180 лари с НДС"
                },
                {
                    "scenario": "Реверс-чарж с зарубежного поставщика",
                    "calculation": "НДС к доплате и зачету = 500 * 18% = 90 лари",
                    "note": "Одновременно начисляем и засчитываем НДС"
                }
            ],
```

```
            "tax_calendar": {
                "monthly_deadlines": [
                    {"task": "Подача декларации НДС", "deadline": "15 число"},
                    {"task": "Уплата НДС", "deadline": "15 число"},
                    {"task": "Отчет по зарплатным налогам", "deadline": "15 число"}
                ],
                "annual_deadlines": [
                    {"task": "Декларация о доходах", "deadline": "31 марта"},
                    {"task": "Аудиторский отчет", "deadline": "31 мая"}
                ]
            }
        },

        "payroll-001": {
            "salary_examples": [
                {
                    "gross_salary": 2000,
                    "income_tax_20": 400,
                    "pension_employee_2": 40,
                    "pension_employer_2": 40,
                    "pension_government_2": 40,
                    "net_salary": 1560
                }
            ],
            "pension_calculator": {
                "annual_limit": 24000,
                "monthly_limit": 2000,
                "note": "Государственное софинансирование до 24,000 лари в год"
            }
        }
    }

    return {
        "module": module,
        "georgian_specific": georgian_materials.get(module_id, {}),
        "interactive_elements": [
            f"simulation_{module_id}",
            f"quiz_{module_id}",
            f"calculator_{module_id}"
        ]
    }

class TrainingTracker:
    def __init__(self):
```

```python
        self.user_progress = {}
        self.completion_certificates = {}

    async def track_progress(self, user_id: str, module_id: str, progress_data: Dict):
        """Отслеживать прогресс обучения"""
        if user_id not in self.user_progress:
            self.user_progress[user_id] = {}

        self.user_progress[user_id][module_id] = {
            "started_at": progress_data.get("started_at", datetime.utcnow()),
            "completed_at": progress_data.get("completed_at"),
            "progress_percent": progress_data.get("progress_percent", 0),
            "assessment_score": progress_data.get("assessment_score"),
            "time_spent_minutes": progress_data.get("time_spent_minutes", 0),
            "status": progress_data.get("status", "in_progress")  # not_started, in_progress, completed, failed
        }

        # Автоматическая выдача сертификата при успешном завершении
        if (progress_data.get("status") == "completed" and
            progress_data.get("assessment_score", 0) >= 80):
            await self.issue_certificate(user_id, module_id)

    async def issue_certificate(self, user_id: str, module_id: str):
        """Выдать сертификат о прохождении"""
        certificate = {
            "certificate_id": str(uuid.uuid4()),
            "user_id": user_id,
            "module_id": module_id,
            "issued_at": datetime.utcnow(),
            "valid_until": datetime.utcnow() + timedelta(days=365),
            "verification_url": f"https://accounting-system.ge/certificates/verify/{certificate['certificate_id']}"
        }

        self.completion_certificates[certificate["certificate_id"]] = certificate

        # Отправить уведомление пользователю
        await self.send_certificate_notification(user_id, certificate)

    def generate_progress_report(self, user_id: str) -> Dict:
        """Генерировать отчет о прогрессе обучения"""
        user_data = self.user_progress.get(user_id, {})

        total_modules = len(user_data)
        completed_modules = len([m for m in user_data.values() if m["status"] == "completed"])
```

```
    in_progress_modules = len([m for m in user_data.values() if m["status"] == "in_progress"])

    average_score = 0
    if completed_modules > 0:
        scores = [m["assessment_score"] for m in user_data.values()
                  if m["status"] == "completed" and m["assessment_score"]]
        average_score = sum(scores) / len(scores) if scores else 0

    return {
        "user_id": user_id,
        "completion_rate": (completed_modules / total_modules * 100) if total_modules > 0 else 0,
        "modules_completed": completed_modules,
        "modules_in_progress": in_progress_modules,
        "average_assessment_score": average_score,
        "total_time_spent_hours": sum(m["time_spent_minutes"] for m in user_data.values()) / 60,
        "certificates_earned": len([c for c in self.completion_certificates.values()
                                    if c["user_id"] == user_id]),
        "next_recommended_modules": self.get_next_modules(user_id)
    }
```

5.5 Production Deployment (Месяц 24)

Blue-Green Deployment Strategy

```yaml
```

```yaml
# deployment/blue-green-deployment.yml
apiVersion: argoproj.io/v1alpha1
kind: Rollout
metadata:
  name: accounting-system
  namespace: accounting-production
spec:
  replicas: 10
  strategy:
    blueGreen:
      # Настройки Blue-Green deployment
      activeService: accounting-active
      previewService: accounting-preview
      autoPromotionEnabled: false
      scaleDownDelaySeconds: 30
      prePromotionAnalysis:
        templates:
        - templateName: success-rate
        args:
        - name: service-name
          value: accounting-preview
      postPromotionAnalysis:
        templates:
        - templateName: success-rate
        - templateName: latency
        args:
        - name: service-name
          value: accounting-active
      previewReplicaCount: 2
      activeMetadata:
        labels:
          version: stable
      previewMetadata:
        labels:
          version: preview
  selector:
    matchLabels:
      app: accounting-system
  template:
    metadata:
      labels:
        app: accounting-system
    spec:
```

```yaml
      containers:
      - name: accounting-api
        image: accounting-system:v2.0.0
        ports:
        - containerPort: 8000
        env:
        - name: ENVIRONMENT
          value: "production"
        - name: DATABASE_URL
          valueFrom:
            secretKeyRef:
              name: db-credentials
              key: url
        resources:
          requests:
            memory: "512Mi"
            cpu: "500m"
          limits:
            memory: "1Gi"
            cpu: "1000m"
        livenessProbe:
          httpGet:
            path: /health/live
            port: 8000
          initialDelaySeconds: 30
          periodSeconds: 10
        readinessProbe:
          httpGet:
            path: /health/ready
            port: 8000
          initialDelaySeconds: 5
          periodSeconds: 5

---
# Analysis Templates для автоматического тестирования
apiVersion: argoproj.io/v1alpha1
kind: AnalysisTemplate
metadata:
  name: success-rate
spec:
  args:
  - name: service-name
  metrics:
  - name: success-rate
```

```
    provider:
      prometheus:
        address: http://prometheus.monitoring.svc.cluster.local:9090
        query: |
          sum(irate(
            http_requests_total{job="{{args.service-name}}",status!~"5.."}[2m]
          )) /
          sum(irate(
            http_requests_total{job="{{args.service-name}}"}[2m]
          )) * 100
    successCondition: result[0] >= 95
    interval: 30s
    count: 5
    failureLimit: 2

---
apiVersion: argoproj.io/v1alpha1
kind: AnalysisTemplate
metadata:
  name: latency
spec:
  args:
  - name: service-name
  metrics:
  - name: latency-95th
    provider:
      prometheus:
        address: http://prometheus.monitoring.svc.cluster.local:9090
        query: |
          histogram_quantile(0.95,
            sum(rate(http_request_duration_seconds_bucket{job="{{args.service-name}}"}[2m]))
            by (le)
          ) * 1000
    successCondition: result[0] <= 2000  # 2 секунды
    interval: 30s
    count: 5
    failureLimit: 2
```

Production checklist

```
python
```

```python
# deployment/production_checklist.py
from dataclasses import dataclass
from typing import List, Dict, Optional
from enum import Enum
import asyncio

class CheckStatus(Enum):
    PENDING = "pending"
    PASSED = "passed"
    FAILED = "failed"
    WARNING = "warning"

@dataclass
class ProductionCheck:
    name: str
    description: str
    status: CheckStatus
    details: Optional[str] = None
    blocker: bool = False  # Блокирует ли деплой

class ProductionReadinessChecker:
    def __init__(self):
        self.checks: List[ProductionCheck] = []

    async def run_all_checks(self) -> Dict:
        """Выполнить все проверки готовности к production"""
        await asyncio.gather(
            self.check_infrastructure(),
            self.check_database(),
            self.check_security(),
            self.check_monitoring(),
            self.check_backup(),
            self.check_performance(),
            self.check_compliance(),
            self.check_documentation()
        )

        # Подсчет результатов
        total = len(self.checks)
        passed = len([c for c in self.checks if c.status == CheckStatus.PASSED])
        failed = len([c for c in self.checks if c.status == CheckStatus.FAILED])
        warnings = len([c for c in self.checks if c.status == CheckStatus.WARNING])
        blockers = len([c for c in self.checks if c.status == CheckStatus.FAILED and c.blocker])
```

```
    return {
        "ready_for_production": blockers == 0,
        "total_checks": total,
        "passed": passed,
        "failed": failed,
        "warnings": warnings,
        "blockers": blockers,
        "checks": self.checks
    }

async def check_infrastructure(self):
    """Проверка инфраструктуры"""
    checks = [
        ProductionCheck(
            "Kubernetes Cluster Health",
            "Verify K8s cluster is healthy and has sufficient resources",
            await self._check_k8s_health(),
            blocker=True
        ),
        ProductionCheck(
            "Load Balancer Configuration",
            "Verify load balancer is properly configured",
            await self._check_load_balancer(),
            blocker=True
        ),
        ProductionCheck(
            "SSL/TLS Certificates",
            "Verify SSL certificates are valid and not expiring soon",
            await self._check_ssl_certificates(),
            blocker=True
        ),
        ProductionCheck(
            "DNS Configuration",
            "Verify DNS records are correctly configured",
            await self._check_dns(),
            blocker=True
        )
    ]
    self.checks.extend(checks)

async def check_database(self):
    """Проверка базы данных"""
    checks = [
```

```
            ProductionCheck(
                "Database Connectivity",
                "Verify application can connect to production database",
                await self._check_db_connectivity(),
                blocker=True
            ),
            ProductionCheck(
                "Database Performance",
                "Verify database performance meets requirements",
                await self._check_db_performance(),
                blocker=False
            ),
            ProductionCheck(
                "Database Backup",
                "Verify automated backups are configured and working",
                await self._check_db_backup(),
                blocker=True
            ),
            ProductionCheck(
                "Database Security",
                "Verify database security settings",
                await self._check_db_security(),
                blocker=True
            )
        ]
        self.checks.extend(checks)

    async def check_compliance(self):
        """Проверка соответствия требованиям"""
        checks = [
            ProductionCheck(
                "Georgian Tax Compliance",
                "Verify compliance with Georgian tax regulations",
                await self._check_georgian_tax_compliance(),
                blocker=True
            ),
            ProductionCheck(
                "IFRS Compliance",
                "Verify IFRS accounting standards compliance",
                await self._check_ifrs_compliance(),
                blocker=True
            ),
            ProductionCheck(
                "Data Privacy Compliance",
```

```
                "Verify Georgian data protection law compliance",
                await self._check_data_privacy(),
                blocker=True
            ),
            ProductionCheck(
                "Audit Trail Completeness",
                "Verify complete audit trail implementation",
                await self._check_audit_trail(),
                blocker=True
            )
        ]
        self.checks.extend(checks)

    async def _check_georgian_tax_compliance(self) -> CheckStatus:
        """Проверка соответствия грузинскому налоговому законодательству"""
        compliance_items = [
            "VAT rate 18% correctly configured",
            "Monthly VAT reporting implemented",
            "100,000 GEL threshold monitoring",
            "RS.ge integration working",
            "Reverse-charge VAT handling",
            "Income tax 20% calculation",
            "Pension system 2+2+2 implemented"
        ]

        # В реальности - проверять каждый пункт
        all_compliant = True  # Результат реальной проверки

        return CheckStatus.PASSED if all_compliant else CheckStatus.FAILED

    async def generate_go_live_report(self) -> str:
        """Генерировать отчет о готовности к запуску"""
        results = await self.run_all_checks()

        report = f"""
# Production Readiness Report
Generated: {datetime.utcnow().isoformat()}

## Executive Summary
{'✅ READY FOR PRODUCTION' if results['ready_for_production'] else '❌ NOT READY FOR PRODUCTION'}

## Statistics
- Total Checks: {results['total_checks']}
- Passed: {results['passed']} ✅
```

```
- Failed: {results['failed']} ❌
- Warnings: {results['warnings']} ⚠️
- Blockers: {results['blockers']} 🚫

## Readiness Score: {(results['passed'] / results['total_checks']) * 100:.1f}%

## Critical Issues
"""

        blockers = [c for c in self.checks if c.status == CheckStatus.FAILED and c.blocker]
        if blockers:
            report += "The following issues MUST be resolved before production deployment:\n"
            for check in blockers:
                report += f"- ❌ {check.name}: {check.description}\n"
        else:
            report += "No critical blocking issues found.\n"

        report += "\n## All Checks Details\n"
        for check in self.checks:
            status_emoji = {
                CheckStatus.PASSED: "✅",
                CheckStatus.FAILED: "❌",
                CheckStatus.WARNING: "⚠️",
                CheckStatus.PENDING: "⏳"
            }

            blocker_flag = " 🚫 BLOCKER" if check.blocker and check.status == CheckStatus.FAILED else ""
            report += f"- {status_emoji[check.status]} {check.name}{blocker_flag}\n"
            if check.details:
                report += f"  Details: {check.details}\n"

        return report

# Go-Live процедура
class GoLiveCoordinator:
    def __init__(self):
        self.readiness_checker = ProductionReadinessChecker()
        self.deployment_steps = self.create_deployment_steps()

    def create_deployment_steps(self) -> List[Dict]:
        """Создать пошаговый план деплоя"""
        return [
            {
                "step": 1,
```

```
    "name": "Pre-deployment verification",
    "description": "Run final production readiness checks",
    "duration_minutes": 30,
    "rollback_possible": True
  },
  {
    "step": 2,
    "name": "Database migration",
    "description": "Apply production database migrations",
    "duration_minutes": 60,
    "rollback_possible": True
  },
  {
    "step": 3,
    "name": "Blue-green deployment start",
    "description": "Deploy new version to preview environment",
    "duration_minutes": 20,
    "rollback_possible": True
  },
  {
    "step": 4,
    "name": "Integration testing",
    "description": "Run integration tests against preview environment",
    "duration_minutes": 45,
    "rollback_possible": True
  },
  {
    "step": 5,
    "name": "Traffic switchover",
    "description": "Switch traffic from blue to green environment",
    "duration_minutes": 5,
    "rollback_possible": True
  },
  {
    "step": 6,
    "name": "Post-deployment verification",
    "description": "Verify all systems operational",
    "duration_minutes": 30,
    "rollback_possible": True
  },
  {
    "step": 7,
    "name": "Monitoring setup",
    "description": "Enable production monitoring and alerting",
```

```
            "duration_minutes": 15,
            "rollback_possible": False
        },
        {
            "step": 8,
            "name": "User notification",
            "description": "Notify users about system availability",
            "duration_minutes": 10,
            "rollback_possible": False
        }
    ]

async def execute_go_live(self) -> Dict:
    """Выполнить процедуру go-live"""
    start_time = datetime.utcnow()
    results = []

    # Предварительная проверка
    readiness_report = await self.readiness_checker.run_all_checks()
    if not readiness_report["ready_for_production"]:
        return {
            "success": False,
            "error": "System not ready for production",
            "readiness_report": readiness_report
        }

    # Выполнение шагов деплоя
    for step in self.deployment_steps:
        step_start = datetime.utcnow()

        try:
            success = await self.execute_deployment_step(step)
            step_result = {
                "step": step["step"],
                "name": step["name"],
                "success": success,
                "start_time": step_start,
                "duration": (datetime.utcnow() - step_start).total_seconds()
            }

            if not success:
                step_result["error"] = f"Step {step['step']} failed"
                results.append(step_result)
```

```
            # Автоматический rollback если возможен
            if step["rollback_possible"]:
                await self.rollback_deployment(step["step"])

            return {
                "success": False,
                "failed_step": step["step"],
                "results": results
            }

        results.append(step_result)

    except Exception as e:
        results.append({
            "step": step["step"],
            "name": step["name"],
            "success": False,
            "error": str(e),
            "start_time": step_start,
            "duration": (datetime.utcnow() - step_start).total_seconds()
        })

        # Rollback при ошибке
        if step["rollback_possible"]:
            await self.rollback_deployment(step["step"])

        return {
            "success": False,
            "failed_step": step["step"],
            "exception": str(e),
            "results": results
        }

total_duration = (datetime.utcnow() - start_time).total_seconds()

return {
    "success": True,
    "total_duration_seconds": total_duration,
    "results": results,
    "go_live_time": start_time.isoformat()
}
```

Результаты Фазы 5:

- ✅ Performance optimization с 2x улучшением скорости
- ✅ Успешное load testing до 1000+ concurrent users
- ✅ Security audit с 95%+ security score
- ✅ Обучение 50+ пользователей
- ✅ Успешный production deployment
- ✅ 99.9% uptime в первый месяц работы

📊 Итоговые результаты миграции

Технические достижения:

- **Производительность**: Улучшение в 3x по сравнению с legacy системой
- **Масштабируемость**: Поддержка до 10,000 пользователей
- **Доступность**: 99.95% uptime SLA
- **Безопасность**: Соответствие всем стандартам безопасности

Бизнес-результаты:

- **Соответствие требованиям**: 100% compliance с Georgian Tax Code и IFRS
- **Время обработки**: Сокращение времени на 70%
- **Автоматизация**: 80% рутинных задач автоматиз # План поэтапной миграции грузинской бухгалтерской системы

🎯 Общая стратегия миграции

Подход: Strangler Fig Pattern - постепенная замена компонентов без остановки работы системы

Продолжительность: 18-24 месяца

Бюджет: Распределен поэтапно для минимизации рисков

📋 Фаза 0: Подготовка и анализ (Месяцы 1-2)

Цели:

- Аудит текущего состояния

- Подготовка инфраструктуры
- Создание команды миграции

Задачи:

Неделя 1-2: Технический аудит

```bash
# Анализ кода
- Инвентаризация всех модулей и зависимостей
- Оценка тестового покрытия (текущий: ~10%, цель: 85%)
- Выявление критических узких мест производительности
- Анализ данных: объемы, структура, quality issues
```

Неделя 3-4: Создание MVP инфраструктуры

```yaml
```

```yaml
# docker-compose-migration.yml
version: '3.8'
services:
  # Текущая система (legacy)
  legacy-app:
    build: ./legacy
    ports:
      - "8080:8080"
    networks:
      - migration-network

  # Новая система (target)
  new-api-gateway:
    build: ./new-system/gateway
    ports:
      - "8000:8000"
    networks:
      - migration-network

  # Shared resources
  postgres-new:
    image: postgres:15
    environment:
      POSTGRES_DB: accounting_new
    networks:
      - migration-network

  redis:
    image: redis:7-alpine
    networks:
      - migration-network

networks:
  migration-network:
    driver: bridge
```

Неделя 5-6: Создание Data Pipeline

```python
```

```python
# migration/data_sync.py
from sqlalchemy import create_engine
import asyncpg
import pandas as pd

class DataSynchronizer:
    def __init__(self):
        self.legacy_engine = create_engine('postgresql://legacy_db')
        self.new_pool = None

    async def sync_accounts(self):
        """Синхронизация справочника счетов"""
        df = pd.read_sql("SELECT * FROM chart_of_accounts", self.legacy_engine)

        # Transform data
        df['id'] = df.apply(lambda x: uuid4(), axis=1)
        df['created_at'] = pd.Timestamp.now()

        # Load to new system
        async with self.new_pool.acquire() as conn:
            await conn.executemany(
                "INSERT INTO accounts (id, code, name, type) VALUES ($1, $2, $3, $4)",
                df[['id', 'code', 'name', 'account_type']].values.tolist()
            )
```

Неделя 7-8: CI/CD Pipeline

yaml

```yaml
# .github/workflows/migration.yml
name: Migration Pipeline
on:
  push:
    branches: [main, migration/*]

jobs:
  test-legacy:
    runs-on: ubuntu-latest
    steps:
      - uses: actions/checkout@v3
      - name: Test Legacy System
        run: |
          docker-compose -f legacy/docker-compose.test.yml up --abort-on-container-exit

  test-new-system:
    runs-on: ubuntu-latest
    steps:
      - uses: actions/checkout@v3
      - name: Test New System
        run: |
          docker-compose -f new-system/docker-compose.test.yml up --abort-on-container-exit

  deploy-staging:
    needs: [test-legacy, test-new-system]
    runs-on: ubuntu-latest
    steps:
      - name: Deploy to Staging
        run: |
          kubectl apply -f k8s/staging/
```

Результаты Фазы 0:

- ✅ Детальный план миграции с временными рамками
- ✅ Настроенная инфраструктура для параллельной работы систем
- ✅ Команда готова к миграции (3-5 разработчиков)
- ✅ Базовая система мониторинга и алертов

🔧 Фаза 1: Модернизация фундамента (Месяцы 3-6)

Цели:

- Замена устаревших компонентов
- Повышение безопасности
- Улучшение производительности

1.1 Модернизация базы данных (Месяц 3)

Неделя 1-2: Новая схема БД

sql

```sql
-- migrations/001_new_schema.sql
CREATE EXTENSION IF NOT EXISTS "uuid-ossp";
CREATE EXTENSION IF NOT EXISTS "pg_stat_statements";

-- Новая таблица счетов с UUID
CREATE TABLE accounts_v2 (
    id UUID PRIMARY KEY DEFAULT gen_random_uuid(),
    code VARCHAR(20) NOT NULL,
    name VARCHAR(100) NOT NULL,
    account_type account_type_enum NOT NULL,
    parent_id UUID REFERENCES accounts_v2(id),
    is_active BOOLEAN DEFAULT TRUE,
    metadata JSONB DEFAULT '{}',
    created_at TIMESTAMPTZ NOT NULL DEFAULT NOW(),
    updated_at TIMESTAMPTZ DEFAULT NOW(),
    version INTEGER DEFAULT 1,

    -- Индексы для производительности
    CONSTRAINT unique_code_per_company UNIQUE (code, company_id)
);

CREATE INDEX idx_accounts_v2_code ON accounts_v2(code);
CREATE INDEX idx_accounts_v2_type ON accounts_v2(account_type);
CREATE INDEX idx_accounts_v2_parent ON accounts_v2(parent_id);
```

Неделя 3-4: Партиционирование для больших таблиц

sql

```sql
-- Партиционирование журнала проводок по месяцам
CREATE TABLE journal_entries_v2 (
    id UUID PRIMARY KEY DEFAULT gen_random_uuid(),
    transaction_id UUID NOT NULL,
    account_id UUID NOT NULL REFERENCES accounts_v2(id),
    debit DECIMAL(15,2) DEFAULT 0.00,
    credit DECIMAL(15,2) DEFAULT 0.00,
    currency_code CHAR(3) NOT NULL DEFAULT 'GEL',
    exchange_rate DECIMAL(15,5) DEFAULT 1.00000,
    description TEXT,
    transaction_date DATE NOT NULL,
    created_at TIMESTAMPTZ NOT NULL DEFAULT NOW(),

    CONSTRAINT check_debit_credit CHECK (
        (debit > 0 AND credit = 0) OR (credit > 0 AND debit = 0)
    )
) PARTITION BY RANGE (transaction_date);

-- Создание партиций на год вперед
CREATE TABLE journal_entries_202501 PARTITION OF journal_entries_v2
    FOR VALUES FROM ('2025-01-01') TO ('2025-02-01');
-- ... остальные месяцы
```

1.2 Новый API слой (Месяц 4)

FastAPI с современными паттернами

python

```python
# new_system/api/main.py
from fastapi import FastAPI, Depends, HTTPException, BackgroundTasks
from fastapi.security import HTTPBearer
from fastapi.middleware.cors import CORSMiddleware
from contextlib import asynccontextmanager
import structlog

logger = structlog.get_logger()

@asynccontextmanager
async def lifespan(app: FastAPI):
    # Startup
    await init_database_pool()
    await init_kafka_producer()
    logger.info("Application started")

    yield

    # Shutdown
    await close_database_pool()
    await close_kafka_producer()
    logger.info("Application stopped")

app = FastAPI(
    title="Georgian Accounting System v2.0",
    description="Modern IFRS-compliant accounting system",
    version="2.0.0",
    lifespan=lifespan
)

app.add_middleware(
    CORSMiddleware,
    allow_origins=["*"],  # Configure properly in production
    allow_credentials=True,
    allow_methods=["*"],
    allow_headers=["*"],
)

# API Routes
from .routes import accounts, transactions, reports

app.include_router(accounts.router, prefix="/api/v1/accounts")
```

```
app.include_router(transactions.router, prefix="/api/v1/transactions")
app.include_router(reports.router, prefix="/api/v1/reports")
```

Современная архитектура с DI

```python
```

```python
# new_system/core/dependencies.py
from dependency_injector import containers, providers
from dependency_injector.wiring import Provide

class Container(containers.DeclarativeContainer):
    # Configuration
    config = providers.Configuration()

    # Database
    db_pool = providers.Singleton(
        create_async_pool,
        config.database.url
    )

    # Repositories
    account_repository = providers.Factory(
        AccountRepository,
        db_pool=db_pool
    )

    transaction_repository = providers.Factory(
        TransactionRepository,
        db_pool=db_pool
    )

    # Services
    accounting_service = providers.Factory(
        AccountingService,
        account_repo=account_repository,
        transaction_repo=transaction_repository
    )

# Dependency injection
async def get_accounting_service(
    service: AccountingService = Depends(Provide[Container.accounting_service])
) -> AccountingService:
    return service
```

1.3 Система безопасности (Месяц 5)

JWT с refresh tokens

```
python
```

```python
# new_system/auth/jwt_handler.py
from jose import JWTError, jwt
from datetime import datetime, timedelta
import secrets

class JWTHandler:
    def __init__(self, secret_key: str):
        self.secret_key = secret_key
        self.algorithm = "HS256"
        self.access_token_expire = timedelta(minutes=30)
        self.refresh_token_expire = timedelta(days=7)

    async def create_tokens(self, user_id: str, permissions: List[str]) -> TokenPair:
        access_payload = {
            "sub": user_id,
            "permissions": permissions,
            "type": "access",
            "exp": datetime.utcnow() + self.access_token_expire,
            "iat": datetime.utcnow(),
            "jti": secrets.token_hex(16)  # JWT ID для отзыва
        }

        refresh_payload = {
            "sub": user_id,
            "type": "refresh",
            "exp": datetime.utcnow() + self.refresh_token_expire,
            "iat": datetime.utcnow(),
            "jti": secrets.token_hex(16)
        }

        access_token = jwt.encode(access_payload, self.secret_key, self.algorithm)
        refresh_token = jwt.encode(refresh_payload, self.secret_key, self.algorithm)

        # Сохранить refresh token в Redis с TTL
        await self.redis.setex(f"refresh:{refresh_payload['jti']}",
                               int(self.refresh_token_expire.total_seconds()),
                               user_id)

        return TokenPair(
            access_token=access_token,
            refresh_token=refresh_token,
```

```
        expires_in=int(self.access_token_expire.total_seconds())
    )
```

Role-Based Access Control

python

```python
# new_system/auth/rbac.py
from enum import Enum
from dataclasses import dataclass
from typing import Set

class Permission(Enum):
    ACCOUNTS_READ = "accounts:read"
    ACCOUNTS_WRITE = "accounts:write"
    TRANSACTIONS_READ = "transactions:read"
    TRANSACTIONS_WRITE = "transactions:write"
    TRANSACTIONS_APPROVE = "transactions:approve"
    REPORTS_FINANCIAL = "reports:financial"
    REPORTS_TAX = "reports:tax"
    ADMIN_USERS = "admin:users"
    ADMIN_SYSTEM = "admin:system"

@dataclass
class Role:
    name: str
    permissions: Set[Permission]

class GeorgianAccountingRoles:
    ACCOUNTANT = Role("accountant", {
        Permission.ACCOUNTS_READ,
        Permission.TRANSACTIONS_READ,
        Permission.TRANSACTIONS_WRITE,
        Permission.REPORTS_FINANCIAL
    })

    CHIEF_ACCOUNTANT = Role("chief_accountant", {
        *ACCOUNTANT.permissions,
        Permission.TRANSACTIONS_APPROVE,
        Permission.REPORTS_TAX,
        Permission.ADMIN_USERS
    })

    TAX_SPECIALIST = Role("tax_specialist", {
        Permission.ACCOUNTS_READ,
        Permission.TRANSACTIONS_READ,
        Permission.REPORTS_TAX
    })

def require_permission(permission: Permission):
```

```
    def decorator(func):
        @wraps(func)
        async def wrapper(*args, current_user = Depends(get_current_user), **kwargs):
            if permission not in current_user.permissions:
                raise HTTPException(403, "Insufficient permissions")
            return await func(*args, **kwargs, current_user=current_user)
        return wrapper
    return decorator
```

1.4 Мониторинг и логирование (Месяц 6)

Структурированное логирование

python

```python
# new_system/core/logging.py
import structlog
from pythonjsonlogger import jsonlogger

def setup_logging():
    structlog.configure(
        processors=[
            structlog.stdlib.filter_by_level,
            structlog.stdlib.add_logger_name,
            structlog.stdlib.add_log_level,
            structlog.stdlib.PositionalArgumentsFormatter(),
            structlog.processors.TimeStamper(fmt="iso"),
            structlog.processors.StackInfoRenderer(),
            structlog.processors.format_exc_info,
            structlog.processors.UnicodeDecoder(),
            structlog.processors.JSONRenderer()
        ],
        context_class=dict,
        logger_factory=structlog.stdlib.LoggerFactory(),
        wrapper_class=structlog.stdlib.BoundLogger,
        cache_logger_on_first_use=True,
    )

# Использование в коде
logger = structlog.get_logger()

async def create_transaction(transaction_data: TransactionCreate):
    logger.info(
        "Transaction creation started",
        transaction_id=transaction_data.id,
        user_id=current_user.id,
        amount=float(transaction_data.total_amount)
    )

    try:
        result = await service.create_transaction(transaction_data)
        logger.info(
            "Transaction created successfully",
            transaction_id=result.id,
            duration_ms=(time.time() - start_time) * 1000
        )
        return result
    except Exception as e:
```

```
        logger.error(
            "Transaction creation failed",
            error=str(e),
            transaction_data=transaction_data.dict()
        )
        raise
```

Prometheus метрики

```python
```

```python
# new_system/core/metrics.py
from prometheus_client import Counter, Histogram, Gauge
import time

# Business metrics
transaction_counter = Counter(
    'accounting_transactions_total',
    'Total number of accounting transactions',
    ['status', 'transaction_type']
)

transaction_amount_histogram = Histogram(
    'accounting_transaction_amount_gel',
    'Distribution of transaction amounts in GEL',
    buckets=[10, 50, 100, 500, 1000, 5000, 10000, 50000, float('inf')]
)

account_balance_gauge = Gauge(
    'accounting_account_balance_gel',
    'Current account balance in GEL',
    ['account_code', 'account_type']
)

# Technical metrics
request_duration = Histogram(
    'http_request_duration_seconds',
    'HTTP request duration',
    ['method', 'endpoint', 'status']
)

class MetricsMiddleware:
    async def __call__(self, request, call_next):
        start_time = time.time()
        response = await call_next(request)
        duration = time.time() - start_time

        request_duration.labels(
            method=request.method,
            endpoint=request.url.path,
            status=response.status_code
        ).observe(duration)
```

```
    return response
```

Результаты Фазы 1:

- ✅ Новая БД схема с UUID и партиционированием
- ✅ Modern FastAPI с async/await
- ✅ JWT authentication с RBAC
- ✅ Структурированное логирование и метрики
- ✅ 60% покрытие тестами новых компонентов

🧬 Фаза 2: Внедрение Event-Driven Architecture (Месяцы 7-10)

Цели:

- Реализация Event Sourcing для audit trail
- CQRS для разделения чтения/записи
- Интеграция с Kafka

2.1 Event Store и Event Sourcing (Месяц 7)

Event Store на PostgreSQL

```sql
```

```sql
-- events/001_event_store.sql
CREATE TABLE event_store (
    id UUID PRIMARY KEY DEFAULT gen_random_uuid(),
    aggregate_id UUID NOT NULL,
    aggregate_type VARCHAR(100) NOT NULL,
    event_type VARCHAR(100) NOT NULL,
    event_data JSONB NOT NULL,
    event_metadata JSONB DEFAULT '{}',
    version INTEGER NOT NULL,
    timestamp TIMESTAMPTZ NOT NULL DEFAULT NOW(),

    CONSTRAINT unique_version_per_aggregate UNIQUE (aggregate_id, version)
);

CREATE INDEX idx_event_store_aggregate ON event_store(aggregate_id);
CREATE INDEX idx_event_store_type ON event_store(event_type);
CREATE INDEX idx_event_store_timestamp ON event_store(timestamp);

-- Snapshots для производительности
CREATE TABLE aggregate_snapshots (
    aggregate_id UUID PRIMARY KEY,
    aggregate_type VARCHAR(100) NOT NULL,
    snapshot_data JSONB NOT NULL,
    version INTEGER NOT NULL,
    timestamp TIMESTAMPTZ NOT NULL DEFAULT NOW()
);
```

Базовые классы для Event Sourcing

```python
```

```python
# new_system/events/base.py
from dataclasses import dataclass
from typing import Any, List, Dict
from abc import ABC, abstractmethod
import uuid
from datetime import datetime

@dataclass(frozen=True)
class DomainEvent:
    """Базовый класс для доменных событий"""
    aggregate_id: uuid.UUID
    event_id: uuid.UUID
    event_type: str
    event_data: Dict[str, Any]
    version: int
    timestamp: datetime
    metadata: Dict[str, Any]

class Aggregate(ABC):
    """Базовый класс для агрегатов"""
    def __init__(self, aggregate_id: uuid.UUID):
        self.id = aggregate_id
        self.version = 0
        self.uncommitted_events: List[DomainEvent] = []

    def apply_event(self, event: DomainEvent):
        """Применить событие к агрегату"""
        self._apply_event(event)
        if event.version > self.version:
            self.version = event.version

    def raise_event(self, event_type: str, event_data: Dict[str, Any], metadata: Dict[str, Any] = None):
        """Поднять новое событие"""
        event = DomainEvent(
            aggregate_id=self.id,
            event_id=uuid.uuid4(),
            event_type=event_type,
            event_data=event_data,
            version=self.version + 1,
            timestamp=datetime.utcnow(),
            metadata=metadata or {}
        )
        self.uncommitted_events.append(event)
```

```
        self.apply_event(event)

    @abstractmethod
    def _apply_event(self, event: DomainEvent):
        """Применить событие к состоянию агрегата"""
        pass

    def mark_events_as_committed(self):
        """Пометить события как сохраненные"""
        self.uncommitted_events.clear()
```

Accounting Aggregate

python

```python
# new_system/domain/aggregates.py
from decimal import Decimal
from dataclasses import dataclass
from typing import List, Optional

@dataclass
class JournalEntryData:
    account_id: uuid.UUID
    debit: Decimal
    credit: Decimal
    description: str

class AccountingTransaction(Aggregate):
    """Агрегат бухгалтерской транзакции"""

    def __init__(self, aggregate_id: uuid.UUID):
        super().__init__(aggregate_id)
        self.transaction_date: Optional[datetime] = None
        self.description: str = ""
        self.entries: List[JournalEntryData] = []
        self.status: str = "draft"
        self.total_debit: Decimal = Decimal('0.00')
        self.total_credit: Decimal = Decimal('0.00')

    def create_transaction(self, transaction_date: datetime, description: str, entries: List[JournalEntryData]):
        """Создать новую транзакцию"""
        if self.status != "":
            raise ValueError("Transaction already exists")

        # Валидация двойной записи
        total_debit = sum(entry.debit for entry in entries)
        total_credit = sum(entry.credit for entry in entries)

        if total_debit != total_credit:
            raise ValueError(f"Unbalanced transaction: debit={total_debit}, credit={total_credit}")

        self.raise_event("TransactionCreated", {
            "transaction_date": transaction_date.isoformat(),
            "description": description,
            "entries": [
                {
                    "account_id": str(entry.account_id),
                    "debit": str(entry.debit),
```

```
                "credit": str(entry.credit),
                "description": entry.description
            }
            for entry in entries
        ],
        "total_amount": str(total_debit)
    })

def approve_transaction(self, approved_by: uuid.UUID):
    """Одобрить транзакцию"""
    if self.status != "draft":
        raise ValueError(f"Cannot approve transaction with status: {self.status}")

    self.raise_event("TransactionApproved", {
        "approved_by": str(approved_by),
        "approved_at": datetime.utcnow().isoformat()
    })

def post_transaction(self, posted_by: uuid.UUID):
    """Провести транзакцию"""
    if self.status != "approved":
        raise ValueError(f"Cannot post transaction with status: {self.status}")

    self.raise_event("TransactionPosted", {
        "posted_by": str(posted_by),
        "posted_at": datetime.utcnow().isoformat()
    })

def _apply_event(self, event: DomainEvent):
    """Применить событие к состоянию транзакции"""
    if event.event_type == "TransactionCreated":
        self.transaction_date = datetime.fromisoformat(event.event_data["transaction_date"])
        self.description = event.event_data["description"]
        self.entries = [
            JournalEntryData(
                account_id=uuid.UUID(entry["account_id"]),
                debit=Decimal(entry["debit"]),
                credit=Decimal(entry["credit"]),
                description=entry["description"]
            )
            for entry in event.event_data["entries"]
        ]
        self.total_debit = self.total_credit = Decimal(event.event_data["total_amount"])
        self.status = "draft"
```

```
        elif event.event_type == "TransactionApproved":
            self.status = "approved"

        elif event.event_type == "TransactionPosted":
            self.status = "posted"
```

2.2 CQRS Implementation (Месяц 8)

Command и Query разделение

python

```python
# new_system/cqrs/commands.py
from dataclasses import dataclass
from abc import ABC, abstractmethod

class Command(ABC):
    """Базовый класс для команд"""
    pass

class CommandHandler(ABC):
    @abstractmethod
    async def handle(self, command: Command) -> Any:
        pass

@dataclass
class CreateTransactionCommand(Command):
    transaction_date: datetime
    description: str
    entries: List[JournalEntryData]
    created_by: uuid.UUID

class CreateTransactionHandler(CommandHandler):
    def __init__(self, event_store: EventStore, event_bus: EventBus):
        self.event_store = event_store
        self.event_bus = event_bus

    async def handle(self, command: CreateTransactionCommand) -> uuid.UUID:
        # Создать агрегат
        transaction_id = uuid.uuid4()
        transaction = AccountingTransaction(transaction_id)

        # Выполнить бизнес-логику
        transaction.create_transaction(
            command.transaction_date,
            command.description,
            command.entries
        )

        # Сохранить события
        await self.event_store.save_events(
            transaction.id,
            transaction.uncommitted_events,
            expected_version=0
        )
```

```
    # Опубликовать события
    for event in transaction.uncommitted_events:
        await self.event_bus.publish(event)

    transaction.mark_events_as_committed()
    return transaction.id
```

Query side (Read Models)

python

```python
# new_system/cqrs/queries.py
@dataclass
class AccountBalanceQuery:
    account_id: uuid.UUID
    as_of_date: Optional[datetime] = None

class AccountBalanceQueryHandler:
    def __init__(self, read_db_pool):
        self.read_db = read_db_pool

    async def handle(self, query: AccountBalanceQuery) -> Decimal:
        async with self.read_db.acquire() as conn:
            if query.as_of_date:
                result = await conn.fetchval(
                    """
                    SELECT balance FROM account_balances_history
                    WHERE account_id = $1 AND date <= $2
                    ORDER BY date DESC LIMIT 1
                    """,
                    query.account_id,
                    query.as_of_date
                )
            else:
                result = await conn.fetchval(
                    "SELECT current_balance FROM account_balances WHERE account_id = $1",
                    query.account_id
                )

            return Decimal(str(result or '0.00'))

# Projection для поддержания read models
class AccountBalanceProjection:
    def __init__(self, read_db_pool):
        self.read_db = read_db_pool

    async def handle_transaction_posted(self, event: DomainEvent):
        """Обновить балансы счетов при проведении транзакции"""
        entries = event.event_data["entries"]

        async with self.read_db.acquire() as conn:
            async with conn.transaction():
                for entry_data in entries:
                    account_id = uuid.UUID(entry_data["account_id"])
```

```
        debit = Decimal(entry_data["debit"])
        credit = Decimal(entry_data["credit"])

        # Обновить текущий баланс
        await conn.execute(
            """
            INSERT INTO account_balances (account_id, current_balance, last_updated)
            VALUES ($1, $2, $3)
            ON CONFLICT (account_id) DO UPDATE SET
                current_balance = account_balances.current_balance + $2,
                last_updated = $3
            """,
            account_id,
            debit - credit,
            event.timestamp
        )

        # Добавить историческую запись
        await conn.execute(
            """
            INSERT INTO account_balance_history
            (account_id, date, balance_change, running_balance, transaction_id)
            VALUES ($1, $2, $3,
                (SELECT current_balance FROM account_balances WHERE account_id = $1),
                $4)
            """,
            account_id,
            event.timestamp.date(),
            debit - credit,
            event.aggregate_id
        )
```

2.3 Kafka Integration (Месяц 9)

Event Bus с Kafka

```
python
```

```python
# new_system/infrastructure/event_bus.py
from aiokafka import AIOKafkaProducer, AIOKafkaConsumer
import json
from typing import Dict, Callable

class KafkaEventBus:
    def __init__(self, bootstrap_servers: str):
        self.bootstrap_servers = bootstrap_servers
        self.producer: Optional[AIOKafkaProducer] = None
        self.consumer = AIOKafkaConsumer(
            *topics,
            bootstrap_servers=self.bootstrap_servers,
            group_id="accounting-system",
            value_deserializer=lambda m: json.loads(m.decode('utf-8'))
        )

        await self.consumer.start()

        try:
            async for msg in self.consumer:
                await self._handle_message(msg)
        finally:
            await self.consumer.stop()

    async def _handle_message(self, msg):
        """Обработать входящее сообщение"""
        try:
            event_data = msg.value
            event_type = event_data["event_type"]

            if event_type in self.handlers:
                for handler in self.handlers[event_type]:
                    await handler(event_data)

        except Exception as e:
            logger.error(
                "Event handling failed",
                error=str(e),
                topic=msg.topic,
                partition=msg.partition,
                offset=msg.offset
            )
```

2.4 Georgian Tax Service Integration (Месяц 10)

Real-time VAT reporting

```python
```

```python
# new_system/integrations/georgian_tax.py
class GeorgianTaxEventHandler:
    def __init__(self, rs_client: RSApiClient):
        self.rs_client = rs_client

    async def handle_transaction_posted(self, event_data: Dict):
        """Обработать проведенную транзакцию для налогового учета"""
        transaction_id = event_data["aggregate_id"]
        entries = event_data["event_data"]["entries"]

        # Найти VAT-related проводки
        vat_entries = []
        for entry in entries:
            account = await self.get_account_info(entry["account_id"])
            if account.account_type == "VAT_PAYABLE" or account.account_type == "VAT_RECEIVABLE":
                vat_entries.append({
                    "account_id": entry["account_id"],
                    "amount": entry["credit"] if entry["credit"] > 0 else entry["debit"],
                    "type": "payable" if account.account_type == "VAT_PAYABLE" else "receivable"
                })

        if vat_entries:
            # Отправить в Georgian Revenue Service
            await self._notify_rs_about_vat_transaction(transaction_id, vat_entries)

    async def _notify_rs_about_vat_transaction(self, transaction_id: str, vat_entries: List[Dict]):
        """Уведомить RS.ge о VAT транзакции"""
        try:
            payload = {
                "transaction_id": transaction_id,
                "timestamp": datetime.utcnow().isoformat(),
                "vat_entries": vat_entries,
                "company_id": self.company_id
            }

            response = await self.rs_client.post("/api/v1/vat/transactions", payload)

            logger.info(
                "VAT transaction reported to RS.ge",
                transaction_id=transaction_id,
                rs_response_status=response.status
            )
```

```
    except Exception as e:
        logger.error(
            "Failed to report VAT transaction to RS.ge",
            transaction_id=transaction_id,
            error=str(e)
        )
        # Отправить в Dead Letter Queue для retry
        await self.send_to_dlq("vat_reporting", payload)
```

Результаты Фазы 2:

- ✅ Event Store с полным audit trail
- ✅ CQRS с разделением read/write моделей
- ✅ Kafka для event streaming
- ✅ Real-time интеграция с Georgian Tax Service
- ✅ 80% покрытие тестами event-driven компонентов

🎯 Фаза 3: Микросервисная архитектура (Месяцы 11-14)

Цели:

- Разделение на независимые сервисы
- API Gateway
- Service Mesh
- Container orchestration

3.1 Декомпозиция на микросервисы (Месяц 11)

Domain-Driven Design подход

```
Bounded Contexts:
├── 📁 accounting-core-service/      # Основные бухгалтерские операции
├── 📁 tax-service/                  # Налоговый учет и отчетность
├── 📁 payroll-service/              # Зарплата и кадры
├── 📁 inventory-service/            # Складской учет
├── 📁 reporting-service/            # Финансовая отчетность
├── 📁 compliance-service/           # Соответствие требованиям
├── 📁 integration-service/          # Внешние интеграции
├── 📁 notification-service/         # Уведомления
└── 📁 audit-service/                # Аудит и логирование
```

Accounting Core Service

python

```python
# services/accounting-core/main.py
from fastapi import FastAPI
from .api import transactions, accounts, fiscal_periods
from .domain import AccountingDomain
from .infrastructure import EventStore, MessageBus

class AccountingCoreService:
    def __init__(self):
        self.app = FastAPI(
            title="Accounting Core Service",
            description="Core accounting operations and journal entries",
            version="1.0.0"
        )

        # Domain layer
        self.domain = AccountingDomain()

        # Infrastructure
        self.event_store = EventStore()
        self.message_bus = MessageBus()

        # API routes
        self.app.include_router(transactions.router, prefix="/transactions")
        self.app.include_router(accounts.router, prefix="/accounts")
        self.app.include_router(fiscal_periods.router, prefix="/fiscal-periods")

        # Health check
        @self.app.get("/health")
        async def health_check():
            return {
                "status": "healthy",
                "service": "accounting-core",
                "version": "1.0.0",
                "dependencies": {
                    "database": await self.check_database(),
                    "event_store": await self.check_event_store(),
                    "message_bus": await self.check_message_bus()
                }
            }

    async def check_database(self) -> str:
        try:
            await self.domain.repository.health_check()
```

```
            return "healthy"
        except:
            return "unhealthy"

if __name__ == "__main__":
    import uvicorn
    service = AccountingCoreService()
    uvicorn.run(service.app, host="0.0.0.0", port=8001)
```

Tax Service (Georgian-specific)

```
python
```

```python
# services/tax-service/domain/georgian_tax.py
from decimal import Decimal
from datetime import date, datetime
from typing import List, Dict

class GeorgianVATCalculator:
    STANDARD_RATE = Decimal('0.18')  # 18% VAT
    REGISTRATION_THRESHOLD = Decimal('100000.00')  # 100,000 GEL

    def __init__(self):
        self.current_month_turnover = Decimal('0.00')
        self.annual_turnover = Decimal('0.00')

    def calculate_vat(self, net_amount: Decimal, is_exempt: bool = False) -> Dict[str, Decimal]:
        """Рассчитать НДС по грузинским правилам"""
        if is_exempt:
            return {
                "net_amount": net_amount,
                "vat_amount": Decimal('0.00'),
                "gross_amount": net_amount,
                "vat_rate": Decimal('0.00')
            }

        vat_amount = net_amount * self.STANDARD_RATE
        gross_amount = net_amount + vat_amount

        return {
            "net_amount": net_amount,
            "vat_amount": vat_amount,
            "gross_amount": gross_amount,
            "vat_rate": self.STANDARD_RATE
        }

    def check_vat_registration_requirement(self, monthly_turnover: Decimal) -> bool:
        """Проверить необходимость регистрации плательщика НДС"""
        return monthly_turnover >= self.REGISTRATION_THRESHOLD

class GeorgianTaxDeclarationGenerator:
    def __init__(self):
        self.rs_integration = RSIntegrationService()

    async def generate_monthly_vat_declaration(self, company_id: str, year: int, month: int) -> VATDeclaration:
        """Создать месячную декларацию НДС"""
```

```
    # Собрать данные за месяц
    transactions = await self.get_vat_transactions(company_id, year, month)

    total_vat_payable = sum(t.vat_amount for t in transactions if t.type == "sale")
    total_vat_deductible = sum(t.vat_amount for t in transactions if t.type == "purchase")
    net_vat = total_vat_payable - total_vat_deductible

    declaration = VATDeclaration(
        company_id=company_id,
        period=f"{year}-{month:02d}",
        total_sales=sum(t.net_amount for t in transactions if t.type == "sale"),
        total_vat_payable=total_vat_payable,
        total_purchases=sum(t.net_amount for t in transactions if t.type == "purchase"),
        total_vat_deductible=total_vat_deductible,
        net_vat_payment=net_vat,
        due_date=date(year, month + 1 if month < 12 else year + 1, 15)
    )

    return declaration

async def submit_to_rs_ge(self, declaration: VATDeclaration) -> RSSubmissionResult:
    """Отправить декларацию в rs.ge"""
    try:
        response = await self.rs_integration.submit_vat_declaration(declaration)
        return RSSubmissionResult(
            success=True,
            submission_id=response.submission_id,
            receipt_number=response.receipt_number
        )
    except Exception as e:
        logger.error("Failed to submit VAT declaration to RS.ge", error=str(e))
        return RSSubmissionResult(
            success=False,
            error_message=str(e)
        )
```

3.2 API Gateway (Месяц 12)

Kong API Gateway configuration

```
yaml
```

```yaml
# kong/kong.yml
_format_version: "3.0"

services:
  - name: accounting-core
    url: http://accounting-core-service:8001
    plugins:
      - name: rate-limiting
        config:
          minute: 1000
          hour: 10000
      - name: jwt
        config:
          secret_is_base64: false
          key_claim_name: kid
      - name: prometheus
        config:
          per_consumer: true

  - name: tax-service
    url: http://tax-service:8002
    plugins:
      - name: rate-limiting
        config:
          minute: 500
          hour: 5000
      - name: jwt
      - name: request-size-limiting
        config:
          allowed_payload_size: 10

routes:
  - name: accounting-transactions
    service: accounting-core
    paths:
      - /api/v1/transactions
    methods:
      - GET
      - POST
      - PUT
    plugins:
      - name: cors
        config:
```

```
        origins: ["*"]
        methods: ["GET", "POST", "PUT", "DELETE"]

  - name: georgian-tax
    service: tax-service
    paths:
      - /api/v1/tax
    plugins:
      - name: request-transformer
        config:
          add:
            headers:
              - "X-Georgian-Tax: true"

consumers:
  - username: accounting-system
    custom_id: accounting-system-001
    jwt_secrets:
      - algorithm: HS256
        key: accounting-jwt-key
        secret: ${JWT_SECRET}

plugins:
  - name: prometheus
    config:
      per_consumer: true
      status_code_metrics: true
      latency_metrics: true
      bandwidth_metrics: true
```

API Gateway с authentication

```python
```

```python
# api-gateway/main.py
from fastapi import FastAPI, Request, HTTPException, Depends
from fastapi.middleware.cors import CORSMiddleware
import httpx
import jwt
from typing import Dict

class APIGateway:
    def __init__(self):
        self.app = FastAPI(
            title="Georgian Accounting API Gateway",
            description="Central API gateway for microservices",
            version="1.0.0"
        )

        self.service_registry = {
            "accounting": "http://accounting-core-service:8001",
            "tax": "http://tax-service:8002",
            "payroll": "http://payroll-service:8003",
            "reporting": "http://reporting-service:8004"
        }

        self.setup_middleware()
        self.setup_routes()

    def setup_middleware(self):
        self.app.add_middleware(
            CORSMiddleware,
            allow_origins=["*"],
            allow_credentials=True,
            allow_methods=["*"],
            allow_headers=["*"],
        )

        @self.app.middleware("http")
        async def add_security_headers(request: Request, call_next):
            response = await call_next(request)
            response.headers["X-Content-Type-Options"] = "nosniff"
            response.headers["X-Frame-Options"] = "DENY"
            response.headers["X-XSS-Protection"] = "1; mode=block"
            return response

    def setup_routes(self):
```

```python
    @self.app.api_route("/api/v1/{service_name}/{path:path}", methods=["GET", "POST", "PUT", "DELETE", "PATCH"])
    async def proxy_request(
        service_name: str,
        path: str,
        request: Request,
        current_user = Depends(self.get_current_user)
    ):
        if service_name not in self.service_registry:
            raise HTTPException(status_code=404, detail="Service not found")

        service_url = self.service_registry[service_name]
        target_url = f"{service_url}/{path}"

        # Forward request
        async with httpx.AsyncClient() as client:
            response = await client.request(
                method=request.method,
                url=target_url,
                content=await request.body(),
                headers={
                    **dict(request.headers),
                    "X-User-ID": str(current_user.id),
                    "X-User-Permissions": ",".join(current_user.permissions)
                },
                params=request.query_params,
                timeout=30.0
            )

        return Response(
            content=response.content,
            status_code=response.status_code,
            headers=dict(response.headers)
        )

async def get_current_user(self, request: Request):
    """Извлечь текущего пользователя из JWT токена"""
    auth_header = request.headers.get("Authorization")
    if not auth_header or not auth_header.startswith("Bearer "):
        raise HTTPException(401, "Missing or invalid authorization header")

    token = auth_header.split(" ")[1]
    try:
        payload = jwt.decode(token, JWT_SECRET, algorithms=["HS256"])
        return User(
```

```
            id=payload["sub"],
            permissions=payload.get("permissions", [])
        )
    except jwt.InvalidTokenError:
        raise HTTPException(401, "Invalid token")
```

3.3 Service Mesh с Istio (Месяц 13)

Istio configuration

```yaml
```

```yaml
# istio/virtual-service.yaml
apiVersion: networking.istio.io/v1beta1
kind: VirtualService
metadata:
  name: accounting-system
spec:
  http:
  - match:
    - uri:
        prefix: /api/v1/transactions
    route:
    - destination:
        host: accounting-core-service
        port:
          number: 8001
    retries:
      attempts: 3
      perTryTimeout: 10s
    timeout: 30s

  - match:
    - uri:
        prefix: /api/v1/tax
    route:
    - destination:
        host: tax-service
        port:
          number: 8002
    fault:
      delay:
        percentage:
          value: 0.1
        fixedDelay: 2s

---
apiVersion: networking.istio.io/v1beta1
kind: DestinationRule
metadata:
  name: accounting-services
spec:
  host: "*.accounting-system.svc.cluster.local"
  trafficPolicy:
    circuitBreaker:
```

```
    consecutiveErrors: 3
    interval: 30s
    baseEjectionTime: 30s
  connectionPool:
    tcp:
      maxConnections: 100
    http:
      http1MaxPendingRequests: 50
      maxRequestsPerConnection: 10
```

Circuit Breaker implementation

```python
```

```python
# shared/circuit_breaker.py
import asyncio
from enum import Enum
from datetime import datetime, timedelta
import logging

class CircuitState(Enum):
    CLOSED = "closed"
    OPEN = "open"
    HALF_OPEN = "half_open"

class CircuitBreaker:
    def __init__(self,
                 failure_threshold: int = 5,
                 timeout: int = 60,
                 success_threshold: int = 2):
        self.failure_threshold = failure_threshold
        self.timeout = timeout
        self.success_threshold = success_threshold

        self.failure_count = 0
        self.success_count = 0
        self.last_failure_time = None
        self.state = CircuitState.CLOSED

    async def call(self, func, *args, **kwargs):
        """Выполнить функцию через circuit breaker"""
        if self.state == CircuitState.OPEN:
            if self._should_attempt_reset():
                self.state = CircuitState.HALF_OPEN
                logging.info("Circuit breaker: Attempting reset")
            else:
                raise CircuitBreakerOpenError("Circuit breaker is open")

        try:
            result = await func(*args, **kwargs)
            self._record_success()
            return result
        except Exception as e:
            self._record_failure()
            raise e

    def _record_success(self):
```

```
        """Записать успешный вызов"""
        if self.state == CircuitState.HALF_OPEN:
            self.success_count += 1
            if self.success_count >= self.success_threshold:
                self.state = CircuitState.CLOSED
                self.failure_count = 0
                self.success_count = 0
                logging.info("Circuit breaker: Reset to CLOSED")

    def _record_failure(self):
        """Записать неудачный вызов"""
        self.failure_count += 1
        self.last_failure_time = datetime.utcnow()

        if self.failure_count >= self.failure_threshold:
            self.state = CircuitState.OPEN
            logging.warning("Circuit breaker: Opened due to failures")

    def _should_attempt_reset(self) -> bool:
        """Проверить, следует ли попытаться сбросить circuit breaker"""
        if self.last_failure_time is None:
            return False

        return datetime.utcnow() - self.last_failure_time >= timedelta(seconds=self.timeout)

# Использование в сервисах
class TaxServiceClient:
    def __init__(self):
        self.circuit_breaker = CircuitBreaker()
        self.base_url = "http://tax-service:8002"

    async def calculate_vat(self, amount: Decimal) -> VATCalculation:
        return await self.circuit_breaker.call(self._calculate_vat_impl, amount)

    async def _calculate_vat_impl(self, amount: Decimal) -> VATCalculation:
        async with httpx.AsyncClient() as client:
            response = await client.post(
                f"{self.base_url}/api/v1/vat/calculate",
                json={"amount": str(amount)}
            )
            response.raise_for_status()
            return VATCalculation(**response.json())
```

3.4 Container Orchestration с Kubernetes (Месяц 14)

Kubernetes deployment manifests

yaml

```yaml
# k8s/accounting-core-deployment.yaml
apiVersion: apps/v1
kind: Deployment
metadata:
  name: accounting-core-service
  namespace: accounting-system
  labels:
    app: accounting-core
    version: v1
spec:
  replicas: 3
  selector:
    matchLabels:
      app: accounting-core
      version: v1
  template:
    metadata:
      labels:
        app: accounting-core
        version: v1
    spec:
      containers:
      - name: accounting-core
        image: accounting-system/accounting-core:v1.0.0
        ports:
        - containerPort: 8001
        env:
        - name: DATABASE_URL
          valueFrom:
            secretKeyRef:
              name: db-credentials
              key: url
        - name: KAFKA_BROKERS
          value: "kafka:9092"
        - name: REDIS_URL
          value: "redis://redis:6379"
        resources:
          requests:
            memory: "256Mi"
            cpu: "250m"
          limits:
            memory: "512Mi"
            cpu: "500m"
```

```yaml
        livenessProbe:
          httpGet:
            path: /health
            port: 8001
          initialDelaySeconds: 30
          periodSeconds: 10
        readinessProbe:
          httpGet:
            path: /health/ready
            port: 8001
          initialDelaySeconds: 5
          periodSeconds: 5
        volumeMounts:
        - name: config
          mountPath: /app/config
          readOnly: true
      volumes:
      - name: config
        configMap:
          name: accounting-core-config

---
apiVersion: v1
kind: Service
metadata:
  name: accounting-core-service
  namespace: accounting-system
  labels:
    app: accounting-core
spec:
  selector:
    app: accounting-core
  ports:
  - name: http
    port: 8001
    targetPort: 8001
  type: ClusterIP

---
apiVersion: autoscaling/v2
kind: HorizontalPodAutoscaler
metadata:
  name: accounting-core-hpa
  namespace: accounting-system
```

```yaml
spec:
  scaleTargetRef:
    apiVersion: apps/v1
    kind: Deployment
    name: accounting-core-service
  minReplicas: 2
  maxReplicas: 10
  metrics:
  - type: Resource
    resource:
      name: cpu
      target:
        type: Utilization
        averageUtilization: 70
  - type: Resource
    resource:
      name: memory
      target:
        type: Utilization
        averageUtilization: 80
```

Helm chart для развертывания

yaml

```yaml
# helm/accounting-system/Chart.yaml
apiVersion: v2
name: accounting-system
description: Georgian IFRS-compliant accounting system
type: application
version: 1.0.0
appVersion: "1.0.0"

dependencies:
  - name: postgresql
    version: 12.1.9
    repository: https://charts.bitnami.com/bitnami
  - name: redis
    version: 17.3.7
    repository: https://charts.bitnami.com/bitnami
  - name: kafka
    version: 20.0.6
    repository: https://charts.bitnami.com/bitnami
```

yaml

```yaml
# helm/accounting-system/values.yaml
global:
  imageRegistry: "registry.accounting-system.com"
  imagePullSecrets: []

accountingCore:
  enabled: true
  image:
    repository: accounting-core
    tag: "v1.0.0"
  replicaCount: 3
  resources:
    requests:
      memory: 256Mi
      cpu: 250m
    limits:
      memory: 512Mi
      cpu: 500m

taxService:
  enabled: true
  image:
    repository: tax-service
    tag: "v1.0.0"
  replicaCount: 2
  georgianTax:
    rsApiUrl: "https://api.rs.ge"
    vatRate: 0.18

postgresql:
  enabled: true
  auth:
    postgresPassword: "secure-password"
    database: "accounting"
  primary:
    persistence:
      size: 100Gi
      storageClass: "fast-ssd"

redis:
  enabled: true
  auth:
    enabled: true
```

```
    password: "redis-password"

  kafka:
    enabled: true
    replicaCount: 3
    persistence:
      size: 50Gi

  ingress:
    enabled: true
    className: "nginx"
    annotations:
      cert-manager.io/cluster-issuer: "letsencrypt-prod"
      nginx.ingress.kubernetes.io/rate-limit: "1000"
    hosts:
      - host: api.accounting-system.ge
        paths:
          - path: /
            pathType: Prefix
    tls:
      - secretName: accounting-system-tls
        hosts:
          - api.accounting-system.ge
```

Результаты Фазы 3:

- ✅ 9 независимых микросервисов
- ✅ API Gateway с authentication/authorization
- ✅ Service mesh с Istio
- ✅ Container orchestration в Kubernetes
- ✅ Auto-scaling и self-healing
- ✅ 90% покрытие тестами всех сервисов

🚀 Фаза 4: Cloud Native и Advanced Features (Месяцы 15-18)

Цели:

- Cloud-native deployment
- Machine Learning для fraud detection
- Advanced analytics

- Multi-tenant architecture

4.2 Machine Learning для Fraud Detection (Месяц 16)

ML Pipeline для аномалии в транзакциях

python

```python
# ml/fraud_detection/models.py
import numpy as np
import pandas as pd
from sklearn.ensemble import IsolationForest
from sklearn.preprocessing import StandardScaler
from sklearn.model_selection import train_test_split
import joblib
from typing import Dict, List, Tuple
import asyncio

class TransactionFraudDetector:
    def __init__(self):
        self.isolation_forest = IsolationForest(
            contamination=0.1,  # 10% аномалий ожидается
            random_state=42,
            n_estimators=200
        )
        self.scaler = StandardScaler()
        self.feature_columns = [
            'amount_gel', 'hour_of_day', 'day_of_week', 'days_since_last_transaction',
            'amount_zscore', 'frequency_last_week', 'account_age_days',
            'transaction_count_today', 'average_transaction_amount'
        ]
        self.is_trained = False

    def extract_features(self, transactions: List[Dict]) -> pd.DataFrame:
        """Извлечь признаки для ML модели"""
        df = pd.DataFrame(transactions)

        # Временные признаки
        df['timestamp'] = pd.to_datetime(df['created_at'])
        df['hour_of_day'] = df['timestamp'].dt.hour
        df['day_of_week'] = df['timestamp'].dt.dayofweek

        # Пользовательские паттерны
        df = df.sort_values(['user_id', 'timestamp'])
        df['days_since_last_transaction'] = df.groupby('user_id')['timestamp'].diff().dt.total_seconds() / (24 * 3600)
        df['days_since_last_transaction'].fillna(0, inplace=True)

        # Статистические признаки
        user_stats = df.groupby('user_id').agg({
            'amount_gel': ['mean', 'std', 'count'],
            'timestamp': ['min']
```

```
        }).reset_index()

        user_stats.columns = ['user_id', 'avg_amount', 'std_amount', 'transaction_count', 'first_transaction']
        user_stats['account_age_days'] = (pd.Timestamp.now() - user_stats['first_transaction']).dt.total_seconds() / (24 * 360

        # Объединение с основными данными
        df = df.merge(user_stats[['user_id', 'avg_amount', 'std_amount', 'account_age_days']], on='user_id')

        # Z-score для суммы
        df['amount_zscore'] = np.abs((df['amount_gel'] - df['avg_amount']) / (df['std_amount'] + 1e-6))

        # Частота транзакций за последнюю неделю
        df['frequency_last_week'] = df.groupby('user_id')['timestamp'].transform(
            lambda x: x.rolling('7D').count()
        )

        # Количество транзакций сегодня
        df['transaction_count_today'] = df.groupby(['user_id', df['timestamp'].dt.date]).cumcount() + 1

        return df[self.feature_columns].fillna(0)

    async def train(self, training_data: List[Dict]):
        """Обучить модель на исторических данных"""
        features_df = self.extract_features(training_data)

        # Нормализация признаков
        features_scaled = self.scaler.fit_transform(features_df)

        # Обучение модели
        self.isolation_forest.fit(features_scaled)
        self.is_trained = True

        # Сохранение модели
        joblib.dump(self.isolation_forest, 'models/fraud_detector.joblib')
        joblib.dump(self.scaler, 'models/fraud_scaler.joblib')

        print(f"Model trained on {len(training_data)} transactions")

    async def predict_fraud_probability(self, transaction: Dict) -> float:
        """Предсказать вероятность мошенничества"""
        if not self.is_trained:
            await self.load_model()

        # Извлечение признаков для одной транзакции
```

```
        features_df = self.extract_features([transaction])
        features_scaled = self.scaler.transform(features_df)

        # Получение anomaly score (-1 = аномалия, 1 = нормальная)
        anomaly_score = self.isolation_forest.decision_function(features_scaled)[0]

        # Преобразование в вероятность (0-1)
        fraud_probability = max(0, min(1, (1 - anomaly_score) / 2))

        return fraud_probability

    async def load_model(self):
        """Загрузить обученную модель"""
        try:
            self.isolation_forest = joblib.load('models/fraud_detector.joblib')
            self.scaler = joblib.load('models/fraud_scaler.joblib')
            self.is_trained = True
        except FileNotFoundError:
            print("Pre-trained model not found. Training new model...")
            # Здесь можно загрузить исторические данные и обучить модель

class FraudDetectionService:
    def __init__(self):
        self.detector = TransactionFraudDetector()
        self.fraud_threshold = 0.7  # Порог для определения мошенничества

    async def analyze_transaction(self, transaction: Dict) -> Dict:
        """Анализ транзакции на предмет мошенничества"""
        fraud_probability = await self.detector.predict_fraud_probability(transaction)

        risk_level = "low"
        if fraud_probability > self.fraud_threshold:
            risk_level = "high"
        elif fraud_probability > 0.4:
            risk_level = "medium"

        return {
            "transaction_id": transaction["id"],
            "fraud_probability": fraud_probability,
            "risk_level": risk_level,
            "requires_review": fraud_probability > self.fraud_threshold,
            "analysis_timestamp": datetime.utcnow().isoformat()
        }
```

```python
    async def handle_transaction_created_event(self, event_data: Dict):
        """Обработать событие создания транзакции для ML анализа"""
        transaction = event_data["event_data"]
        analysis_result = await self.analyze_transaction(transaction)

        if analysis_result["requires_review"]:
            # Отправить алерт для ручной проверки
            await self.send_fraud_alert(analysis_result)

            # Заблокировать транзакцию до проверки
            await self.flag_transaction_for_review(transaction["id"])

        # Сохранить результат анализа
        await self.save_fraud_analysis(analysis_result)

    async def send_fraud_alert(self, analysis_result: Dict):
        """Отправить уведомление о подозрительной транзакции"""
        alert = {
            "alert_type": "fraud_detection",
            "severity": "high",
            "transaction_id": analysis_result["transaction_id"],
            "fraud_probability": analysis_result["fraud_probability"],
            "message": f"High fraud probability detected: {analysis_result['fraud_probability']:.2%}"
        }

        # Отправка через notification service
        await self.notification_service.send_alert(alert)
```

Real-time ML inference

python

```python
# ml/realtime_inference/inference_service.py
from kafka import KafkaConsumer, KafkaProducer
import json
import asyncio
from concurrent.futures import ThreadPoolExecutor
import logging

class RealtimeMLInferenceService:
    def __init__(self):
        self.fraud_detector = FraudDetectionService()
        self.consumer = KafkaConsumer(
            'accounting.transactioncreated',
            bootstrap_servers=['kafka:9092'],
            value_deserializer=lambda m: json.loads(m.decode('utf-8')),
            group_id='ml-fraud-detection'
        )
        self.producer = KafkaProducer(
            bootstrap_servers=['kafka:9092'],
            value_serializer=lambda v: json.dumps(v, default=str).encode('utf-8')
        )
        self.executor = ThreadPoolExecutor(max_workers=10)

    async def start_processing(self):
        """Запуск real-time обработки транзакций"""
        logger.info("Starting ML inference service...")

        loop = asyncio.get_event_loop()

        for message in self.consumer:
            # Обработка в отдельном потоке для неблокирующей работы
            future = loop.run_in_executor(
                self.executor,
                self.process_transaction_message,
                message.value
            )

            # Не ждем завершения, чтобы обрабатывать следующие сообщения
            asyncio.create_task(self.handle_inference_result(future))

    def process_transaction_message(self, event_data: Dict) -> Dict:
        """Обработать сообщение о транзакции"""
        try:
            analysis_result = asyncio.run(
```

```
            self.fraud_detector.analyze_transaction(event_data)
        )
        return analysis_result
    except Exception as e:
        logger.error(f"ML inference failed: {e}")
        return {
            "error": str(e),
            "transaction_id": event_data.get("aggregate_id")
        }

async def handle_inference_result(self, future):
    """Обработать результат ML inference"""
    try:
        result = await future

        # Отправить результат в Kafka
        self.producer.send('ml.fraud-analysis-result', result)

        if result.get("requires_review"):
            # Отправить в high-priority топик для немедленной обработки
            self.producer.send('alerts.high-priority', {
                "type": "fraud_detection",
                "data": result
            })

    except Exception as e:
        logger.error(f"Failed to handle inference result: {e}")
```

4.3 Advanced Analytics и BI (Месяц 17)

Real-time Analytics с ClickHouse

python

```python
# analytics/clickhouse_client.py
from clickhouse_driver import Client
from typing import List, Dict
import asyncio

class ClickHouseAnalytics:
    def __init__(self, host='clickhouse', port=9000):
        self.client = Client(host=host, port=port)
        self.setup_tables()

    def setup_tables(self):
        """Создать таблицы для аналитики"""
        # Таблица для транзакций (оптимизированная для анализа)
        self.client.execute('''
            CREATE TABLE IF NOT EXISTS transactions_analytics (
                transaction_id UUID,
                transaction_date Date,
                transaction_timestamp DateTime,
                company_id UUID,
                user_id UUID,
                total_amount Decimal(15, 2),
                currency_code String,
                account_debit_id UUID,
                account_credit_id UUID,
                account_debit_type String,
                account_credit_type String,
                is_approved UInt8,
                is_posted UInt8,
                created_at DateTime
            ) ENGINE = MergeTree()
            PARTITION BY toYYYYMM(transaction_date)
            ORDER BY (company_id, transaction_date, transaction_id)
        ''')

        # Материализованное представление для real-time агрегации
        self.client.execute('''
            CREATE MATERIALIZED VIEW IF NOT EXISTS daily_transactions_mv
            TO daily_transactions_summary
            AS SELECT
                company_id,
                transaction_date,
                count() as transaction_count,
                sum(total_amount) as total_amount,
```

```
            avg(total_amount) as avg_amount,
            countIf(is_posted = 1) as posted_count,
            sumIf(total_amount, is_posted = 1) as posted_amount
        FROM transactions_analytics
        GROUP BY company_id, transaction_date
    ''')

    # Таблица для КПП (ключевые показатели производительности)
    self.client.execute('''
        CREATE TABLE IF NOT EXISTS kpi_metrics (
            company_id UUID,
            metric_date Date,
            metric_name String,
            metric_value Decimal(15, 2),
            metric_currency String DEFAULT 'GEL',
            created_at DateTime DEFAULT now()
        ) ENGINE = ReplacingMergeTree(created_at)
        PARTITION BY toYYYYMM(metric_date)
        ORDER BY (company_id, metric_date, metric_name)
    ''')

async def insert_transaction(self, transaction_data: Dict):
    """Вставить данные транзакции для аналитики"""
    await asyncio.to_thread(
        self.client.execute,
        'INSERT INTO transactions_analytics VALUES',
        [transaction_data]
    )

async def get_financial_kpis(self, company_id: str, start_date: str, end_date: str) -> Dict:
    """Получить финансовые КПП за период"""
    query = '''
        SELECT
            -- Оборот
            sum(total_amount) as total_revenue,
            count() as transaction_count,
            avg(total_amount) as avg_transaction_amount,

            -- По типам счетов
            sumIf(total_amount, account_credit_type = 'REVENUE') as revenue,
            sumIf(total_amount, account_debit_type = 'EXPENSE') as expenses,

            -- Активы и обязательства
            sumIf(total_amount, account_debit_type = 'ASSET') as total_assets_increase,
```

```
            sumIf(total_amount, account_credit_type = 'LIABILITY') as total_liabilities_increase,

            -- Рентабельность
            (sumIf(total_amount, account_credit_type = 'REVENUE') -
             sumIf(total_amount, account_debit_type = 'EXPENSE')) as profit_loss

        FROM transactions_analytics
        WHERE company_id = %(company_id)s
        AND transaction_date BETWEEN %(start_date)s AND %(end_date)s
        AND is_posted = 1
    '''

    result = await asyncio.to_thread(
        self.client.execute,
        query,
        {'company_id': company_id, 'start_date': start_date, 'end_date': end_date}
    )

    return {
        'total_revenue': float(result[0][0] or 0),
        'transaction_count': result[0][1],
        'avg_transaction_amount': float(result[0][2] or 0),
        'revenue': float(result[0][3] or 0),
        'expenses': float(result[0][4] or 0),
        'total_assets_increase': float(result[0][5] or 0),
        'total_liabilities_increase': float(result[0][6] or 0),
        'profit_loss': float(result[0][7] or 0)
    }

class RealTimeAnalyticsService:
    def __init__(self):
        self.clickhouse = ClickHouseAnalytics()
        self.redis_client = redis.Redis(host='redis', port=6379, decode_responses=True)

    async def handle_transaction_posted_event(self, event_data: Dict):
        """Обработать событие проведения транзакции для аналитики"""
        transaction = event_data['event_data']

        # Вставить в ClickHouse для долгосрочной аналитики
        analytics_record = {
            'transaction_id': event_data['aggregate_id'],
            'transaction_date': transaction['transaction_date'][:10],
            'transaction_timestamp': transaction['transaction_date'],
            'company_id': transaction['company_id'],
```

```
            'user_id': transaction['created_by'],
            'total_amount': float(transaction['total_amount']),
            'currency_code': transaction.get('currency_code', 'GEL'),
            'is_posted': 1,
            'created_at': datetime.utcnow().strftime('%Y-%m-%d %H:%M:%S')
        }

        await self.clickhouse.insert_transaction(analytics_record)

        # Обновить real-time метрики в Redis
        await self.update_realtime_metrics(transaction)

    async def update_realtime_metrics(self, transaction: Dict):
        """Обновить метрики в реальном времени"""
        company_id = transaction['company_id']
        date_key = transaction['transaction_date'][:10]

        # Счетчики транзакций
        await self.redis_client.hincrby(
            f"metrics:daily:{company_id}:{date_key}",
            "transaction_count",
            1
        )

        # Сумма транзакций
        await self.redis_client.hincrbyfloat(
            f"metrics:daily:{company_id}:{date_key}",
            "total_amount",
            float(transaction['total_amount'])
        )

        # Установить TTL для автоматической очистки старых данных (30 дней)
        await self.redis_client.expire(
            f"metrics:daily:{company_id}:{date_key}",
            30 * 24 * 3600
        )
```

Business Intelligence Dashboard

python

```python
# analytics/dashboard_api.py
from fastapi import FastAPI, Depends, Query
from datetime import datetime, timedelta
import plotly.graph_objects as go
import plotly.express as px

class BIDashboardAPI:
    def __init__(self):
        self.app = FastAPI(title="Accounting Analytics Dashboard")
        self.clickhouse = ClickHouseAnalytics()
        self.setup_routes()

    def setup_routes(self):
        @self.app.get("/api/v1/dashboard/overview")
        async def get_overview(
            company_id: str,
            period: str = Query("30d", regex="^(7d|30d|90d|1y)$")
        ):
            """Получить обзорную информацию для dashboard"""
            end_date = datetime.now().date()

            if period == "7d":
                start_date = end_date - timedelta(days=7)
            elif period == "30d":
                start_date = end_date - timedelta(days=30)
            elif period == "90d":
                start_date = end_date - timedelta(days=90)
            else:  # 1y
                start_date = end_date - timedelta(days=365)

            kpis = await self.clickhouse.get_financial_kpis(
                company_id, str(start_date), str(end_date)
            )

            # Тренд за период
            trend_data = await self.get_trend_data(company_id, start_date, end_date)

            return {
                "period": period,
                "kpis": kpis,
                "trends": trend_data,
                "generated_at": datetime.utcnow().isoformat()
            }
```

```python
@self.app.get("/api/v1/dashboard/profit-loss-chart")
async def get_profit_loss_chart(company_id: str, period: str = "30d"):
    """График прибыли и убытков"""
    # Получение данных из ClickHouse
    query = '''
        SELECT
            transaction_date,
            sumIf(total_amount, account_credit_type = 'REVENUE') as revenue,
            sumIf(total_amount, account_debit_type = 'EXPENSE') as expenses
        FROM transactions_analytics
        WHERE company_id = %(company_id)s
        AND transaction_date >= today() - 30
        GROUP BY transaction_date
        ORDER BY transaction_date
    '''

    data = await asyncio.to_thread(
        self.clickhouse.client.execute,
        query,
        {'company_id': company_id}
    )

    # Создание Plotly графика
    dates = [row[0] for row in data]
    revenues = [float(row[1] or 0) for row in data]
    expenses = [float(row[2] or 0) for row in data]
    profit = [r - e for r, e in zip(revenues, expenses)]

    fig = go.Figure()

    fig.add_trace(go.Scatter(
        x=dates,
        y=revenues,
        mode='lines+markers',
        name='Доходы',
        line=dict(color='green')
    ))

    fig.add_trace(go.Scatter(
        x=dates,
        y=expenses,
        mode='lines+markers',
        name='Расходы',
```

```
        line=dict(color='red')
    ))

    fig.add_trace(go.Scatter(
        x=dates,
        y=profit,
        mode='lines+markers',
        name='Прибыль',
        line=dict(color='blue'),
        fill='tonexty'
    ))

    fig.update_layout(
        title="Динамика прибыли и убытков",
        xaxis_title="Дата",
        yaxis_title="Сумма (ლარი)",
        hovermode='x unified'
    )

    return fig.to_json()

@self.app.get("/api/v1/dashboard/account-balances")
async def get_account_balances(company_id: str):
    """Балансы по типам счетов"""
    query = '''
        SELECT
            account_type,
            sum(current_balance) as total_balance
        FROM account_balances ab
        JOIN accounts a ON ab.account_id = a.id
        WHERE a.company_id = %(company_id)s
        GROUP BY account_type
        ORDER BY total_balance DESC
    '''

    # Это запрос к основной PostgreSQL базе, не ClickHouse
    # Здесь нужно использовать соответствующий клиент

    return {
        "account_balances": [
            {"type": "Активы", "balance": 150000.00},
            {"type": "Обязательства", "balance": 75000.00},
            {"type": "Капитал", "balance": 75000.00}
```

```
        ]
    }
```

4.4 Multi-tenant Architecture (Месяц 18)

Tenant isolation

python

```python
# tenancy/tenant_context.py
from contextvars import ContextVar
from typing import Optional
import uuid

# Контекстная переменная для текущего тенанта
current_tenant: ContextVar[Optional[str]] = ContextVar('current_tenant', default=None)

class TenantContext:
    def __init__(self, tenant_id: str):
        self.tenant_id = tenant_id
        self.token = None

    def __enter__(self):
        self.token = current_tenant.set(self.tenant_id)
        return self

    def __exit__(self, exc_type, exc_val, exc_tb):
        if self.token:
            current_tenant.reset(self.token)

class TenantAwareRepository:
    """Базовый класс для tenant-aware репозиториев"""

    def __init__(self, db_pool):
        self.db_pool = db_pool

    def get_tenant_id(self) -> str:
        tenant_id = current_tenant.get()
        if not tenant_id:
            raise ValueError("No tenant context set")
        return tenant_id

    async def execute_query(self, query: str, params: list = None, tenant_filter: bool = True):
        """Выполнить запрос с автоматической фильтрацией по tenant"""
        if tenant_filter and "WHERE" in query.upper():
            # Добавить фильтр по tenant_id
            query = query.replace("WHERE", f"WHERE tenant_id = %s AND", 1)
            params = [self.get_tenant_id()] + (params or [])
        elif tenant_filter:
            # Добавить WHERE clause если его нет
            if "ORDER BY" in query.upper():
                query = query.replace("ORDER BY", "WHERE tenant_id = %s ORDER BY", 1)
```

```
            else:
                query += " WHERE tenant_id = %s"
            params = (params or []) + [self.get_tenant_id()]

        async with self.db_pool.acquire() as conn:
            return await conn.fetch(query, *params)

class AccountRepository(TenantAwareRepository):
    async def get_all_accounts(self) -> List[Account]:
        """Получить все счета для текущего тенанта"""
        query = """
            SELECT id, code, name, account_type, parent_id, is_active
            FROM accounts
            ORDER BY code
        """
        rows = await self.execute_query(query)
        return [Account(**dict(row)) for row in rows]

    async def create_account(self, account_data: AccountCreate) -> Account:
        """Создать новый счет для текущего тенанта"""
        query = """
            INSERT INTO accounts (id, tenant_id, code, name, account_type, parent_id, is_active)
            VALUES ($1, $2, $3, $4, $5, $6, $7)
            RETURNING *
        """
        account_id = uuid.uuid4()
        tenant_id = self.get_tenant_id()

        row = await self.execute_query(
            query,
            [account_id, tenant_id, account_data.code, account_data.name,
             account_data.account_type, account_data.parent_id, True],
            tenant_filter=False  # Уже добавили tenant_id вручную
        )
        return Account(**dict(row[0]))

# Middleware для извлечения tenant из запроса
class TenantMiddleware:
    def __init__(self, app):
        self.app = app

    async def __call__(self, scope, receive, send):
        if scope["type"] == "http":
            # Извлечь tenant_id из заголовка или JWT токена
```

```
        headers = dict(scope["headers"])
        tenant_id = self.extract_tenant_id(headers)

        if tenant_id:
            with TenantContext(tenant_id):
                await self.app(scope, receive, send)
        else:
            # Вернуть ошибку если tenant не определен
            response = Response(
                content="Tenant ID required",
                status_code=400
            )
            await response(scope, receive, send)
    else:
        await self.app(scope, receive, send)

def extract_tenant_id(self, headers) -> Optional[str]:
    # Попробовать извлечь из заголовка
    tenant_header = headers.get(b'x-tenant-id')
    if tenant_header:
        return tenant_header.decode()

    # Попробовать извлечь из JWT токена
    auth_header = headers.get(b'authorization')
    if auth_header and auth_header.startswith(b'Bearer '):
        token = auth_header[7:].decode()
        try:
            payload = jwt.decode(token, JWT_SECRET, algorithms=["HS256"])
            return payload.get('tenant_id')
        except:
            pass

    return None
```

Database schema для multi-tenancy

```
sql
```

```sql
-- migration: add_tenant_support.sql

-- Добавить tenant_id ко всем основным таблицам
ALTER TABLE companies ADD COLUMN IF NOT EXISTS tenant_id UUID;
ALTER TABLE users ADD COLUMN IF NOT EXISTS tenant_id UUID;
ALTER TABLE accounts ADD COLUMN IF NOT EXISTS tenant_id UUID;
ALTER TABLE journal_entries ADD COLUMN IF NOT EXISTS tenant_id UUID;
ALTER TABLE invoices ADD COLUMN IF NOT EXISTS tenant_id UUID;
ALTER TABLE products ADD COLUMN IF NOT EXISTS tenant_id UUID;
ALTER TABLE employees ADD COLUMN IF NOT EXISTS tenant_id UUID;

-- Создать таблицу тенантов
CREATE TABLE IF NOT EXISTS tenants (
    id UUID PRIMARY KEY DEFAULT gen_random_uuid(),
    name VARCHAR(255) NOT NULL,
    subdomain VARCHAR(100) UNIQUE,
    plan VARCHAR(50) DEFAULT 'basic',
    max_users INTEGER DEFAULT 10,
    max_companies INTEGER DEFAULT 1,
    is_active BOOLEAN DEFAULT TRUE,
    created_at TIMESTAMPTZ NOT NULL DEFAULT NOW(),
    updated_at TIMESTAMPTZ DEFAULT NOW(),

    -- Georgian-specific settings
    default_currency CHAR(3) DEFAULT 'GEL',
    vat_rate DECIMAL(5,4) DEFAULT 0.1800,
    tax_period VARCHAR(20) DEFAULT 'monthly',

    -- Feature flags
    features JSONB DEFAULT '{
        "advanced_reporting": false,
        "api_access": false,
        "multi_currency": true,
        "audit_trail": true,
        "ml_fraud_detection": false
    }'::jsonb
);

-- Подписки тенантов
CREATE TABLE tenant_subscriptions (
    id UUID PRIMARY KEY DEFAULT gen_random_uuid(),
    tenant_id UUID NOT NULL REFERENCES tenants(id),
    plan_name VARCHAR(50) NOT NULL,
```

```
    started_at TIMESTAMPTZ NOT NULL,
    expires_at TIMESTAMPTZ,
    is_active BOOLEAN DEFAULT TRUE,
    monthly_price DECIMAL(10,2),
    currency CHAR(3) DEFAULT 'GEL',

    -- Ограничения плана
    limits JSONB DEFAULT '{
        "max_users": 10,
        "max_companies": 1,
        "max_transactions_per_month": 1000,
        "storage_gb": 10
    }'::jsonb,

    created_at TIMESTAMPTZ NOT NULL DEFAULT NOW()
);

-- Обновить существующие индексы
DROP INDEX IF EXISTS idx_accounts_code;
CREATE INDEX idx_accounts_code_tenant ON accounts(tenant_id, code);

DROP INDEX IF EXISTS idx_journal_entries_account;
CREATE INDEX idx_journal_entries_account_tenant ON journal_entries(tenant_id, account_id, transaction_date);

-- Row Level Security (RLS) для дополнительной изоляции
ALTER TABLE accounts ENABLE ROW LEVEL SECURITY;
ALTER TABLE journal_entries ENABLE ROW LEVEL SECURITY;
ALTER TABLE invoices ENABLE ROW LEVEL SECURITY;

-- Политики RLS
CREATE POLICY accounts_tenant_isolation ON accounts
    FOR ALL TO authenticated_users
    USING (tenant_id = current_setting('app.current_tenant_id')::uuid);

CREATE POLICY journal_entries_tenant_isolation ON journal_entries.1 Cloud Deployment (Месяц 15)

#### Infrastructure as Code с Terraform
```hcl
# terraform/main.tf
provider "google" {
  project = var.project_id
  region  = var.region
}
```
```

```
# GKE Cluster
resource "google_container_cluster" "accounting_cluster" {
  name     = "accounting-system"
  location = var.region

  remove_default_node_pool = true
  initial_node_count       = 1

  network    = google_compute_network.vpc.name
  subnetwork = google_compute_subnetwork.subnet.name

  master_auth {
    client_certificate_config {
      issue_client_certificate = false
    }
  }

  workload_identity_config {
    workload_pool = "${var.project_id}.svc.id.goog"
  }

  addons_config {
    istio_config {
      disabled = false
      auth     = "AUTH_MUTUAL_TLS"
    }
  }
}

# Node pools
resource "google_container_node_pool" "primary_nodes" {
  name       = "primary-node-pool"
  location   = var.region
  cluster    = google_container_cluster.accounting_cluster.name
  node_count = 3

  node_config {
    preemptible  = false
    machine_type = "e2-standard-4"

    service_account = google_service_account.gke_service_account.email
    oauth_scopes = [
      "https://www.googleapis.com/auth/cloud-platform"
    ]
```

```
    labels = {
      environment = var.environment
    }

    tags = ["accounting-system-node"]
  }

  autoscaling {
    min_node_count = 2
    max_node_count = 20
  }

  management {
    auto_repair  = true
    auto_upgrade = true
  }
}

# Cloud SQL (PostgreSQL)
resource "google_sql_database_instance" "accounting_db" {
  name             = "accounting-db-${var.environment}"
  database_version = "POSTGRES_14"
  region           = var.region

  settings {
    tier              = "db-standard-4"
    availability_type = "REGIONAL"
    disk_type         = "PD_SSD"
    disk_size         = 500
    disk_autoresize   = true

    backup_configuration {
      enabled                        = true
      start_time                     = "02:00"
      point_in_time_recovery_enabled = true
      transaction_log_retention_days = 7
      backup_retention_settings {
        retained_backups = 30
      }
    }

    ip_configuration {
      ipv4_enabled                                  = false
```

```
      private_network                 = google_compute_network.vpc.id
      enable_private_path_for_google_cloud_services = true
    }

    database_flags {
      name  = "max_connections"
      value = "1000"
    }

    insights_config {
      query_insights_enabled  = true
      query_string_length     = 1024
      record_application_tags = true
      record_client_address   = true
    }
  }

  deletion_protection = true
}

# Redis (Memorystore)
resource "google_redis_instance" "accounting_cache" {
  name           = "accounting-cache"
  tier           = "STANDARD_HA"
  memory_size_gb = 16
  region         = var.region

  authorized_network = google_compute_network.vpc.id

  redis_version = "REDIS_7_0"
  display_name  = "Accounting System Cache"
}
```

GitOps с ArgoCD

```
yaml
```

```yaml
# argocd/applications/accounting-system.yaml
apiVersion: argoproj.io/v1alpha1
kind: Application
metadata:
  name: accounting-system
  namespace: argocd
spec:
  project: default

  source:
    repoURL: https://github.com/accounting-system/k8s-manifests
    targetRevision: HEAD
    path: environments/production

  destination:
    server: https://kubernetes.default.svc
    namespace: accounting-system

  syncPolicy:
    automated:
      prune: true
      selfHeal: true
      allowEmpty: false
    syncOptions:
      - CreateNamespace=true
      - PrunePropagationPolicy=foreground
      - PruneLast=true
    retry:
      limit: 5
      backoff:
        duration: 5s
        factor: 2
        maxDuration: 3m

  revisionHistoryLimit: 10
```

4: Optional[AIOKafkaConsumer] = None

```
    self.handlers: Dict[str, List[Callable]] = {}

async def start(self):
    self.producer = AIOKafkaProducer(
```

```
        bootstrap_servers=self.bootstrap_servers,
        value_serializer=lambda v: json.dumps(v, default=str).encode('utf-8')
    )
    await self.producer.start()

async def publish(self, event: DomainEvent):
    """Опубликовать событие"""
    topic = f"accounting.{event.event_type.lower()}"

    event_payload = {
        "event_id": str(event.event_id),
        "aggregate_id": str(event.aggregate_id),
        "event_type": event.event_type,
        "event_data": event.event_data,
        "version": event.version,
        "timestamp": event.timestamp.isoformat(),
        "metadata": event.metadata
    }

    await self.producer.send(topic, event_payload)

    logger.info(
        "Event published",
        event_type=event.event_type,
        aggregate_id=str(event.aggregate_id),
        topic=topic
    )

async def subscribe(self, event_type: str, handler: Callable):
    """Подписаться на тип события"""
    if event_type not in self.handlers:
        self.handlers[event_type] = []
    self.handlers[event_type].append(handler)

async def start_consuming(self):
    """Начать обработку событий"""
    topics = [f"accounting.{event_type.lower()}" for event_type in self.handlers.keys()]

    self.consumer
```