

# Building High-Performance Agentic Systems

A comprehensive tutorial on designing low-latency, scalable AI agent architectures using patterns from Document Intelligence AI v3.0.

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## 1. Introduction

### The Challenge

Building production-grade AI agent systems requires solving several interconnected challenges:

1. **Long-running LLM calls** (5-30 seconds) that can starve other operations
2. **Thread pool exhaustion** when all workers are blocked on I/O
3. **Database connection limits** with multiple concurrent event loops
4. **Token usage tracking** across async boundaries and thread pools
5. **Graceful degradation** when services fail or become unavailable

### Design Principles

This tutorial demonstrates five core principles:

1. **NON-BLOCKING EVENT LOOP**  
Never block the main asyncio event loop with synchronous I/O
2. **WORKLOAD ISOLATION**  
Separate thread pools for LLM, I/O, and query operations
3. **MULTI-LAYER CACHING**  
Cache at every layer to minimize expensive operations
4. **BACKGROUND PROCESSING**  
Defer non-critical operations (audit logs, usage tracking)
5. **GRACEFUL DEGRADATION**  
Fallbacks when primary services are unavailable

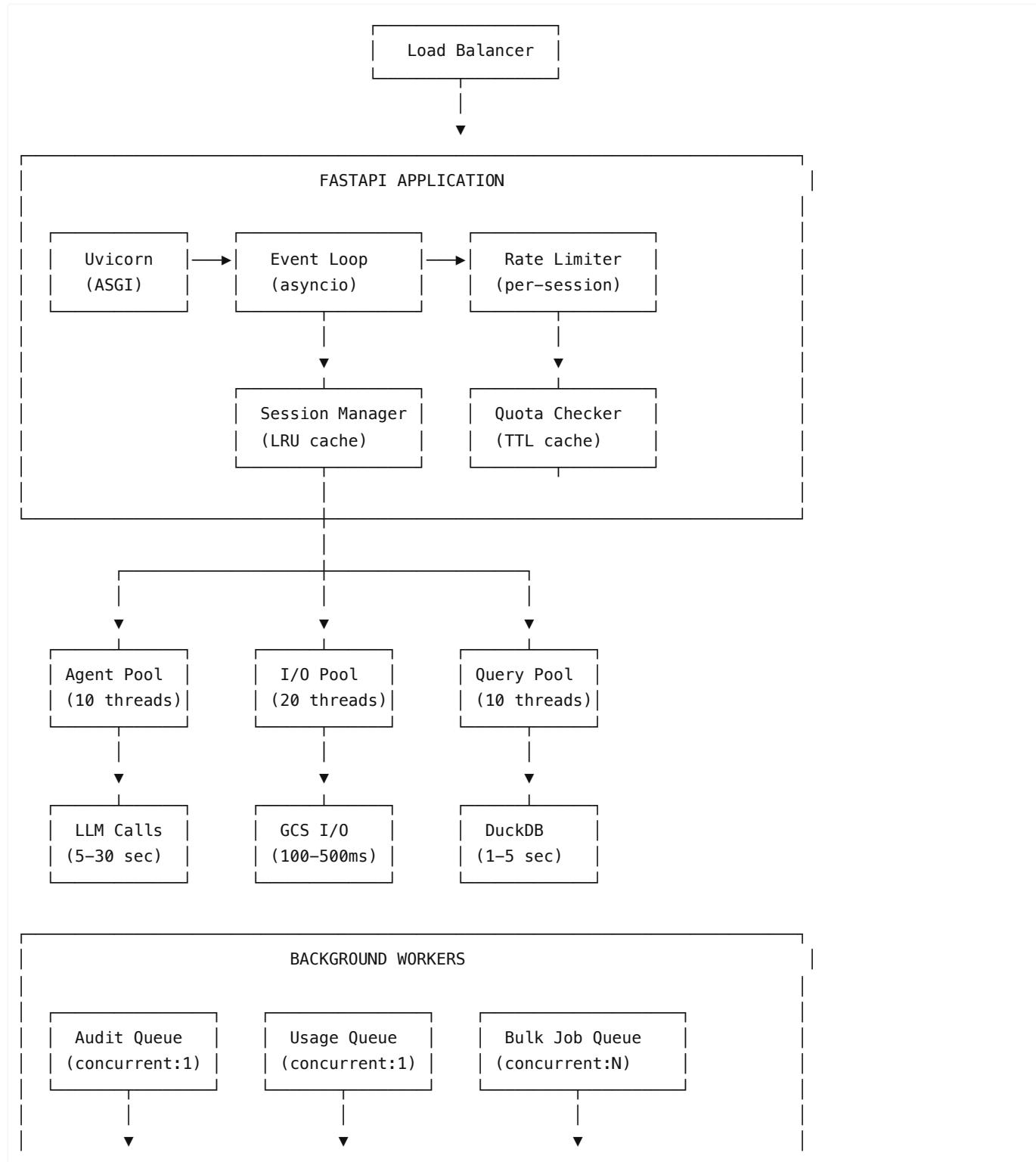
### What You'll Learn

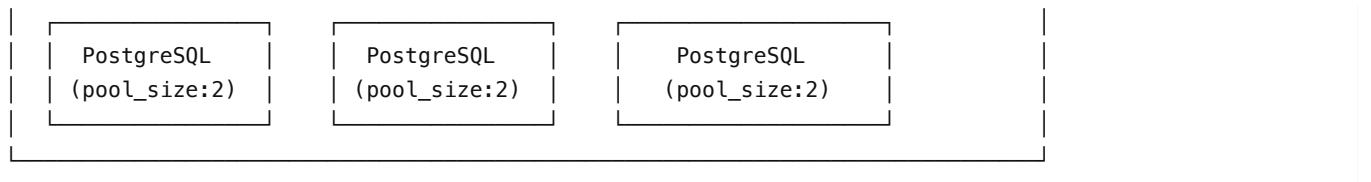
By the end of this tutorial, you'll understand how to:

- Design executor pools that prevent resource starvation
- Propagate context across async boundaries and thread pools
- Implement multi-layer caching for 100-1000x speedups
- Build background queues with proper database lifecycle
- Add resilience with retry logic and model fallbacks
- Track token usage without blocking the main application

## 2. Architecture Overview

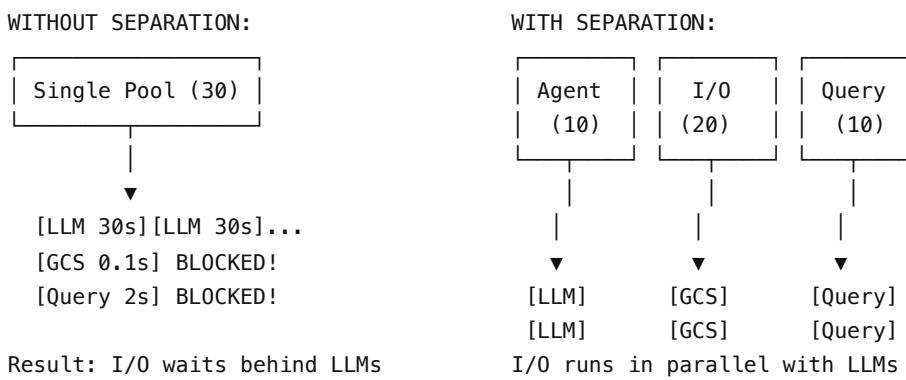
### High-Level Request Flow





## Key Insight: Workload Isolation

The most important architectural decision is **separating thread pools by workload type**. Without this, a few long-running LLM calls can block all other operations:



## 3. Executor Pool Design

### Implementation

File: `src/core/executors.py`

```
"""Centralized thread pool executor management for different workload types.
```

This module provides dedicated thread pools for different types of operations:

- Agent pool: For heavy LLM agent invocations (long-running, 5–30s)
- I/O pool: For GCS/file operations (quick, 100–500ms)
- Query pool: For DuckDB/SQL queries (medium, 1–5s)

Separating executors prevents long-running agent operations from starving I/O operations and provides bounded, tunable concurrency control.

=====

```
from concurrent.futures import ThreadPoolExecutor
from typing import Optional
import os

# Configurable pool sizes via environment variables
AGENT_POOL_SIZE = int(os.getenv("AGENT_EXECUTOR_POOL_SIZE", "10"))
IO_POOL_SIZE = int(os.getenv("IO_EXECUTOR_POOL_SIZE", "20"))
QUERY_POOL_SIZE = int(os.getenv("QUERY_EXECUTOR_POOL_SIZE", "10"))
```

```
class ExecutorRegistry:
    """Manages dedicated thread pools by workload type."""

    def __init__(self):
        self.agent_executor = ThreadPoolExecutor(
            max_workers=AGENT_POOL_SIZE,
```

```

        thread_name_prefix="agent-"
    )
    self.io_executor = ThreadPoolExecutor(
        max_workers=I0_POOL_SIZE,
        thread_name_prefix="io-"
    )
    self.query_executor = ThreadPoolExecutor(
        max_workers=QUERY_POOL_SIZE,
        thread_name_prefix="query-"
    )

def shutdown(self, wait: bool = True, cancel_futures: bool = False):
    """Shutdown all executors gracefully."""
    self.agent_executor.shutdown(wait=wait, cancel_futures=cancel_futures)
    self.io_executor.shutdown(wait=wait, cancel_futures=cancel_futures)
    self.query_executor.shutdown(wait=wait, cancel_futures=cancel_futures)

def get_stats(self) -> dict:
    """Return current executor configuration for monitoring."""
    return {
        "agent_pool": {"max_workers": AGENT_POOL_SIZE},
        "io_pool": {"max_workers": I0_POOL_SIZE},
        "query_pool": {"max_workers": QUERY_POOL_SIZE},
    }

# Module-level singleton
_registry: Optional[ExecutorRegistry] = None

def get_executors() -> ExecutorRegistry:
    """Get or create the global executor registry singleton."""
    global _registry
    if _registry is None:
        _registry = ExecutorRegistry()
    return _registry

def shutdown_executors(wait: bool = True):
    """Shutdown the global executor registry."""
    global _registry
    if _registry is not None:
        _registry.shutdown(wait=wait)
        _registry = None

```

## Configuration

Executor	Default Size	Environment Variable	Use Case
Agent	10 threads	AGENT_EXECUTOR_POOL_SIZE	Heavy LLM operations (5-30s)
I/O	20 threads	I0_EXECUTOR_POOL_SIZE	GCS, filesystem (100-500ms)
Query	10 threads	QUERY_EXECUTOR_POOL_SIZE	DuckDB, SQL (1-5s)

## Usage Pattern

```

from src.core.executors import get_executors
import asyncio

async def upload_to_gcs(content: str, path: str):
    """Upload to GCS using dedicated I/O pool."""
    loop = asyncio.get_running_loop()

    # Use I/O executor - won't be blocked by LLM calls
    await loop.run_in_executor(
        get_executors().io_executor,
        lambda: gcs_client.upload(content, path)
    )

async def invoke_agent(query: str):
    """Invoke LLM agent using dedicated agent pool."""
    loop = asyncio.get_running_loop()

    # Use agent executor - isolated from I/O operations
    return await loop.run_in_executor(
        get_executors().agent_executor,
        lambda: agent.invoke({"query": query})
    )

```

## 4. Async I/O Patterns

### Pattern 1: run\_in\_executor for Blocking I/O

File: src/storage/gcs.py

The `run_in_executor` pattern moves blocking I/O to a thread pool, keeping the event loop free:

```

async def save(self, content: str, filename: str) -> str:
    """Save content to GCS without blocking the event loop."""
    loop = asyncio.get_running_loop()

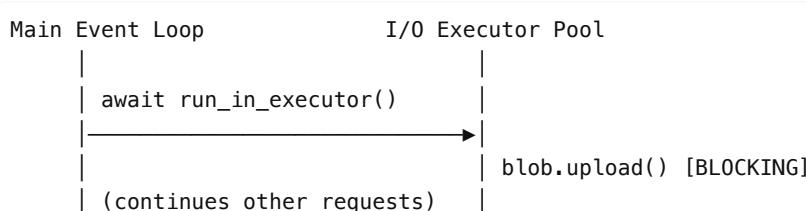
    # Create blob reference
    blob = self._bucket.blob(filename)

    # Run blocking upload in I/O executor
    await loop.run_in_executor(
        get_executors().io_executor, # Dedicated I/O pool
        partial(blob.upload_from_string, content),
    )

    return f"gs://{self._bucket.name}/{filename}"

```

#### Request Flow:





## Pattern 2: asyncio.gather() for Parallel Operations

File: `src/api/routers/documents.py`

When you need multiple independent operations, run them in parallel:

```

# ❌ Sequential (slow - 300ms total):
summary = await check_cached_summary()      # 100ms
faqs = await check_cached_faqs()            # 100ms
questions = await check_cached_questions()  # 100ms

# ✅ Parallel (fast - 100ms total):
summary, faqs, questions = await asyncio.gather(
    check_cached_summary(),
    check_cached_faqs(),
    check_cached_questions()
)
  
```

### Timing Diagram:

SEQUENTIAL:	—summary (100ms)— —faqs (100ms)— —questions (100ms)—
	Total: 300ms
PARALLEL:	—summary (100ms)—   —faqs (100ms)——   —questions (100ms)  Total: 100ms (3x faster)

## Pattern 3: Handling Nested Event Loops

File: `src/utils/async_utils.py`

LangChain tools run synchronously but may be called from async contexts. Handle this gracefully:

```

def run_async(coro: Coroutine[Any, Any, T]) -> T:
    """
    Run an async coroutine from a sync context.

    Handles various edge cases:
    - No event loop running: Creates a new one
    - Event loop already running: Uses nest_asyncio for nested calls
    - RuntimeError: Falls back to asyncio.run()
    """

    try:
        loop = asyncio.get_event_loop()
        if loop.is_running():
            # Event loop already running - need nest_asyncio
            import nest_asyncio
            nest_asyncio.apply()
        return loop.run_until_complete(coro)
    
```

```

    else:
        return loop.run_until_complete(coro)
    except RuntimeError:
        # No event loop exists - create one
        return asyncio.run(coro)

```

## Pattern 4: Async Context Manager for Resources

File: src/db/connection.py

```

@asynccontextmanager
async def session() -> AsyncGenerator[AsyncSession, None]:
    """Provide a transactional scope with automatic cleanup."""
    session = self._session_factory()
    try:
        yield session
        await session.commit()
    except Exception:
        await session.rollback()
        raise
    finally:
        await session.close()

```

---

## 5. Context Propagation

### The Challenge

When running LLM agents in thread pool executors, context variables (like organization ID, user ID, and request metadata) are lost because each thread has its own context.

### Solution: Context Variable Copying

File: src/utils/async\_utils.py

```

async def run_in_executor_with_context(executor, func, *args, **kwargs):
    """
    Run a synchronous function in a thread pool executor with context propagation.

    This function copies the current contextvars context before submitting
    to the executor, ensuring that context variables (like usage_context)
    are available in the executor thread.

    This is essential for token tracking in LangChain agents that run in
    thread pool executors.
    """

    import functools
    from contextvars import copy_context

    # Capture current context before submitting to executor
    ctx = copy_context()

    # Prepare the function with kwargs if any
    if kwargs:
        func = functools.partial(func, **kwargs)

```

```

# Create a wrapper that runs the function in the copied context
def run_with_context():
    return ctx.run(func, *args)

loop = asyncio.get_running_loop()
return await loop.run_in_executor(executor, run_with_context)

```

## Usage Context Implementation

File: `src/core/usage/context.py`

```

from contextvars import ContextVar
from contextlib import contextmanager
from dataclasses import dataclass
from typing import Optional, Dict, Any

@dataclass
class UsageContext:
    """Context for usage tracking across async boundaries."""
    org_id: str
    feature: str
    user_id: Optional[str] = None
    session_id: Optional[str] = None
    request_id: Optional[str] = None
    metadata: Optional[Dict[str, Any]] = None

    # Thread-local context variable
    _usage_context: ContextVar[Optional[UsageContext]] = ContextVar(
        "usage_context", default=None
    )

    @contextmanager
    def usage_context(
        org_id: str,
        feature: str,
        user_id: Optional[str] = None,
        session_id: Optional[str] = None,
        request_id: Optional[str] = None,
        metadata: Optional[Dict[str, Any]] = None,
    ):
        """
        Context manager for usage tracking.

        Example:
            with usage_context(org_id="org_123", feature="document_agent"):
                result = await agent.invoke(query)
                # Token usage automatically tracked with org_id
        """

        ctx = UsageContext(
            org_id=org_id,
            feature=feature,
            user_id=user_id,
            session_id=session_id,
            request_id=request_id,
        )
        _usage_context.set(ctx)
        try:
            yield ctx
        finally:
            _usage_context.reset()

```

```

        metadata=metadata,
    )
    token = _usage_context.set(ctx)
    try:
        yield ctx
    finally:
        _usage_context.reset(token)

def get_current_context() -> Optional[UsageContext]:
    """Get current usage context (if any)."""
    return _usage_context.get()

```

## Complete Example: Agent Invocation with Context

```

from src.core.usage.context import usage_context
from src.utils.async_utils import run_in_executor_with_context
from src.core.executors import get_executors

async def process_document(org_id: str, query: str, session_id: str):
    """Process document with full context propagation."""

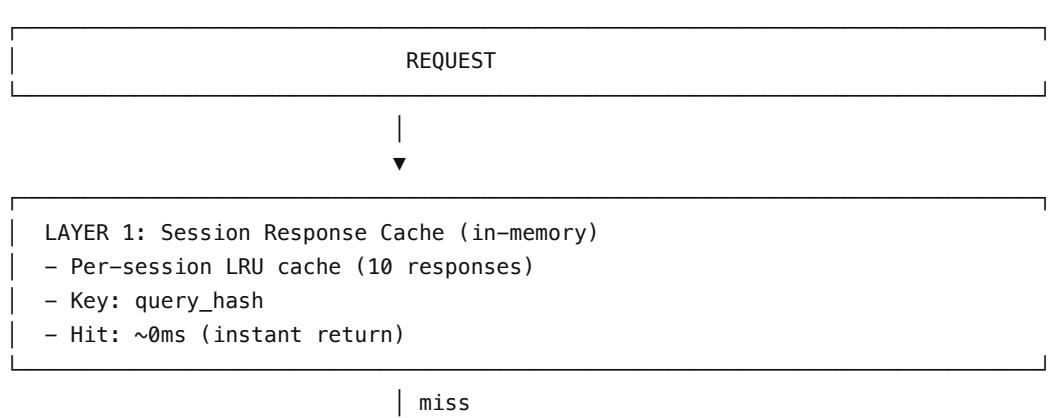
    # Set up usage context
    with usage_context(
        org_id=org_id,
        feature="document_agent",
        session_id=session_id,
    ):
        # Run agent in executor WITH context propagation
        result = await run_in_executor_with_context(
            get_executors().agent_executor,
            agent.invoke,
            {"query": query}
        )

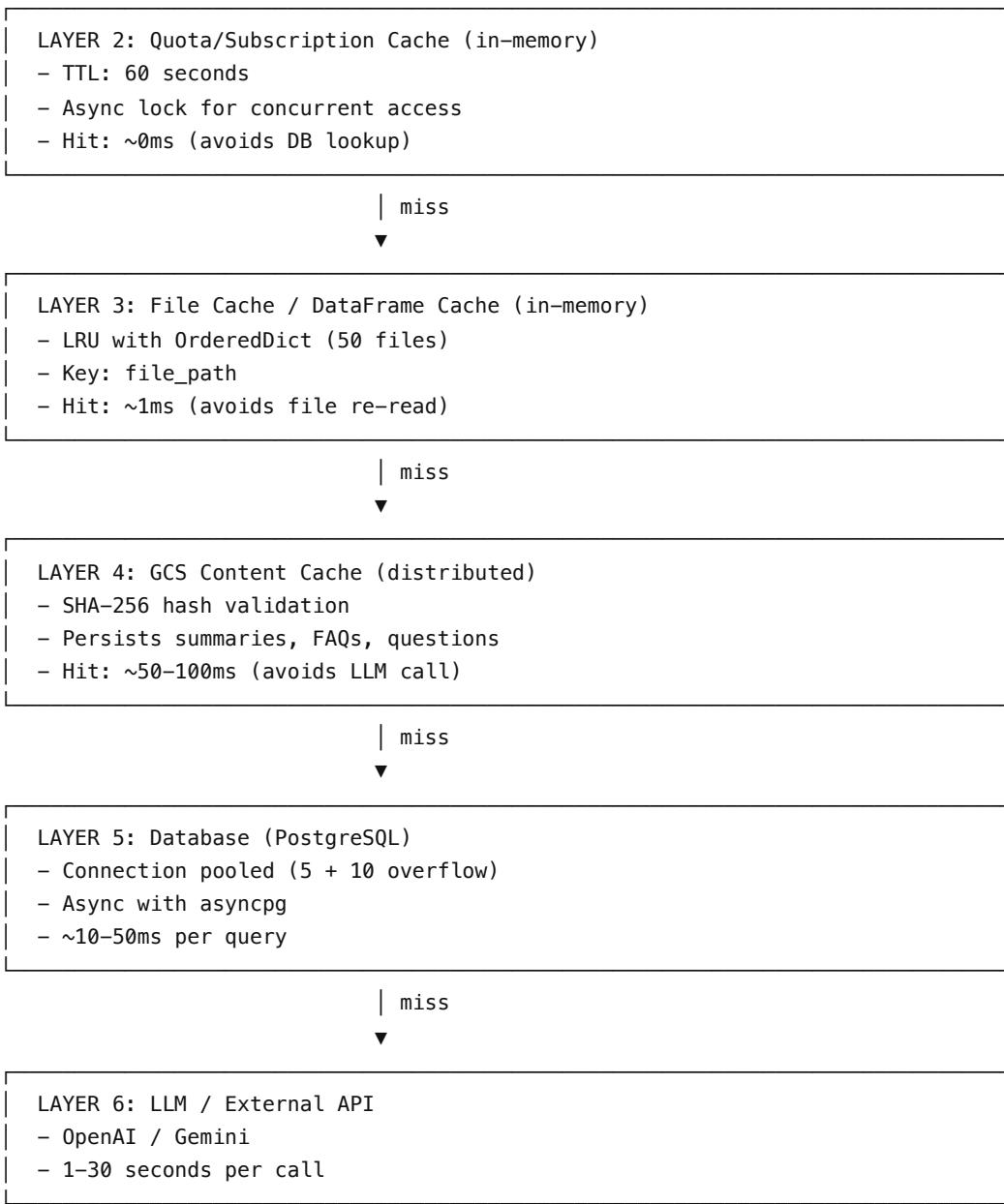
    # Token tracking callback will see org_id in context
    return result

```

## 6. Multi-Layer Caching

### Cache Hierarchy





## Cache Implementations Summary

Layer	Type	TTL	Size	File
Session Response	LRU	Session lifetime	10/session	<code>session_manager.py</code>
Quota	TTL	60s	Unlimited	<code>quota_checker.py</code>
Tier Config	TTL	1 hour	10 tiers	<code>subscription_manager.py</code>
File/DataFrame	LRU	Unlimited	50 files	<code>cache.py</code>
GCS Content	Persistent	Unlimited	GCS storage	<code>gcs_cache.py</code>
Store Metadata	TTL	5 minutes	Unlimited	<code>gemini_file_store.py</code>

## LRU File Cache Implementation

File: `src/agents/sheets/cache.py`

```

from collections import OrderedDict
from threading import Lock
from typing import Optional, Tuple
import pandas as pd

class FileCache:
    """Thread-safe LRU cache for DataFrames with hit/miss tracking."""

    def __init__(self, max_size: int = 50):
        self._cache: OrderedDict[str, pd.DataFrame] = OrderedDict()
        self._max_size = max_size
        self._lock = Lock()
        self._hits = 0
        self._misses = 0

    def get(self, key: str) -> Optional[pd.DataFrame]:
        """Get item from cache, updating LRU order."""
        with self._lock:
            if key in self._cache:
                # Move to end (most recently used)
                self._cache.move_to_end(key)
                self._hits += 1
                return self._cache[key]
            self._misses += 1
            return None

    def put(self, key: str, value: pd.DataFrame) -> None:
        """Add item to cache, evicting oldest if at capacity."""
        with self._lock:
            if key in self._cache:
                self._cache.move_to_end(key)
            else:
                if len(self._cache) >= self._max_size:
                    # Remove oldest (first) item
                    self._cache.popitem(last=False)
                self._cache[key] = value

    def get_stats(self) -> dict:
        """Return cache statistics."""
        with self._lock:
            total = self._hits + self._misses
            return {
                "size": len(self._cache),
                "max_size": self._max_size,
                "hits": self._hits,
                "misses": self._misses,
                "hit_rate_percent": (self._hits / total * 100) if total > 0 else 0,
            }

```

## GCS Content Cache with Hash Validation

File: src/agents/document/gcs\_cache.py

```

import hashlib
import json

```

```
from typing import Optional, Tuple

def compute_content_hash(content: str) -> str:
    """Compute SHA-256 hash of content for cache validation."""
    return hashlib.sha256(content.encode()).hexdigest()

async def check_and_read_cached_summary(
    storage: GCSSStorage,
    document_name: str,
    source_content: str,
) -> Tuple[bool, Optional[dict]]:
    """
    Check if valid cached summary exists for document.

    Returns:
        Tuple of (cache_hit, cached_data)
        - cache_hit: True if valid cache exists
        - cached_data: The cached summary dict, or None
    """
    cache_path = f"generated/{document_name}/summary.json"

    # Check if cache file exists
    if not await storage.exists(cache_path):
        return False, None

    try:
        # Read cached content
        cached_json = await storage.read(cache_path)
        cached_data = json.loads(cached_json)

        # Validate hash matches current source
        cached_hash = cached_data.get("source_hash", "")
        current_hash = compute_content_hash(source_content)

        if cached_hash == current_hash:
            return True, cached_data
        else:
            # Source changed - cache is stale
            return False, None
    except Exception:
        return False, None

async def save_cached_summary(
    storage: GCSSStorage,
    document_name: str,
    source_content: str,
    summary: str,
) -> None:
    """
    Save summary to GCS cache with hash for validation.
    """
    cache_path = f"generated/{document_name}/summary.json"

    cache_data = {
```

```

        "summary": summary,
        "source_hash": compute_content_hash(source_content),
        "cached_at": datetime.utcnow().isoformat(),
    }

    await storage.save(json.dumps(cache_data), cache_path)

```

## 7. Connection Pooling

### The Challenge: Multiple Event Loops

In a system with background queues, each queue runs in its own thread with its own event loop. SQLAlchemy async engines are bound to a single event loop, causing "Future attached to different loop" errors.

### Solution: Per-Event-Loop Resource Management

File: src/db/connection.py

```

class DatabaseManager:
    """
    Manages database connections with per-event-loop resource tracking.

    Key insight: Each event loop (main API loop, usage queue loop, audit queue loop)
    needs its own engine and session factory to avoid cross-loop errors.
    """

    def __init__(self):
        self._connectors: Dict[int, Any] = {} # loop_id -> Connector
        self._engines: Dict[int, AsyncEngine] = {} # loop_id -> Engine
        self._session_factories: Dict[int, async_sessionmaker] = {}
        self._main_loop_id: Optional[int] = None
        self._lock = threading.Lock()

    @async def get_engine_async(self) -> AsyncEngine:
        """Get or create engine for current event loop."""
        loop = asyncio.get_running_loop()
        loop_id = id(loop)

        with self._lock:
            if loop_id in self._engines:
                return self._engines[loop_id]

            # First loop seen becomes "main" (larger pool)
            is_main = self._main_loop_id is None
            if is_main:
                self._main_loop_id = loop_id

            # Create engine with appropriate pool size
            pool_size = 3 if is_main else 2 # Main gets larger pool
            engine = await self._create_engine(pool_size)

            with self._lock:
                self._engines[loop_id] = engine
                self._session_factories[loop_id] = async_sessionmaker(
                    engine, expire_on_commit=False

```

```

    )

return engine

@asynccontextmanager
async def session(self) -> AsyncGenerator[AsyncSession, None]:
    """Get session for current event loop."""
    loop_id = id(asyncio.get_running_loop())

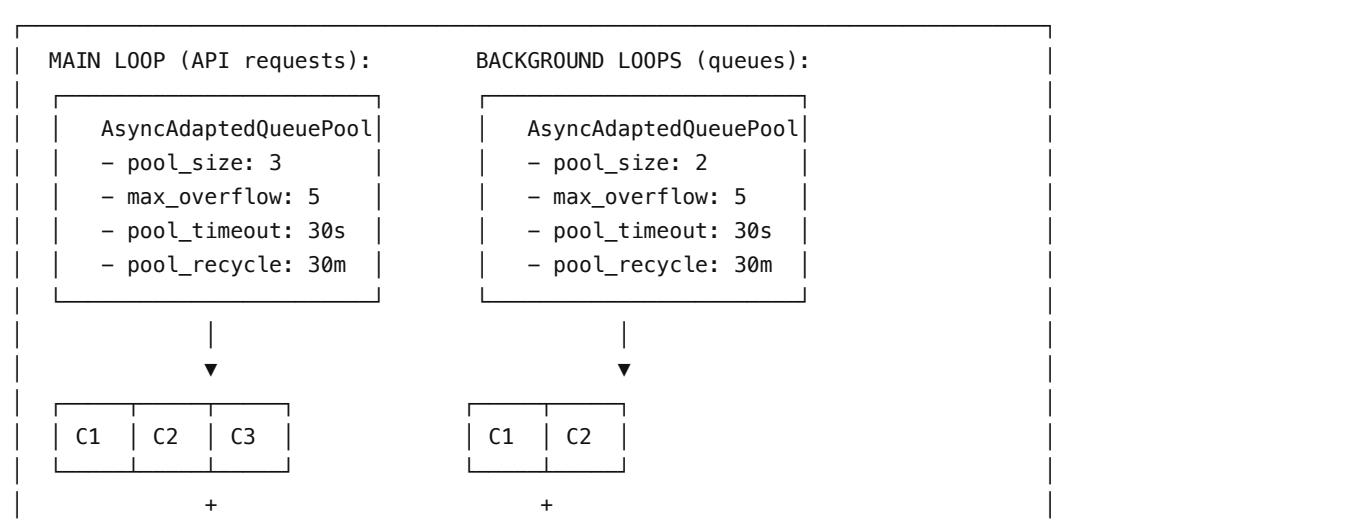
    with self._lock:
        factory = self._session_factories.get(loop_id)
        if not factory:
            # Ensure engine exists for this loop
            await self.get_engine_async()
            factory = self._session_factories[loop_id]

    async with factory() as session:
        try:
            yield session
            await session.commit()
        except Exception:
            await session.rollback()
            raise

def get_pool_stats(self) -> dict:
    """Return pool statistics for monitoring."""
    with self._lock:
        stats = {"pools_count": len(self._engines), "pools": {}}
        for loop_id, engine in self._engines.items():
            pool = engine.pool
            stats["pools"][str(loop_id)] = {
                "size": pool.size(),
                "checked_out": pool.checkedout(),
                "overflow": pool.overflow(),
                "checked_in": pool.checkedin(),
            }
        return stats

```

## Pool Size Strategy



Overflow (up to 5)

Overflow (up to 5)

## DuckDB Connection Pool

File: `src/agents/sheets/tools.py`

For in-memory databases like DuckDB, a simple pool prevents connection creation overhead:

```
class DuckDBPool:
    """Thread-safe connection pool for DuckDB."""

    def __init__(self, max_size: int = 5):
        self._pool: List[duckdb.DuckDBPyConnection] = []
        self._max = max_size
        self._lock = threading.Lock()

    def get_connection(self) -> duckdb.DuckDBPyConnection:
        """Get a connection from pool or create new one."""
        with self._lock:
            if self._pool:
                return self._pool.pop()
        return duckdb.connect(":memory:")

    def return_connection(self, conn: duckdb.DuckDBPyConnection) -> None:
        """Return connection to pool or close if pool is full."""
        with self._lock:
            if len(self._pool) < self._max:
                self._pool.append(conn)
            else:
                conn.close()

    @contextmanager
    def connection(self):
        """Context manager for connection lifecycle."""
        conn = self.get_connection()
        try:
            yield conn
        finally:
            self.return_connection(conn)
```

## 8. Background Queue Processing

### Base Queue Architecture

File: `src/core/queues/base_queue.py`

All background queues extend an abstract base class that provides:

- Thread-safe singleton pattern
- Dedicated background thread with persistent event loop
- Configurable concurrent event processing (via semaphore)
- Database connection lifecycle management
- Graceful shutdown with pending task completion

```
class BackgroundQueue(Generic[T], ThreadSafeSingleton, ABC):
    """
    Abstract base class for background queue processing.

    Subclasses must implement:
    - `._get_queue_name()`: Return queue name for logging
    - `._process_event(event)`: Process a single event
    """

    def __init__(self) -> None:
        """Initialize queue resources."""
        self._queue: queue.Queue[Optional[T]] = queue.Queue(maxsize=1000)
        self._thread: Optional[threading.Thread] = None
        self._loop: Optional[asyncio.AbstractEventLoop] = None
        self._shutdown_event = threading.Event()
        self._started = False
        self._pending_tasks: Set[asyncio.Task] = set()
        atexit.register(self.shutdown)

    @abstractmethod
    def _get_queue_name(self) -> str:
        """Return the queue name for logging."""
        pass

    @abstractmethod
    async def _process_event(self, event: T) -> None:
        """Process a single event from the queue."""
        pass

    def __get_max_concurrent(self) -> int:
        """Override in subclasses for parallel processing."""
        return 1 # Default: sequential

    def start(self) -> None:
        """Start the background processing thread."""
        if self._started:
            return

        self._thread = threading.Thread(
            target=self._run_loop,
            name=self._get_queue_name(),
            daemon=True,
        )
        self._thread.start()
        self._started = True

    def _run_loop(self) -> None:
        """Background thread with persistent event loop."""
        self._loop = asyncio.new_event_loop()
        asyncio.set_event_loop(self._loop)

        try:
            self._loop.run_until_complete(self._process_events())
        finally:
            # Cleanup database connections
            self._loop.run_until_complete(self._cleanup_db())
```

```

        self._loop.close()

async def _process_events(self) -> None:
    """Process events with semaphore-controlled concurrency."""
    await self._init_db_for_loop()

    max_concurrent = self._get_max_concurrent()
    semaphore = asyncio.Semaphore(max_concurrent)

    while not self._shutdown_event.is_set():
        try:
            event = await asyncio.get_event_loop().run_in_executor(
                None, lambda: self._queue.get(timeout=0.5)
            )

            if event is None: # Poison pill
                break

            # Create task for concurrent processing
            task = asyncio.create_task(
                self._process_with_semaphore(event, semaphore)
            )
            self._pending_tasks.add(task)
            task.add_done_callback(self._pending_tasks.discard)

        except queue.Empty:
            continue

    # Wait for pending tasks on shutdown
    if self._pending_tasks:
        await asyncio.gather(*self._pending_tasks, return_exceptions=True)

def enqueue(self, event: T) -> None:
    """Add event to queue (non-blocking)."""
    if not self._started:
        self.start()
    try:
        self._queue.put_nowait(event)
    except queue.Full:
        logger.warning(f"{self._get_queue_name()} full, dropping event")

def shutdown(self, wait: bool = True, timeout: float = 5.0) -> None:
    """Shutdown the queue gracefully."""
    if not self._started:
        return

    self._shutdown_event.set()
    self._queue.put_nowait(None) # Poison pill

    if wait and self._thread and self._thread.is_alive():
        self._thread.join(timeout=timeout)

    self._started = False

```

## Usage Queue Example

File: src/core/usage/usage\_queue.py

```
@dataclass
class UsageEvent:
    """Usage event to be logged."""
    event_type: Literal["token", "resource"]
    org_id: str
    created_at: datetime = field(default_factory=datetime.utcnow)

    # Token usage fields
    feature: Optional[str] = None
    provider: Optional[str] = None
    model: Optional[str] = None
    input_tokens: int = 0
    output_tokens: int = 0
    total_tokens: int = 0

class UsageQueue(BackgroundQueue[UsageEvent]):
    """Thread-safe usage queue with dedicated event loop."""

    def _get_queue_name(self) -> str:
        return "usage-queue"

    @async def _process_event(self, event: UsageEvent) -> None:
        """Process a single usage event."""
        service = get_usage_service()

        if event.event_type == "token":
            await service.log_token_usage(
                org_id=event.org_id,
                feature=event.feature or "unknown",
                usage=TokenUsage(
                    input_tokens=event.input_tokens,
                    output_tokens=event.output_tokens,
                    total_tokens=event.total_tokens,
                ),
            )
        )

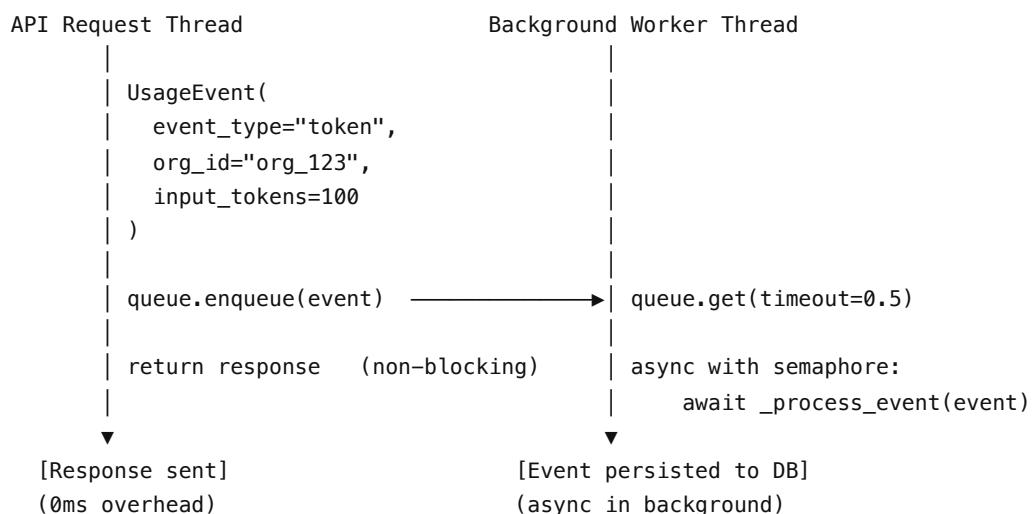
    def enqueue_token_usage(
        org_id: str,
        feature: str,
        model: str,
        provider: str,
        input_tokens: int,
        output_tokens: int,
        **kwargs,
    ):
        """Convenience function to enqueue a token usage event."""
        event = UsageEvent(
            event_type="token",
            org_id=org_id,
            feature=feature,
            model=model,
            provider=provider,
```

```

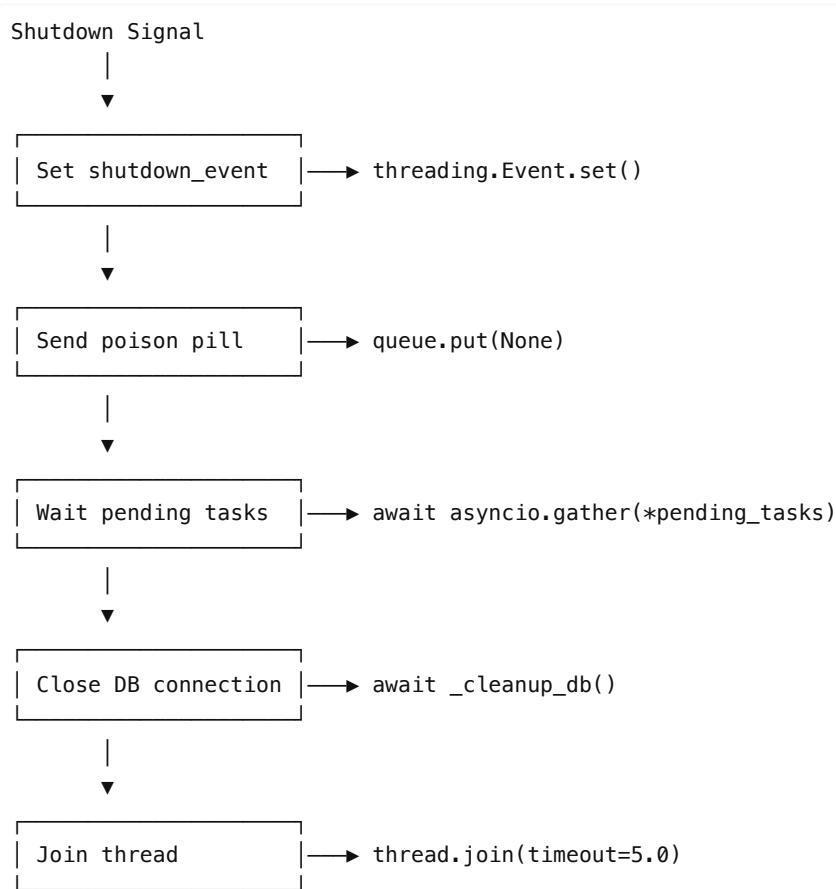
        input_tokens=input_tokens,
        output_tokens=output_tokens,
        total_tokens=input_tokens + output_tokens,
        **kwargs,
    )
UsageQueue.get_instance().enqueue(event)

```

## Event Flow Diagram



## Graceful Shutdown



## 9. Resilience Patterns

### Pattern 1: Exponential Backoff Retry

File: `src/agents/core/middleware/resilience.py`

```
from tenacity import (
    retry,
    stop_after_attempt,
    wait_exponential,
    retry_if_exception_type,
    before_sleep_log
)

class ModelRetry:
    """Exponential backoff retry for model calls."""

    def __init__(
        self,
        max_attempts: int = 3,
        initial_delay: float = 1.0,
        max_delay: float = 10.0
    ):
        self.max_attempts = max_attempts
        self.initial_delay = initial_delay
        self.max_delay = max_delay

    def wrap(self, func: Callable) -> Callable:
        """Wrap a function with retry logic."""
        return retry(
            stop=stop_after_attempt(self.max_attempts),
            wait=wait_exponential(
                multiplier=self.initial_delay,
                max=self.max_delay
            ),
            retry=retry_if_exception_type((
                TimeoutError,
                ConnectionError,
                OSError,
            )),
            reraise=True,
            before_sleep=before_sleep_log(logger, logging.WARNING)
        )(func)
```

#### Retry Timeline:

```
Attempt 1: Call fails (ConnectionError)
  |
  ▼
  Wait 1.0s (initial_delay)
  |
  ▼
Attempt 2: Call fails (ConnectionError)
  |
  ▼
```

```

    Wait 2.0s (exponential backoff)
    |
    ▼
Attempt 3: Call succeeds ✓
|
▼
Return result

```

## Pattern 2: Model Fallback

File: src/agents/core/middleware/resilience.py

```

class ModelFallback:
    """Falls back to alternative model when primary fails."""

    def __init__(
        self,
        primary_model: str,
        primary_provider: str,
        fallback_model: str = "gpt-4o-mini",
        fallback_provider: str = "openai",
    ):
        self.primary_model = primary_model
        self.fallback_model = fallback_model
        self._fallback_llm = None

    @property
    def fallback_llm(self):
        """Lazy initialization of fallback LLM."""
        if self._fallback_llm is None:
            self._fallback_llm = init_chat_model(
                model=self.fallback_model,
                model_provider=self.fallback_provider,
            )
        return self._fallback_llm

    async def execute_with_fallback(
        self,
        primary_func: Callable,
        fallback_func: Optional[Callable] = None,
        *args,
        **kwargs
    ) -> Any:
        """Execute primary function, fall back on failure."""
        try:
            return await primary_func(*args, **kwargs)
        except Exception as e:
            logger.warning(
                f"Primary model ({self.primary_model}) failed: {e}. "
                f"Falling back to {self.fallback_model}"
            )
            if fallback_func:
                return await fallback_func(*args, **kwargs)
            raise

```

### Pattern 3: Tool Retry

```
class ToolRetry:  
    """Retry logic specifically for tool execution."""  
  
    def __init__(self, max_attempts: int = 2, delay: float = 1.0):  
        self.max_attempts = max_attempts  
        self.delay = delay  
  
    def wrap_tool(self, tool):  
        """Wrap a tool's _run method with retry logic."""  
        original_run = tool._run  
  
        @retry(  
            stop=stop_after_attempt(self.max_attempts),  
            wait=wait_exponential(multiplier=self.delay, max=5),  
            reraise=True,  
        )  
        def wrapped_run(*args, **kwargs):  
            return original_run(*args, **kwargs)  
  
        tool._run = wrapped_run  
        return tool
```

## 10. Token Tracking & Callbacks

### LangChain Callback Handler

File: src/core/usage/callback\_handler.py

```
class TokenTrackingCallbackHandler(BaseCallbackHandler):  
    """  
    LangChain callback handler for automatic token tracking.  
  
    Intercepts on_llm_end() to extract actual token counts from  
    LLM responses and log them via the usage queue.  
  
    Supports two modes:  
    1. Explicit org_id: Passed at construction (per-request handler)  
    2. Context-based: Uses thread-local UsageContext (singleton handler)  
    """  
  
    def __init__(  
        self,  
        org_id: str = "",  
        feature: str = "unknown",  
        use_context: bool = False,  
    ):  
        super().__init__()  
        self.org_id = org_id  
        self.feature = feature  
        self.use_context = use_context  
        self._accumulated_usage = TokenUsage()  
        self._call_count = 0
```

```

def _get_effective_context(self):
    """Get org_id from context or instance."""
    if self.use_context:
        ctx = get_current_context()
        if ctx:
            return ctx.org_id, ctx.feature or self.feature
    return self.org_id, self.feature

def on_llm_end(self, response: LLMResult, **kwargs) -> None:
    """Called when LLM completes generation."""
    org_id, feature = self._get_effective_context()

    try:
        # Extract token usage from LangChain response
        usage = extract_from_langchain_response(response)
        self._accumulated_usage = self._accumulated_usage + usage

        # Enqueue for background processing
        if usage.total_tokens > 0:
            enqueue_token_usage(
                org_id=org_id,
                feature=feature,
                model=usage.model or "unknown",
                provider=usage.provider or "unknown",
                input_tokens=usage.input_tokens,
                output_tokens=usage.output_tokens,
            )
    except Exception as e:
        # Never fail the LLM call due to tracking errors
        logger.warning(f"Failed to track token usage: {e}")

@property
def total_usage(self) -> TokenUsage:
    """Get total accumulated usage across all LLM calls."""
    return self._accumulated_usage

```

## Token Extraction from Different Providers

File: src/core/usage/token\_extractors.py

```

def extract_from_langchain_response(response: LLMResult) -> TokenUsage:
    """
    Extract token counts from LangChain LLMResult.

    Handles different provider formats (OpenAI, Gemini, etc.)
    """
    llm_output = response.llm_output or {}

    # Try OpenAI format
    token_usage = llm_output.get("token_usage", {})
    if token_usage:
        return TokenUsage(
            input_tokens=token_usage.get("prompt_tokens", 0),
            output_tokens=token_usage.get("completion_tokens", 0),
            total_tokens=token_usage.get("total_tokens", 0),
        )

```

```

        cached_tokens=token_usage.get("prompt_tokens_details", {})
            .get("cached_tokens", 0),
        provider="openai",
        model=llm_output.get("model_name", ""),
    )

# Try Gemini format
usage_metadata = llm_output.get("usage_metadata", {})
if usage_metadata:
    return TokenUsage(
        input_tokens=usage_metadata.get("prompt_token_count", 0),
        output_tokens=usage_metadata.get("candidates_token_count", 0),
        total_tokens=usage_metadata.get("total_token_count", 0),
        provider="google",
        model=llm_output.get("model_name", ""),
    )

return TokenUsage()

```

## Usage with Agents

```

# Option 1: Explicit org_id (per-request)
handler = TokenTrackingCallbackHandler(
    org_id="org_123",
    feature="document_agent",
)
agent = create_react_agent(llm, tools, callbacks=[handler])
result = agent.invoke({"query": "..."})
print(f"Tokens used: {handler.total_usage.total_tokens}")

# Option 2: Context-based (singleton handler)
handler = TokenTrackingCallbackHandler(
    feature="document_agent",
    use_context=True, # Will read org_id from context
)
agent = create_react_agent(llm, tools, callbacks=[handler])

# At request time:
with usage_context(org_id="org_123", feature="document_agent"):
    result = agent.invoke({"query": "..."})
    # Token usage automatically tracked with org_id from context

```

---

## 11. Rate Limiting

### Sliding Window Algorithm

File: `src/agents/core/rate_limiter.py`

```

class RateLimiter:
    """Per-session sliding window rate limiter."""

    def __init__(
        self,
        max_requests: int = 10,

```

```

        window_seconds: int = 60
    ):
        self.max_requests = max_requests
        self.window_seconds = window_seconds
        self.requests: Dict[str, List[float]] = defaultdict(list)
        self._lock = threading.Lock()

    def is_allowed(self, session_id: str) -> bool:
        """Check if request is allowed and record if so."""
        with self._lock:
            now = time.time()
            window_start = now - self.window_seconds

            # Remove expired requests
            self.requests[session_id] = [
                t for t in self.requests[session_id]
                if t > window_start
            ]

            # Check limit
            if len(self.requests[session_id]) >= self.max_requests:
                return False

            # Record request
            self.requests[session_id].append(now)

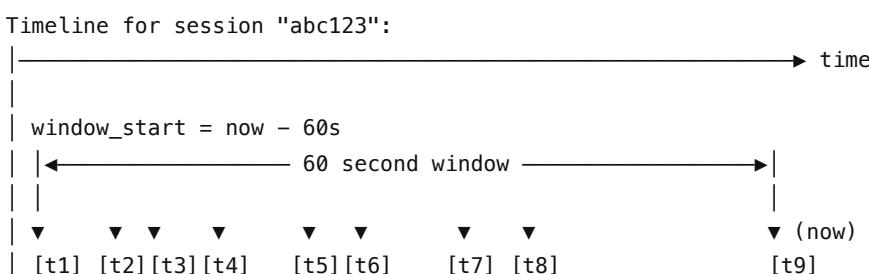
        return True

    def get_retry_after(self, session_id: str) -> float:
        """Get seconds until next request is allowed."""
        with self._lock:
            if not self.requests[session_id]:
                return 0
            oldest = self.requests[session_id][0]
            return max(0, oldest + self.window_seconds - time.time())

    def get_remaining(self, session_id: str) -> int:
        """Get remaining requests in current window."""
        with self._lock:
            now = time.time()
            window_start = now - self.window_seconds
            current = len([
                t for t in self.requests[session_id]
                if t > window_start
            ])
            return max(0, self.max_requests - current)

```

#### Sliding Window Visualization:



```

| |---|
| ^                                         |
| expired (removed)           ← 8 requests in window → |
| |
| is_allowed() returns: True (8 < 10)
| After call: 9 requests in window

```

## 12. Lifecycle Management

### Startup Sequence

File: src/api/app.py

```

@asynccontextmanager
async def lifespan(app: FastAPI):
    """Application lifespan manager."""

    # ----- STARTUP -----
    # 1. Initialize Database Connection Pool
    await db.get_engine_async()
    logger.info("Database connection pool initialized")

    # 2. Start Background Queues
    get_usage_queue().start()
    get_audit_queue().start()
    start_bulk_queue()
    logger.info("Background queues started")

    # 3. Pre-warm Executor DB Connections
    await _prewarm_executor_db_connections()
    logger.info("Executor DB connections pre-warmed")

    # 4. Initialize Agents
    app.state.document_agent = DocumentAgent()
    app.state.sheets_agent = SheetsAgent()
    logger.info("Agents initialized")

    # 5. Start Periodic Cleanup Task
    cleanup_task = asyncio.create_task(_periodic_cleanup())
    logger.info("Cleanup task started")

    # 6. Ready to Serve
    logger.info("Application startup complete")

    yield # ----- RUNNING -----

    # ----- SHUTDOWN -----

    # 0. Cancel Cleanup Task
    cleanup_task.cancel()
    try:
        await cleanup_task
    except asyncio.CancelledError:
        pass

```

```

# 1. Shutdown Agents (may enqueue final audit logs)
app.state.document_agent.shutdown(wait=True)
app.state.sheets_agent.shutdown(wait=True)

# 2. Shutdown Executor Pools
shutdown_executors(wait=True)

# 3. Shutdown Queues (in order: usage → bulk → audit)
get_usage_queue().shutdown(wait=True, timeout=10.0)
stop_bulk_queue(wait=True)
get_audit_queue().shutdown(wait=True, timeout=10.0)

# 4. Close Database Connections
await db.close_all()

logger.info("Application shutdown complete")

```

## Connection Pre-warming

Cloud SQL connector initialization takes ~1.2 seconds for the first connection. Pre-warming during startup eliminates this latency:

```

async def _prewarm_executor_db_connections():
    """Pre-warm database connections for executor thread pools."""
    executors = get_executors()
    loop = asyncio.get_running_loop()

    def run_init():
        """Sync wrapper for async init in executor thread."""
        thread_loop = asyncio.new_event_loop()
        asyncio.set_event_loop(thread_loop)
        try:
            thread_loop.run_until_complete(db.get_engine_async())
        finally:
            thread_loop.close()

    # Warm up multiple executor threads
    num_threads = min(3, executors.agent_executor._max_workers)
    futures = [
        loop.run_in_executor(executors.agent_executor, run_init)
        for _ in range(num_threads)
    ]

    # Wait with timeout (non-blocking if startup is slow)
    await asyncio.wait_for(
        asyncio.gather(*futures, return_exceptions=True),
        timeout=30.0
    )

```

## Shutdown Order Matters

**IMPORTANT:** Shutdown order prevents data loss

1. Agents first → They may enqueue final audit/usage logs
2. Executor pools → Wait for pending futures

- |                   |   |
|-------------------|---|
| 3. Usage queue    | → Process remaining token usage records |
| 4. Bulk job queue | → Complete in-progress jobs             |
| 5. Audit queue    | → Persist final audit events            |
| 6. Database       | → Close all connections                 |
- 

## 13. Performance Benchmarks

### Latency Improvements

Pattern	Before	After	Improvement
Sequential cache checks	300ms	100ms	3x faster
Blocking GCS I/O	Blocks loop	Non-blocking	100+ concurrent
No file caching	100-500ms/file	~1ms (cached)	100-500x faster
No response cache	Full LLM call	~0ms (cached)	1000x+ faster
Sequential DB lookups	N × 10ms	max(N × 10ms)	N times faster
Sync audit logging	+50ms/request	+0ms/request	Eliminated
Cold DB connections	+1.2s first call	~0ms (pre-warmed)	Eliminated

### Throughput Improvements

Component	Single-Threaded	With Pools	Improvement
Agent invocations	1 concurrent	10 concurrent	10x
GCS operations	1 concurrent	20 concurrent	20x
SQL queries	1 concurrent	10 concurrent	10x
Bulk document processing	1 sequential	N concurrent	Nx
Overall requests	~10 RPS	100+ RPS	10x+

### Resource Efficiency

Resource	Strategy	Impact
Database connections	Pooled (5+10)	Reuse eliminates handshake
Memory	LRU caches with limits	Bounded memory usage
CPU	Async I/O	No wasted cycles on I/O wait
Threads	Workload-specific pools	No starvation

---

### Key Files Reference

Component	File
Executor Pools	src/core/executors.py
Async Utilities	src/utils/async_utils.py

Database Connection	src/db/connection.py
Usage Context	src/core/usage/context.py
Token Callback	src/core/usage/callback_handler.py
Usage Queue	src/core/usage/usage_queue.py
Background Queue Base	src/core/queues/base_queue.py
GCS Cache	src/agents/document/gcs_cache.py
File Cache	src/agents/sheets/cache.py
Session Manager	src/agents/core/session_manager.py
Rate Limiter	src/agents/core/rate_limiter.py
Resilience Middleware	src/agents/core/middleware/resilience.py
GCS Storage	src/storage/gcs.py
App Lifecycle	src/api/app.py
Quota Cache	src/core/usage/quota_checker.py
Tier Cache	src/core/usage/subscription_manager.py

## Configuration Reference

### Environment Variables

```

# Executor Pool Sizes
AGENT_EXECUTOR_POOL_SIZE=10          # LLM agent invocations
IO_EXECUTOR_POOL_SIZE=20              # GCS/file I/O operations
QUERY_EXECUTOR_POOL_SIZE=10           # DuckDB/SQL queries

# Database Pool (per-loop differentiation)
DB_POOL_SIZE=3                      # Main loop pool size
DB_BACKGROUND_POOL_SIZE=2             # Background loop pool size
DB_MAX_OVERFLOW=5                    # Overflow connections
DB_POOL_TIMEOUT=30                  # Connection acquire timeout (seconds)
DB_POOL_RECYCLE=1800                 # Connection recycle time (30 minutes)

# Rate Limiting
RATE_LIMIT_REQUESTS=10               # Max requests per window
RATE_LIMIT_WINDOW=60                 # Window size (seconds)

# Session
SESSION_TIMEOUT_MINUTES=30          # Session inactivity timeout

# Cleanup
CLEANUP_INTERVAL_SECONDS=300         # Periodic cleanup interval (5 minutes)

# Cache TTLs
QUOTA_CACHE_TTL_SECONDS=60           # Quota check cache TTL
TIER_CACHE_TTL_SECONDS=3600           # Subscription tier cache TTL (1 hour)
STORE_CACHE_TTL_SECONDS=300           # File store metadata cache TTL (5 minutes)

```

```
# Bulk Processing
BULK_CONCURRENT_DOCUMENTS=5          # Max concurrent documents in bulk queue
```

## Summary

Building high-performance agentic systems requires careful attention to:

1. **Workload Isolation:** Separate thread pools for different operation types
2. **Context Propagation:** Use `copy_context()` when crossing thread boundaries
3. **Multi-Layer Caching:** Cache at every layer for exponential speedups
4. **Background Processing:** Never block the event loop with non-critical operations
5. **Resilience:** Retry logic, fallbacks, and graceful degradation
6. **Connection Management:** Per-event-loop database resources
7. **Lifecycle Management:** Proper startup/shutdown ordering

These patterns enable systems that can handle thousands of concurrent users while maintaining low latency and high reliability.