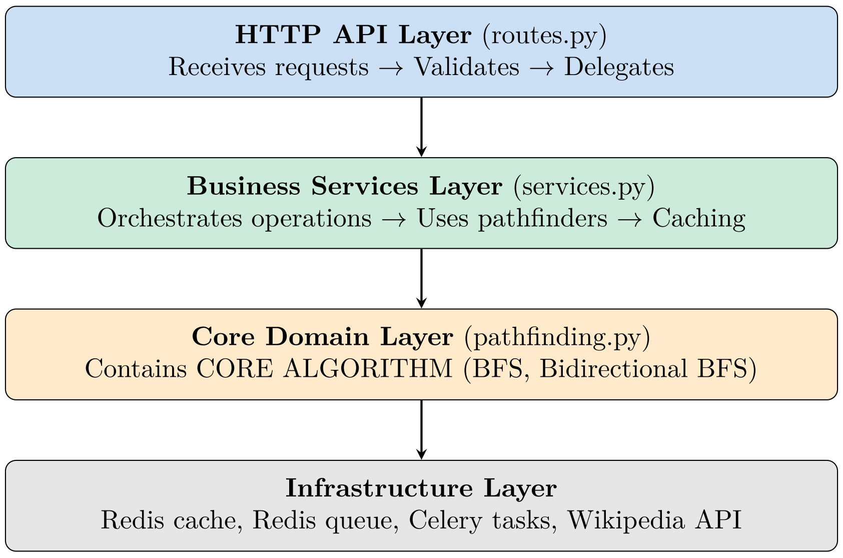
Iris Backend Architecture Guide

Wikipedia Pathfinding Engine


HTTP API Layer (routes.py)
Receives requests → Validates → Delegates
Business Services Layer (services.py)
Orchestrates operations → Uses pathfinders → Caching
Core Domain Layer (pathfinding.py)
Contains CORE ALGORITHM (BFS, Bidirectional BFS)
Infrastructure Layer
Redis cache, Redis queue, Celery tasks, Wikipedia API

Interview Preparation & Development Reference

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Contents

1 Project Structure Overview

The Iris backend follows a **Clean Architecture** pattern with clear separation of concerns.

```
iris-web-backend/
|-- app/                          # Main application package
|   |-- __init__.py              # Flask app factory & Celery setup
|   |-- api/                     # HTTP API layer
|   |   |-- routes.py            # API endpoints (Flask blueprints)
|   |   |-- middleware.py        # Decorators: error handling, logging, CORS
|   |   |-- schemas.py           # Marshmallow schemas for validation
|   |-- core/                    # Core business logic (THE BRAIN)
|   |   |-- factory.py           # Dependency Injection (ServiceFactory)
|   |   |-- interfaces.py        # Abstract interfaces (contracts)
|   |   |-- models.py            # Data models (dataclasses)
|   |   |-- pathfinding.py       # CORE ALGORITHM (BFS)
|   |   |-- services.py          # Business services orchestration
|   |-- external/                # External API integrations
|   |   |-- wikipedia.py         # Wikipedia API client
|   |-- infrastructure/          # Infrastructure concerns
|   |   |-- cache.py             # Redis cache implementation
|   |   |-- redis_queue.py       # Redis queue for BFS state
|   |   |-- tasks.py             # Celery background tasks
|   |-- utils/                   # Utilities
|       |-- exceptions.py        # Custom exception hierarchy
|       |-- logging.py           # Logging configuration
|-- config/                      # Configuration classes
|-- tests/                       # Test suites
|-- run.py                       # Application entry point
|-- celery_worker.py             # Celery worker entry point
```

Listing 1: Project Directory Structure

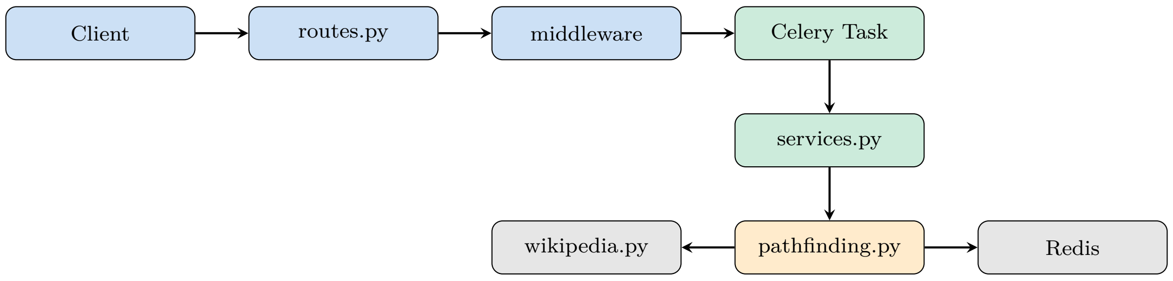
2 Architecture Layers

The codebase follows a **layered architecture** similar to Clean Architecture. Each layer has a single responsibility.

2.1 Layer Descriptions

Layer	Responsibility
HTTP API Layer `app/api/`	Receives HTTP requests, validates input using Marshmallow schemas, applies cross-cutting middleware (CORS, logging, error handling), delegates to business services, and formats JSON responses.
Business Services `app/core/services.py`	Orchestrates business operations. Checks cache before invoking pathfinding, coordinates between pathfinders and Wikipedia client, encapsulates use cases like “find path” or “explore page.”
Core Domain `app/core/pathfinding.py`	Contains the pure BFS algorithm. No knowledge of HTTP, Redis, or Flask. Only knows about abstract interfaces. This is where the graph traversal logic lives.
Infrastructure `app/infrastructure/`	Concrete implementations: Redis cache, Redis queue for BFS state, Celery tasks for background processing, Wikipedia API client. All “how” details live here.

2.2 Data Flow Diagram



3 Engineering Architecture Decisions

This section justifies key technical decisions from a **distributed systems** and **scalability** perspective. These are the answers that demonstrate engineering depth.

3.1 High-Level Architecture Decisions

Decision: Asynchronous Task Processing with Celery

Problem: Wikipedia pathfinding can take 30 seconds to 5+ minutes. HTTP requests would timeout.
Decision: Offload pathfinding to Celery background workers. API returns a task ID immediately; client polls for results.
Why This Scales:

- **Horizontal Scaling:** Spin up N Celery workers to handle N concurrent searches.
- **Decoupling:** Web servers handle HTTP; workers handle compute. Each scales independently.
- **Resilience:** If a worker crashes, the task stays in Redis and another worker picks it up.

Trade-off: Added complexity of polling. Considered WebSockets but polling is simpler to implement and debug.

Decision: Redis as Cache

Problem: Need caching, a job queue, and result storage. Using 3 different systems increases operational overhead.
Decision: Use Redis for all three: Wikipedia link cache, Celery broker, and Celery result backend.
Why This Scales:

- **Single Point of Expertise:** Operations team only needs to master one system.
- **Redis Cluster:** Can scale to hundreds of thousands of operations/second.
- **Memory Efficiency:** Redis is optimized for this exact use case.

Trade-off: Redis is a single point of failure. Mitigated with Redis Sentinel or Redis Cluster in production.

Decision: Stateless Web Servers

Problem: Need to scale web tier horizontally behind a load balancer.
Decision: All application state lives in Redis. Flask servers are completely stateless.
Why This Scales:

- **Instant Horizontal Scaling:** Add/remove web servers without session migration.
- **Zero Downtime Deploys:** Rolling restarts don't lose user state.
- **Container-Friendly:** Perfect for Kubernetes/Docker deployments.

Decision: Separation of API and Worker Deployments

Problem: API servers need to respond quickly; workers need CPU for graph traversal.
Decision: Deploy API servers and Celery workers as separate services with different resource profiles.
Why This Scales:

- **Independent Scaling:** Scale workers based on queue depth; scale API based on request rate.
- **Resource Isolation:** Workers can use 100% CPU without affecting API latency.
- **Cost Optimization:** Use different instance types (API: network-optimized; Workers: compute-optimized).

3.2 Low-Level Implementation Decisions

Decision: Redis-Based BFS Queue Instead of In-Memory Deque

Problem: BFS at depth 5+ can involve millions of nodes. Python's `deque` would exhaust worker memory.
Decision: Store BFS queue and visited set in Redis with session-specific keys.
Engineering Justification:

- **Memory Safety:** Worker memory stays constant regardless of search depth.
- **Crash Recovery:** If worker dies, search state persists (though we restart fresh currently).
- **Observability:** Can inspect queue depth via Redis CLI for debugging.

Trade-off: Higher latency per operation (network hop to Redis). Mitigated by batching operations.

Decision: Connection Pooling via Singleton Pattern

Problem: Creating new TCP connections to Redis/Wikipedia on every request is expensive.
Decision: Use lazy-loaded singletons for `RedisClient` and `WikipediaClient`.
Engineering Justification:

- **Redis:** Uses `redis.ConnectionPool` – amortizes TCP handshake across requests.
- **Wikipedia:** Uses `requests.Session` – enables HTTP Keep-Alive and connection reuse.
- **TLS Overhead:** Wikipedia uses HTTPS. Reusing connections avoids repeated TLS handshakes (100-300ms saved per request).

Decision: Bulk Wikipedia API Requests with ThreadPoolExecutor

Problem: Fetching links for 50 pages sequentially takes 50x the latency of one request.
Decision: Batch pages into groups of 50 (Wikipedia API limit) and fetch in parallel using `ThreadPoolExecutor`.
Engineering Justification:

- **I/O Bound:** Wikipedia API calls are network-bound; threads maximize throughput.
- **Configurable:** `WIKIPEDIA_MAX_WORKERS` controls parallelism (default: 10).
- **Rate Limiting:** Implicit rate limiting via thread pool size prevents hammering Wikipedia.

Decision: Cache TTLs Tuned to Data Volatility

Problem: Wikipedia pages change, but not frequently. Need to balance freshness vs. cache hit rate.
Decision: Different TTLs for different data types.
Engineering Justification:

- `wiki_links:*` – 24 hours. Page links rarely change; high reuse value.
- `path:*:*` – 1 hour. Paths are computed results; shorter TTL ensures freshness.
- `bfs_*` – 1 hour with explicit cleanup. Ephemeral search state; cleaned after use.

Decision: UUID-Based Session Isolation for BFS State

Problem: Multiple concurrent searches must not interfere with each other's BFS state.
Decision: Each search generates a UUID. All Redis keys are prefixed: `bfs_queue:<uuid>`, `bfs_visited:<uuid>:*`.
Engineering Justification:

- **No Locking Required:** Each search operates on its own keyspace.
- **Easy Cleanup:** Pattern-based deletion: `DEL bfs_*:<uuid>:*`.
- **Debugging:** Can trace a specific search by its UUID in logs and Redis.

Decision: Dependency Injection via Factory Pattern

Problem: Need testable code without complex DI frameworks.
Decision: Hand-rolled `ServiceFactory` with constructor injection.
Engineering Justification:

- **Testability:** Tests inject mocks directly via constructor.
- **No Magic:** Unlike `@inject` decorators, the wiring is explicit and traceable.
- **Cleanup Method:** `ServiceFactory.cleanup()` resets singletons between tests.

3.3 Scalability Characteristics Summary

Dimension	How It Scales
Concurrent Searches	Add more Celery workers (horizontal).
API Request Rate	Add more Flask/Gunicorn instances behind load balancer.
Cache Size	Redis Cluster with sharding or increase instance memory.
Wikipedia Rate Limits	Configurable thread pool; add delay; use multiple API keys.
Storage (Results)	Redis with TTL-based eviction; results auto-expire after 1 hour.

4 Service Lifecycle & Initialization

Understanding precisely **when**, **where**, and **how** services are initialized demonstrates production awareness.

4.1 The "When": Lazy Initialization

Services are **not** initialized when you run `python run.py`. They are created **on first use**.

- **Flask Process:** First API request triggers service initialization.
- **Celery Worker:** First task pickup triggers service initialization.

4.2 Component Lifecycle Table

Component	Lifecycle	Reasoning
Redis Client	Singleton	Maintains `ConnectionPool`; avoids TCP handshake overhead per request.
Wikipedia Client	Singleton	Holds `requests.Session`; enables HTTP Keep-Alive and TLS session reuse.
Cache Service	Singleton	Shared serialization logic wrapping the Redis client.
Pathfinding Service	Transient	New instance per task. Allows request-specific `progress_callback` and algorithm.

4.3 Initialization Flow

When a Celery task starts:

1. `find_path_task` starts in `infrastructure/tasks.py`.
2. Calls `get_pathfinding_service(algorithm, progress_callback)`.
3. `ServiceFactory` checks `_wikipedia_client`. It's `None` → creates it.
4. To create Wikipedia client, needs `_cache_service`. It's `None` → creates it.
5. To create cache, needs `_redis_client`. It's `None` → creates it.
6. Dependencies wired together via constructor injection; `PathFindingService` returned.
7. **Next task:** Singletons already exist → instant return.

Important

Singletons are Per-Process. If Gunicorn runs 4 workers, there are 4 independent Wikipedia Clients. They share state via the common Redis database, not via shared memory.

5 Progress Callback System

The progress callback allows clients to see **live search progress** rather than waiting blindly.

5.1 The Problem

A BFS search can take minutes. Without progress updates, the client has no idea:

- Is the search still running or stuck?
- How deep has it gone?
- How many nodes has it explored?

5.2 The Solution: Callback Injection

1. **Task creates a callback function** that updates Celery task state.
2. **Callback is injected** into `PathFindingService` via constructor.
3. **BFS algorithm calls the callback** every N nodes explored.
4. **Client polls** `/tasks/status/<id>` and sees real-time progress.

5.3 Code Flow

5.3.1 Step 1: Task Defines the Callback

```python
@celery.task(bind=True)
def find_path_task(self, start_page, end_page, algorithm="bfs"):

    # Define a closure that captures 'self' (the Celery task)
    def progress_update(progress_data):
        self.update_state(
            state="PROGRESS",
            meta=progress_data  # Contains nodes_explored, current_depth, etc.
        )

    # Pass the callback to the service factory
    pathfinding_service = get_pathfinding_service(
        algorithm=algorithm,
        progress_callback=progress_update  # <-- Injected here
    )

    result = pathfinding_service.find_path(search_request)
```

Listing 2: tasks.py – Creating the Progress Callback

5.3.2 Step 2: Factory Passes Callback to PathFinder

```python
@classmethod
def create_pathfinding_service(cls, algorithm="bfs", progress_callback=None):
    # ... get singletons ...

    path_finder = RedisBasedBFSPathFinder(
        wikipedia_client,
        cache_service,
        queue_service,
        max_depth,
        batch_size,
        progress_callback  # <-- Passed to the algorithm
    )

    return PathFindingService(path_finder, cache_service, wikipedia_client)
```

Listing 3: factory.py – Injecting the Callback

5.3.3 Step 3: BFS Calls the Callback Periodically

```python
def _perform_bfs_search(self, start_page, end_page, ...):
    nodes_explored = 0

    while self.queue_service.length(queue_key) > 0:
        current_item = self.queue_service.pop(queue_key)
        nodes_explored += 1

        # Report progress every 3 nodes
        if self.progress_callback and nodes_explored % 3 == 0:
            self.progress_callback({
                "status": "Searching...",
                "search_stats": {
                    "nodes_explored": nodes_explored,
                    "current_depth": current_depth,
                    "last_node": current_page,
                    "queue_size": self.queue_service.length(queue_key),
                },
                "search_time_elapsed": time.time() - start_time,
            })

        # ... rest of BFS logic ...
```

Listing 4: pathfinding.py – Invoking the Callback

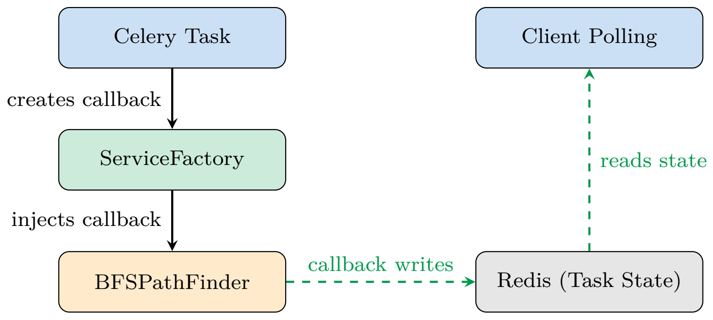
5.3.4 Step 4: Client Sees Progress via Polling

```
GET /tasks/status/abc-123

{
    "status": "IN_PROGRESS",
    "task_id": "abc-123",
    "progress": {
        "status": "Searching...",
        "search_stats": {
            "nodes_explored": 42,
            "current_depth": 3,
            "last_node": "Machine learning",
            "queue_size": 150
        },
        "search_time_elapsed": 5.2
    }
}
```

Listing 5: Client Polling Response

5.4 Architecture Diagram: Callback Flow



5.5 Why This Design?

Benefit	Explanation
Decoupling	The BFS algorithm doesn't know about Celery. It just calls a function.
Testability	In tests, pass a mock callback that records calls instead of updating Celery.
Flexibility	Easy to change reporting frequency or add more metrics without touching BFS.
No Polling Inside Worker	Worker doesn't poll; it pushes. Client pulls on its own schedule.

6 Dependency Injection (DI) Explained

Note

Location: `app/core/factory.py` – `ServiceFactory` class

6.1 The Pattern: Singleton + Factory

```python
class ServiceFactory:
    _redis_client = None      # Singleton storage
    _cache_service = None
    _wikipedia_client = None

    @classmethod
    def get_cache_service(cls):
        if cls._cache_service is None:
            redis_client = cls.get_redis_client()
            cls._cache_service = RedisCache(redis_client)
        return cls._cache_service

    @classmethod
    def create_pathfinding_service(cls, algorithm="bfs", progress_callback=None):
        # Retrieve singletons, then inject into new instance
        wiki = cls.get_wikipedia_client()
        cache = cls.get_cache_service()
        queue = cls.get_queue_service()

        path_finder = RedisBasedBFSPathFinder(wiki, cache, queue,
    progress_callback)
        return PathFindingService(path_finder, cache, wiki)
```

Listing 6: ServiceFactory Implementation

6.2 Swapping Implementations

To use Memcached instead of Redis:

1. Create `MemcachedCache` implementing `CacheServiceInterface`.
2. Modify `ServiceFactory.get_cache_service()` to return `MemcachedCache`.
3. Done. All services automatically use the new cache.

7 File-by-File Breakdown

7.1 Core Files

File	Purpose
`app/core/pathfinding.py`	**CORE ALGORITHM**. Redis-based BFS. Modify for algorithm changes.
`app/core/services.py`	Business orchestration. Cache checking, validation, timing.
`app/core/factory.py`	DI container. Manages singletons and object creation.
`app/core/interfaces.py`	Abstract contracts for testability and loose coupling.
`app/core/models.py`	Dataclasses for requests, results, and DTOs.

7.2 Infrastructure Files

File	Purpose
`app/infrastructure/cache.py`	Redis cache implementation with connection pooling.
`app/infrastructure/redis_queue.py`	FIFO queue for BFS state (push, pop, length).
`app/infrastructure/tasks.py`	Celery task definitions with retry logic and progress updates.
`app/external/wikipedia.py`	Wikipedia API client with bulk fetching and redirect handling.

8 Caching Strategy

Key Pattern	TTL	Purpose
`wiki_links:{page}`	24h	Caches Wikipedia page links. High reuse.
`path:{start}:{end}`	1h	Caches completed path results.
`bfs_visited:<uuid>:*`	1h	Temporary visited set. Cleaned after search.
`bfs_paths:<uuid>:*`	1h	Temporary path tracking. Cleaned after search.
`bfs_queue:<uuid>`	Session	BFS queue. Explicitly deleted after search.

9 Interview Q&A Cheat Sheet

Q: If you had to modify the core pathfinding algorithm

Answer: `app/core/pathfinding.py` – specifically the `RedisBasedBFSPathFinder` class and its `find_shortest_path()` method.

Q: When and where do services get initialized?

Answer: Services are **lazily initialized** by `ServiceFactory` (`app/core/factory.py`) on first use. Not at app startup. Flask: first request. Celery: first task.

Q: Which objects are reused vs. created fresh?

Answer:
- **Reused (Singletons):** Redis Client, Wikipedia Client, Cache Service. Maintains connection pools.
- **Fresh (Transient):** PathFindingService. New per task for isolated callbacks.

Q: How does the progress callback work?

Answer:
1. Celery task defines a closure that calls `self.update_state()`.
2. This closure is passed to `ServiceFactory.create_pathfinding_service()`.
3. Factory injects it into `RedisBasedBFSPathFinder` constructor.
4. BFS calls the callback every N nodes, writing progress to Redis.
5. Client polls `/tasks/status/<id>` to read progress.

Q: Why use Celery instead of handling pathfinding synchronously?

Answer: Pathfinding can take minutes. Synchronous handling would:

- Timeout HTTP connections (typically 30-60s limit).
- Block web server threads, reducing throughput.
- Provide no progress visibility to users.

Celery enables horizontal scaling, resilience, and real-time progress.

Q: Why Redis for BFS queue instead of Python deque?

Answer: Memory safety. BFS at depth 5+ can involve millions of nodes. Redis:

- Offloads memory from worker process.
- Enables inspection via Redis CLI.
- Provides crash-recovery potential (state persists).

Trade-off: Network latency per operation (mitigated by batching).

Q: How does the system scale horizontally?

Answer:

- **API:** Stateless Flask servers behind load balancer.
- **Workers:** Add Celery workers to increase search throughput.
- **Cache:** Redis Cluster for sharding and replication.

Q: Explain singletons across processes.

Answer: Singletons are per-process. 4 Gunicorn workers = 4 Wikipedia Clients. They share state via Redis (the database is the shared memory), not in-process memory.

Q: Why is the Wikipedia Client a singleton?

Answer: It holds a `requests.Session` which provides:

- HTTP Keep-Alive (connection reuse).
- TLS session resumption (avoids 100-300ms handshake).
- Cookie persistence if needed.

Creating new clients per request would destroy these benefits.

Q: How would you add a new pathfinding algorithm?

Answer:

1. Create class implementing `PathFinderInterface` in `pathfinding.py`.
2. Add case in `ServiceFactory.create_pathfinding_service()`.
3. Update API schema to accept new algorithm name.
4. Add tests in `tests/integration/test_pathfinding.py`.

10 Quick Reference: Where to Make Changes

Goal	Location
Modify BFS algorithm	`app/core/pathfinding.py`
Add new API endpoint	`app/api/routes.py`
Change request validation	`app/api/schemas.py`
Add new Celery task	`app/infrastructure/tasks.py`
Swap cache implementation	Implement interface, update `factory.py`
Add new exception type	`app/utils/exceptions.py`
Change configuration	`config/base.py`
Modify Wikipedia API logic	`app/external/wikipedia.py`

11 API Endpoints Reference

Method	**Endpoint**	**Description**
POST	`/getPath`	Start pathfinding. Returns task ID.
GET	`/tasks/status/<id>`	Poll for task status and progress.
POST	`/explore`	Explore links from a page.
GET	`/health`	System health check.
GET	`/api`	API information.
POST	`/cache/clear`	Admin: clear cache by pattern.

12 Configuration Reference

Variable	**Default**	**Description**
`REDIS_URL`	localhost:6379	Redis connection URL.
`MAX_SEARCH_DEPTH`	6	Maximum BFS depth.
`BFS_BATCH_SIZE`	50	Pages per batch in BFS.
`CACHE_TTL`	86400	Default cache TTL (24h).
`WIKIPEDIA_MAX_WORKERS`	10	Thread pool for Wikipedia API.
`CELERY_TASK_SOFT_TIME_LIMIT`	300	Soft timeout (5m).
`CELERY_TASK_TIME_LIMIT`	600	Hard timeout (10m).