

Building Reliable LLM Abstractions and API Wrappers

Architecture, Implementation, and Production Engineering

Design and build a production-grade, provider-agnostic LLM integration library with proven patterns, full code, and real-world best practices.



Full Code

A complete Python codebase, chapter by chapter



Proven Patterns

Battle-tested designs for real-world systems



Production Focus

Reliability, security, observability and ops



For Experienced Engineers

Backend developers, library authors, architects

TOMAS NOVAK

Building Reliable LLM Abstractions and API Wrappers

Architecture, Implementation, and Production Engineering

Steve Publications

This book is available at

<https://leanpub.com/buildingreliablellmabstractionsandapiwrappers>

This version was published on 2026-09-27



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Architecture, Implementation, and Production Engineering

A rigorous engineering guide to designing and building a production-grade, provider-agnostic LLM integration library. This book takes you from foundational architectural principles through a complete reference implementation, covering everything from API design and provider adapters to reliability patterns, observability, security, and production operations. Every concept is demonstrated with full runnable code in a cohesive Python codebase that evolves across the chapters. Targeted at experienced software engineers, backend developers, library authors, and systems architects who need to build reliable LLM integrations without vendor lock-in or reliability trade-offs.

Introduction

On December 11, 2024, OpenAI experienced a four-hour global outage that brought down ChatGPT, the API, and every product built on top of them. The cause was a telemetry service deployment that overwhelmed Kubernetes control planes and broke DNS service discovery. The postmortem read like any other infrastructure failure. The impact did not. Thousands of applications that depended on a single provider suddenly became unreliable single points of failure themselves, and the outage made a simple point undeniable: any production system that calls LLM providers directly inherits all of their reliability problems without any defense mechanism to absorb them [1].

This book is about building that defense mechanism.

Most engineers who integrate LLMs into production start with a straightforward pattern. They import an SDK, instantiate a client, call a method with a prompt, and use the response. This works for prototypes and internal tools. It also works until one of several predictable things happens.

The provider changes their API in a way that breaks your code. A model you depend on gets deprecated. Your costs spike because you are sending simple requests to a flagship model. A rate limit kicks in during peak traffic. A provider goes down for an hour and your entire service degrades. You want to A/B test a cheaper model but your code is tightly coupled to one provider. You want to add retries, circuit breaking, observability, or fallback logic but every feature you add leaks provider-specific details into your business logic.

These are not edge cases. They are the standard lifecycle of any LLM integration that moves past the prototype stage.

The solution that most teams converge on is some form of abstraction layer. You write code that sits between your application and the provider APIs, and your application depends only on your abstraction. This sounds simple until you try to design an abstraction that is actually useful.

There are two failure modes for LLM abstraction libraries, and both are common.

The first is over-abstraction. You design a perfectly clean unified API that hides all provider details. It looks elegant until you need to use a provider-specific feature like structured outputs, extended thinking, system prompt caching, or a particular streaming format. Your abstraction either forces you to use the lowest common denominator or requires ugly escape hatches that defeat the purpose.

The second is under-abstraction. You write thin wrappers around each provider SDK that normalize almost nothing. Every piece of application code still needs to know whether it is talking to OpenAI or Anthropic. You have eliminated vendor lock-in in name only, because the cost of switching providers is now scattered across hundreds of files instead of one SDK import.

Both patterns exist in the wild. Large frameworks tend toward over-abstraction because they target a wide audience and want a clean public interface. Internal gateway implementations tend toward under-abstraction because they are built incrementally to solve immediate problems without a coherent design.

This book is about finding the right middle path: an abstraction that is clean enough to simplify your architecture and powerful enough to preserve provider capabilities when you need them.

The book will walk you through building a complete reference implementation from the ground up. We will use Python because it is the dominant language for LLM development, and we will build the library as if it were a real production product that multiple teams depend on. The implementation will start with a minimal core and evolve across the chapters so that every new feature integrates with the existing architecture. By the end, you will have a library that supports multiple providers, streaming responses, structured outputs, tool calling, multimodal inputs, retry logic, circuit breaking, fallback chains, observability, cost tracking, and security controls.

Here is what you need to know before we start.

The reference implementation uses Python 3.11 as the baseline with Pydantic v2 for data models, httpx for HTTP transport, structlog for logging, and OpenTelemetry for tracing. The library will support four primary providers as detailed examples: OpenAI, Anthropic, Google Vertex AI, and Together AI. These providers represent the diversity of the ecosystem in terms of API design, authentication mechanisms, response formats, and feature sets. The architecture is designed to accommodate any additional provider through

adapter implementations without changing the core interface.

The book assumes you are already comfortable with Python, `async/await`, type annotations, and basic software architecture patterns. You should understand HTTP, JSON, and API design. If you have built a production service that makes external API calls you will recognize the patterns. If you have used any LLM provider SDK you will recognize the problems we are solving.

The book does not cover prompt engineering, model training, evaluation frameworks, or agent design. These are important topics but they live above the layer this book focuses on. The library we build will be the substrate that makes those higher-level systems reliable and provider-agnostic. If you are building agents, RAG pipelines, or multi-model applications, the reliability and abstraction patterns in this book are exactly what keep those systems running when the real world happens.

We will organize the material into a logical progression that mirrors how you would actually build this library in practice. We start with the problem space and architectural principles that guide the design. Then we establish the project structure and implement the foundational types and interfaces. From there we build provider adapters that demonstrate how to handle real API heterogeneity. We add advanced capabilities like structured outputs, tool calling, and multimodal support. We layer in reliability engineering patterns for retries, circuit breaking, and graceful degradation. Finally we cover observability, testing, security, and production operations.

Every chapter builds on the previous ones. The codebase is cohesive and evolving. When you read Chapter 10 on tool calling you will see code that depends on the adapter interface defined in Chapter 5 and the request model defined in Chapter 4. This is intentional. Real library design is about how pieces fit together, not about isolated concepts.

The implementation decisions in this book are opinionated but defended. We choose a `ProviderAdapter` protocol over inheritance because protocols enable cleaner testing and extension. We choose `httpx` over `aiohttp` or `requests` because it handles both sync and async cleanly with HTTP/2 support. We choose `Pydantic v2` for data models because it provides strong validation and JSON schema generation without boilerplate. We choose `async-first` design because LLM calls are inherently I/O bound and `async` composition is natural for concurrent operations. These choices are explained when they appear and alternatives are discussed.

The book will also confront uncomfortable realities about building abstractions in a rapidly changing ecosystem. Provider APIs evolve faster than most software. Features that are cutting-edge today become standard tomorrow, and standard features become deprecated next year. Your abstraction layer has to be stable enough that your application code does not need to change every time a provider updates their SDK, but flexible enough to support new features when you want to use them. This tension cannot be eliminated, but it can be managed through deliberate design.

Let us get started.

References

[1] OpenAI Status, “API, ChatGPT & Sora Facing Issues,” December 11, 2024. <https://status.openai.com/incidents/ctrsv3lwd797>

Chapter 1: The Problem Space

Building a reliable LLM abstraction layer starts with understanding the problem it is trying to solve. Most engineers who need an abstraction layer arrive at it the same way: they build something directly against a provider API, it works for a while, and then reality reveals a series of costs and constraints that were invisible during initial development. By the time those costs are apparent, the code is already deployed in production with dependencies woven through multiple services.

This chapter analyzes the specific failures that occur when you integrate LLM providers directly into your application architecture. We will look at why these failures happen, what they cost, and what they tell us about the requirements for a robust abstraction layer.

Direct Provider Integration Anti-Patterns

The most common pattern for initial LLM integration is straightforward. You import the official SDK, configure it with an API key, and call the provider API from your application code. In Python this looks roughly like this:

```
1  import os
2  from openai import OpenAI
3
4  client = OpenAI(api_key=os.environ["OPENAI_API_KEY"])
5
6  def generate_summary(text: str) -> str:
7      """Generate a summary of the given text."""
8      response = client.chat.completions.create(
9          model="gpt-4o-mini",
10         messages=[
11             {"role": "system", "content": "Summarize the following text."},
12             {"role": "user", "content": text}
13         ],
14         max_tokens=500,
15         temperature=0.3
16     )
17     return response.choices[0].message.content
```

This code works. It is simple and it delivers value. It is also architecturally fragile in several specific ways.

The first fragility is provider coupling. Your function signature hides the dependency, but the implementation is explicitly tied to OpenAI. If you want to switch to Anthropic, you must rewrite the function body, change the message format, adjust parameters, and handle a different response structure. In a small codebase with one or two LLM calls this is manageable. In a large application with dozens or hundreds of LLM integrations across multiple services this becomes a significant refactoring effort. The refactoring is risky because provider APIs have subtle behavioral differences that only surface under production load.

The second fragility is error handling. Provider SDKs raise their own exception types with their own semantics. The OpenAI SDK raises `RateLimitError`, `APIConnectionError`, `APIStatusError`, and several others. Anthropic raises different exceptions. Google raises different exceptions. When each service in your architecture calls a different provider directly, you end up with provider-specific exception handling scattered throughout your codebase. Your monitoring system sees different error types for what are conceptually the same failures. You cannot implement a unified retry policy because each provider signals retryability differently.

The third fragility is parameter drift. LLM provider APIs evolve rapidly. Parameters are added, deprecated, and renamed. OpenAI deprecated the `functions` parameter in favor of `tools`. Anthropic deprecates `temperature`, `top_k`, and `top_p` on newer models in favor of a different sampling model. Google updates their generation config structure regularly. If your codebase calls provider APIs directly, every API evolution requires changes across your entire codebase, not just in one adapter layer.

The fourth fragility is observability. Provider SDKs do not emit telemetry in a format that integrates naturally with your existing observability stack. The OpenAI SDK logs at a basic level. Anthropic provides some structured output but in their own format. Neither provider integrates with your tracing system, your log aggregation pipeline, or your metrics collection by default. When you need to debug a latency issue, track token usage, or correlate LLM calls with application behavior, you have to build custom instrumentation around each SDK call. This instrumentation is duplicated across your codebase and inconsistent by design.

The fifth fragility is cost management. Without an abstraction layer, each service that calls an LLM provider has its own API key. Each key has its own spending pattern. You cannot implement centralized cost controls, per-project budgeting, or cross-service cost attribution. When costs spike, you have to investigate which service is responsible by checking each provider dashboard separately, and the provider dashboards rarely give you the level of granularity you need to pinpoint the source of unexpected charges.

None of these fragilities are immediate showstoppers. That is the problem. They accumulate slowly as your integration deepens, and by the time they become expensive enough to justify a refactor, the cost of changing your architecture has grown proportionally. The decision to build an abstraction layer is usually made not when the first problem appears but when the fifth problem coincides with a production incident that could have been prevented.

The Cost of Vendor Lock-In and Fragmentation

Vendor lock-in is a familiar concept in software engineering, but LLM vendor lock-in has unique characteristics that make it more insidious than traditional cloud or database lock-in.

Traditional vendor lock-in is usually about data portability and migration cost. Moving databases from one provider to another is hard because you have to migrate schemas, data, and application logic. Moving compute from one cloud provider to another is hard because you have to adapt to different APIs and deployment mechanisms. LLM vendor lock-in is similar but with two additional dimensions.

The first additional dimension is model behavior. Different LLM models produce different outputs for the same input. If your application logic is tuned to the particular capabilities and quirks of one model, switching to another model may degrade quality even if the technical migration is straightforward. This is not just about raw capability differences. It is about prompt engineering that is optimized for a specific model, evaluation suites that are calibrated against one model's behavior, and user expectations that are shaped by one model's style.

The second additional dimension is feature lock-in. Providers add features that are not available elsewhere, and applications that use those features

become dependent on that provider. If your application uses OpenAI's structured outputs with strict schema validation, or Anthropic's prompt caching, or Google's native multimodal capabilities, switching providers requires finding equivalent features or accepting degraded functionality. As providers differentiate their feature sets, feature lock-in becomes a stronger binding force than raw model quality.

These lock-in risks are compounded by API fragmentation across providers. Each major provider has designed their API with different assumptions and conventions. OpenAI models their API on a chat completion metaphor with message arrays. Anthropic uses a similar metaphor but with different message content structures and separate system prompt handling. Google Vertex AI uses a content and parts model that is quite different from both. Together AI adopts the OpenAI API format but with subtle differences in parameter handling. This fragmentation means that even if you want to use multiple providers for load balancing or cost optimization, you cannot write code that calls them uniformly without an adaptation layer.

The fragmentation is not just about top-level API structure. It extends to every detail of the interaction. Consider just a few examples:

- **Streaming:** OpenAI uses Server-Sent Events with data prefixed JSON. Anthropic uses a similar SSE format but with different event types. Google uses a streaming `generateContent` endpoint with a different chunk structure.
- **Tool calling:** OpenAI uses a `tools` parameter with function objects and JSON Schema. Anthropic uses `tools` with `input_schema` but in a different structure. Google uses `functionDeclaration` with OpenAPI Schema. The result formats differ as well.
- **Authentication:** OpenAI uses bearer tokens. Anthropic uses an API key header. Google uses OAuth2 service accounts with access tokens. Together AI uses bearer tokens. Each has different rotation and management requirements.
- **Error handling:** Each provider uses different status codes, error types, and retry signals. OpenAI uses `retry-after-ms` on 429 responses. Anthropic uses `retry-after` in seconds. Google uses Google RPC error codes wrapped in HTTP responses.
- **Token counting:** Each provider tokenizes differently. The same input string may consume different numbers of tokens depending on which

model you use. There is no universal token count that lets you plan context window usage across providers.

This fragmentation is real and it is not going away. Providers are competing on API design as well as model quality, and they have no incentive to converge on a single standard. The OpenAI API format has become a de facto standard that many providers emulate, but even OpenAI-compatible APIs have subtle differences that break naive integrations.

The cost of fragmentation becomes apparent when you try to do anything beyond basic single-provider integration. A/B testing requires calling two providers simultaneously with the same input. Failover requires switching providers when one is unavailable. Cost optimization requires routing requests to the cheapest capable provider. All of these require normalizing provider differences into a consistent interface that your application code can depend on.

What Abstraction Should and Should Not Do

Given the problems that direct provider integration creates and the fragmentation that exists across providers, the natural impulse is to build an abstraction layer that eliminates all differences. You design a clean, minimal interface that your application code calls, and the implementation handles all provider-specific details.

This impulse is correct but it has to be constrained. The history of API abstraction in software engineering is littered with abstractions that were too thin to be useful or too thick to extend. LLM abstractions have to avoid both extremes.

An effective LLM abstraction should provide the following:

- A stable public interface that your application code depends on. This interface should not change when providers update their APIs or when you add new providers to your integration.
- Normalized request and response types. A single message format, a single response type with token usage and metadata, and a single error taxonomy that maps provider-specific errors into consistent categories.

- Provider adapters that encapsulate all provider-specific details. Each adapter knows how to authenticate with its provider, translate your unified request into the provider's format, parse the provider's response, handle streaming, and map errors.
- Execution semantics. Support for synchronous and asynchronous calls, streaming responses, timeouts, and cancellation. These should be part of the interface, not an afterthought.
- Extensibility. The ability to add new providers by implementing an adapter without changing the core interface. The ability to add provider-specific options when you need them without breaking the uniform API.
- Observability hooks. Structured logging, tracing, and metrics that integrate with standard observability tools and are consistent across all providers.

An effective LLM abstraction should not do the following:

- Hide important provider-specific capabilities. If a provider offers a feature that matters for your use case, the abstraction should make it accessible, not require you to bypass the abstraction entirely. This does not mean every provider-specific option appears in the public interface. It means there is a clean mechanism to access them when needed.
- Force you to use the lowest common denominator. Just because one provider does not support structured outputs does not mean you cannot use structured outputs when calling providers that do. The abstraction should support capabilities selectively based on what the chosen provider can do.
- Abstract away error semantics to the point where you cannot distinguish between retryable and non-retryable failures. Error classification is one of the most important pieces of information your abstraction can provide, and over-abstraction here creates reliability problems.
- Become a framework. An abstraction layer is not an orchestration framework, not a prompt management system, not an evaluation toolkit. Those are higher-level concerns that sit on top of the abstraction layer. Mixing them creates coupling and bloat.
- Assume a single model or a single provider. The abstraction should be designed from the start to handle multiple providers and models. If it is designed as a wrapper around one provider and then extended to others, the design will show seams.

The tension between “stable and simple” and “capable and extensible” is the central design challenge for any LLM abstraction layer. We will confront this tension throughout the book and make explicit trade-offs when we encounter it.

A useful mental model is to think of the abstraction layer as having three responsibilities, in order of priority:

- First, correctness. Every request your application makes through the abstraction should reach the intended provider with the intended parameters, and every response should be returned correctly with accurate metadata. Nothing else matters if this is not right.
- Second, reliability. The abstraction should handle transient failures gracefully. It should retry when appropriate, fail fast when appropriate, provide useful error information, and give your application the tools to implement fallback strategies.
- Third, convenience. The abstraction should make common operations easy and provider-specific operations accessible. Good defaults matter. Clear documentation matters. But convenience is secondary to correctness and reliability.

Many existing LLM abstraction libraries invert this priority order. They prioritize convenience and feature richness over reliability and correctness, which leads to subtle bugs that only appear under production load. The library we will build in this book puts reliability first.

Defining the Success Criteria

Before we move to architecture and implementation, we need to establish clear success criteria for the abstraction layer. These criteria will guide design decisions throughout the book and provide a concrete standard for evaluating whether the implementation is working.

The first criterion is provider independence. Your application code should depend on the abstraction layer, not on any specific provider. Adding a new provider should require implementing an adapter but should not require changes to application code. Switching which provider is used for a particular call should be a configuration change, not a code change. You should be able

to write tests that mock the abstraction layer without mocking any provider SDK.

The second criterion is capability preservation. Every capability that a provider offers should be accessible through the abstraction layer. This does not mean every capability appears in the core interface. It means that when you need a provider-specific feature, you can access it through a defined extension mechanism without bypassing the abstraction entirely. The abstraction should never force you to choose between a clean architecture and the features you need.

The third criterion is error transparency. When a call fails, the error should include enough information to understand what went wrong. Is it a client error that means you sent an invalid request? Is it a server error that means the provider is having problems? Is it a rate limit that means you should back off? Is it an authentication error that means your credentials are wrong? The error taxonomy should make these distinctions clear and consistent across all providers.

The fourth criterion is observability completeness. Every call through the abstraction layer should produce observable telemetry. You should be able to see which model was called, how many tokens were consumed, how long the call took, whether it succeeded or failed, and if it failed why. This telemetry should integrate with standard observability tools and should be consistent across all providers so you can compare latency, costs, and error rates without provider-specific parsing.

The fifth criterion is reliability under failure. The abstraction layer should handle transient failures without losing requests or producing partial results. It should support retry policies that are configurable at appropriate levels. It should support circuit breaking so a failing provider does not cascade failures through your entire system. It should support timeout semantics that are unambiguous about whether a request was processed.

The sixth criterion is cost visibility. Every call through the abstraction layer should produce cost information. You should be able to see how much each call cost, which provider was used, which model was used, and how much your total spend is per service, per feature, and per time period. This does not require the abstraction to manage billing or API keys, but it requires the telemetry that makes cost management possible.

The seventh criterion is backward compatibility. Once your application

code depends on the abstraction layer, the public interface should be stable. New features should be additive. Deprecations should be announced and supported for a reasonable migration period. You should be able to update the abstraction layer without updating all the code that uses it.

These criteria are ambitious. Meeting all of them requires careful design and disciplined implementation. They are also achievable. The patterns and techniques required are well-understood in software engineering, even if they are not always applied consistently in LLM integration. The rest of this book is about applying those patterns to build an abstraction layer that meets these criteria in practice.

A Realistic Scope for Provider Agnostic Design

Provider agnostic design sounds like a simple goal: make it so your code does not care which provider it is calling. In practice, true provider agnosticism is impossible because providers are fundamentally different. They have different models with different capabilities. They have different APIs with different parameter semantics. They have different pricing models with different cost implications. They have different reliability characteristics and different outage histories.

The realistic goal is not provider agnosticism in the sense that providers are interchangeable. The realistic goal is provider optionality in the sense that you can choose which provider to use for which requests without rewriting your application code.

This distinction matters because it shapes the architecture. If providers are not interchangeable, your abstraction layer cannot pretend they are. It cannot normalize away every difference because some differences are real and important. Instead, it should provide a consistent interface for the capabilities that are common across providers, and a clean extension mechanism for capabilities that are provider-specific.

The abstraction layer we will build recognizes three levels of provider variation:

At the first level are core capabilities that every provider supports. Every provider takes text input and produces text output. Every provider supports conversation-style prompting with message history. Every provider supports

basic sampling parameters like temperature. These capabilities can be fully normalized into a unified interface.

At the second level are advanced capabilities that most providers support but implement differently. Structured outputs are supported by OpenAI, Anthropic, and Google but with different parameter names and different schema constraints. Tool calling is supported by most major providers but with different function definition formats. Streaming is universal but the event formats differ. These capabilities can be normalized with some effort, but the normalization has to accommodate provider-specific constraints.

At the third level are provider-specific capabilities that only some providers offer. Prompt caching, extended thinking modes, system prompt variations, image generation, audio output, and many others are provider-specific. These cannot be normalized into a unified interface without creating artificial uniformity. Instead, the abstraction layer should expose them through a provider-specific options mechanism that is accessible but not required.

This layered approach to provider variation is the foundation of the architecture we will design. It allows us to build a clean, consistent interface for the capabilities that matter most while preserving access to provider-specific features when you need them. It also allows the abstraction to evolve as providers converge on new standards or diverge with new innovations.

The reference implementation will demonstrate this approach in concrete terms. We will define a core interface that works across all providers. We will implement normalization for advanced capabilities like structured outputs and tool calling. We will design extension points for provider-specific options. And we will build adapters for real providers that show how the architecture handles real-world API differences.

If you approach this problem expecting a perfectly clean abstraction that makes every provider look identical, you will be disappointed. If you approach it expecting a pragmatic abstraction that simplifies the common case while preserving flexibility for the complex case, you will find that provider optionality is not just possible but straightforward.

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[1] OpenAI Status, “API, ChatGPT & Sora Facing Issues,” December 11, 2024. <https://status.openai.com/incidents/ctrsv3lwd797>

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Chapter 2: Architectural Principles and Requirements

Having established the problem space, we now derive the architectural principles that will guide the design and implementation of our library. Principles are not optional guidelines. They are the decisions you make once that prevent hundreds of ad-hoc decisions later.

The principles in this chapter are derived from the failure modes identified in Chapter 1 and the success criteria we defined. They are also informed by lessons from existing abstraction libraries, including their strengths and their mistakes. We will examine each principle, explain why it matters, and show how it constrains design choices.

Stability Over Novelty in API Design

The public interface of your abstraction layer will be depended upon by application code. That code may be in your repository or in other teams' repositories. It may be used in production systems that cannot tolerate breaking changes. When you design the interface, stability is the dominant concern.

Stability means that once a feature is part of the public API, you cannot remove it or change its semantics without careful consideration and a migration path. It does not mean you never add features. It means additions are additive and backward compatible. It means deprecations are announced and honored. It means the interface evolves slowly and deliberately rather than tracking every new feature that providers introduce.

This principle has several concrete implications for our design:

The first implication is that we should resist the temptation to include every provider feature in the public interface. Provider APIs evolve rapidly, and features appear and disappear faster than a stable library interface can track. If you include every feature, your interface becomes large and brittle.

Instead, the interface should include core capabilities that are proven to be widely useful and likely to persist. Provider-specific or experimental features can be accessed through extension mechanisms that are explicitly opt-in and not part of the stable contract.

The second implication is that our types should be designed with extension in mind. We should use protocols and abstract types rather than concrete classes in our public interface, so that new functionality can be added without modifying existing types. We should use sealed unions where possible to make the set of valid values explicit, so that callers can exhaustively handle all cases and we can add new cases in future versions with clear upgrade paths.

The third implication is that we should separate the interface from the implementation more aggressively than feels natural. The interface should be minimal and stable. The implementation can evolve rapidly to support new providers and new features without affecting the interface. This separation requires discipline because it means you cannot take shortcuts by exposing implementation details through the interface.

The fourth implication is that we should version our public API and be explicit about compatibility guarantees. Semantic versioning is the standard convention: major version changes introduce breaking changes, minor versions add backward-compatible features, patch versions fix bugs. For a library that is infrastructure-critical to its users, the cost of breaking changes is high, so major versions should be rare and migration paths should be thorough.

In practice this means our public interface will look something like this:

- A core request type that defines how you ask for a model response
- A core response type that defines what you get back
- A core error taxonomy that defines how failures are classified
- A client interface that defines how you configure and invoke the library
- Extension points for provider-specific options and advanced features

Each of these will be designed once and changed only for good reasons. When we add support for a new capability like audio input or reasoning effort, we will evaluate whether it belongs in the core interface or in an extension point, and we will choose conservatively.

Capability Preservation Versus Uniformity

The central tension in abstraction layer design is between uniformity and capability preservation. Uniformity makes the interface simple and consistent. Capability preservation ensures you can actually do what you need to do. If you prioritize uniformity too aggressively, your abstraction becomes too limiting. If you prioritize capability preservation too aggressively, your abstraction becomes a thin wrapper with little value.

The design decision is not about choosing one over the other. It is about defining where each applies.

For core capabilities that are universal across providers, uniformity is the priority. Every provider supports text-to-text generation with message history. Every provider supports basic sampling parameters. The interface for these capabilities should be completely uniform. Your application code should not need to know which provider it is calling to construct a basic request.

For advanced capabilities that are common but implemented differently, the interface should be uniform in intent but flexible in implementation. Structured outputs are a good example. Multiple providers support them but with different parameter names, different schema constraints, and different error handling. Our interface should define what a structured output request is in abstract terms: a request with a schema that the response must match. The provider adapter is responsible for translating that abstract definition into the provider's specific mechanism. If one provider does not support structured outputs at all, the adapter should fail fast with a clear error rather than silently degrading.

For provider-specific capabilities that only some providers offer, capability preservation is the priority. These should not be part of the core interface because they would make the interface provider-dependent by definition. Instead, they should be accessible through a provider-specific options mechanism that is explicitly typed and validated.

This three-tiered approach requires a clear definition of what counts as core, advanced, and provider-specific. We will define that classification explicitly as we build the library, but the general rule is:

- Core: supported by all major providers with similar semantics

- Advanced: supported by most major providers but with meaningful implementation differences
- Provider-specific: supported by one provider or a small subset with unique semantics

A practical consequence of this principle is that our adapter interface must support two kinds of options: normalized options that map to unified interface features, and passthrough options that are forwarded directly to the provider. The passthrough mechanism is not an escape hatch or a hack. It is a first-class part of the design that acknowledges that providers will always innovate in ways that cannot be immediately normalized.

The passthrough mechanism must be designed carefully. It should be explicitly typed so that it is clear what kind of data it accepts. It should be validated so that invalid options are caught early rather than causing cryptic provider errors. It should be documented so that users know when and how to use it. Most importantly, it should not undermine the value of the normalized interface. If users are regularly resorting to passthrough options for common functionality, that is a signal that the normalized interface is missing something important and should be extended.

Explicit Error Semantics and Classification

Error handling is one of the most important aspects of reliability engineering, and error semantics are one of the most common failures in abstraction layer design. Many libraries either re-raise provider-specific exceptions directly or wrap everything in a single generic exception type. Both approaches create problems.

Re-raising provider exceptions leaks implementation details into application code and makes it impossible to write provider-independent error handling. Wrapping everything in a generic exception makes it impossible to distinguish between different kinds of failures and handle them appropriately.

Our principle is explicit error semantics: every error that propagates from the library should be classifiable by the caller into a known category, and the category should determine how the error should be handled. The error taxonomy is part of the public contract.

We will define the following error categories:

- Client errors: The request was invalid. Examples include malformed messages, invalid parameters, or exceeding model constraints. Client errors should never be retried because retrying will produce the same failure.
- Authentication errors: The credentials are invalid, expired, or insufficiently authorized. These should never be retried without credential changes.
- Rate limit errors: The provider is throttling requests. These are retryable after a backoff period, and the error should include the recommended wait time if the provider provides it.
- Server errors: The provider experienced an internal failure. These are generally retryable but should trigger circuit breaker logic if they occur too frequently.
- Connection errors: The HTTP connection failed due to network issues, timeouts, or DNS failures. These are retryable but should also trigger circuit breaker logic.
- Capability errors: The request asked for a capability that the chosen provider or model does not support. These are not retryable because the provider will not suddenly support the missing capability.

Each error should include:

- The error category for programmatic classification
- The underlying provider error for debugging
- A human-readable message that explains what went wrong
- Context about the request that failed (model, provider, request ID if available)
- A retry recommendation if applicable

This error taxonomy makes it possible to write error handling logic that is provider-independent. Your retry policy can check whether an error is retryable. Your circuit breaker can trigger on server or connection errors. Your fallback logic can skip rate limit errors for a provider that is being throttled. Your logging can categorize errors for monitoring and alerting.

The taxonomy also makes testing easier. You can write tests that verify error classification by checking error categories rather than provider-specific exception types or status codes. This is important because error handling

is one of the most critical paths in reliability engineering, and it should be thoroughly tested.

The implementation will define a base `LlmError` class and subclasses for each category. Provider adapters will map their native exceptions into this taxonomy using a translation layer that is tested against known error patterns for each provider.

Idempotency and Request Safety Guarantees

LLM API calls are not inherently idempotent. If you send the same prompt twice, you may get different responses because models are stochastic by default. This creates a fundamental problem for retry logic: if a request times out or fails after being processed, retrying it may produce a different result or may cause the provider to process the request twice, resulting in double charges.

Some providers address this with idempotency keys. OpenAI supports an `x-idempotency-key` header that ensures a retried request is treated as a duplicate and returns the original response. Anthropic and Google also support similar mechanisms. These keys make it safe to retry requests without risk of duplicate processing, which is essential for reliable operation.

Our principle is that the library should support idempotency keys for providers that offer them, and should make it clear when requests are not idempotent. This has several implications:

The first implication is that the request interface should include an optional idempotency key field. Callers can provide their own keys or the library can generate them. The library should pass the key to the provider adapter, which is responsible for including it in the provider request.

The second implication is that streaming requests and non-idempotent operations should be distinguished from regular requests. If you are streaming a response and the connection drops after partial delivery, retrying the request is not safe because the provider may generate a different response. The library should make this distinction clear through the API and should not automatically retry streaming requests.

The third implication is that retry policies should be aware of idempotency. Retry logic should use idempotency keys when available and should not retry

operations that are known to be non-idempotent without explicit configuration.

The fourth implication is that documentation should be explicit about idempotency guarantees. Callers need to understand when a request is safe to retry and when it is not, so that they can design their error handling and recovery logic appropriately.

Idempotency is often treated as an afterthought in LLM integration because most examples and tutorials do not address production-scale reliability. In production, where requests are processed automatically and failures are handled by retry loops, idempotency is not optional. It is a prerequisite for safe error recovery.

The Provider Adapter Pattern as Core Abstraction

The Provider Adapter pattern is the architectural foundation of our library. Every provider is integrated through an adapter that implements a well-defined interface. The adapter is responsible for all provider-specific details: authentication, request formatting, response parsing, streaming, error mapping, and capability reporting.

This pattern is not novel, but it is essential. It provides a clear separation between the unified interface that application code depends on and the provider-specific implementations that talk to actual APIs. It makes adding new providers a matter of implementing a new adapter rather than modifying core code. It makes testing easier because adapters can be mocked or stubbed independently.

The adapter interface we will design has several key responsibilities:

- **Authentication:** The adapter knows how to authenticate with its provider using the configured credentials. This may involve API keys, OAuth tokens, signed requests, or other mechanisms. The core library does not need to know these details.
- **Request translation:** The adapter translates our unified `LlmRequest` type into the provider's native request format. This includes mapping message roles and content, translating parameters, and adding provider-specific fields.

- Response parsing: The adapter parses the provider's native response into our unified LlmResponse type. This includes extracting the response text, token usage, finish reason, and metadata.
- Streaming support: If the provider supports streaming, the adapter implements a streaming interface that yields response chunks in our normalized format.
- Error mapping: The adapter catches provider-specific exceptions and maps them into our error taxonomy.
- Capability reporting: The adapter reports what capabilities the provider supports, so that the library can validate requests and fail fast if a requested capability is not available.

The adapter interface should be defined as a Python protocol, not an abstract base class. Protocols provide structural typing, which means any class that implements the required methods is considered an adapter, even if it does not explicitly inherit from a base class. This makes it easier to create adapters in different packages and reduces coupling.

Here is a sketch of the interface:

```

1  from typing import Protocol, AsyncIterator
2
3  class ProviderAdapter(Protocol):
4      """Protocol for LLM provider adapters."""
5
6      def capabilities(self) -> ProviderCapabilities:
7          """Return the capabilities supported by this provider."""
8          ...
9
10     async def complete(self, request: LlmRequest) -> LlmResponse:
11         """Execute a completion request and return the response."""
12         ...
13
14     async def stream(self, request: LlmRequest) ->
15         ↪ AsyncIterator[LlmStreamChunk]:
16         """Execute a streaming completion request."""
17         ...
18
19     async def count_tokens(self, request: LlmRequest) -> int:
20         """Count tokens for a request, if supported."""
21         ...

```

Each method has a clear responsibility. Each can be tested independently. Each can be implemented differently for each provider. The protocol enforces

that every adapter provides the same surface area, so the core library can depend on the protocol without knowing about specific providers.

Observability as a First-Class Requirement

Observability is not an optional feature that gets added after the core functionality works. It is a first-class requirement that shapes the design of every component.

The reason is straightforward: you cannot debug, tune, or operate a system you cannot observe. LLM integration introduces new kinds of failures and performance characteristics that are invisible without explicit telemetry. Latency spikes when a provider is under load. Token usage patterns that indicate prompts are too long. Error rates that correlate with specific models or providers. Cost anomalies that indicate a prompt leak or a runaway loop. All of these require telemetry that is collected automatically and consistently.

Our principle is that the library should emit observability signals automatically for every operation, and these signals should integrate with standard observability tools. Specifically:

- **Structured logging:** Every request and response should be logged with consistent fields that include the provider, model, token usage, latency, error information, and request identifiers. Logs should be JSON-formatted for easy ingestion by log aggregation systems.
- **Metrics:** Key metrics should be emitted, including request counts, latency histograms, token usage totals, error rates, and cost estimates. These should follow standard naming conventions so they integrate with metrics systems like Prometheus.
- **Distributed tracing:** Every request should be traced using OpenTelemetry, with spans that capture the full request lifecycle including adapter processing, HTTP transport, and response parsing. Traces should propagate context so they can be correlated with application-level traces.
- **Redaction:** Prompts, responses, and other sensitive data should be redacted by default in logs and traces. There should be configuration options to enable full logging for debugging purposes, but the default should be safe.

Observability is not just about collecting data. It is about collecting the right data in a format that is useful for the people who need it. The telemetry should be queryable, aggregatable, and alertable. It should support the common operational questions:

- Which provider is experiencing the most errors right now?
- What is the p99 latency for our most common model?
- How much have we spent on LLM calls in the last hour?
- Which endpoint in our application is generating the most tokens?
- When did error rates increase and what changed at that time?

The implementation will integrate structlog for logging and OpenTelemetry for metrics and tracing. These are well-established tools with broad ecosystem support, and they integrate cleanly with Python async code. We will design the telemetry infrastructure so that it is enabled by default with sensible defaults and can be disabled or customized as needed.

The observability design will also include a hook mechanism that allows callers to attach custom telemetry handlers. This makes it possible to integrate with proprietary observability platforms or to capture application-specific metrics without modifying the library.

Observability is the foundation of reliability. Without it, you are operating blind. The library we build will make observability automatic so that every user gets it without having to add instrumentation manually.

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