Build AI Applications with Spring AI

FU CHENG

Build AI Applications with Spring AI

RAG, MCP and Agents with Spring AI 1.1

Fu Cheng

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Spring AI Basics

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Getting Started

Let’s start the journey with Spring AI from a simple application.

Prerequisites

Before writing Spring AI applications, we need to prepare the local development environment. Obviously, we need to have Java installed and configured. We also need to have a large language model (LLM) ready for testing.

Java

Spring AI requires a minimal Java version of 17. It’s recommended to use Java 21 or Java 25 LTS, so we can leverage the power of virtual threads.

Source code of this book is tested using Java 21 with virtual threads enabled.

Spring AI

This book uses Spring AI `1.1.0`. Example applications in this book use Maven to manage dependencies.

To simplify dependency management of related modules, the `spring-ai-bom` dependency can be imported to set versions of Spring AI dependencies.

Figure 1. Spring AI dependency management using BOM

```xml
<dependencyManagement>
  <dependencies>
    <dependency>
      <groupId>org.springframework.ai</groupId>
      <artifactId>spring-ai-bom</artifactId>
      <version>${spring-ai.version}</version>
      <type>pom</type>
      <scope>import</scope>
    </dependency>
  </dependencies>
</dependencyManagement>
```

Language Model

A language model is required for development, testing and production deployments. This language model can run locally or on the cloud, as long as it provides an API endpoint to access its service.

- To run a model locally, there are many options available, including Ollama, vLLM, and LM Studio.
- To use a cloud-based model service, you need to open an account and pay the service by tokens.

Here let's start from using Ollama.

Ollama is a tool to run large language models locally. You can simply download Ollama and install it on your local machine. After installation, you can open a terminal window and use Ollama CLI command `ollama` to work with it.

There are many models available for use with Ollama, see Ollama's models page for a full list.

We can use `ollama pull` to pull a model. Here we are using Qwen3.

Figure 2. Ollama pull a model

```
ollama pull qwen3:0.6b
```

The size of `qwen3:0.6b` is only 523MB. It's good for local development and testing.

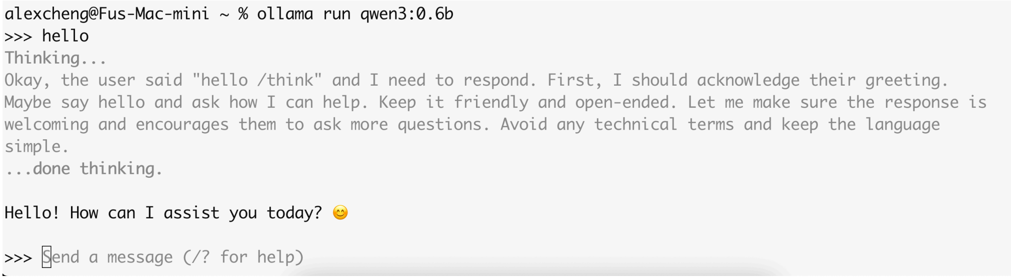
After the model is pulled, it can be run using `ollama run`.

Figure 3. Ollama run a model

```
ollama run qwen3:0.6b
```

`ollama run` command pulls non-existing models automatically.

`ollama run` starts a command-line session with the LLM. You can simply type any text to receive completions from LLM.



```
alexcheng@Fus-Mac-mini ~ % ollama run qwen3:0.6b
>>> hello
Thinking...
Okay, the user said "hello /think" and I need to respond. First, I should acknowledge their greeting.
Maybe say hello and ask how I can help. Keep it friendly and open-ended. Let me make sure the response is
welcoming and encourages them to ask more questions. Avoid any technical terms and keep the language
simple.
...done thinking.

Hello! How can I assist you today? 😊

>>> Send a message (/? for help)
```

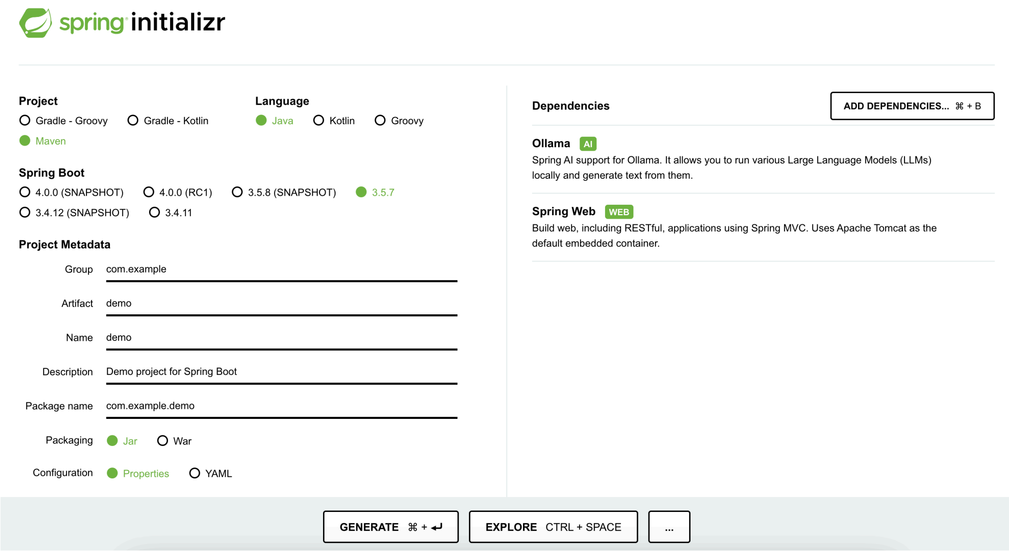
Figure 4. ollama run

By default, Ollama provides its API endpoint at port `11434`.

Spring Boot Application

The easiest way to create a new Spring AI application is using Spring Initializr. When adding the project's dependencies, `Ollama` should be selected. This enables Spring AI to interact with Ollama. `Spring Web` is also added to create a simple REST API.

Below is the screenshot of Spring Initializr.



Project
○ Gradle - Groovy ○ Gradle - Kotlin
● Maven

Language
● Java ○ Kotlin ○ Groovy

Spring Boot
○ 4.0.0 (SNAPSHOT) ○ 4.0.0 (RC1) ○ 3.5.8 (SNAPSHOT) ● 3.5.7
○ 3.4.12 (SNAPSHOT) ○ 3.4.11

Project Metadata

Group: com.example
Artifact: demo
Name: demo
Description: Demo project for Spring Boot
Package name: com.example.demo
Packaging: ● Jar ○ War
Configuration: ● Properties ○ YAML

Dependencies

Ollama AI
Spring AI support for Ollama. It allows you to run various Large Language Models (LLMs) locally and generate text from them.

Spring Web WEB
Build web, including RESTful, applications using Spring MVC. Uses Apache Tomcat as the default embedded container.

Figure 5. Spring Initializr UI

Now we can download the created application and open it using IntelliJ IDEA.

Adding the `Ollama` dependency actually includes the `spring-ai-starter-model-ollama` to the Maven project. This Spring Boot starter will create necessary beans to work with Spring AI.

Figure 6. Spring Boot Ollama starter

```xml
<dependency>
  <groupId>org.springframework.ai</groupId>
  <artifactId>spring-ai-starter-model-ollama</artifactId>
</dependency>
```

Here we need to add an `application.yaml` file to configure the Spring Boot application. This is because `qwen3` model should be used. By default, Ollama uses Mistral model. The property to configure the Ollama model is `spring.ai.ollama.chat.options.model`.

Figure 7. Spring Boot configuration for Spring AI using Ollama

```yaml
spring:
  ai:
    ollama:
      chat:
        options:
          model: "qwen3:0.6b"
```

Now we add a REST endpoint to chat with an LLM. The `ChatClient.Builder` instance is injected into the REST controller to create `ChatClient` instances. This instance is provided by Ollama Spring Boot starter. A `ChatClient` is created from this `ChatClient.Builder` using the `build` method. `chatClient.prompt().user(message).call().content()` sends a request to Ollama API endpoint and receives the output.

Figure 8. REST Controller

```java
@RestController
public class ChatController {

  private final ChatClient chatClient;

  public ChatController(ChatClient.Builder builder,
      LoggingAdvisor loggingAdvisor) {
    this.chatClient = builder.defaultAdvisors(loggingAdvisor).build();
  }

  @GetMapping("/chat")
  public String chat(@RequestParam(value = "message") String message) {
    return chatClient.prompt().user(message).call().content();
  }
}
```

Now we can start the Spring Boot application. Once the application is started, we can use any REST client tool to interact with the REST API.

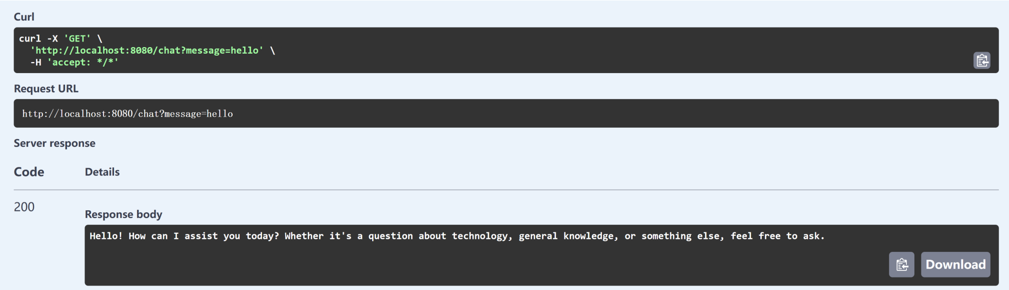
Here we use SpringDoc to expose OpenAPI endpoint and Swagger UI to test the API.

Figure 9. SpringDoc dependency

```xml
<dependency>
  <groupId>org.springdoc</groupId>
  <artifactId>springdoc-openapi-starter-webmvc-ui</artifactId>
  <version>2.8.9</version>
</dependency>
```

We can open a browser window and navigate to `http://localhost:8080/swagger-ui/`, then use Swagger UI to try the API.

Below is the result of testing the API using Swagger UI.



```
curl -X 'GET' \
  'http://localhost:8080/chat?message=hello' \
  -H 'accept: */*'
```

```
http://localhost:8080/chat?message=hello
```

200

```
Hello! How can I assist you today? Whether it's a question about technology, general knowledge, or something else, feel free to ask.
```

Figure 10. Use Swagger UI

Use Model Service

While Ollama is great for local development and testing, we usually use cloud-based model services for production. All major cloud platforms provide AI models as services, including Google, Amazon, and Microsoft. Spring AI supports major AI model services. Here OpenAI is used as an example.

For Spring Boot, the easiest way is adding the Spring Boot starter dependency. For OpenAI support, the dependency is `spring-ai-starter-model-openai`.

Figure 11. OpenAI Spring Boot starter dependency

```xml
<dependency>
  <groupId>org.springframework.ai</groupId>
  <artifactId>spring-ai-starter-model-openai</artifactId>
</dependency>
```

An OpenAI API key is required to use OpenAI services. In the configuration below, OpenAI API key is read from environment variable `OPENAI_API_KEY`.

Figure 12. Set OpenAI API key

```yaml
spring:
  ai:
    openai:
      apiKey: ${OPENAI_API_KEY}
```

Consolidate Local and Production Environment

If we use Ollama for local development and OpenAI for production, we need to have add both model dependencies in Spring AI. These two dependencies will conflict with each other. We should consolidate these two models. We can use only OpenAI model but different API endpoints in development and production.

Many model services provide an API which is compatible with OpenAI. Ollama also has this API. After Ollama is started, this API can be accessed from base URL `http://localhost:11434/v1/`.

⚠ OpenAI compatibility of Ollama is experimental and is subject to major adjustments including breaking changes. Only parts of OpenAI API are supported.

We can use Spring profiles to apply configurations for different environments. For the development profile, `spring.ai.openai.baseUrl` is configured to `http://localhost:11434/v1`. The API key is required for configuration, but will be ignored, so the value can be anything.

Figure 13. Use Ollama OpenAI compatible API in development profile

```yaml
spring:
  ai:
    openai:
      baseUrl: http://localhost:11434/v1
      apiKey: ollama
```

In the production profile `application-prod.yaml`, `spring.ai.openai.baseUrl` is configured to `https://api.openai.com/v1`, which is the endpoint of OpenAI API.

Figure 14. Use OpenAI in production profile

```yaml
spring:
  ai:
    openai:
      baseUrl: https://api.openai.com/v1
      apiKey: ${OPENAI_API_KEY}
```

Profiles can be switched using the option `-Dspring.profiles.active`, e.g. `-Dspring.profiles.active=prod`.

Depends on whether you want to run models locally, there are two recommendations about setup of development environment.

Cloud-based Model Services

Cloud-based model services are actually cheap to use. One option is to simply use model services for both development and production. Spring AI provides integration modules for popular model service platforms. We only need to include the Spring AI module and configure it.

Let's use Anthropic Claude as an example. In a Spring Boot application, we can add the dependency of `spring-ai-starter-model-anthropic` module.

Figure 15. Anthropic module dependency

```xml
<dependency>
  <groupId>org.springframework.ai</groupId>
  <artifactId>spring-ai-starter-model-anthropic</artifactId>
</dependency>
```

Then we can configure Anthropic Claude. The prefix of configuration properties is `spring.ai.anthropic`. An API key is required to be configured as environment variable `ANTHROPIC_API_KEY`. The model `claude-opus-4-0` is used.

Figure 16. Configure Anthropic Claude

```yaml
spring:
  ai:
    anthropic:
      apiKey: ${ANTHROPIC_API_KEY}
      chat:
        options:
          model: claude-opus-4-0
```

Use Container

If you want to run models locally, It's recommended to run models in a container. Container tools like Docker and Podman have already been used extensively in development. You may already use containers to run databases, message brokers, and other tools. Running models in a container means that you don't need to install other tools.

llama.cpp

A popular choice is using llama.cpp to run models. `llama.cpp` provides an OpenAI compatible API to interact with the model. Model files can be downloaded from Hugging Face.

In the Docker compose file below, the model file of `Qwen3-0.6B` is downloaded from Hugging Face, then `llama.cpp` is started to serve this model.

Figure 17. Docker compose file to run models using llama.cpp

```yaml
services:
  model-runner:
    image: ghcr.io/ggml-org/llama.cpp:server
    volumes:
      - model-files:/models
    command:
      - "--host"
      - "0.0.0.0"
      - "--port"
      - "8080"
      - "-n"
      - "512"
      - "-m"
      - "/models/Qwen3-0.6B-Q8_0.gguf"
    ports:
      - "8180:8080"
    depends_on:
      model-downloader:
        condition: service_completed_successfully

  model-downloader:
    image: ghcr.io/alexcheng1982/model-downloader
    restart: "no"
    volumes:
      - model-files:/models
    command:
      - "hf"
      - "download"
      - "unsloth/Qwen3-0.6B-GGUF"
      - "Qwen3-0.6B-Q8_0.gguf"
      - "--local-dir"
      - "/models"

```

```yaml
volumes:
  model-files:
```

After the container is started, the model API can be accessed from `http://localhost:8180`. In Spring AI, we can create a new profile which sets the configuration key `spring.ai.openai.baseUrl` to `http://localhost:8180`. The `apiKey` can be set to anything.

Figure 18. Use OpenAI compatible API running in the container

```yaml
spring:
  ai:
    openai:
      baseUrl: http://localhost:8180
      apiKey: demo
```

ℹ llama.cpp provides a web UI to interact with the model. You can access this UI at `http://localhost:8180` using a browser.

Ollama

Ollama can also run in a container, which means we don't need to install Ollama on local machine.

In the Docker compose file below, Ollama is started in a container. Another container is used to pull the `qwen3:0.6b` model.

Figure 19. Docker compose file to run models using Ollama

```yaml
services:
  ollama:
    image: ollama/ollama
    container_name: ollama
    ports:
      - "11434:11434"
    volumes:
      - ollama:/root/.ollama
    restart: unless-stopped
    healthcheck:
      test: ["CMD", "curl", "-f", "http://localhost:11434"]
      interval: 30s
      timeout: 10s
      retries: 5
    command: ["/bin/ollama", "serve"]

  ollama-pull-qwen3:
    image: ollama/ollama
    container_name: ollama-pull-qwen3
    volumes:
      - ollama:/root/.ollama
    depends_on:
      ollama:
        condition: service_healthy
    command: ["/bin/ollama", "pull", "qwen3:0.6b"]

volumes:
  ollama:
    driver: local
```

Chat Completion

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Model

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ChatModel

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Message

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ChatOptions

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Generation

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ChatResponseMetadata

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Create Prompts

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Chat Response

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ChatClient

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Build Prompts

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Call Models

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Handle Response

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ChatClient Builder

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Use Custom Chat Options

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Global Default Chat Options

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Request Level Chat Options

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Prompt Template

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PromptTemplate

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Builder

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Custom `TemplateRenderer`

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Advisor

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`Advisor`

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`CallAdvisor`

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`StreamAdvisor`

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`BaseAdvisor`

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Update `ChatClientRequest`

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`LoggingAdvisor`

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Use `AdvisorSpec`

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Enable `Advisors`

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Advisors Order

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Recursive Advisor

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Streaming Chat Completion

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StreamingChatModel

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Streaming Web Application

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Streaming JSON Events

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Structured Output Converter

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StructuredOutputConverter

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ListOutputConverter

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MapOutputConverter

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BeanOutputConverter

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Use ChatClient

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Multimodal Input

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Media

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Image Understanding

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Retrieval-Augmented Generation

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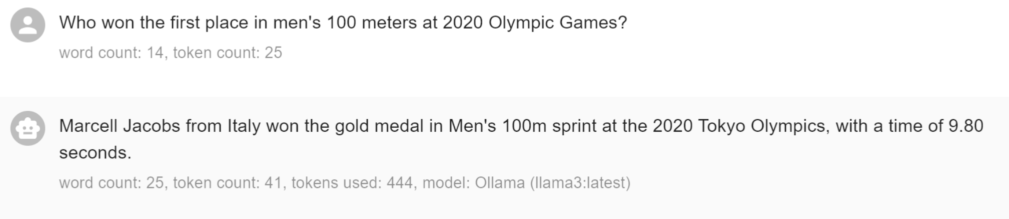
RAG Introduction

In this part, we'll start the journey of building Retrieval-Augmented Generation (RAG) applications using Spring AI. RAG applications have already gained a lot of attentions from industry. It's a typical area where AI technology has practical usage.

Reduce Hallucinations

The main goal of using RAG is to reduce hallucinations when using language models for chat completions. Language models are trained using material from various sources. Once a language model is trained, its parametric knowledge is frozen. When the prompt to a language model contains information not seen in the training materials, the output will hallucinate.

For example, when asking a language model (Llama 3) the following question: *Who won the gold medal in men's 100 meters at 2020 Olympic Games?*. The language model can provide the correct result.



Who won the first place in men's 100 meters at 2020 Olympic Games?

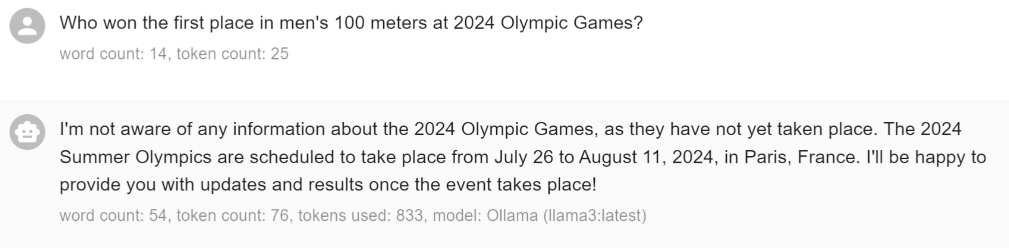
word count: 14, token count: 25

Marcell Jacobs from Italy won the gold medal in Men's 100m sprint at the 2020 Tokyo Olympics, with a time of 9.80 seconds.

word count: 25, token count: 41, tokens used: 444, model: Ollama (llama3:latest)

Figure 20. QA using model internal knowledge

If we change the question to *Who won the gold medal in men's 100 meters at 2024 Olympic Games?*, the language model cannot provide a meaningful answer.



Who won the first place in men's 100 meters at 2024 Olympic Games?

word count: 14, token count: 25

I'm not aware of any information about the 2024 Olympic Games, as they have not yet taken place. The 2024 Summer Olympics are scheduled to take place from July 26 to August 11, 2024, in Paris, France. I'll be happy to provide you with updates and results once the event takes place!

word count: 54, token count: 76, tokens used: 833, model: Ollama (llama3:latest)

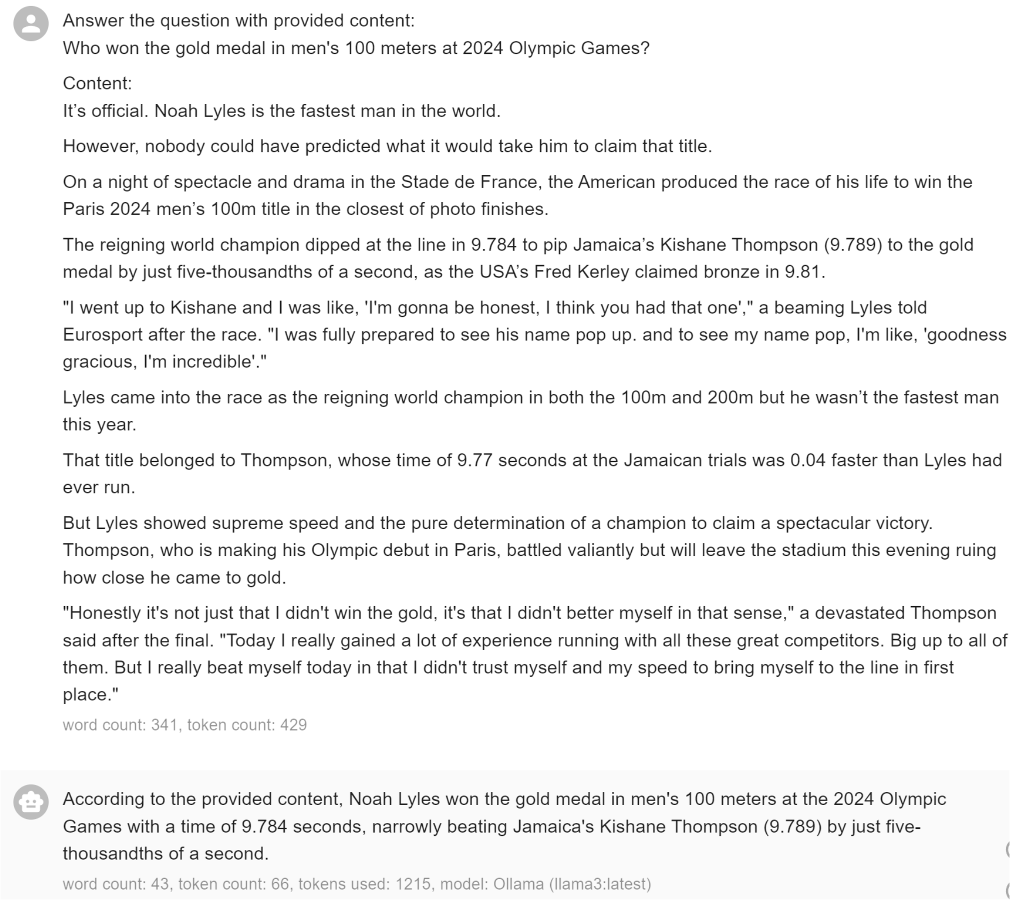
Figure 21. QA without model internal knowledge

There are three approaches to reduce hallucinations, model fine-tuning, tools, and RAG.

- **Model fine-tuning** works by fine-tuning the model to include extra materials.
- **Tools** allow a model to interact with external systems to provide necessary information.
- **RAG** works by augmenting the original prompts with retrieved content for a model to generate output.

The idea behind RAG is quite simple. A frozen language model itself lacks information to generate output for certain prompts. If we augment the prompt to include content from external sources, the model can leverage the provided content to generate the output. The included content is retrieved from an external system and must be semantically similar with the original prompt.

Let's go back to the example above. If we augment the original prompt with the content from a web page, the model can generate meaningful output.



Answer the question with provided content:
Who won the gold medal in men's 100 meters at 2024 Olympic Games?

Content:
It’s official. Noah Lyles is the fastest man in the world.

However, nobody could have predicted what it would take him to claim that title.

On a night of spectacle and drama in the Stade de France, the American produced the race of his life to win the Paris 2024 men’s 100m title in the closest of photo finishes.

The reigning world champion dipped at the line in 9.784 to pip Jamaica’s Kishane Thompson (9.789) to the gold medal by just five-thousandths of a second, as the USA’s Fred Kerley claimed bronze in 9.81.

"I went up to Kishane and I was like, 'I'm gonna be honest, I think you had that one'," a beaming Lyles told Eurosport after the race. "I was fully prepared to see his name pop up. and to see my name pop, I'm like, 'goodness gracious, I'm incredible'."

Lyles came into the race as the reigning world champion in both the 100m and 200m but he wasn’t the fastest man this year.

That title belonged to Thompson, whose time of 9.77 seconds at the Jamaican trials was 0.04 faster than Lyles had ever run.

But Lyles showed supreme speed and the pure determination of a champion to claim a spectacular victory. Thompson, who is making his Olympic debut in Paris, battled valiantly but will leave the stadium this evening ruing how close he came to gold.

"Honestly it's not just that I didn't win the gold, it's that I didn't better myself in that sense," a devastated Thompson said after the final. "Today I really gained a lot of experience running with all these great competitors. Big up to all of them. But I really beat myself today in that I didn't trust myself and my speed to bring myself to the line in first place."

word count: 341, token count: 429

According to the provided content, Noah Lyles won the gold medal in men's 100 meters at the 2024 Olympic Games with a time of 9.784 seconds, narrowly beating Jamaica's Kishane Thompson (9.789) by just five-thousandths of a second.

word count: 43, token count: 66, tokens used: 1215, model: Ollama (llama3:latest)

Figure 22. QA with provided content

Naive RAG

Naive RAG is a simple way to implement RAG. As the name suggests, naive RAG may not provide best results. However, naive RAG is a good starting point to leverage RAG.

The diagram below shows the architecture of naive RAG. Given a user prompt, similar documents related the prompt are retrieved from a vector database. Similar documents and the original prompt are combined together to form the final input to a language model to generate the output.

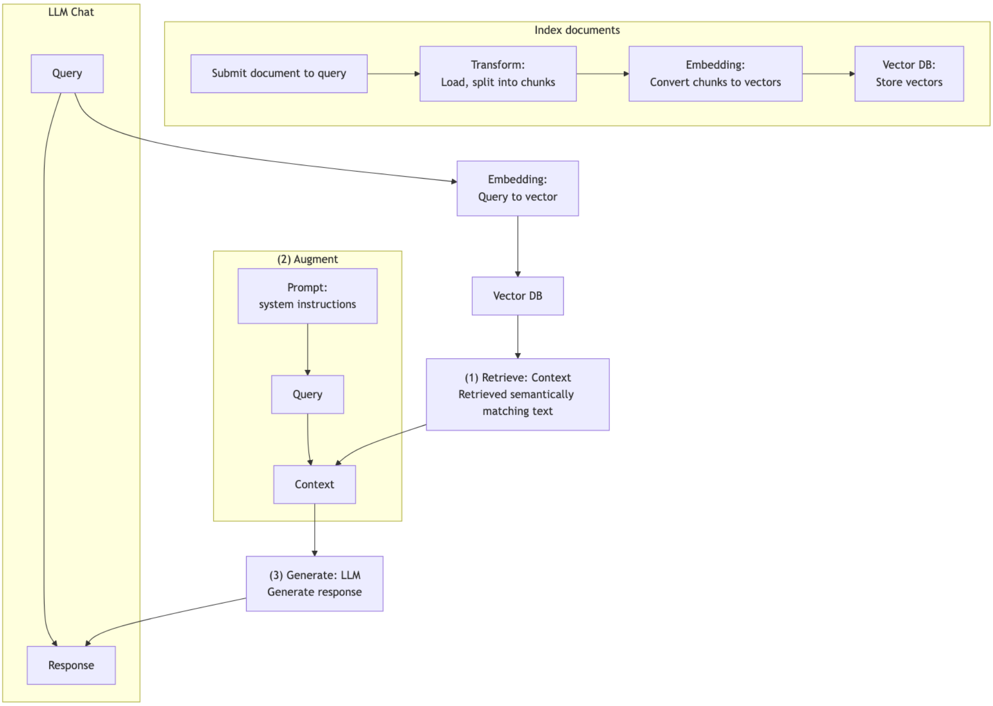


Figure 23. Naive RAG

Vector databases play an important role in RAG. Reference documents are stored in vector databases. Text content is converted to a vector (an array of floating point numbers) using a text embedding model. For a given document, its content and embedding vector are both stored in a vector database. For a prompt, its content is also converted to a vector using the same embedding model. Similarity between the vector of prompt and vectors of reference documents are calculated using vector similarity algorithms. By doing this, similarity between documents is converted to similarity between vectors.

After retrieving similar documents from the vector database, these documents are combined with the original prompt. The combination is usually done with a predefined template. In the template below, we instruct the language model to answer the question using provided content.

Figure 24. Prompt template

```
Answer the question using provided content:

Question: {question}

Provided content: {content}

Answer:
```

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