Hands-on with LlamaIndex: First Steps for Retrieval-Augmented Generation (RAG)

DataScience Portugal, Aveiro
2024-05-29

$ whoami

Hello, I’m Guilherme!

Head of Data Science & AI team at Scotty AI

Focused on improving the interaction between humans and chatbots

I work with NLP and LLM technologies.

I like Software Development and Cyber security a bit.

- in www.linkedin.com/in/luminoso
- https://github.com/luminoso
- @ luminoso@proton.me

Agenda

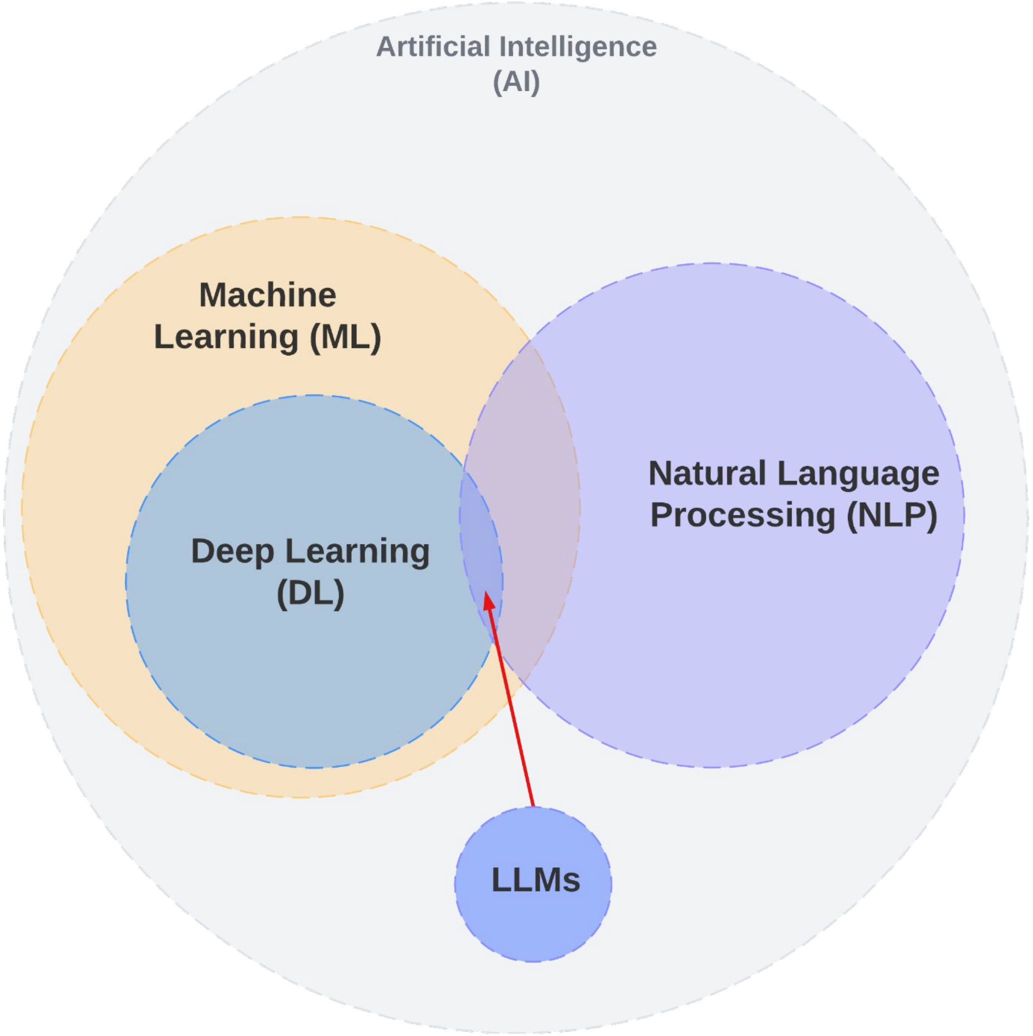
1. (quick) LLM contextualization
2. Retrieval-Augmented Generation (RAG)
    a. What is it
    b. Why we need it
    c. How it works
    d. Biggest challenges
3. Hands-on
    a. Common RAG implementation pattern
    b. Implementing a RAG pipeline with Llamaindex

LLM Contextualization

LLMs in AI

Where do LLMs fit in the AI space?

- Artificial Intelligence (AI) is *something* that mimics human intelligence
- Machine Learning (ML) is one way of archiving AI
- Deep Learning (DL) is one implementation of ML
- DL is the technique applied to archive Large Language models (LLMs)


Artificial Intelligence (AI)
Machine Learning (ML)
Deep Learning (DL)
Natural Language Processing (NLP)
LLMs

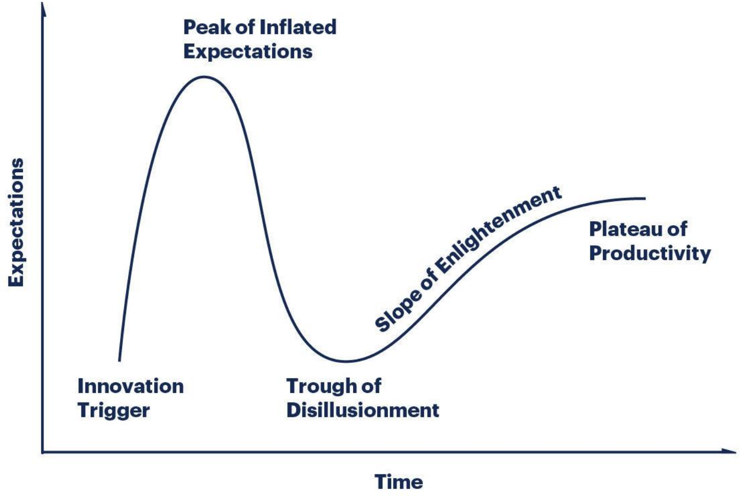
(Chat)GPT Hype cycle

- ChatGPT can “destroy” Google in two years, says Gmail creator (financialexpress.com)

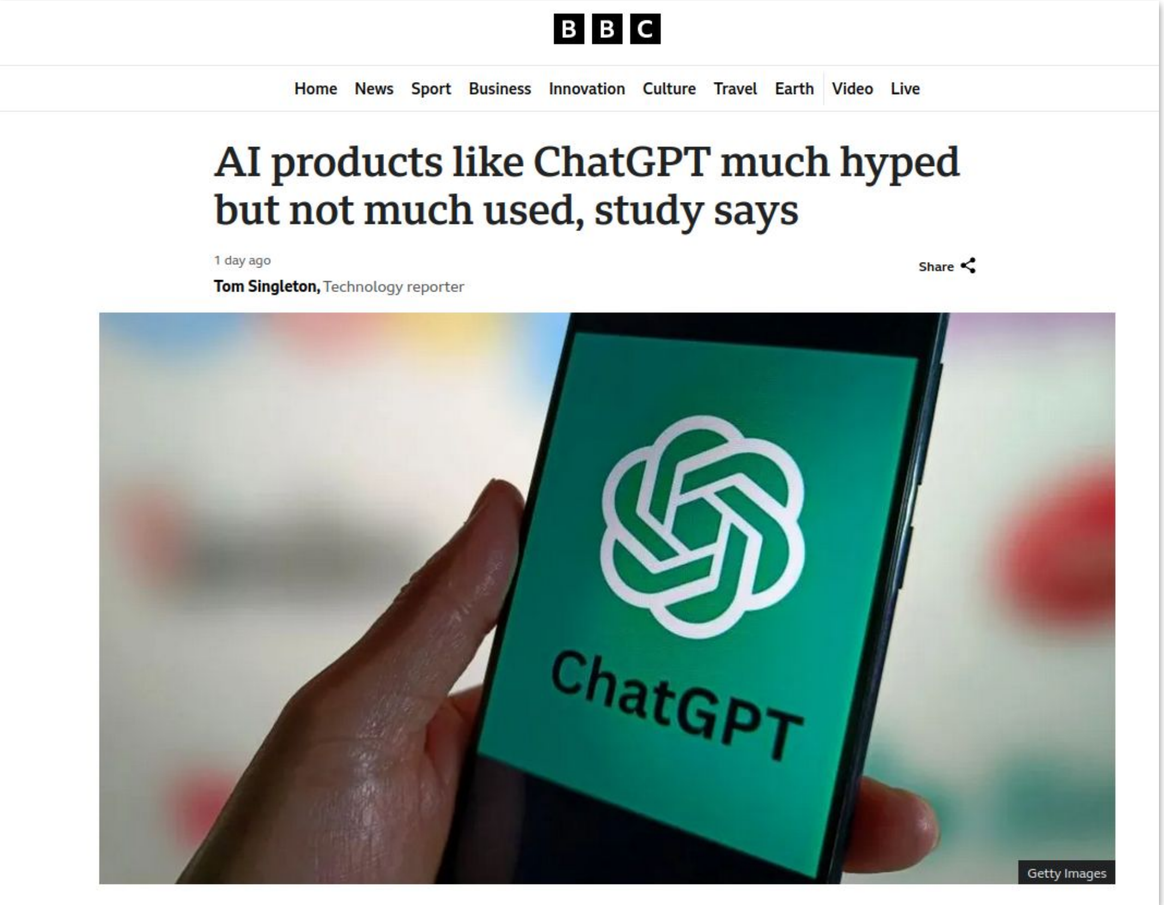
- Google losing sleep over ChatGPT, starts working on its AI search engine and 21 new AI products (indiatoday)

- Why Google’s search dominance is feeling the heat from ChatGPT

- ChatGPT will replace:
  - Developers
  - Designers
  - Copywriters
  - Storytellers
  - …



and today…



BBC

Home News Sport Business Innovation Culture Travel Earth Video Live

AI products like ChatGPT much hyped but not much used, study says

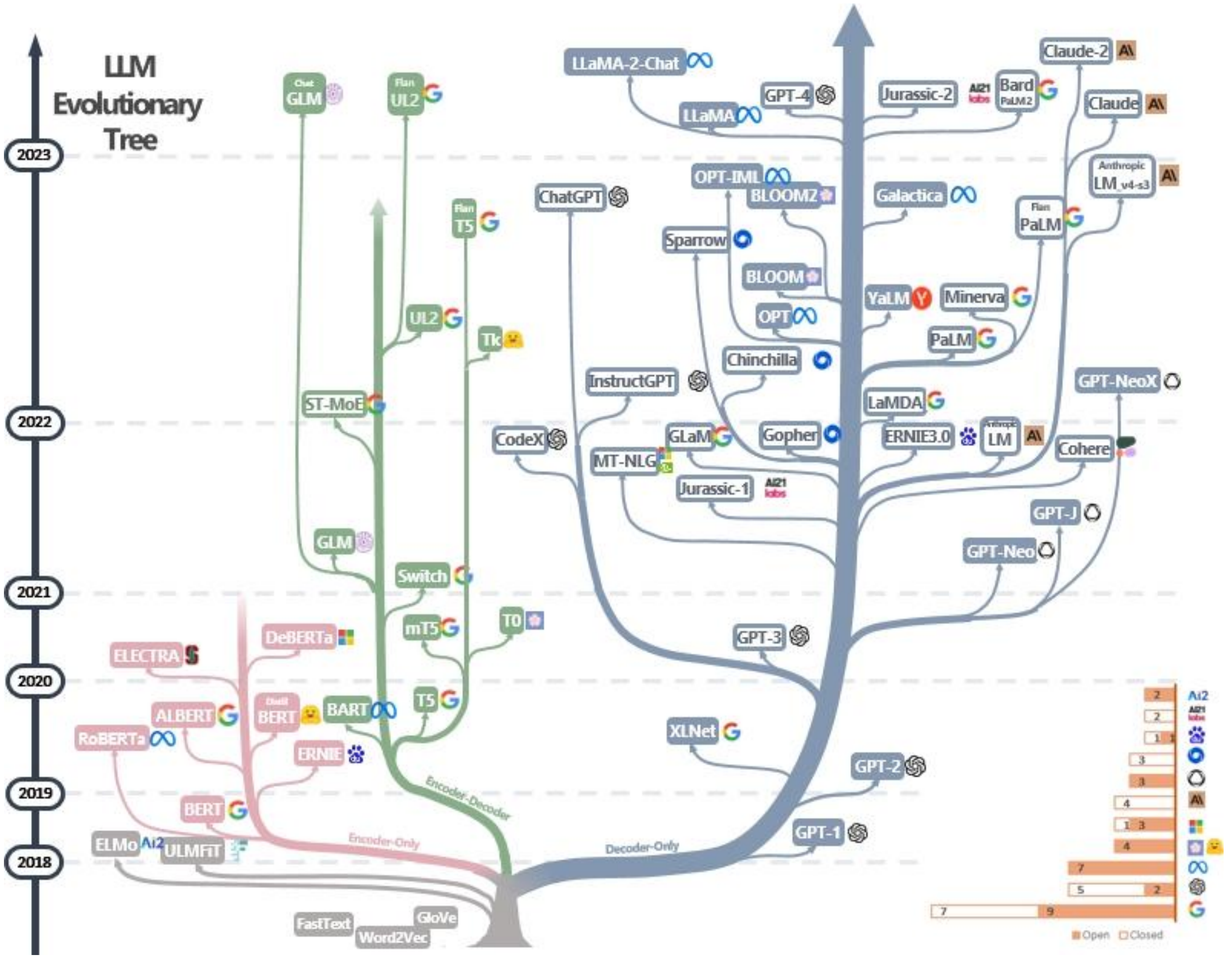
1 day ago

Share

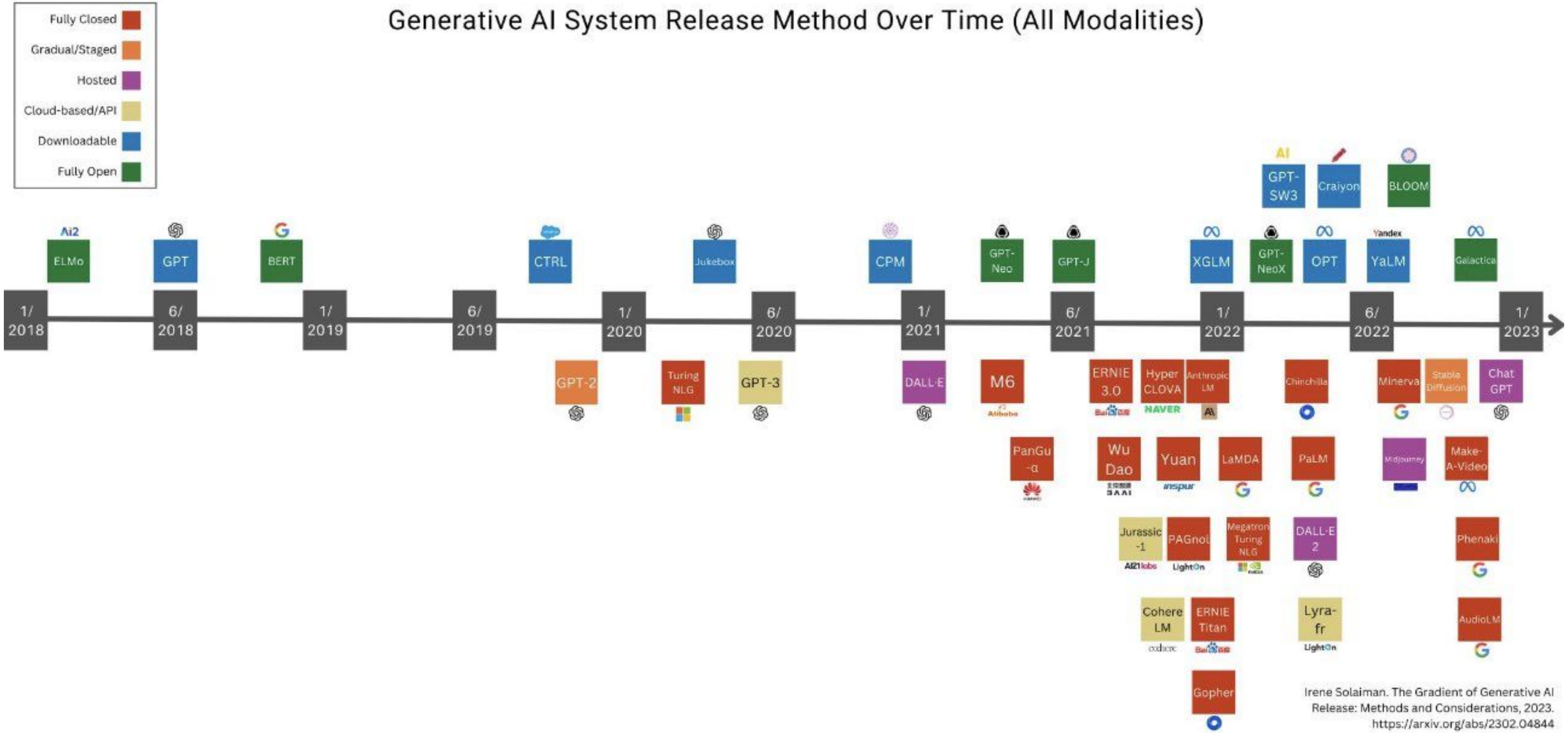
Tom Singleton, Technology reporter

https://www.bbc.com/news/articles/c511x4g7x7jo 2024-04-29

GPT Family


LLM Evolutionary Tree
2023
2022
2021
2020
2019
2018
Chat GLM
Flan UL2
Flan T5
UL2
Tk
ST-MoE
GLM
Switch
mT5
T0
T5
BART
ELECTRA
DeBERTa
ALBERT
Distill BERT
RoBERTa
ERNIE
BERT
ELMo
Ai2
ULMFiT
FastText
GloVe
Word2Vec
Encoder-Only
Encoder-Decoder
Decoder-Only
LLaMA-2-Chat
LLaMA
GPT-4
Jurassic-2
AI21 labs
Bard PaLM2
Claude-2
Claude
Anthropic LM_v4-s3
ChatGPT
OPT-IML
BLOOMZ
Galactica
Flan PaLM
Sparrow
BLOOM
YaLM
Minerva
OPT
PaLM
Chinchilla
InstructGPT
GPT-NeoX
LaMDA
CodeX
GLaM
Gopher
ERNIE3.0
Anthropic LM
Cohere
MT-NLG
Jurassic-1
AI21 labs
GPT-J
GPT-Neo
GPT-3
XLNet
GPT-2
GPT-1
2
2
1
1
3
3
4
1
3
4
7
5
2
7
9
Ai2
AI21 labs
Open
Closed

Not just LLMs, but also Generative AI



Generative AI System Release Method Over Time (All Modalities)

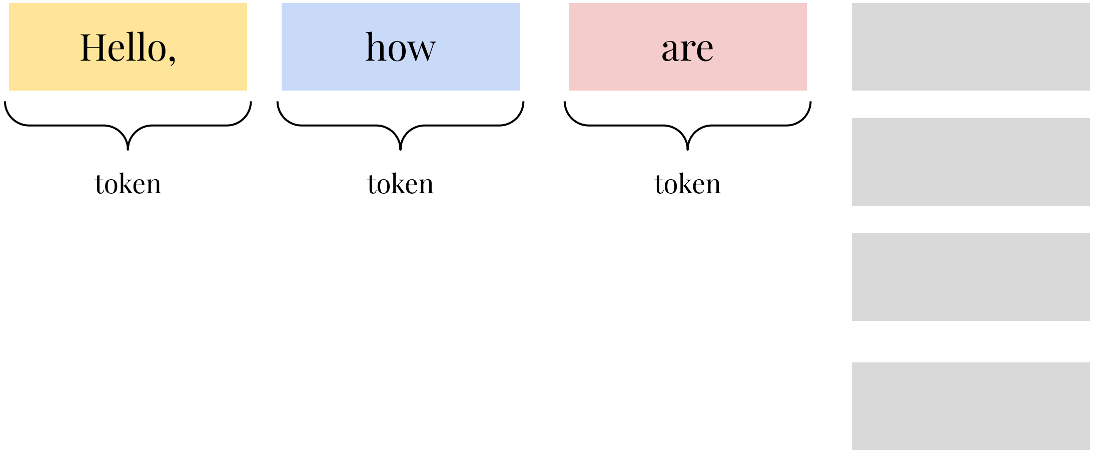
Irene Solaiman. The Gradient of Generative AI Release: Methods and Considerations, 2023. https://arxiv.org/abs/2302.04844

LLMs jungle

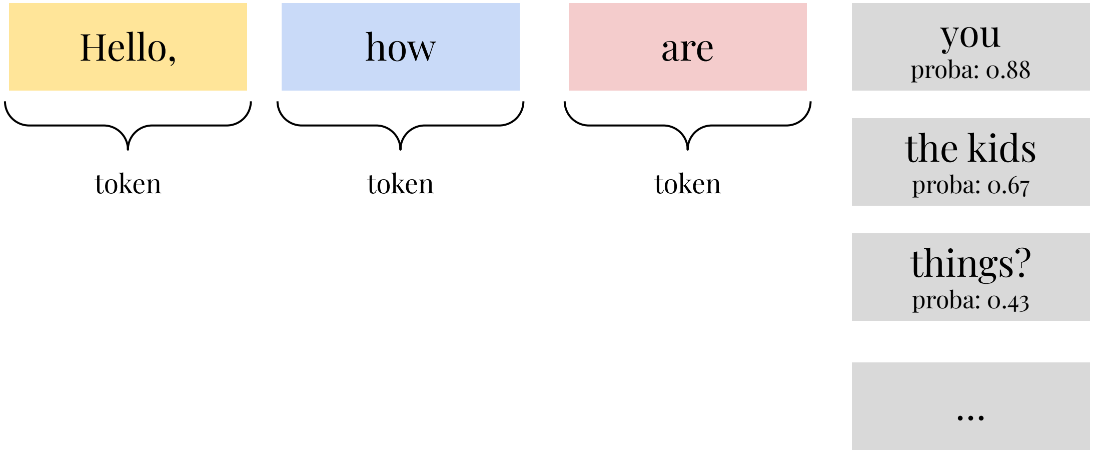
Very recent and extremely active field so some distinctions are needed.

- **GPT**
  - Family of models specifically designed for natural language processing (NLP) tasks
  - GPT models excel in understanding the semantic meaning of text
- **ChatGPT**
  - ChatGPT is a variant of the GPT model that is specifically designed for conversational interactions
  - It excels in generating coherent and contextually relevant responses in a conversational setting
- **BERT/Transformers**
  - BERT is a different type of language model that, unlike GPT models, considers the entire input sequence bidirectionally during training, allowing it to understand the context from both preceding and succeeding words.
  - Effective in tasks that require a deep understanding of context and subtle nuances in language.

LLM are generative



LLM are generative



Hello, how are

token token token

you
proba: 0.88

the kids
proba: 0.67

things?
proba: 0.43

...

LLMs jungle - Multipurpose LLM Challenges

- **Reliability**
  - Hallucinations are a big problem
- **Transparency**
  - It’s a black box
- **Security and privacy**
  - How to control the information we give to the model, and how much it gives away to other users
- **Sustainability**
  - Models are powerful, but resource-hungry

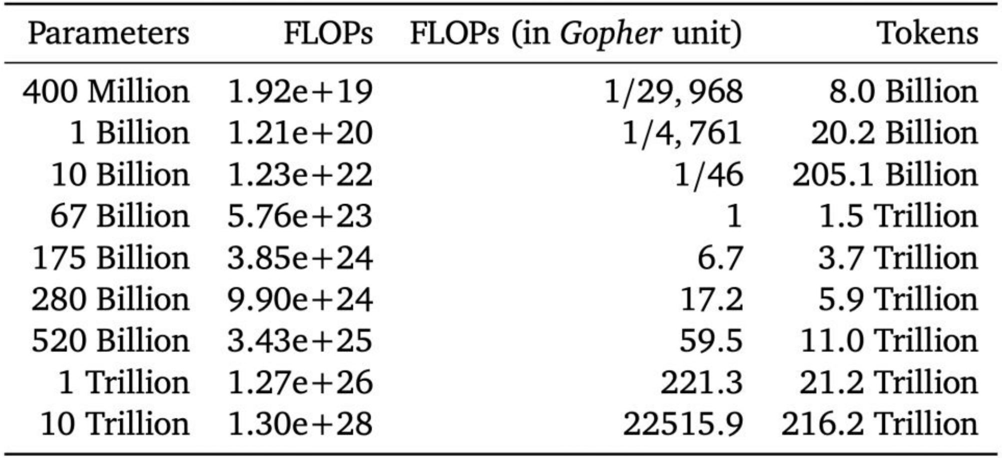
Hallucination demo

“Write an paper abstract for data science portugal meetup in aveiro where we speak about GPT for a small student group”

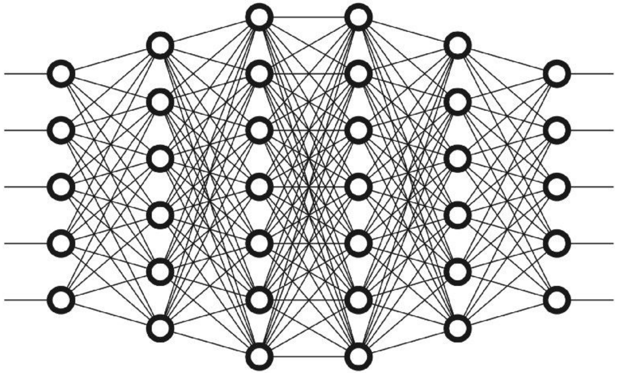
LLMs deployments

- Scalability challenges
- Bandwidth requirements (req/second, latency)

LLMs deployments



Parameters	FLOPs	FLOPs (in *Gopher* unit)	Tokens
400 Million	1.92e+19	1/29, 968	8.0 Billion
1 Billion	1.21e+20	1/4, 761	20.2 Billion
10 Billion	1.23e+22	1/46	205.1 Billion
67 Billion	5.76e+23	1	1.5 Trillion
175 Billion	3.85e+24	6.7	3.7 Trillion
280 Billion	9.90e+24	17.2	5.9 Trillion
520 Billion	3.43e+25	59.5	11.0 Trillion
1 Trillion	1.27e+26	221.3	21.2 Trillion
10 Trillion	1.30e+28	22515.9	216.2 Trillion

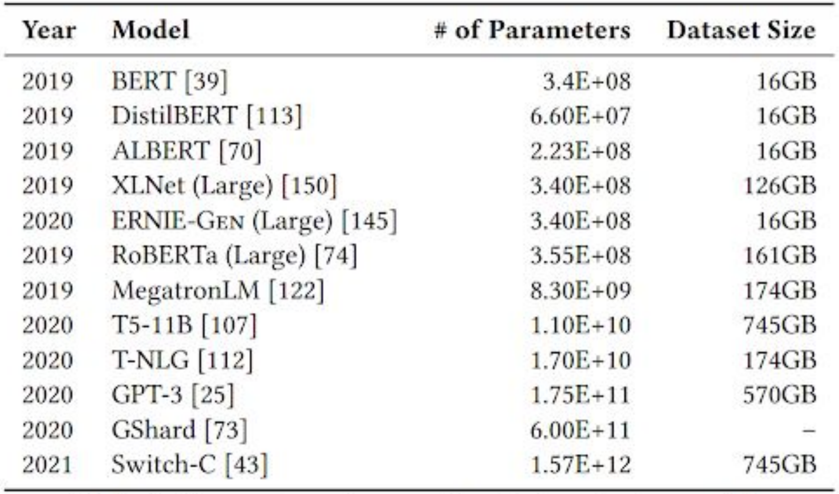


LLMs deployments

Storage capacity

GPT3 model is ~ 300 GB.

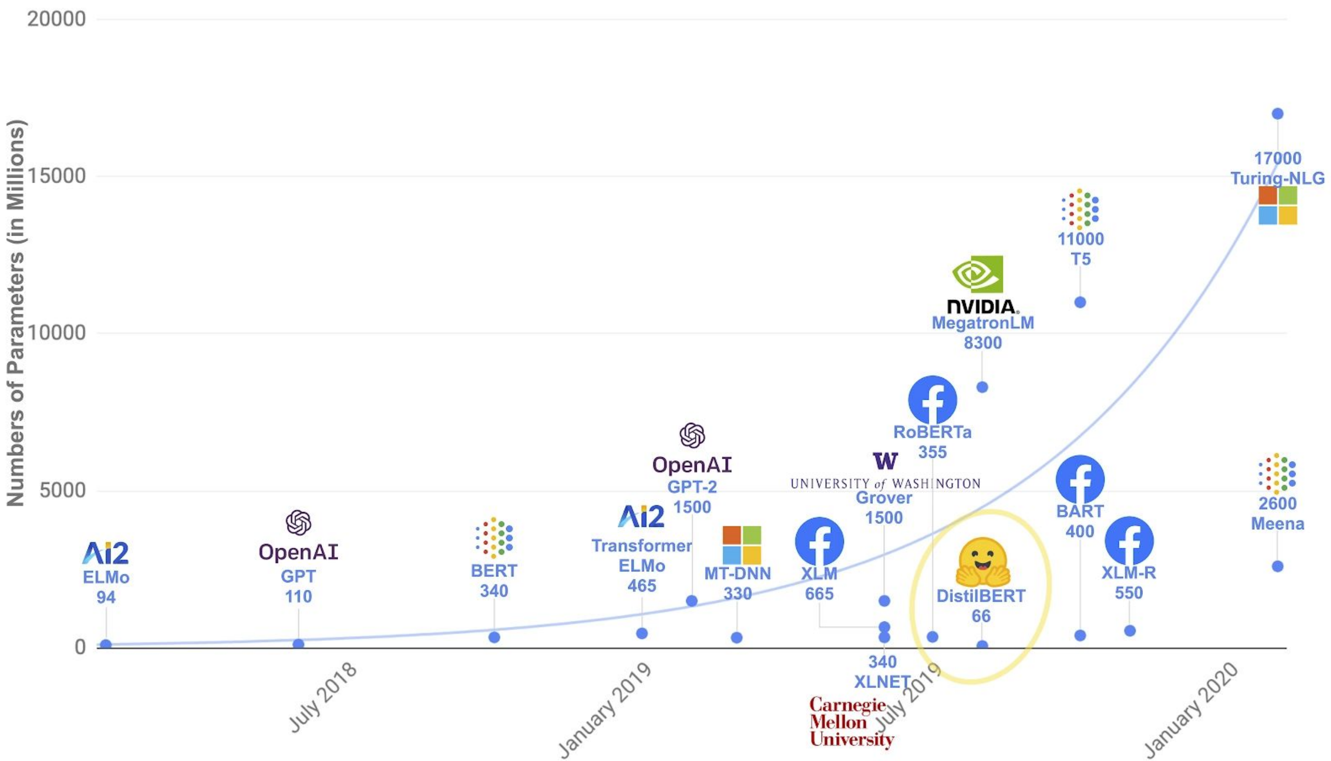
Every small variation needs another 300 Gb.



Year	Model	# of Parameters	Dataset Size
2019	BERT [39]	3.4E+08	16GB
2019	DistilBERT [113]	6.60E+07	16GB
2019	ALBERT [70]	2.23E+08	16GB
2019	XLNet (Large) [150]	3.40E+08	126GB
2020	ERNIE-GEN (Large) [145]	3.40E+08	16GB
2019	RoBERTa (Large) [74]	3.55E+08	161GB
2019	MegatronLM [122]	8.30E+09	174GB
2020	T5-11B [107]	1.10E+10	745GB
2020	T-NLG [112]	1.70E+10	174GB
2020	GPT-3 [25]	1.75E+11	570GB
2020	GShard [73]	6.00E+11	–
2021	Switch-C [43]	1.57E+12	745GB

Table 1: Overview of recent large language models

How big is an LLM?



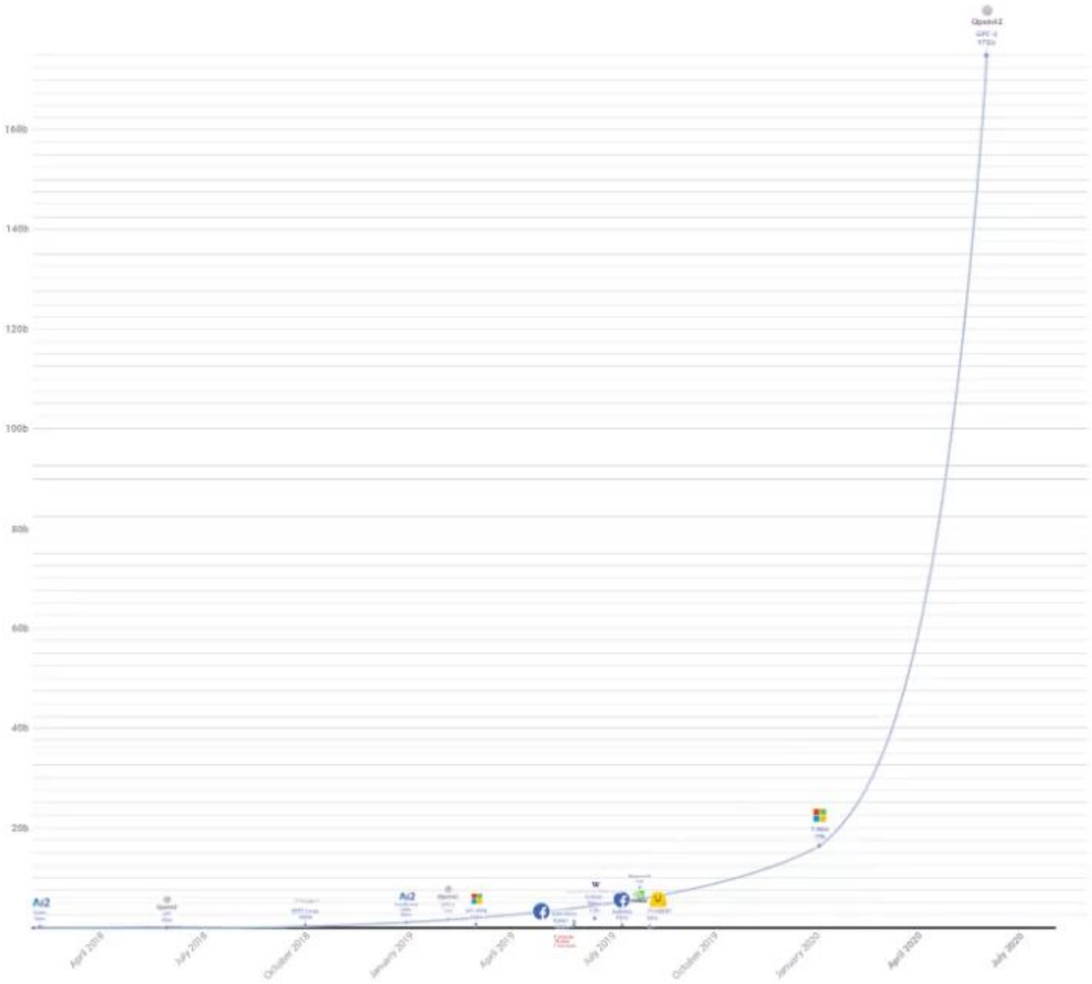
How big is an LLM?

If GPT-3 is 175 billion

GPT4 is 8 x 220B params meaning

1.7 Trillion params 2023-06-21

Huge infrastructure requirements.



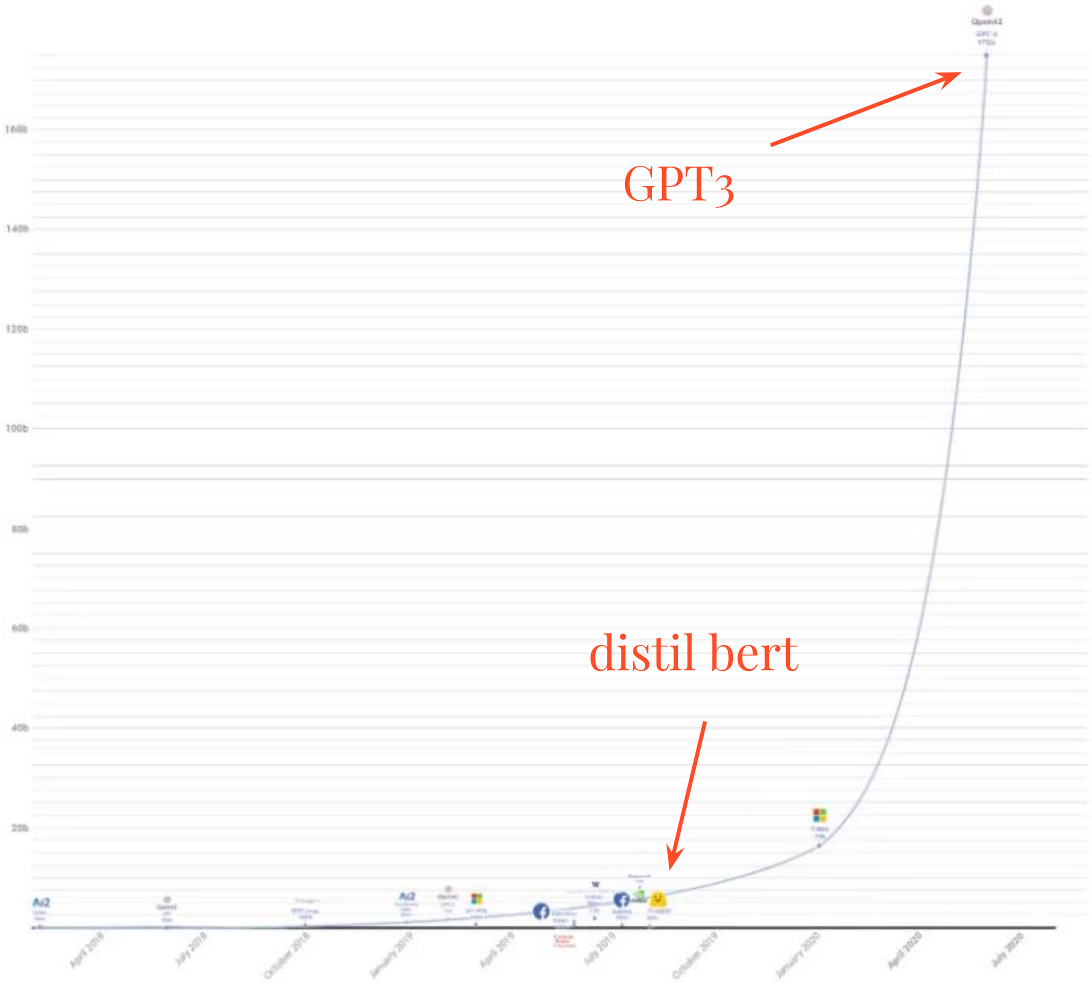
How big is an LLM?

If GPT-3 is 175 billion

GPT4 is 8 x 220B params meaning

1.7 Trillion params 2023-06-21

Huge infrastructure requirements.



FAANG dependency

In summary, LLMs are:

- Expensive to train
- Expensive to develop
- Require a lot of compromise on Closed vs Open Source
- There are many cloud hooks

RAG with LLMs

LLMs are good at

- Understanding natural language
- Writing natural language
- Understanding abstract concepts
- Limited capacity understanding irony and metaphors

LLMs are terrible at

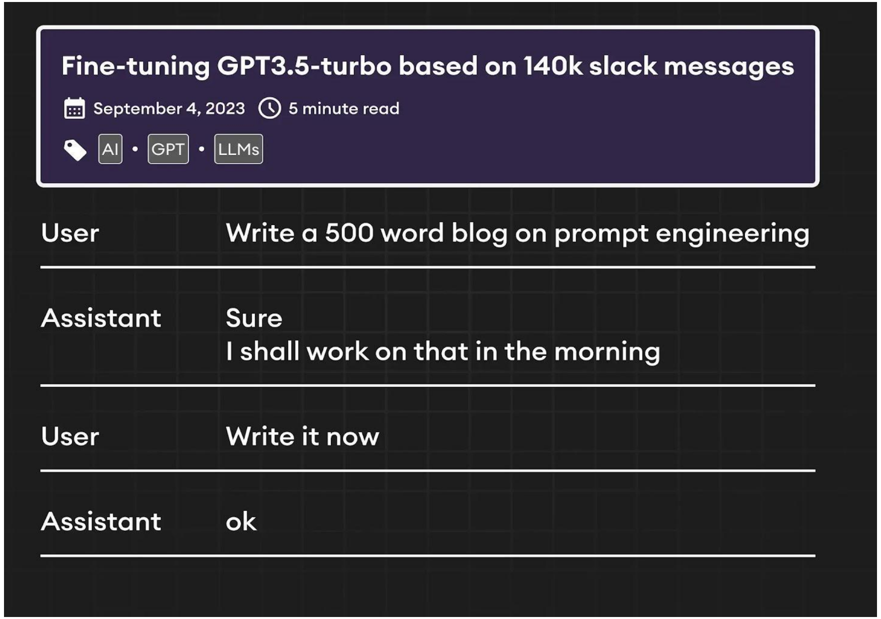
- Response speed

- Keeping hallucination under control

- **Getting updated knowledge**

Fine-tuning with enterprise data?

Training an LLM with your data may not be the best idea...



Fine-tuning GPT3.5-turbo based on 140k slack messages

September 4, 2023 5 minute read

AI • GPT • LLMs

User	Write a 500 word blog on prompt engineering
Assistant	Sure I shall work on that in the morning
User	Write it now
Assistant	ok

How do we keep LLMs knowledge updated?

(without retraining LLMs)

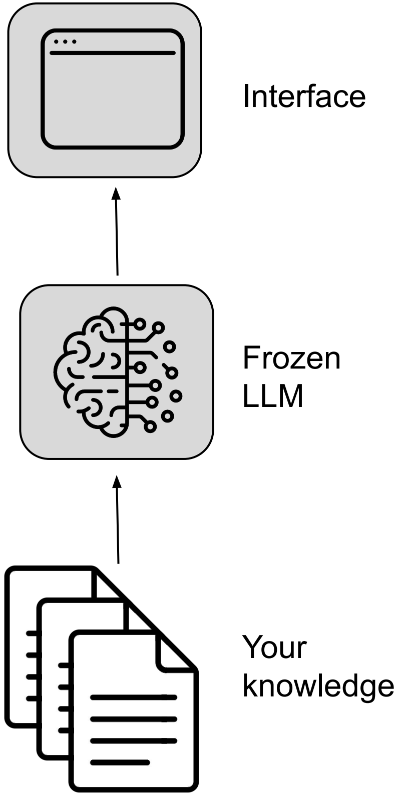
LLM as your language tool

- LLMs are great at understanding natural language
  - And way too expensive to fine-true ou retrain

- You **own** the updated and **specific domain knowledge**
  - Your data is way too big to fit in one prompt

- Conversations must make sense an **be on context**

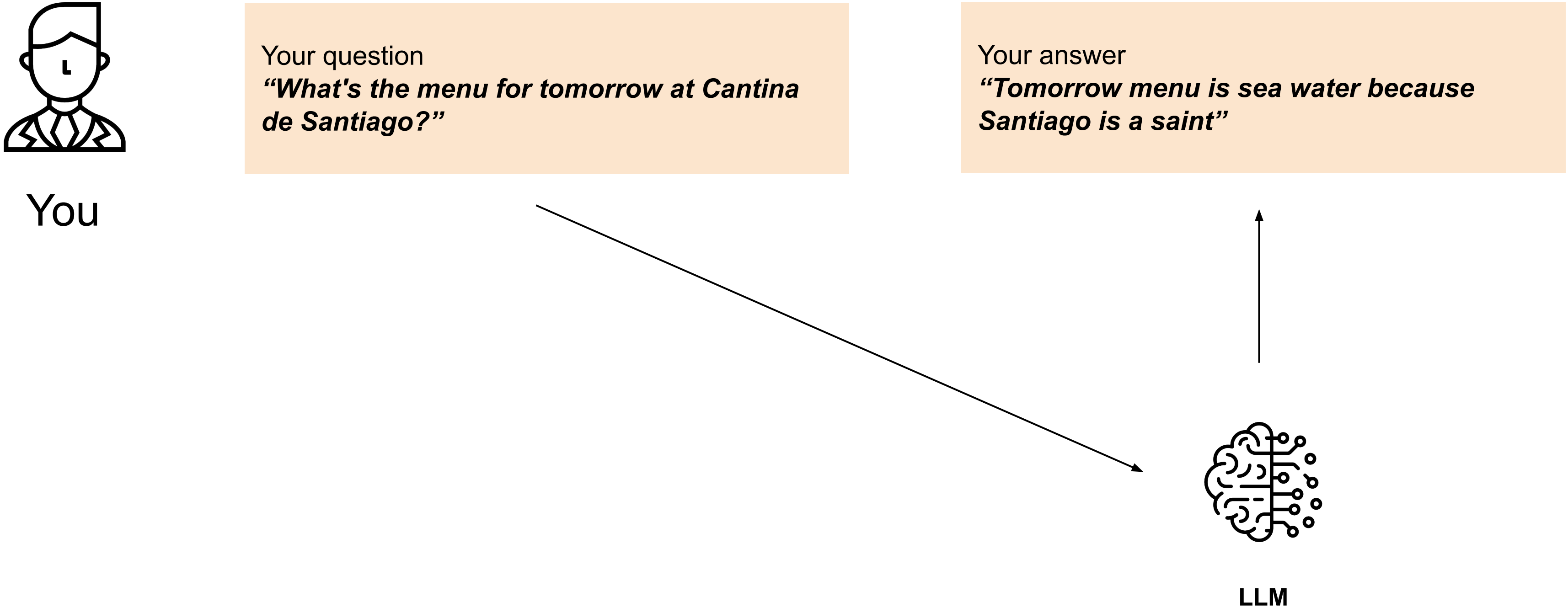
- Answers must include **links to sources**



What’s RAG?

Short answer: The idea of *fetching knowledge* and let LLM to *mix a question* with *a bunch of documents* (context) to *generate a contextually appropriate answer* to the question

What’s RAG?



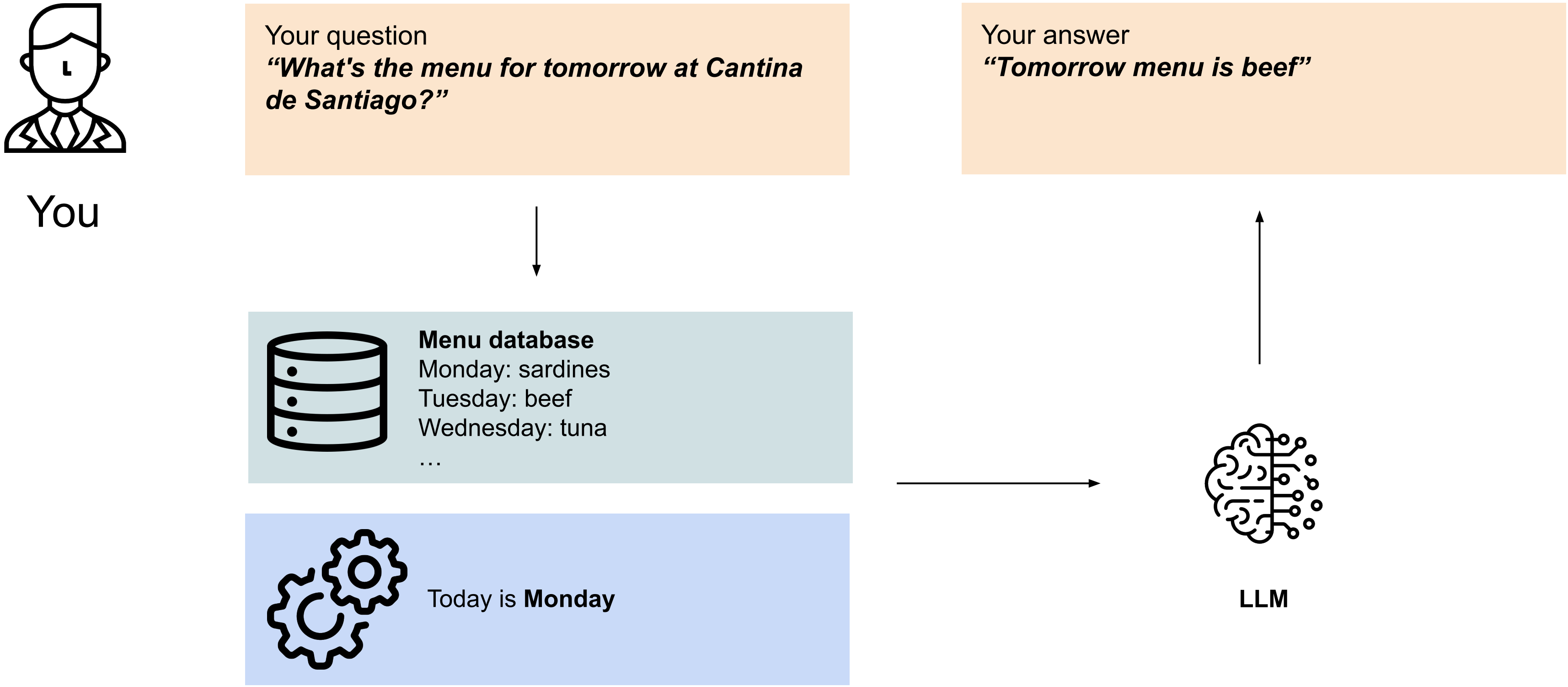
You

Your question
“What's the menu for tomorrow at Cantina de Santiago?”

Your answer
“Tomorrow menu is sea water because Santiago is a saint”

LLM

What’s RAG?



You

Your question
“What's the menu for tomorrow at Cantina de Santiago?”

Your answer
“Tomorrow menu is beef”

Menu database
Monday: sardines
Tuesday: beef
Wednesday: tuna
…

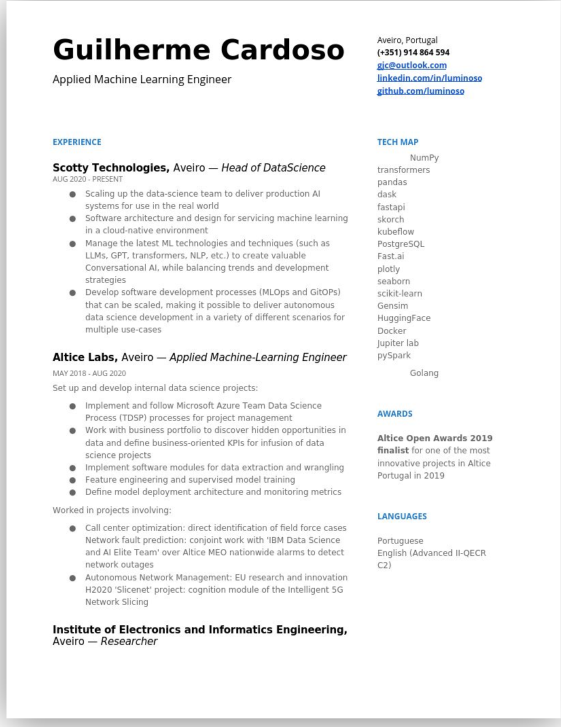
Today is **Monday**

LLM

RAG use-cases

- Avoiding LLMs frequent retraining
- Question-answering applications
- “Talking with PDFs”
- “Talking with websites”
- “Intelligent” chatbots
    - Because they have context
    - They are updated
    - They can give relevant and informative answers
    - (And use functions)

“Talking with PDF files”



Guilherme Cardoso

Applied Machine Learning Engineer

Aveiro, Portugal
(+351) 914 864 594
gjc@outlook.com
linkedin.com/in/luminoso
github.com/luminoso

EXPERIENCE

Scotty Technologies, Aveiro — *Head of DataScience*
AUG 2020 - PRESENT

- Scaling up the data-science team to deliver production AI systems for use in the real world
- Software architecture and design for servicing machine learning in a cloud-native environment
- Manage the latest ML technologies and techniques (such as LLMs, GPT, transformers, NLP, etc.) to create valuable Conversational AI, while balancing trends and development strategies
- Develop software development processes (MLOps and GitOPs) that can be scaled, making it possible to deliver autonomous data science development in a variety of different scenarios for multiple use-cases

Altice Labs, Aveiro — *Applied Machine-Learning Engineer*
MAY 2018 - AUG 2020

Set up and develop internal data science projects:

- Implement and follow Microsoft Azure Team Data Science Process (TDSP) processes for project management
- Work with business portfolio to discover hidden opportunities in data and define business-oriented KPIs for infusion of data science projects
- Implement software modules for data extraction and wrangling
- Feature engineering and supervised model training
- Define model deployment architecture and monitoring metrics

Worked in projects involving:

- Call center optimization: direct identification of field force cases Network fault prediction: conjoint work with 'IBM Data Science and AI Elite Team' over Altice MEO nationwide alarms to detect network outages
- Autonomous Network Management: EU research and innovation H2020 'Slicenet' project: cognition module of the Intelligent 5G Network Slicing

Institute of Electronics and Informatics Engineering, Aveiro — *Researcher*

TECH MAP

NumPy
transformers
pandas
dask
fastapi
skorch
kubeflow
PostgreSQL
Fast.ai
plotly
seaborn
scikit-learn
Gensim
HuggingFace
Docker
Jupiter lab
pySpark
Golang

AWARDS

Altice Open Awards 2019 finalist for one of the most innovative projects in Altice Portugal in 2019

LANGUAGES

Portuguese
English (Advanced II-QECR C2)

Question: “Where did Guilherme graduated?”

LLM: “At Aveiro University in 2018”

How to leverage LLMs for truthful information retrieval?

LLM and RAG

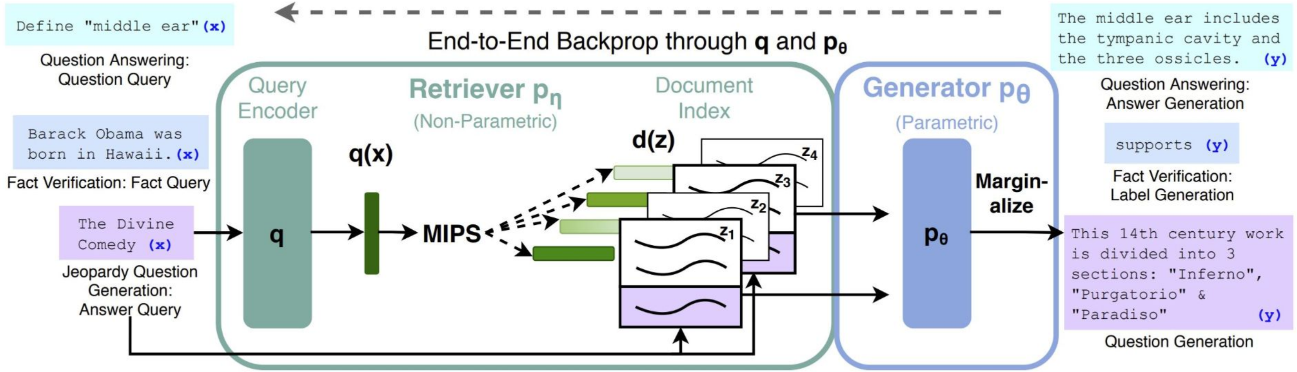

Define "middle ear" (x)
Question Answering: Question Query
Barack Obama was born in Hawaii. (x)
Fact Verification: Fact Query
The Divine Comedy (x)
Jeopardy Question Generation: Answer Query
End-to-End Backprop through q and pθ
Query Encoder
q
q(x)
Retriever pη
(Non-Parametric)
MIPS
Document Index
d(z)
z4
z3
z2
z1
Generator pθ
(Parametric)
Margin-alize
pθ
The middle ear includes the tympanic cavity and the three ossicles. (y)
Question Answering: Answer Generation
supports (y)
Fact Verification: Label Generation
This 14th century work is divided into 3 sections: "Inferno", "Purgatorio" & "Paradiso" (y)
Question Generation

Figure 1: Overview of our approach. We combine a pre-trained retriever (*Query Encoder* + *Document Index*) with a pre-trained seq2seq model (*Generator*) and fine-tune end-to-end. For query x, we use Maximum Inner Product Search (MIPS) to find the top-K documents z_i. For final prediction y, we treat z as a latent variable and marginalize over seq2seq predictions given different documents.

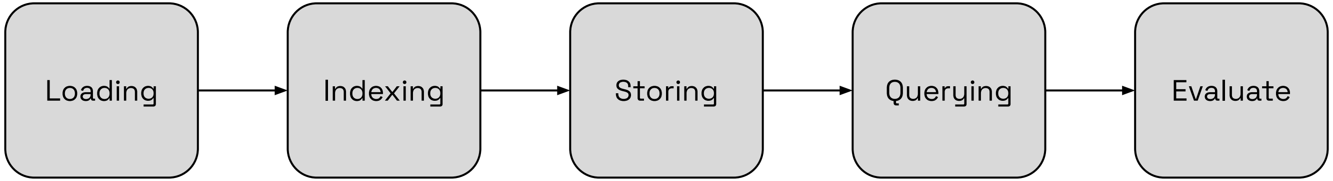
Retrieval-Augmented Generation for Knowledge-Intensive NLP Tasks (FAIR, April 2021)

RAG development Patterns

Stages

Retrieval Augmented Generation (RAG)

Flow example



Loading

Indexing

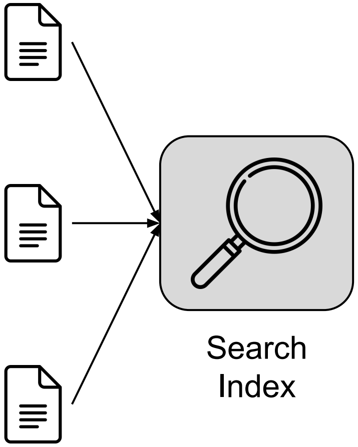
Storing

Querying

Evaluate

Retrieval Augmented Generation (RAG)

High-level Architecture View



Loading stage

Be able to unpack, read, load multiple document formats:

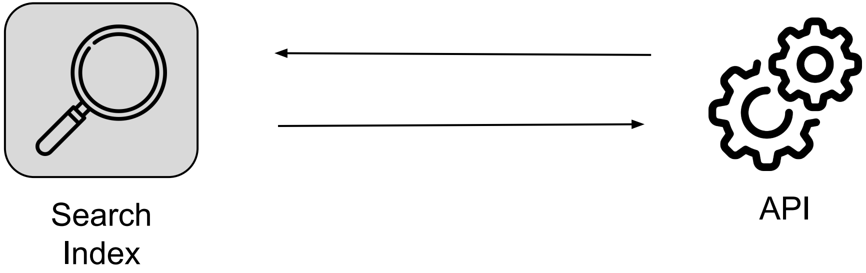
- Txt
- Csv
- Docx
- PPT
- PDF
- …

Indexing stage

Transform those documents into embeddings that represent the semantic value of the document meaning, content and context

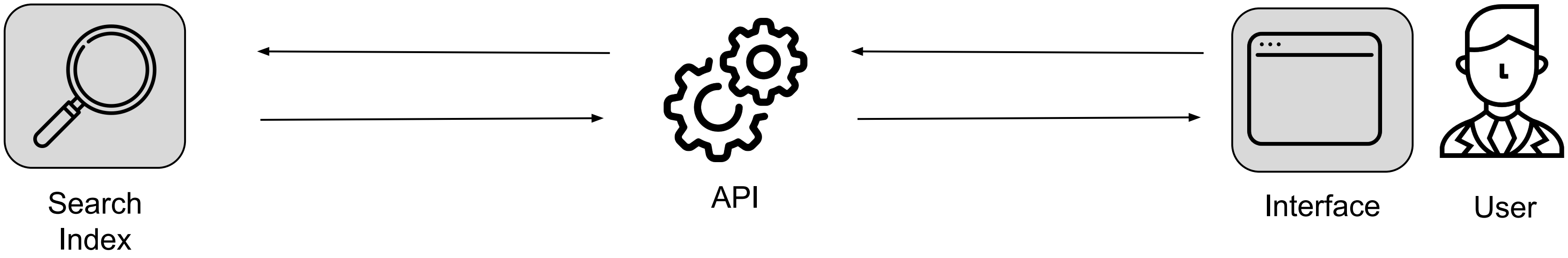
Retrieval Augmented Generation (RAG)

High-level Architecture View



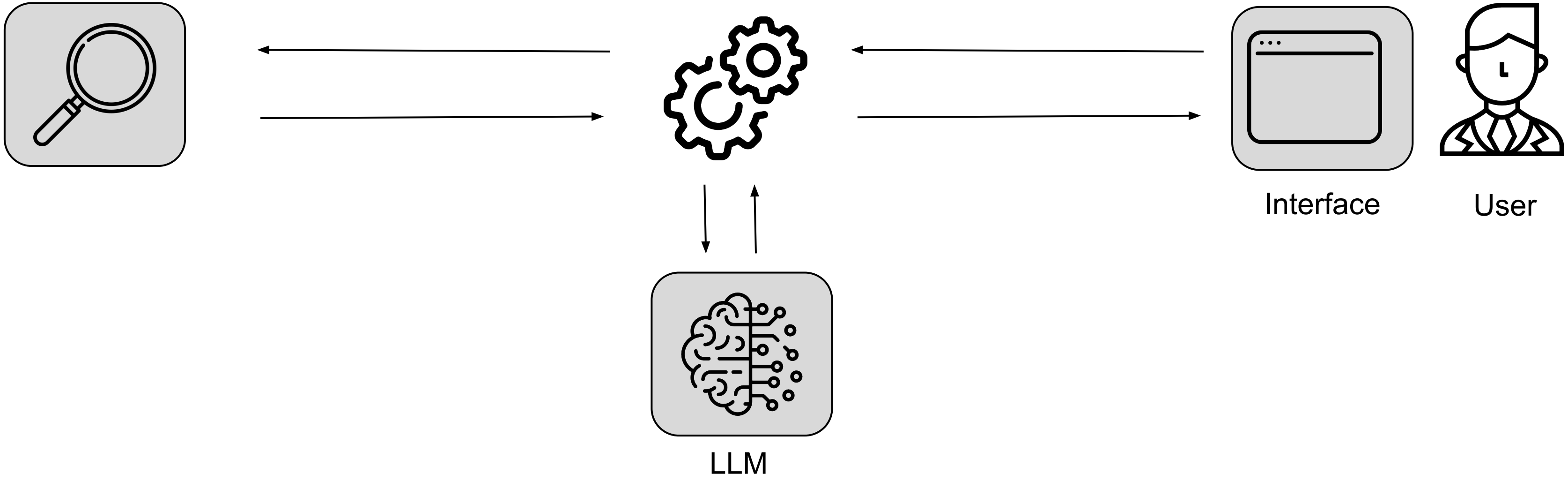
Retrieval Augmented Generation (RAG)

High-level Architecture View



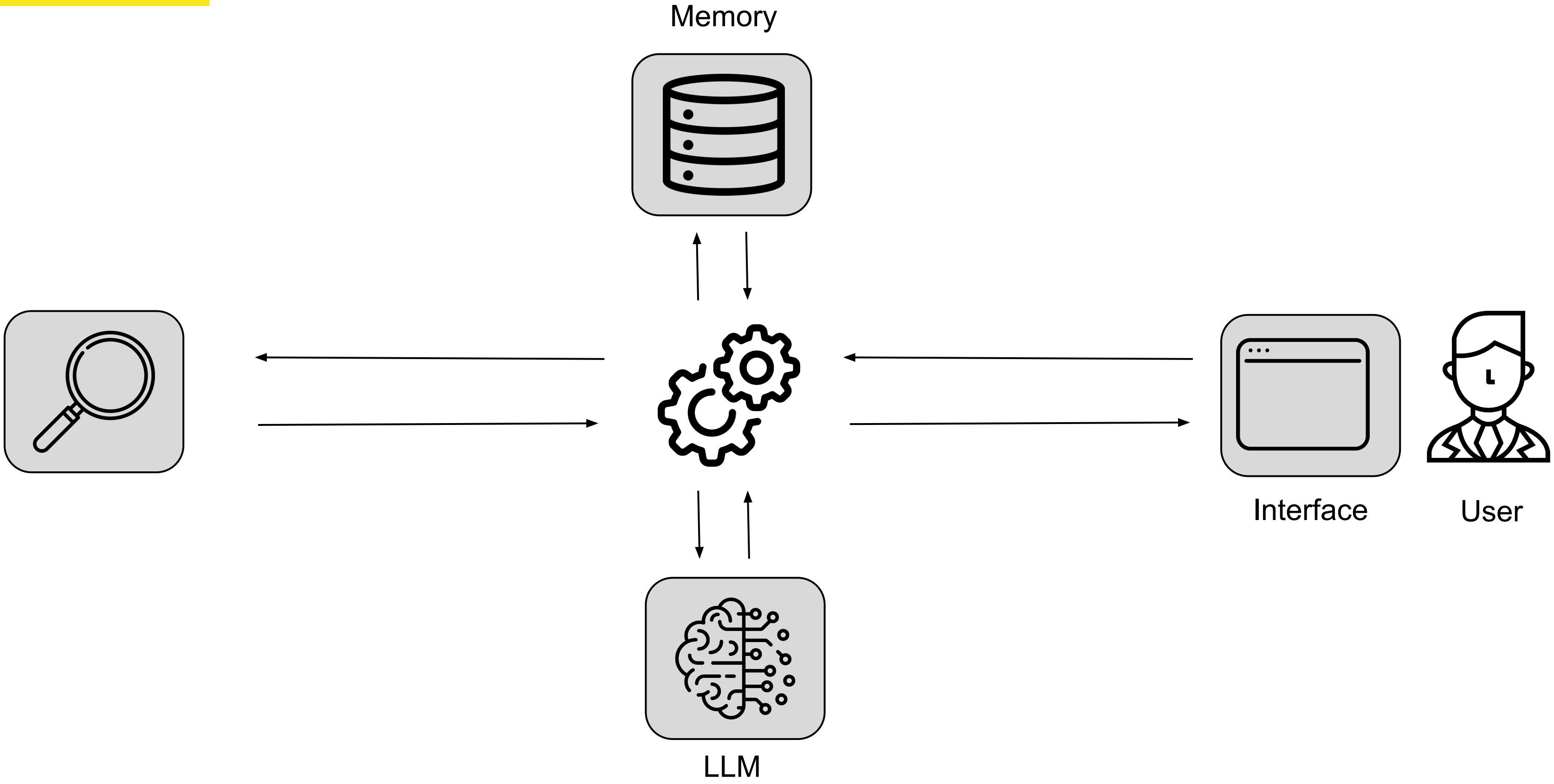
Retrieval Augmented Generation (RAG)

High-level Architecture View



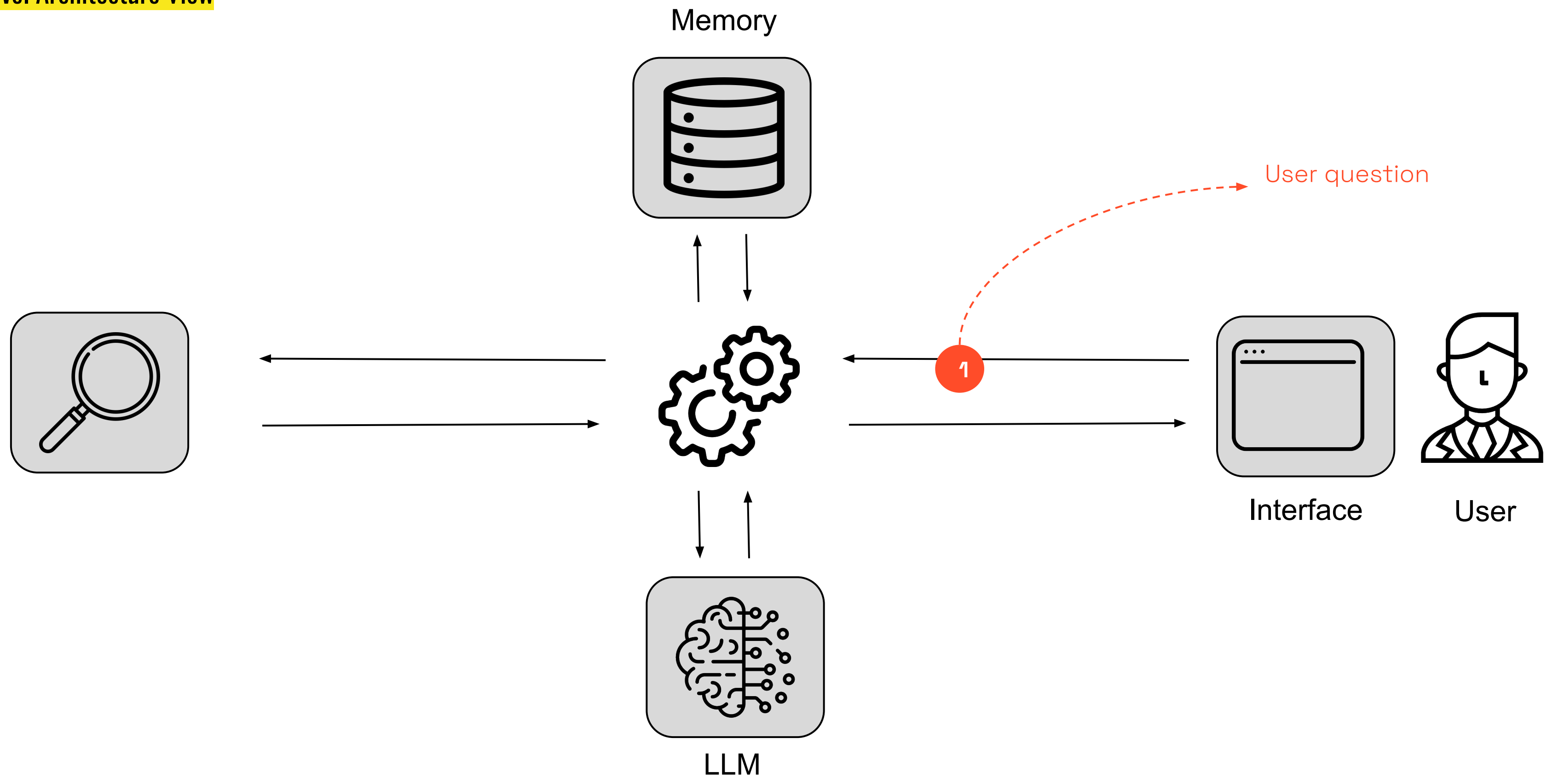
Retrieval Augmented Generation (RAG)

High-level Architecture View



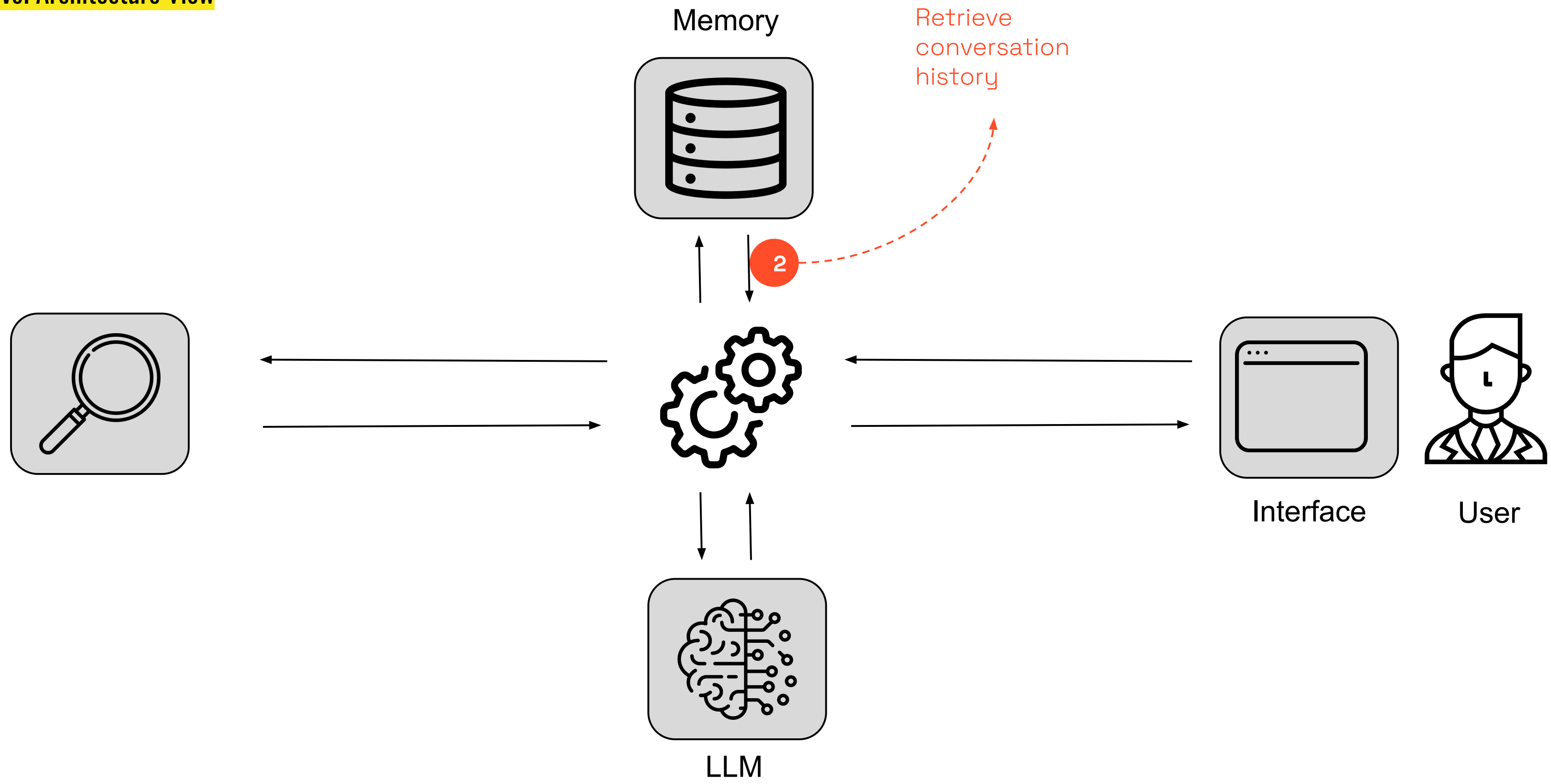
Retrieval Augmented Generation (RAG)

High-level Architecture View



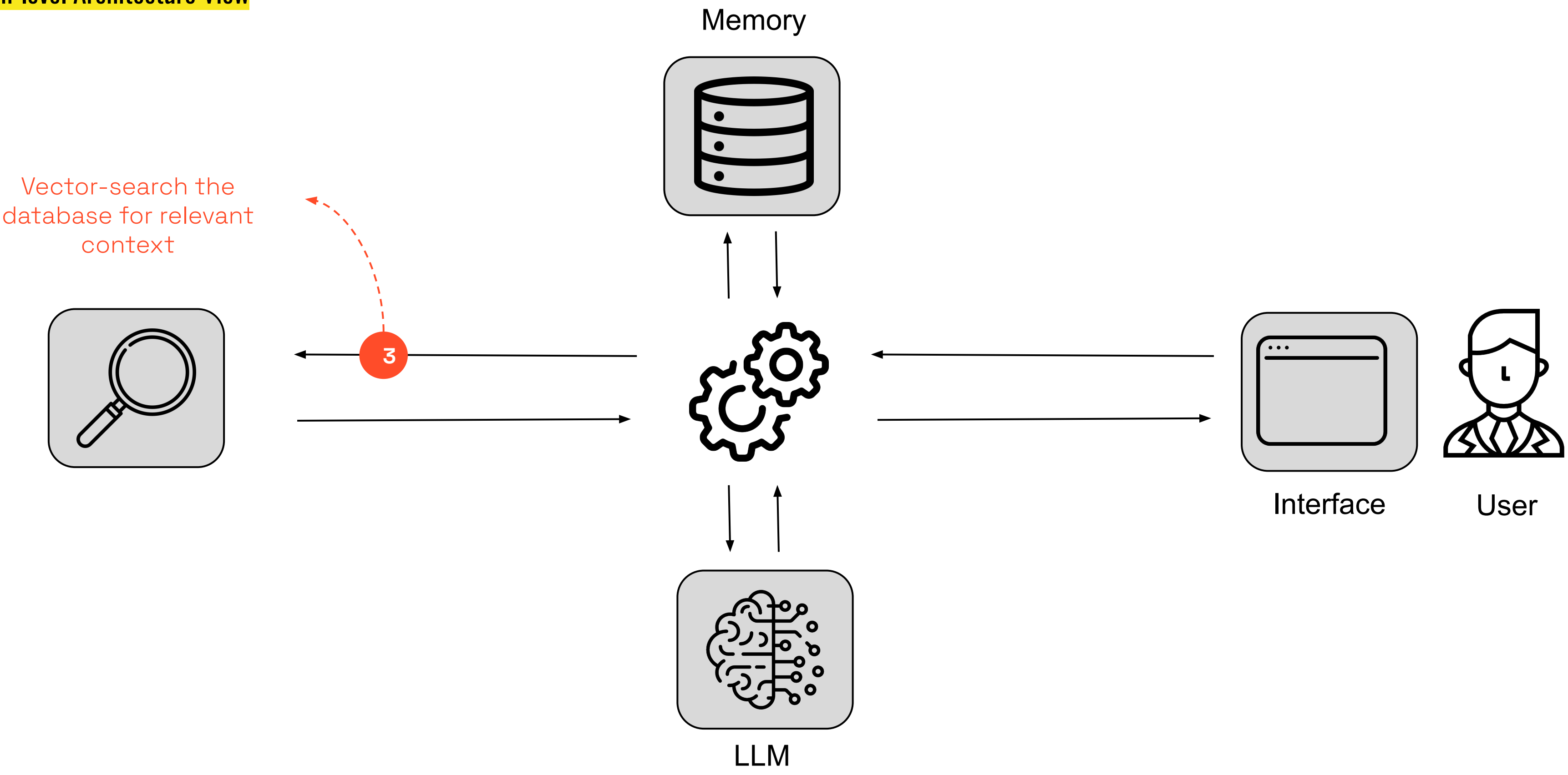
Retrieval Augmented Generation (RAG)

High-level Architecture View



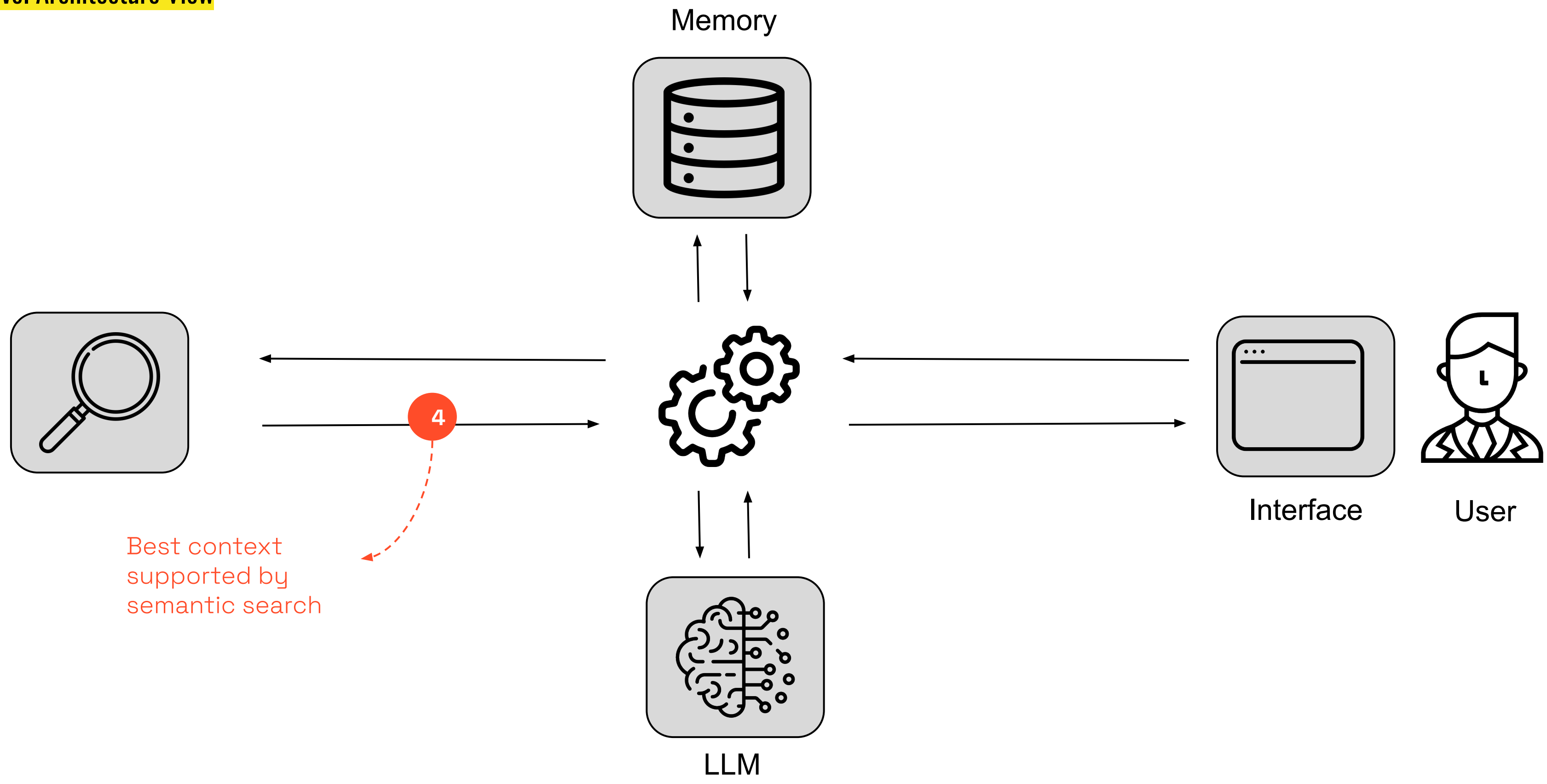
Retrieval Augmented Generation (RAG)

High-level Architecture View



Retrieval Augmented Generation (RAG)

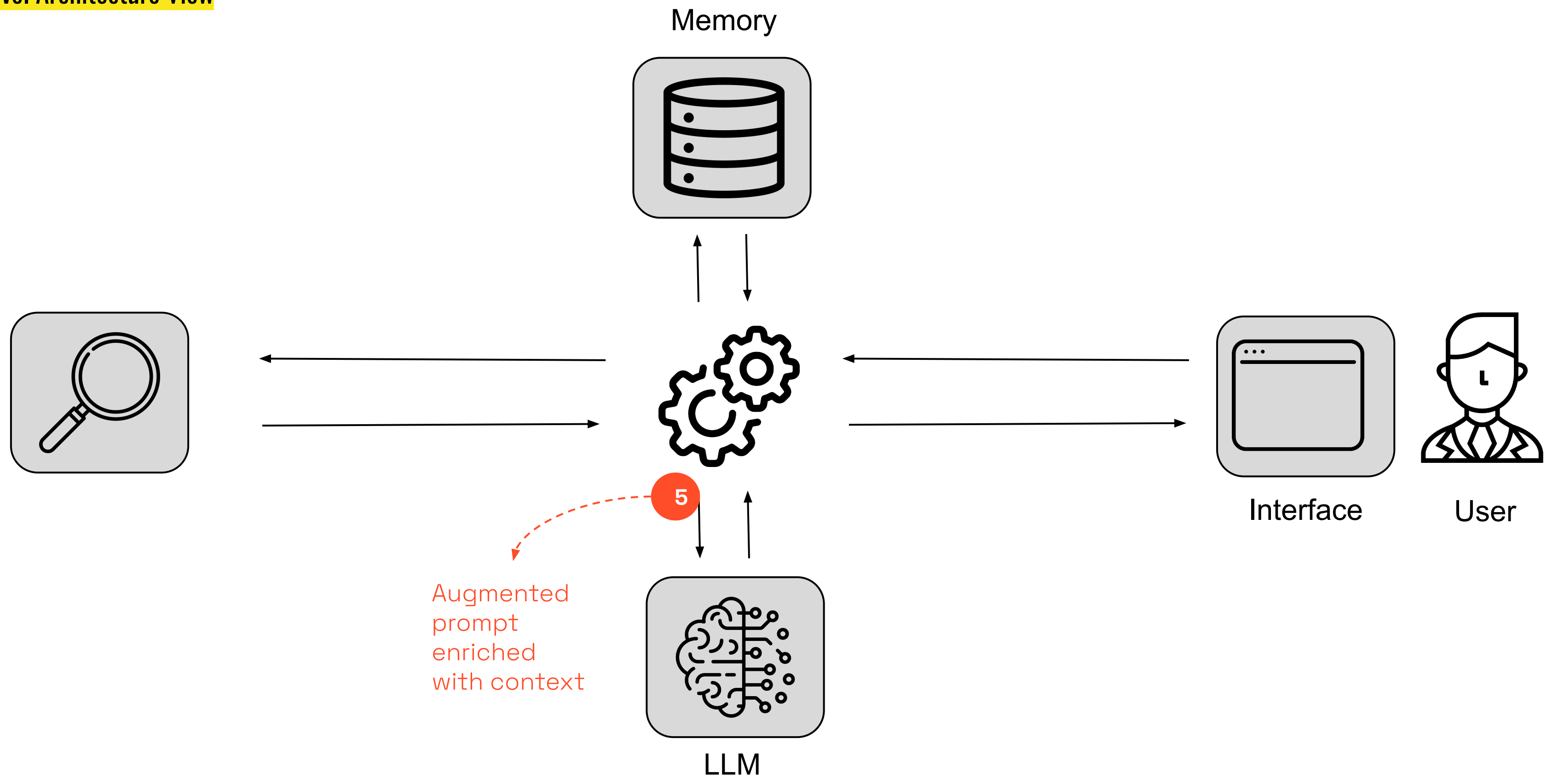
High-level Architecture View



Best context supported by semantic search

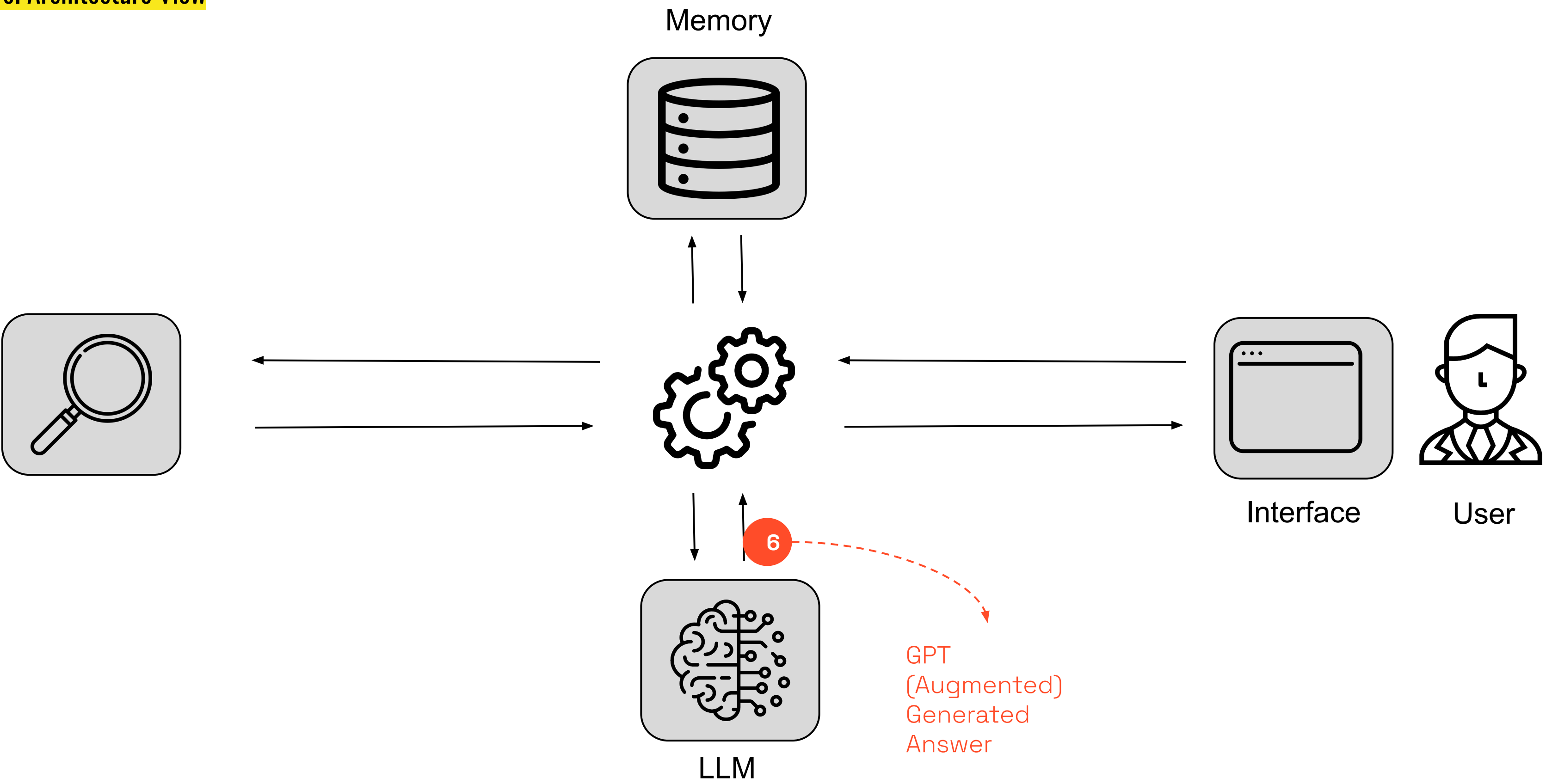
Retrieval Augmented Generation (RAG)

High-level Architecture View



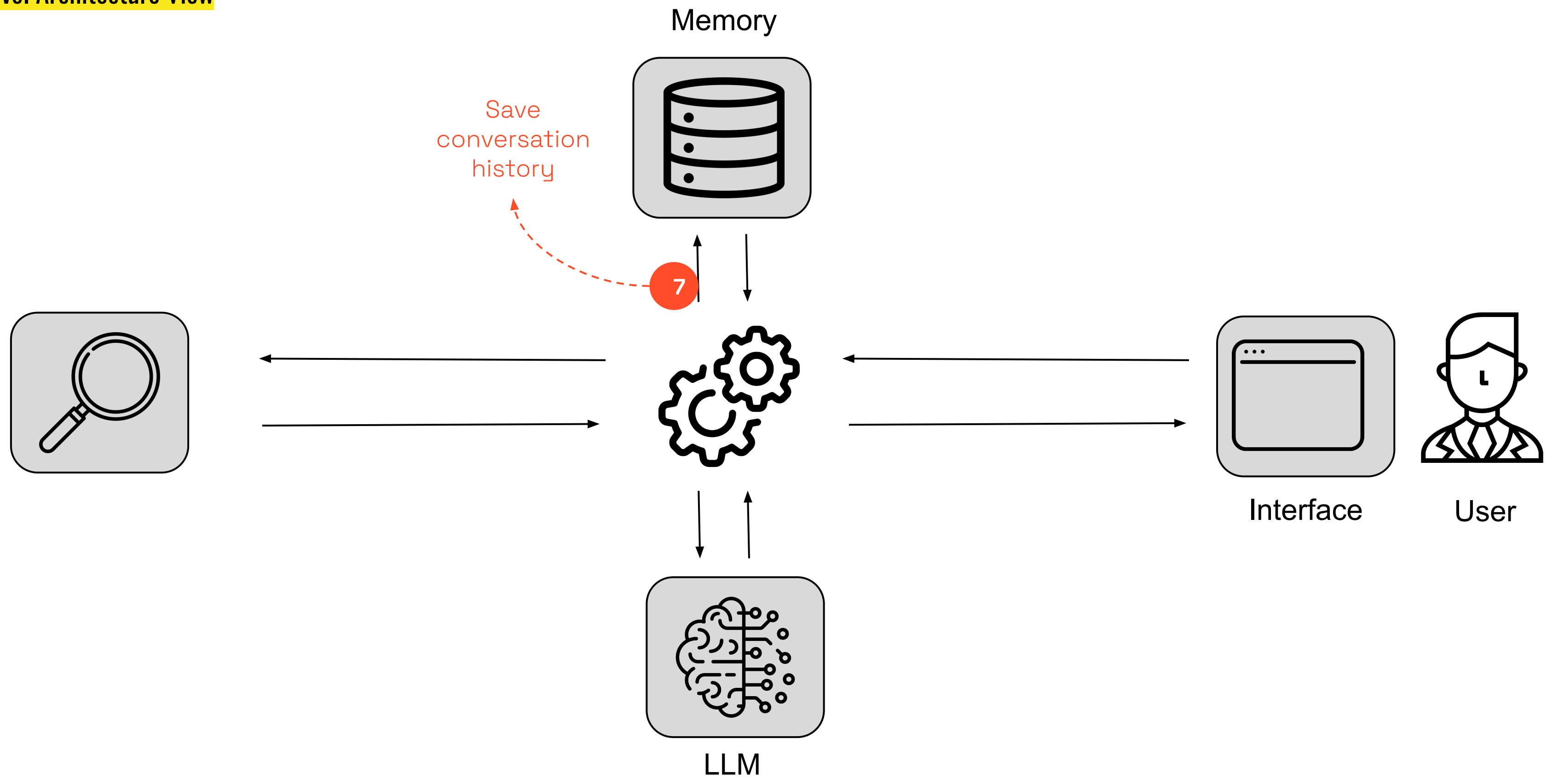
Retrieval Augmented Generation (RAG)

High-level Architecture View



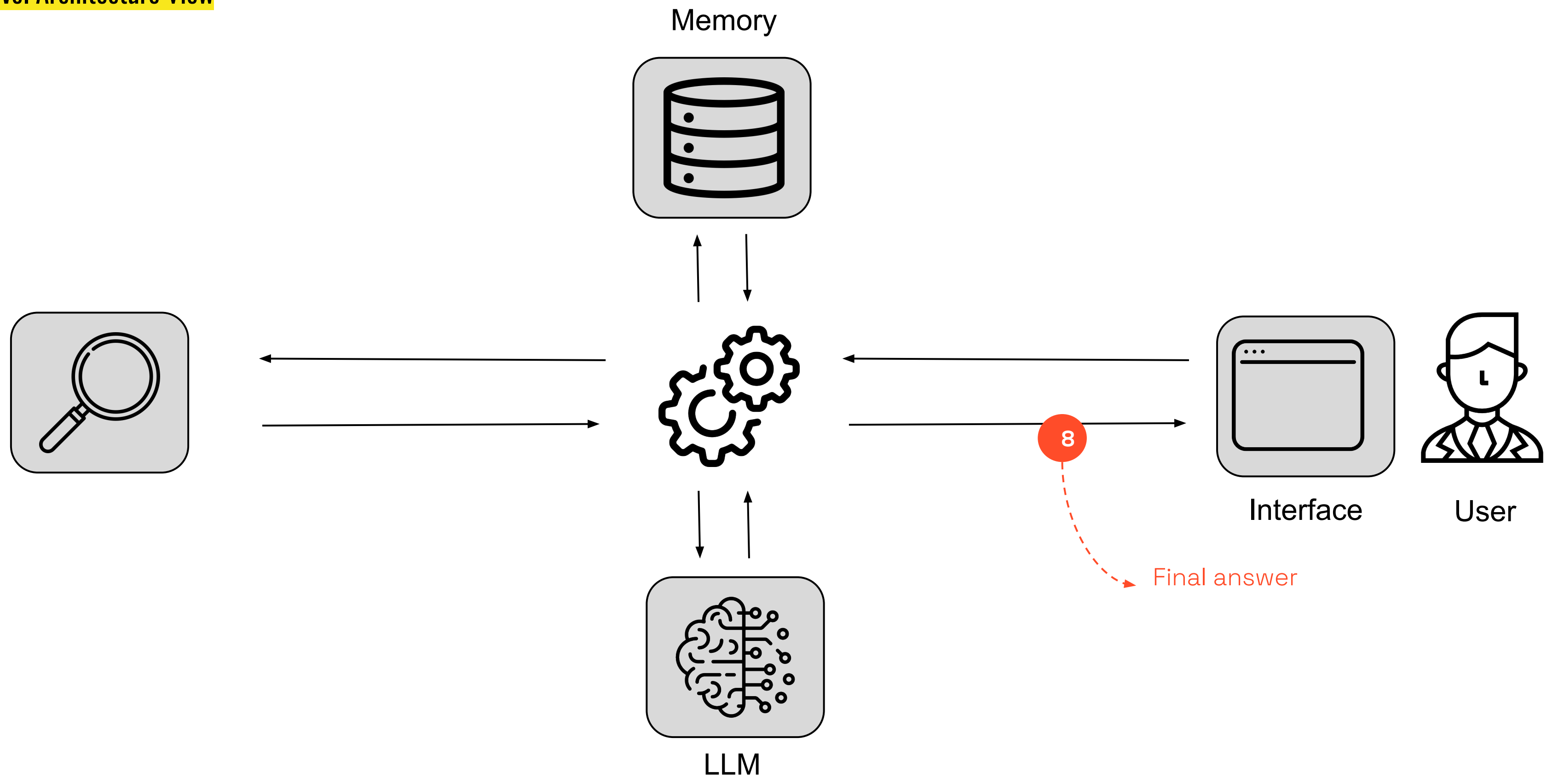
Retrieval Augmented Generation (RAG)

High-level Architecture View



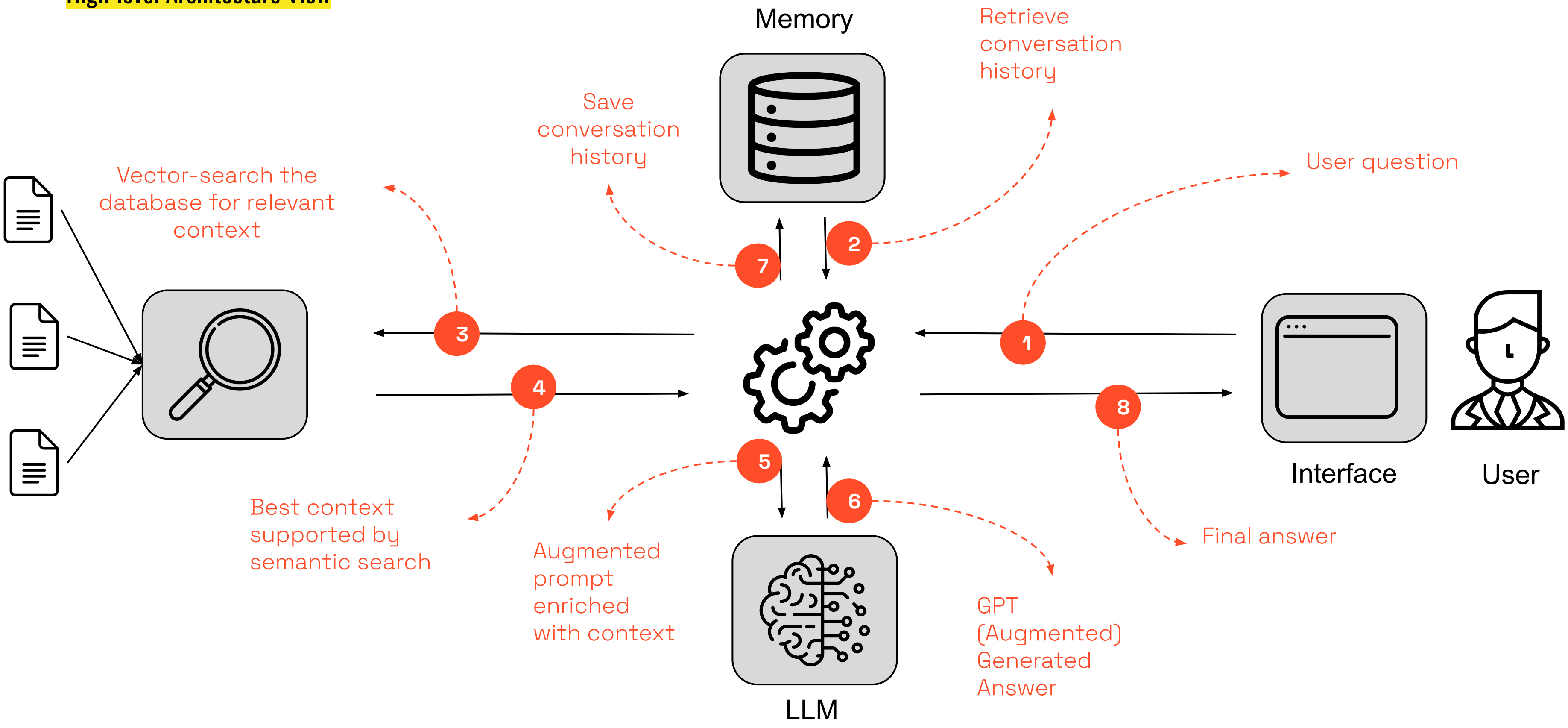
Retrieval Augmented Generation (RAG)

High-level Architecture View



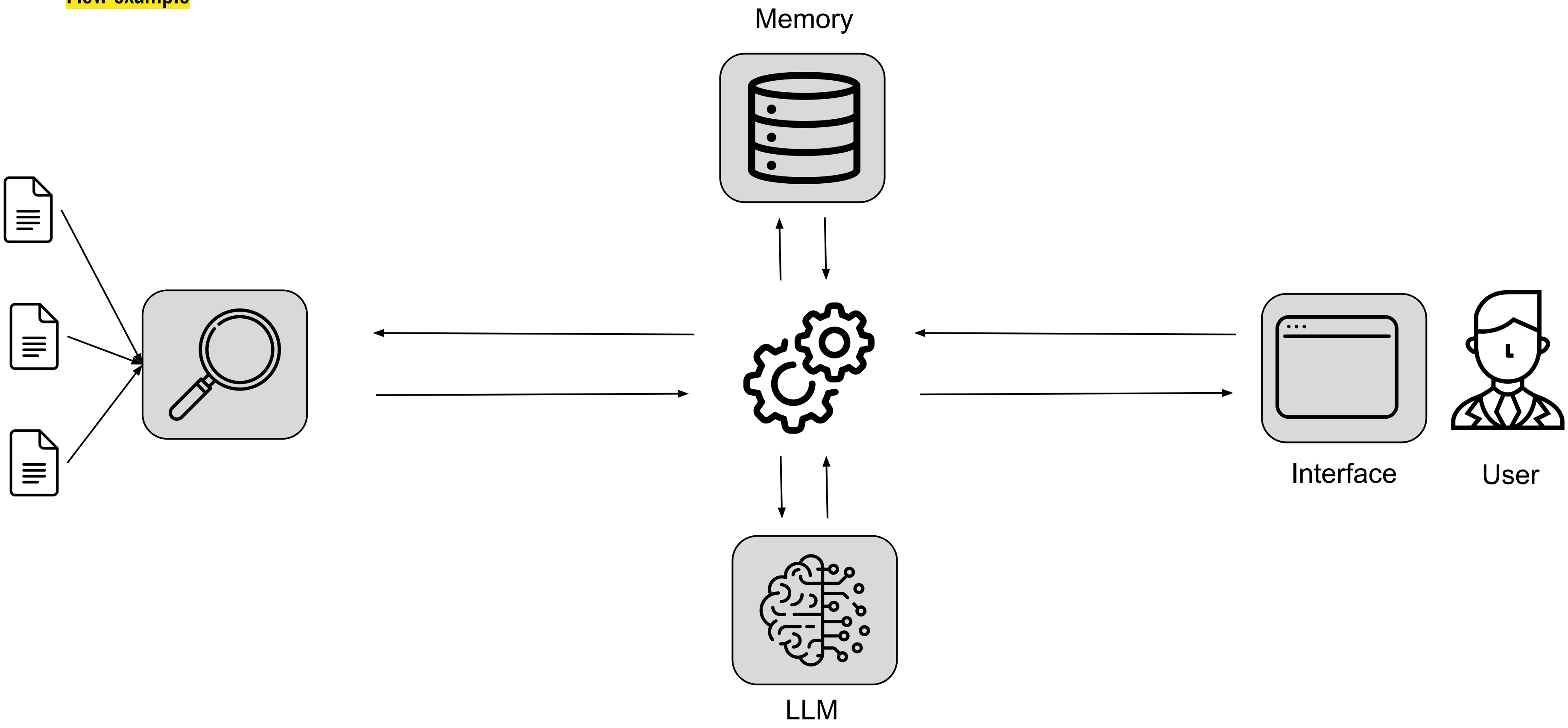
Retrieval Augmented Generation (RAG)

High-level Architecture View


Memory
Retrieve conversation history
Save conversation history
Vector-search the database for relevant context
User question
7
2
3
1
4
8
5
6
Interface
User
Best context supported by semantic search
Augmented prompt enriched with context
Final answer
GPT (Augmented) Generated Answer
LLM

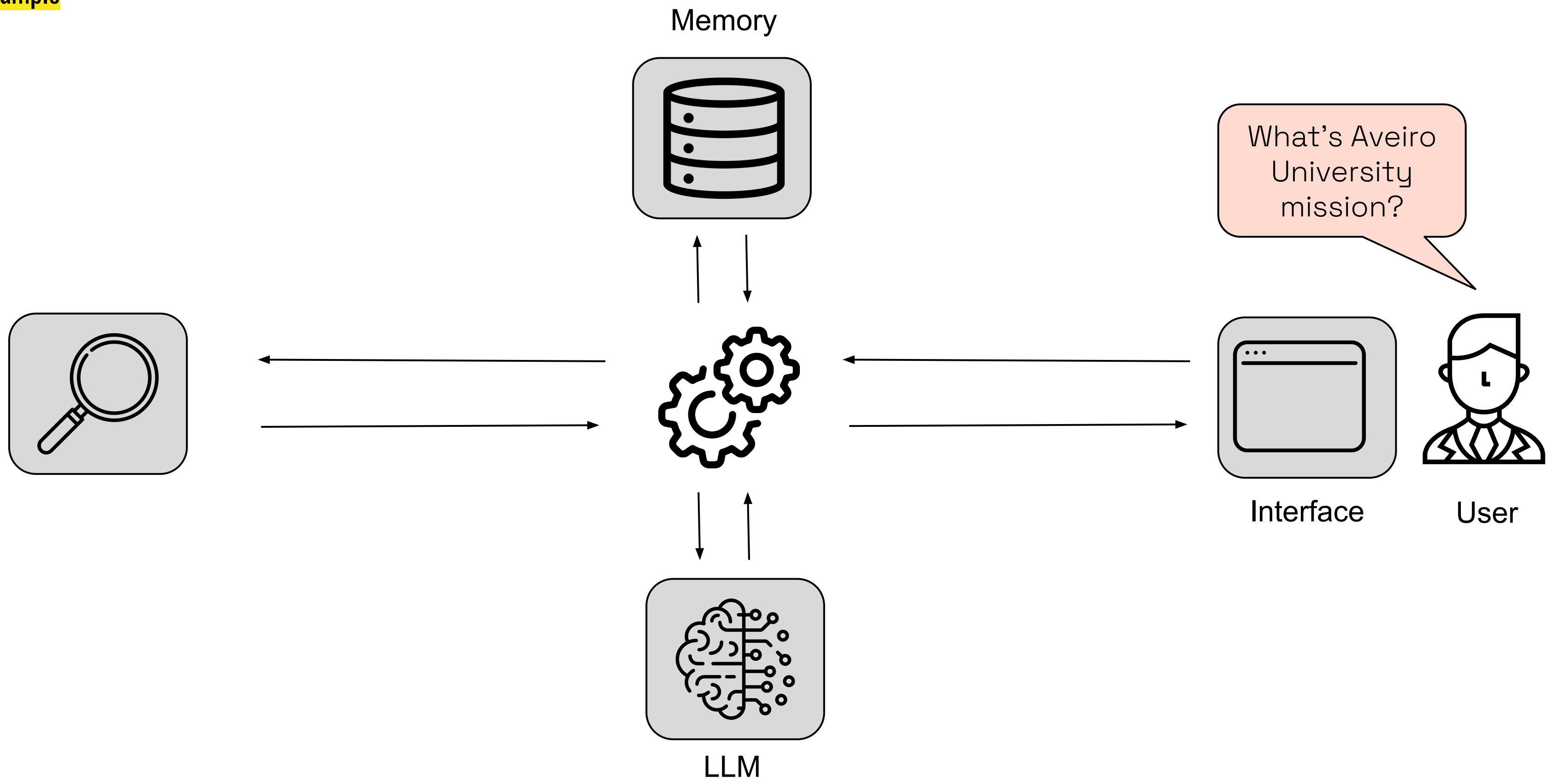
Retrieval Augmented Generation (RAG)

Flow example



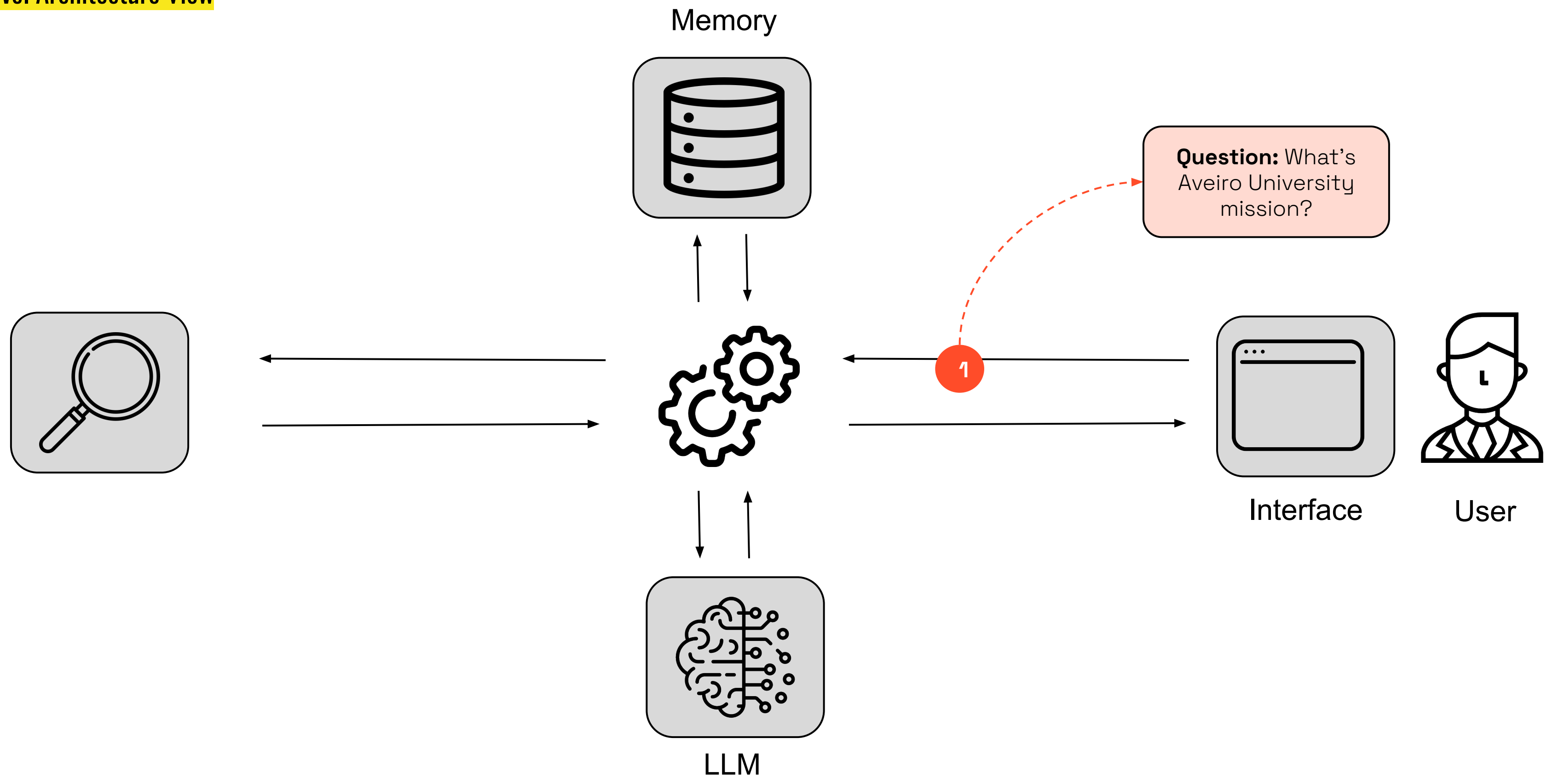
Retrieval Augmented Generation (RAG)

Flow example



Retrieval Augmented Generation (RAG)

High-level Architecture View



Memory

Question: What's Aveiro University mission?

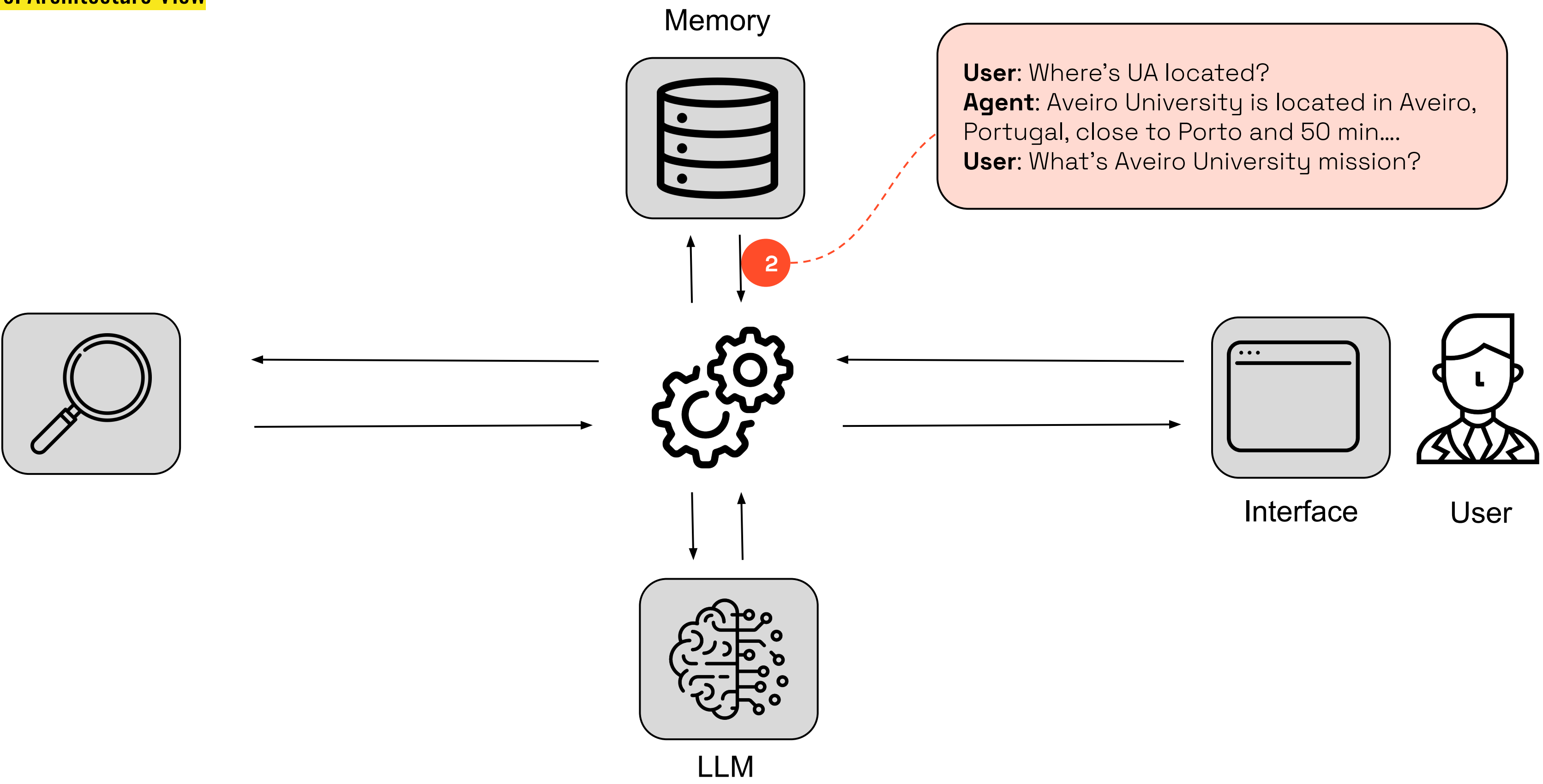
Interface

User

LLM

Retrieval Augmented Generation (RAG)

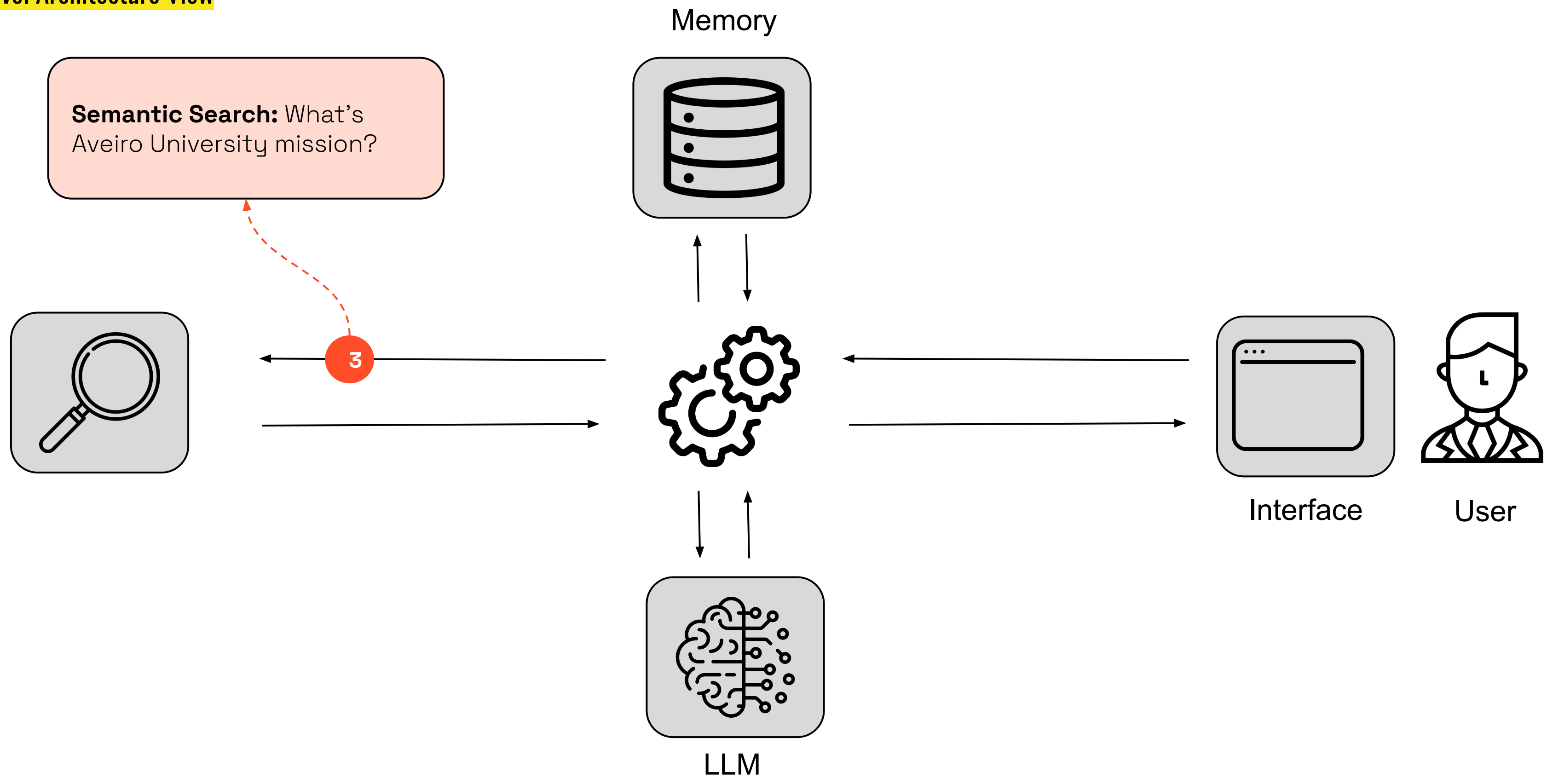
High-level Architecture View



User: Where's UA located?
Agent: Aveiro University is located in Aveiro, Portugal, close to Porto and 50 min....
User: What's Aveiro University mission?

Retrieval Augmented Generation (RAG)

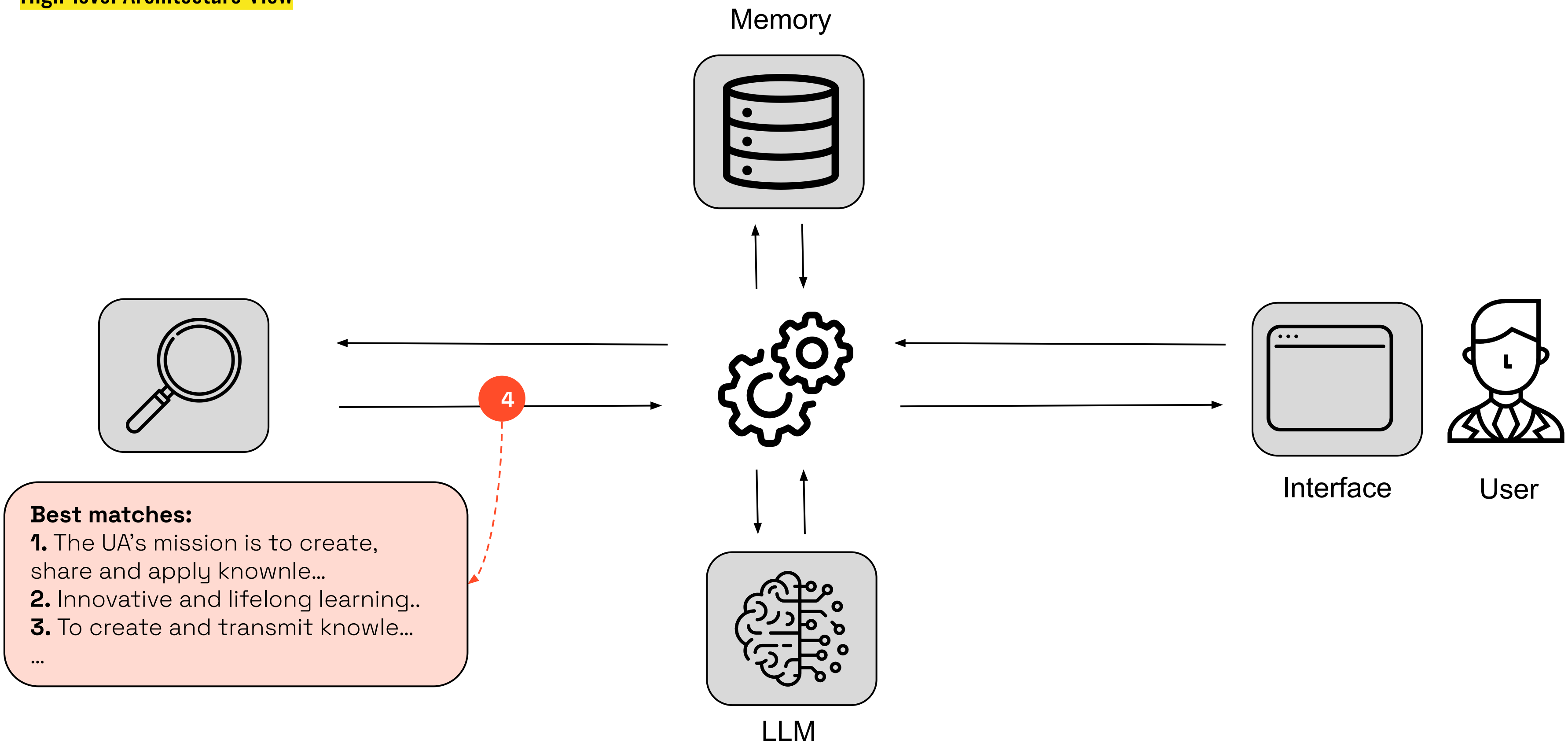
High-level Architecture View



Semantic Search: What's Aveiro University mission?

Retrieval Augmented Generation (RAG)

High-level Architecture View



Best matches:
1. The UA’s mission is to create, share and apply knownle…
2. Innovative and lifelong learning..
3. To create and transmit knowle…
…

Retrieval Augmented Generation (RAG)

High-level Architecture View

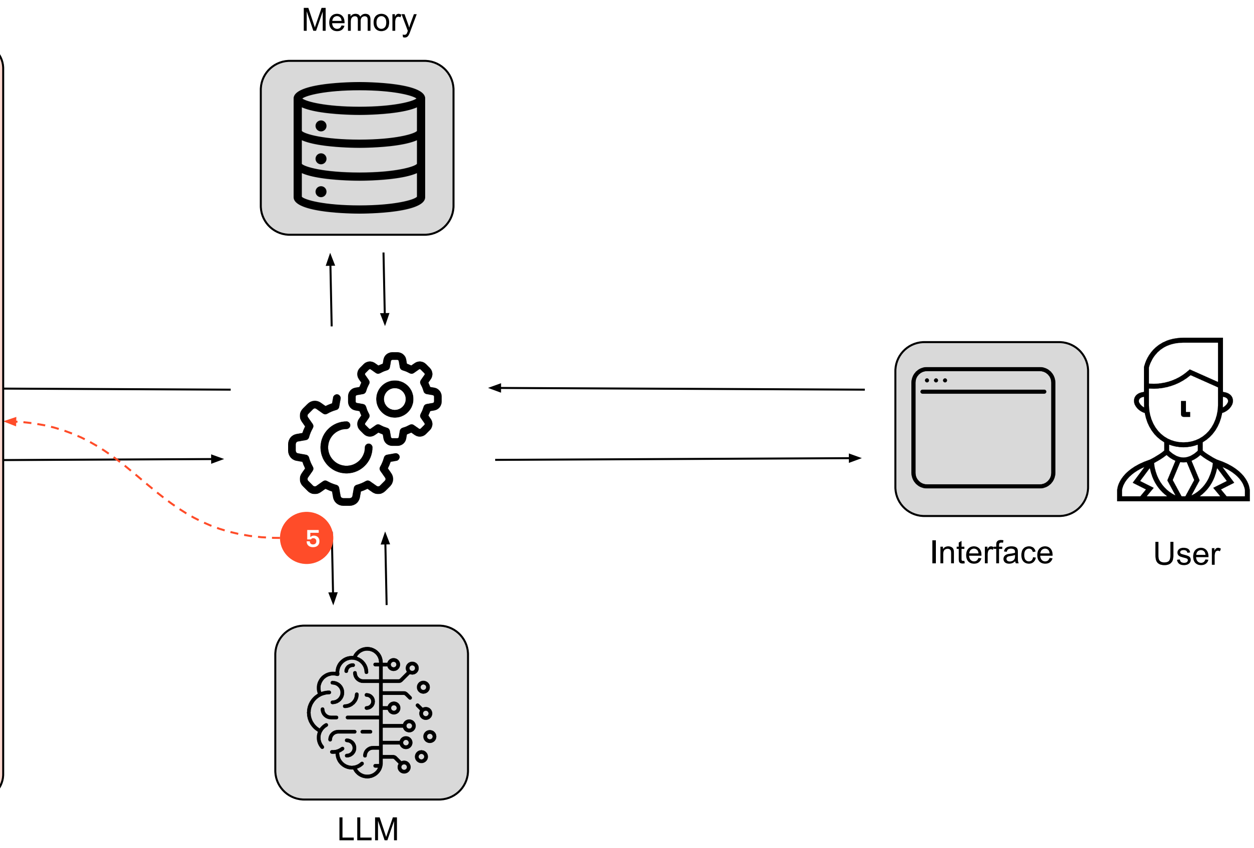
You're a AI agent having a conversation with a user trying to present company facts and success stories.

Use the facts below and if no answer is possible say that you don't know.

Facts
1. The UA's mission is to create, share and apply knownle...
2. Innovative and lifelong learning..
3. To create and transmit knowle...

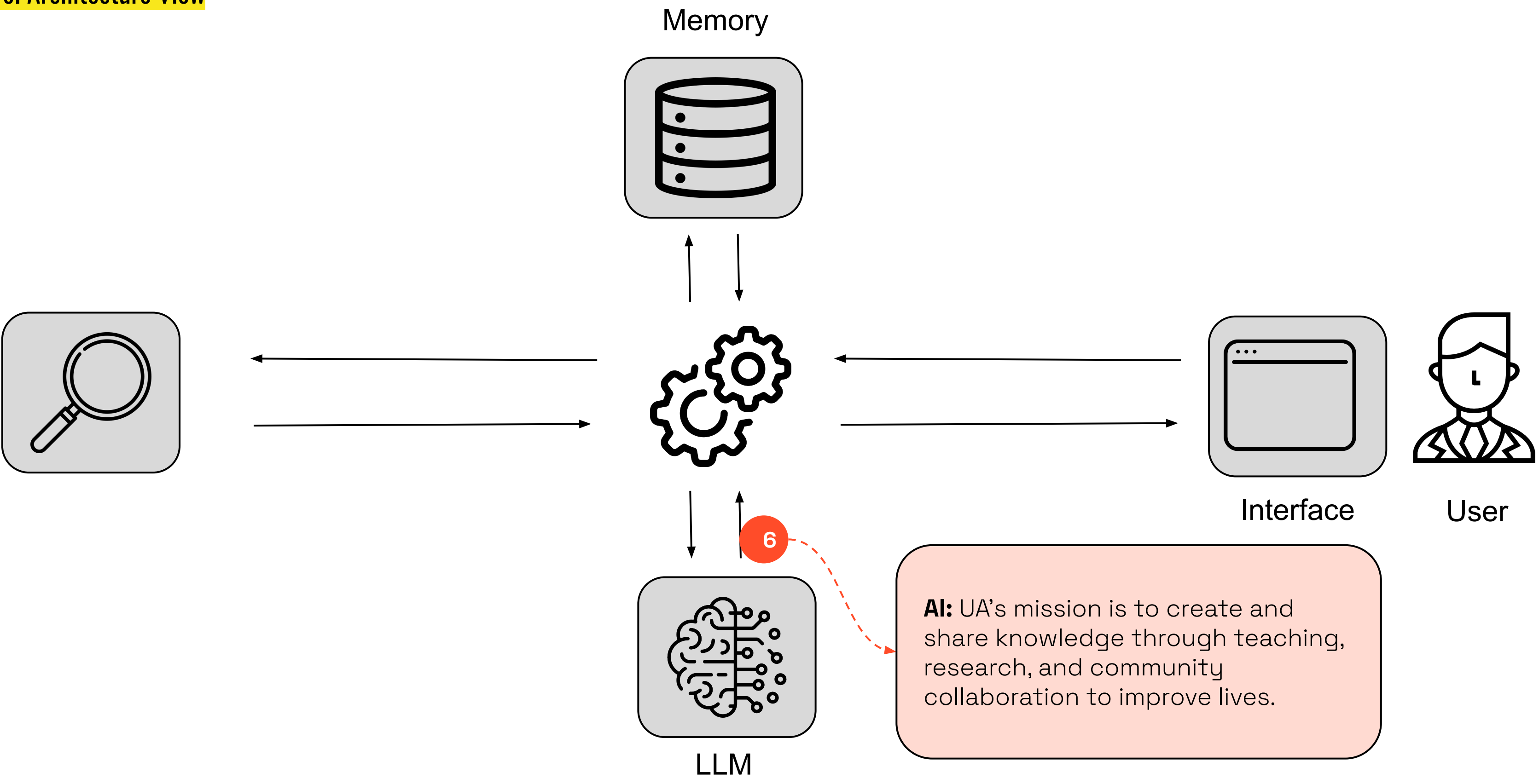
History:
User: Where's UA located?
Agent: Aveiro University...
User: What's Aveiro University mission?

User: What's Aveiro University mission?
AI:



Retrieval Augmented Generation (RAG)

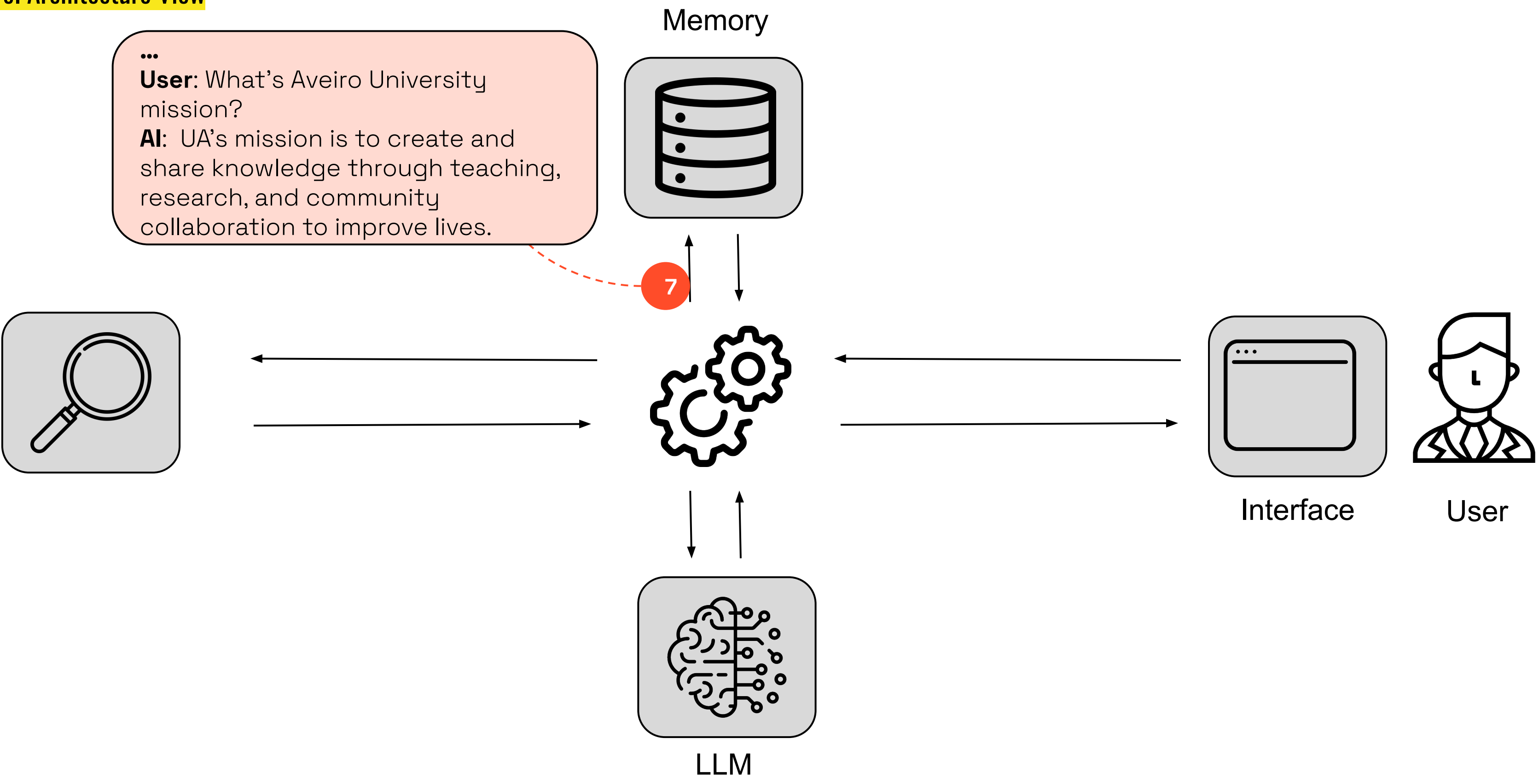
High-level Architecture View



AI: UA's mission is to create and share knowledge through teaching, research, and community collaboration to improve lives.

Retrieval Augmented Generation (RAG)

High-level Architecture View



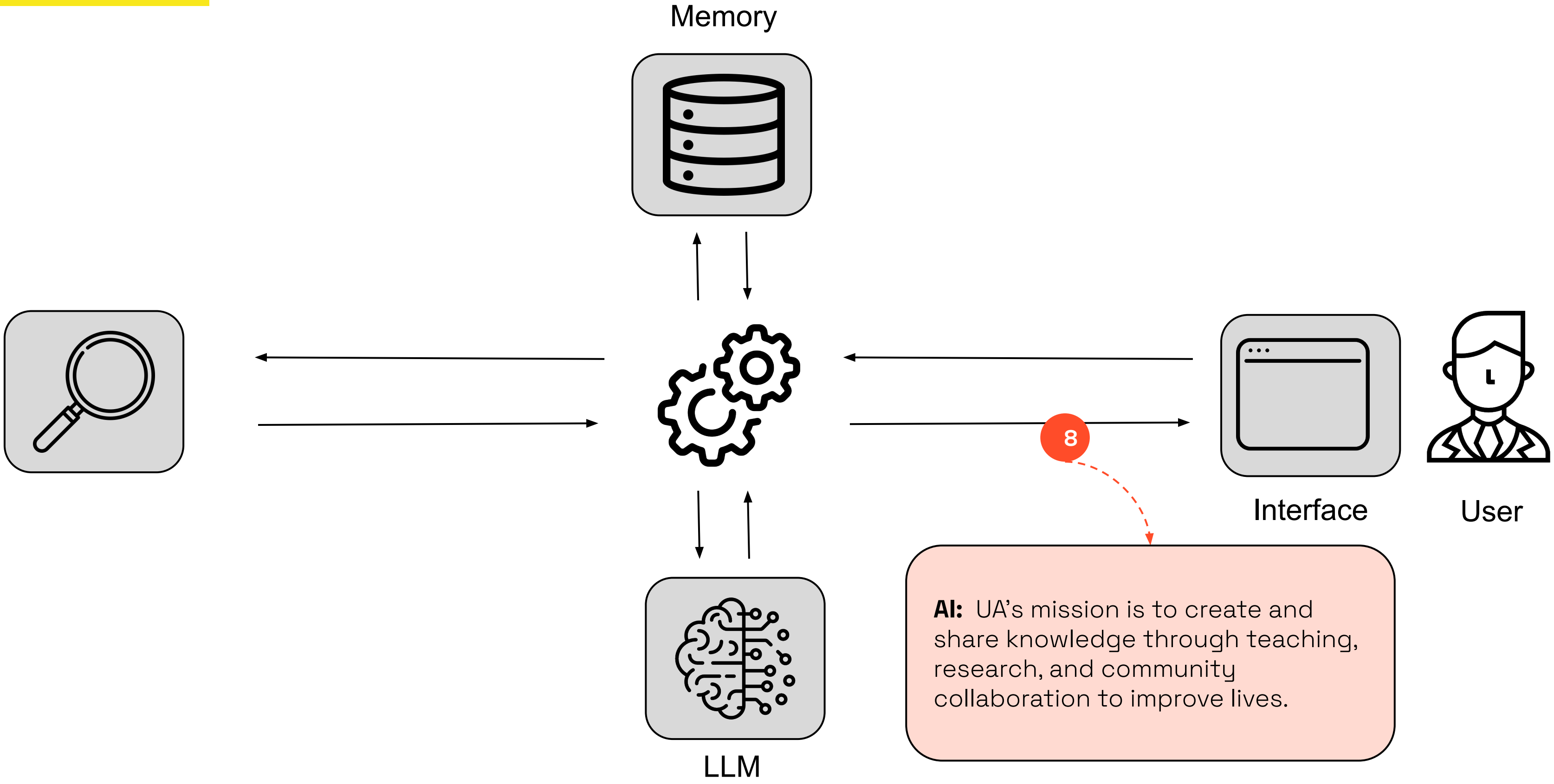
…

User: What's Aveiro University mission?

AI: UA's mission is to create and share knowledge through teaching, research, and community collaboration to improve lives.

Retrieval Augmented Generation (RAG)

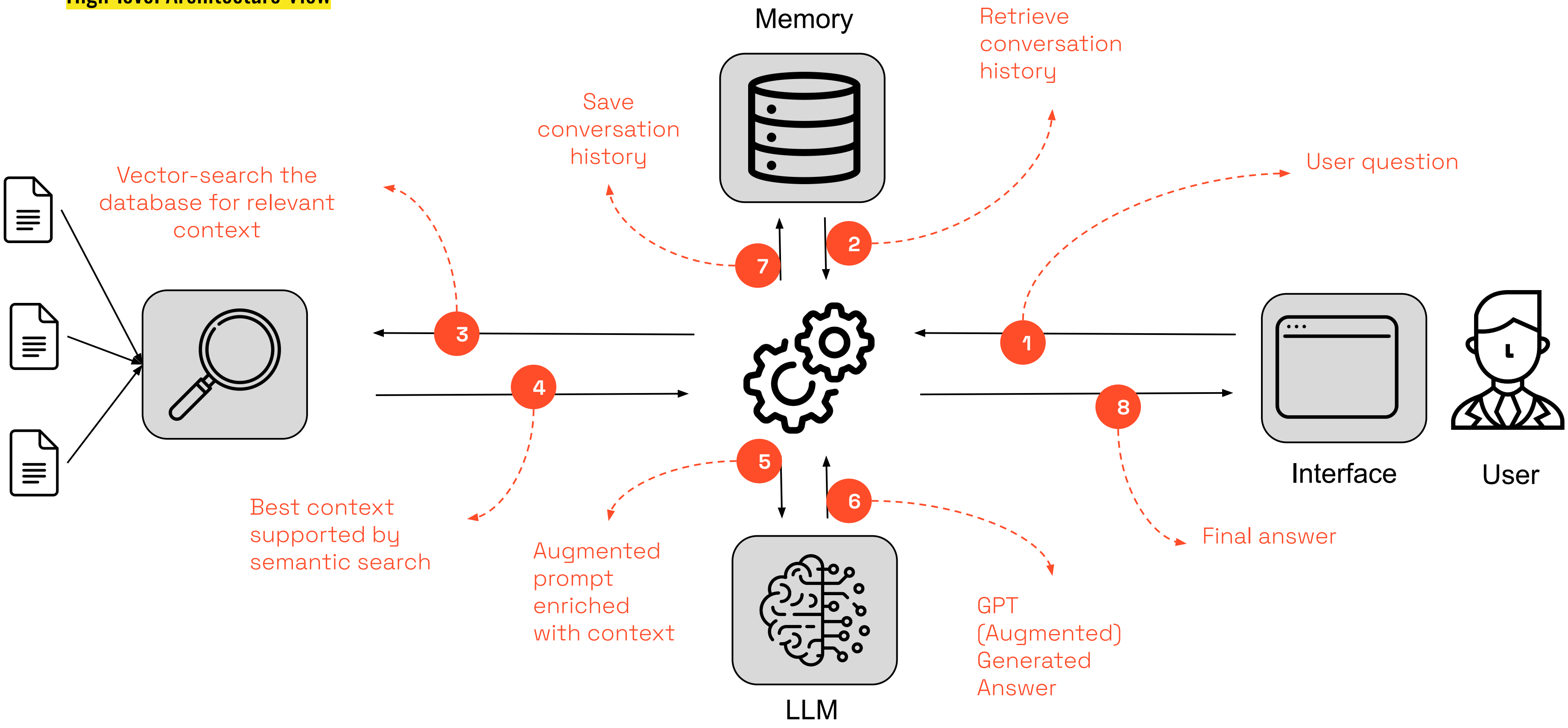
High-level Architecture View



AI: UA's mission is to create and share knowledge through teaching, research, and community collaboration to improve lives.

Retrieval Augmented Generation (RAG)

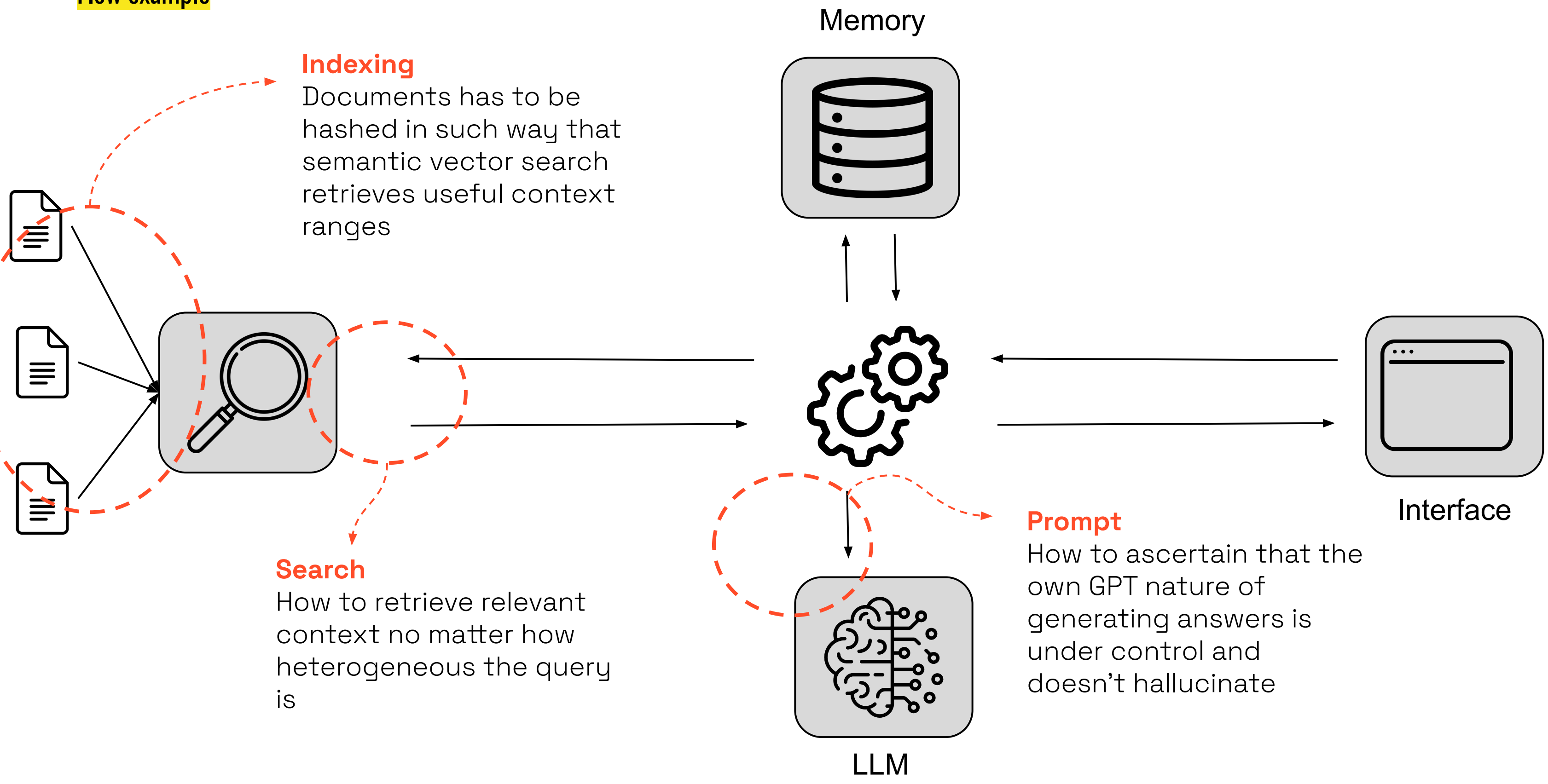
High-level Architecture View


Memory
Retrieve conversation history
Save conversation history
Vector-search the database for relevant context
User question
7
2
3
1
4
8
5
6
Interface
User
Best context supported by semantic search
Final answer
Augmented prompt enriched with context
GPT (Augmented) Generated Answer
LLM

Main RAG Challenges

Retrieval Augmented Generation (RAG)

Flow example



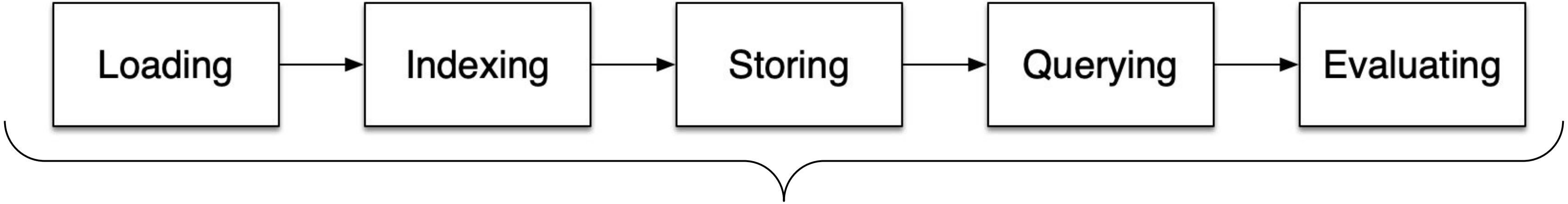
Indexing
Documents has to be hashed in such way that semantic vector search retrieves useful context ranges

Search
How to retrieve relevant context no matter how heterogeneous the query is

Prompt
How to ascertain that the own GPT nature of generating answers is under control and doesn’t hallucinate

Hands on!

LlamaIndex



Loading

Indexing

Storing

Querying

Evaluating

Why LlamaIndex?

- Supports the whole chain
- Opensource

Has interfaces for:

- > 40 vector stores
- > 40 LLMs
- > 160 data sources

Alternatives:

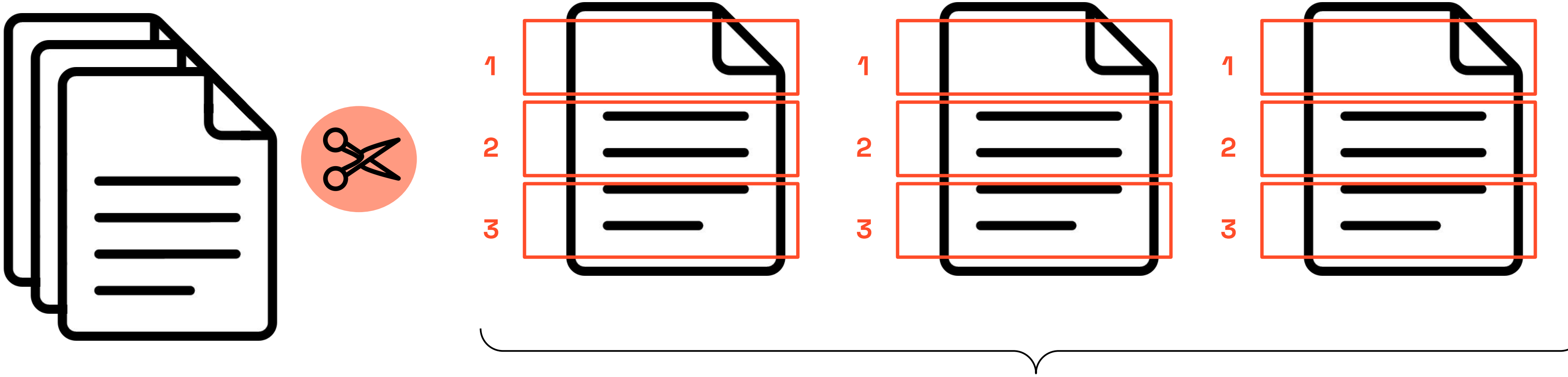
- Haystack
- RAGFlow
- Graphlit
- Llangchain (kinda)

Notebook

- https://github.com/luminoso/dspt-handson-llamaindex

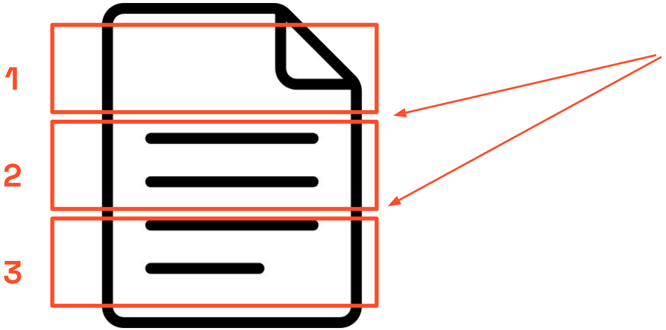
Chunking

Document chunking



One paragraph per chunk

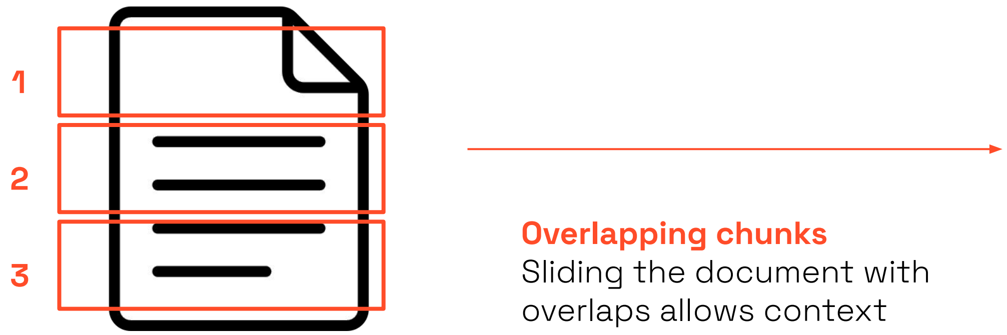
Document chunking



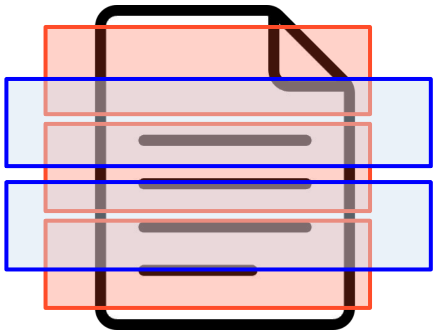
Chunk could crop or make context inconsistent

Probability of losing context

Document chunking

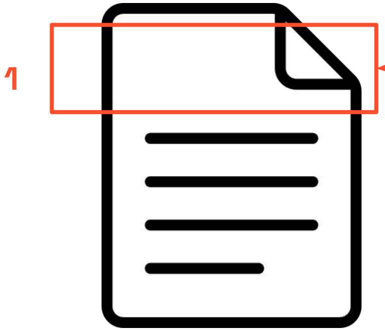


Overlapping chunks
Sliding the document with overlaps allows context preservation



Embedding

Embeddings

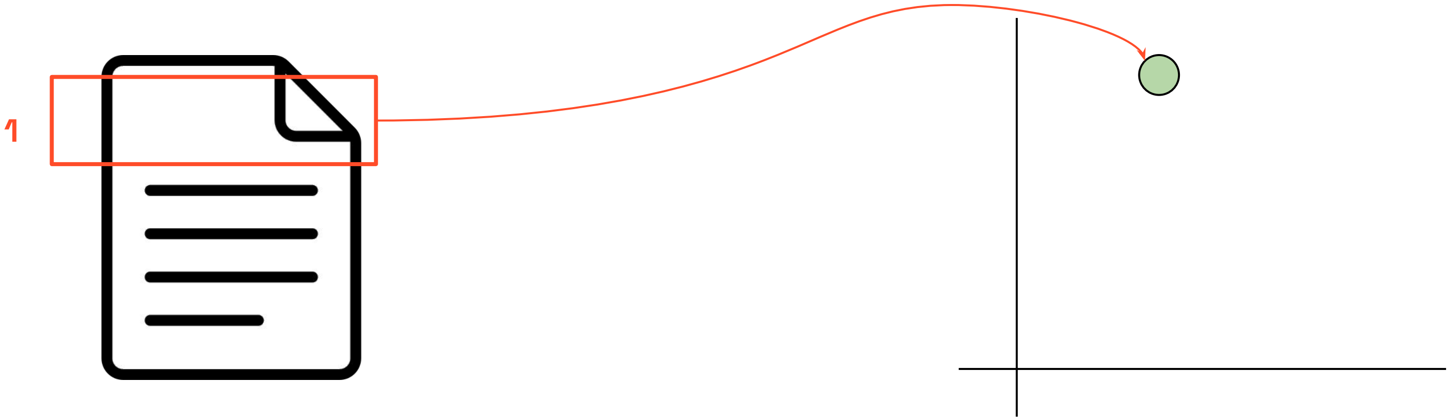


Created in 1976 by architect Firmino Trabulo, the original signature of the University of Aveiro incorporates several symbols (a griffon, a book, the armillary sphere, and the Greek words “theoria”, “poiesis”, “praxis”) that personify the importance that the University of Aveiro has attributed, since its foundation, to the connection to the region; to the defense of wisdom, in the teaching and research aspects; to the universality of knowledge; and to the various aspects of theoretical, technological, artistic and humanistic crea….

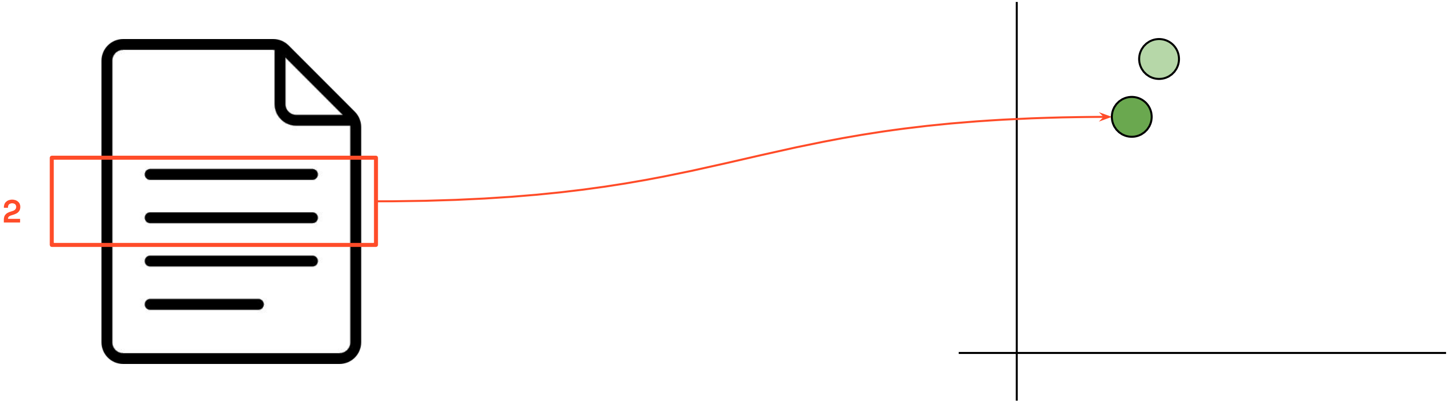
Text meaning is translate into a compressed vector that represents its meaning

```
[-0.0032757148146629333, -0.011690735816955566, 0.041559211909770966,
-0.03814808651804924,....
```

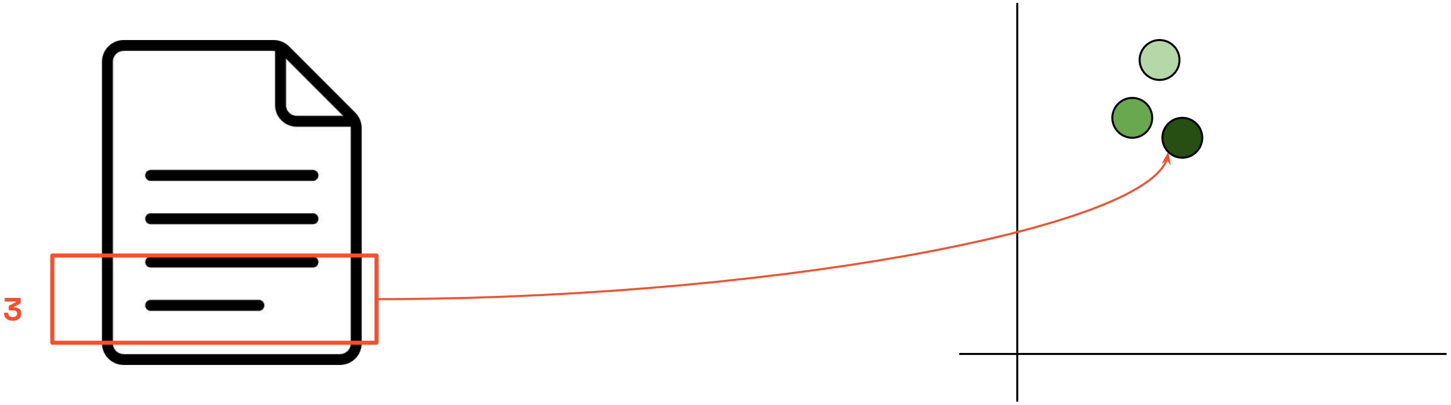
Embeddings



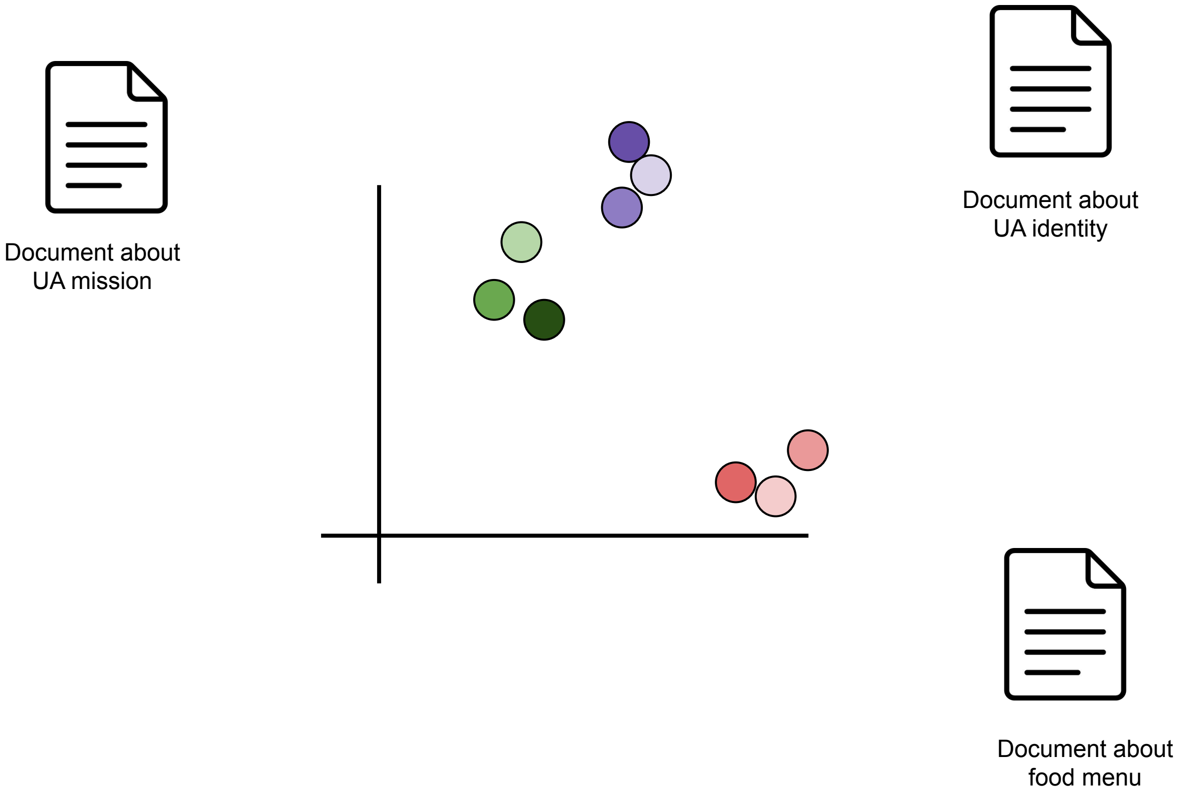
Embeddings



Embeddings



Embeddings for multiple documents

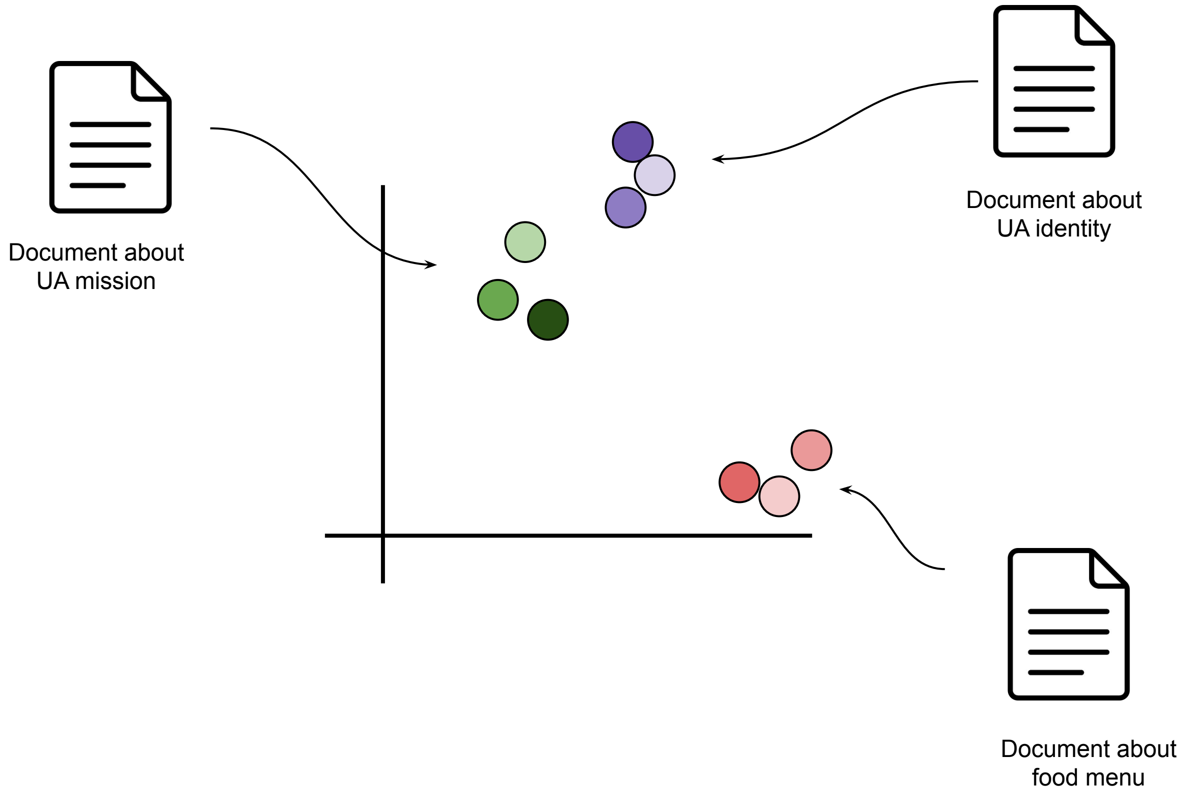


Document about
UA mission

Document about
UA identity

Document about
food menu

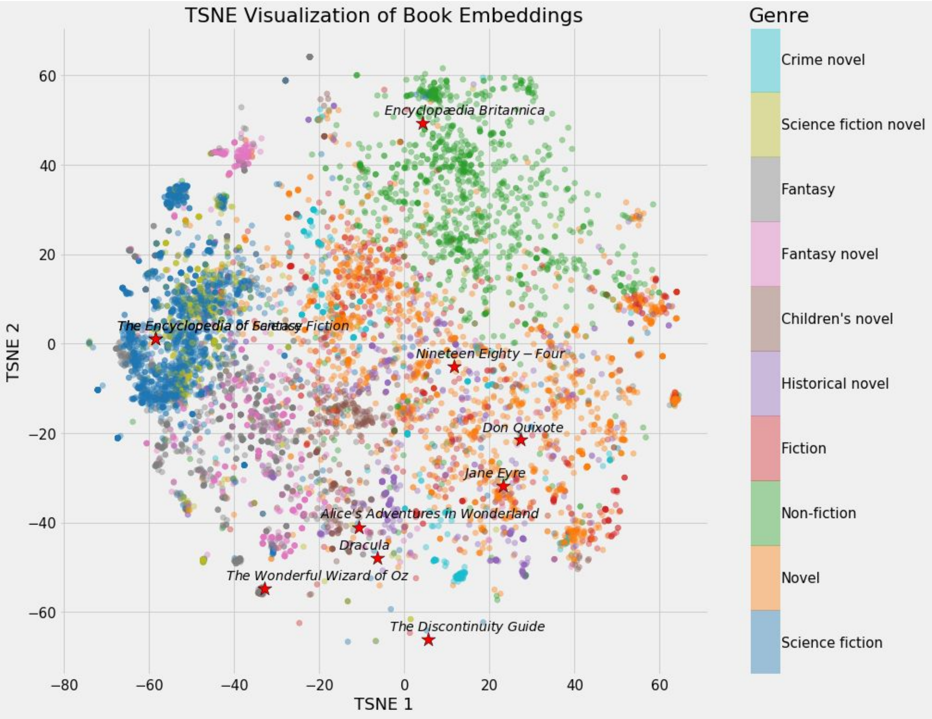
Embeddings for multiple documents


Document about
UA mission

Document about
UA identity

Document about
food menu

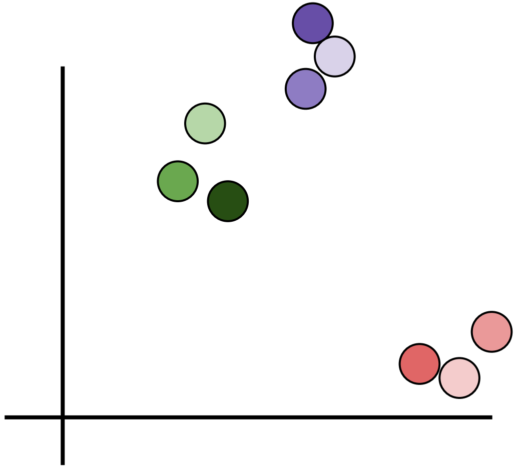
Embeddings real world example



Querying

Embeddings for multiple documents

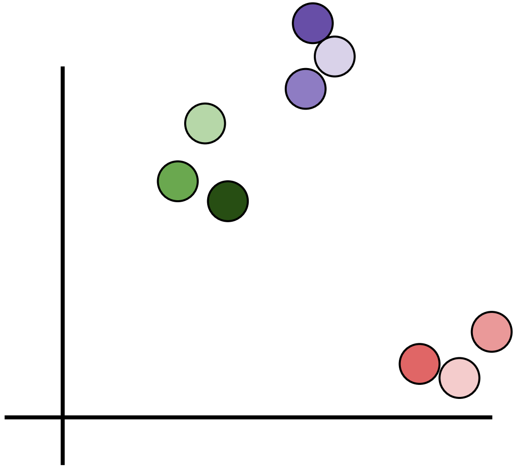
Your question
"What's in the food menu for friday dinner?"



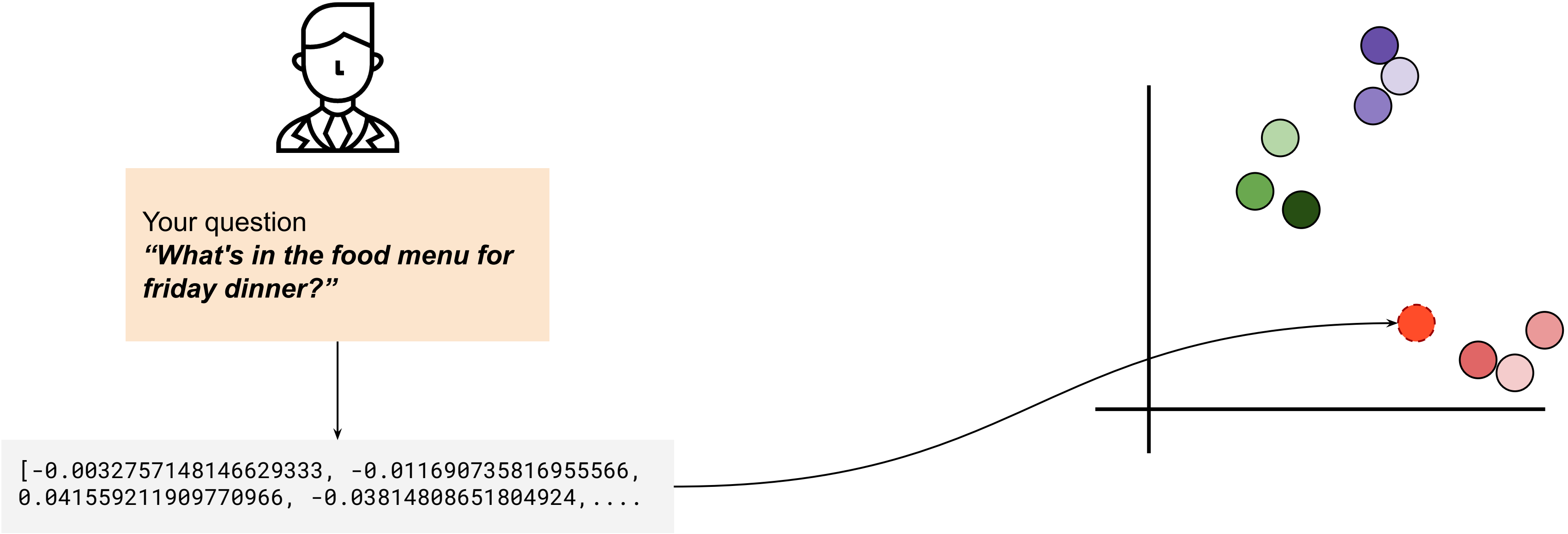
Embeddings for multiple documents

Your question
“What's in the food menu for friday dinner?”

```
[-0.0032757148146629333, -0.011690735816955566,
0.041559211909770966, -0.03814808651804924,....
```



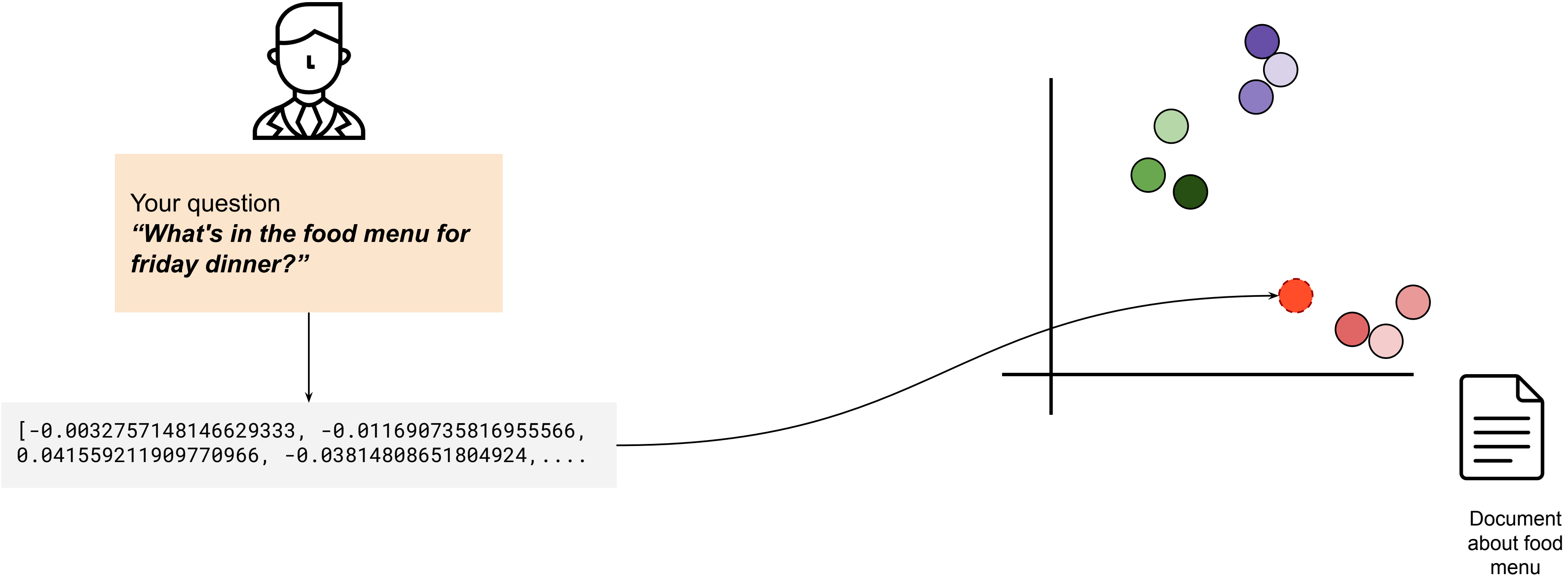
Embeddings for multiple documents



Your question
“What's in the food menu for friday dinner?”

```
[-0.0032757148146629333, -0.011690735816955566,
0.041559211909770966, -0.03814808651804924,....
```

Embeddings for multiple documents



Your question
“What's in the food menu for friday dinner?”

```
[-0.0032757148146629333, -0.011690735816955566,
0.041559211909770966, -0.03814808651804924,....
```

Document about food menu

Our experience

- v1:
- deixar pq é rag não substitui uma equipa de DS
    - pq precisamos de customizar, escalar
- alguns numeros?
- como usamos na scotty
- tirar fora a memória pq n é demoed

The end

Questions?

…and thank you!

References

Sources and references:

1. **The Retrieval Augmented Generation Pattern - André Vala - Cloud Solution Architect | Data & AI @ Microsoft - DataMakers Fest 2023**
2. Retrieval-Augmented Generation for Knowledge-Intensive NLP Tasks (FAIR, April 2021) https://arxiv.org/abs/2005.11401
3. https://docs.llamaindex.ai/en/stable/getting_started/concepts.html
4. https://research.aimultiple.com/gpt/
5. https://pub.towardsai.net/how-do-8-smaller-models-in-gpt4-work-7335ccdfcf05
6. https://github.com/DataSciencePortugal/large-language-models
7. https://www.promptingguide.ai/techniques/
8. TheAiEdge.io: Search in vector database: locality-sensitive hashing
9. Icons from Flaticon.com
10. https://www.thenationalnews.com/business/technology/2023/04/23/why-googles-search-dominance-is-feeling-the-heat-from-chatgpt/
11. https://www.financialexpress.com/life/technology-chatgpt-can-destroy-google-in-two-years-says-gmail-creator-2962712/lite/