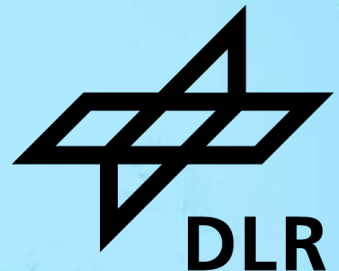


UTILIZING THE POWER OF LLMS FOR THE ECSS STANDARDS IN SPACE PROJECTS

Laura van Uffelt, **Nico Borgsmüller**, Tamara Gutierrez Rojo, Andreas Lund, Daniel Lüdtke



- ECSS is a framework for cooperation on scientific and technical research projects. These are widely adopted in the space industry to ensure high-quality software products. However, following these standards can be time-consuming and require significant expertise.
- The goal of this practical project is to implement and evaluate technique(s) based on LLM technology to decrease the time used on ECSS.

Motivation

- ECSS standards are extensive
- >140 standards >15000 pages
- Time-consuming to find answers to specific questions
- Required in many space related projects



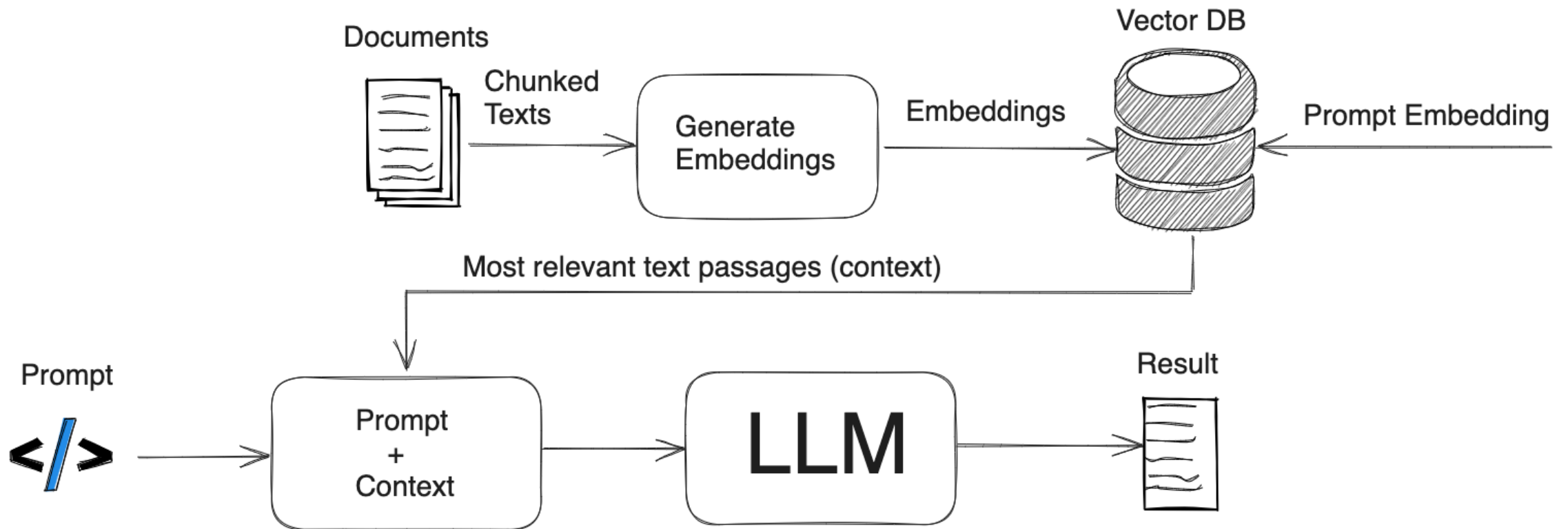
Idea



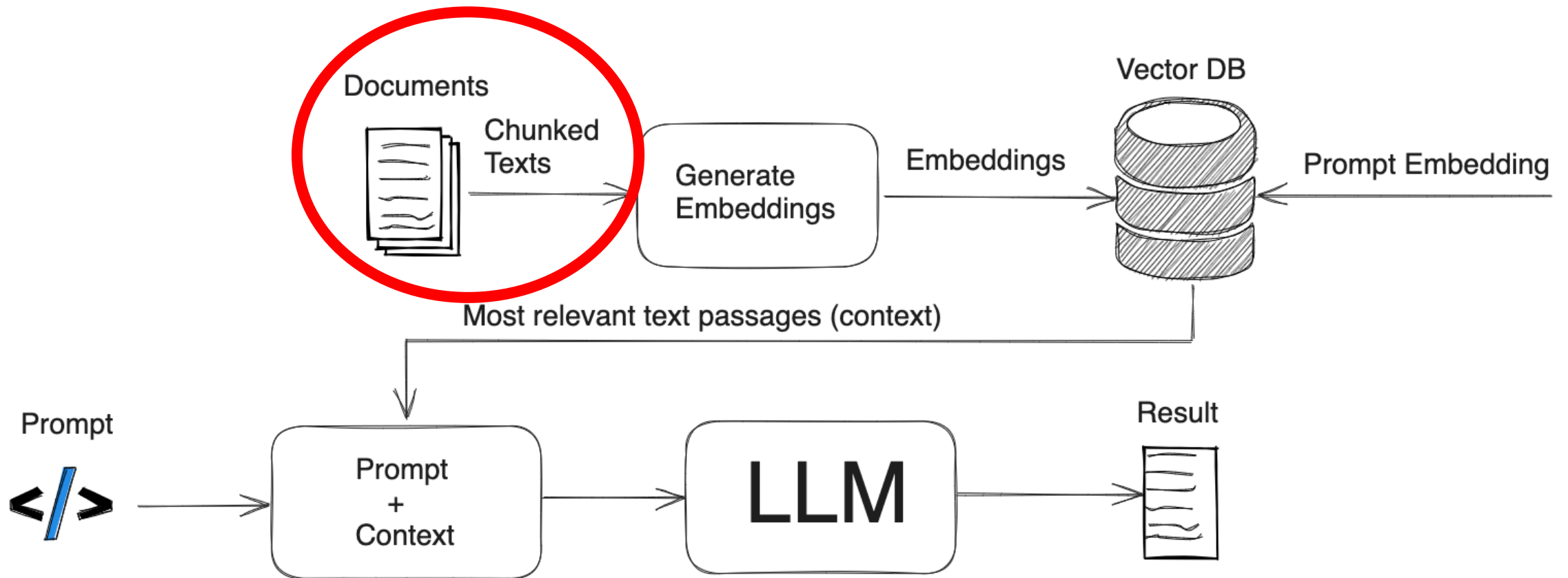
- Make the use of ECSS easier
- Develop a chatbot like ChatGPT or Ollama
- Chatbot should be able to answer specific questions about ECSS
- Should give references to locations in the documents



RAG (Retrieval-Augmented Generation)

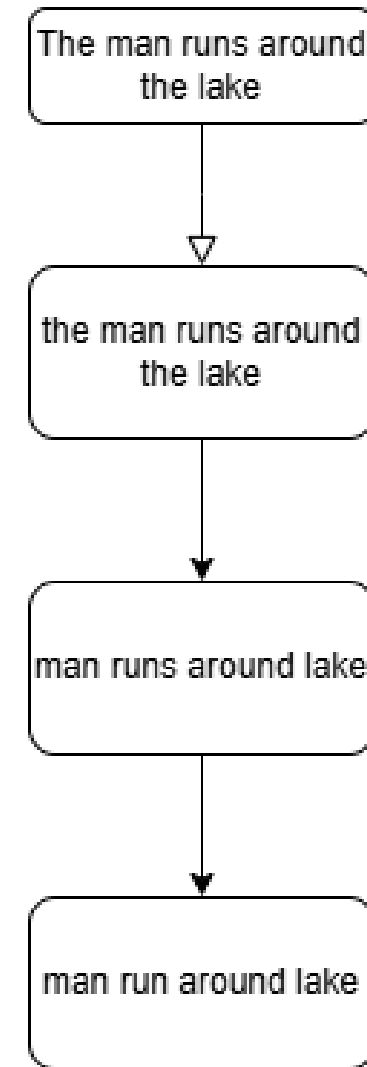


RAG (Retrieval-Augmented Generation)

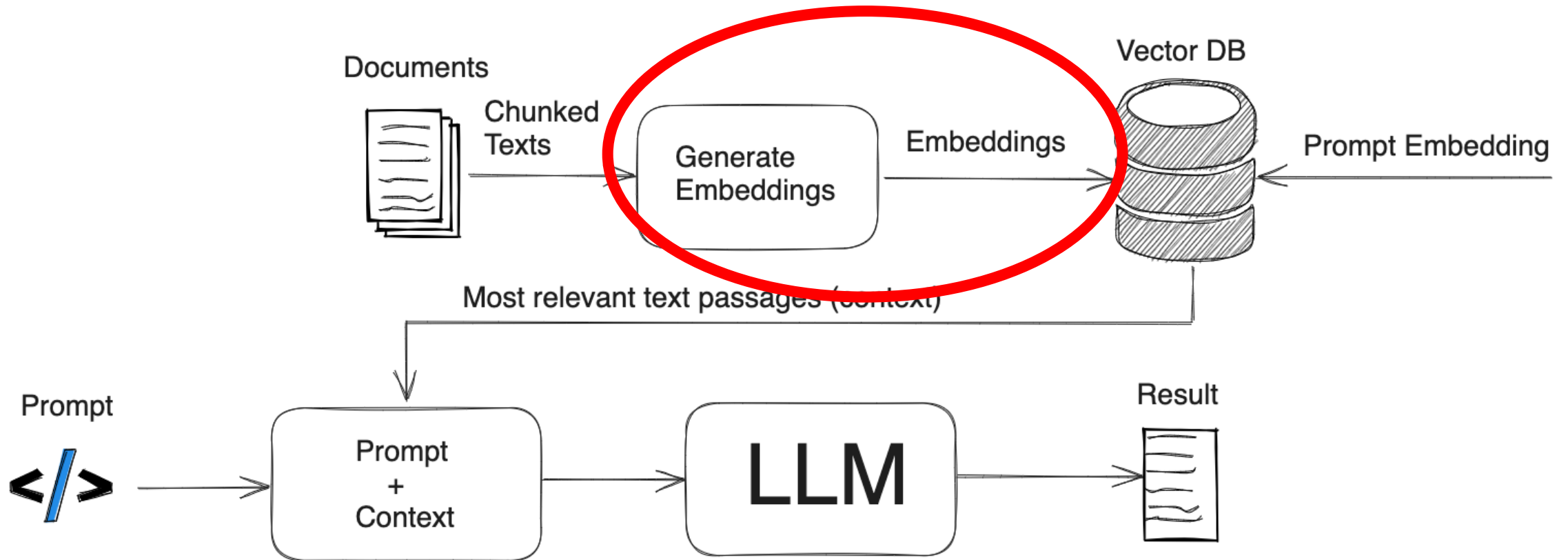


Text preparation

- Extract the text from PDFs with pyPDF2
- Lower the text
- Remove stop words
- Lemmatize
- Before: The man runs around the lake
- After: man run around lake
- Tables / Figures get lost



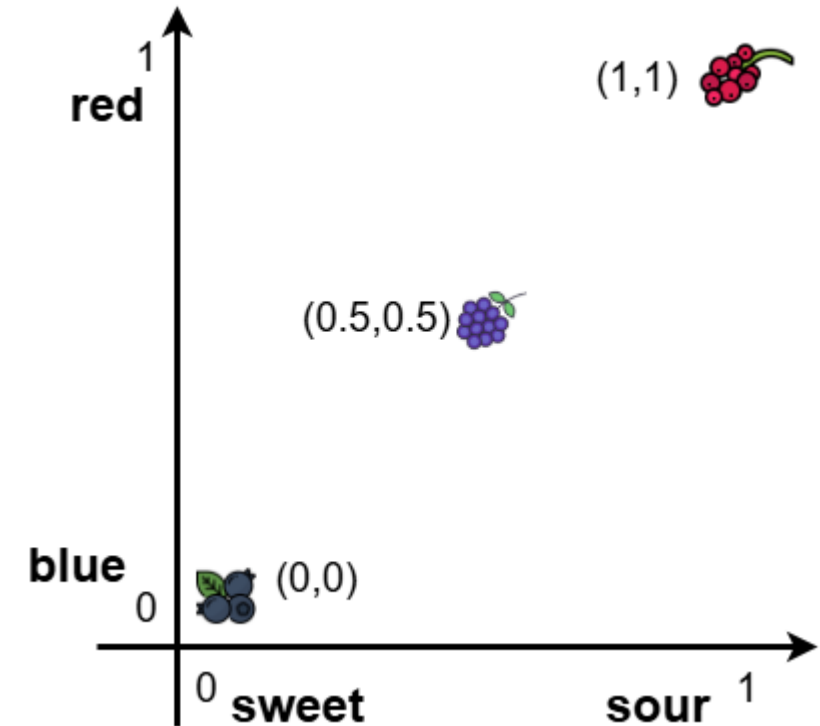
RAG (Retrieval-Augmented Generation)



Embedding vectors



- Embeddings represent text
- Embeddings are vectors with multiple dimensions



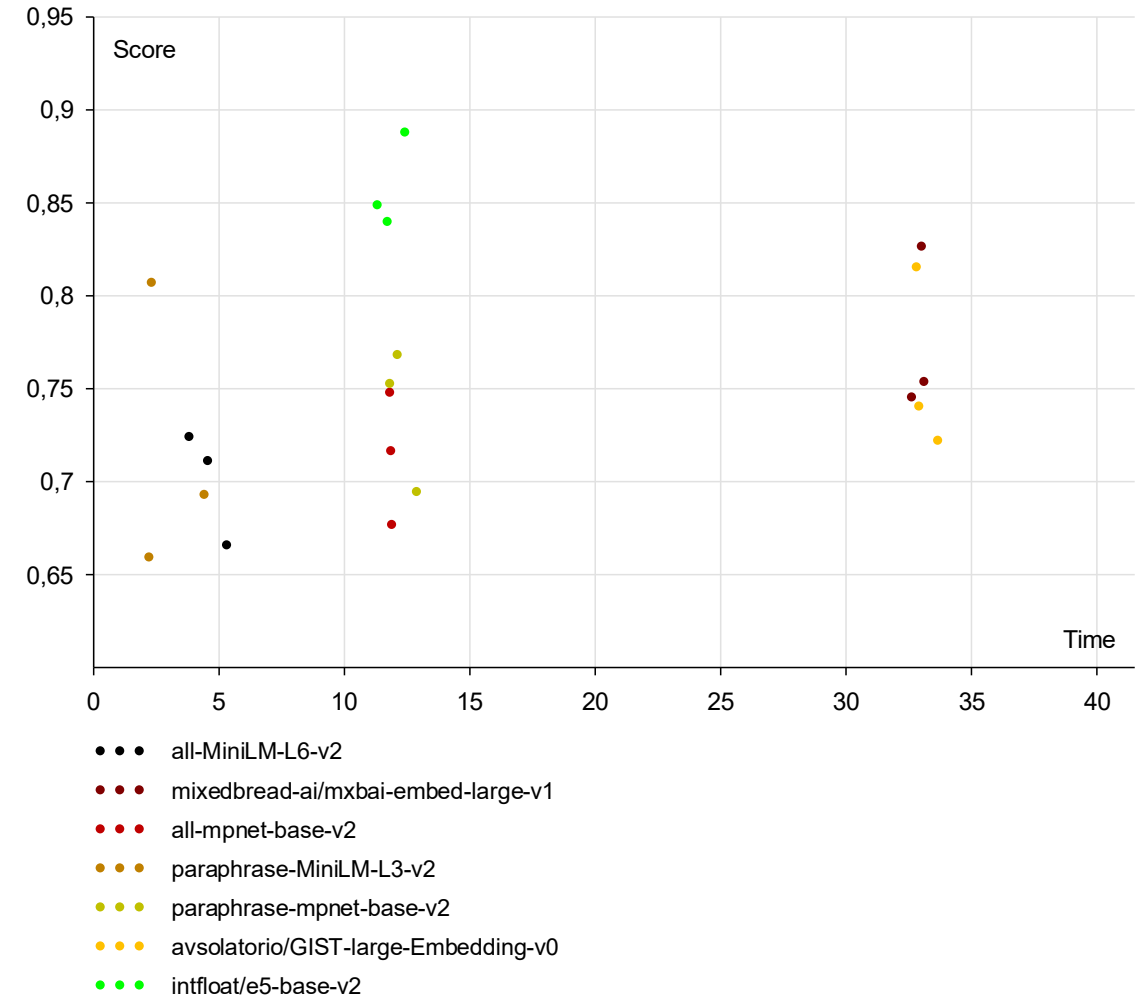
Embedding models



- Score is cosine similarity

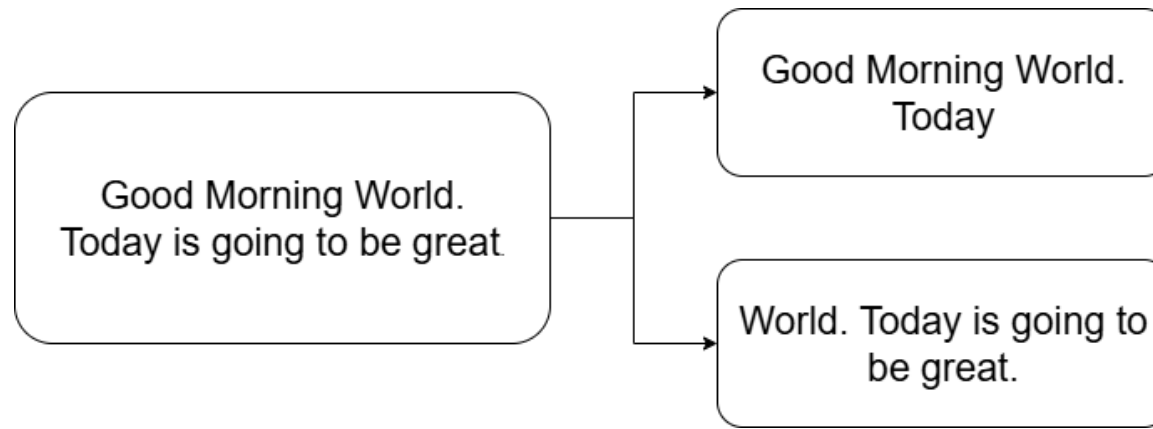
$$\text{cos_sim} = \frac{x \cdot y}{|x| * |y|}$$

- Requirements: open source, no quota limitation
- Accuracy over speed
- MTEB Leaderboard used for selection of models (as of February)



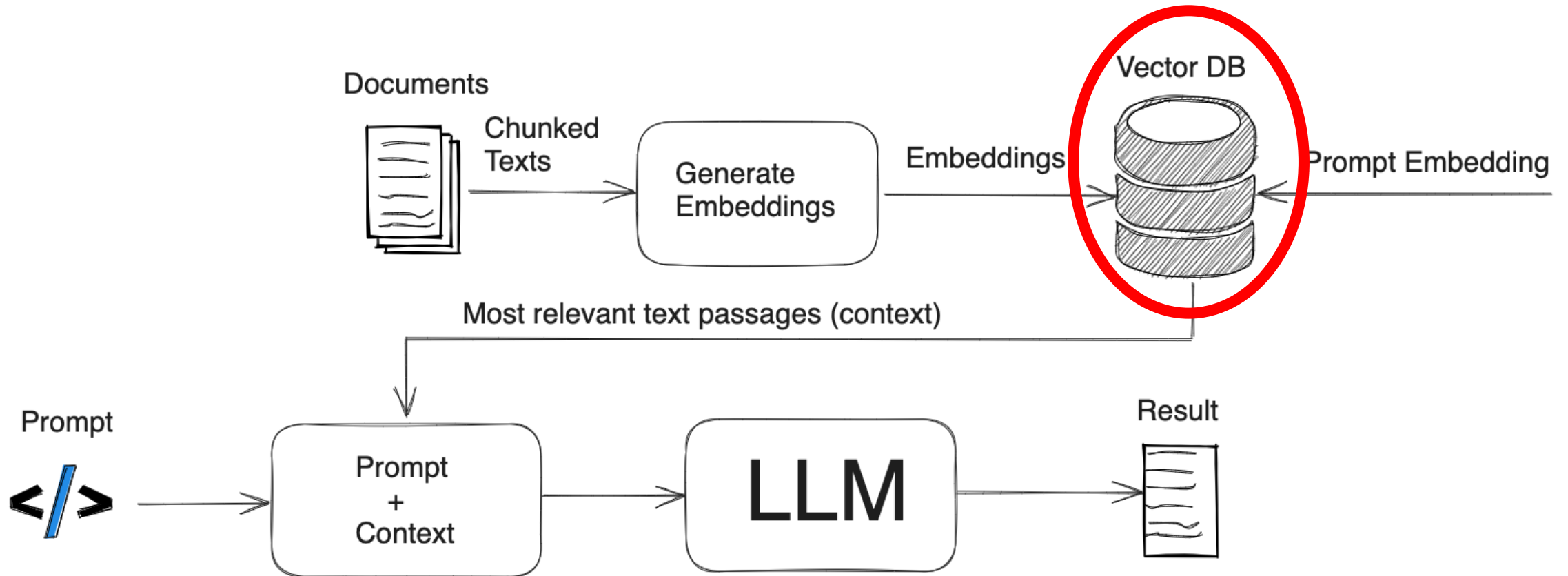
Embedding creation implementation

- Chunk the text using the RecursiveCharacterTextSplitter and an overlap



- Creation uses intfloat/e5-base-v2 model
- Stores chunks and embeddings in JSON files
- JSON can be loaded into the database (no need for regeneration)

RAG (Retrieval-Augmented Generation)



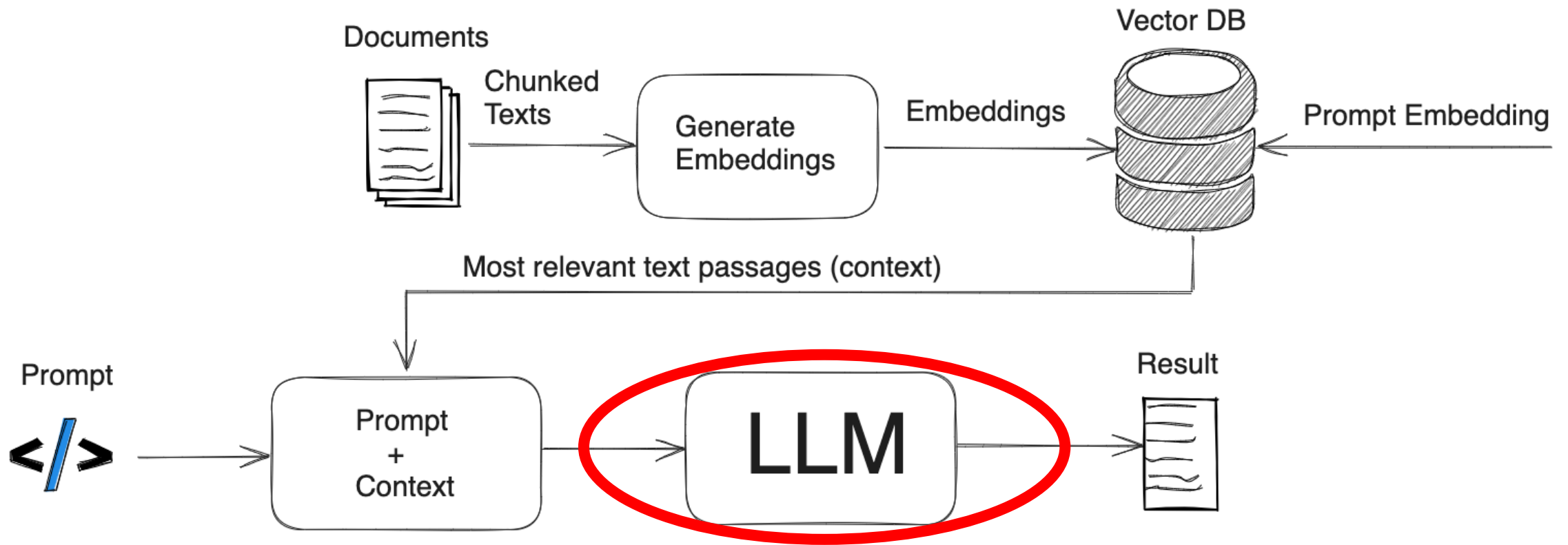
Vector databases



- Requirements:
 - Local execution without docker
 - Open-source nature
 - Integrated search functions
- Several models where evaluated

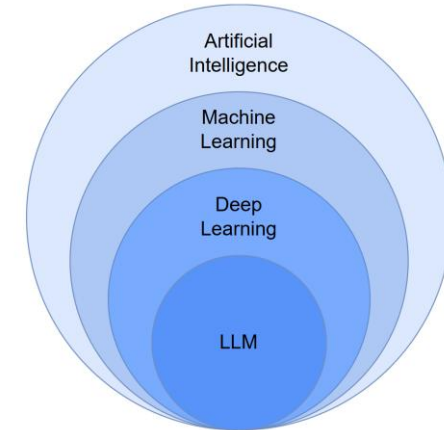
Properties	FAISS	Qdrant	Chroma
Developer	Facebook	Open-source	open-source
Integrated search functions	No hybrid functions	yes	yes
Use without docker	yes	Yes, but not free of charge	yes

RAG (Retrieval-Augmented Generation)



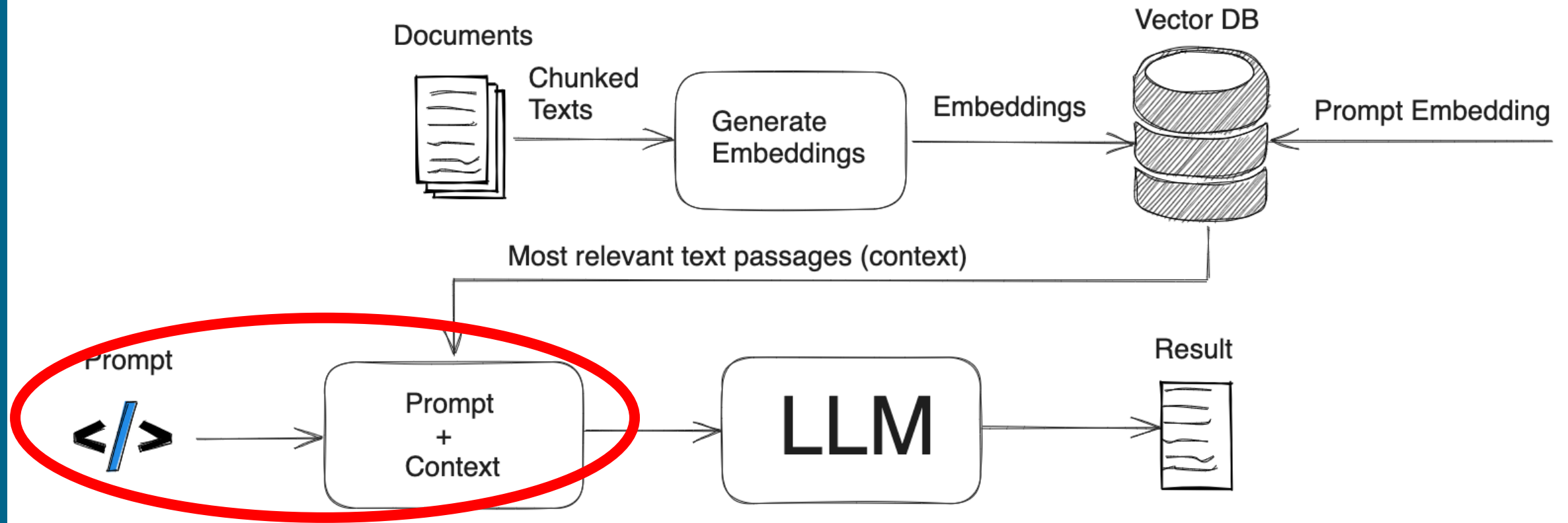
LLM (Large Language Model)

- Machine learning model used for natural language processing
- Use of principles like deep learning
- Many layers and parameters in neural network



properties	Llama3.2	GPT-3 (OpenAI)
opensource	yes	no
parameters	3 - 65 billion	175 billion
data-processing	local	In cloud
Use cases	multimodal	Specialized on text based

RAG (Retrieval-Augmented Generation)

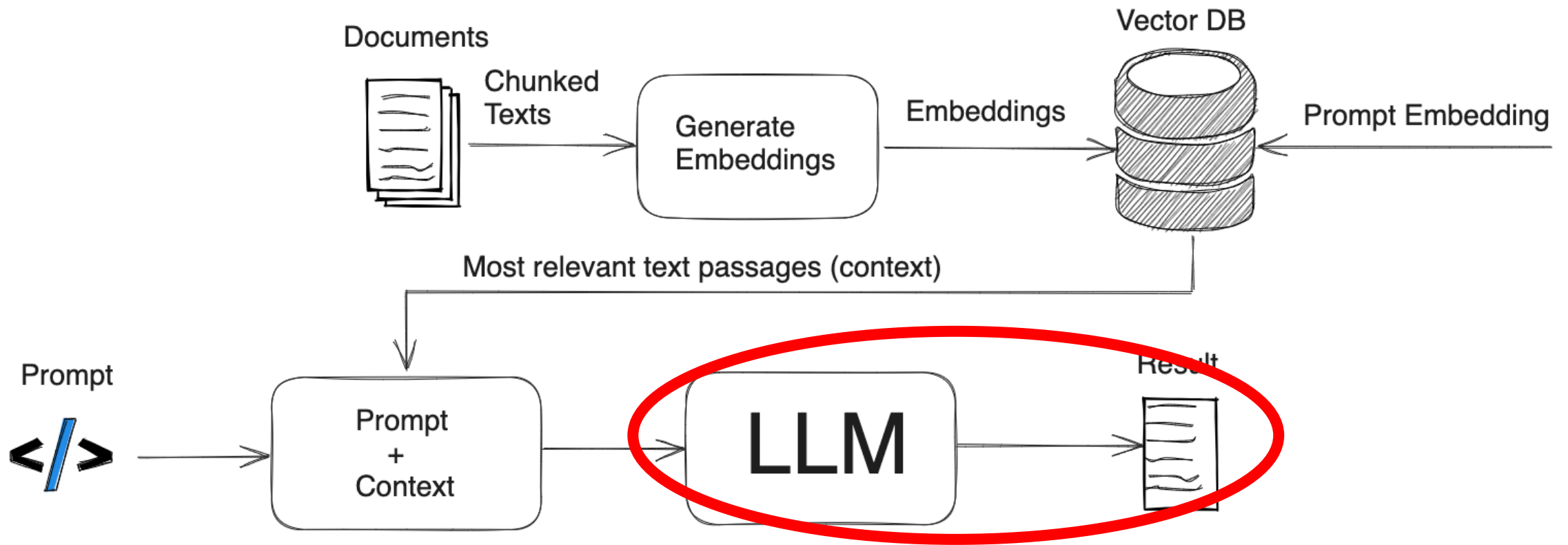


Database access and search



- From prompt: Generate embeddings
- Retrieve closest matches from vector database
- To provide more context neighboring embeddings are also included
- Structured result includes embedding values and corresponding text snippets

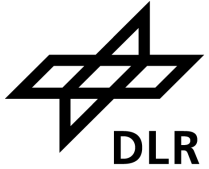
RAG (Retrieval-Augmented Generation)



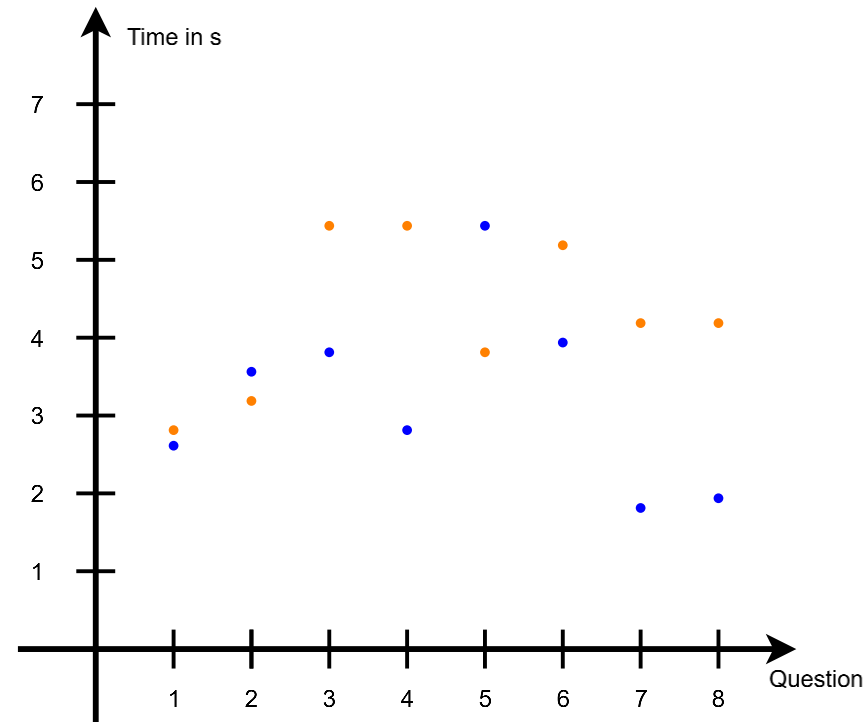
- Combine System Prompt, Embeddings and User query
- Llama3.2 is only used for response generation
- Llama3.2 gets the query, the retrieved embeddings and all previous queries and answers

`“You are a helpful reading assistant who answers questions based on snippets of text provided about ECSS. ECSS is the European cooperation for space standardization. Answer using the context provided, being as concise as possible. Always give references. If you're unsure, just say that you don't know.”`

Performance

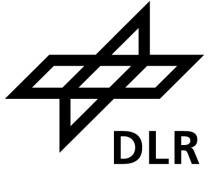


- Intel Core i9-13900K, 2x32GB RAM
 - NVIDIA GeForce RTX3060
 - Multiuser
-
- Depends on question asked
 - Some questions take up to 30 seconds
 - The fastest measured were about 3 seconds
-
- Embedding creation takes a lot of time (not measured)



- Llama 3.2
 - tailored model
- 1 What is ECSS?
 - 2 What is my role as software product assurance manager?
 - 3 Give me Details about ECSS
 - 4 Which documentation shall be delivered at CDR?
 - 5 Which metrics should be collected on the developed software?
 - 6 Which steps are necessary for defining the verification and validation processes?
 - 7 About ECSS tailoring: Which standard documents are applicable to a software-only product?
 - 8 How many ECSS standards are there?

Quality of the answers



	Llama3.2	Tailored model
What is ECSS?	ECSS stands for European Cooperation in the Exploration of Space. It is an intergovernmental organization that facilitates cooperation among European countries in space exploration and development. ECSS was established in 1975 and has since played a significant role in promoting European collaboration in space-related activities. ...	ECSS stands for European Cooperation for Space Standardization. It is a framework that provides standardization and guidelines for the development, operation, and maintenance of space products and systems in Europe. ...
What is the Q Branch about?	The Q Branch of the European Cooperation in the Exploration of Space (ECSS) is specifically focused on **Quality Standards**. ...	According to the provided text, the Q Branch of ECSS seems to be related to "Product Assurance" and "Quality Assurance". ...

Examples

what do you want to know? -> Which steps are necessary for defining the verification and validation processes?

Based on the provided text, it appears that the verification process defined in ESS (European cooperation for space standardization) is done in three steps:

1. Early verification: Compatibility ICD interface requirement, resulting in a signed version of the ICD supplier and customer part approval process.
2. Standalone interface end demonstration compliance ICD taking account verification requirements associated interface requirements, performed by the supplier with responsibility for relevant product prior to delivery of the product.
3. Joint verification: Interface term function performance involving different interfacing products, performed in collaboration with the customer with supplier support and integration of various products, taking into account higher-level verification requirements.

Additionally, the document mentions the need to define the:

- * Verification approach
- * Model philosophy
- * Verification strategy

These steps are likely necessary for defining the verification and validation processes. However, I don't have more information on the specific details of these steps.

--- 84.2856183052063 seconds ---

what do you want to know? -> What is the recommended structure of a Software User Manual (SUM)?

According to ECSS, a SUM (Software User Manual) should contain:

1. Operational Organisation
2. Reference Schedule
3. Operational Profile
4. List of Elementary Operations carried out at the Site
5. Order for Operation at the Site
6. Personnel Responsible

(Source: ECSS E ST 40C, March 2009, page 121)

Please note that this is a general structure and may vary depending on the specific requirements of the software and its intended use.

Would you like me to clarify or expand on any of these points?

--- 85.95658612251282 seconds ---

what do you want to know? -> |

Problems



- If model gets one answer wrong, it takes this wrong answer into account for the following queries.
- Retrieved context is very limited. The response often states a single requirement from ECSS as the only aspect about a certain topic.
- Slow response times

Future work



- Conduct user study thoroughly
 - User should have time to experiment with the models
- Store documents differently
- Use more complex search algorithm
- Use more complex version of RAG
- Experiment with different language models