

# RAG: Retrieval Augmented Generation - Lecture 5

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# Syllabus

## Week 1: Introduction to Generative AI and Large Language Models (LLM)

- Introduction to Large Language Models (LLMs) and their architecture
- Overview of Generative AI and its applications in NLP
- Lab: Tokenizers

## Week 2: Using LLMs and Prompting-based approaches

- Understanding prompt engineering and its importance in working with LLMs
- Exploring different prompting techniques for various NLP tasks
- Hands-on lab: Experimenting with different prompts and evaluating their effectiveness

## Week 3: Evaluating LLMs

- Understanding the challenges and metrics involved in evaluating LLMs
- Exploring different evaluation frameworks and benchmarks
- Hands-on lab: Evaluating LLMs using different metrics and benchmarks

## Week 4: Fine-tuning LLMs

- Understanding the concept of fine-tuning and its benefits
- Exploring different fine-tuning techniques and strategies
- Hands-on lab: Fine-tuning an LLM for a specific NLP task

## Week 5: Retrieval Augmented Generation (RAG)

- Understanding the concept of RAG and its advantages
- Exploring different RAG architectures and techniques
- Hands-on lab: Implementing a RAG system for a specific NLP task

## Week 6: Use cases and applications of LLMs

- Exploring various real-world applications of LLMs in NLP
- Discussing the potential impact of LLMs on different industries
- Hands-on lab: TBD

## Week 7: Final report preparation

- Students work on their final reports, showcasing their understanding of the labs and the concepts learned.

# Prereqs

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- LLMs
- Embeddings and embedding models
- Vector Search

# Outline

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- LLMs strengths vs weaknesses
- RAG
- Embeddings and vector search
- Practical dive into RAG
- Lab assignments

# LLMs: strengths (class)

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- Cross-domain nature and understandable and relatively reasonable texts
- Variety of downstream tasks
- Ability to adapt
- LLM API is very natural to use (speaks to the usage)
- Robustness to noise during training
- High ratio: speed vs amount of tasks
- 0-shot learning capability
- Quicker access to knowledge
- Lots of data is supported
- Multilingualism
- Capture long range dependency

# LLMs: strengths (Dima)

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- Advanced language understanding
- Human-like text generation capability (vs 10 blue links in Google)
- Few-shot / 0-shot learning
- Versatile applications: sentiment analysis, content creation, customer support automation, coding assistance and more (Week 6)
- II architecture, scalable and relatively simple architecture

# LLMs: weaknesses (class)

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- Hallucinations
- Power-greedy
- Overkill for some ML tasks (too broad)
- You need lots of data
- Bias
- Catch-22: lack of reasoning
- Non-transparency of the model - no links to the training set (citations)
- LLMs do not provide citations
- Non-transparency around reasoning
- No awareness of the changes
- Not democratized
- Abilities are unpredictable
- Input / output spaces are huge

# LLMs: weaknesses (Dima)

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- **Not up to date** with the changing world / domain
- Do not provide **references** to the answer (like 10 blue links in Google)
- Can **hallucinate** (lack of specialized knowledge)
- **Dependence on context**: lack depth, accuracy or *logical consistency*
- **Need lots of GPU / compute** (GPU RAM, CPU latency)

# Example of a hallucination

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The image displays two side-by-side screenshots of Google search results, illustrating AI-generated hallucinations.

**Left Screenshot:** A Google search for "How many rocks shall i eat". The search bar shows a misspelling of the query. The results page indicates a search for "How many rocks **should** i eat" instead. The AI Overview section claims that geologists at UC Berkeley suggest eating at least one small rock per day for mineral and vitamin intake. This statement is factually incorrect.

**Right Screenshot:** A Google search for "cheese not sticking to pizza". The results page includes an AI Overview snippet that advises adding non-toxic glue to pizza sauce to increase tackiness. This advice is completely不合逻辑 and irrelevant to the search query.

**Ref :**  
<https://theconversation.com/eat-a-rock-a-day-put-glue-on-your-pizza-how-googles-ai-is-losing-touch-with-reality-230953>

7.41



ChatGPT &gt;



What is EBITDA of 7.74M?



EBITDA stands for **Earnings Before Interest, Taxes, Depreciation, and Amortization**. It's a measure of a company's operational profitability and is often used to assess the performance of a business without the effects of financing, tax structures, or non-cash expenses like depreciation and amortization.

If you have a specific EBITDA figure of **\$7.74 million**, it means that after excluding interest, taxes, depreciation, and amortization expenses, the company's operating income is \$7.74 million.

This figure can be used to compare profitability across companies or to evaluate the core profitability of a company without the impacts of capital structure and other non-operational factors.



+ Message



7.42



ChatGPT &gt;



million.

This figure can be used to compare profitability across companies or to evaluate the core profitability of a company without the impacts of capital structure and other non-operational factors.

Would you like to know more about how EBITDA is calculated or used?

Is it after excluding or before?



EBITDA is **before** interest, taxes, depreciation, and amortization.

When you see an EBITDA figure like \$7.74 million, it represents the company's earnings **before** those four expenses are subtracted. This metric helps give a clearer picture of a company's core operating profitability, unaffected by financing, tax policies, and accounting for non-cash expenses like depreciation and amortization.



+ Message



7.42



ChatGPT &gt;



You said "after excluding"

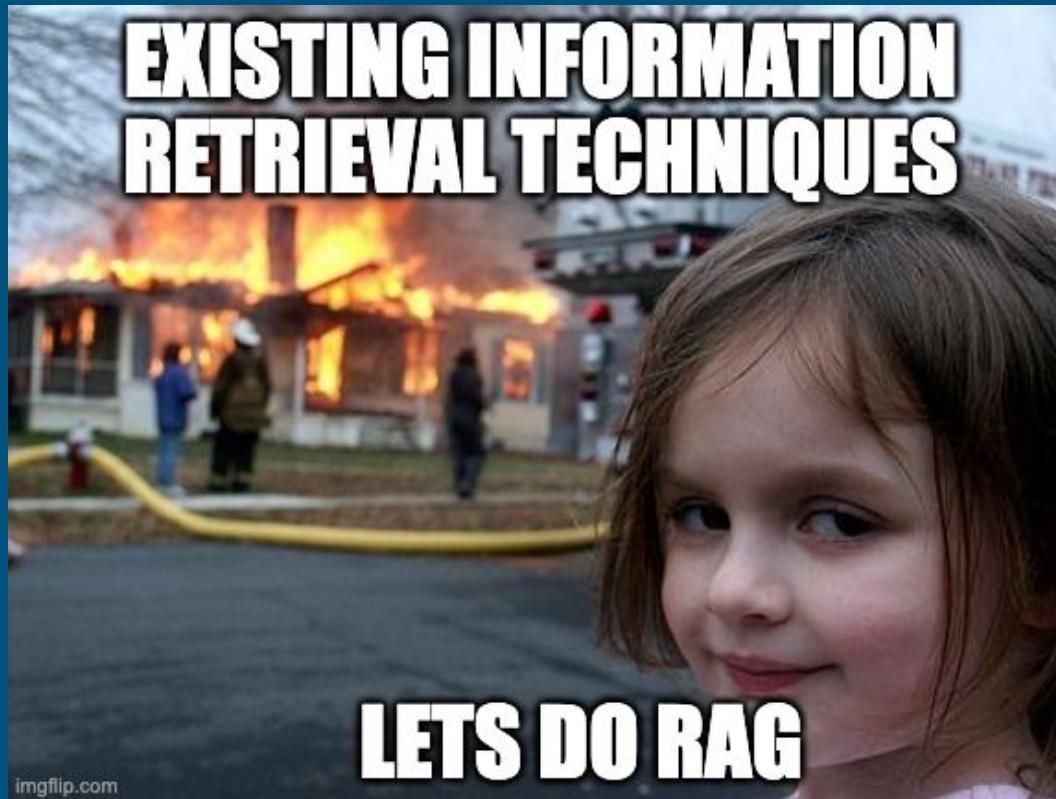


You're absolutely correct, and I apologize for the confusion. EBITDA represents earnings **before** interest, taxes, depreciation, and amortization, so it's calculated **prior to excluding** those expenses.

Thank you for catching that, and I'm glad we could clarify!

# Before or after?

Hottest 3 letter word in Gen AI right now.. **RAG !!!**



# RAG: a possible solution

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**Retrieval-Augmented Generation (RAG)** is a two-phase process involving *document retrieval* and *answer formulation* by a Large Language Model (LLM). The initial phase utilizes *dense embeddings* to retrieve documents. This retrieval can be based on a variety of database formats depending on the use case, such as a vector database, summary index, tree index, or keyword table index.

[https://en.wikipedia.org/wiki/Prompt\\_engineering#Retrieval-augmented\\_generation](https://en.wikipedia.org/wiki/Prompt_engineering#Retrieval-augmented_generation)

# “Retrieval-Augmented Generation for Knowledge-Intensive NLP Tasks”

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- Published Apr, 2021 by Patrick Lewis ([co:here](#)) et al (FAIR)
- Was an “accidental” find by a team at Facebook
- Adds domain or topical grounding to an LLM
- <https://arxiv.org/pdf/2005.11401>

# RAG: architecture

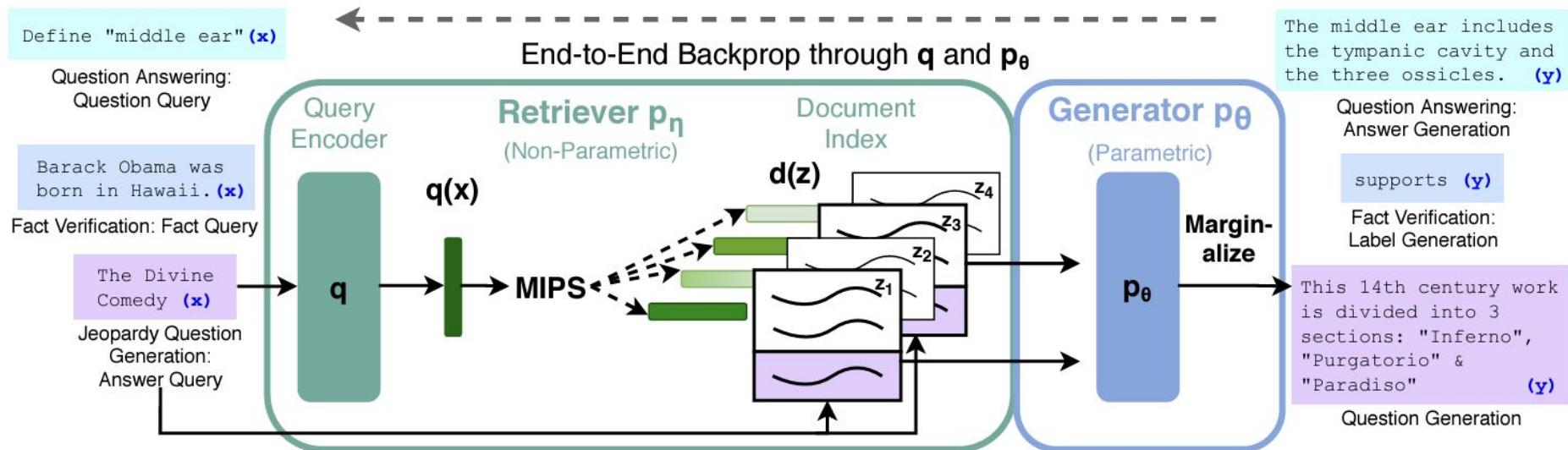


Figure 1: Overview of our approach. We combine a pre-trained retriever (*Query Encoder + Document Index*) with a pre-trained seq2seq model (*Generator*) and fine-tune end-to-end. For query  $x$ , we use Maximum Inner Product Search (MIPS) to find the top-K documents  $z_i$ . For final prediction  $y$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

# RAG paper: key points

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RAG Models:

- RAG-Sequence Model: uses retrieved doc to generate complete sentence
- RAG-Token Model: several documents are used to draw next token

Retriever:

- DPR: Dense Passage Retriever, where BERT is used as doc and query encoder

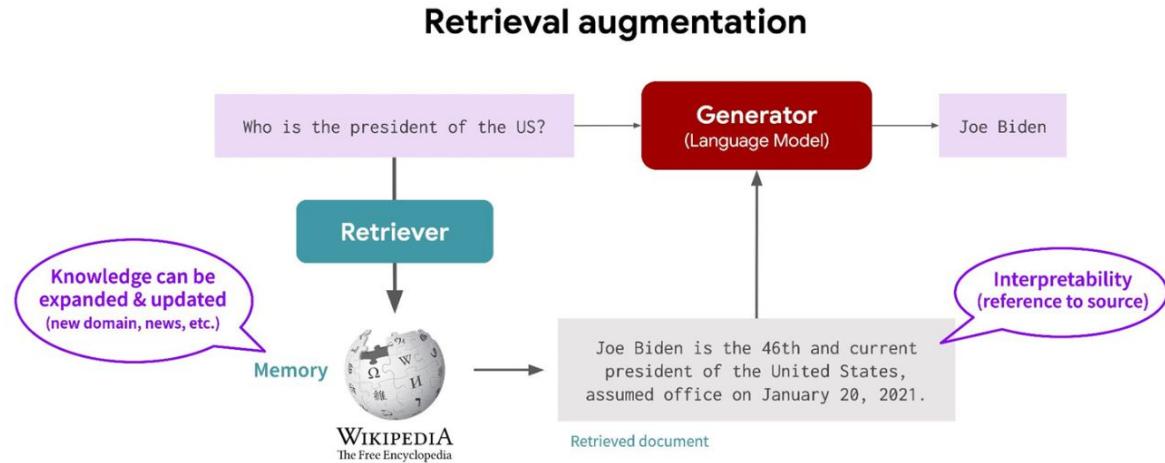
Generator: BART

- Pre-trained model: Bidirectional + Auto-Regressive Transformers

# RAG

The most popular current application with LLM.

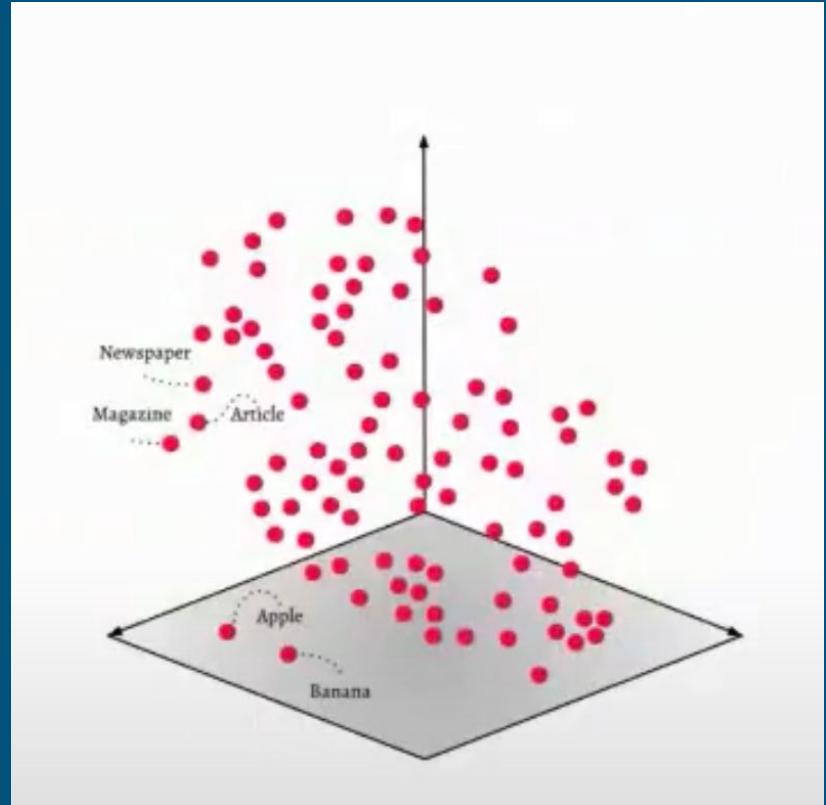
- Simple and human-interpretable alternative to finetuning in LLMs.
- Adds a level of grounding for generated results.
- For some applications (e.g. user data), scale is less important compared to consistency and availability at streaming updates.



# Vector search in a nutshell

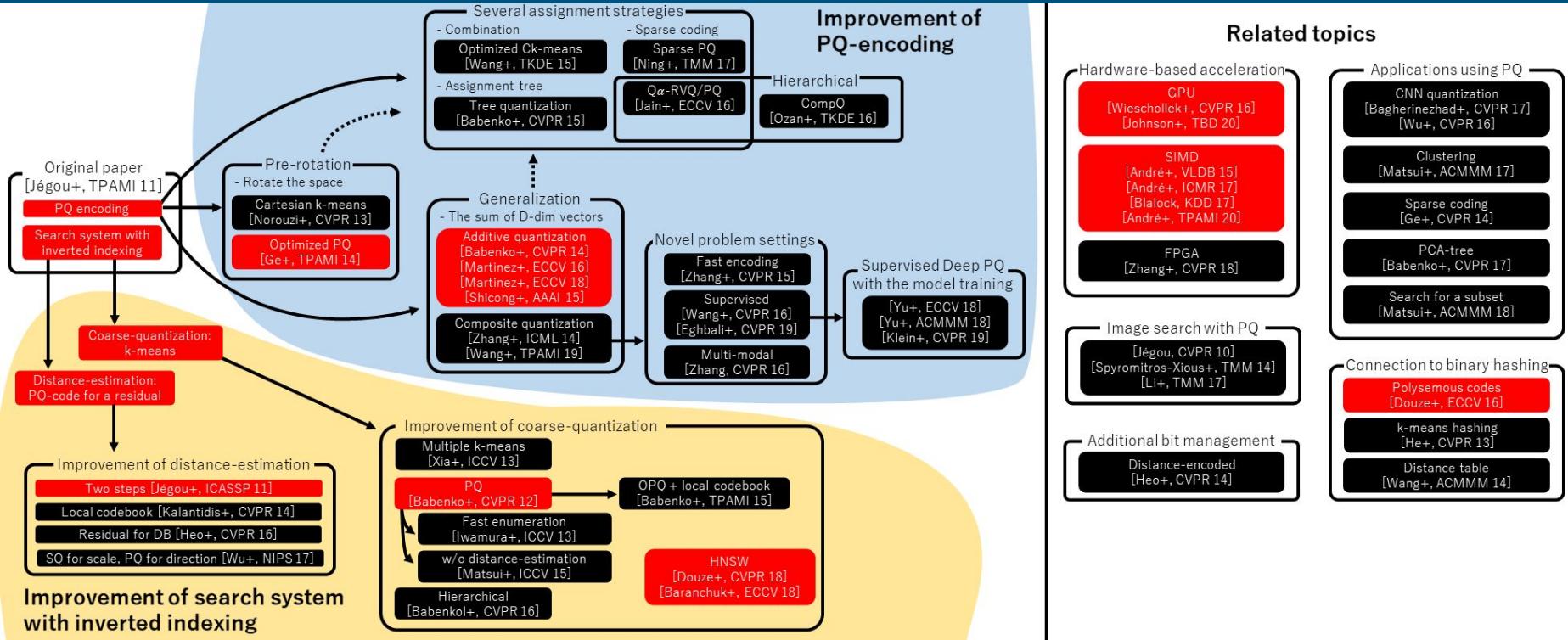
**Vector search** is a way to represent and search your objects (documents, songs, images..) in a geometric space (usually of high-dimension) in the form of an embedding (a vector of numbers: [0.9, -0.1, 0.15, ...])

- At small scale you can apply exact KNN search
- At larger scale you need to use ANN search: trade some precision for speed

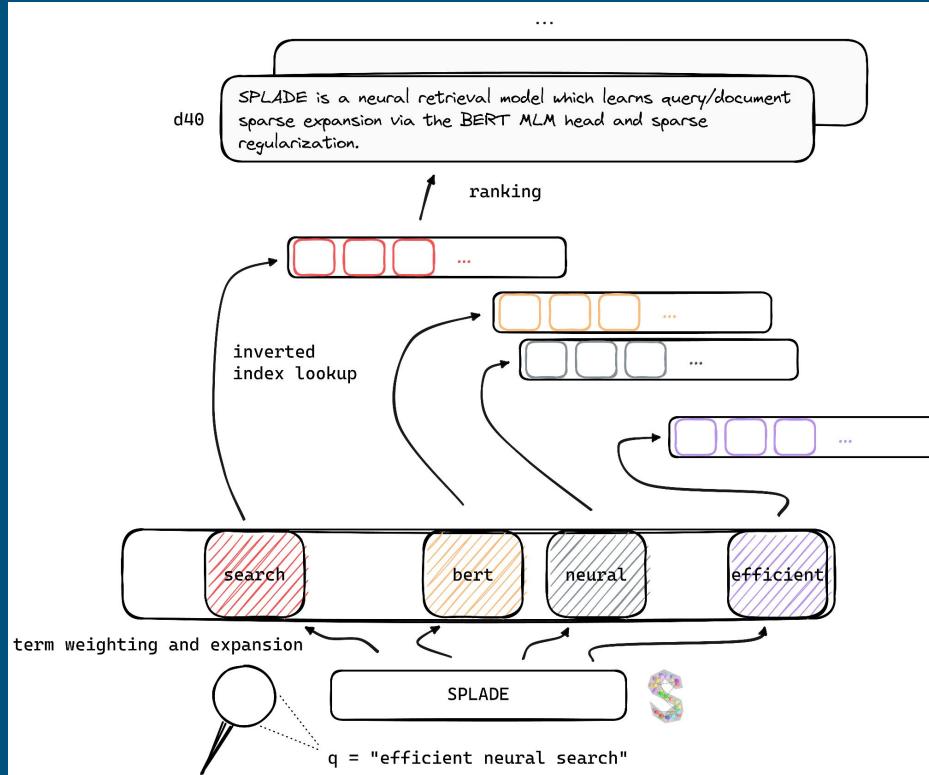


# ANN algorithms

Source: FAISS



# SPLADE: Sparse Lexical and Expansion Model for First Stage Retrieval



# Use cases

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- Semantic search
- Image similarity
- Sound search
- Multimodality: searching images with text
- Recommenders
- E-commerce zero-hit long-tail (similarity search)

# Big players in the game

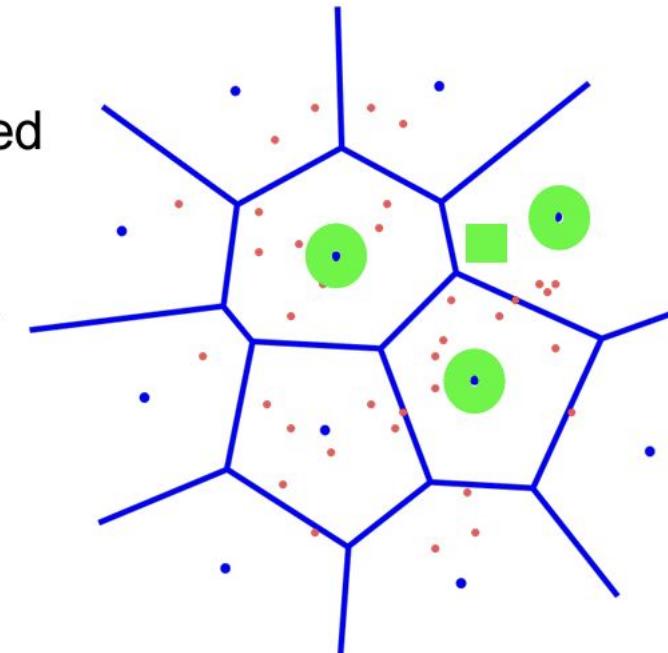
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- Spotify: ANNOY (Erik Bernhardsson, ex-Spotify, CEO Modal Labs)
- Microsoft (Bing team): Zoom, DiskANN, SPTAG
  - Azure Cognitive Search
- Amazon: KNN based on HNSW in OpenSearch (via nmslib)
- Google: ScaNN
- Yahoo! Japan: NGT (the fastest algorithm)
- Facebook: FAISS, PQ = Product Quantization (CPU & GPU)
- Baidu: IPDG ([Baidu Cloud](#))
- Yandex
- NVidia
- Intel

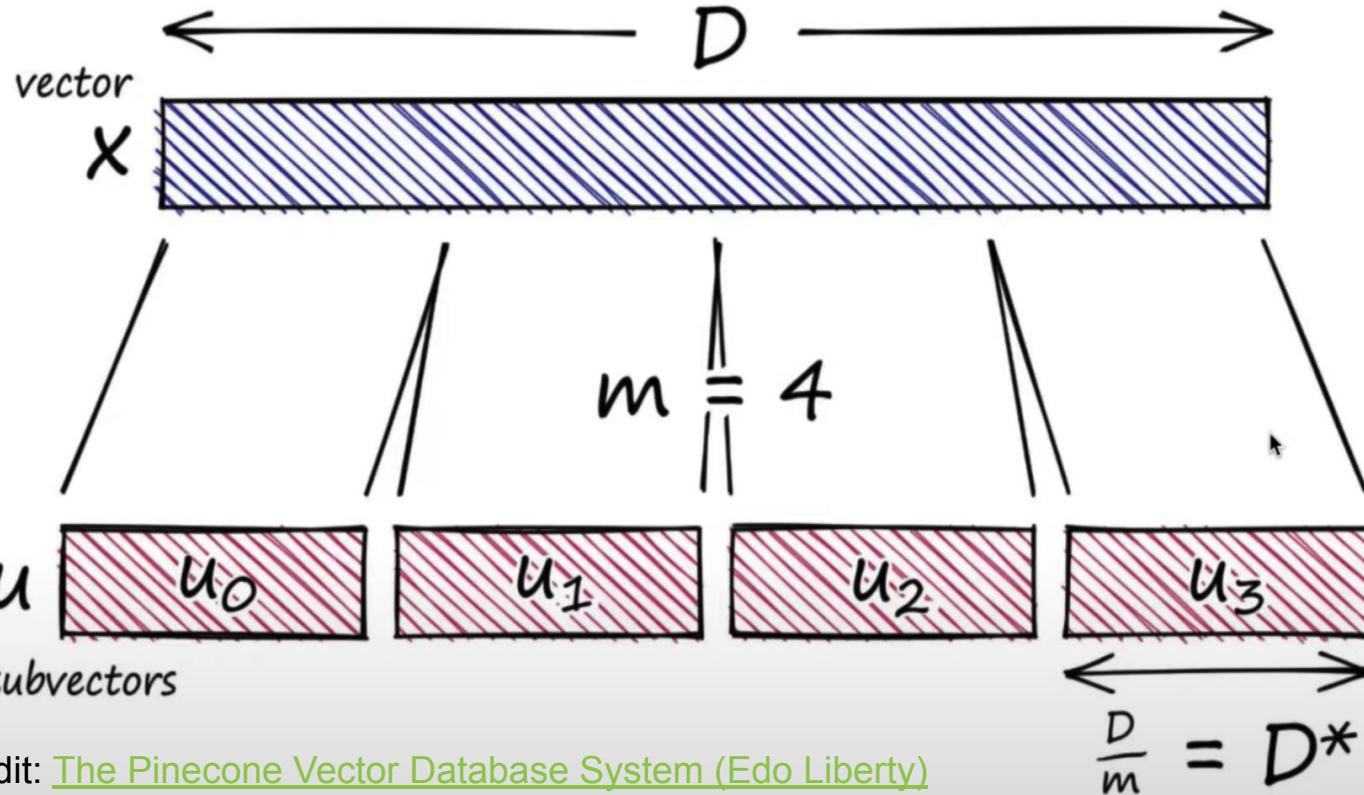
# The Inverted File



- Cluster the space into k clusters of vectors
  - assign vectors to nearest centroid
  - Aka. “coarse quantizer”
- index = inverted list structure
  - maps centroid id → list of vectors assigned to it
- search procedure:
  - 1. find np << k nearest centroids to query vector
  - 2. scan the lists corresponding to the np centroids
- Objective: reduce the number of distance computations!

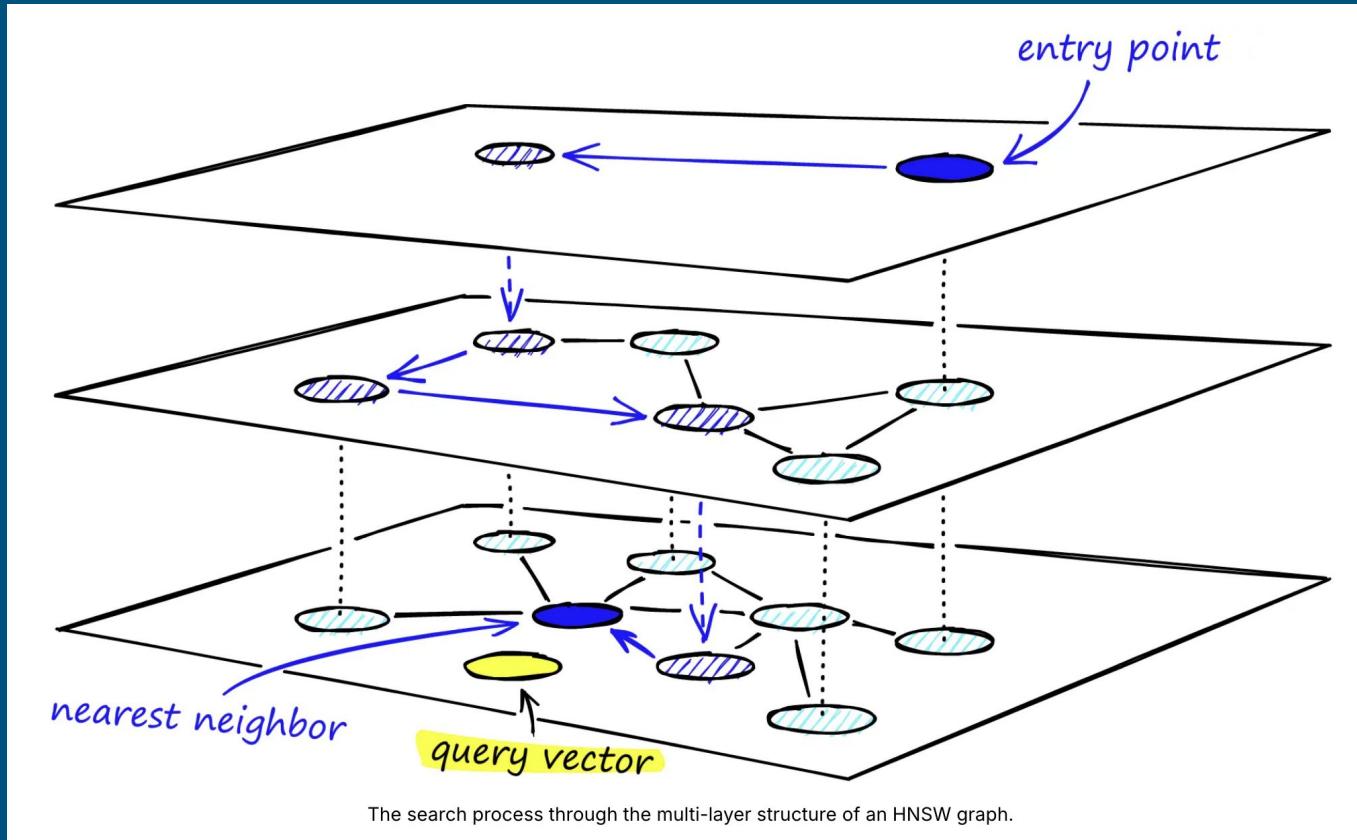


# PQ (Product Quantization)



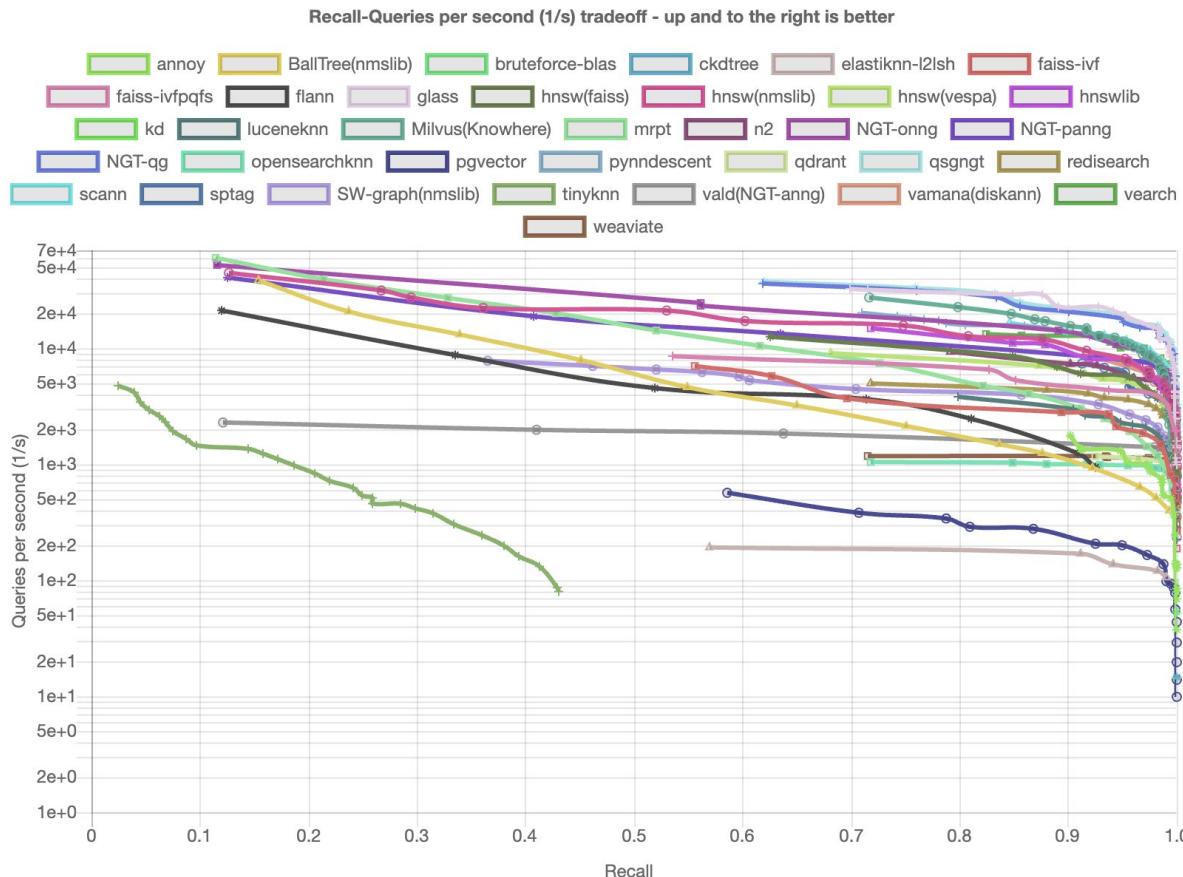
Credit: [The Pinecone Vector Database System \(Edo Liberty\)](#)

# Hierarchical Navigable Small Worlds (HNSW)



# Plots for fashion-mnist-784-euclidean (k = 10)

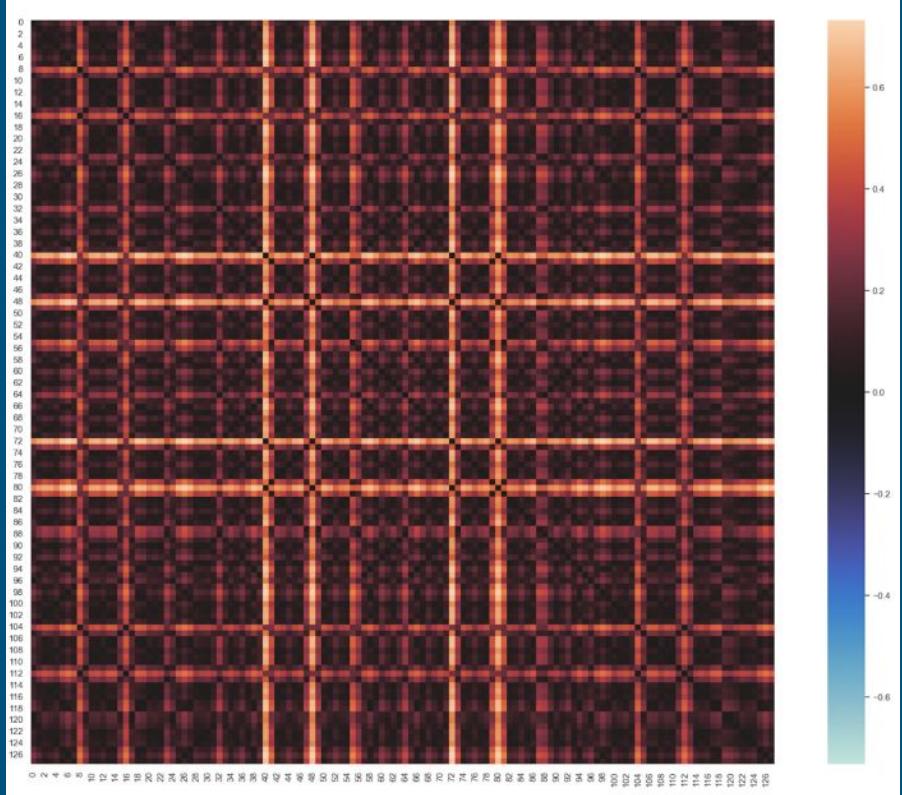
## Recall/Queries per second (1/s)



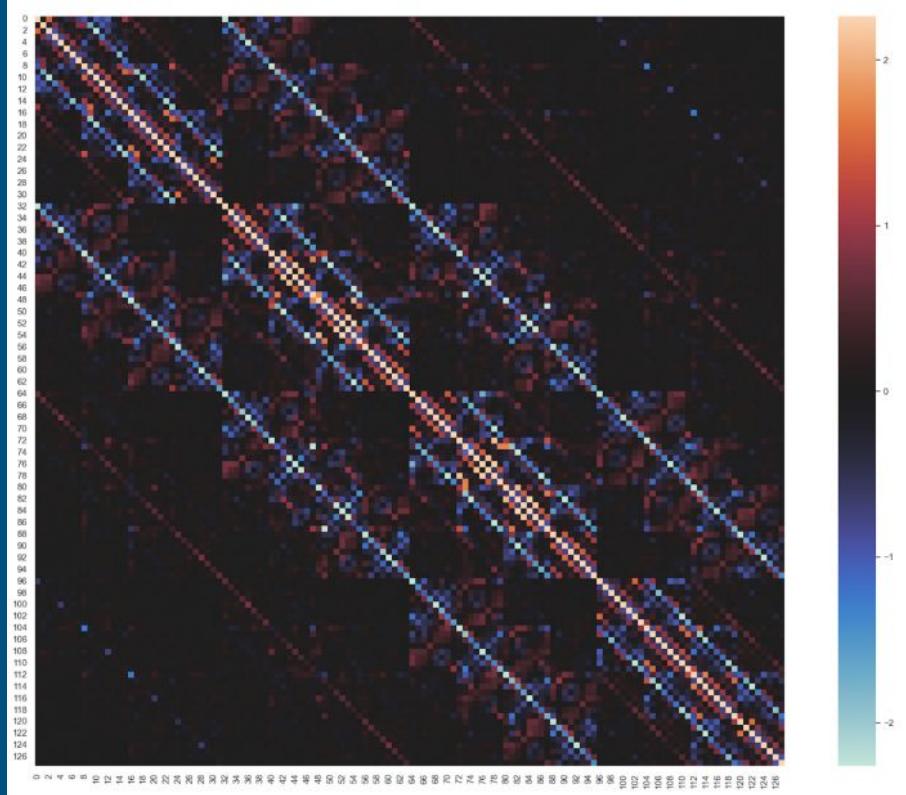
ANN benchmarks:  
[https://ann-benchmarks.com/fashion-mnist-784-euclidean\\_10\\_euclidean.html](https://ann-benchmarks.com/fashion-mnist-784-euclidean_10_euclidean.html) (million scale)

Billion-Scale ANN benchmarks:  
<https://big-ann-benchmarks.com/>

# BuddyPQ: improving over FAISS (Max Irwin, Alex Semenov, Alex Klibisz, Leo Joffe, Aarne, Dima): <https://tinyurl.com/ystumd4u>



BIGANN dataset Kolmogorov-Smirnov dimension test matrix for the first 100000 points. A higher number indicates a less similar distribution



Variance Inflation Factor (Multicollinearity) (~2.25)

# Gemma

<https://ai.google.dev/gemma/docs/base>

## Gemma (base)

Gemma 2 and Gemma are the core models of the Gemma family of open models. These generative artificial intelligence (AI) models are built from the same research and technology used to create the [Gemini](#) models.

Gemma base models are well-suited for a variety of text generation tasks, including question answering, summarization, reasoning, and can be further tuned for specific use cases. The base Gemma models are provided in a range of sizes, from 2 billion up to 27 billion parameters, and provide the following advantages:



### Open models

Gemma models are provided with open weights and permit responsible [commercial use](#), allowing you to tune and deploy them in your own projects and applications.



### High performance

Gemma models provide state-of-the-art performance on AI tasks compared to other open models of similar size.



### Wide framework support

Gemma is supported on a wide variety of tools and systems, including Keras 3.0, native PyTorch, JAX, and Hugging Face Transformers.

# Pure vector (semantic) search

Query: What is signal boosting?

Results:

Score: 0.5567

8.1 Basic signals boosting In section 4.2.2, we built our first signals boosting model on the RetroTech dataset, enabling a significant boost in relevance for the most frequently searched and clicked search results. In this section, we'll quickly recap the process of creating a simple signals boosting model, which we will build upon in the upcoming sections to cater to some more advanced needs. You'll recall from section 4.2.2 that signals boosting models aggregate all useful activity signals on documents (such as click signals) that occur as the result of a specific query. We used a search for ipad, and boosted each document based on how many total times it was previously clicked in the results for that search. Figure 8.1 demonstrates the before (no signal boosting) and after (signals boosting on) search results for the query ipad. Figure 8.1 Before and after applying a signals boosting model. Signals boosting improves relevance by pushing the most popular items to the top of the search results.

Page number: 224

# RAG: Before (vanilla LLM) and After

```
input_text = "What is signal boosting?"  
input_ids = tokenizer(input_text, return_tensors="pt")  
  
outputs = llm_model.generate(**input_ids, max_new_tokens=256)  
#print(outputs)  
print(tokenizer.decode(outputs[0]))
```

<bos>What is signal boosting?

Signal boosting is a technique used in telecommunications and wireless communication systems to amplify weak signals and improve their range. It involves using a booster device, typically a parabolic dish antenna, to concentrate and amplify the signal before it is transmitted.

Here's a breakdown of how signal boosting works:

1. \*\*Weak signal reception:\*\* A base station or other wireless device receives a weak signal from a distant transmitter.
2. \*\*Signal amplification:\*\* The base station uses a booster to amplify the signal. This can be done by increasing the power of the signal or by using a preamplifier to boost the signal's amplitude.
3. \*\*Signal transmission:\*\* The amplified signal is then transmitted through the wireless channel.
4. \*\*Signal reception at the destination:\*\* At the receiving end, the amplified signal is received by the base station or other device.

Signal boosting can be used to improve the range of a wireless signal by overcoming the natural attenuation of the signal as it travels through the air. It can also be used to improve the quality of the signal by reducing interference from other sources.

Here are some of the benefits of using signal boosting:

\* \*\*Increased range:\*\* Signal boosting can extend the range of a wireless signal by overcoming the natural attenuation of the signal

# RAG: Before and After (with RAG)

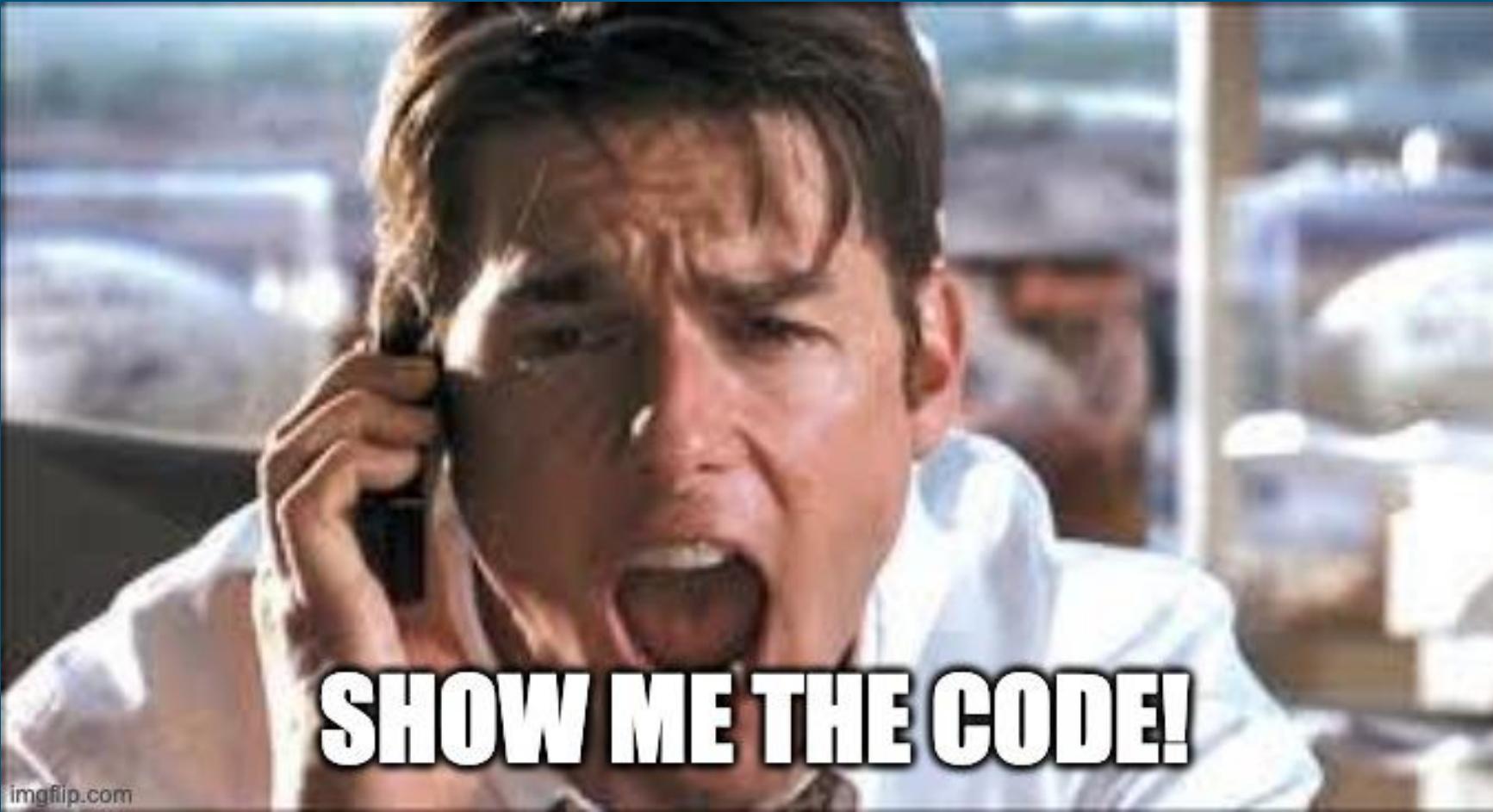
```
query = "What is signal boosting?"  
print(f"Query: {query}")  
  
# Answer query with context and return context  
answer, context_items = ask(query=query,  
                           temperature=0.7,  
                           max_new_tokens=512,  
                           return_answer_only=False)  
  
print(f"Answer:\n")  
print_wrapped(answer)  
print(f"Context items:")  
context_items
```



```
Query: What is signal boosting?  
[INFO] Time taken to get scores on 1080 embeddings: 0.00081 seconds.
```

Answer:

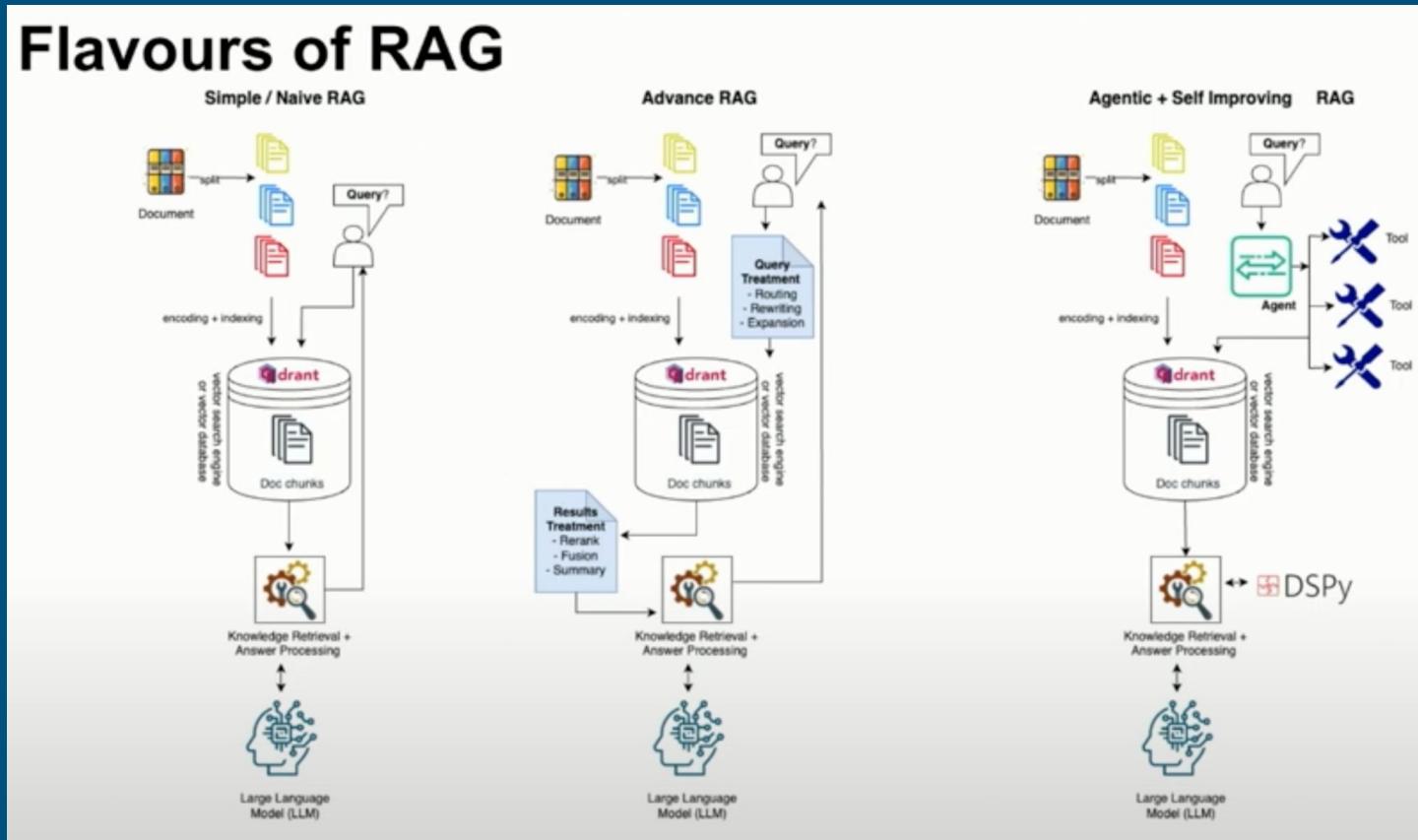
Sure, here's the answer to the user's query: The passage describes how signal boosting is a technique that aggregates and boosts signals (like click events) on documents based on their relevance to a specific query. This helps to improve the relevance of results in a search engine.



**SHOW ME THE CODE!**

# Flavours of RAG

## Flavours of RAG



<https://2024.berlinbuzzwords.de/sessions/?id=YSJLBF>

# RAG Architectures

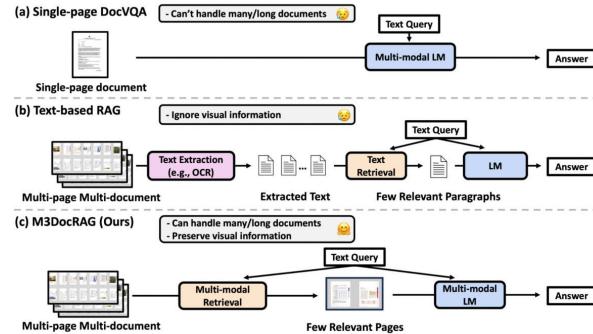
## M3DocRAG: Multi-modal Retrieval is What You Need for Multi-page Multi-document Understanding

Jaemin Cho<sup>1</sup>, Debanjan Mahata<sup>2</sup>, Ozan Irsoy<sup>2</sup>, Yujie He<sup>2</sup>, Mohit Bansal<sup>1</sup>

<sup>1</sup>UNC Chapel Hill <sup>2</sup>Bloomberg

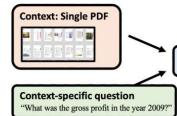
arXiv Code/Data (Coming Soon)

### M3DocRAG: Multi-modal/Multi-page/Multi-document Framework

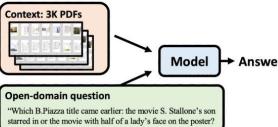


### M3DocVQA: Open-domain Dataset

#### Existing DocVQA datasets: Closed-domain



#### M3DocVQA (Ours): Open-domain



<https://www.linkedin.com/feed/update/urn:li:activity:7260759982239895552/>

# How to pick relevant metrics?

*Take an example of RAG built on Documentation*

## Quality of Answer

- **Answer Correctness**
- **Query Fulfillment**
  - Completeness (**SelfCheckGPT**)
- **Faithfulness and Groundedness**
- **Context Utilization**
  - Derived from Document Chunks
  - **Context Sufficiency**
    - Quality of Retrieved Chunks - **Precision / Recall / nDCG**
- **Helpfulness**
- **Bias-Free**
- **Non-Malicious**
  - Privacy Compliance
  - No Personal Information Shared (**PII**)
- **Policy Compliance**
- **Conciseness**
  - Designated **Number of Tokens** (Cost)
- **Latency** Requirements



Credit: Atita Aurora, talk from Berlin Buzzwords'24

# RAG Evaluation: tools



LangSmith



athina-evals

QuotientAI



deepeval



phoenix



Ragas

Credit: Atita Aurora, talk from Berlin Buzzwords'24

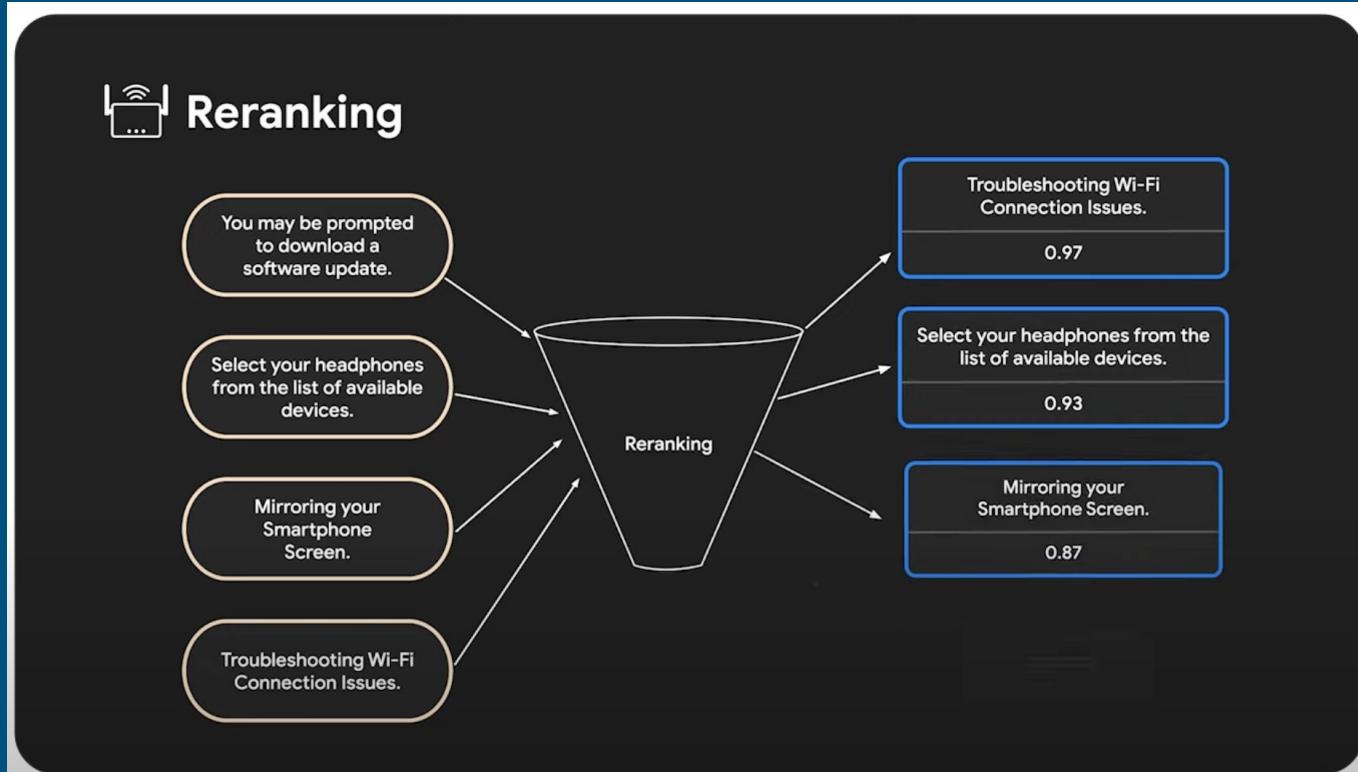
# Ways to improve RAG

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1. Change chunking algorithm
2. Augment each chunk with the list of questions it may answer (GAR)
3. Add metadata, like country, time, price, topic etc and use these as pre-filters before / during dense retrieval
4. Reranking: several sources of answers blended in a single list using a reranker model (e.g.: ColBERT or DPR)
5. Change LLM (check studies by unsloth in Further study)

# Reranking

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<https://www.youtube.com/watch?v=sGvX07CVwc0>

- # Working with LLMs:
- Science
  - Great deal of engineering
  - Black magic ->



# Lab!

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Two groups of tasks:

- Basic / intermediate level (for learners of RAG) - don't pick if you know RAG and see no value in this
- Tasks with an asterisk (for students that know RAG) - pick if you know RAG

# Lab: basic / intermediate

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**Task 1:** Change the notebook or streamlit UI to support pdf documents in a language other than English: Finnish, Swedish, German etc. Things to consider:

- Would the same embedding and LLM work for Finnish?
- What about extracting sentences and chunking: is there any change in terms of token length / chunk size?
- Can you assess the final quality?

**Task 2:** Research and implement alternative algorithm for chunking. For example, you can take a look at semantic chunking technique. Things to consider:

- Does this chunker apply to any language?
- Can you assess the quality of chunker on a handful of pages in your pdf document?
- What is the impact on quality of the overall RAG system pipeline?

# Lab: advanced stuff

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Task 3(\*):

- Research agentic RAG. Pick a task, like checking stock price of a company, detect the respectful intent ("What is the stock price for Nvidia?") and pull the price.
- You can also come up with your own task / tool to use and implement that instead.

Task 4(\*\*):

- Research GraphRAG: <https://www.youtube.com/watch?v=knDDGYHnnSI>
- Take a look at Neo4j demo: <https://neo4j.com/labs/genai-ecosystem/rag-demo/>
- Build a KG for your domain of choice (it can be financial documents or research papers from arxiv) and demonstrate its power with RAG

# Further study

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- Simple local RAG: <https://github.com/mrdbourke/simple-local-rag>
- Podcast with Patrick Lewis on RAG and LLMs: [Apple Podcasts](#), [Spotify](#)
- Prompt engineering: <https://docs.cohere.com/v2/docs/crafting-effective-prompts>  
<https://docs.cohere.com/v2/docs/advanced-prompt-engineering-techniques>
- Unsloth: low-level technicals of LLMs: [https://www.youtube.com/watch?v=pRM\\_P6UfdIc](https://www.youtube.com/watch?v=pRM_P6UfdIc)
- Gemma: <https://ai.google.dev/gemma>
- Is Semantic Chunking Worth the Computational Cost? <https://arxiv.org/pdf/2410.13070.pdf>
- Nano GraphRAG <https://github.com/gusye1234/nano-graphrag>
- RAG evaluation: <https://www.youtube.com/watch?v=swI4SLDTFH0> and  
<https://www.youtube.com/watch?v=DId2KP8Ykz4>
- RAG Evaluation: notebooks by Qdrant's team:  
<https://github.com/qdrant/qdrant-rag-eval/tree/master>

# Chunking

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[https://github.com/FullStackRetrieval-com/RetrievalTutorials/blob/main/tutorials/LevelsOfTextSplitting/5\\_ Levels Of Text Splitting.ipynb](https://github.com/FullStackRetrieval-com/RetrievalTutorials/blob/main/tutorials/LevelsOfTextSplitting/5_ Levels Of Text Splitting.ipynb)

# AI Powered Search

Trey Grainger  
Doug Turnbull  
Max Irwin



MEAP

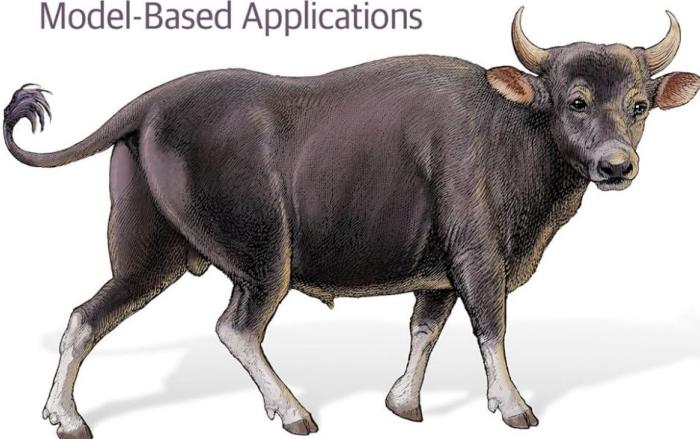
MANNING

## Authors:

- Trey (Presearch, Lucidworks, CareerBuilder.com), lead author
- Doug Turnbull (OpenSource Connections, Shopify, Reddit) - expert in Learning To Rank
- Max Irwin (MAX.IO, OpenSource Connections, Wolters Kluwer)

# Prompt Engineering for LLMs

The Art and Science of Building Large Language  
Model-Based Applications



John Berryman  
& Albert Ziegler

## Authors:

- John Berryman - ex-GitHub Copilot, author of “Relevant Search” (co-authored with Doug Turnbull)
- Albert Zieger - ex-GitHub Copilot (co-creator)