Building a Semantic Search Engine (workshop)

SCAN ME

Outline

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1. Sparse Embedding
2. Dense Embedding
3. Approximate Nearest Neighbor (ANN)
5. Production Considerations

About Us

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Linkedin

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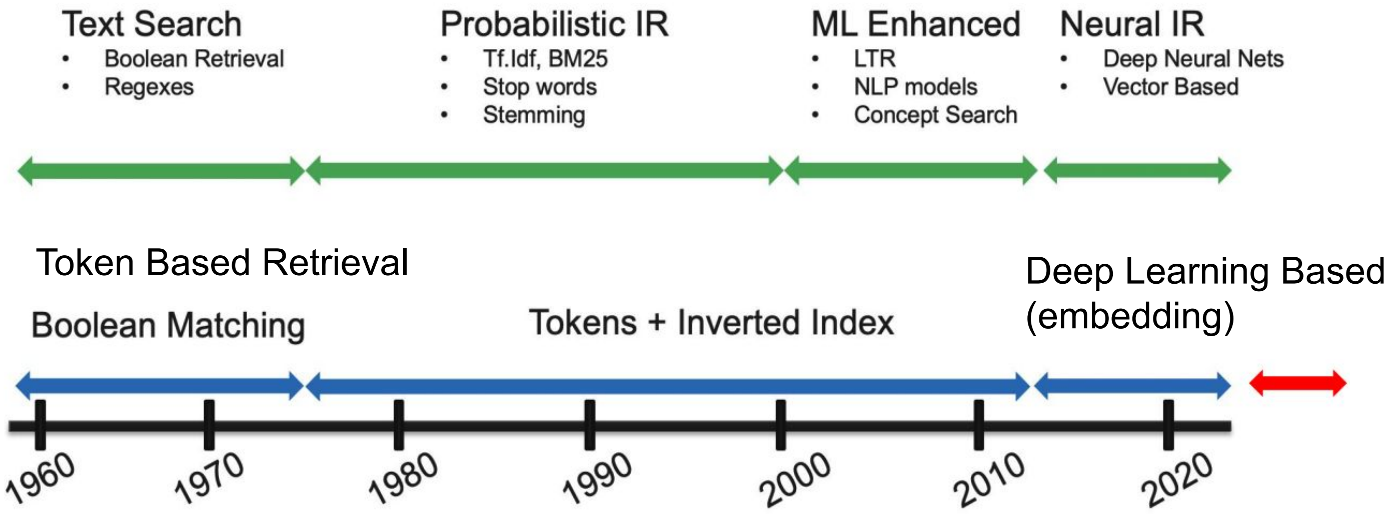
Walmart: ML Engineers on the Search team

History of Information Retrieval

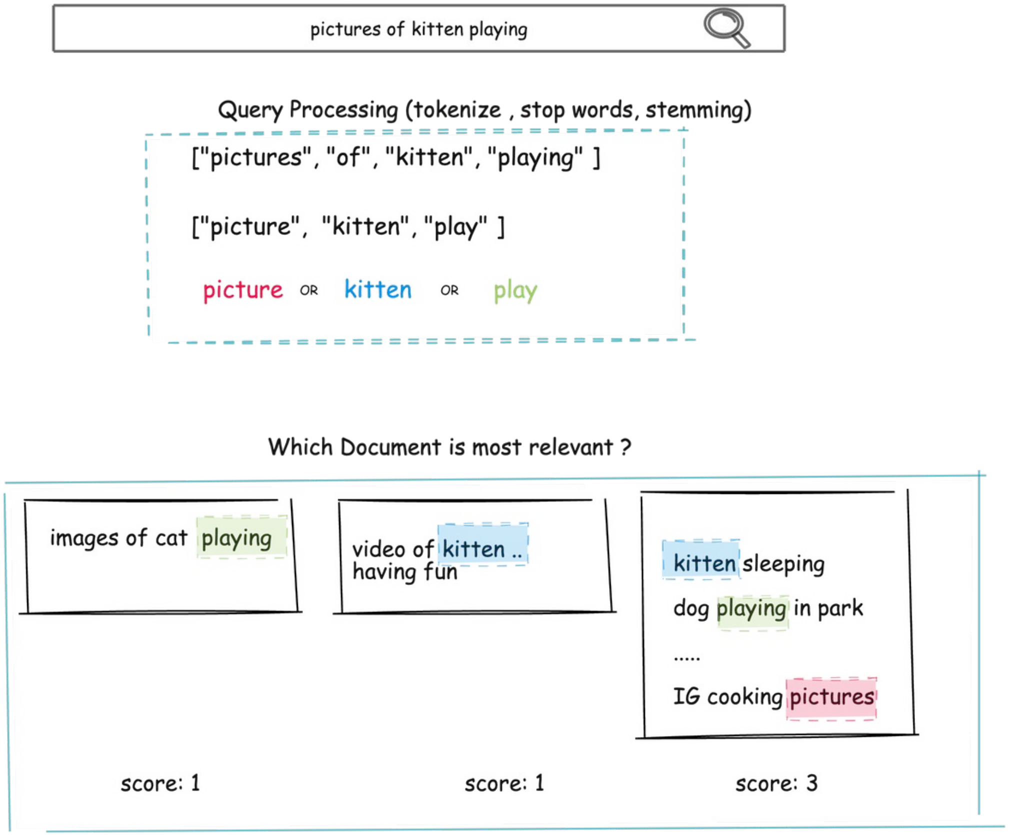


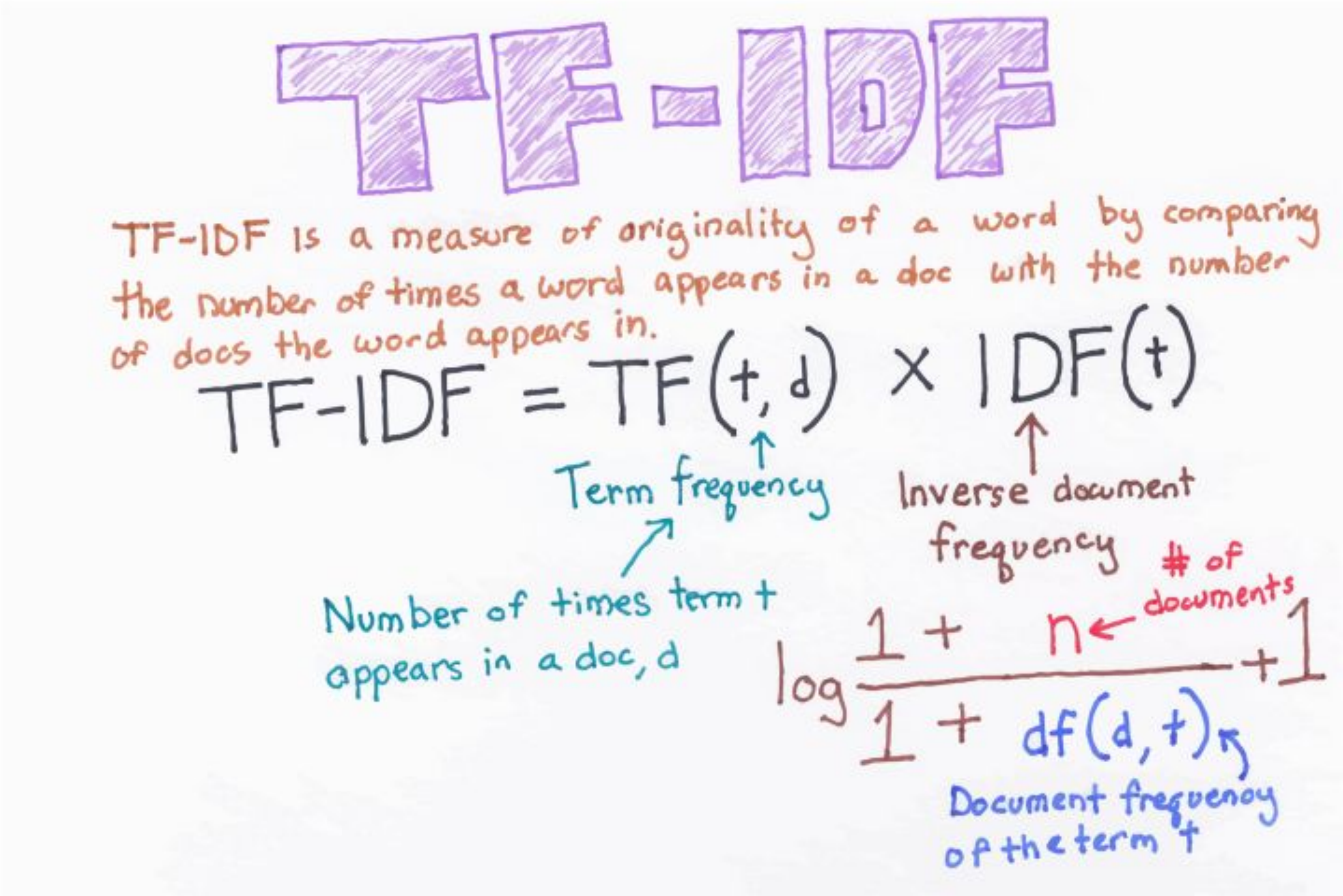
Hughes, Simon. "Semantic Product Search – Vector Search for E-Commerce." Conference Presentation at Haystack 2021, https://haystackconf.com/files/slides/haystack2021/Hughes-Haystack_2021_Semantic_Product_Search.pdf, September 29, 2021.

Token based retrieval

Boolean Retrieval

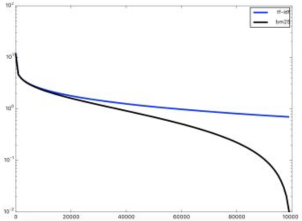
- Queries and documents are represented as bag of words
- Query terms are connected with boolean operators
- Disadvantages:
  - Filtering more than retrieval
  - Terms have same weights
  - No ranking





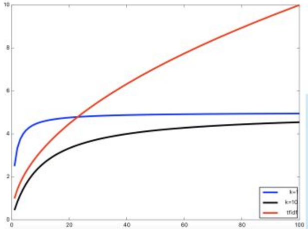
Credit : Chris Albon @ https://machinelearningflashcards.com/

BM25



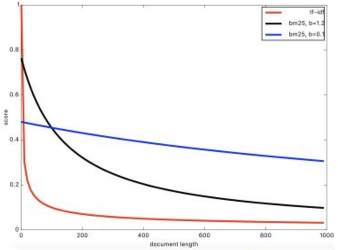
idf - how popular is the term in the corpus?

$$\mathrm{bm25}(d) = \sum_{t\in q, f_{t,d}>0} \log\left(1+\frac{N-df_t+0.5}{df_t+0.5}\right)\cdot\frac{f_{t,d}}{f_{t,d}+k\cdot\left(1-b+b\frac{\mathrm{l}(d)}{avgdl}\right)}$$



saturation curve - limit influence of tf on the score

length weighing - tweak influence of document length



elastic{on}

73

elastic

Weber, Britta. "Improved Text Scoring with BM25." Conference Presentation at ElasticCon 2016, https://speakerdeck.com/elastic/improved-text-scoring-with-bm25, February 11, 2016.

ElasticSearch

- Open source search engine based on Lucene library
- Supports BM25 and other similarities (link)
- Supports boosting , filtering , phrase match, autocomplete
- Distributed : index shards, replicas

elasticsearch

ElasticSearch Schema

```
{
  "mappings": {
    "properties": {
                          full text field
      "title":            { "type": "text"    },
      "description":      { "type": "text"    },

      "brand":            { "type": "keyword" },
      "product_type":     { "type": "keyword" },
                          regular text field

      "price":            { "type": "double"  }
                          numeric field
    }
  }
}
```

Possible schema for an e-commerce item

ElasticSearch Query

Query: Nike shoes under 100$

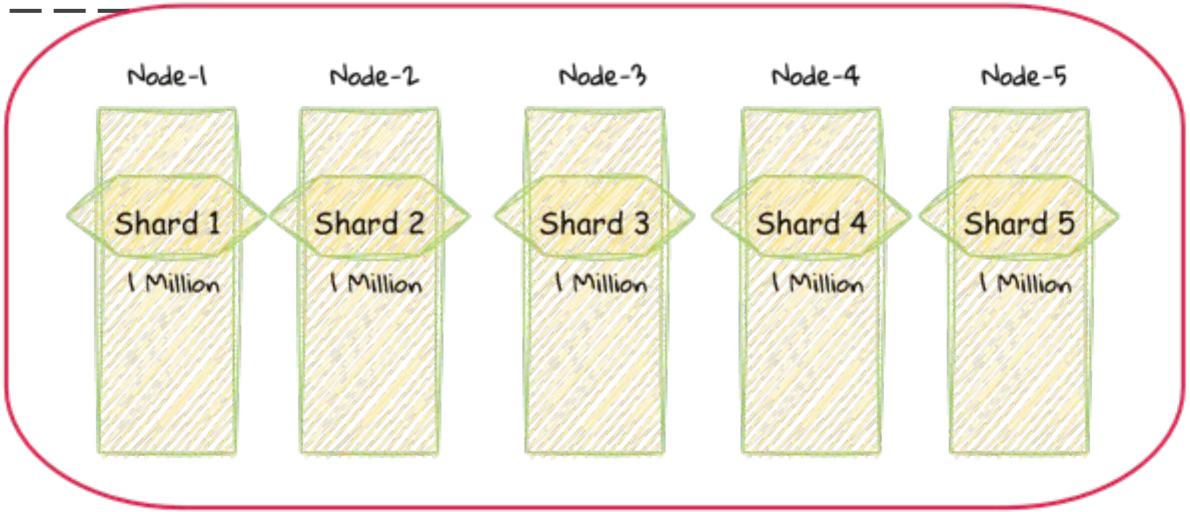
```
{
  "query": {

    "multi_match": {
        "query": "Nike shoe under 100$",
        "fields": ["title^2", "Description^1"]
    }

    ,"bool": {
      "filter": [
        { "term": { "brand": "nike" }}
      ]
    }
    ,"filtered": {
        "filter": {
            "range":  {
                "price" : {  "lte": 100 }
            }
        }
    }
}
```

Search for query tokens in title and description
weight matches found in title double

filter items who has brand nike

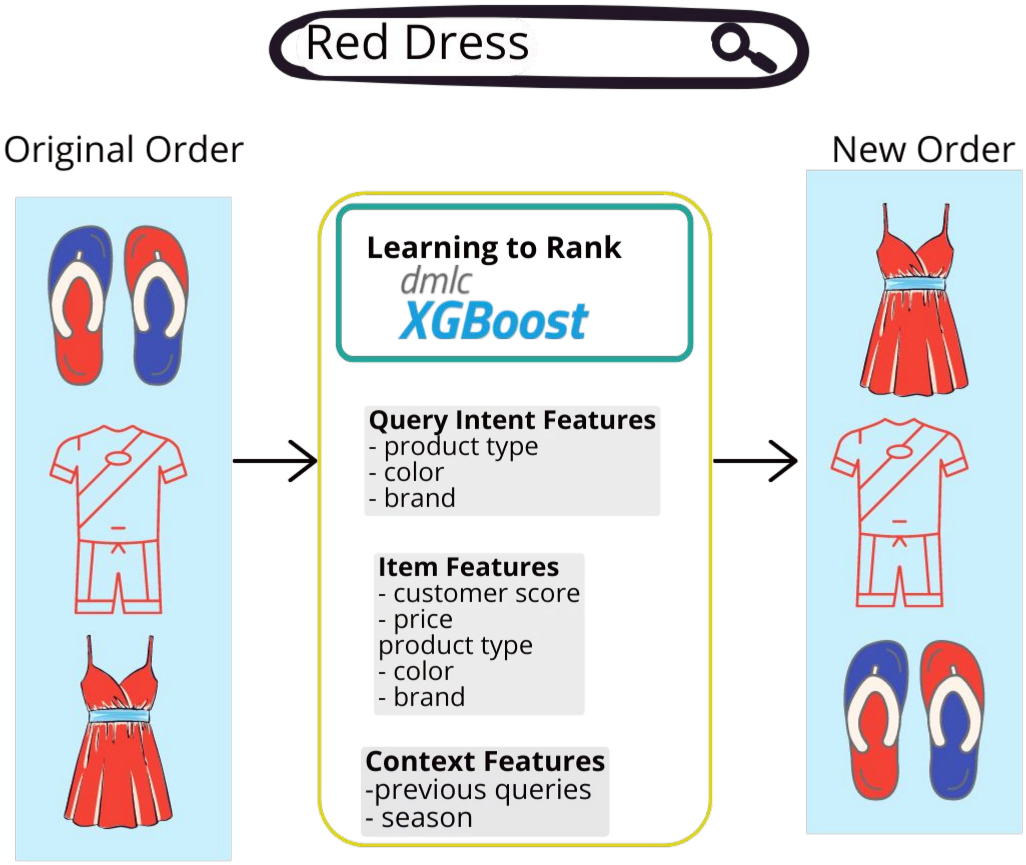
filter items with price <= 100

Index with multiple shards



- Index can be composed of shards
- Reading / Writing can be faster

Learning to Rank



Issues with Sparse Representation

- Lexical GAP: Covid vs Coronavirus vs Omicron variant
- Ambiguity: bank (institution) vs bank (geography)
- Position matters: “river bank” vs “bank river”
- Lack of Contextualized embeddings

  She will ***park*** the car so we can walk in the ***park***.

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Lab

Jupyter Hub: https://hub.np.training

Repo:https://bit.ly/search-workshop-2022

Lab 1 Goals

- Explore tokenization and some preprocessing
- Building a simple in-memory retrieval system using BM-25 (elastic search)

Query: Two dogs playing in the snow

Photo title: two white dogs

Photo by Konstantin Pudan on Unsplash

Distance: 14.775831

Photo title: Two baby elephants playing

Photo by Jason Zhao on Unsplash

Distance: 14.002172

Query: boy and girl on a beach

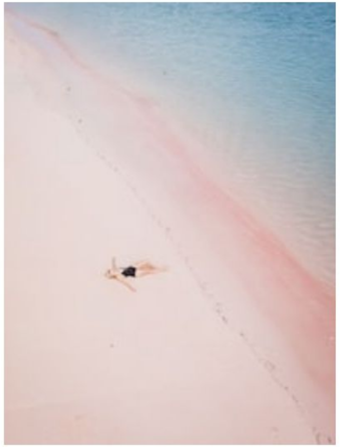


Photo title: A drone shot of a girl laying on Pink Beach in Indonesia
Photo by Marcus Woodbridge on Unsplash
Distance: 12.359471

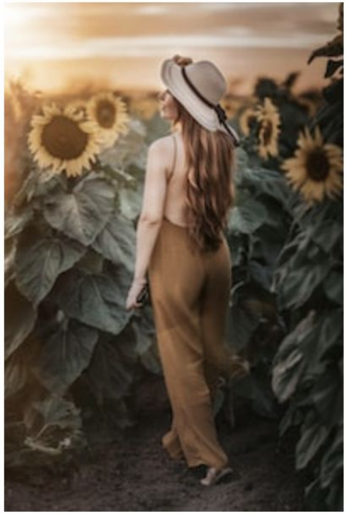


Photo title: Beautiful girl on a sunflower field
Photo by Marina Montoya on Unsplash
Distance: 11.130171

Query: light at the end of the tunnel

Photo title: At the end of the tunnel

Photo by Dejan Zakic on Unsplash

Distance: 25.557308

Photo title: Beach at the end of a day

Photo by Angelo Pantazis on Unsplash

Distance: 15.358174

Embedding Based Retrieval

Dense Embeddings

Word Representation

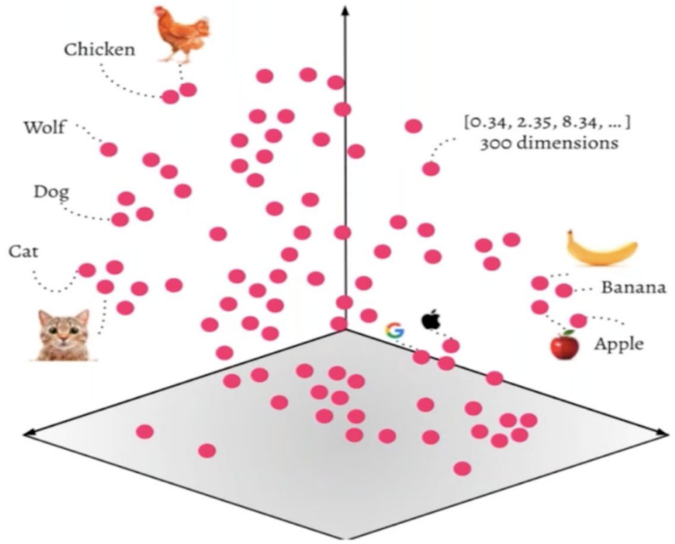
car: [0.2 , 0.3, 0.7]

automobile: [0.2 , 0.3, 0.7]

Similar concepts have similar embeddings

Regardless of content length, similar items should have similar embeddings

Size of embedding is independent of #tokens

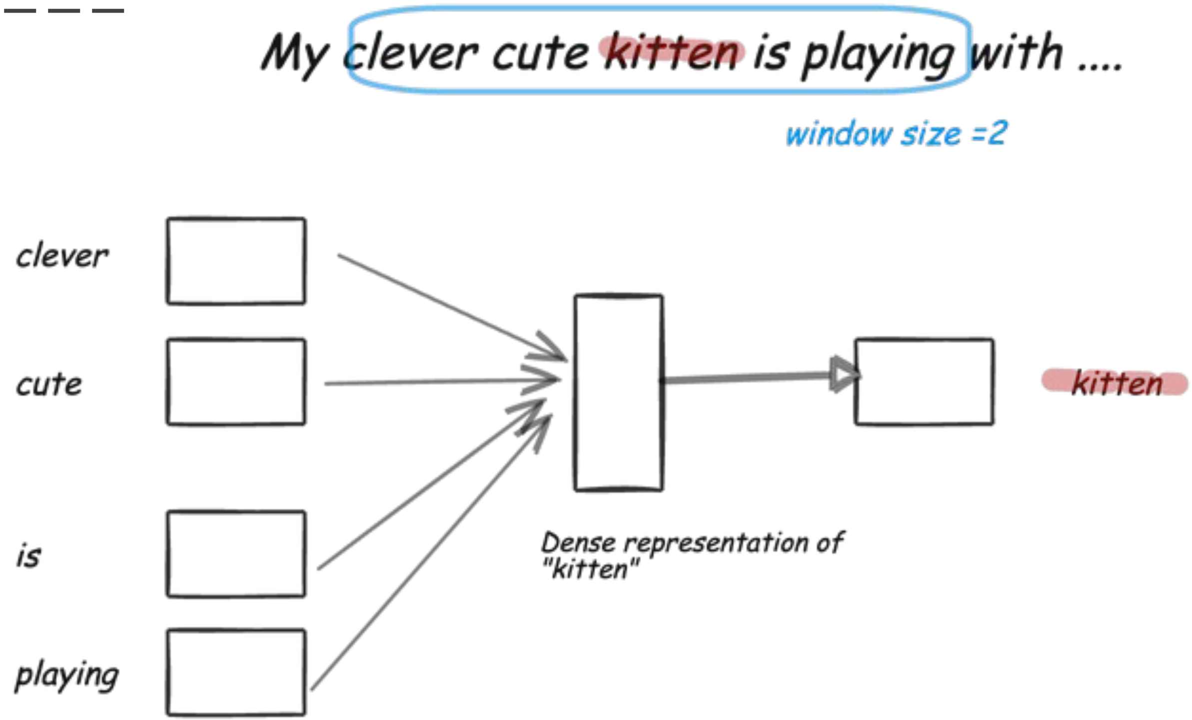


Review Representation

Review 1: was great [0.5 , 0.1, … , 0.6]
Review 2: Chocolate ice cream was the best .. [0.5 , 0.1, … , 0.5]

Image from https://odsc.com/blog/getting-started-with-vector-based-search.

Word2Vec

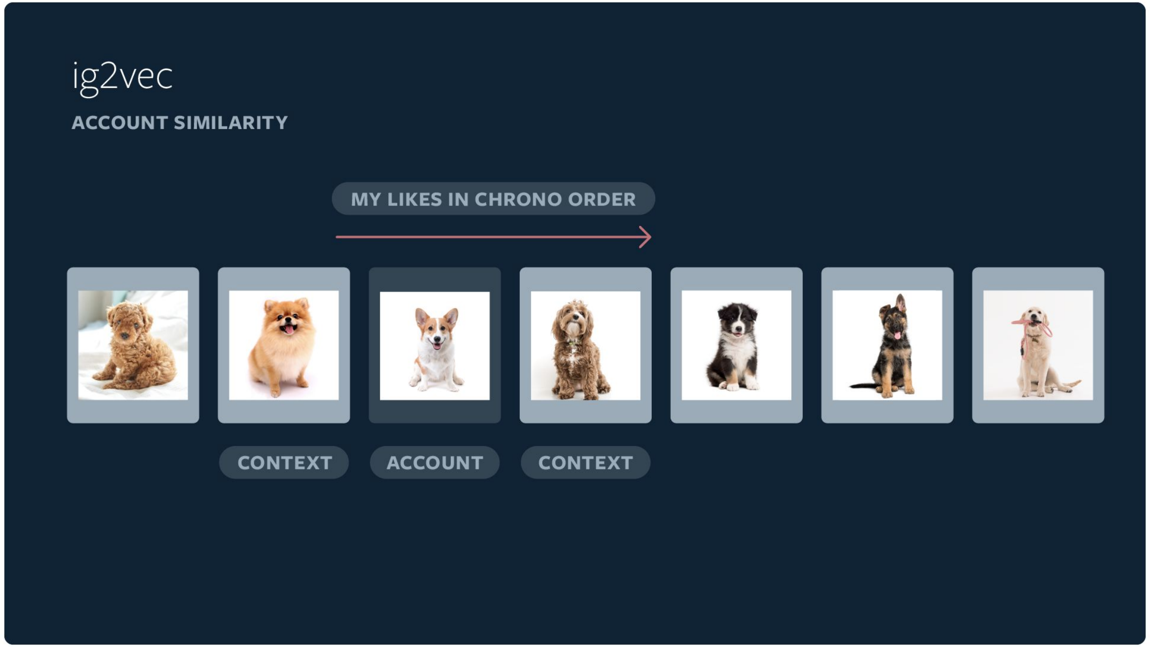


W2Vec Continuous Bag of Words

- Published in 2013
- Represent each word as a dense vector

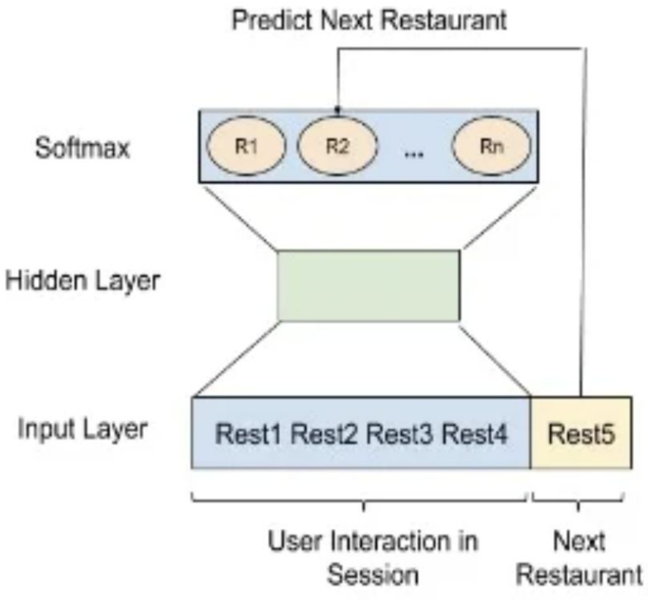
- Uses a neural network model to capture linguistic concept of words

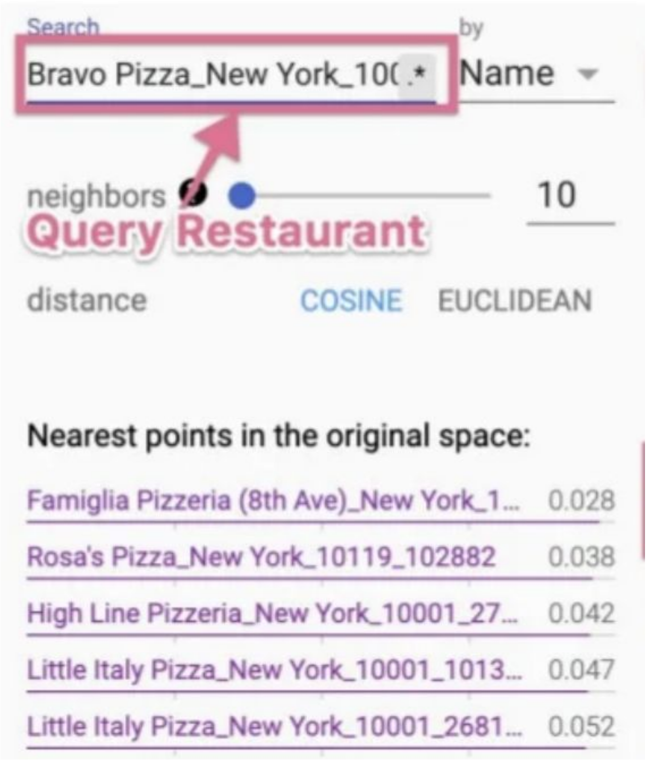
Instagram: ig2Vec



Medvedev, Ivan, Haotian Wu, and Taylor Gordon. “Powered by AI: Instagram’s Explore Recommender System.” Powered by AI: Instagram’s Explore recommender system, November 2019. https://ai.facebook.com/blog/powered-by-ai-instagrams-explore-recommender-system/

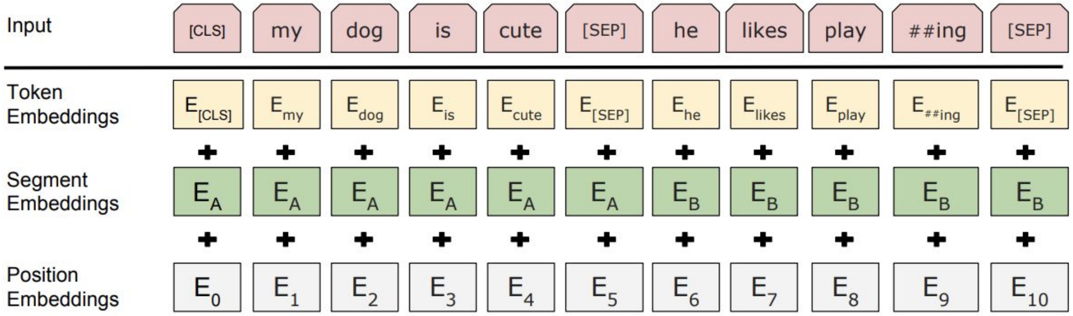
Grubhub: Rest2Vec





Content from Pydata Talk “Alex Egg, Emily A Ray, Parin Choganwala: Discover your latent food graph with this 1 weird trick | PyData New York 2019”
https://www.youtube.com/watch?v=aRUaEt1q7BY&t=3s&ab_channel=PyData

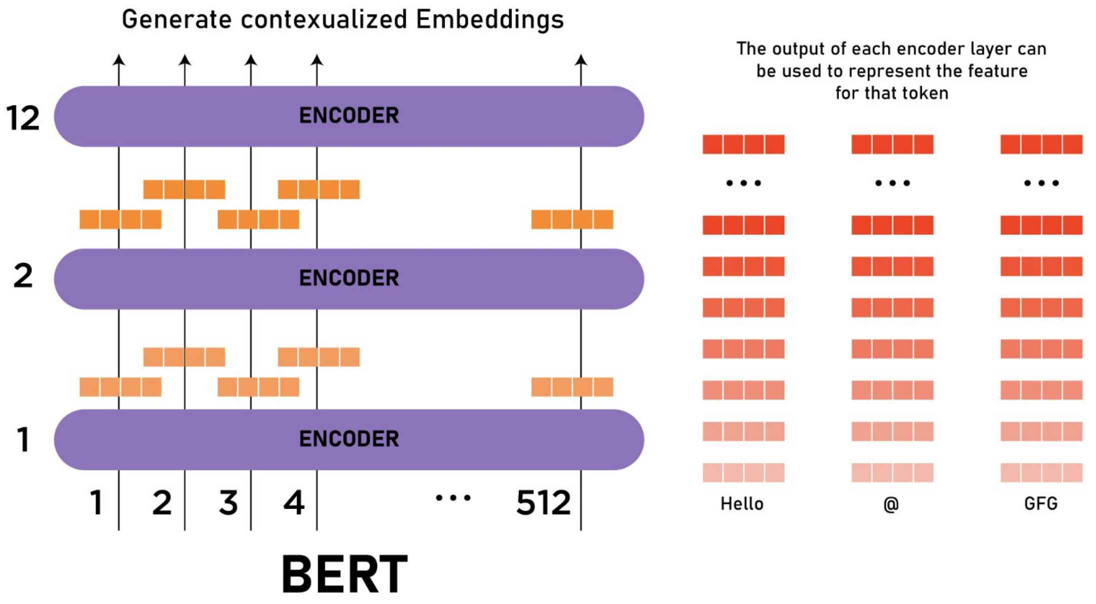
Bidirectional Encoder Representations from Transformers (BERT)



Input to the model, contains token , segment and position embedding

Image from BERT paper https://arxiv.org/pdf/1810.04805.pdf

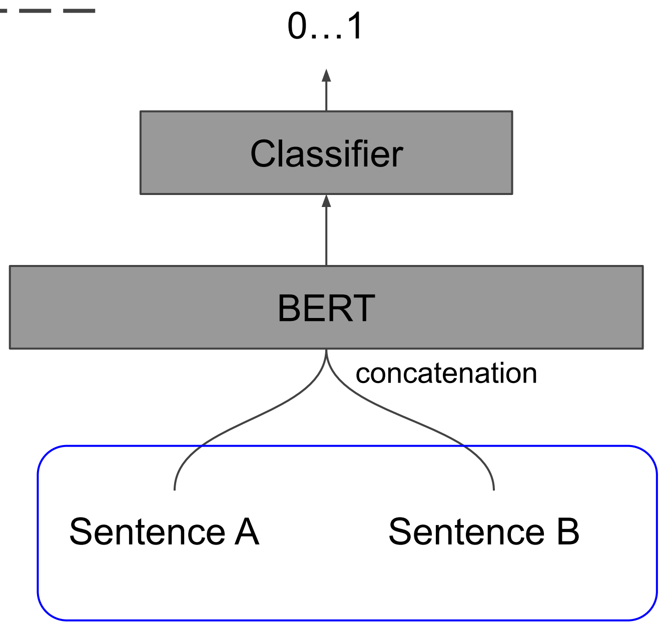
BERT



- BERT is composed of multiple encoders
- There is embedding for each token after each encoder
- Sentence embedding can be created from pooling
- Pooled embeddings are not best for similarity search

Image from https://www.geeksforgeeks.org/explanation-of-bert-model-nlp/

Sentence Pair Encoder - Cross-encoder



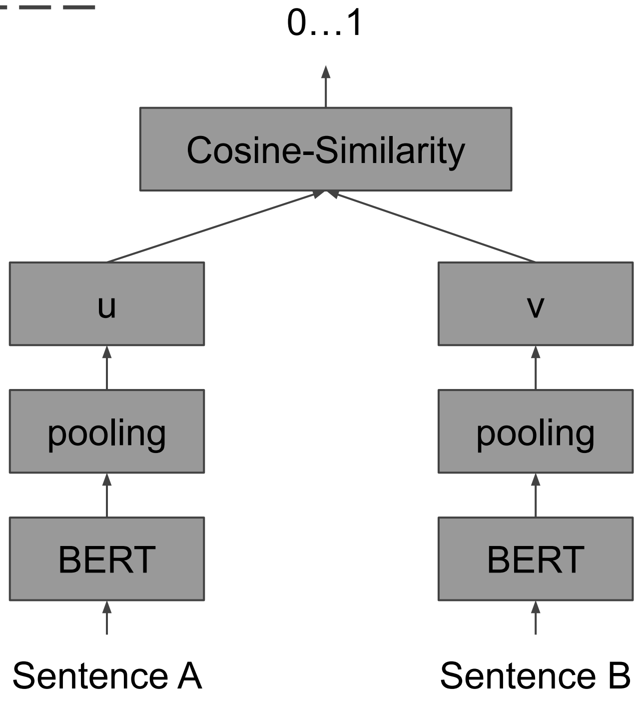
Pros

- Accurate classification

Cons

- Need new encoding for each pair
- Computationally inefficient for information retrieval.

Sentence Pair Encoder - Bi-Encoder



Pros

- Each sentence is encoded separately
- Distance between two sentence embeddings can be measured
- Faster and more computationally efficient

Cons

- Bi-encoders performance is poor compared to cross-encoders for supervised learning problems

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Lab

Jupyter Hub: https://hub.np.training

Repo:https://bit.ly/search-workshop-2022

Lab 2 Goals

- Explore Text Embedding model
- ANN Retrieval using Milvus

Query: Two dogs playing in the snow

Photo title: brown and black dogs running on snow

Photo by Luka Vovk on Unsplash

Distance: 0.7353920340538025

Photo title: tan dog playing on snow

Photo by Hitter Rudolf on Unsplash

Distance: 0.6460988521575928

Query: boy and girl on a beach

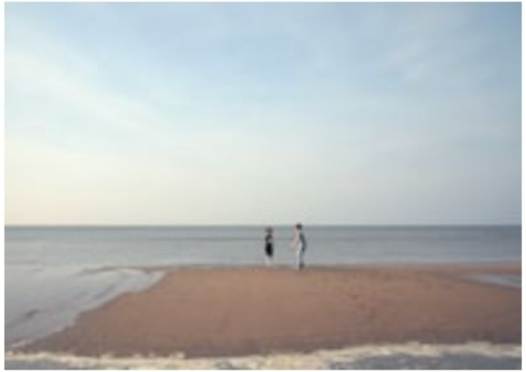


Photo title: children enjoying the beach
Photo by Daria Nepriakhina on Unsplash
Distance: 0.7077873945236206

Photo title: Couple on the beach
Photo by Scott Webb on Unsplash
Distance: 0.6981672048568726

Query: light at the end of the tunnel

Photo title: Light Keyhole

Photo by Leon LEE on Unsplash

Distance: 0.5932173728942871

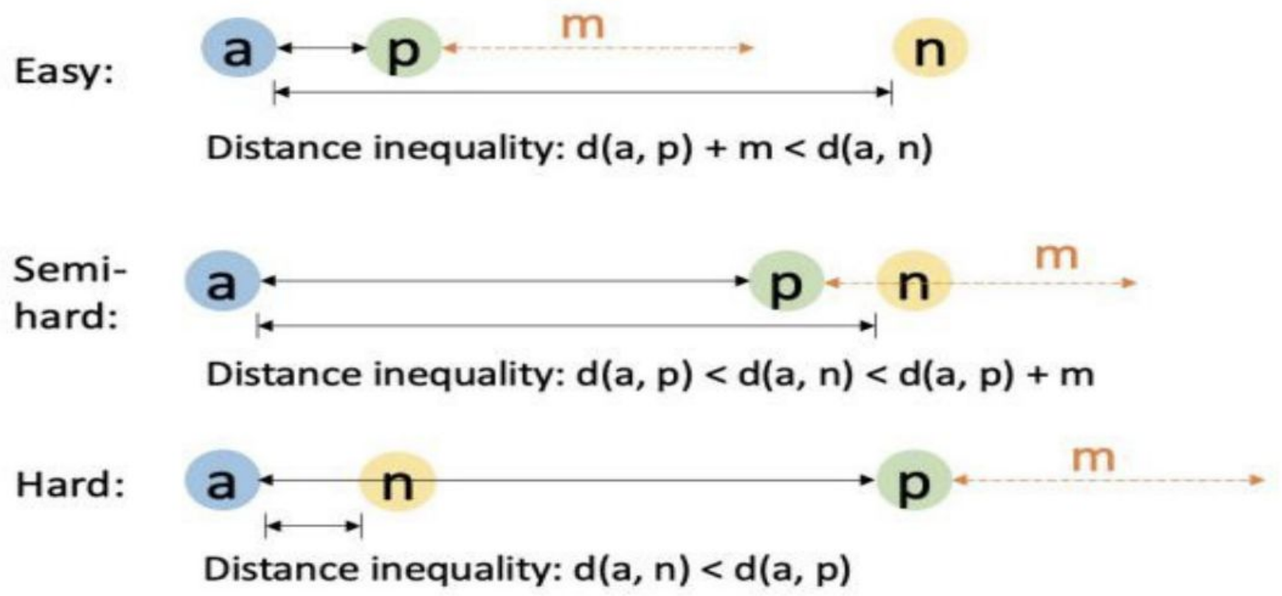
Photo title: light direction

Photo by Zhang Kenny on Unsplash

Distance: 0.5392670035362244

Different types of negatives

Anchor, Positive Ex, Negative Ex



Wang, Zeyu, Xiaoyu Liang, και Cheng Wang. 'Controllable Text-to-Image Generation with Enhanced Text Encoder and Edge-Preserving Embedding'. Journal of Physics: Conference Series 1856 (04 2021): 012003. https://doi.org/10.1088/1742-6596/1856/1/012003.

Multiple Modality: Vision Transformers (ViT)

- Vision Transformer models like CLIP model uses two encoders (text and image).
- These two models are trained in parallel and optimized via a contrastive loss function
- End result is where you can search by text or image

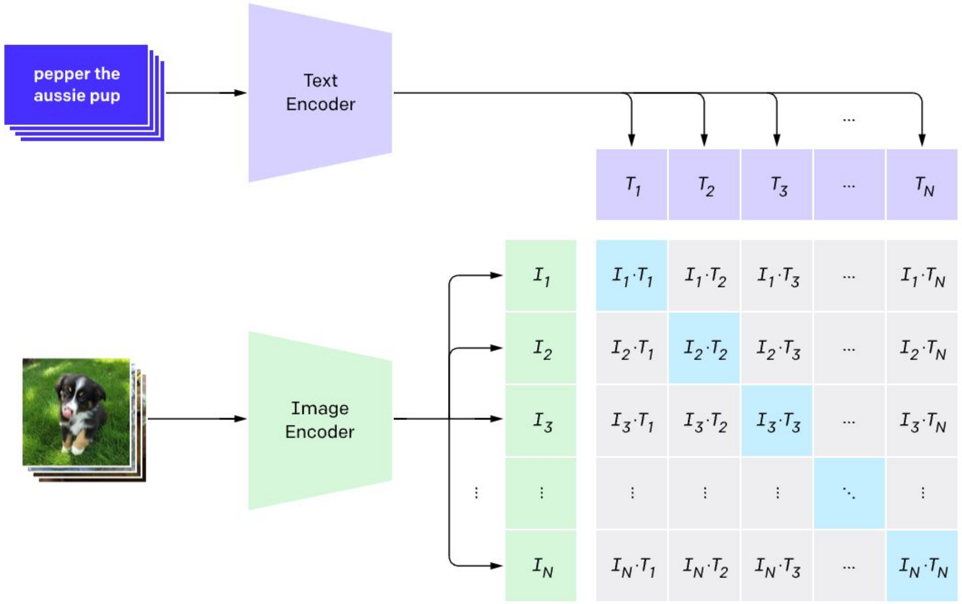


Image from OpenAi CLip blog
https://openai.com/blog/clip/

Encoder can include multiple features

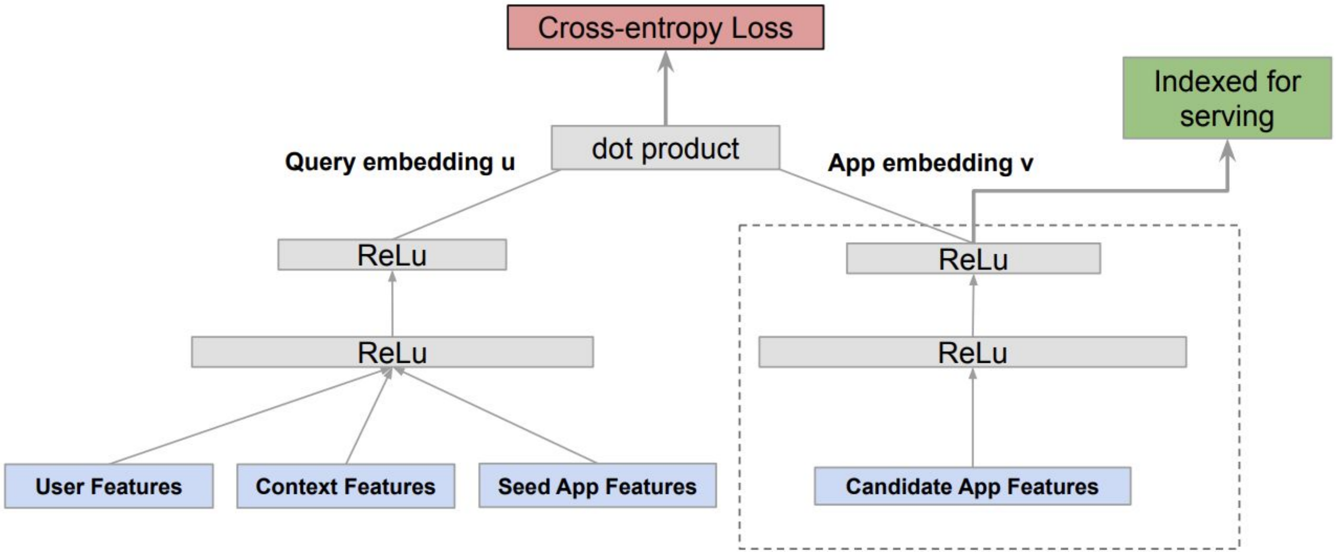


Figure 5: Two-tower model architecture for Google Play app recommendation.

Yang, Ji, Xinyang Yi, Derek Zhiyuan Cheng, Lichan Hong, Yang Li, Simon Xiaoming Wang, Taibai Xu, και Ed H. Chi. 'Mixed Negative Sampling for Learning Two-Tower Neural Networks in Recommendations'. Στο Companion Proceedings of the Web Conference 2020, 441–47. WWW '20. New York, NY, USA: Association for Computing Machinery, 2020. https://doi.org/10.1145/3366424.3386195.

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Lab 3 Goals

- Building a simple in-memory retrieval system using a multi-modal model like CLIP

Query: Two dogs playing in the snow

Photo title: brown and black dogs running on snow

Photo by Luka Vovk on Unsplash

Distance: 0.31937479502958604

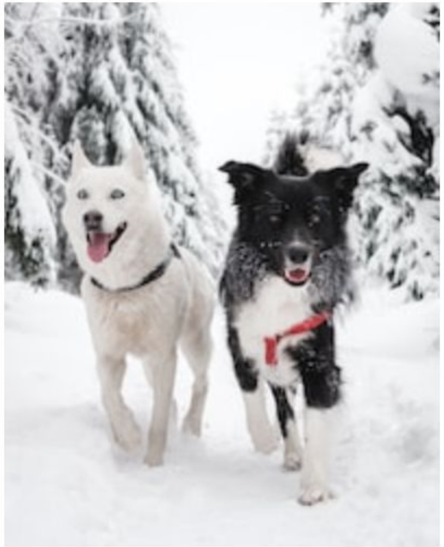


Photo title: Friends will be friends

Photo by Tadeusz Lakota on Unsplash

Distance: 0.309985660979709

Query: boy and girl on a beach

Photo title: White sands

Photo by Toa Heftiba on Unsplash

Distance: 0.3079377628510268

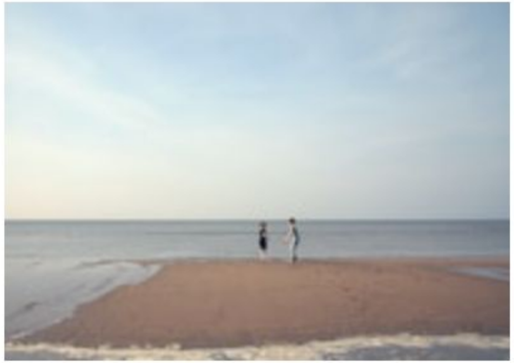


Photo title: children enjoying the beach

Photo by Daria Nepriakhina on Unsplash

Distance: 0.3019976757862893

Query: light at the end of the tunnel

Photo title: Gateway to heaven

Photo by Niklas Schweinzer on Unsplash

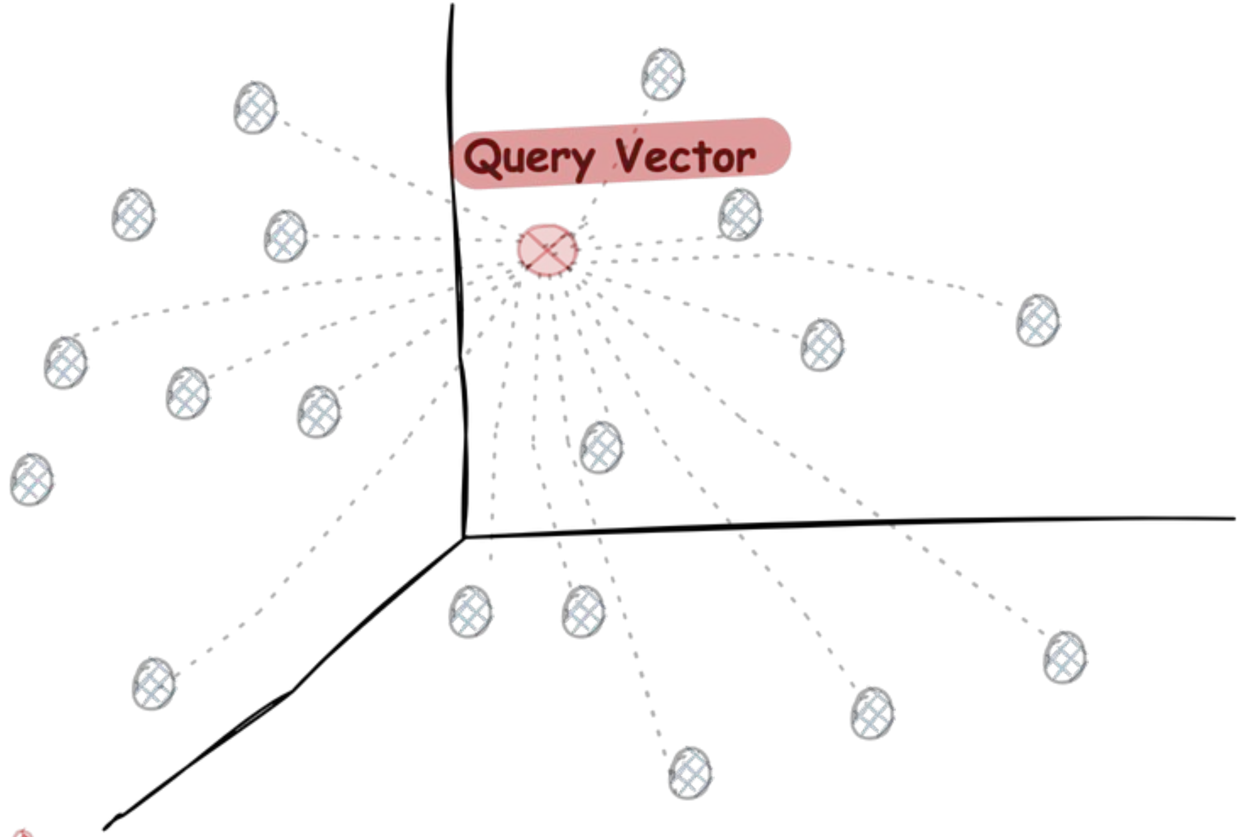
Distance: 0.2948713358039129

Photo title: cave during golden hour

Photo by kiwi thompson on Unsplash

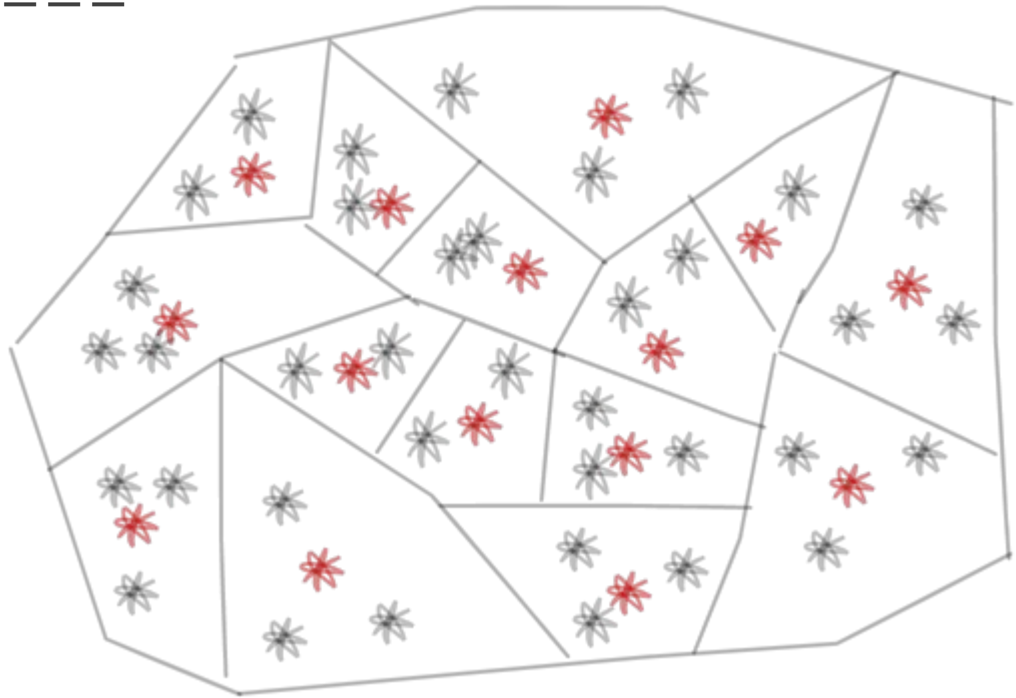
Distance: 0.292107594402263

Approximate Nearest Neighbors



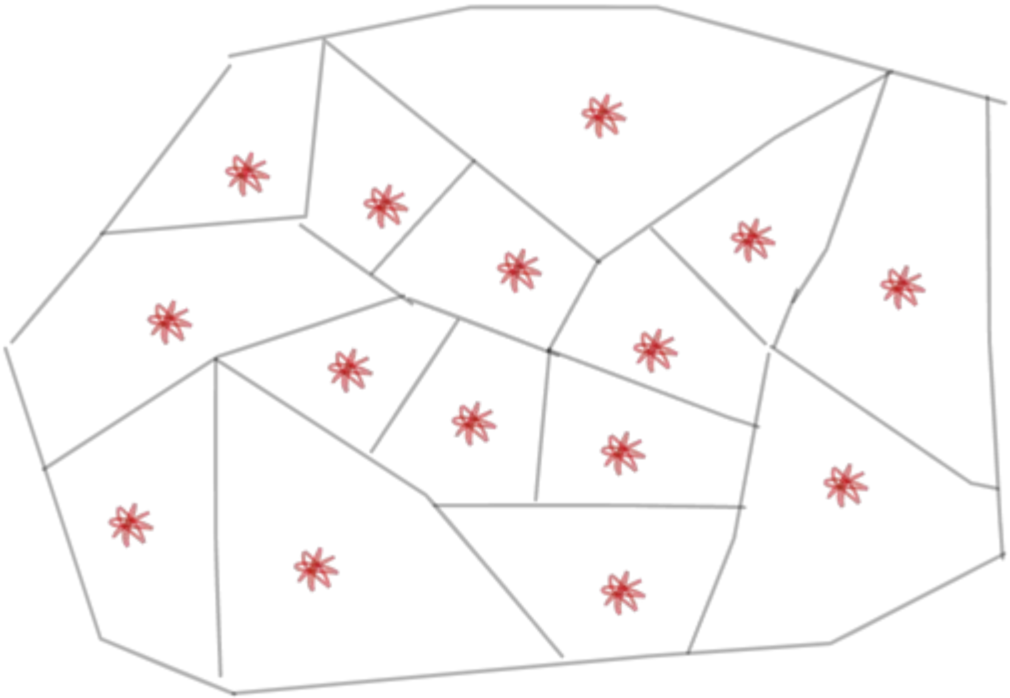
In a flat index / no index, our query vector is compared against all the vectors in the database.

Inverted File Index: Building



- Find centroid and create Voronoi Cells
- Number of centroids is determined by **nlist** parameter

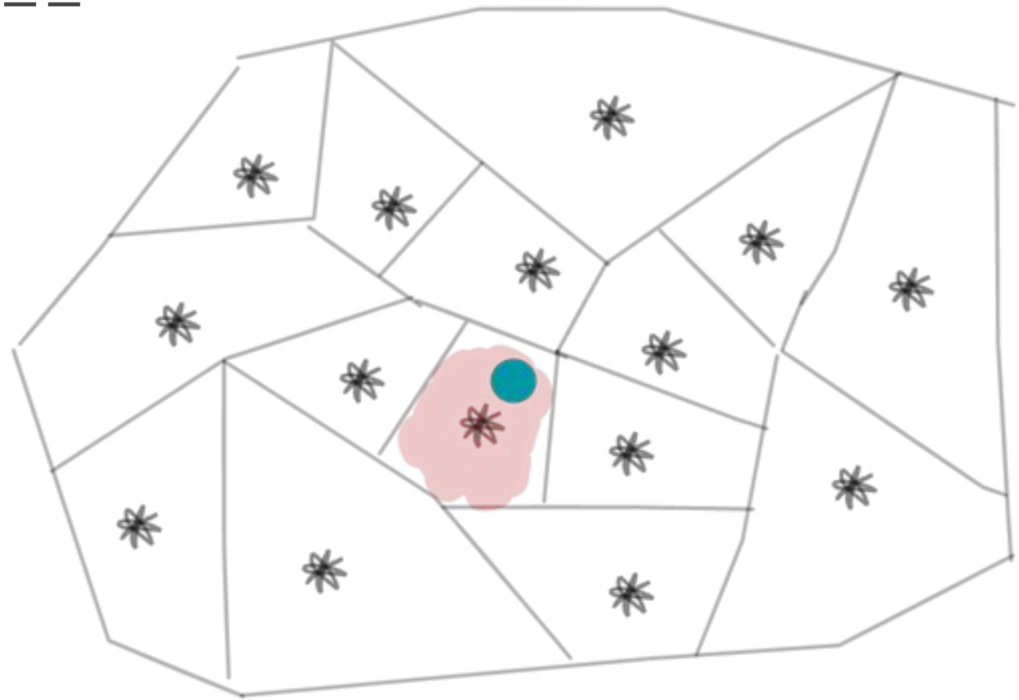
Inverted File Index: Building



- Built Voronoi Index with 15 centroids

- Memory usage is not reduced
- But retrieval is faster

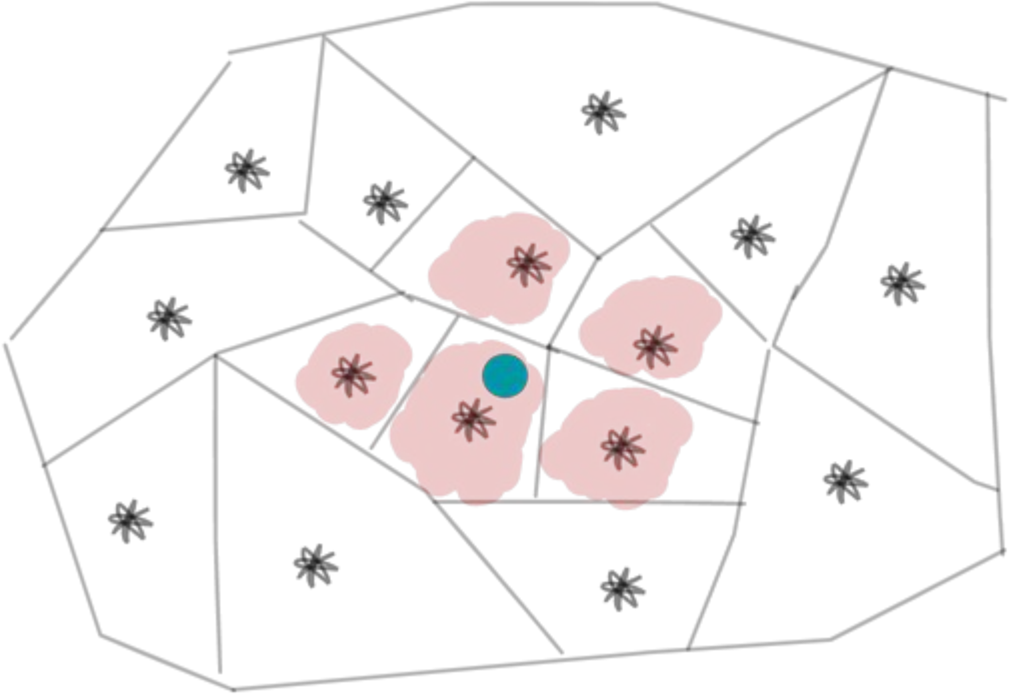
Inverted File Index: Searching



nprobe = 1

- Find the distance between query vector and all the centroids
- Query all the elements inside the n closest cluster determined by **nprobe** parameter

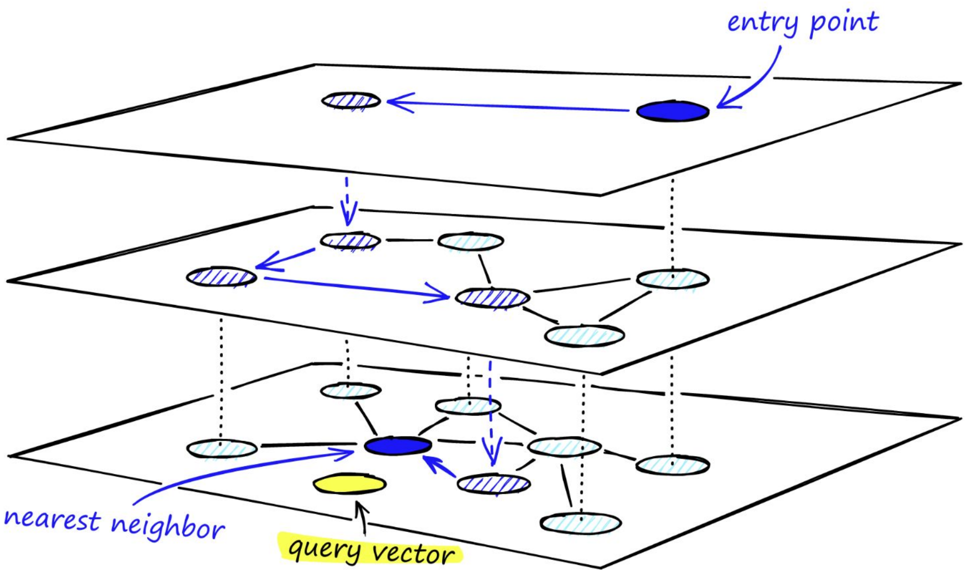
Inverted File Index: Searching



nprobe = 5

- Increasing the value of **nprobe**, improves recall but increases latency
- If nprobe=nlist, similar to flat index

Hierarchical Navigable Small Worlds (HNSW)



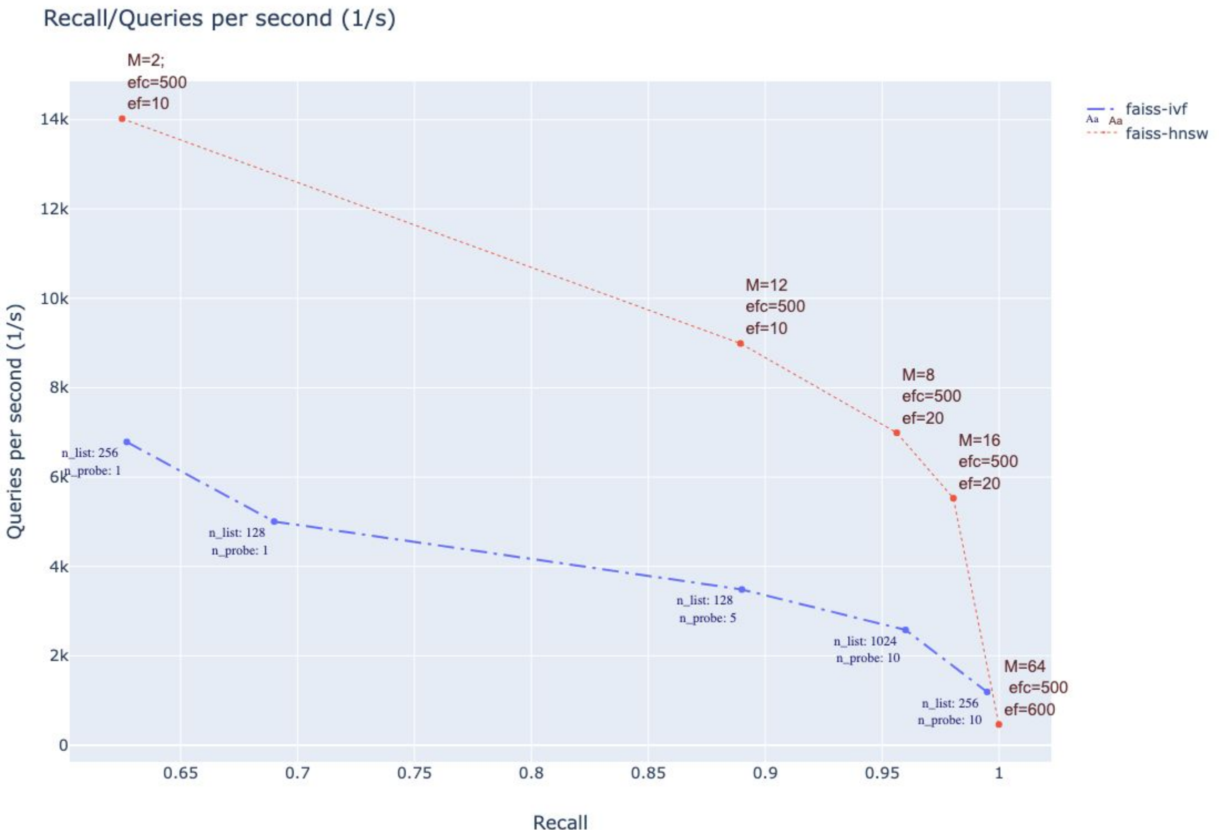
The search process through the multi-layer structure of an HNSW graph.

- Hierarchical Graph
- Every layer stores neighbors
- Earlier layers are sparse

- Common implementation in most production ANN databases

Image from https://www.pinecone.io/learn/hnsw/

ANN Benchmarks



Source:
ANN Benchmarks

Subset

Lot of ANN Option

FAISS

milvus

Weaviate

Pinecone

elastic

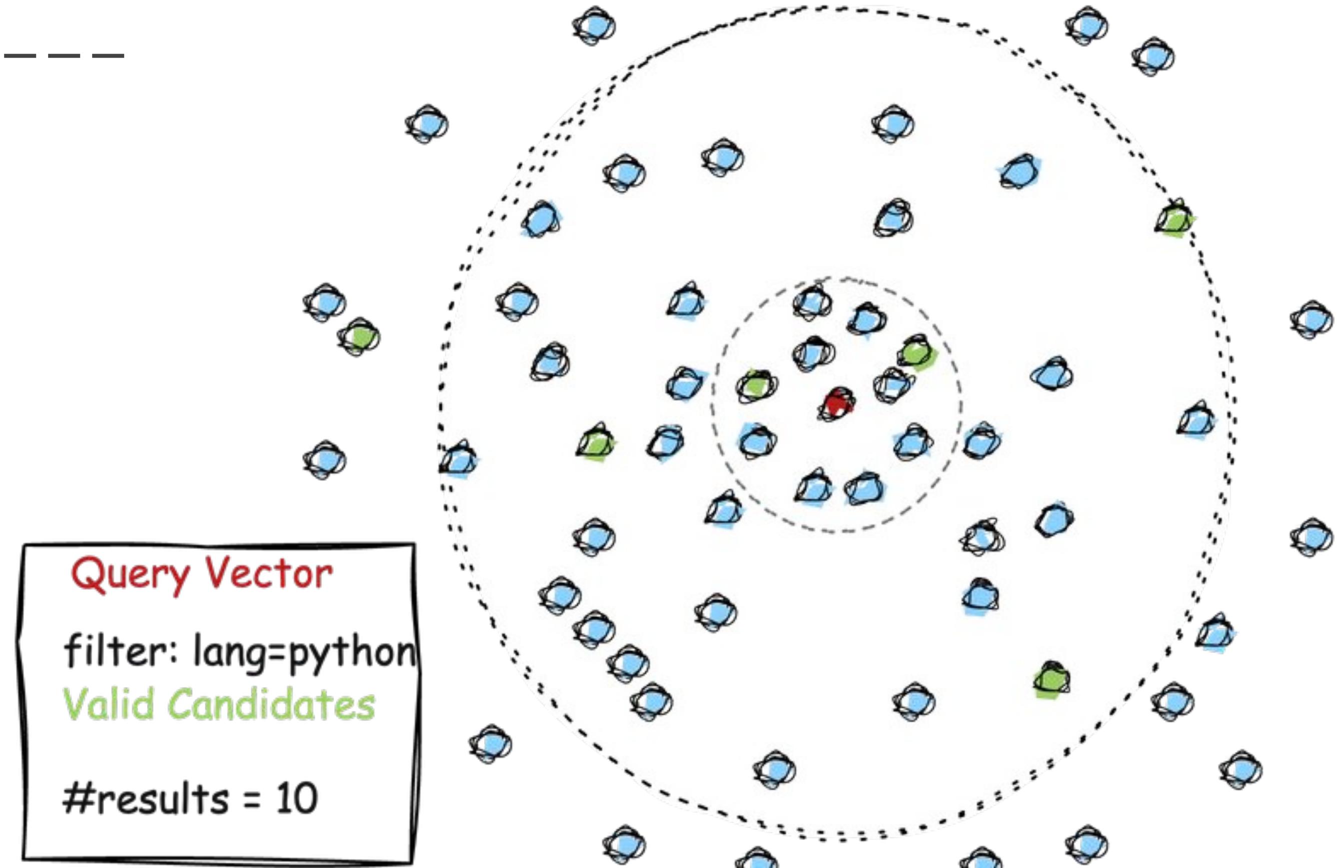
Matching Engine

vespa

Evaluation Considerations

- Managed vs Self-hosted
- Performance
- Update Embeddings / Partial Updates
- Metadata Filtering
- Filtering / Hybrid Retrieval
- Plugins

Filtering



Closest 10 candidates don’t meet our filter

Hybrid / Full Retrieval

Supports

elastic vespa

- In ES, **disjunction** of knn and bm25 match.
- The score of each hit is the sum of the knn and query scores. A boost can be specified

```
POST image-index/_search
{
  "query": {
    "match": {
      "title": {
        "query": "mountain lake",
        "boost": 0.9
      }
    }
  },
  "knn": {
    "field": "image-vector",
    "query_vector": [54, 10, -2],
    "k": 5,
    "num_candidates": 50,
    "boost": 0.1
  },
  "size": 10
}
```

ElasticSearch example of Hybrid Retrieval

Ex from Elastic Doc [link]

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Lab

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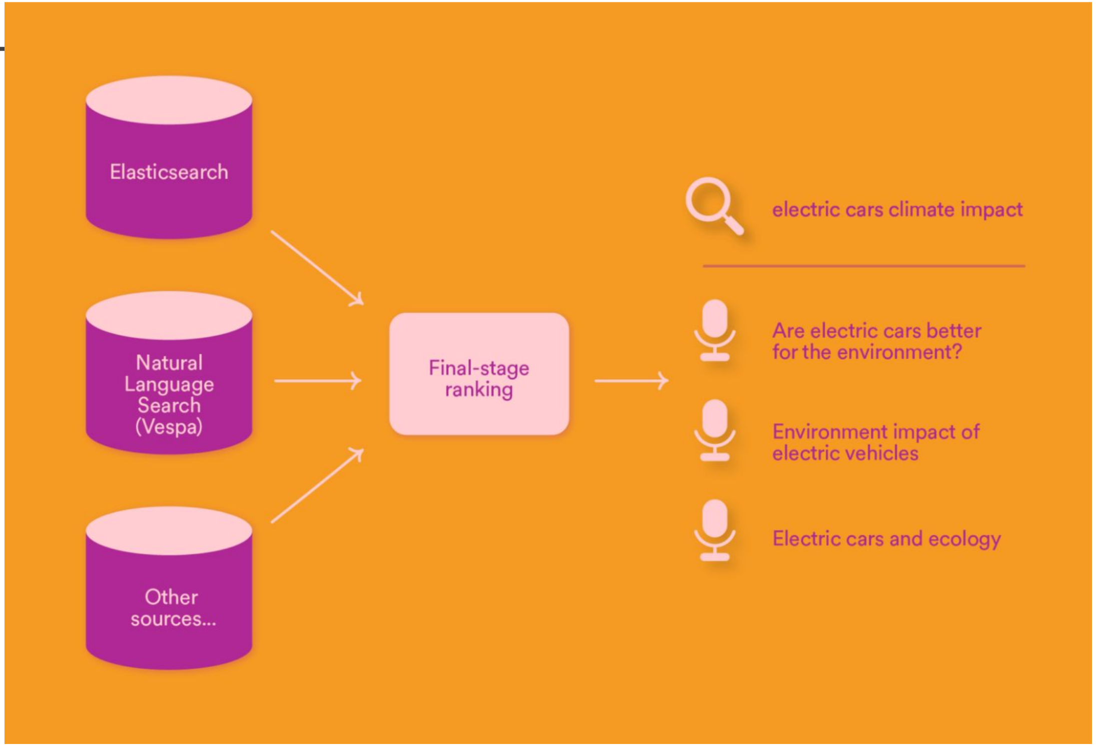
Lab 4 Goals

- Build a flat ANN index
- Optimize retrieval by building an IVF Index

Conclusion

Multi Source Retrieval

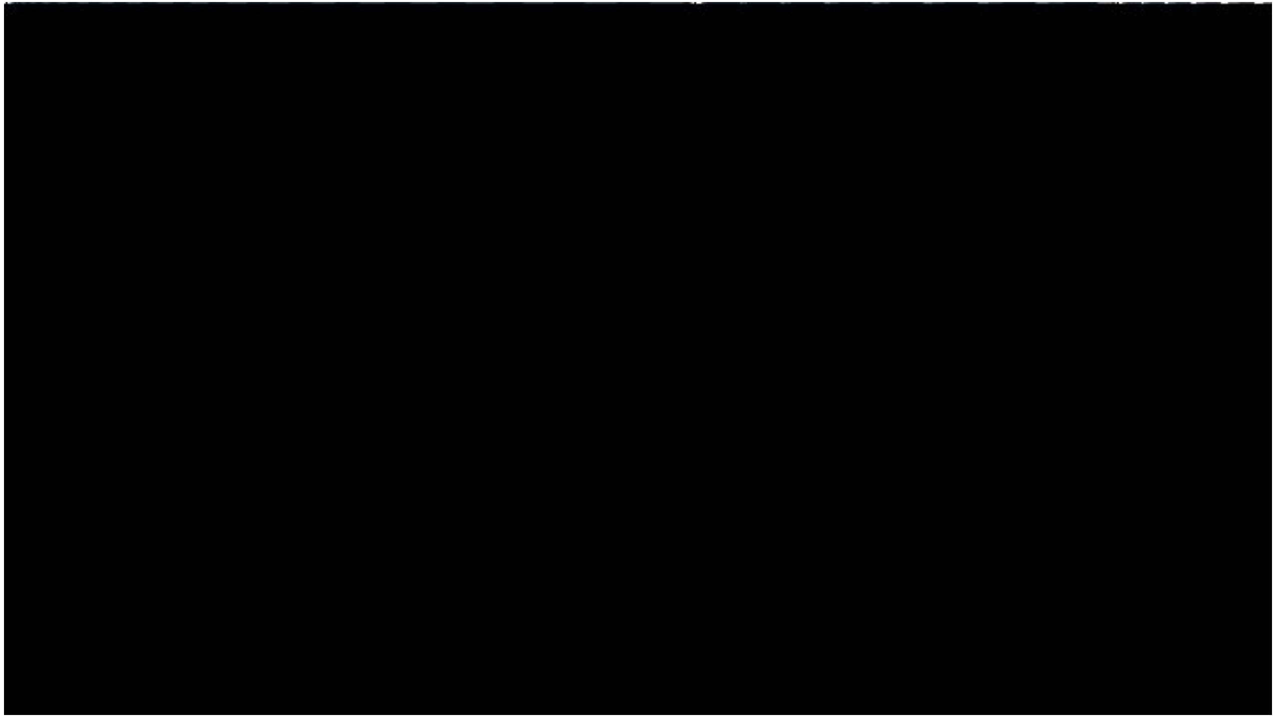


Spotify Podcast Episode Search

Retrieval from ES + ANN + other sources

Tamborrino, Alexandre . “Introducing Natural Language Search for Podcast Episodes - Spotify Engineering.” Introducing Natural Language Search for Podcast Episodes, March 17, 2022. https://engineering.atspotify.com/2022/03/introducing-natural-language-search-for-podcast-episodes/.

Multi Stage Retrieval and Ranking

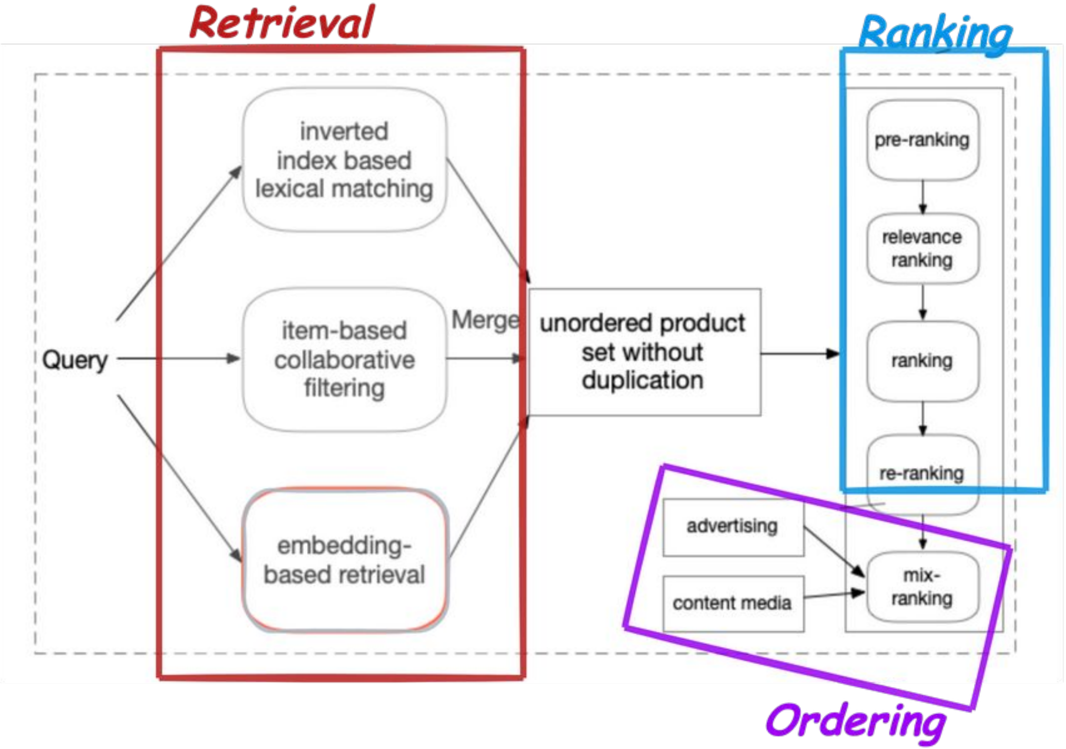


In 2019, Instagram Explore feed was made of

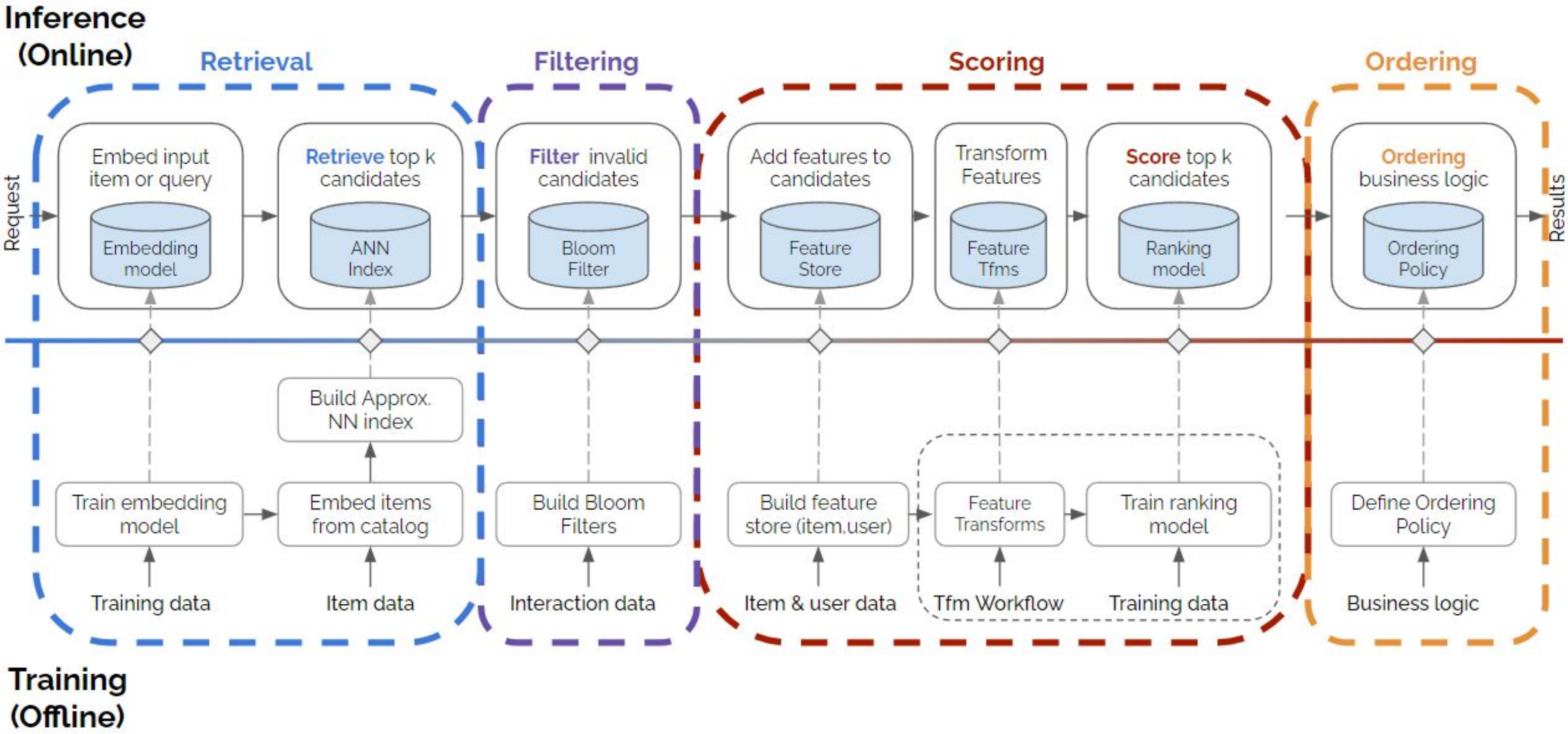
- Sparse Retriever: 500 candidates
- Lightweight NN: 150 ->50
- Deep Neural Network: 50 -> 25

Medvedev, Ivan, Haotian Wu, and Taylor Gordon. "Powered by AI: Instagram's Explore Recommender System." Powered by AI: Instagram's Explore recommender system, November 2019. https://ai.facebook.com/blog/powered-by-ai-instagrams-explore-recommender-system/

Overview of Taobao Search



Li, Sen, Fuyu Lv, Taiwei Jin, Guli Lin, Keping Yang, Xiaoyi Zeng, Xiao-Ming Wu, και Qianli Ma. 'Embedding-based Product Retrieval in Taobao Search'. arXiv, 2021. https://doi.org/10.48550/ARXIV.2106.09297.

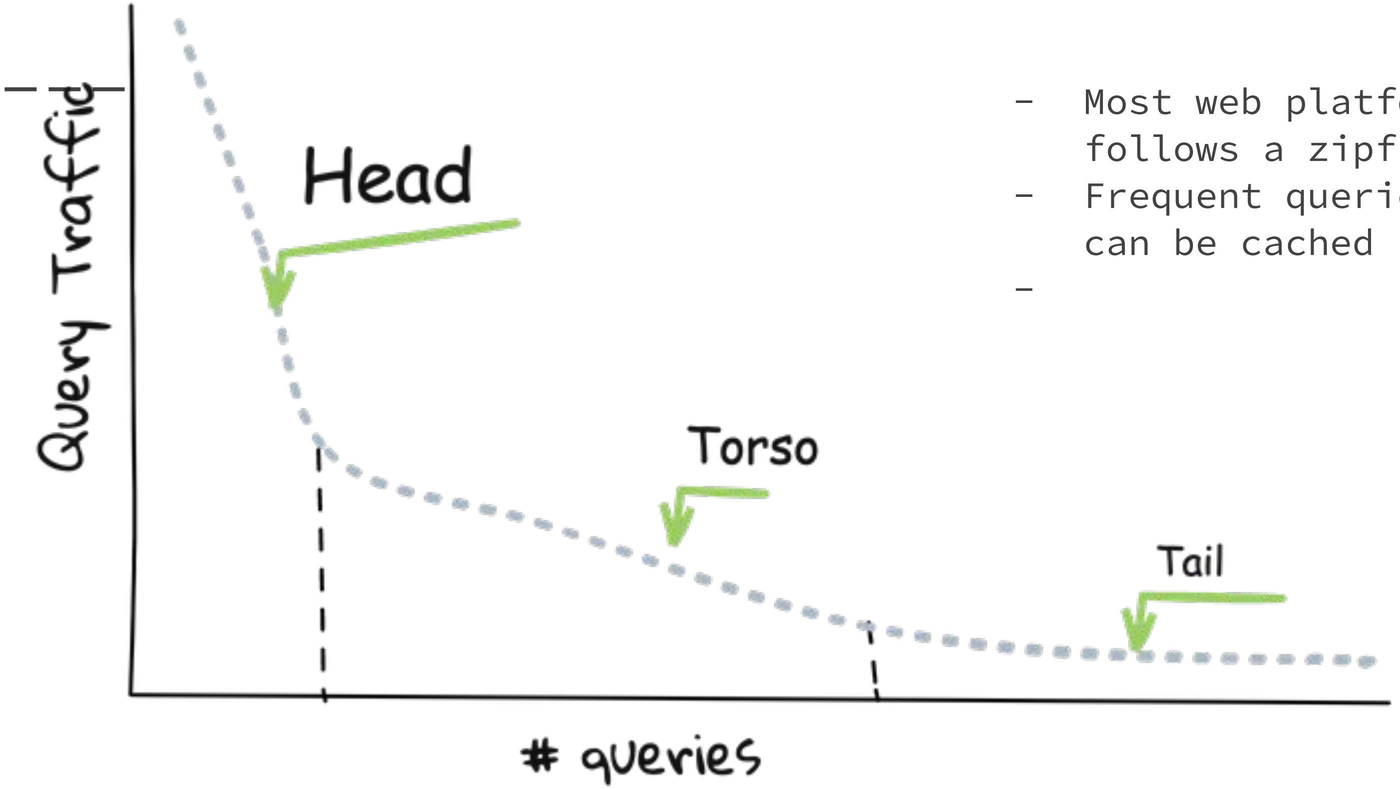


Oldridge, Even. "Recommender Systems, Not Just Recommender Models | by Even Oldridge | NVIDIA Merlin | Medium." Medium, June 27, 2022. https://medium.com/nvidia-merlin/recommender-systems-not-just-recommender-models-485c161c755e.

	Retrieval	Filtering	Scoring	Ordering
Music Discovery	Find similar songs based on nearest neighbour search	Remove tracks users listened before	Predict likelihood that a user will listen to a song	Trade-Off between score, similarity, BPM, etc
Social Media	Find new posts in user's network	Remove posts from blocked and muted users	Predict likelihood that a user will interact with it	Change order that adjust posts are from different authors
Online Store	Find items which are usually co-purchased	Remove items which are out of stock	Predict likelihood that a user will purchase an item	Reorder items based on price points
Streaming Service	Find items based on different rows/shelves/topics	Remove items which are not available for user's country	Predict user's stream time per item	Organize recommendations to fit genre distributions

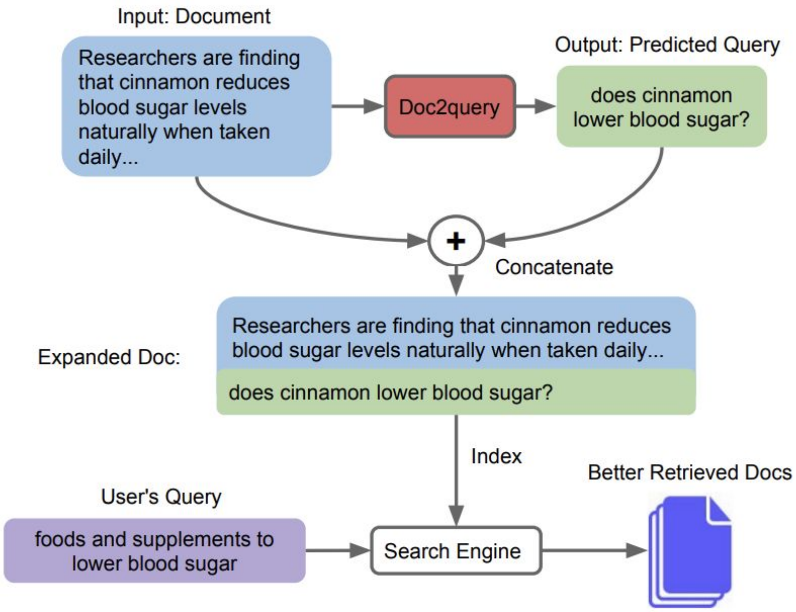
Oldridge, Even. "Recommender Systems, Not Just Recommender Models | by Even Oldridge | NVIDIA Merlin | Medium." Medium, June 27, 2022. https://medium.com/nvidia-merlin/recommender-systems-not-just-recommender-models-485c161c755e.

Zipfian Distribution of Web Traffic



- Most web platforms traffic follows a zipfian distribution
- Frequent queries / head traffic can be cached
-

Enhancing Sparse Index: Doc2Query / Doc2T5Query



- Use a causal language model to generate additional text to add to documents when indexing.
- At retrieval time, use BM25

Nogueira, Rodrigo, Wei Yang, Jimmy Lin, και Kyunghyun Cho. ‘Document Expansion by Query Prediction’. arXiv, 2019. https://doi.org/10.48550/ARXIV.1904.08375.

Benchmarking

Dataset	BM25	Dense (TAS-B)		BM25 on docT5query	BM25 + Cross Encoder
Baseline (MS MARCO)	0.228	0.408	-	0.338	0.413
Quora	0.789	0.835	-	0.802	0.825
DBPedia	0.313	0.384	-	0.331	0.409
-	-	-	-	-	-
TREC-COVID (Medical)	0.656	0.481	-	0.713	0.757
Signal-1M (Tweets)	0.330	0.289	-	0.325	0.338

Do models trained on MS MARCO work for different datasets ?

Dense Retrieval performs well on similar domain

COVID/Tweets are out of domain

BM25 + DR perform best

Cost to Serve

Model	Dimension	Latency (CPU)	Latency (GPU)	Index Size
BM-25	-	20 ms	-	0.4 GB
docT5Query	-	30 ms	-	0.4 GB
Dense Embedding Passage Retrieval	768	230 ms	19 ms	3 GB
BM25 + Cross Encoder	-	6100 ms	450 ms	0.4 GB

Estimated average retrieval latency and index sizes

Dataset: DBPedia (1 million docs)

Lower Latency and Index Size is preferred

CPU: 8 core Intel Xeon Platinum 8168 CPU @ 2.70GHz

GPU: 1 Nvidia Tesla V100

Thakur, Nandan, Nils Reimers, Andreas Rücklé, Abhishek Srivastava, και Iryna Gurevych. 'BEIR: A Heterogenous Benchmark for Zero-shot Evaluation of Information Retrieval Models'. arXiv, 2021. https://doi.org/10.48550/ARXIV.2104.08663.

Resources

- Faiss Missing Manual (Pinecone)
- Natural Language Processing (NLP) for Semantic Search (Pinecone)

- CIKM 2021 Tutorial: IR From Bag-of-words to BERT

- Haystack US 2021 - Semantic Product Search - Vector Search for E-Commerce - Simon Hughes