Section 2:
Definition & Preliminaries

A Retrieval-based LM: Definition

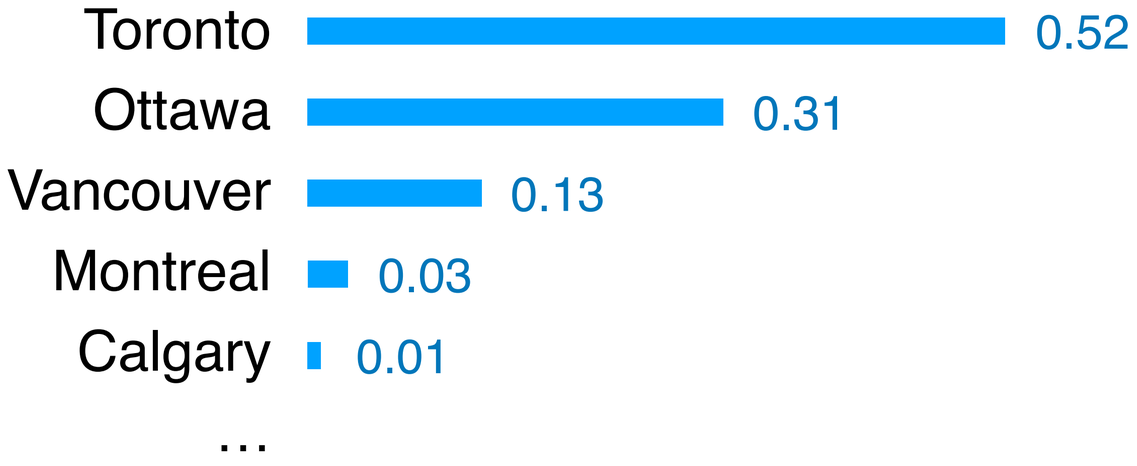
A language model (LM) that uses an external datastore at test time

A Retrieval-based LM: Definition

A language model (LM) that uses an external datastore at test time

A language model (LM)

$$P(x_n \mid x_1, x_2, \cdots, x_{n-1})$$



Language model (Transformers)

The capital city of Ontario is

x_1 x_2 … x_{n-1}

A language model (LM): Categories

Toronto

Autoregressive LM

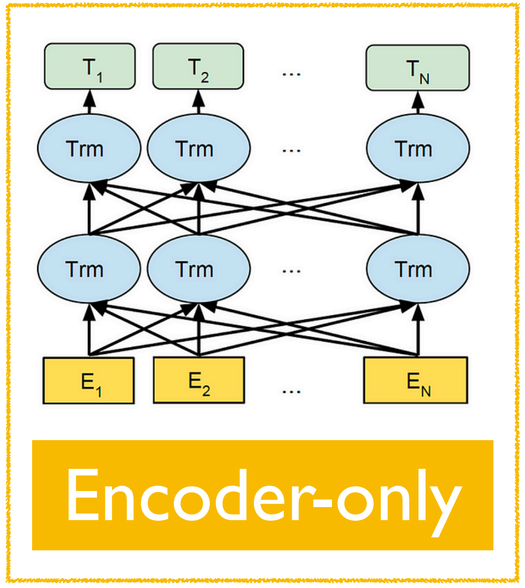
The capital city of Ontario is _____

vs

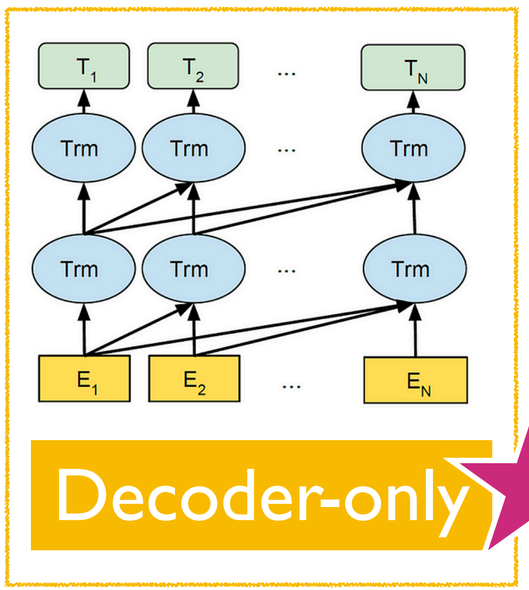
capital Ontario

Masked LM

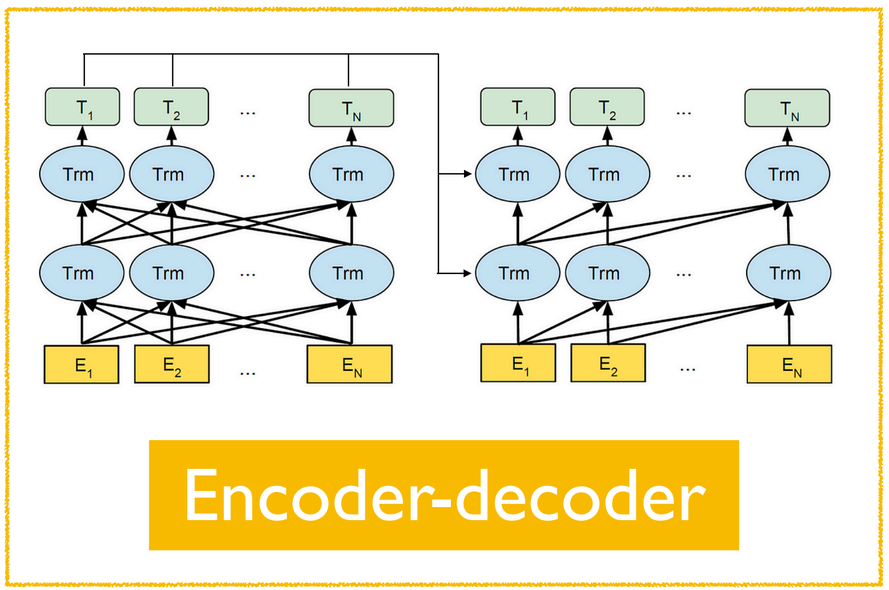
The _____ city of _____ is Toronto



Encoder-only



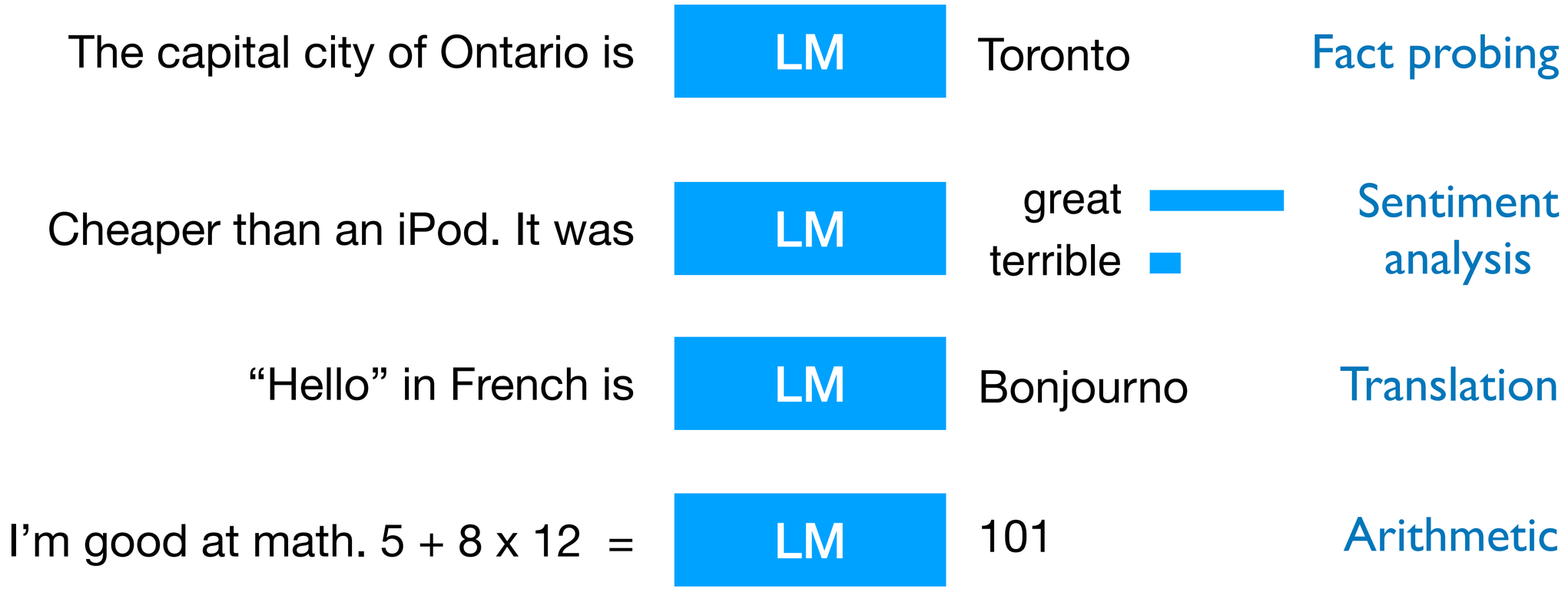
Decoder-only



Encoder-decoder

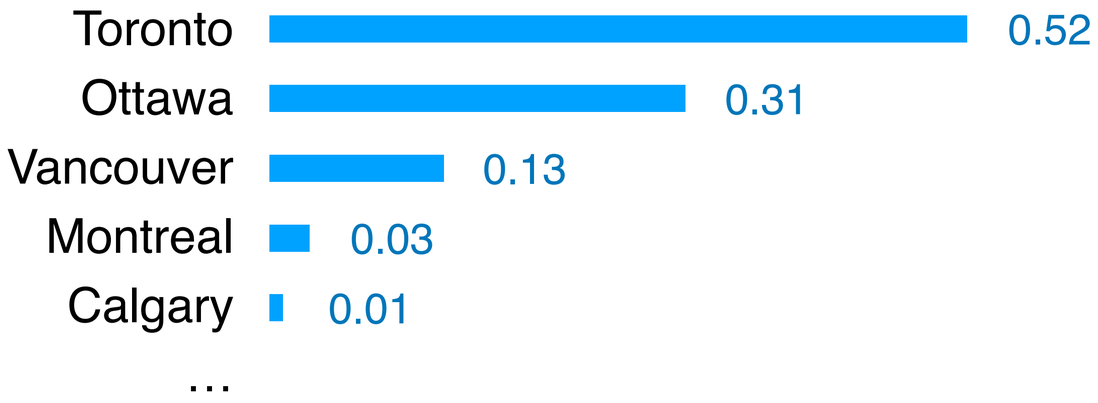
Image source: Devlin et al. 2019. BERT: Pre-training of Deep Bidirectional Transformers for Language Understanding

A language model (LM): Prompting



A language model (LM)

Often evaluated with



$$-\log(0.52) = 0.284$$

Perplexity

Cheaper than an iPod. It was

Prediction: `positive` ✓

Downstream accuracy

(Zero-shot or few-shot in-context learning, or fine-tuning)

(More in Section 5)

A Retrieval-based LM: Definition

A language model (LM) that uses an external datastore at test time

A Retrieval-based LM: Definition

A language model (LM) that uses
an external datastore at test time

External datastore

The capital city of Ontario is **Toronto**

LM

Training time

The capital city of Ontario is _____

LM

Test time

External datastore

The capital city of Ontario is **Toronto**

LM

Training time

The capital city of Ontario is _____

LM

Test time

Inference

Datastore

Query

Index

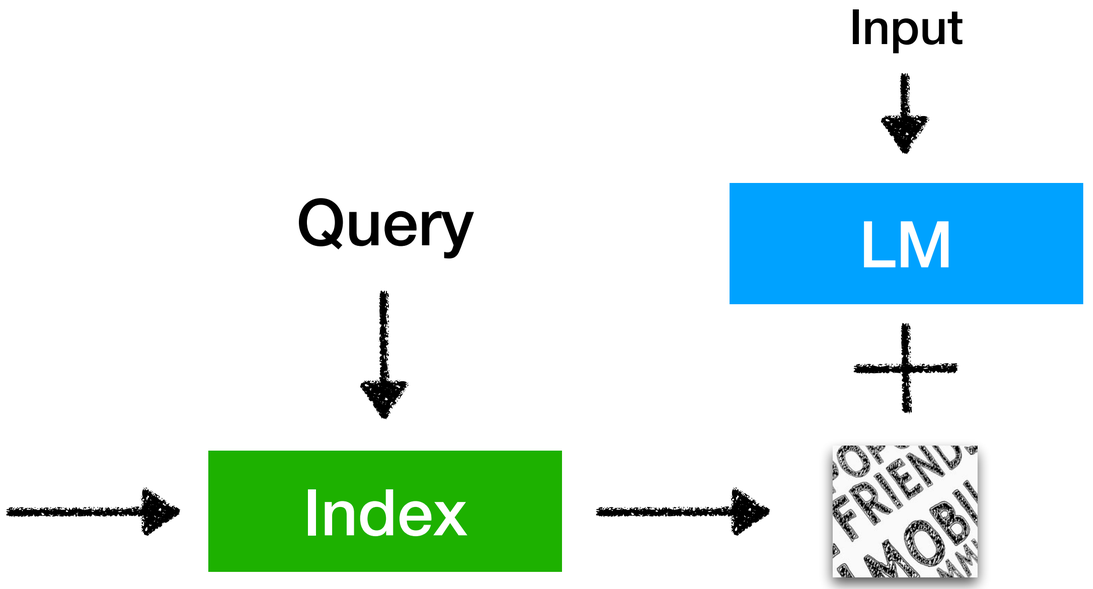
Input

LM

Inference: Datastore

Datastore

Raw text corpus

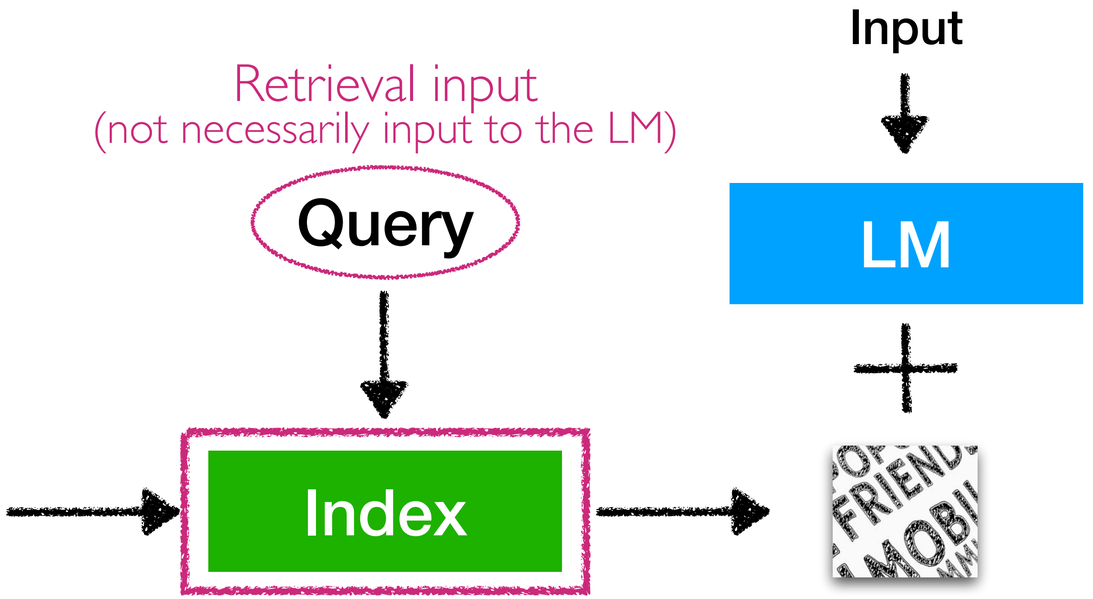


At least billions~trillions of tokens
Not labeled datasets
Not structured data (knowledge bases)

(We'll talk about other cases later)

Inference: Index

Datastore



Find a small subset of elements in a datastore that are the most similar to the query

Inference: Index

Goal: find a small subset of elements in a datastore that are the most similar to the query

sim: a similarity score between two pieces of text

Example $\text{sim}(i, j) = \text{tf}_{i,j} \times \log \frac{N}{\text{df}_i}$

$\text{tf}_{i,j}$: # of occurrences of i in j

N: # of total docs

df_i: # of docs containing i

Example $\text{sim}(i, j) = \text{Encoder}(i) \cdot \text{Encoder}(j)$

Maps the text into an h-dimensional vector

An entire field of study on how to get (or learn) the similarity function better

(We'll see some in Section 4)

Inference: Index

Goal: find a small subset of elements in a datastore
that are the most similar to the query

$\mathbf{sim}$: a similarity score between two pieces of text

Can be a totally separate research area on how to do this fast & accurate

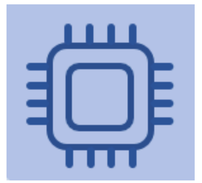
Index: given q, return $\mathbf{argTopk}_{d \in \mathcal{D}} \mathbf{sim}(q, d)$ through fast nearest neighbor search

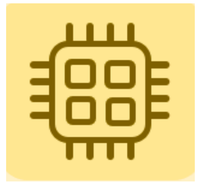
A subset of a datastore

Software: FAISS, Distributed FAISS, SCaNN, etc…

Method	Class name	index_factory	Main parameters	Bytes/vector	Exhaustive	Comments
Exact Search for L2	IndexFlatL2	"Flat"	d	4*d	yes	brute-force
Exact Search for Inner Product	IndexFlatIP	"Flat"	d	4*d	yes	also for cosine (normalize vectors beforehand)
Hierarchical Navigable Small World graph exploration	IndexHNSWFlat	"HNSW,Flat"	d, M	4*d + x * M * 2 * 4	no	
Inverted file with exact post-verification	IndexIVFFlat	"IVFx,Flat"	quantizer, d, nlists, metric	4*d + 8	no	Takes another index to assign vectors to inverted lists. The 8 additional bytes are the vector id that needs to be stored.
Locality-Sensitive Hashing (binary flat index)	IndexLSH	-	d, nbits	ceil(nbits/8)	yes	optimized by using random rotation instead of random projections
Scalar quantizer (SQ) in flat mode	IndexScalarQuantizer	"SQ8"	d	d	yes	4 and 6 bits per component are also implemented.
Product quantizer (PQ) in flat mode	IndexPQ	"PQx", "PQ"M"x"nbits	d, M, nbits	ceil(M * nbits / 8)	yes	
IVF and scalar quantizer	IndexIVFScalarQuantizer	"IVFx,SQ4" "IVFx,SQ8"	quantizer, d, nlists, qtype	SQfp16: 2 * d + 8, SQ8: d + 8 or SQ4: d/2 + 8	no	Same as the IndexScalarQuantizer
IVFADC (coarse quantizer+PQ on residuals)	IndexIVFPQ	"IVFx,PQ"y"x"nbits	quantizer, d, nlists, M, nbits	ceil(M * nbits/8)+8	no	
IVFADC+R (same as IVFADC with re-ranking based on codes)	IndexIVFPQR	"IVFx,PQy+z"	quantizer, d, nlists, M, nbits, M_refine, nbits_refine	M+M_refine+8	no	

Exact Search





CPU vs. GPU

Approximate Search
(Relatively easy to scale to ~1B elements)

More info: https://github.com/facebookresearch/faiss/wiki

Inference: Search

Datastore

Query

Index

fast nearest neighbor search

In this tutorial, we assume we can do it fast & accurate

Input

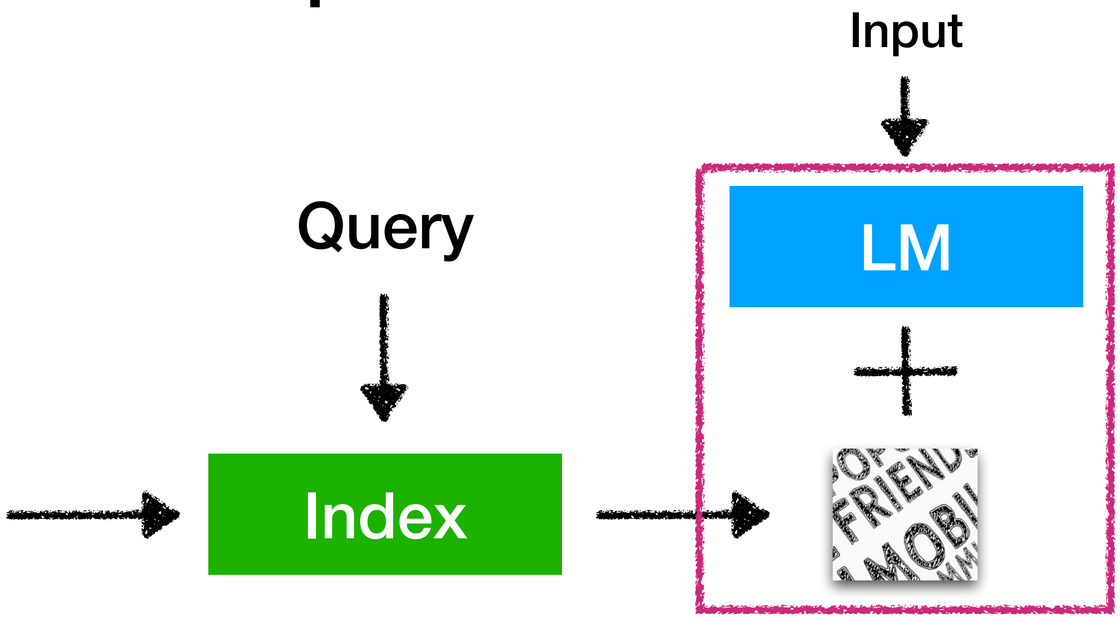
LM

+

Retrieval

Inference: Incorporation

Datastore



Questions to answer

Datastore

What's the query & when do we retrieve?

Query

Index

Input

LM

+

How do we use retrieval?

What do we retrieve?

We'll answer these questions in Section 3!

Notations

Datastore

$\mathscr{D}$