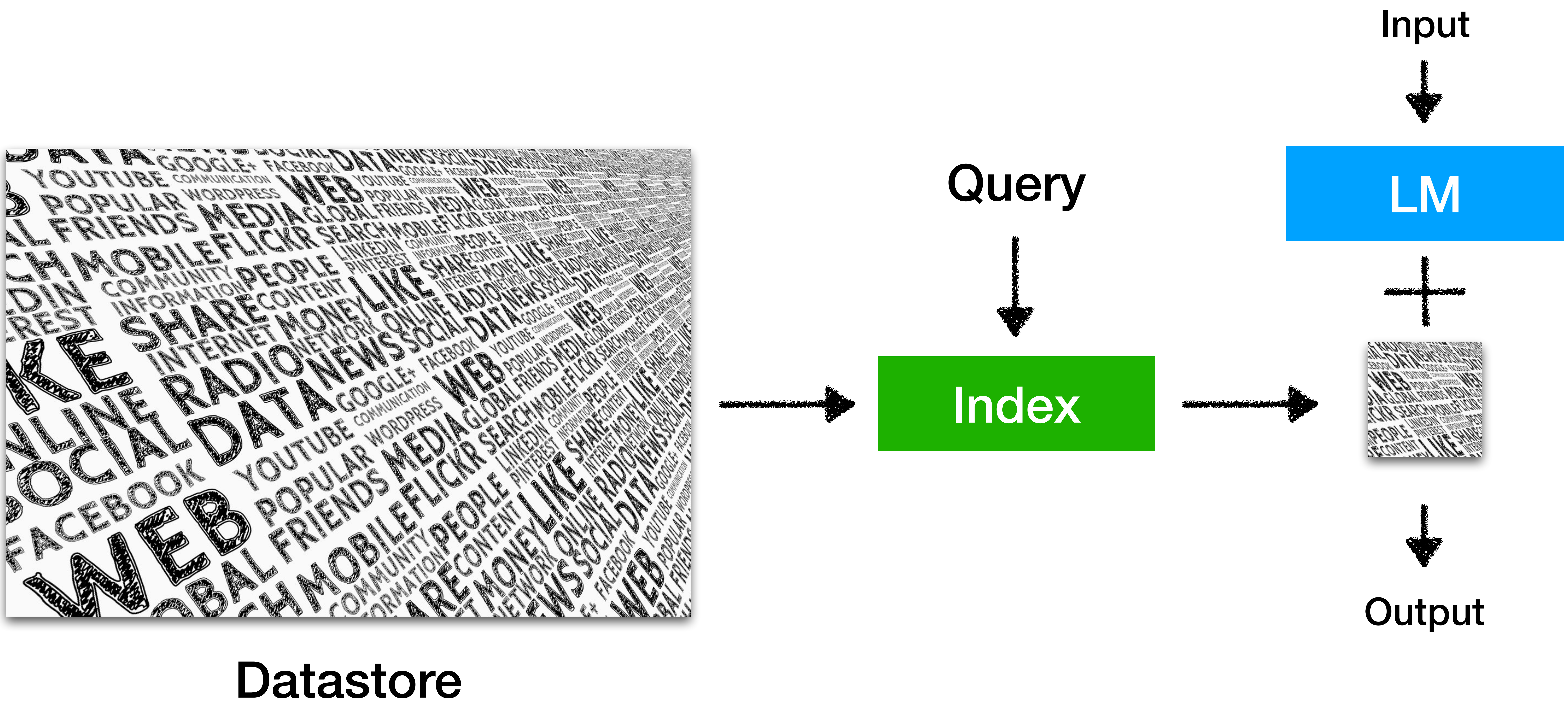
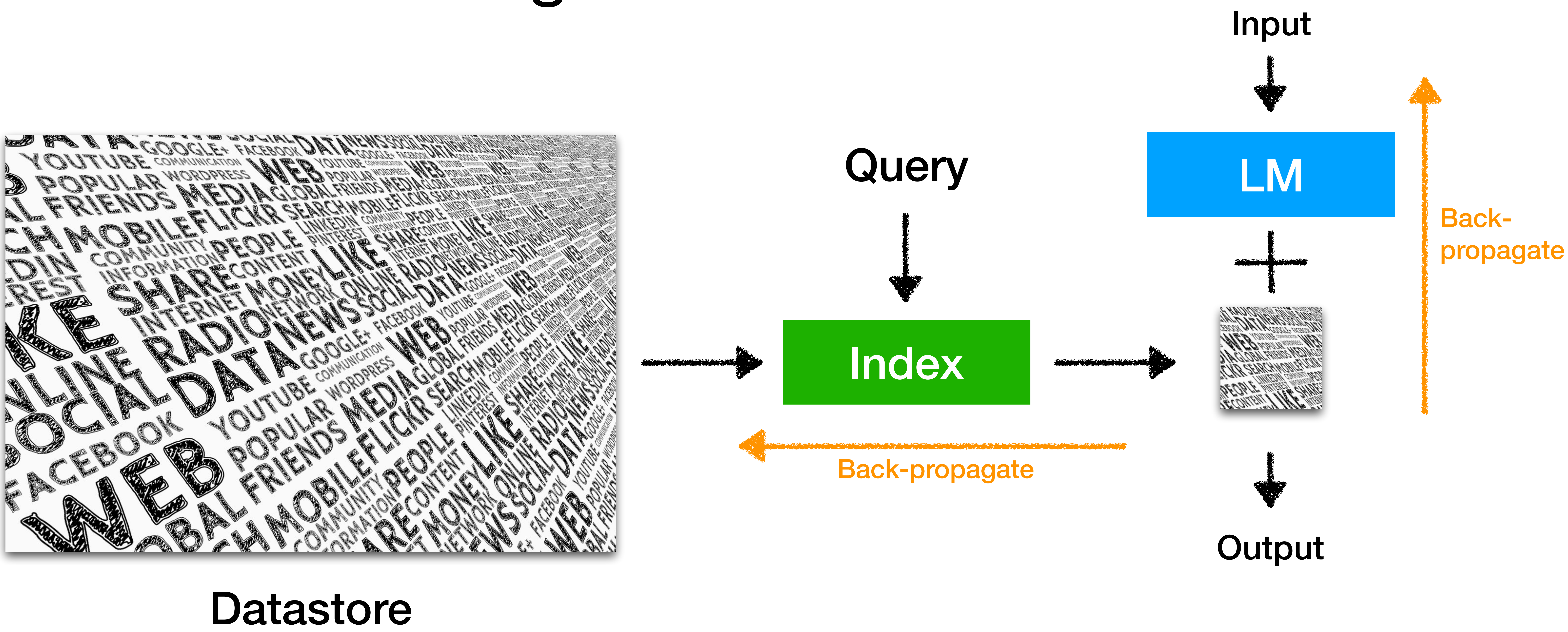
Section 4:
Retrieval-based LMs: Training

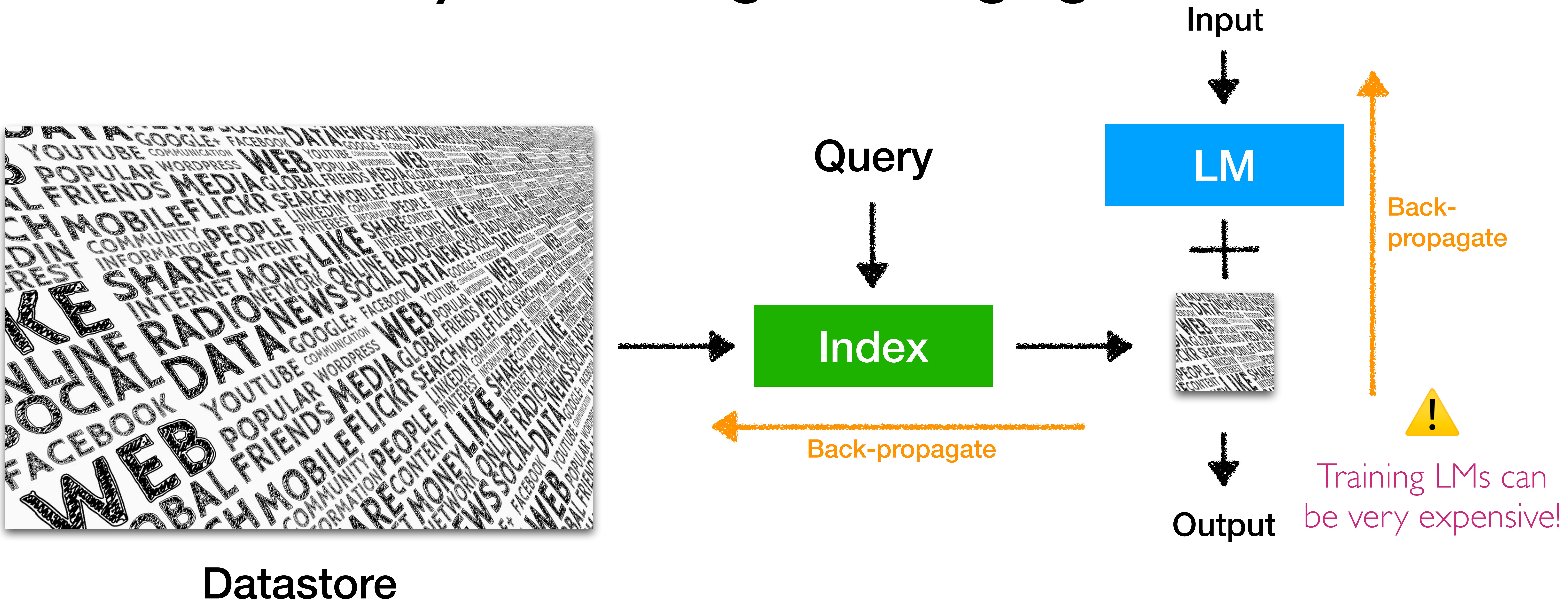
Retrieval-based LMs



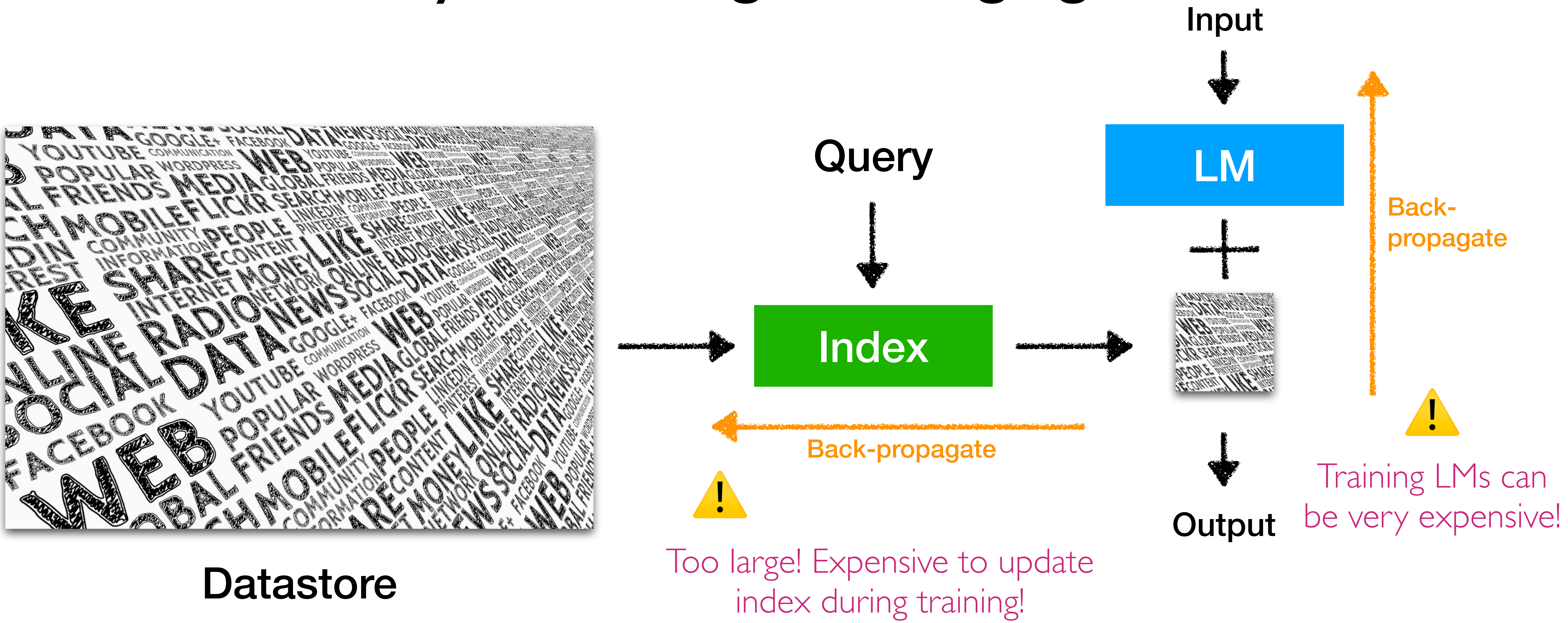
Training retrieval-based LMs



Why is training challenging?



Why is training challenging?



Challenges of updating retrieval models

Datastore

$\mathbf{x}_1$

$\mathbf{x}_2$ → Encoder → Index

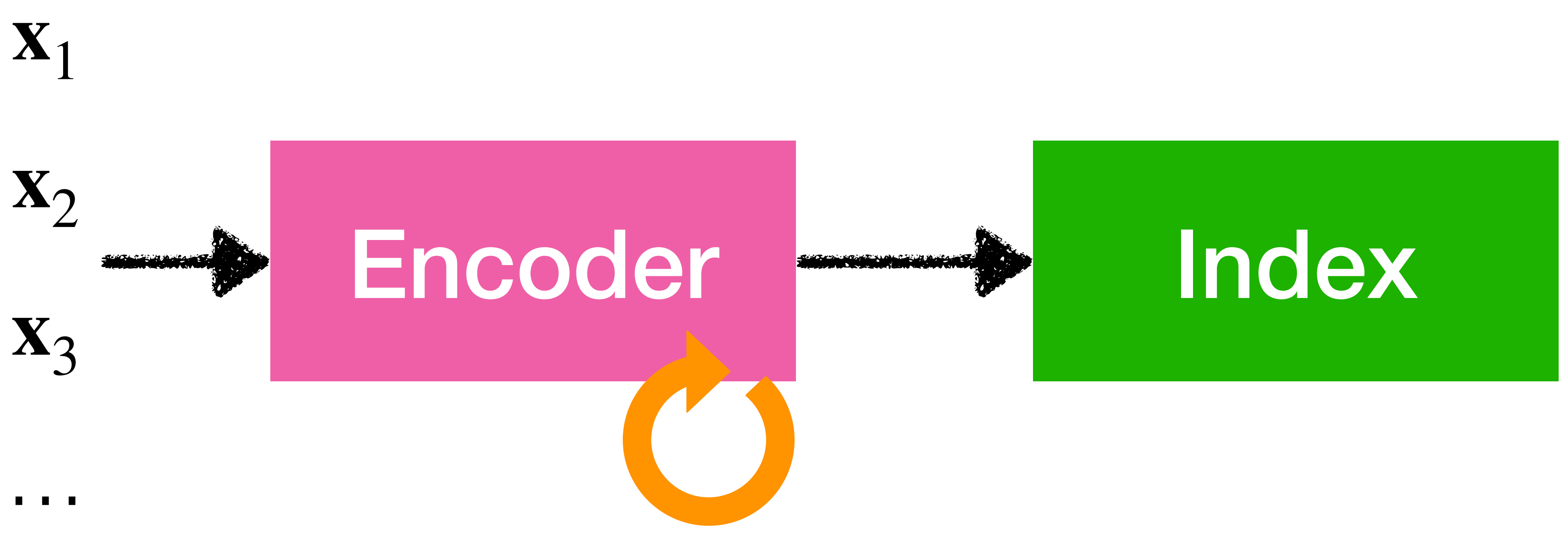
$\mathbf{x}_3$

…

We may encode a lot of (>100M) text chunks using the encoder!

Challenges of updating retrieval models

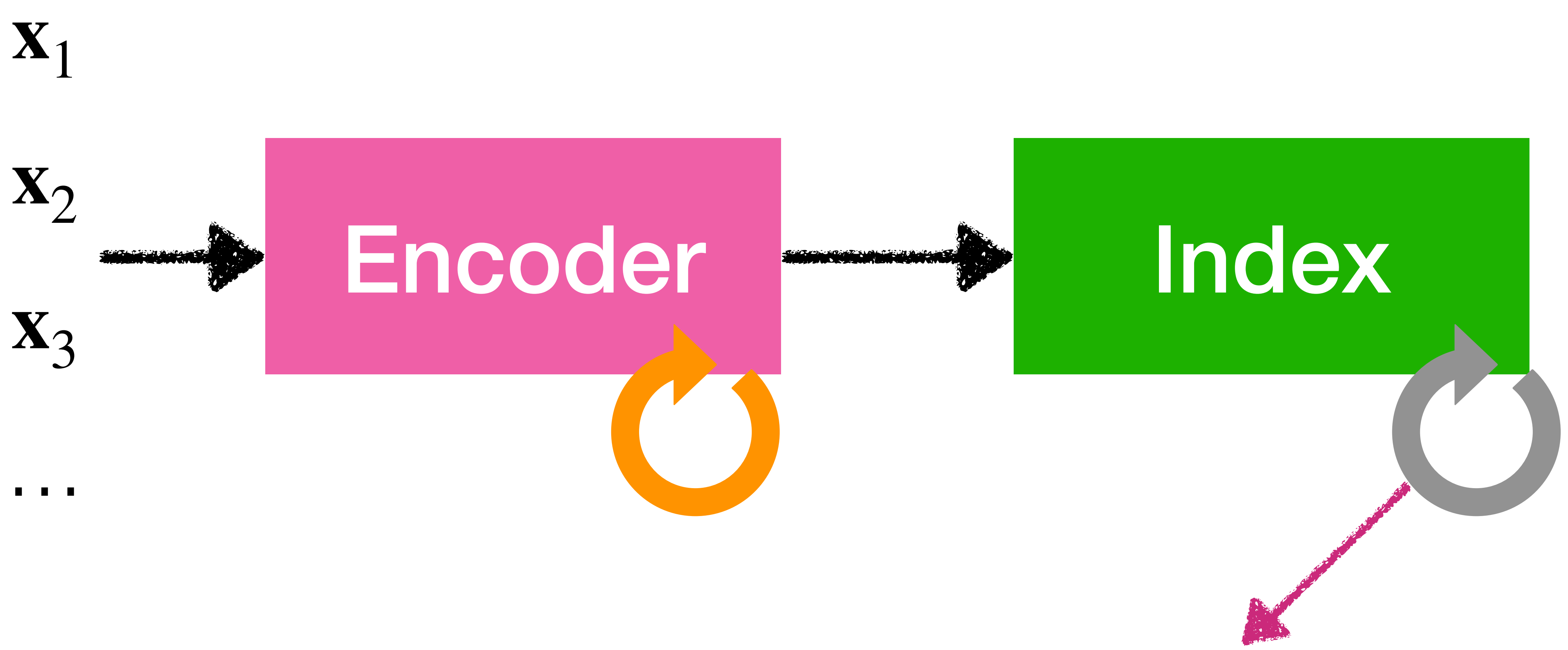
Datastore



During training, we will update the encoder

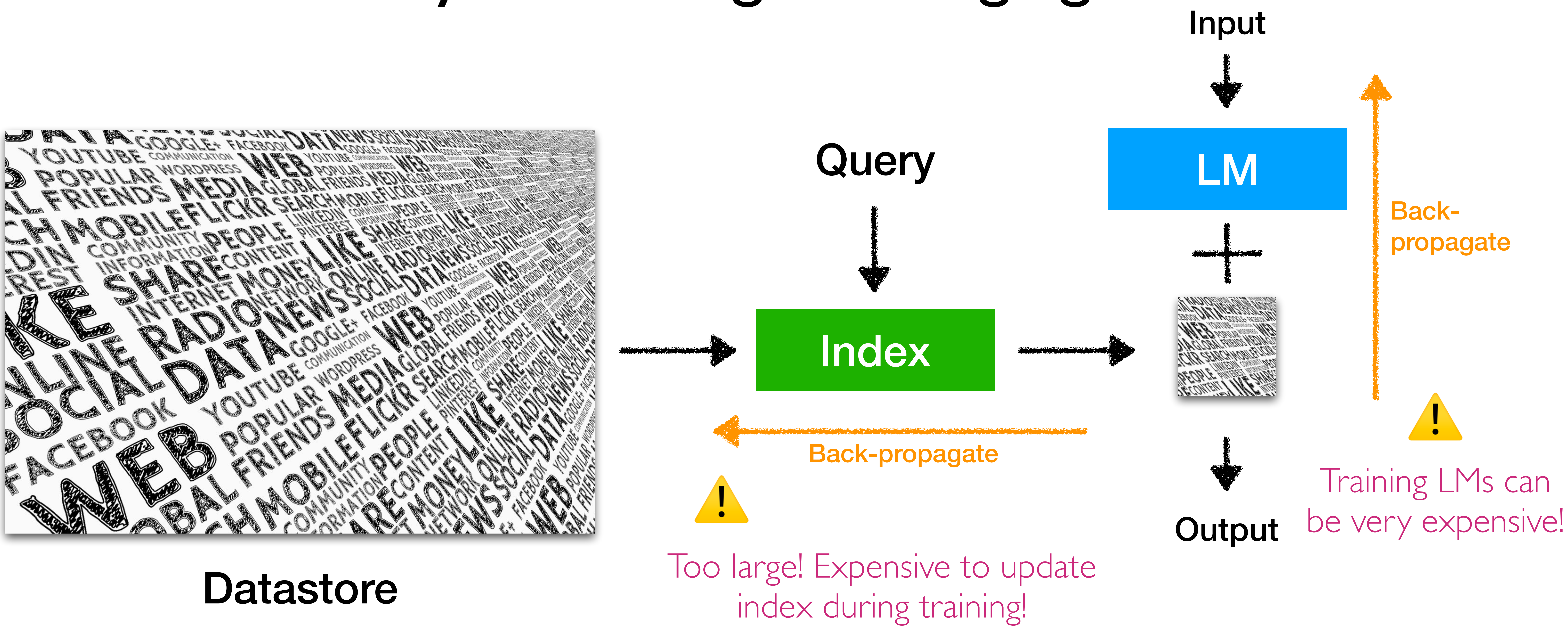
Challenges of updating retrieval models

Datastore



Re-indexing will be very expensive!

Why is training challenging?



Training methods for retrieval-based LMs

- Independent training
- Sequential training
- Joint training w/ asynchronous index update
- Joint training w/ in-batch approximation

Training methods for retrieval-based LMs

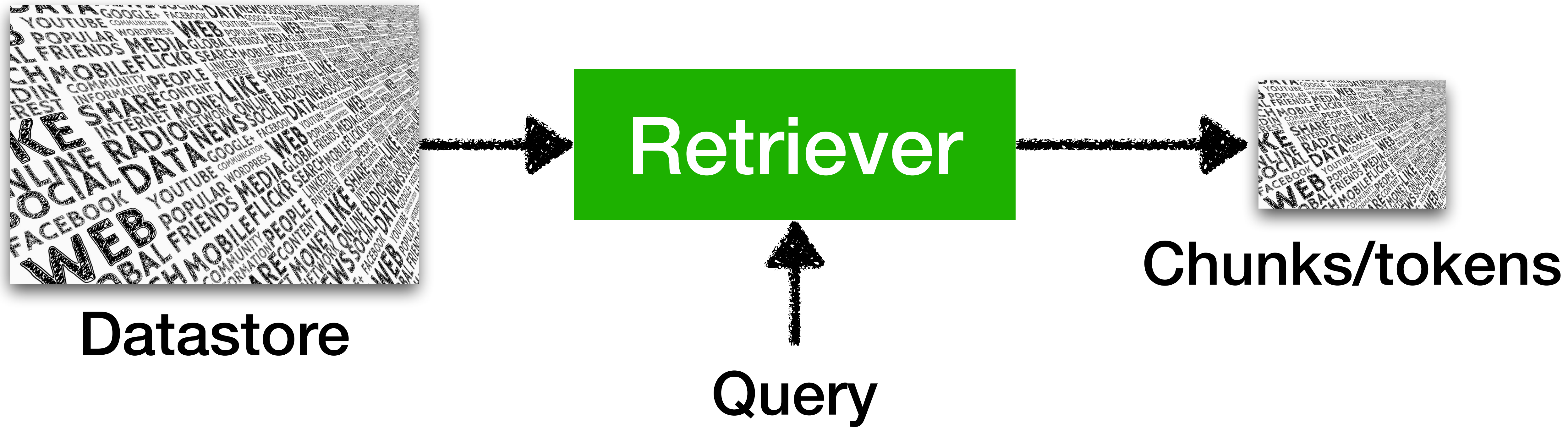
- **Independent training**
- Sequential training
- Joint training w/ asynchronous index update
- Joint training w/ in-batch approximation

Independent training

Retrieval models and language models are trained **independently**

- Training language models

- Training retrieval models

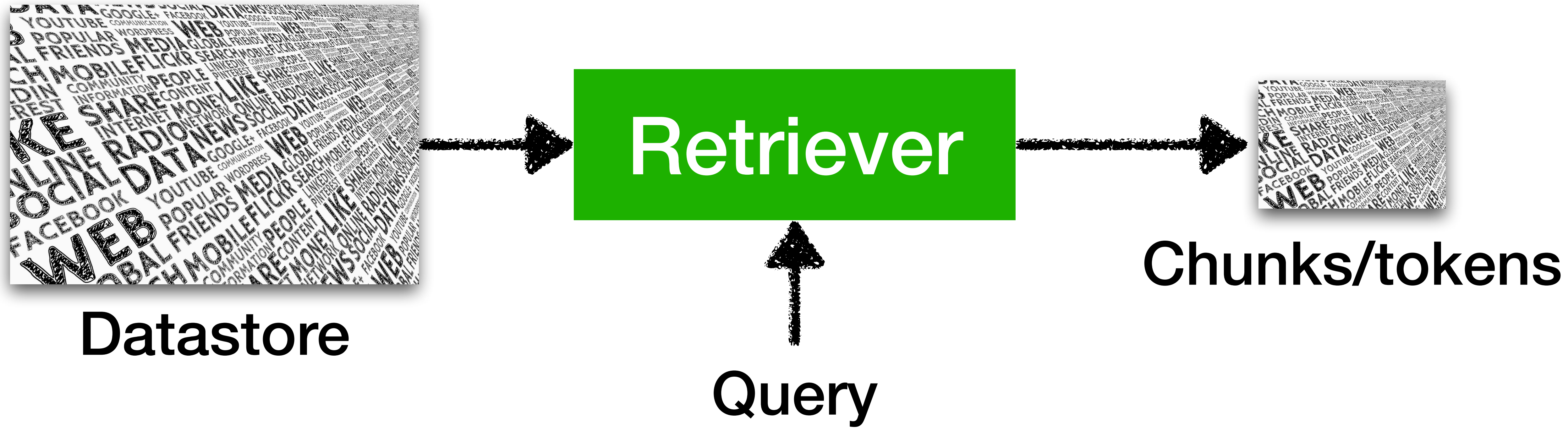


Independent training

Retrieval models and language models are trained **independently**

- Training language models

- Training retrieval models



Training language models

Minimize $-\log P_{\mathrm{LM}}(y \mid x)$

Training language models

Input → LM → Output

← Back-propagate

Minimize $\quad -\log P_{\mathrm{LM}}(y \mid x)$

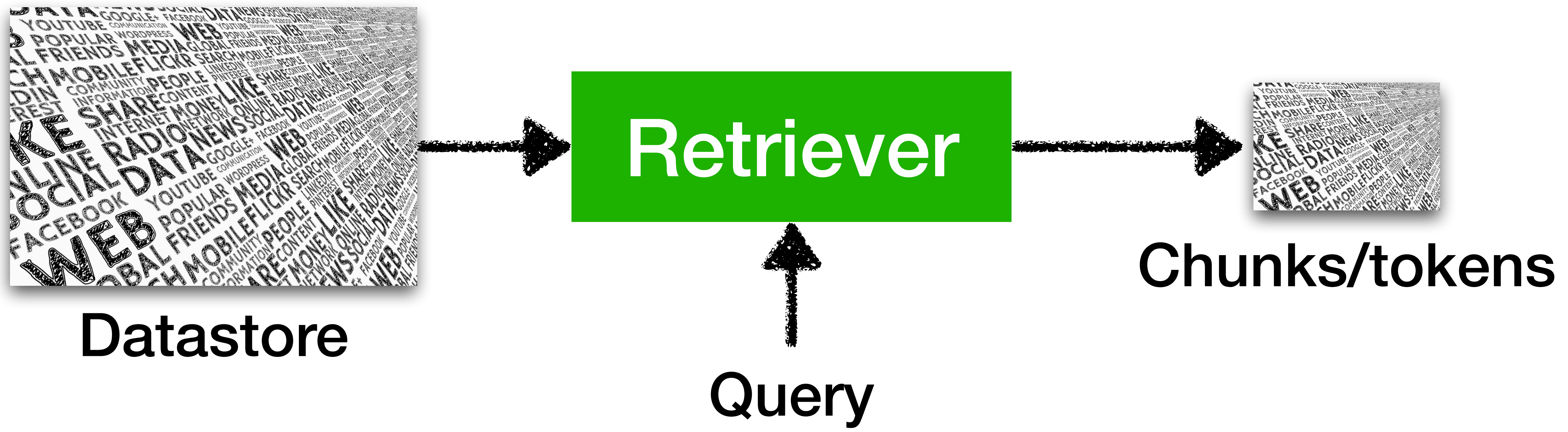
GPT PaLM LLaMA GPT-J ……

Independent training

Retrieval models and language models are trained **independently**

- Training language models

- Training retrieval models



Sparse retrieval models: TF-IDF / BM25

In 1997, Apple merged with NeXT, and Steve Jobs became CEO of …

Jobs returned to Apple as CEO after the company's acquisition …

→

[0, 0, 0.4, 0, 0.8, 0.7, …]

[0, 1.2, 0.4, 0, 0.8, 0, …]

Lexical overlap

Text chunks

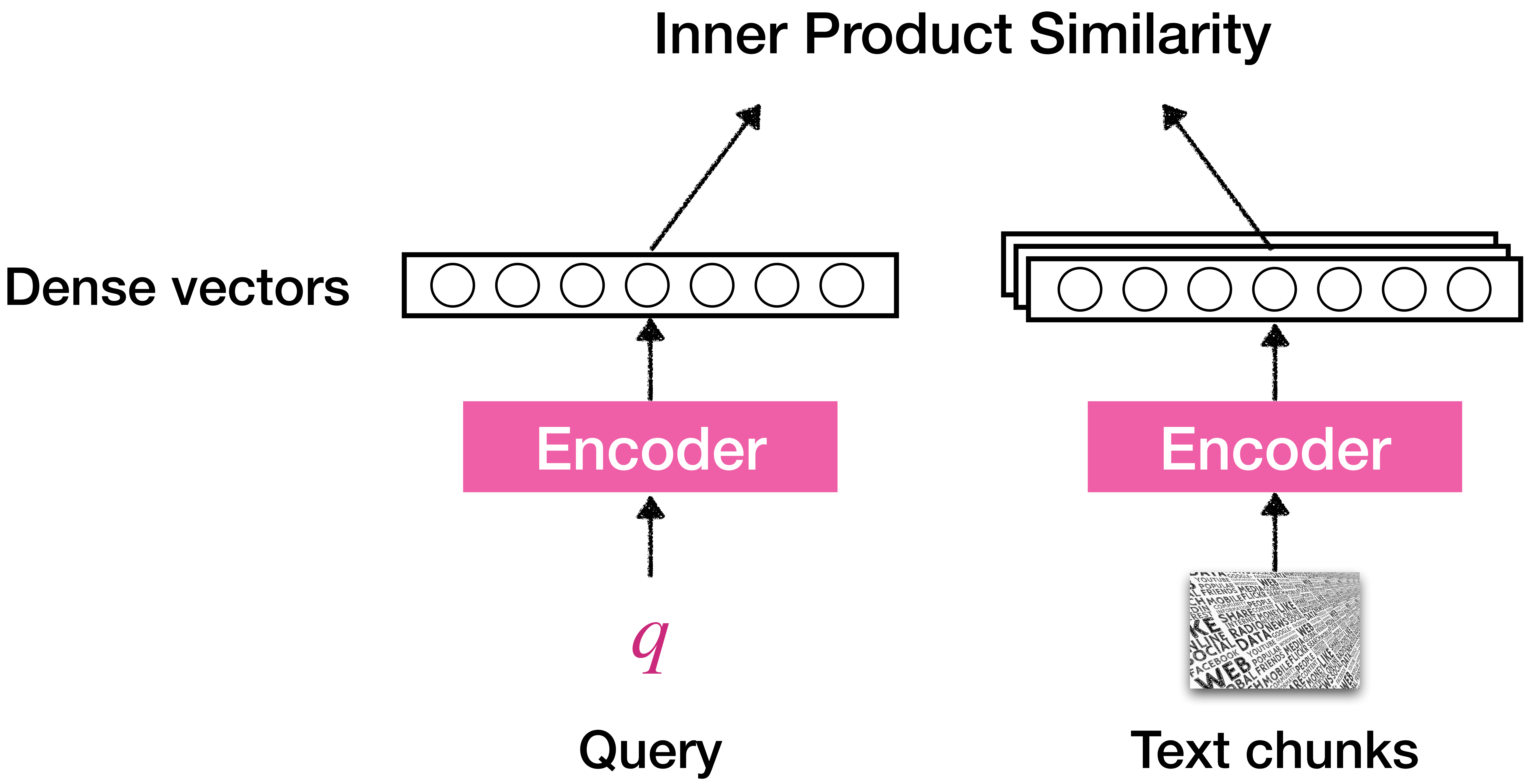
Sparse vectors

No training needed!

Ramos, 2003. "Using TF-IDF to Determine Word Relevance in Document Queries"

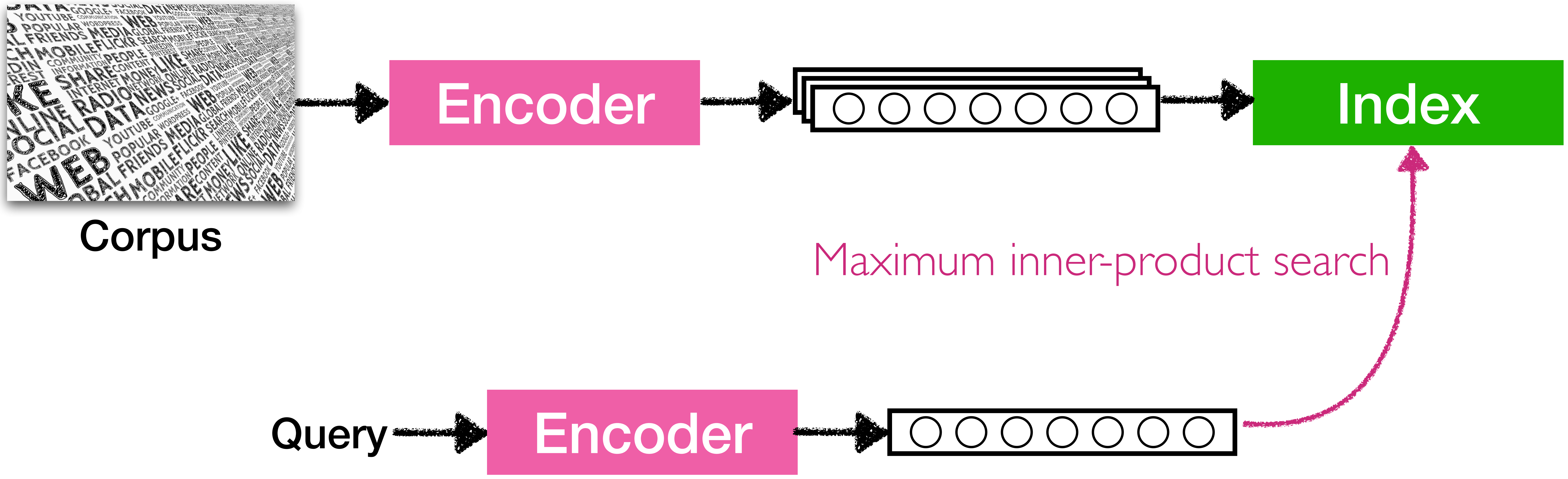
Robertson and Zaragoza, 2009. "The Probabilistic Relevance Framework: BM25 and Beyond"

Dense retrieval models: DPR (Karpukhin et al. 2020)

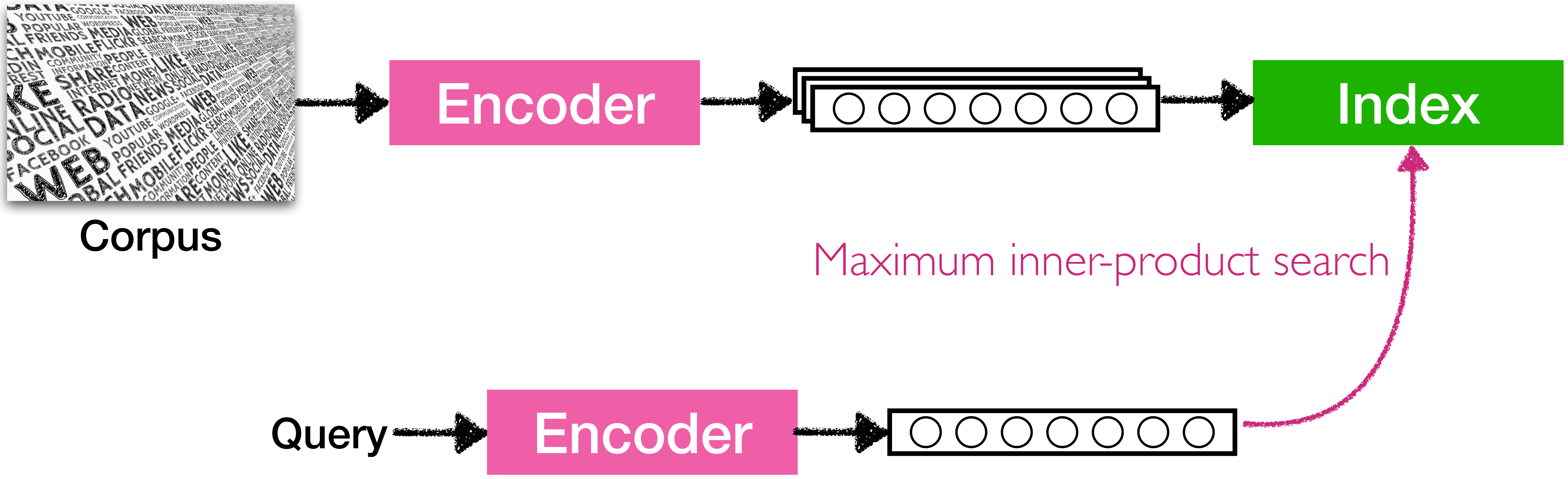


Karpukhin et al., 2020. “Dense Passage Retrieval for Open-Domain Question Answering”

Dense retrievers: Inference

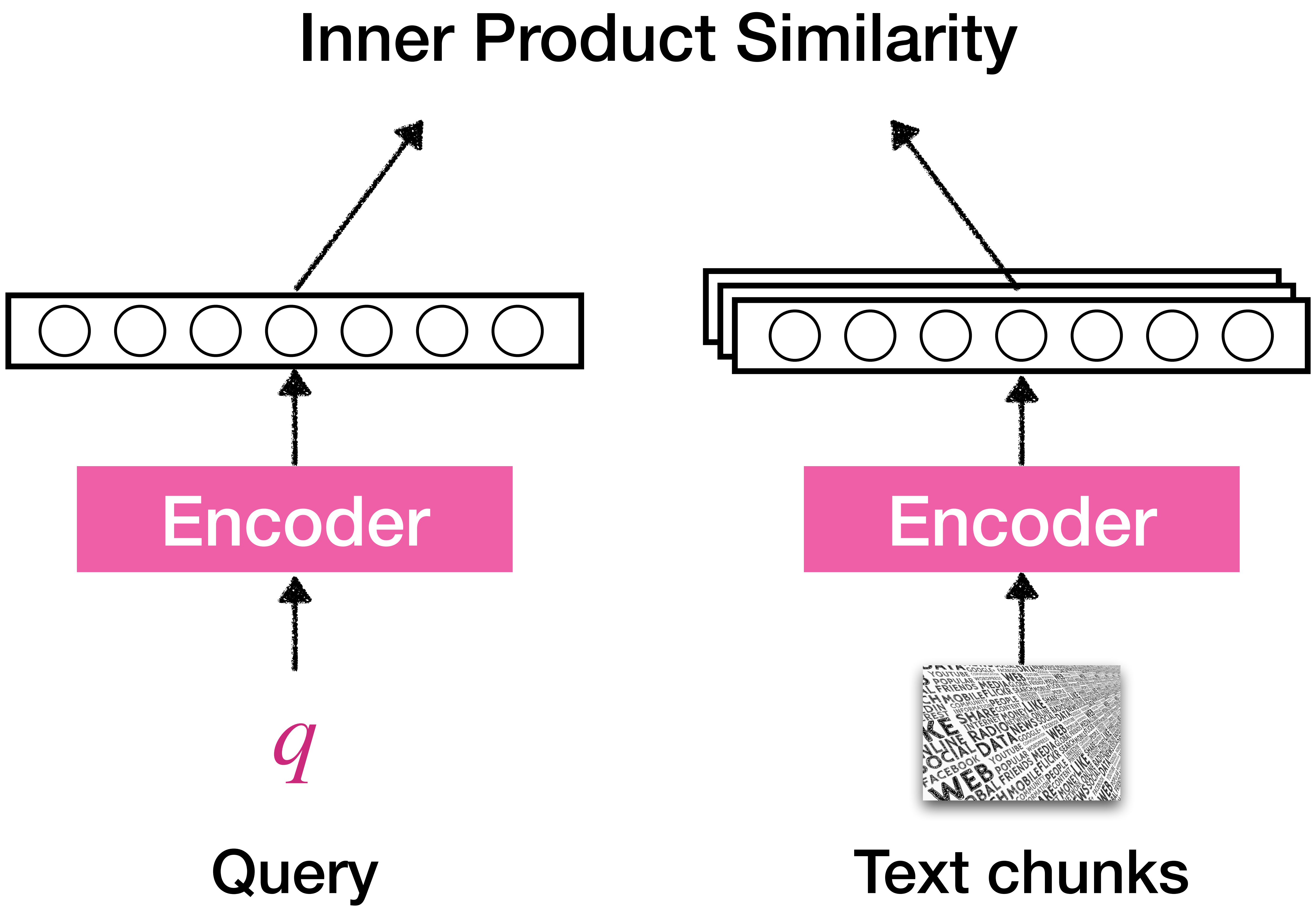


Dense retrievers: Inference

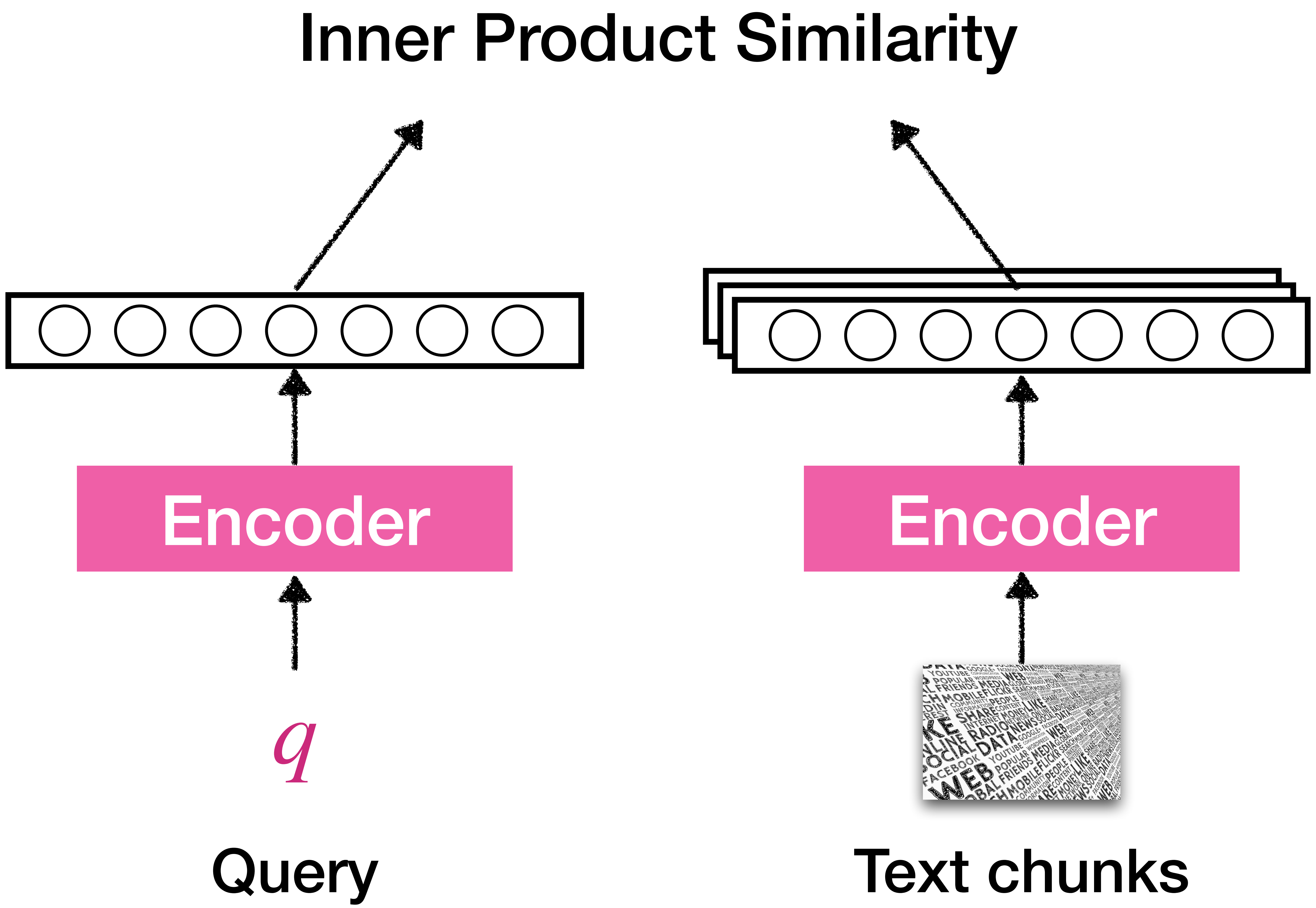


How to train dense retrieval models?

Training dense retrieval models: DPR



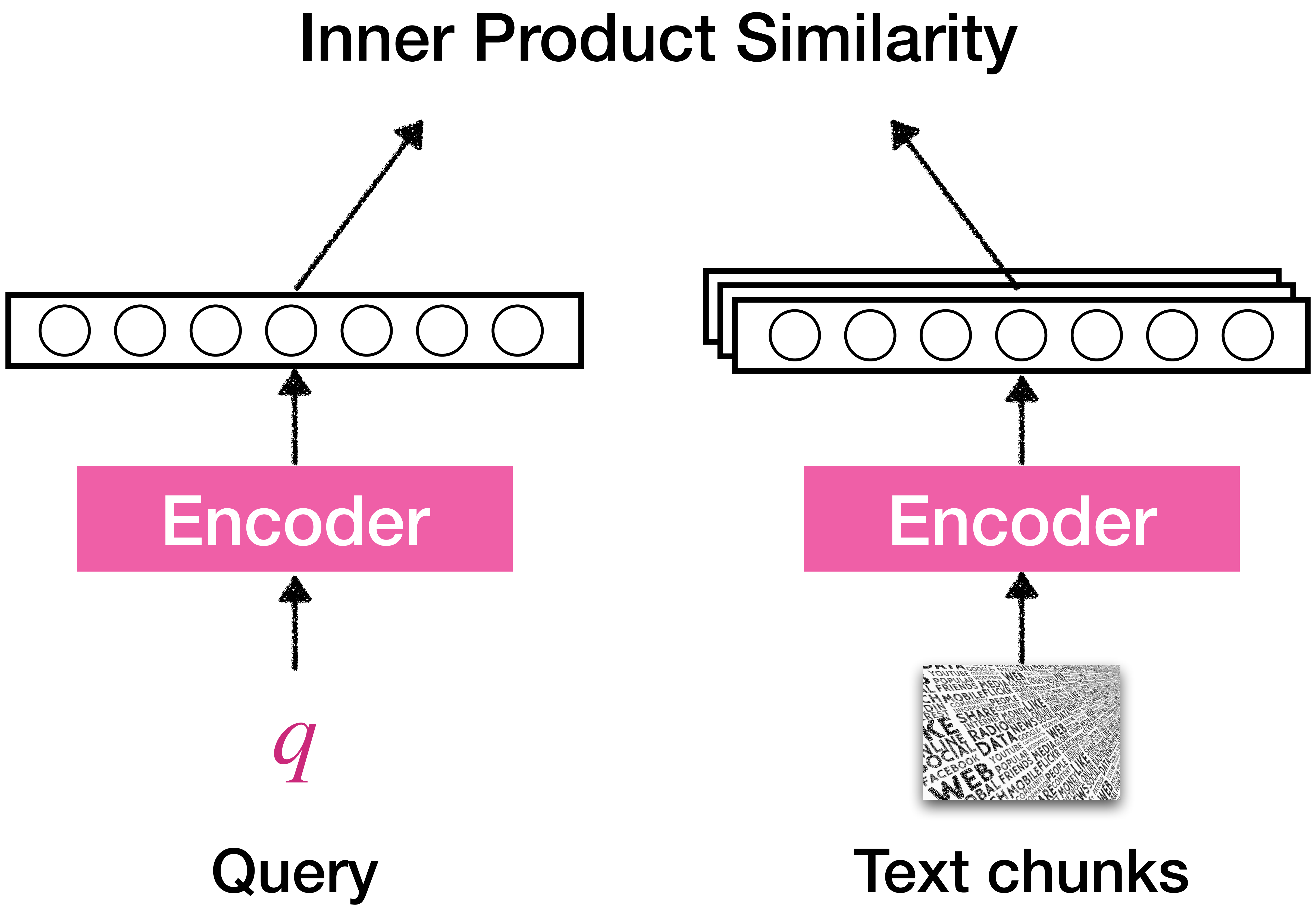
Training dense retrieval models: DPR



$$L(q, p^+, p_1^-, p_2^-, \ldots, p_n^-)$$

$$= -\log \frac{\exp(\mathrm{sim}(q, p^+))}{\exp(\mathrm{sim}(q, p^+)) + \sum_{j=1}^{n} \exp(\mathrm{sim}(q, p_j^-))}$$

Training dense retrieval models: DPR

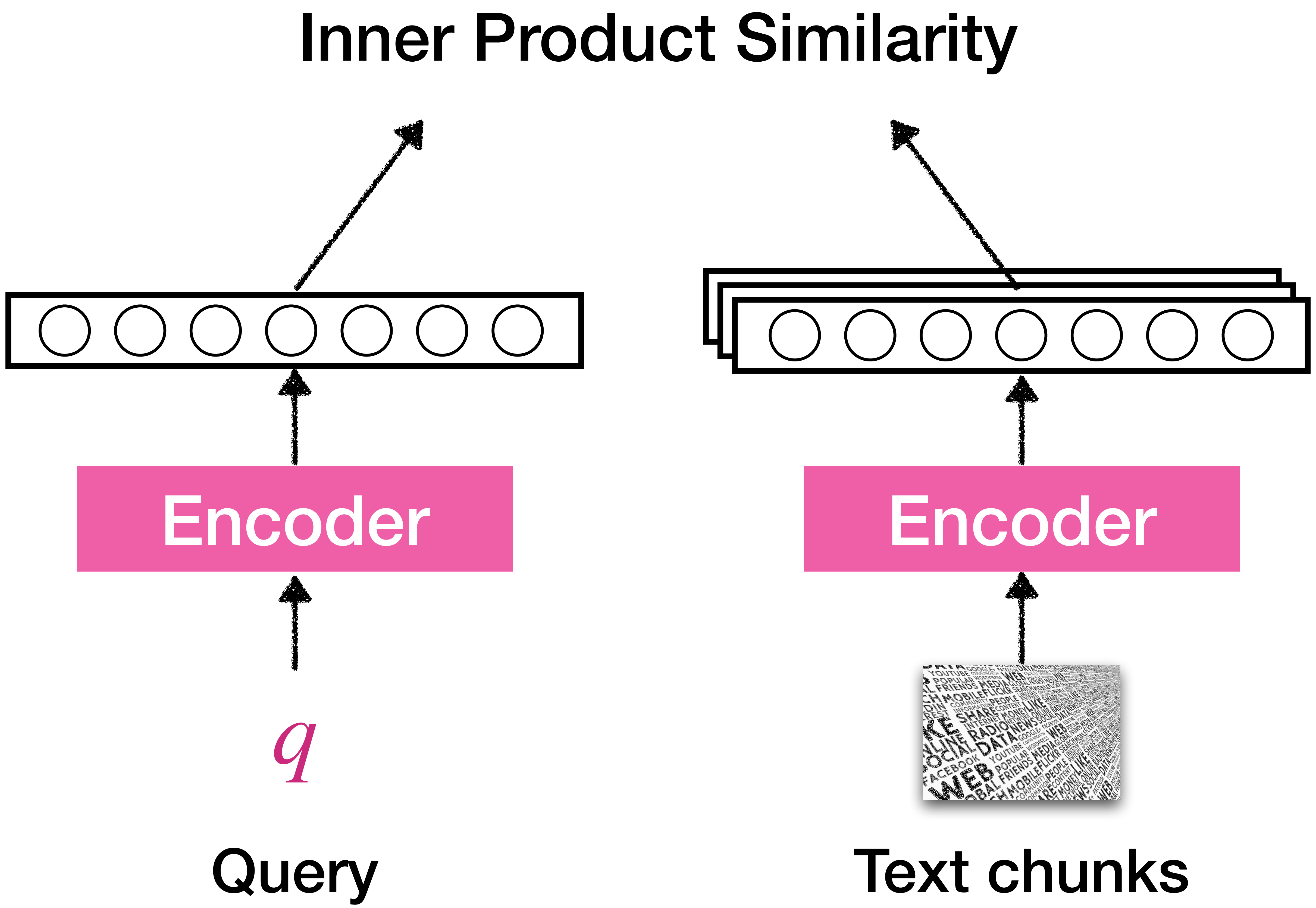


$$L(q, p^+, p_1^-, p_2^-, \ldots, p_n^-)$$

$$= -\log \frac{\exp(\mathrm{sim}(q, p^+))}{\exp(\mathrm{sim}(q, p^+)) + \sum_{j=1}^{n} \exp(\mathrm{sim}(q, p_j^-))}$$

Contrastive learning

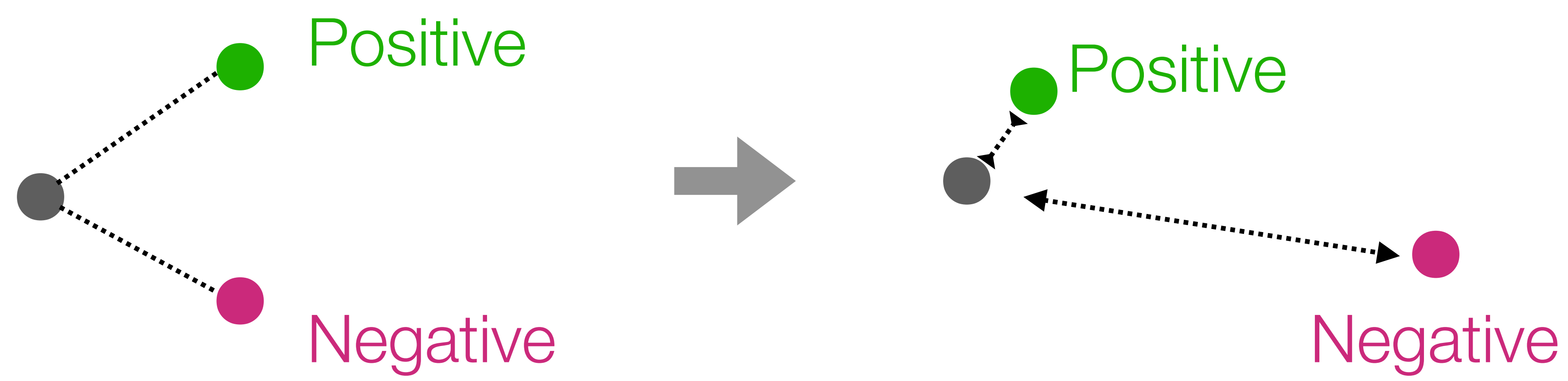
Training dense retrieval models: DPR



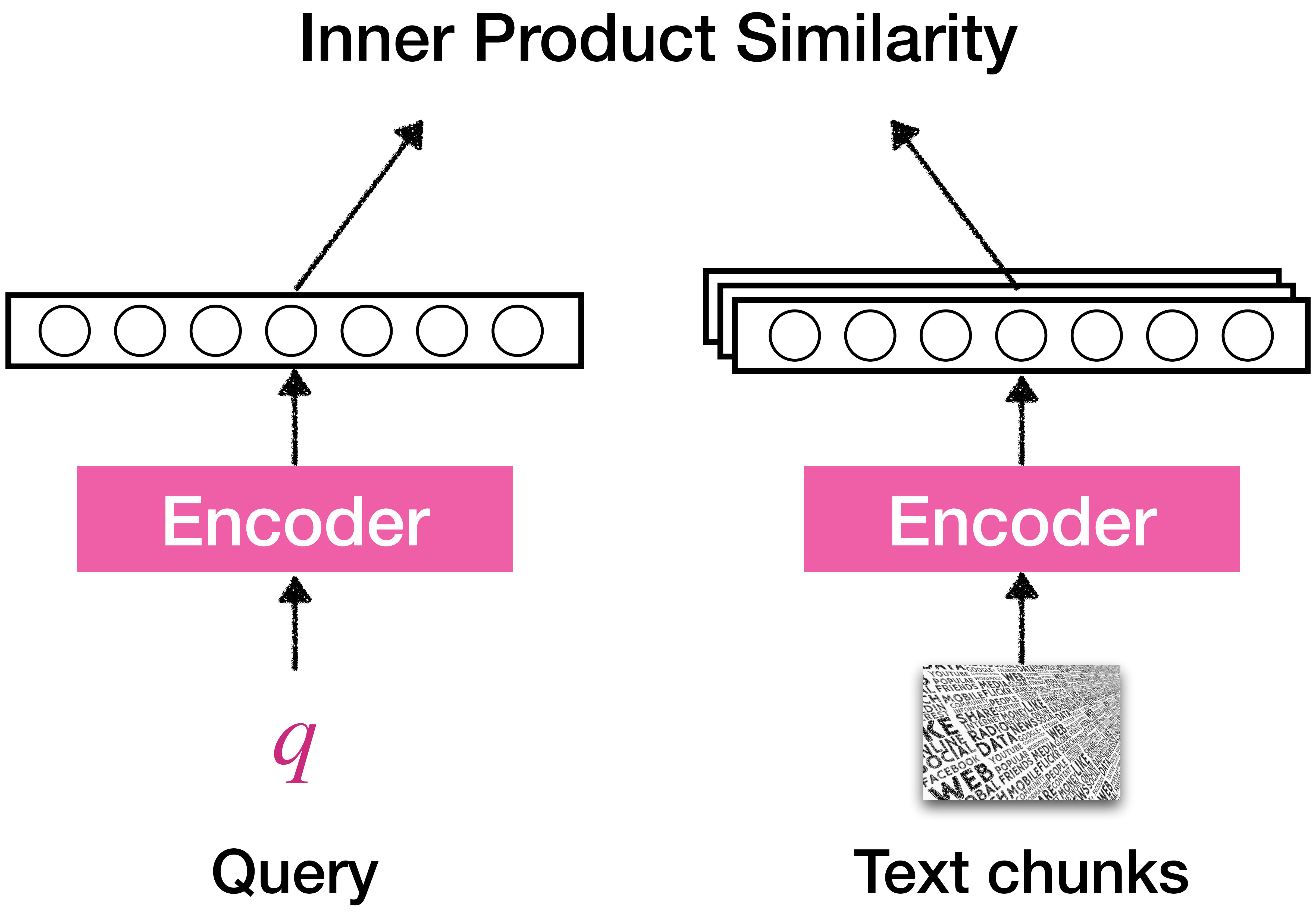
$$L(q, p^+, p_1^-, p_2^-, \ldots, p_n^-)$$

$$= -\log \frac{\exp(\mathrm{sim}(q, p^+))}{\exp(\mathrm{sim}(q, p^+)) + \sum_{j=1}^{n} \exp(\mathrm{sim}(q, p_j^-))}$$

Contrastive learning



Training dense retrieval models: DPR

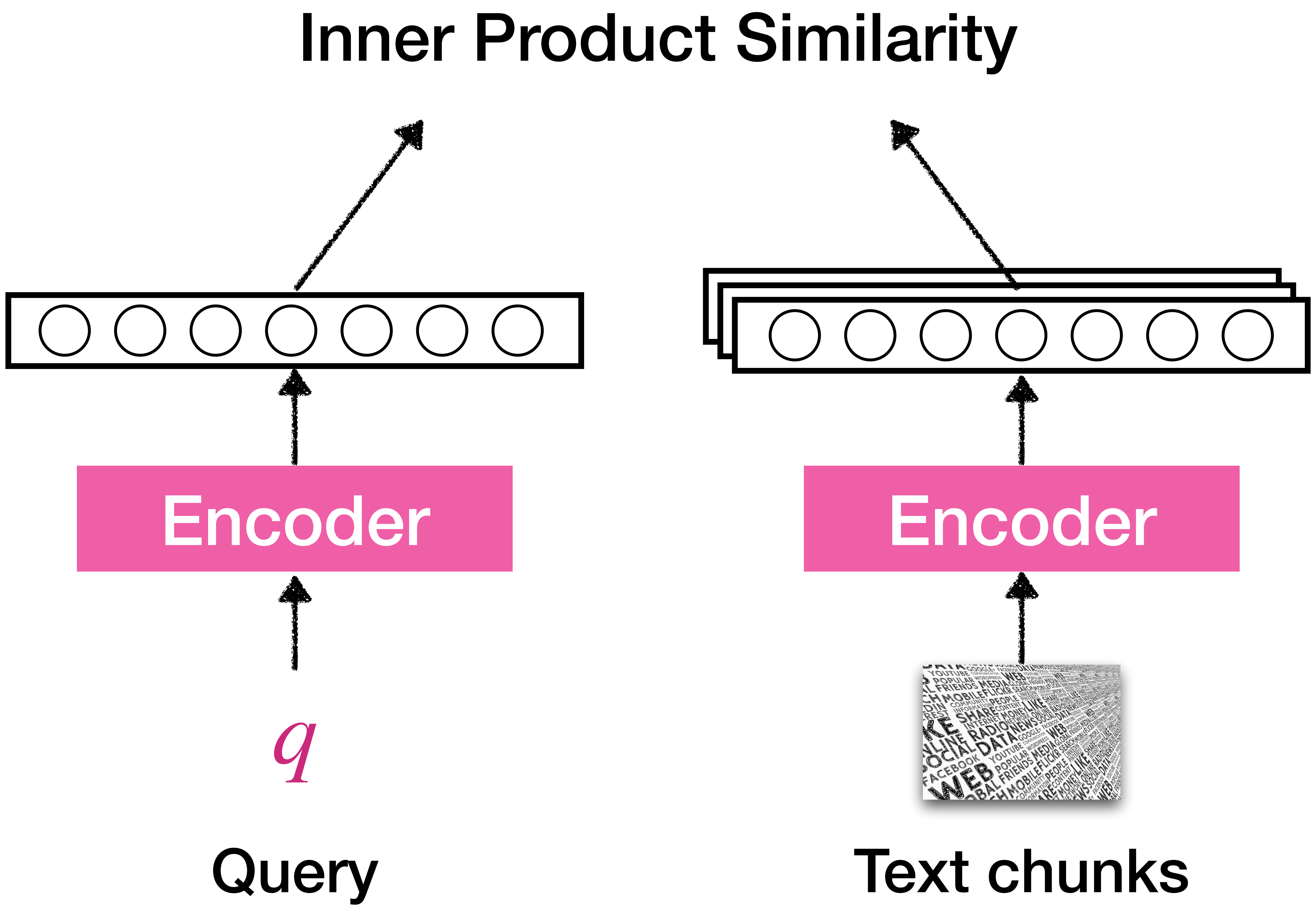


$$L(q, p^+, p_1^-, p_2^-, \ldots, p_n^-)$$

Positive passage

$$= -\log \frac{\exp(\mathrm{sim}(q, p^+))}{\exp(\mathrm{sim}(q, p^+)) + \sum_{j=1}^{n} \exp(\mathrm{sim}(q, p_j^-))}$$

Training dense retrieval models: DPR



Negative passages
Too expensive to consider all negatives!

$$L(q, p^+, p_1^-, p_2^-, \ldots, p_n^-)$$

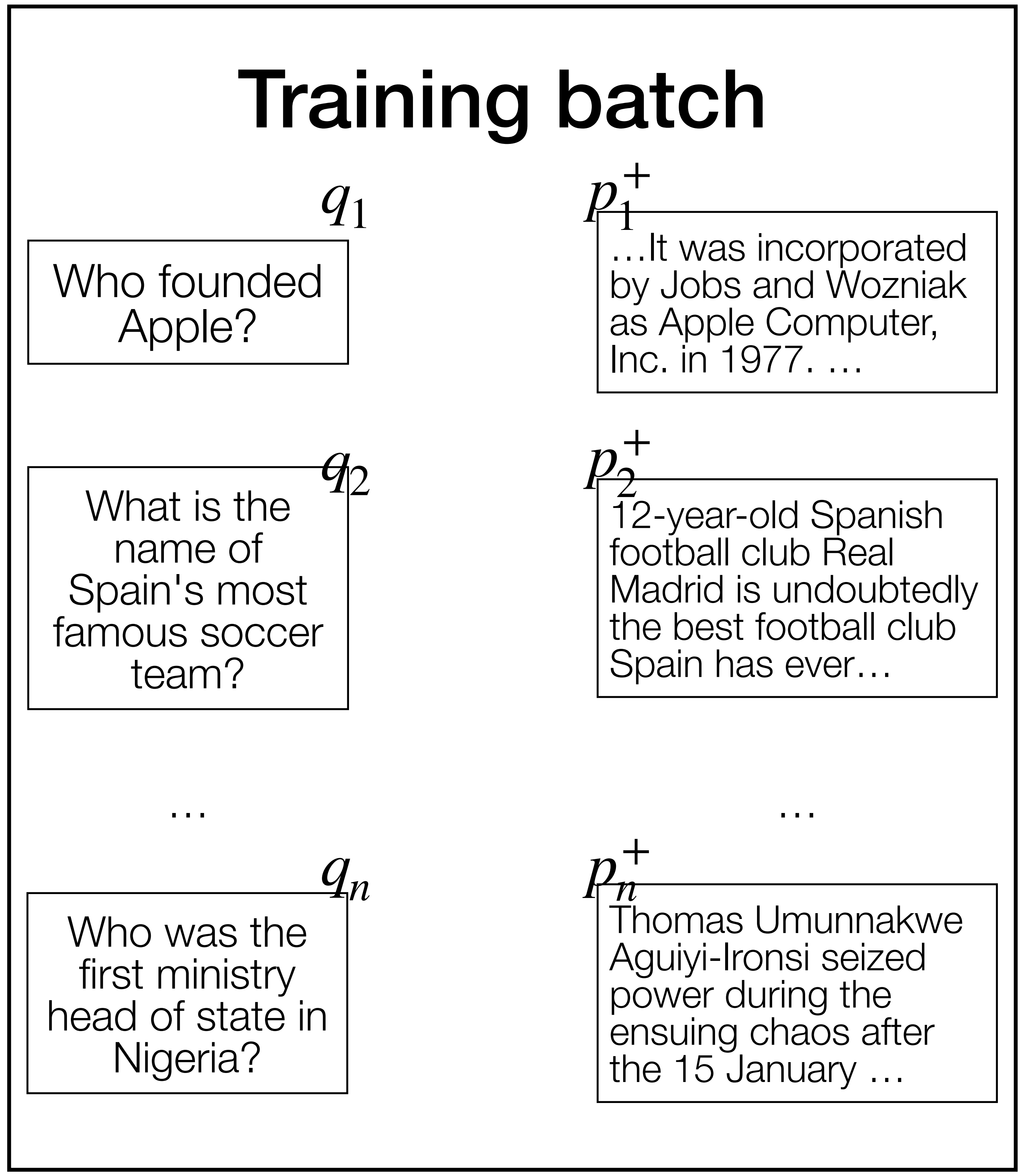
Positive passage

$$= -\log \frac{\exp(\mathrm{sim}(q, p^+))}{\exp(\mathrm{sim}(q, p^+)) + \sum_{j=1}^{n} \exp(\mathrm{sim}(q, p_j^-))}$$

Training with "in-batch" negatives

$$L(q, p^+, p_1^-, p_2^-, \ldots, p_n^-)$$

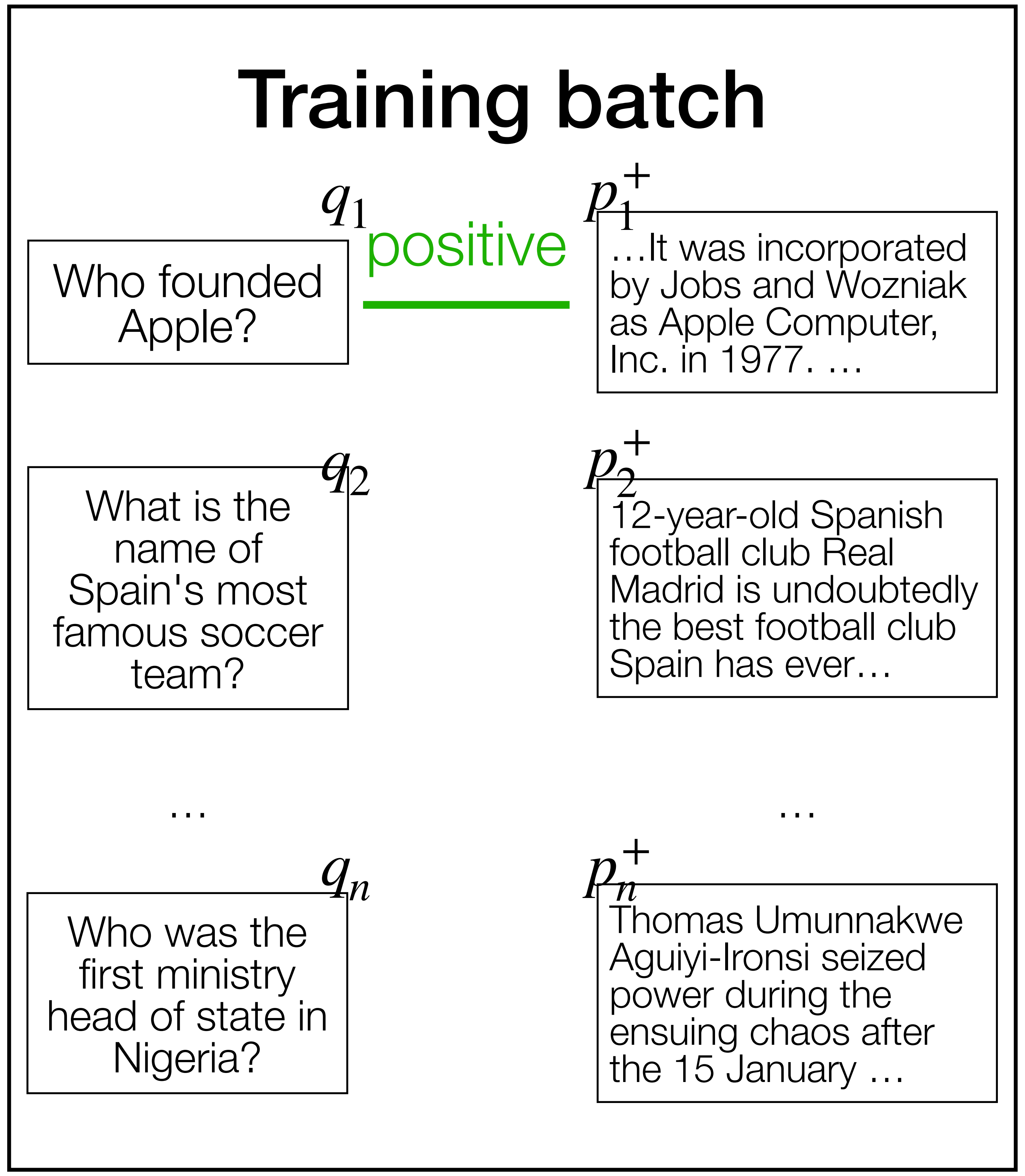
$$= -\log \frac{\exp(\mathrm{sim}(q, p^+))}{\exp(\mathrm{sim}(q, p^+)) + \sum_{j=1}^{n} \exp(\mathrm{sim}(q, p_j^-))}$$



Training with “in-batch” negatives

$$L(q, \boxed{p^+}, p_1^-, p_2^-, \ldots, p_n^-)$$

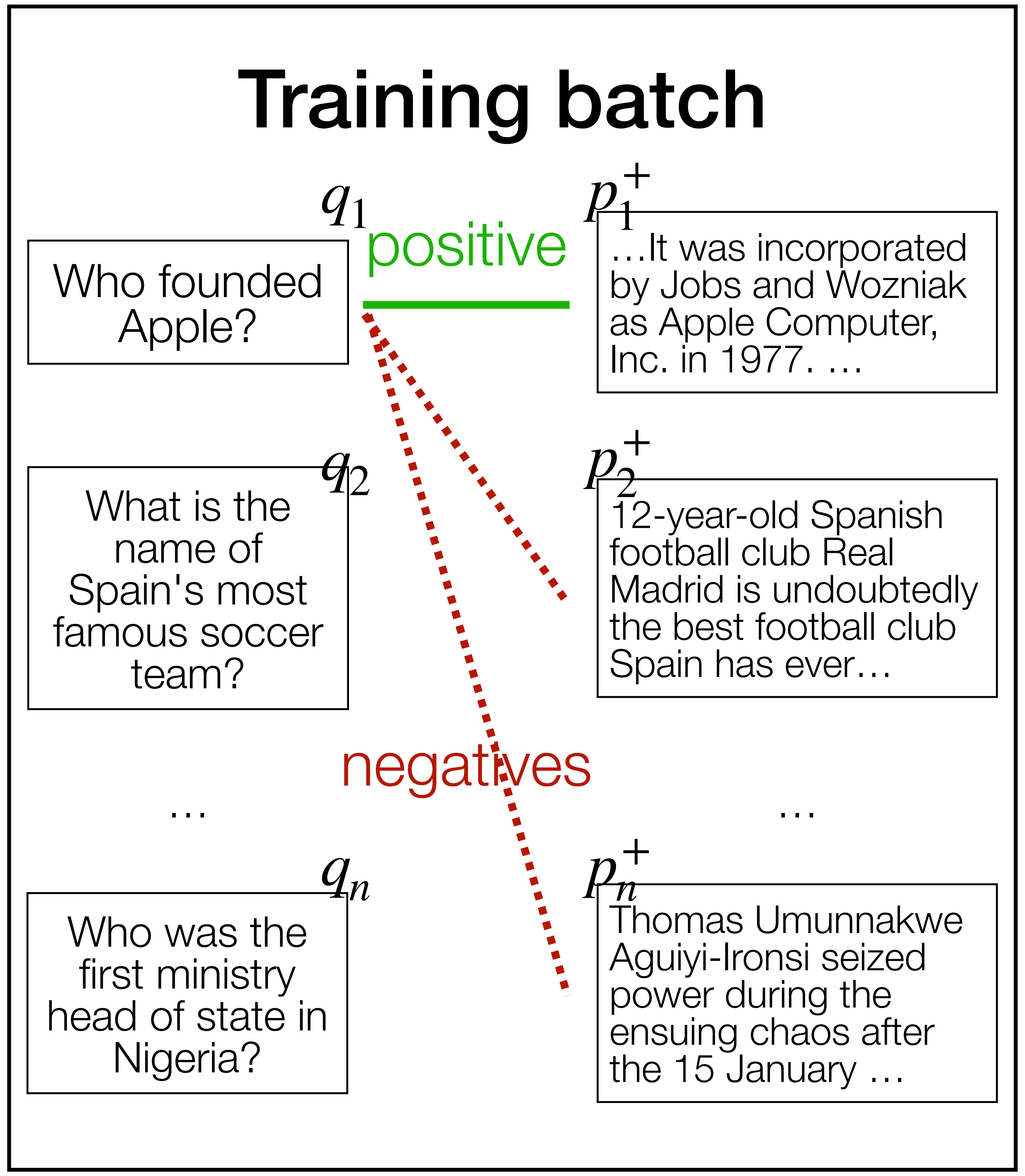
$$= -\log \frac{\exp(\mathrm{sim}(q, p^+))}{\exp(\mathrm{sim}(q, p^+)) + \sum_{j=1}^{n} \exp(\mathrm{sim}(q, p_j^-))}$$



Training with “in-batch” negatives

$$L(q, \boxed{p^+}, \boxed{p_1^-, p_2^-, \ldots, p_n^-})$$

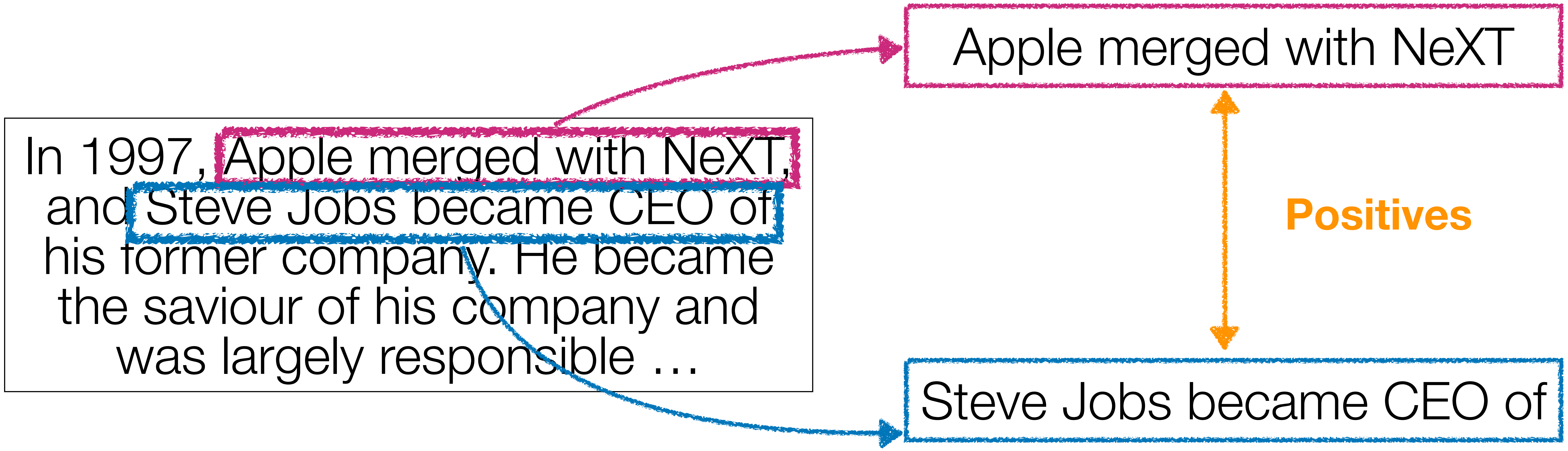
$$= -\log \frac{\exp(\mathrm{sim}(q, p^+))}{\exp(\mathrm{sim}(q, p^+)) + \sum_{j=1}^{n} \exp(\mathrm{sim}(q, p_j^-))}$$



Back-propagation to all in-batch negatives!

Contriever (Izacard et al. 2022)

Independent Cropping



Unsupervised dense retrieval model!

Izacard et al., 2022. “Unsupervised Dense Information Retrieval with Contrastive Learning”

Retrieval-in-context in LM (Ram et al. 2023)

x = World Cup 2022 was the last with 32 teams, before the increase to

World Cup 2022 was the last with 32 teams, before the increase to

↓

Retrieval Model

↓

FIFA World Cup 2026 will expand to 48 teams. World Cup 2022 was the last with 32 teams, before the increase to

↓

LM

↓

48 in the 2026 tournament.

Ram et al. 2023. “In-Context Retrieval-Augmented Language Models”

Retrieval-in-context in LM (Ram et al. 2023)

x = World Cup 2022 was the last with 32 teams, before the increase to

World Cup 2022 was the last with 32 teams, before the increase to

Retrieval Model

BM25, DPR, Contriever, …

FIFA World Cup 2026 will expand to 48 teams. World Cup 2022 was the last with 32 teams, before the increase to

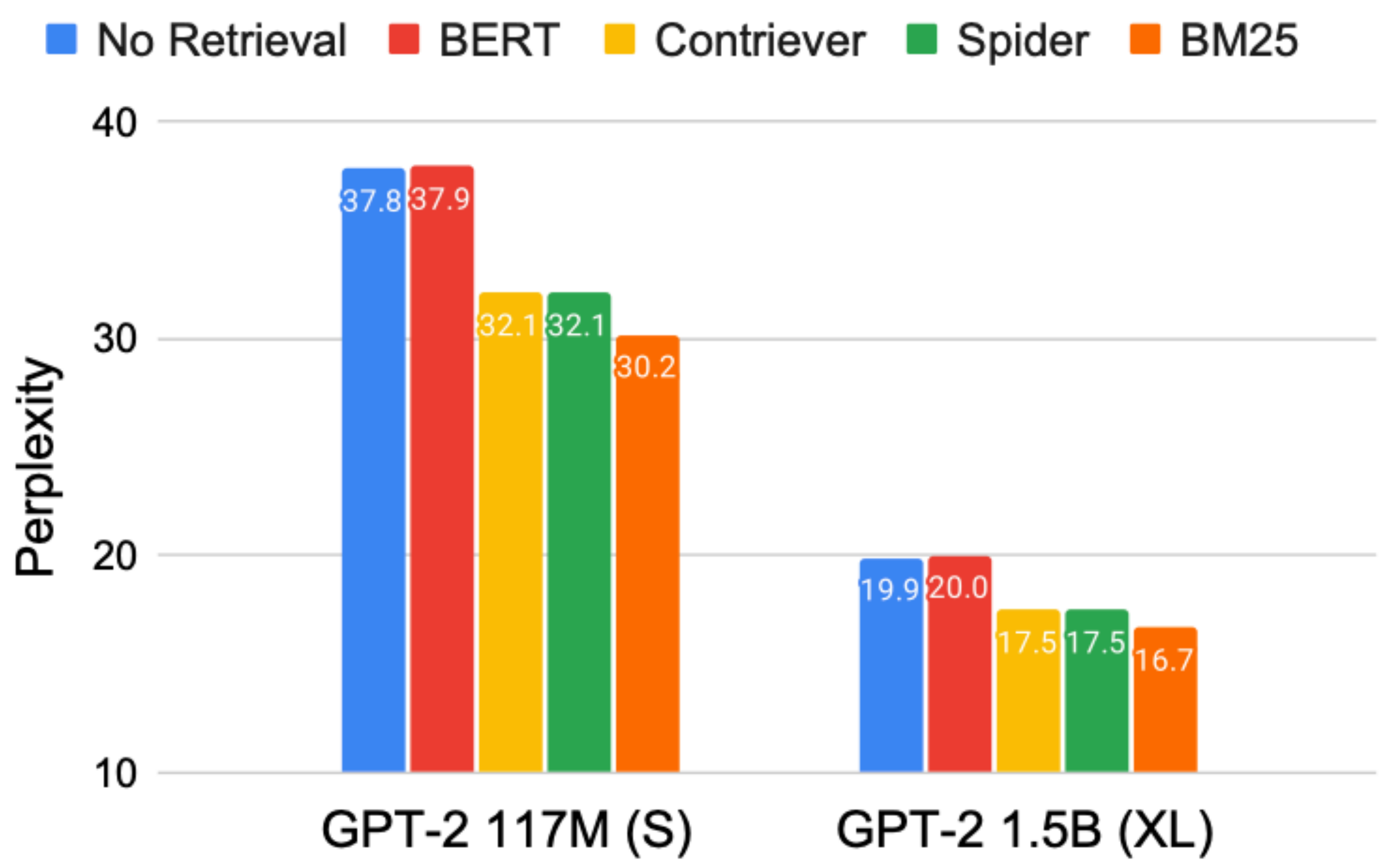
LM

GPT, OPT, LLaMA, …

48 in the 2026 tournament.

Ram et al. 2023. "In-Context Retrieval-Augmented Language Models"

Retrieval-in-context in LM

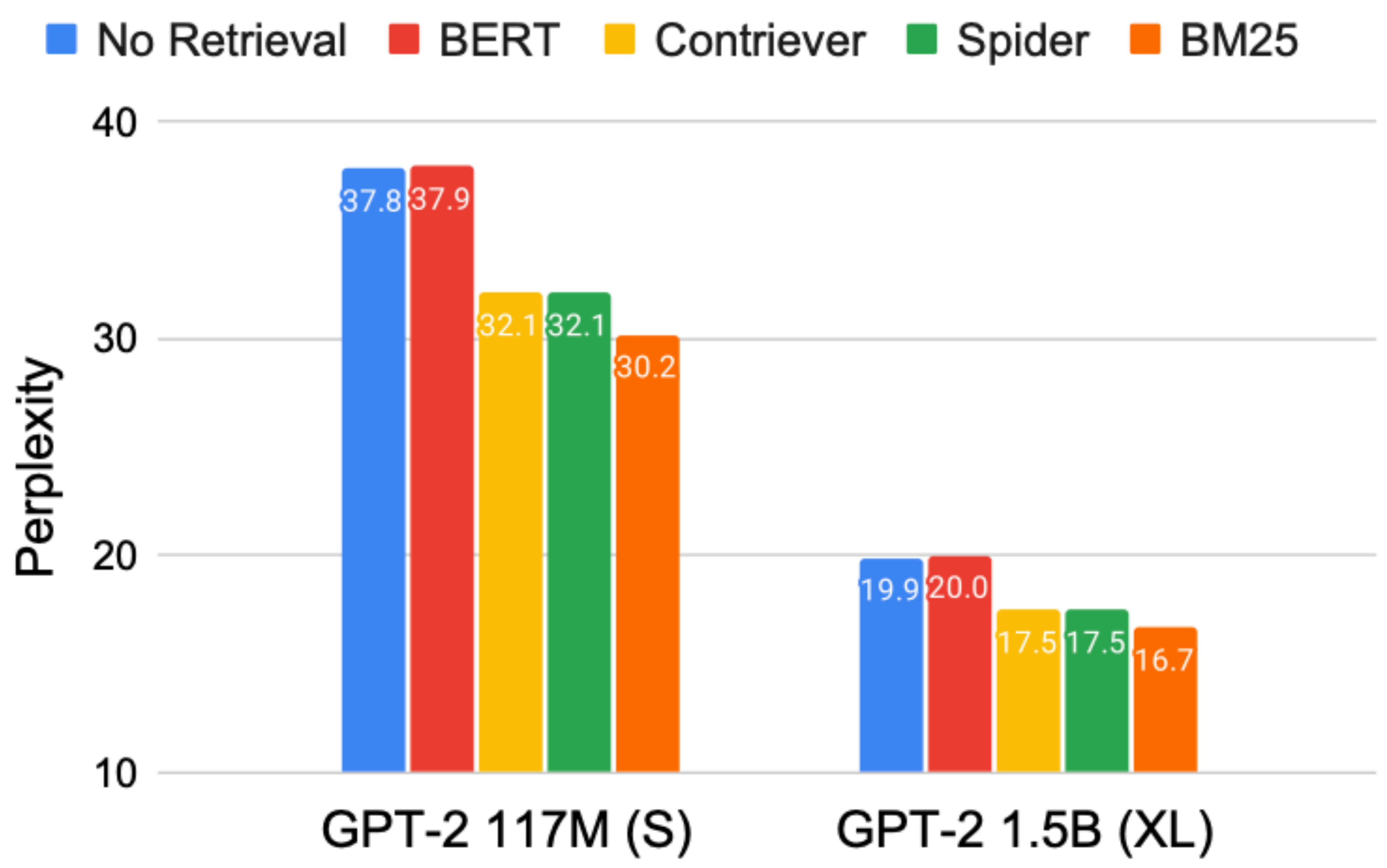


Better retrieval model

Better base LMs

→ Better **retrieval-based LMs**

Retrieval-in-context in LM



Better retrieval model

Better base LMs

→ Better **retrieval-based LMs**

Each component can be improved separately

kNN-LM (Khandelwal et al. 2020)

Inference

$$P_{k\mathrm{NN}}(y \mid x) \propto \sum_{(k,v) \in \mathcal{D}} \mathbb{I}[v = y] \exp(-d(\mathrm{Enc}(k), \mathrm{Enc}(x))$$

$$P_{k\mathrm{NN-LM}}(y \mid x) = \lambda P_{\mathrm{LM}}(y \mid x) + (1 - \lambda) P_{k\mathrm{NN}}(y \mid x)$$

Khandelwal et al., 2020. "Generalization through Memorization: Nearest Neighbor Language Models"

kNN-LM (Khandelwal et al. 2020)

Inference

Re-use the LM encoder. No training needed!

$$P_{k\mathrm{NN}}(y \mid x) \propto \sum_{(k,v)\in\mathcal{D}} \mathbb{1}[v = y]\exp(-d(\mathrm{Enc}(k), \mathrm{Enc}(x)))$$

$$P_{k\mathrm{NN-LM}}(y \mid x) = \lambda P_{\mathrm{LM}}(y \mid x) + (1-\lambda)P_{k\mathrm{NN}}(y \mid x)$$

Khandelwal et al., 2020. "Generalization through Memorization: Nearest Neighbor Language Models"

kNN-LM (Khandelwal et al. 2020)

Inference

Re-use the LM encoder. No training needed!

$$P_{k\mathrm{NN}}(y \mid x) \propto \sum_{(k,v)\in\mathcal{D}} \mathbb{1}[v = y]\exp(-d(\mathrm{Enc}(k), \mathrm{Enc}(x)))$$

$$P_{k\mathrm{NN-LM}}(y \mid x) = \lambda P_{\mathrm{LM}}(y \mid x) + (1-\lambda) P_{k\mathrm{NN}}(y \mid x)$$

Training

Minimize $-\log P_{\mathrm{LM}}(y \mid x)$

Khandelwal et al., 2020. “Generalization through Memorization: Nearest Neighbor Language Models”

Independent training

- Work with off-the-shelf models (no extra training required)
- Each part can be improved independently

Independent training

- 👍 Work with off-the-shelf models (no extra training required)
- 👍 Each part can be improved independently
- 👎 LMs are not trained to leverage retrieval
- 👎 Retrieval models are not optimized for LM tasks/domains

Training methods for retrieval-based LMs

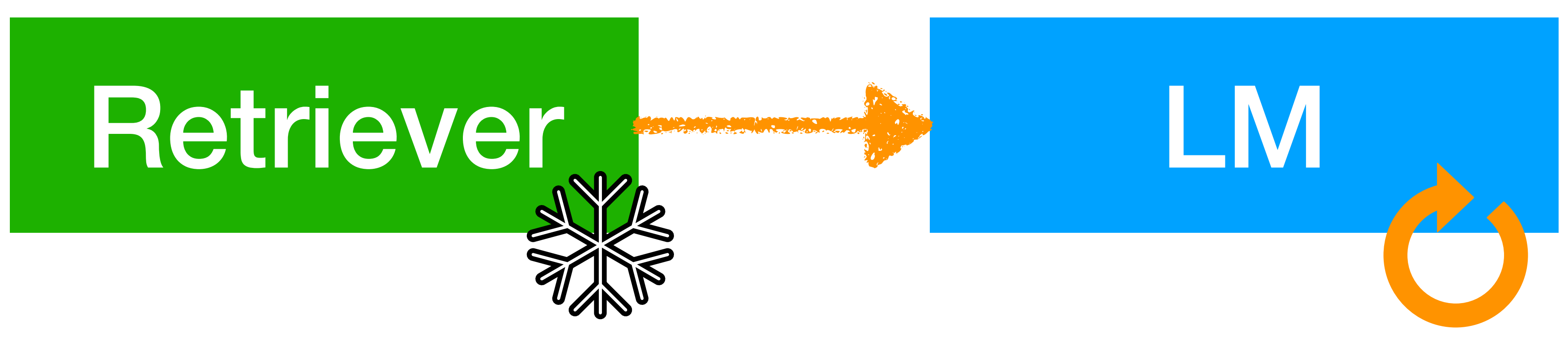
- Independent training
- **Sequential training**
- Joint training w/ asynchronous index update
- Joint training w/ in-batch approximation

Sequential training

- One component is first trained independently and then fixed
- The other component is trained with an objective that depends on the first one

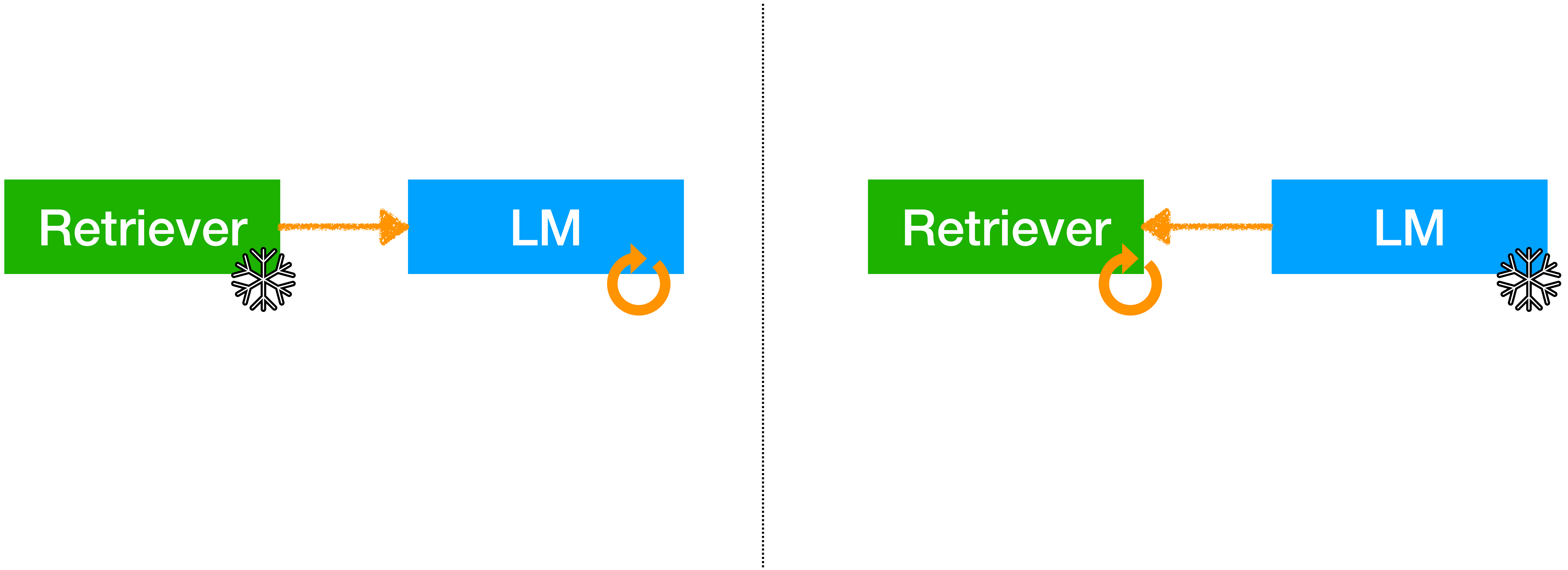
Sequential training

- One component is first trained independently and then fixed
- The other component is trained with an objective that depends on the first one



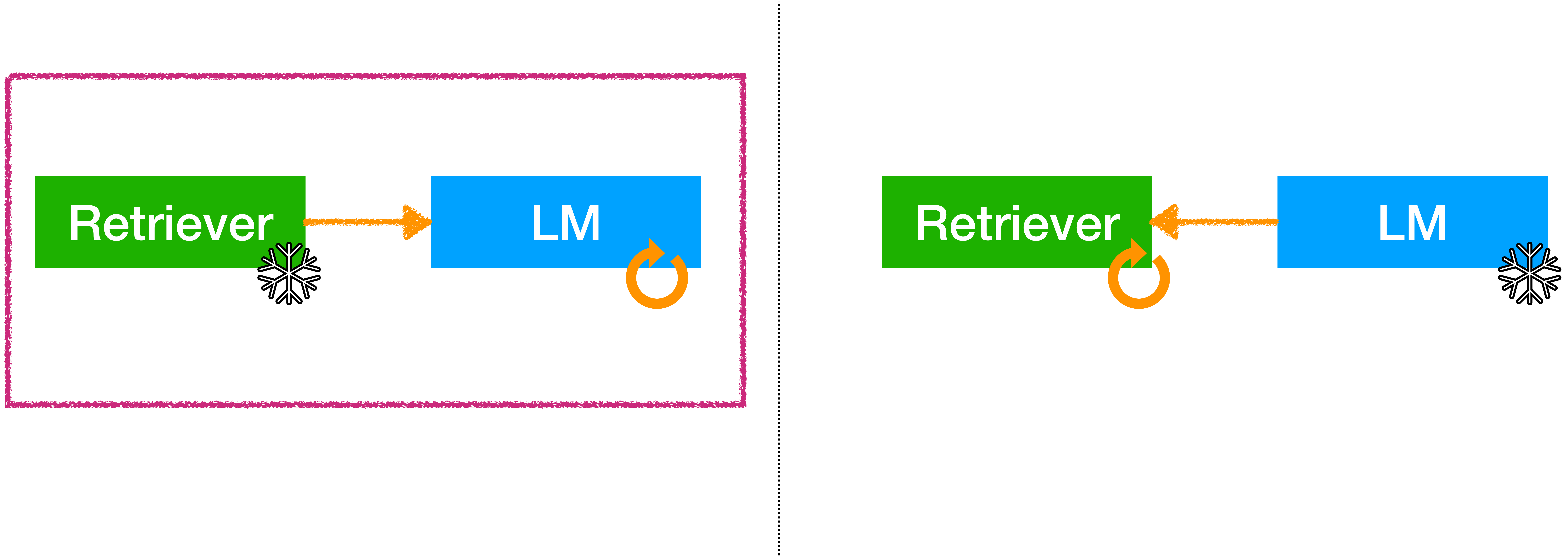
Sequential training

- One component is first trained independently and then fixed
- The other component is trained with an objective that depends on the first one



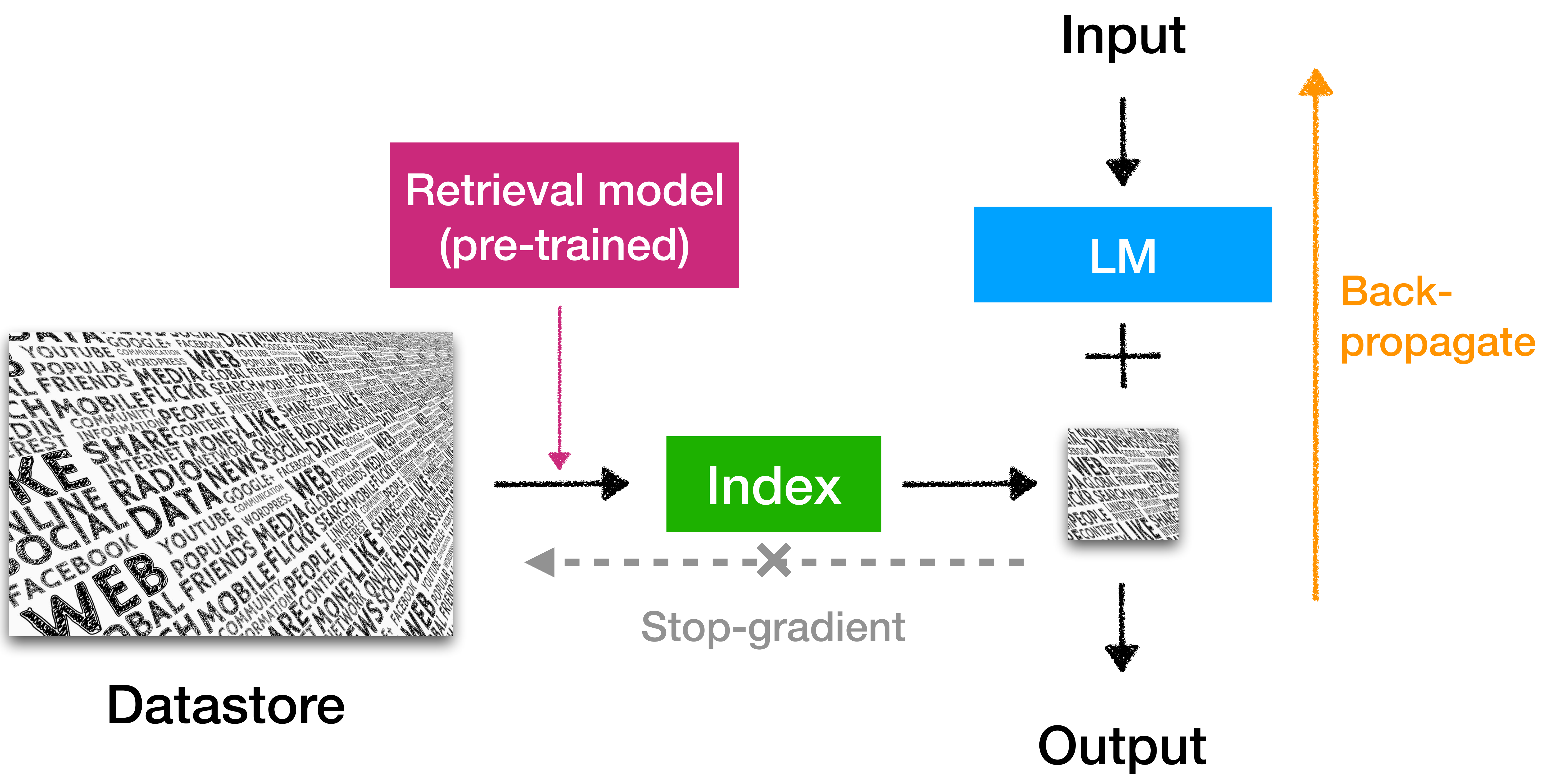
Sequential training

- One component is first trained independently and then fixed
- The other component is trained with an objective that depends on the first one



Sequential training

- Retrieval models are first trained independently and then fixed
- Language models are trained with an objective that depends on the retrieval



RETRO (Borgeaud et al. 2021)

$\boldsymbol{x}$ = World Cup 2022 was / the last with 32 teams, / before the increase to

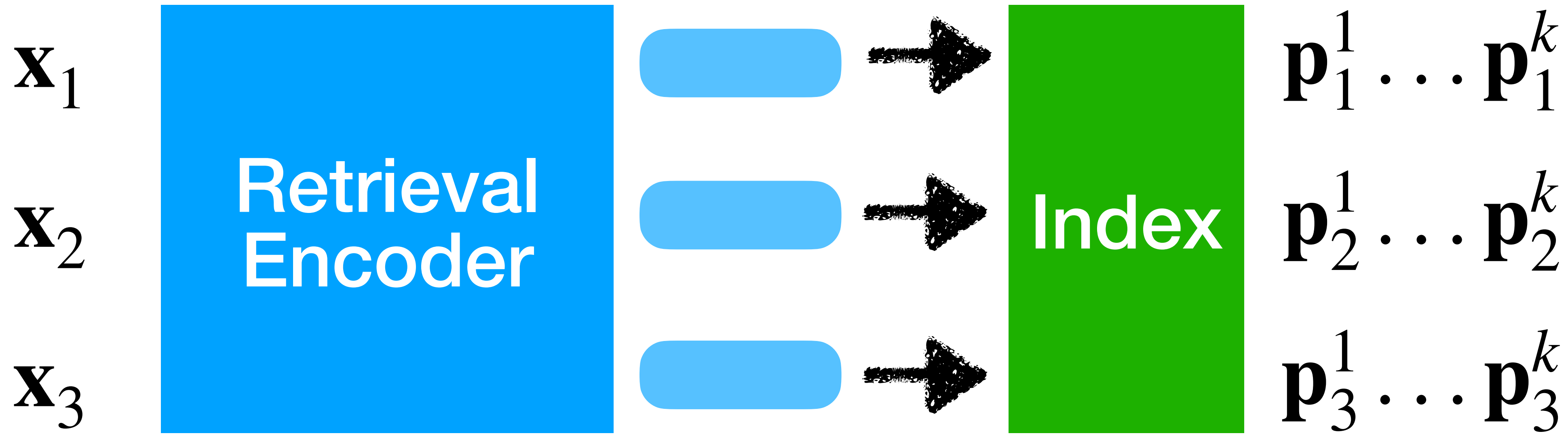
$\mathbf{x}_1$ $\mathbf{x}_2$ $\mathbf{x}_3$

Borgeaud et al., 2021. "Improving language models by retrieving from trillions of tokens"

RETRO (Borgeaud et al. 2021)

$\boldsymbol{x}$ = World Cup 2022 was the last with 32 teams, before the increase to

$\mathbf{x}_1$ $\mathbf{x}_2$ $\mathbf{x}_3$

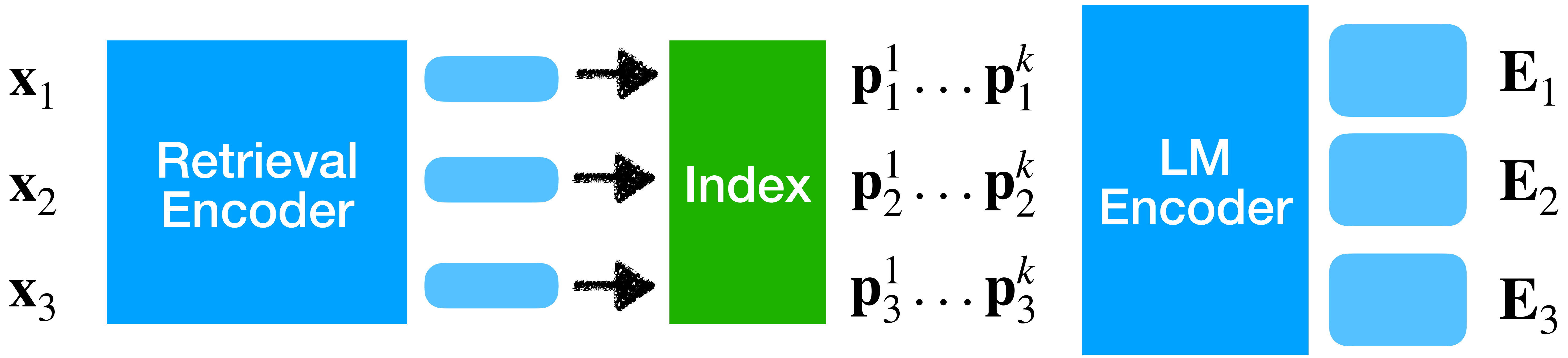


RETRO (Borgeaud et al. 2021)

$\boldsymbol{x}$ = World Cup 2022 was | the last with 32 teams, | before the increase to

$\mathbf{x}_1$ $\mathbf{x}_2$ $\mathbf{x}_3$

(k chunks of text per split)

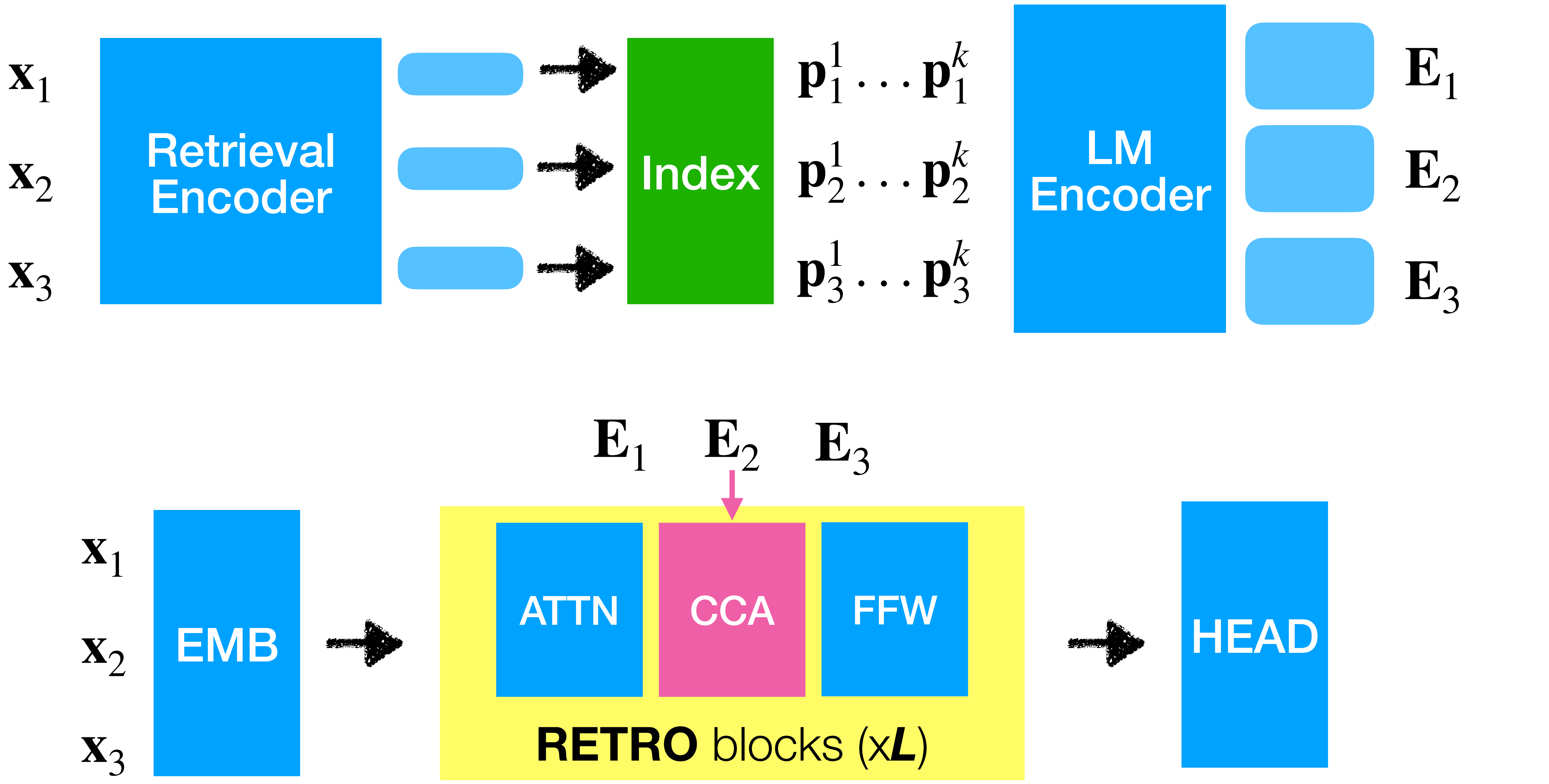


RETRO (Borgeaud et al. 2021)

$\boldsymbol{x}$ = World Cup 2022 was the last with 32 teams, before the increase to

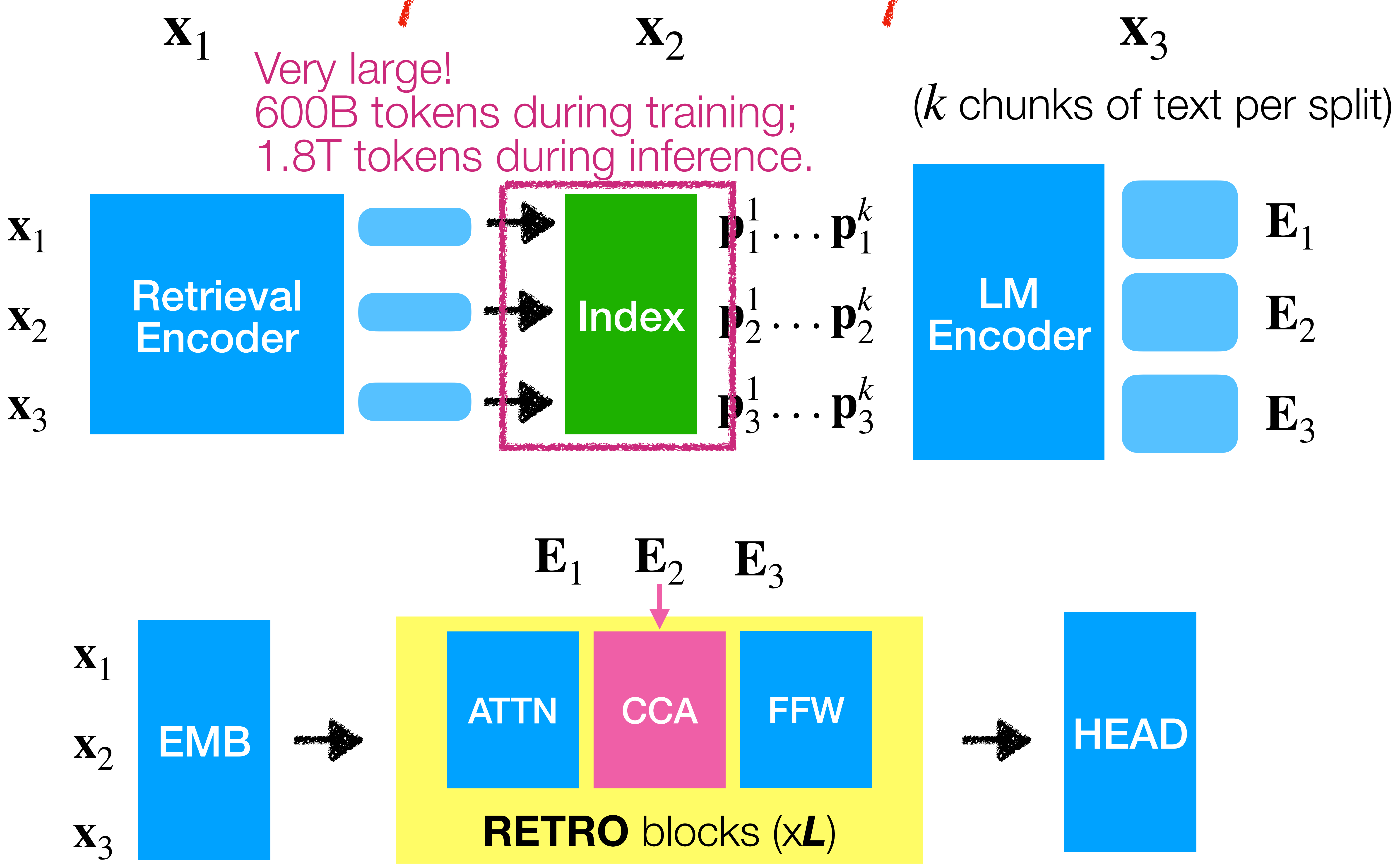
$\mathbf{x}_1$ $\mathbf{x}_2$ $\mathbf{x}_3$

(k chunks of text per split)

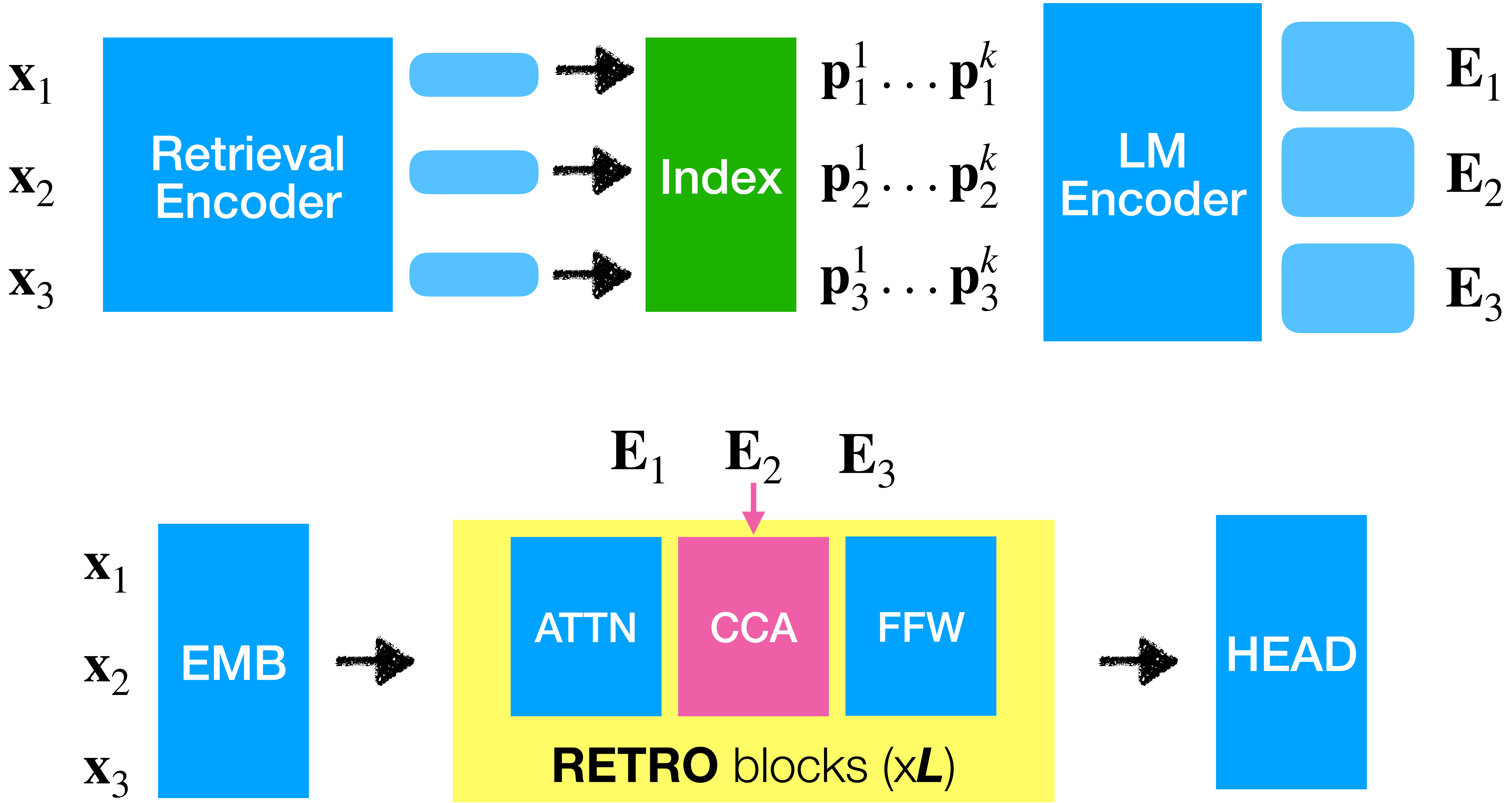


RETRO (Borgeaud et al. 2021)

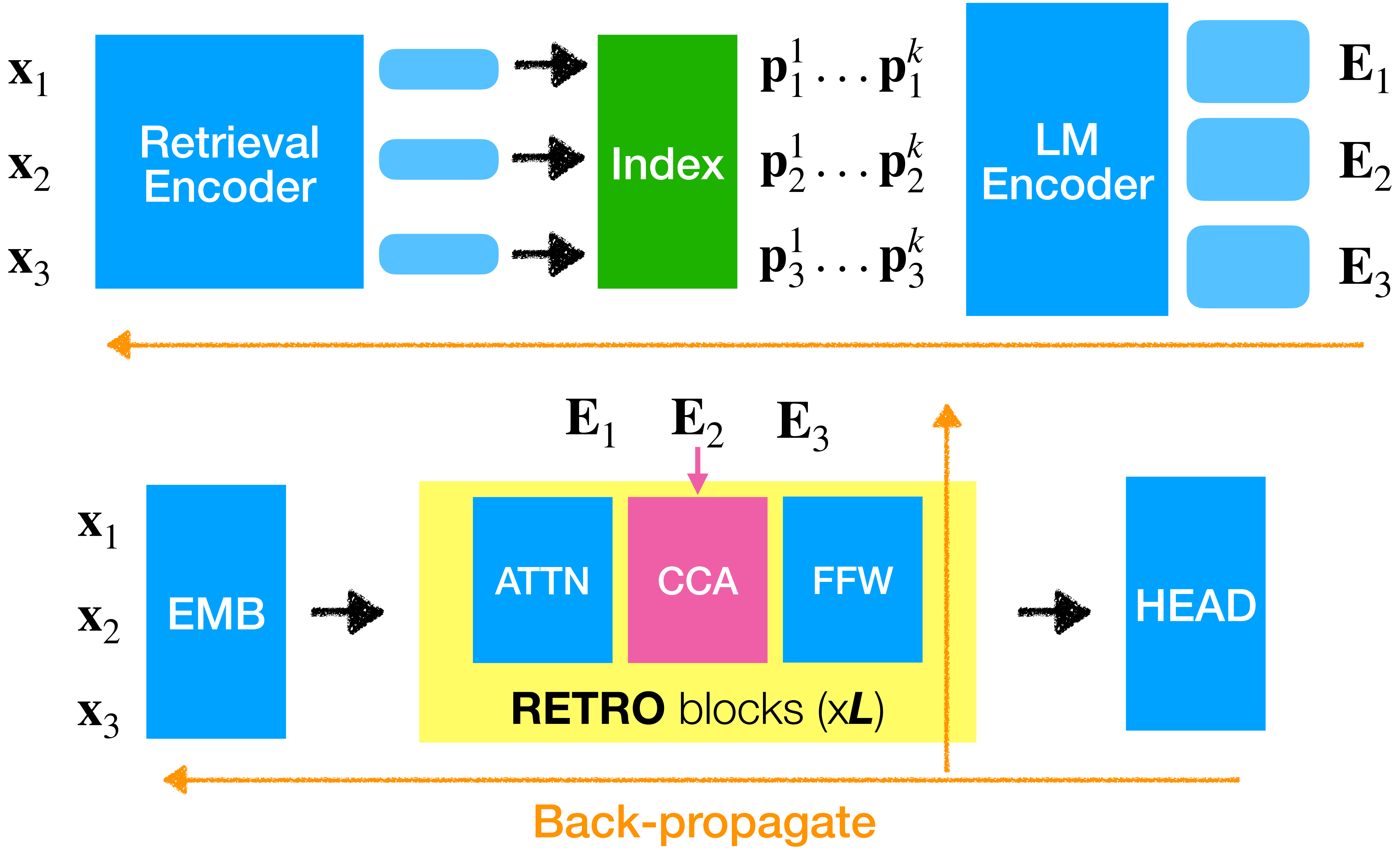
$\boldsymbol{x}$ = World Cup 2022 was the last with 32 teams, before the increase to



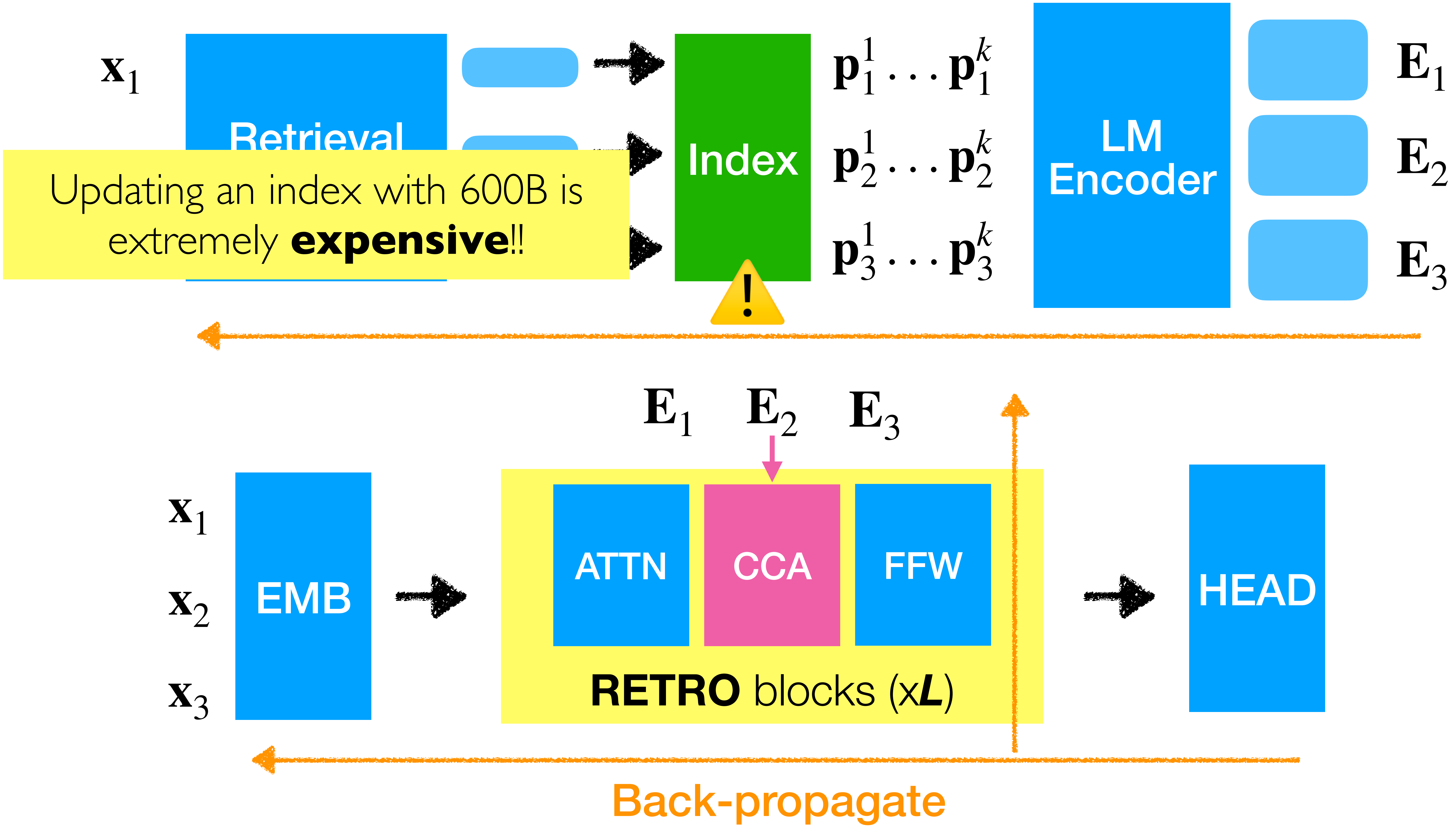
RETRO: Training



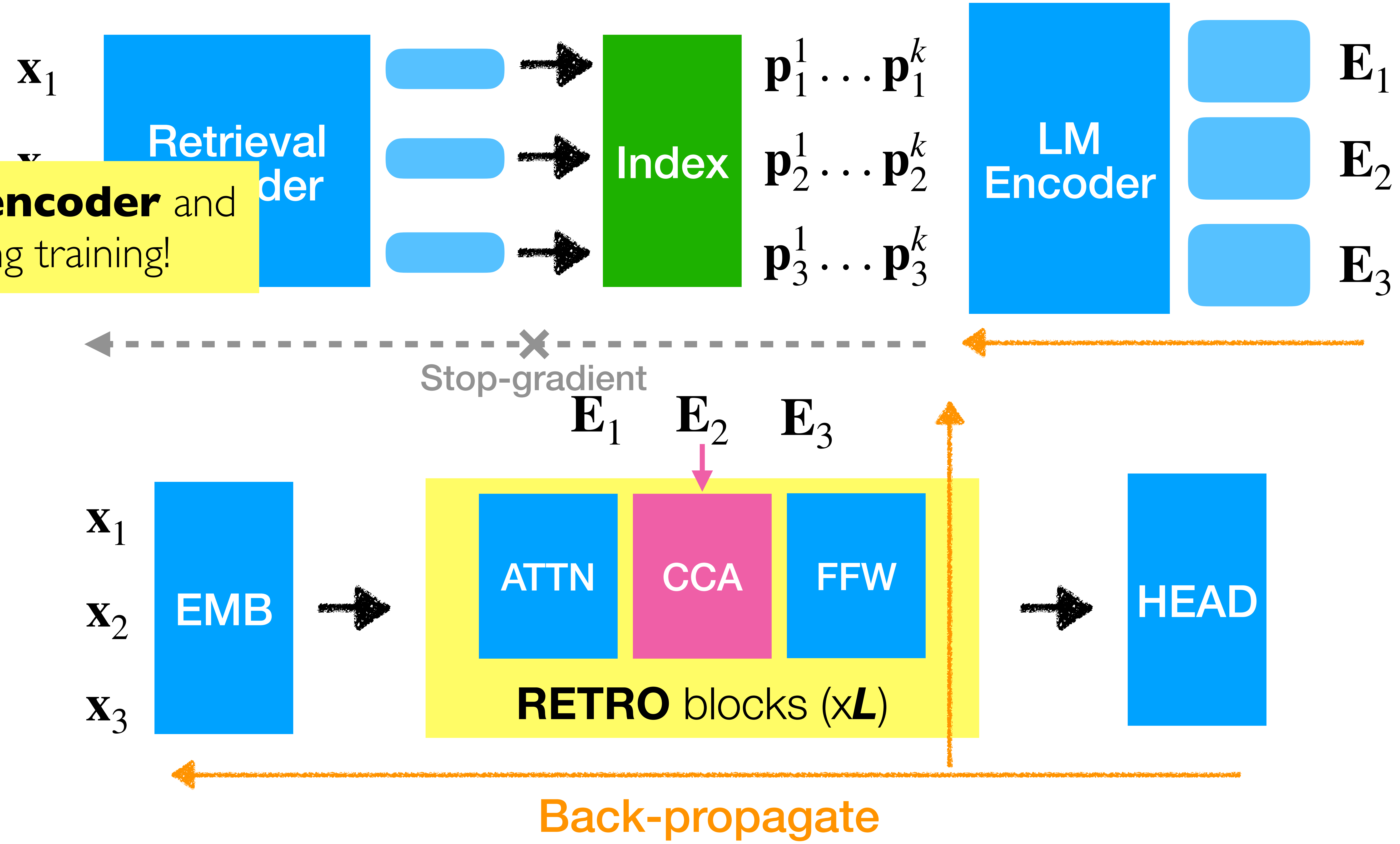
RETRO: Training



RETRO: Training



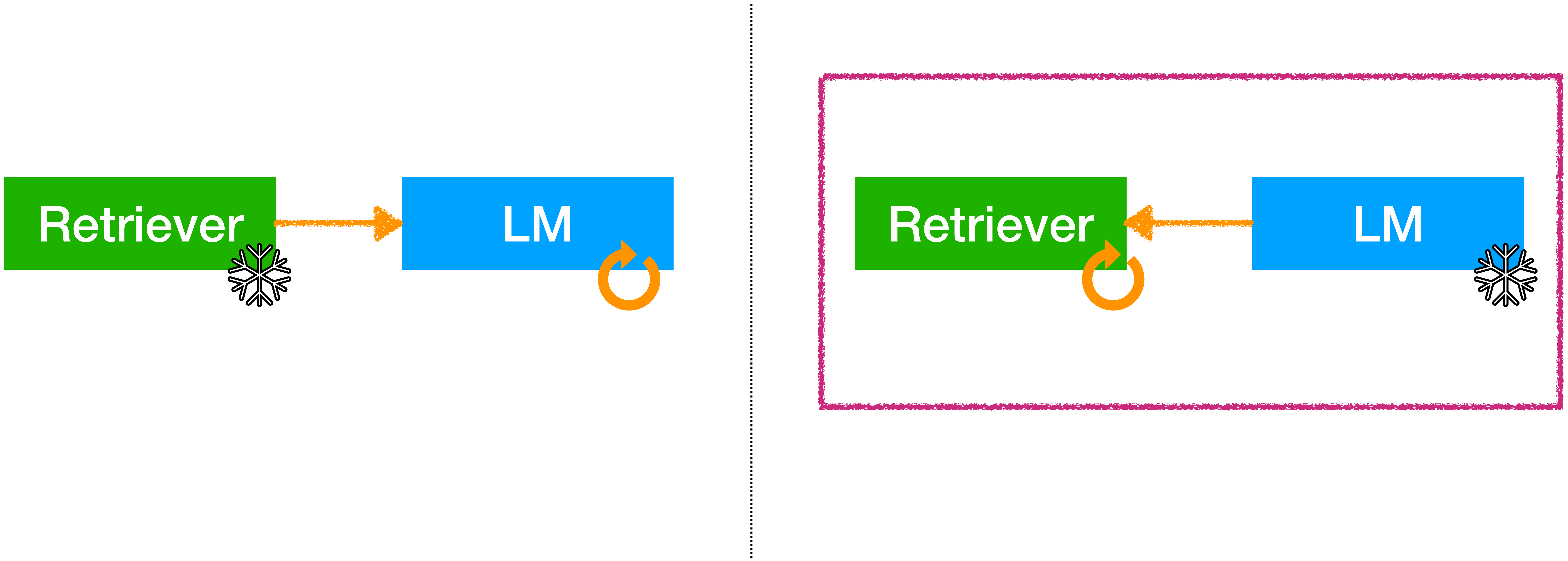
RETRO: Training



Fix the **retrieval encoder** and the **index** during training!

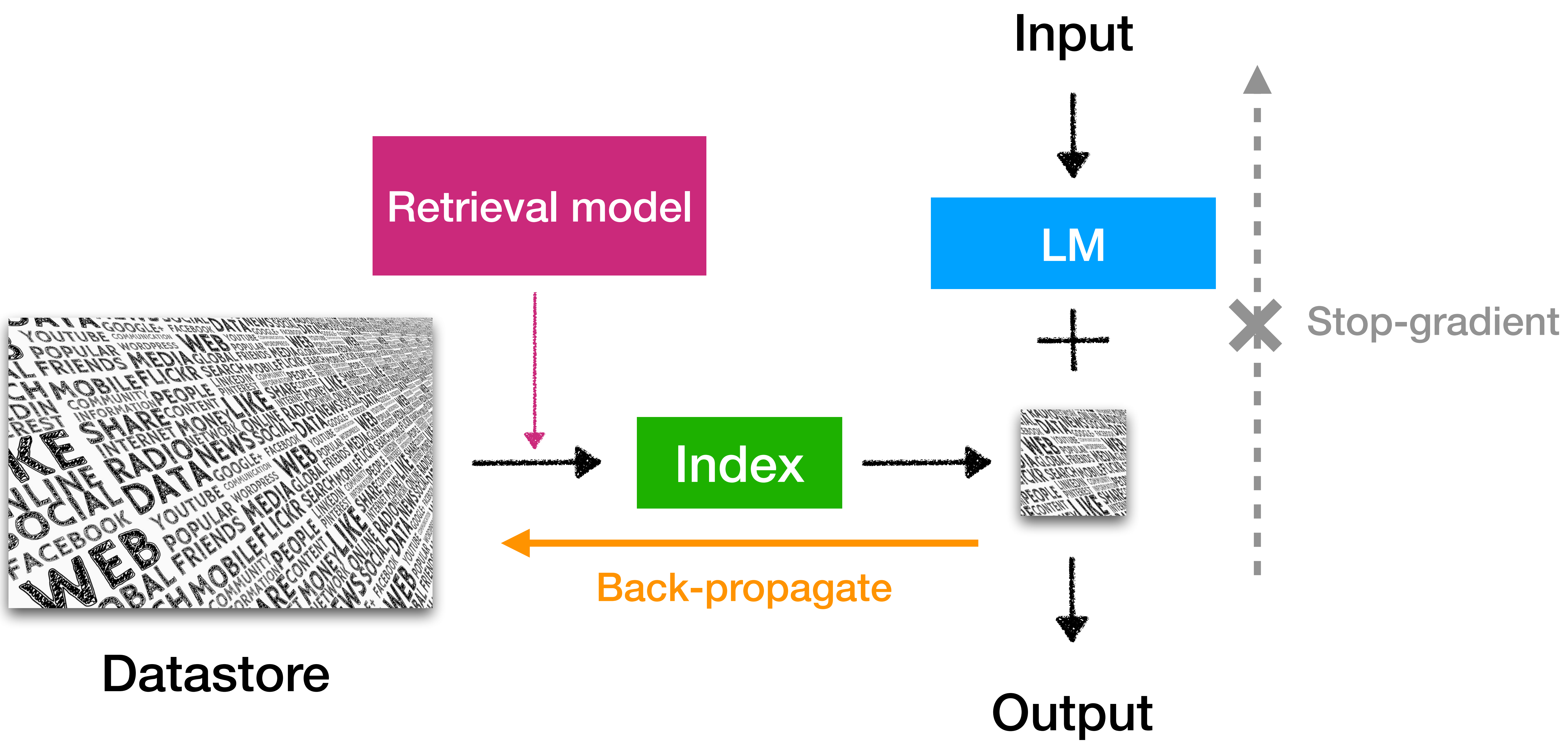
Sequential training

- One component is first trained independently and then fixed
- The other component is trained with an objective that depends on the first one

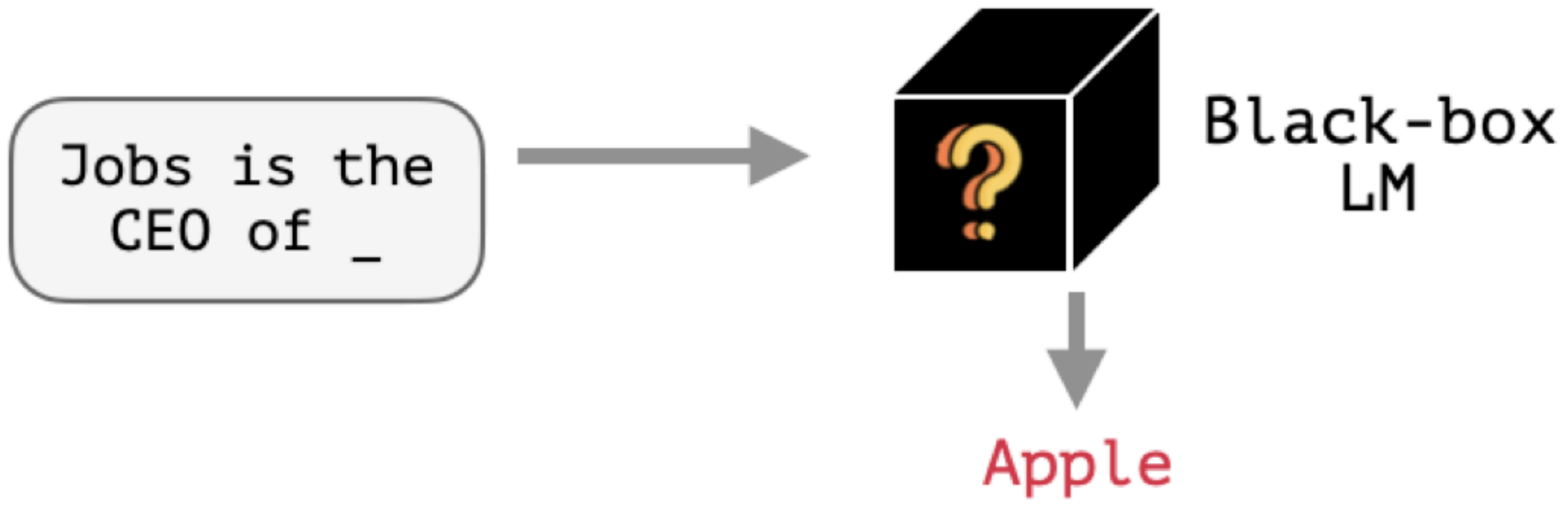


Sequential training

- Language models are first trained independently and then fixed
- Retrieval models are trained/fine-tuned with supervisions from LMs

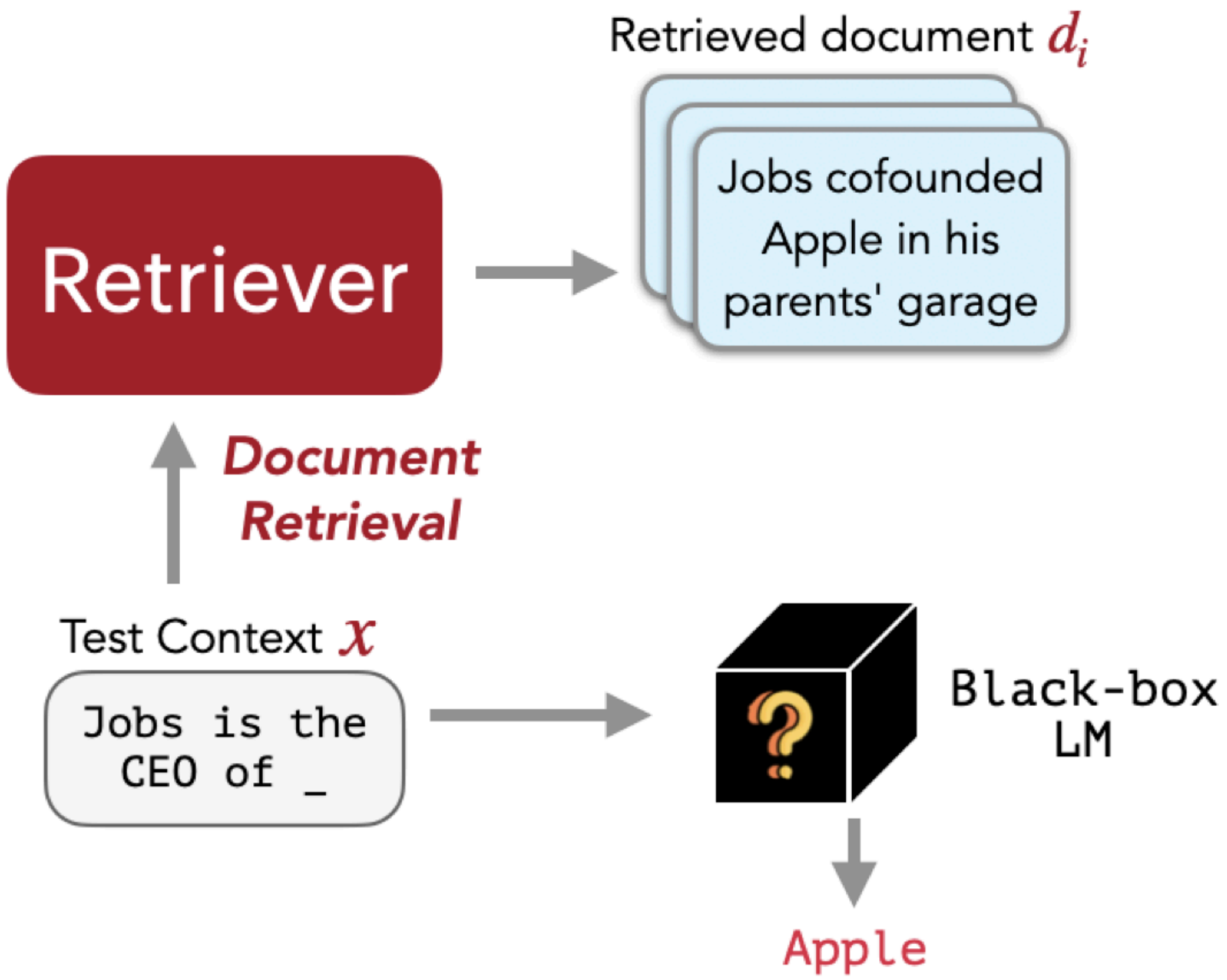


REPLUG (Shi et al. 2023)



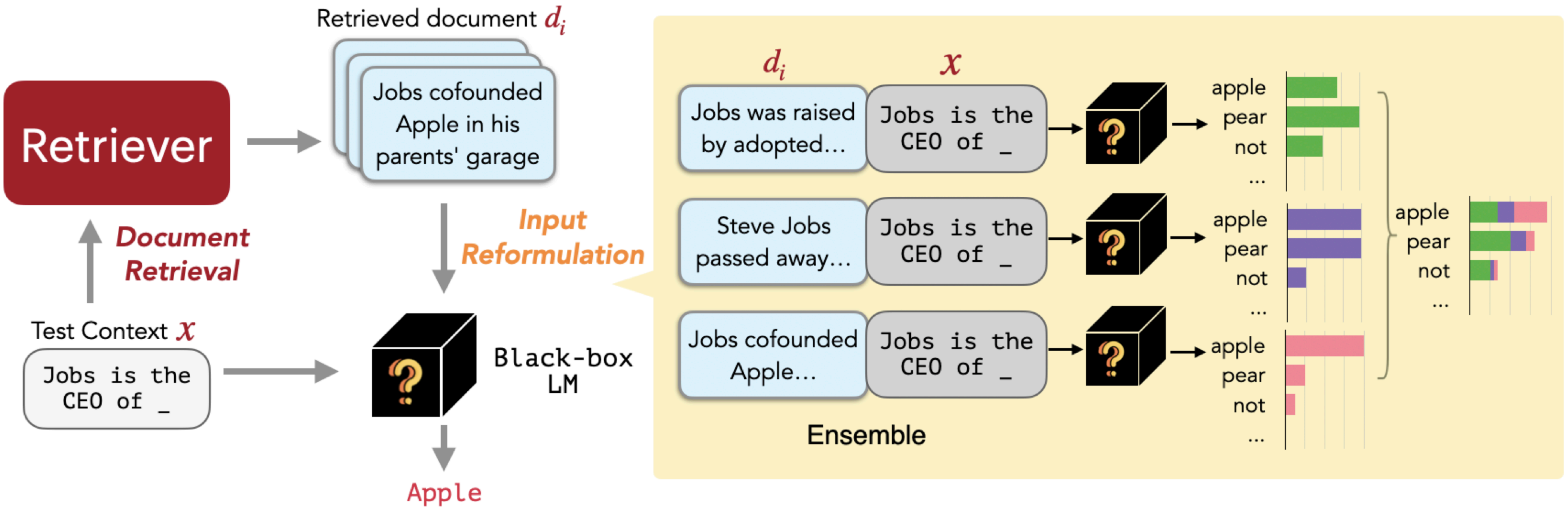
Shi et al., 2023. "REPLUG: Retrieval-Augmented Black-Box Language Models"

REPLUG (Shi et al. 2023)



Shi et al., 2023. “REPLUG: Retrieval-Augmented Black-Box Language Models”

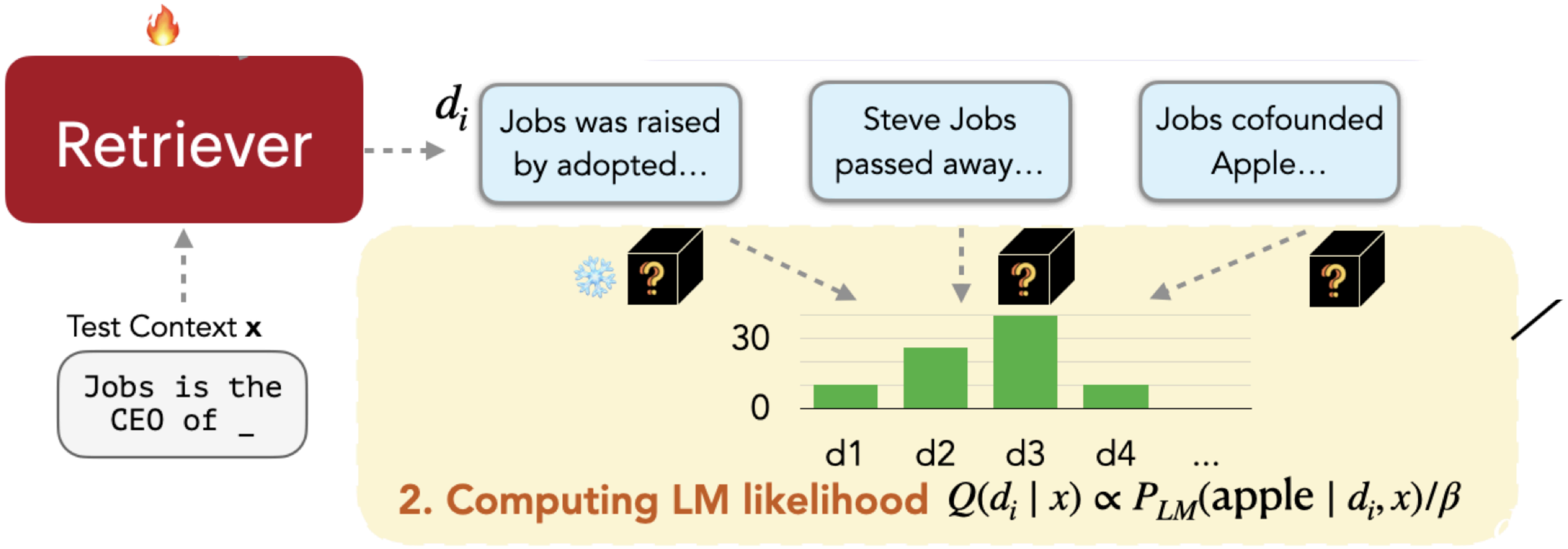
REPLUG (Shi et al. 2023)



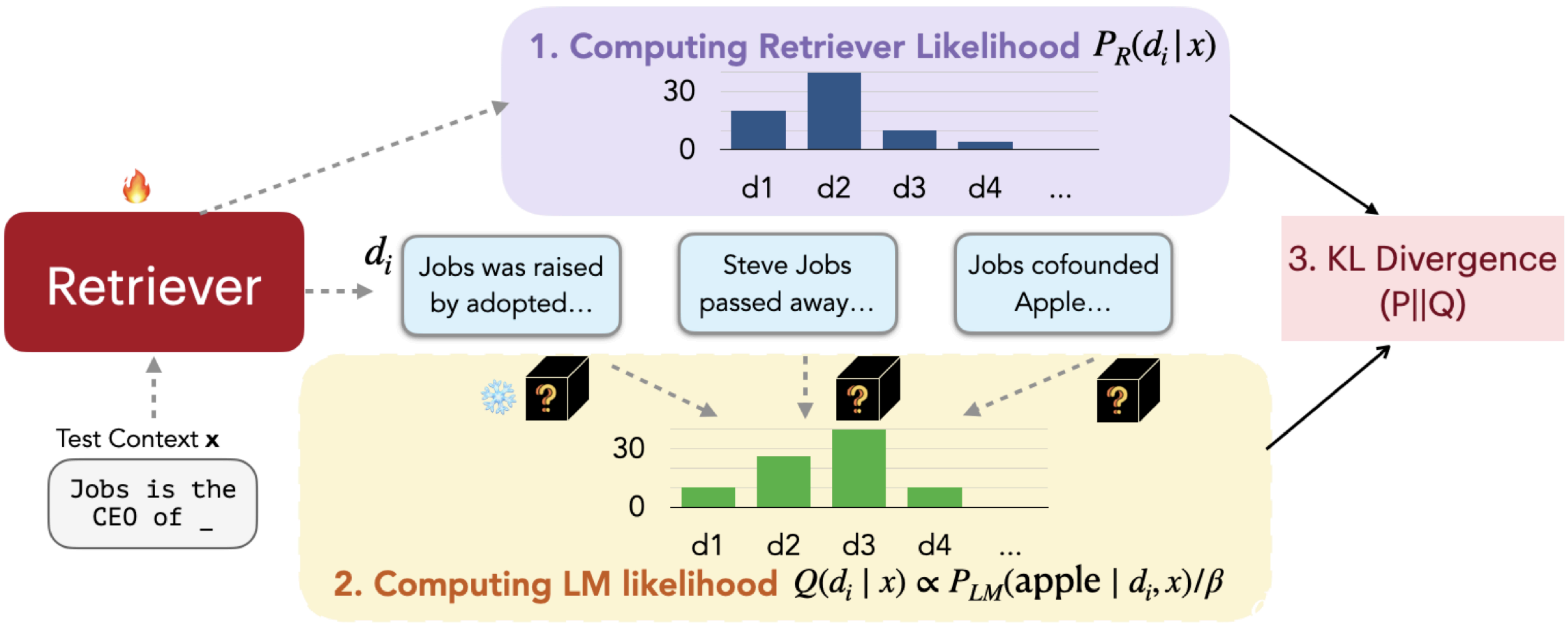
Shi et al., 2023. "REPLUG: Retrieval-Augmented Black-Box Language Models"

REPLUG LSR (LM-Supervised Retrieval)

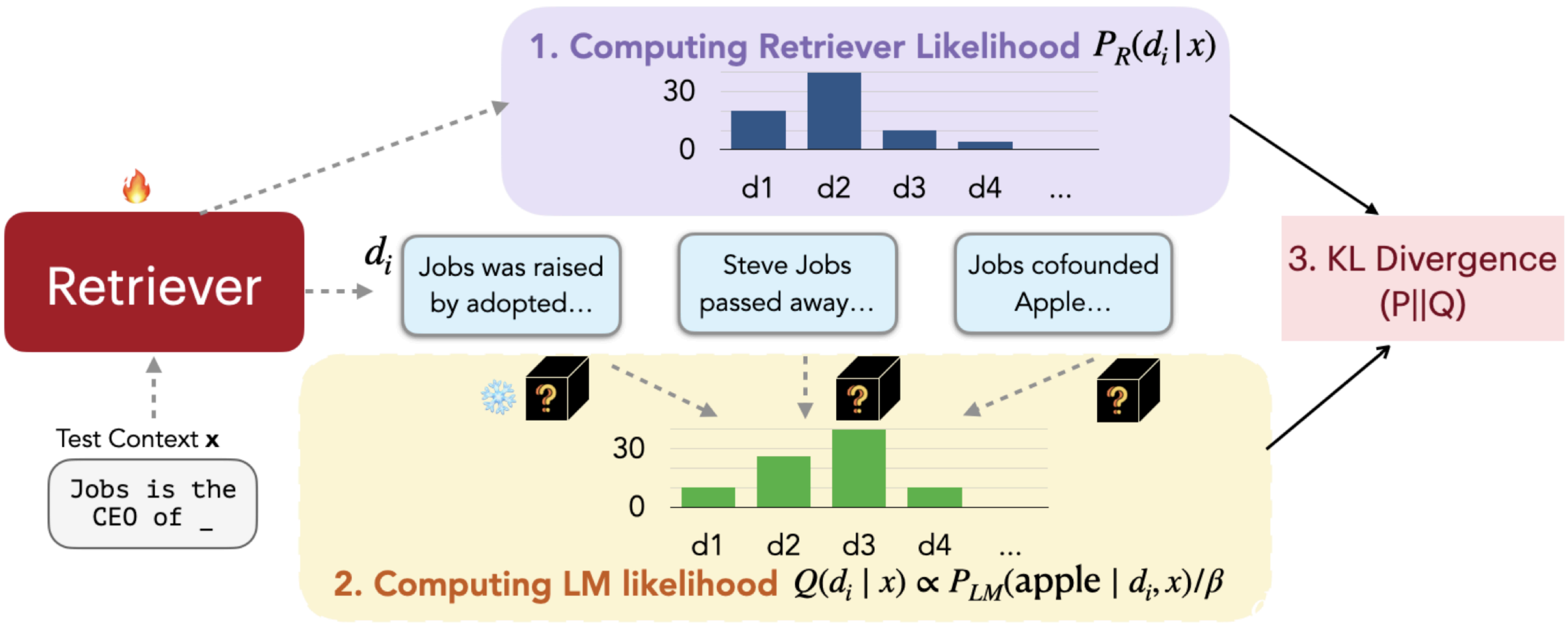
REPLUG LSR (LM-Supervised Retrieval)



REPLUG LSR (LM-Supervised Retrieval)



REPLUG LSR (LM-Supervised Retrieval)



Updating retrieval encoder ⟶ Retrieval Index becomes "stale"

How to deal with this issue? We will talk about it soon!

"Asynchronous update"

REPLUG results

Bits per byte (BPB): The lower the better

Model		# Parameters	Original
GPT-2	Small	117M	1.33
	Medium	345M	1.20
	Large	774M	1.19
	XL	1.5B	1.16
GPT-3 (black-box)	Ada	350M	1.05
	Babbage	1.3B	0.95
	Curie	6.7B	0.88
	Davinci	175B	0.80

REPLUG results

With Contriever, "**independent training**"

Model		# Parameters	Original	+ REPLUG	Gain %
GPT-2	Small	117M	1.33	1.26	5.3
	Medium	345M	1.20	1.14	5.0
	Large	774M	1.19	1.15	3.4
	XL	1.5B	1.16	1.09	6.0
GPT-3 (black-box)	Ada	350M	1.05	0.98	6.7
	Babbage	1.3B	0.95	0.90	5.3
	Curie	6.7B	0.88	0.85	3.4
	Davinci	175B	0.80	0.77	3.8

REPLUG results

Fine-tuning Contriever with
LM-supervised training
"**Sequential training**"

Model		# Parameters	Original	+ REPLUG	Gain %	+ REPLUG LSR	Gain %
GPT-2	Small	117M	1.33	1.26	5.3	1.21	9.0
	Medium	345M	1.20	1.14	5.0	1.11	7.5
	Large	774M	1.19	1.15	3.4	1.09	8.4
	XL	1.5B	1.16	1.09	6.0	1.07	7.8
GPT-3 (black-box)	Ada	350M	1.05	0.98	6.7	0.96	8.6
	Babbage	1.3B	0.95	0.90	5.3	0.88	7.4
	Curie	6.7B	0.88	0.85	3.4	0.82	6.8
	Davinci	175B	0.80	0.77	3.8	0.75	6.3

Sequential training

- Work with off-the-shelf components (either a large index or a powerful LM)
- LMs are trained to effectively leverage retrieval results
- Retrievers are trained to provide text that helps LMs the most
- One component is still fixed and not trained

Let’s jointly train retrieval models and LMs!

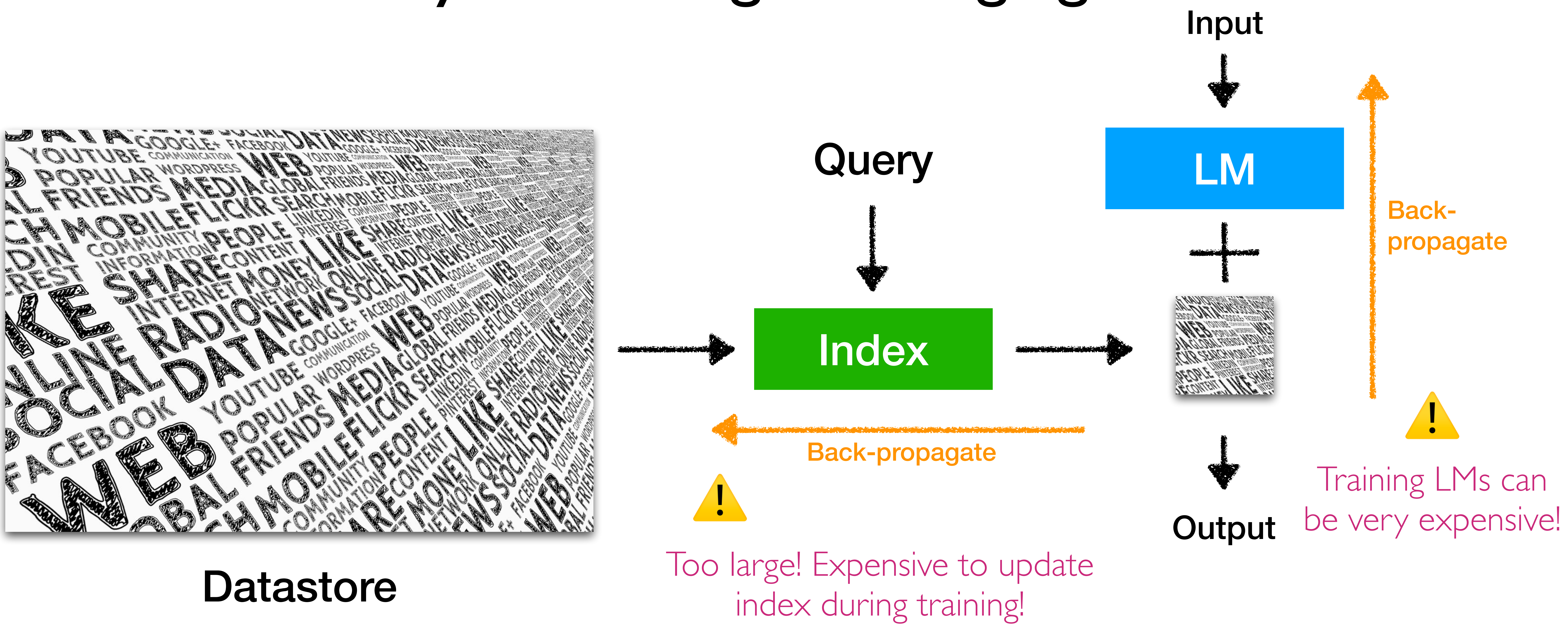
Q & A

coffee break

We'll be back soon!

Section 4:
Retrieval-based LMs: Training (cont'd)

Why is training challenging?



Training methods for retrieval-based LMs

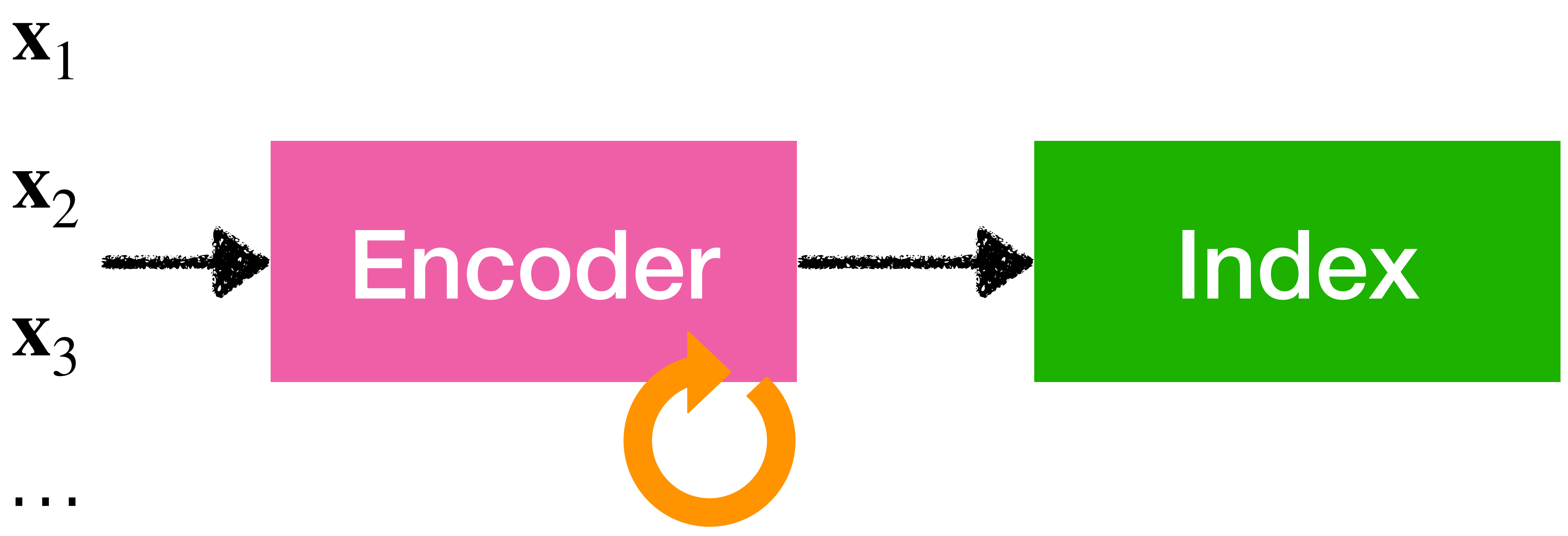
- Independent training
- Sequential training
- Joint training w/ asynchronous index update
- Joint training w/ in-batch approximation

Training methods for retrieval-based LMs

- Independent training
- Sequential training
- **Joint training w/ asynchronous index update**
- **Joint training w/ in-batch approximation**

Challenges of updating retrieval models

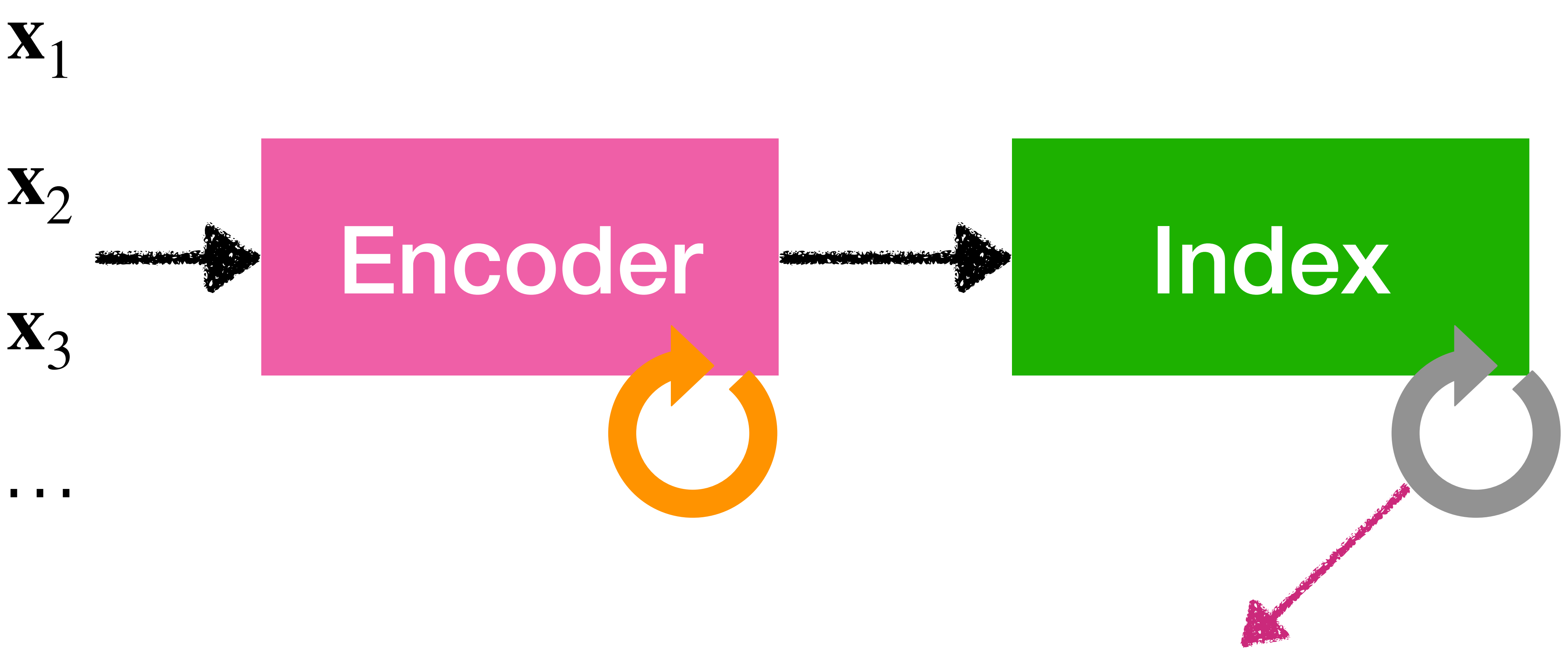
Datastore



During training, we will update the encoder

Challenges of updating retrieval models

Datastore



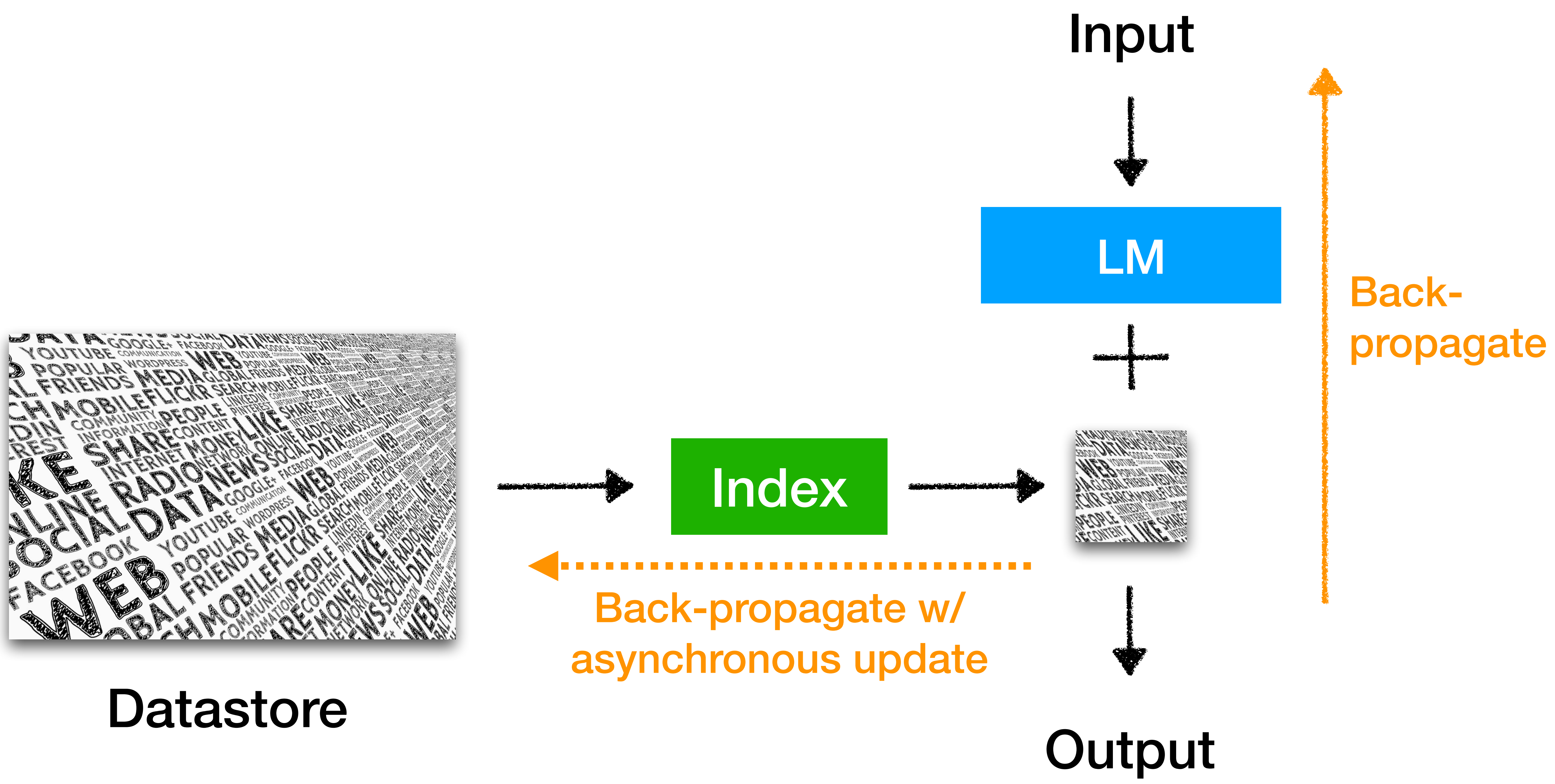
Re-indexing will be very expensive!

Training methods for retrieval-based LMs

- Independent training
- Sequential training
- **Joint training w/ asynchronous index update**
- Joint training w/ in-batch approximation

Joint training w/ asynchronous index update

- Retrieval models and language models are trained jointly
- Allow the index to be "**stale**"; rebuild the retrieval index every T steps



Asynchronous index update

Datastore

$\mathbf{x}_1$

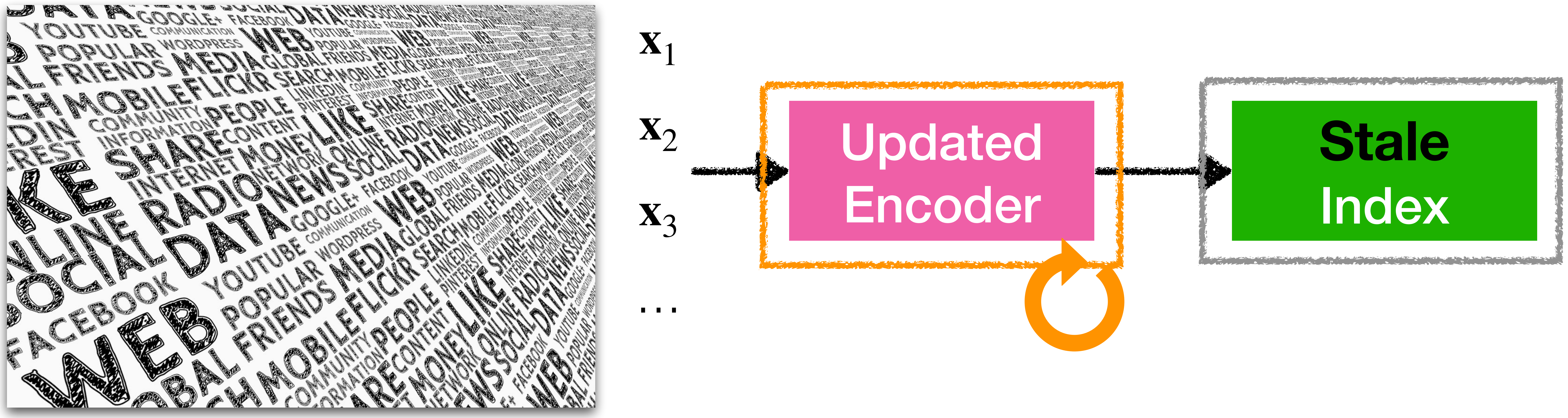
$\mathbf{x}_2$

$\mathbf{x}_3$

$\ldots$

$\rightarrow$ Encoder $\rightarrow$ Index

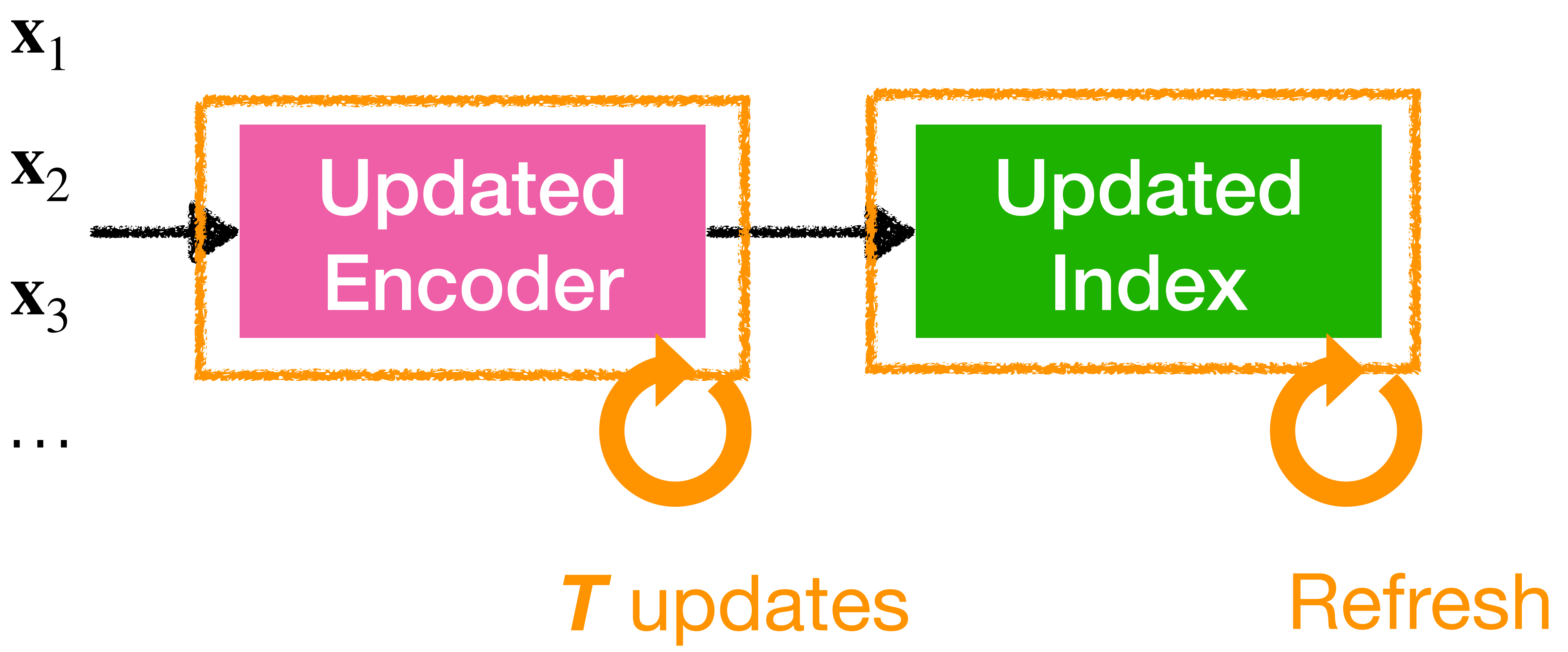
Asynchronous index update



Datastore

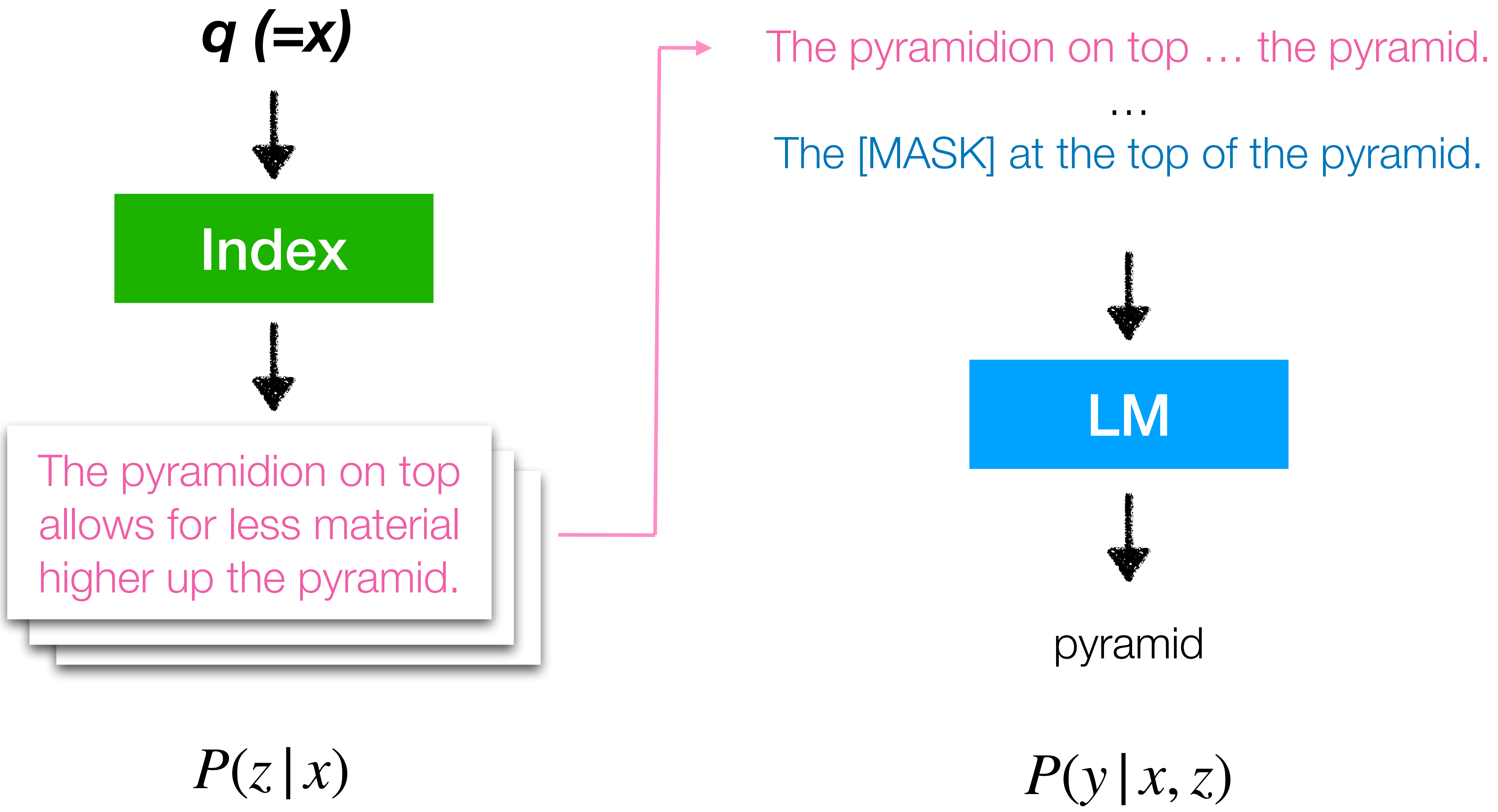
Asynchronous index update

Datastore



REALM (Guu et al. 2020)

x = The [MASK] at the top of the pyramid.



Guu et al., 2020. "REALM: Retrieval-Augmented Language Model Pre-Training"

REALM: Training

Objective: $\text{maximize} \sum_{z \in \mathcal{Z}_\theta} P_\theta(z \mid q) P_\theta(y \mid q, z)$

q (=x)

Index

$\mathcal{Z}_\theta$: top-K retrieved chunks

The pyramidion on top allows for less material higher up the pyramid.

$P_\theta(z \mid x)$

The pyramidion on top … the pyramid.

…

The [MASK] at the top of the pyramid.

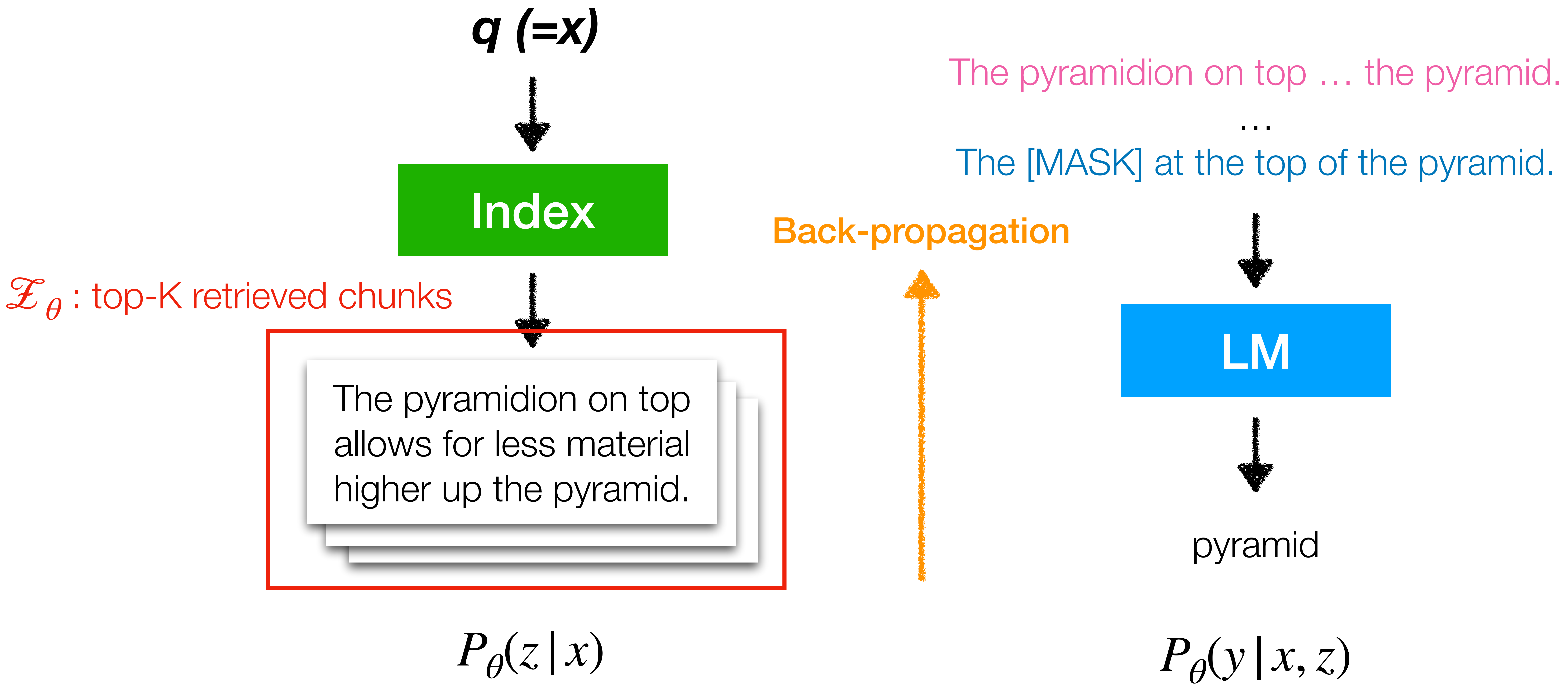
LM

pyramid

$P_\theta(y \mid x, z)$

REALM: Training

Objective: $\text{maximize} \sum_{z \in \mathcal{Z}_\theta} P_\theta(z \mid q) P_\theta(y \mid q, z)$



REALM: Training

Objective: $\text{maximize} \sum_{z \in \mathcal{Z}_\theta} P_\theta(z \mid q) P_\theta(y \mid q, z)$

q (=x)

Stale index;
Update every T steps

Index

$\mathcal{Z}_\theta$: top-K retrieved chunks

The pyramidion on top allows for less material higher up the pyramid.

$P_{\theta_{\text{new}}}(z \mid x)$

The pyramidion on top … the pyramid.

…

The [MASK] at the top of the pyramid.

LM

pyramid

$P_{\theta_{\text{new}}}(y \mid x, z)$

Up-to-date parameters

REALM: Index update rate

How often should we update the retrieval index?

- Frequency too high: expensive
- Frequency too slow: out-dated

REALM: Index update rate

How often should we update the retrieval index?

- Frequency too high: expensive
- Frequency too slow: out-dated

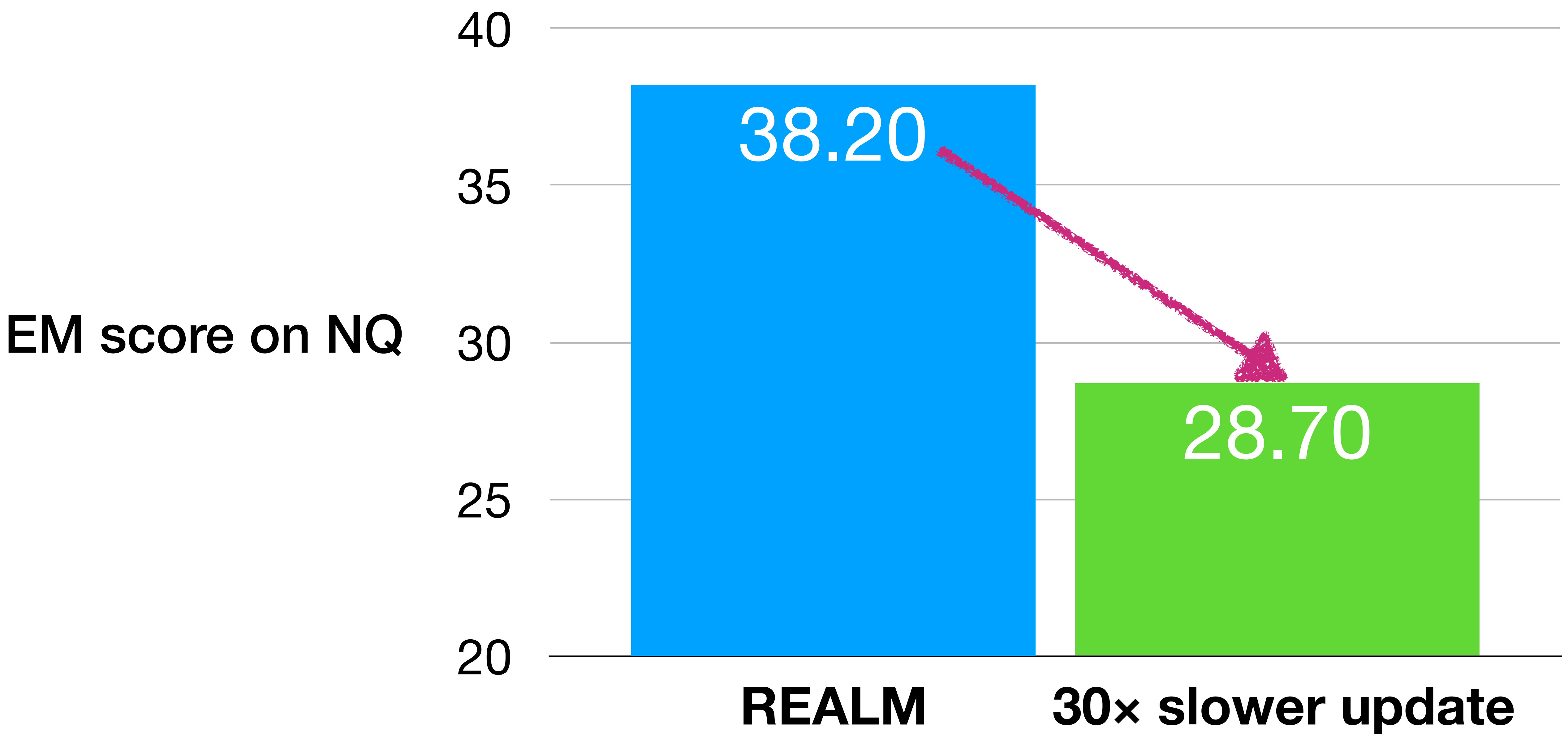
REALM: updating the index every 500 training steps

REALM: Index update rate

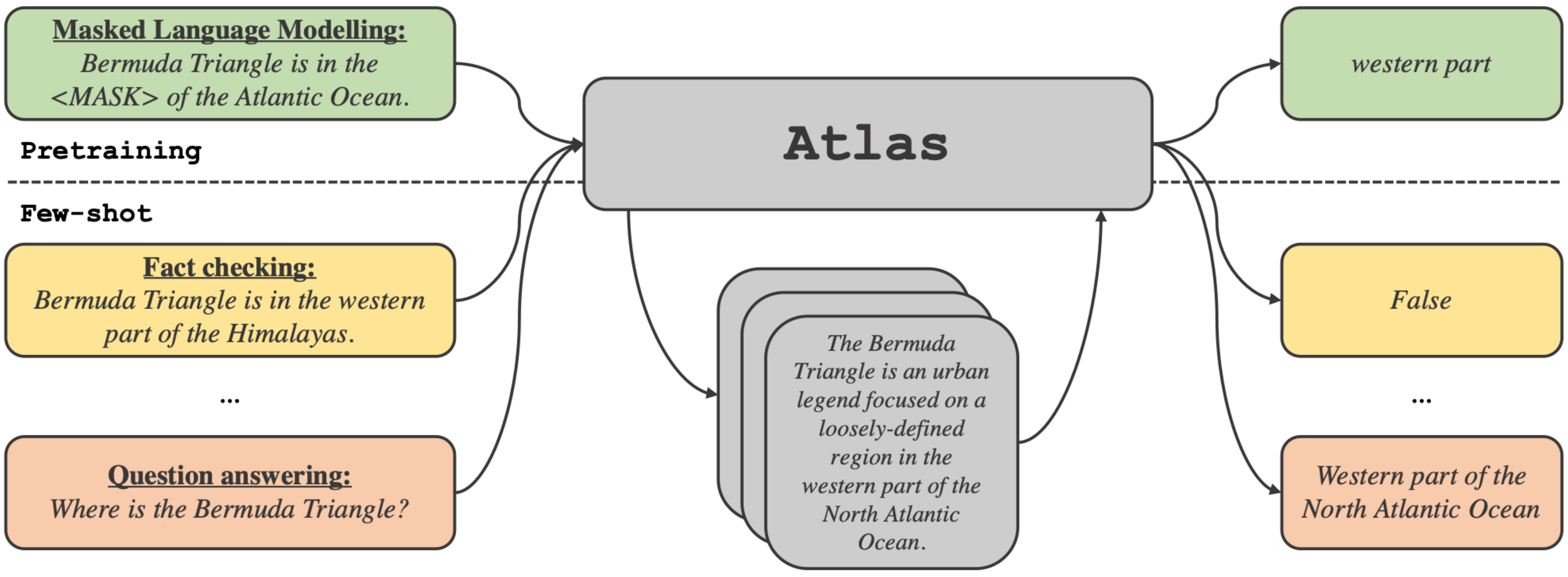
How often should we update the retrieval index?

- Frequency too high: expensive
- Frequency too slow: out-dated

REALM: updating the index every 500 training steps



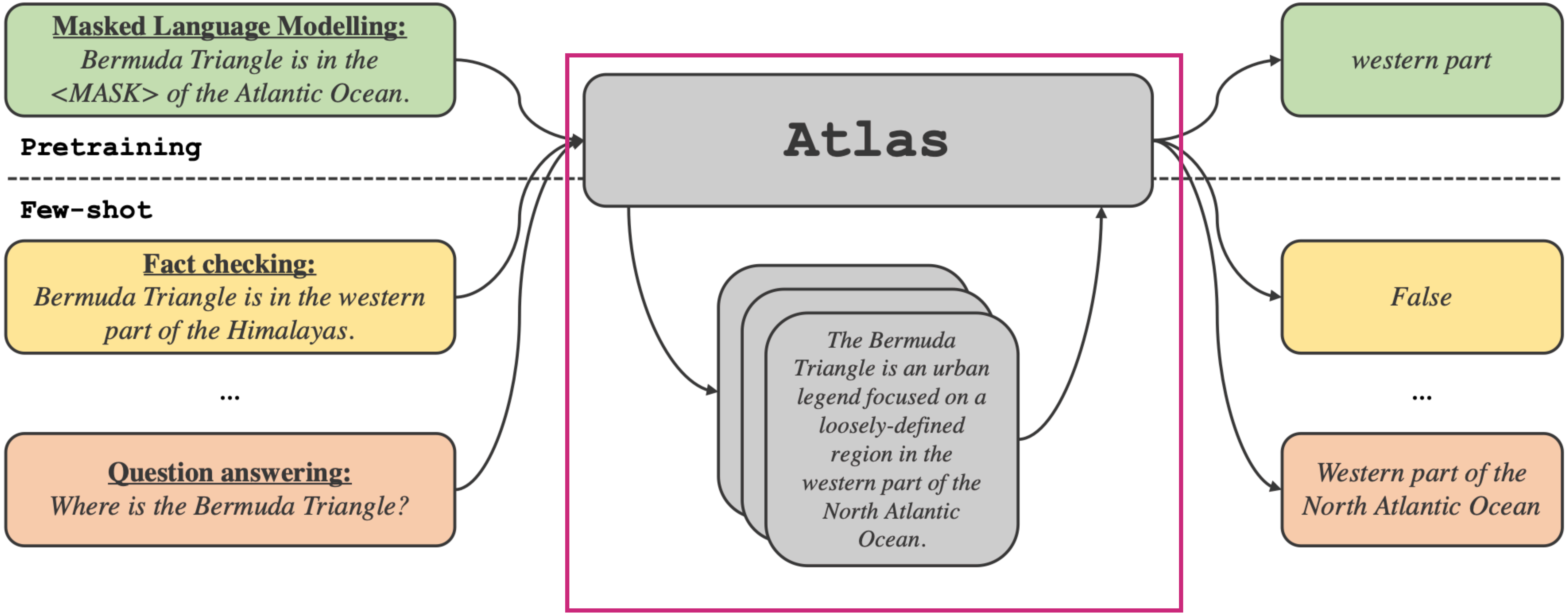
Atlas (Izacard et al. 2022)



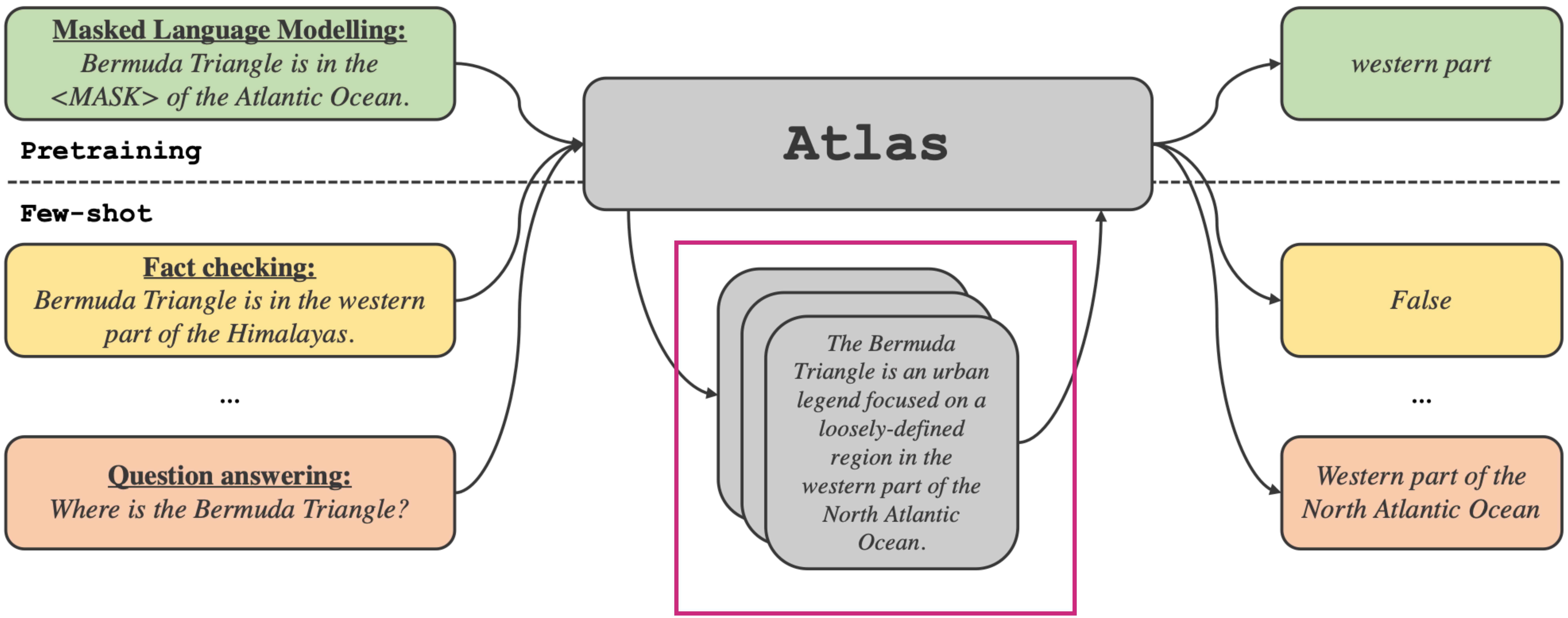
Izacard et al., 2022. "Atlas: Few-shot Learning with Retrieval Augmented Language Models"

Atlas (Izacard et al. 2022)

Retrieval-based encoder-decoder model



Atlas (Izacard et al. 2022)



Process each doc independently using "Fusion-in-Decoder"

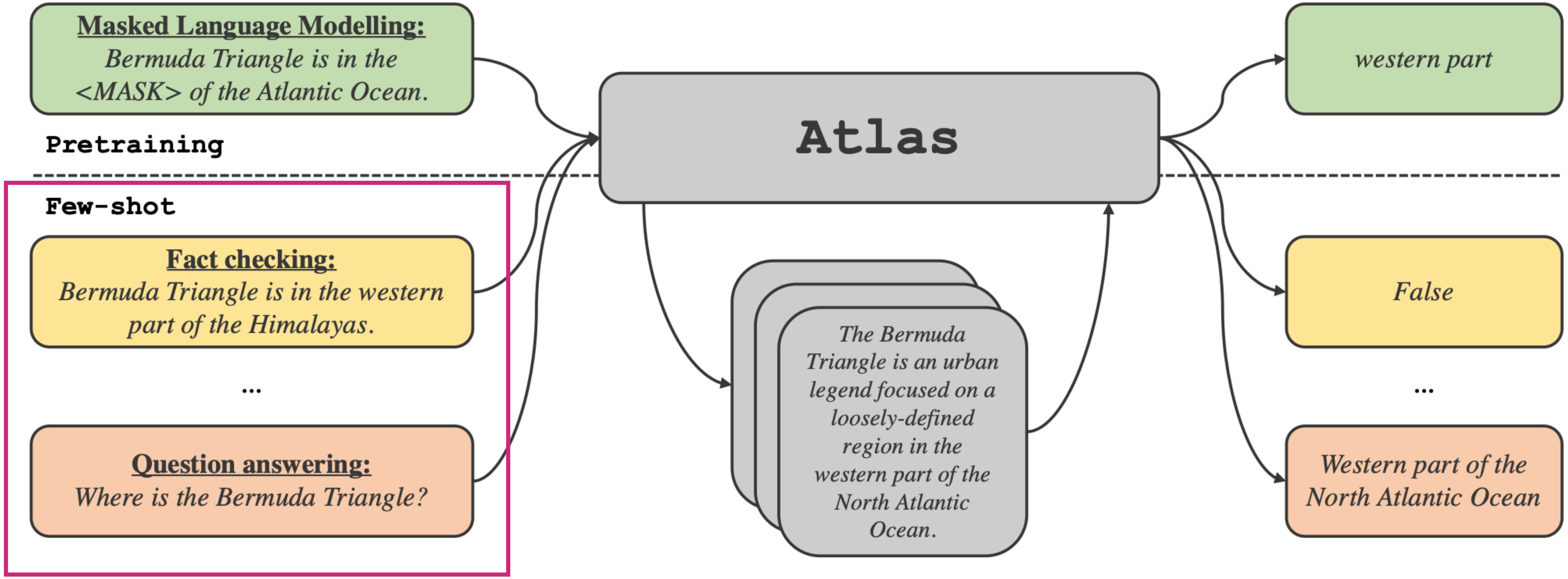
Izacard and Grave., 2020. "Leveraging Passage Retrieval with Generative Models for Open Domain Question Answering"

Atlas (Izacard et al. 2022)

"Fusion-in-decoder"

Izacard and Grave., 2020. "Leveraging Passage Retrieval with Generative Models for Open Domain Question Answering"

Atlas (Izacard et al. 2022)



Adapted to a lot of downstream tasks! (Section 5)

Atlas: Retriever training

Perplexity Distillation

Retrieve the text that can help LM encoders improve perplexity

$$P_{\text{retr}}(z \mid q) = \frac{\exp(s(z, q))}{\sum_{k=1}^{K} \exp(s(z_k, q))} \longleftrightarrow P_{\text{ppl}}(z \mid q, y) = \frac{\exp(\log P_{\text{LM}}(y \mid q, z))}{\sum_{k=1}^{K} \exp(\log P_{\text{LM}}(y \mid q, z_k))}$$

How likely each document is retrieved

How much each document improves the ppl

Atlas: Retriever training

Similarity based on retrieval encoder

$$P_{\text{retr}}(z \mid q) = \frac{\exp(s(z, q))}{\sum_{k=1}^{K} \exp(s(z_k, q))}$$

How likely each document is retrieved

KL Divergence

$$\longleftrightarrow$$

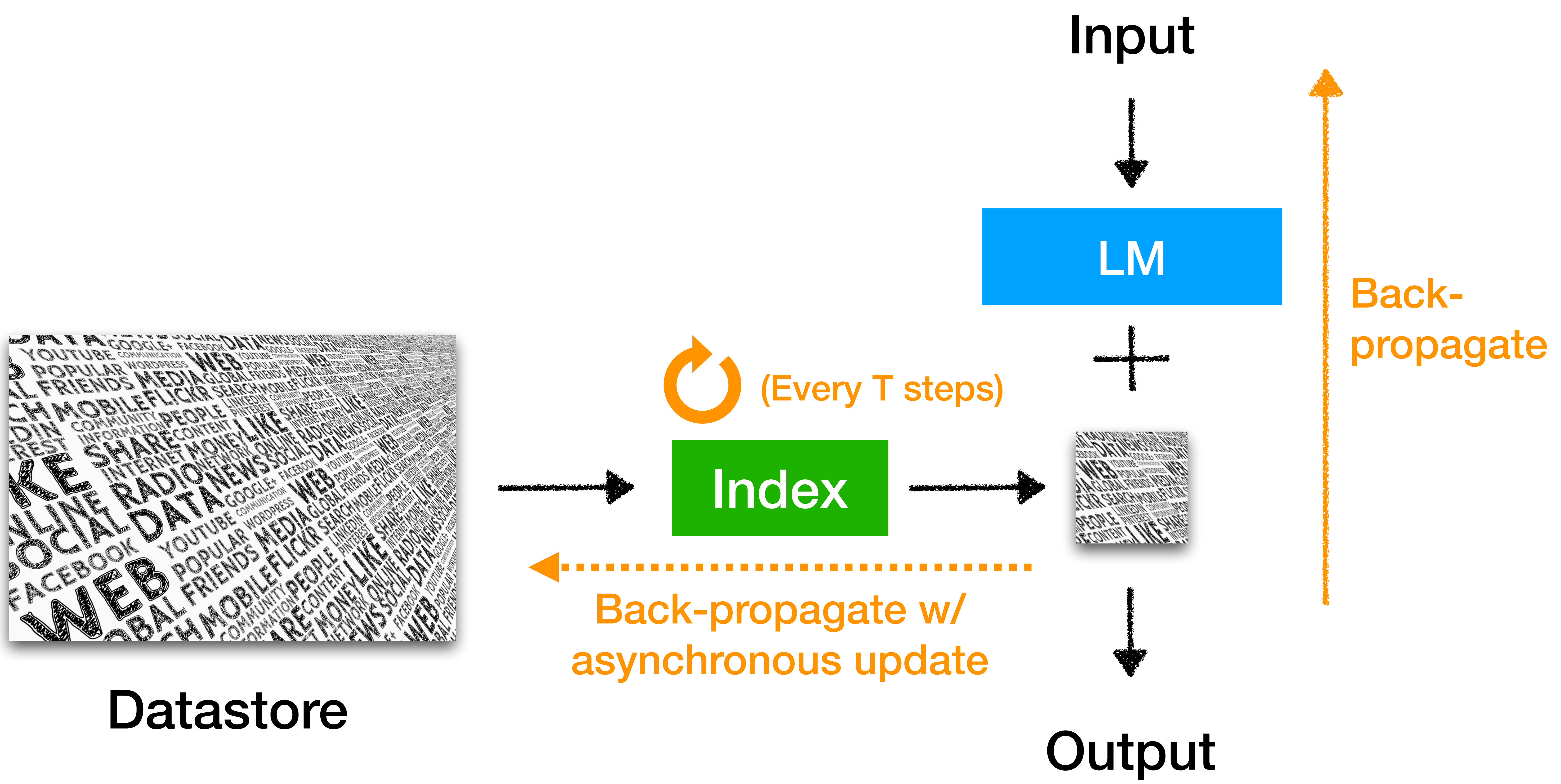
Prob of the gold labels if augmenting this text chunk

$$P_{\text{ppl}}(z \mid q, y) = \frac{\exp(\log P_{\text{LM}}(y \mid q, z))}{\sum_{k=1}^{K} \exp(\log P_{\text{LM}}(y \mid q, z_k))}$$

How much each document improves the ppl

Perplexity Distillation

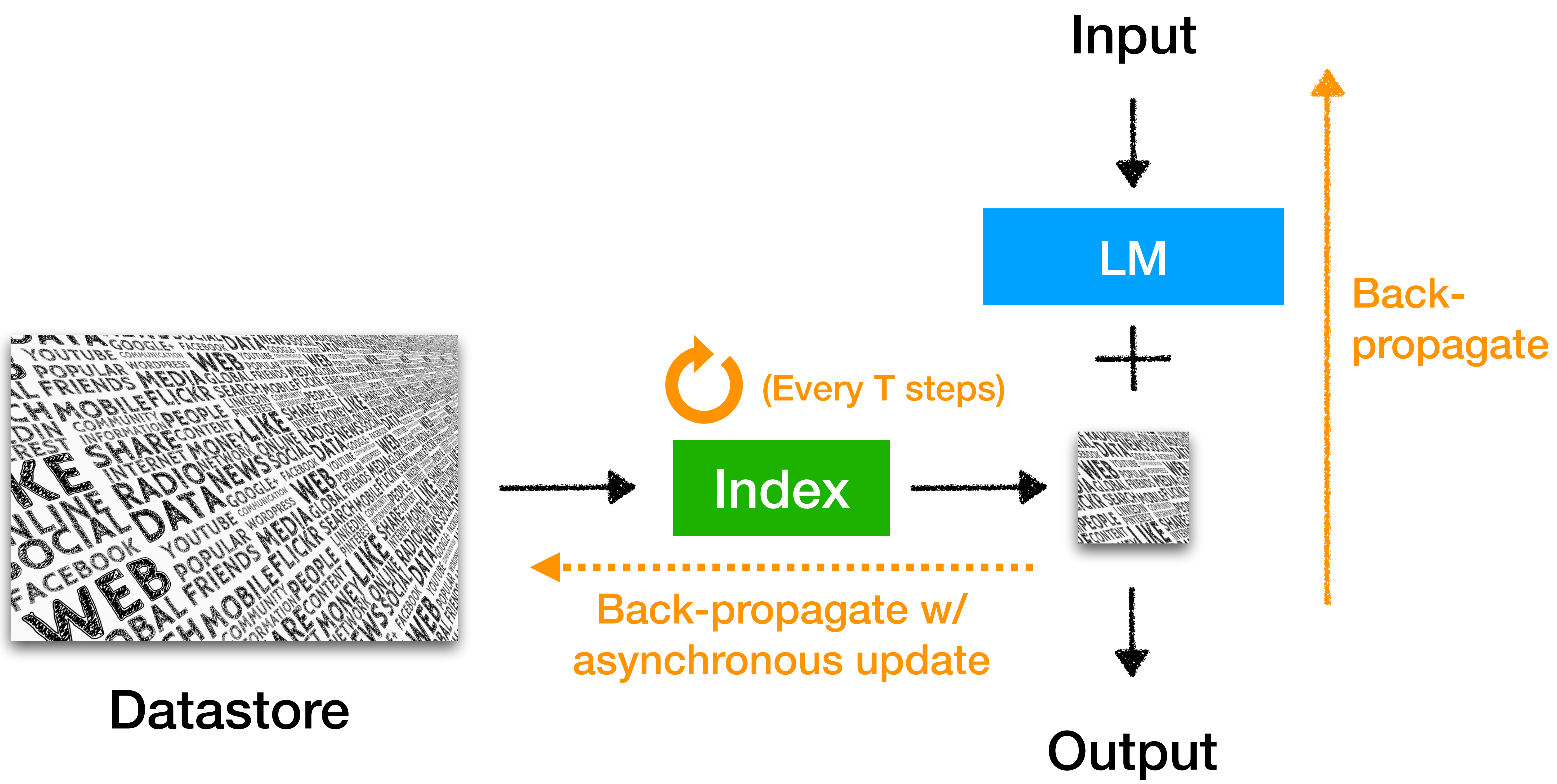
Atlas: Asynchronous index update



Update the index every T steps

30% overhead for asynchronous update on Wikipedia

Atlas: Asynchronous index update



Update the index every T steps

30% overhead for asynchronous update on Wikipedia

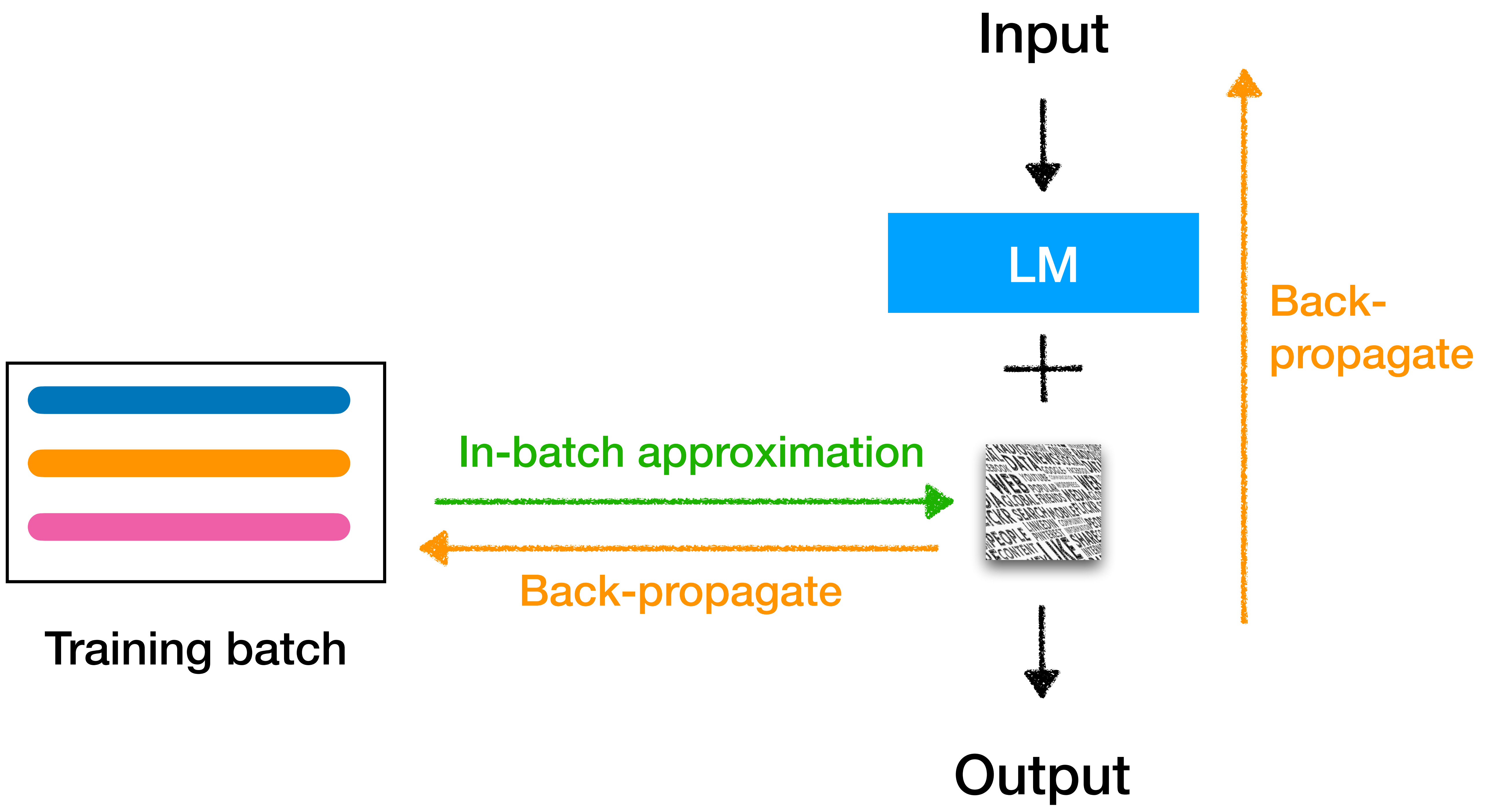
How can we get rid of this?

Training methods for retrieval-based LMs

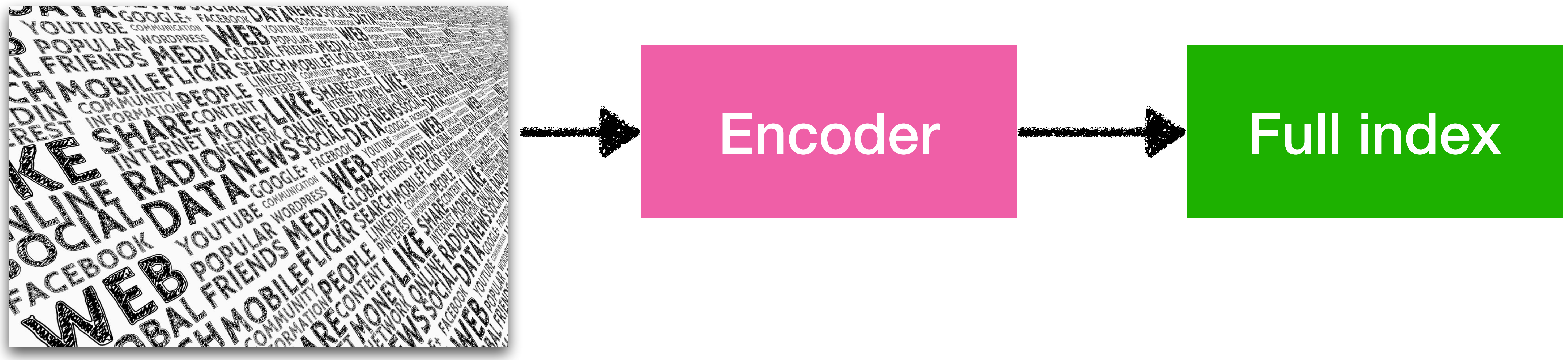
- Independent training
- Sequential training
- Joint training w/ asynchronous index update
- **Joint training w/ in-batch approximation**

Joint training w/ in-batch approximation

- Retrieval models and language models are trained jointly
- Use "in-batch index" instead of full index



In-batch approximation



Full corpus

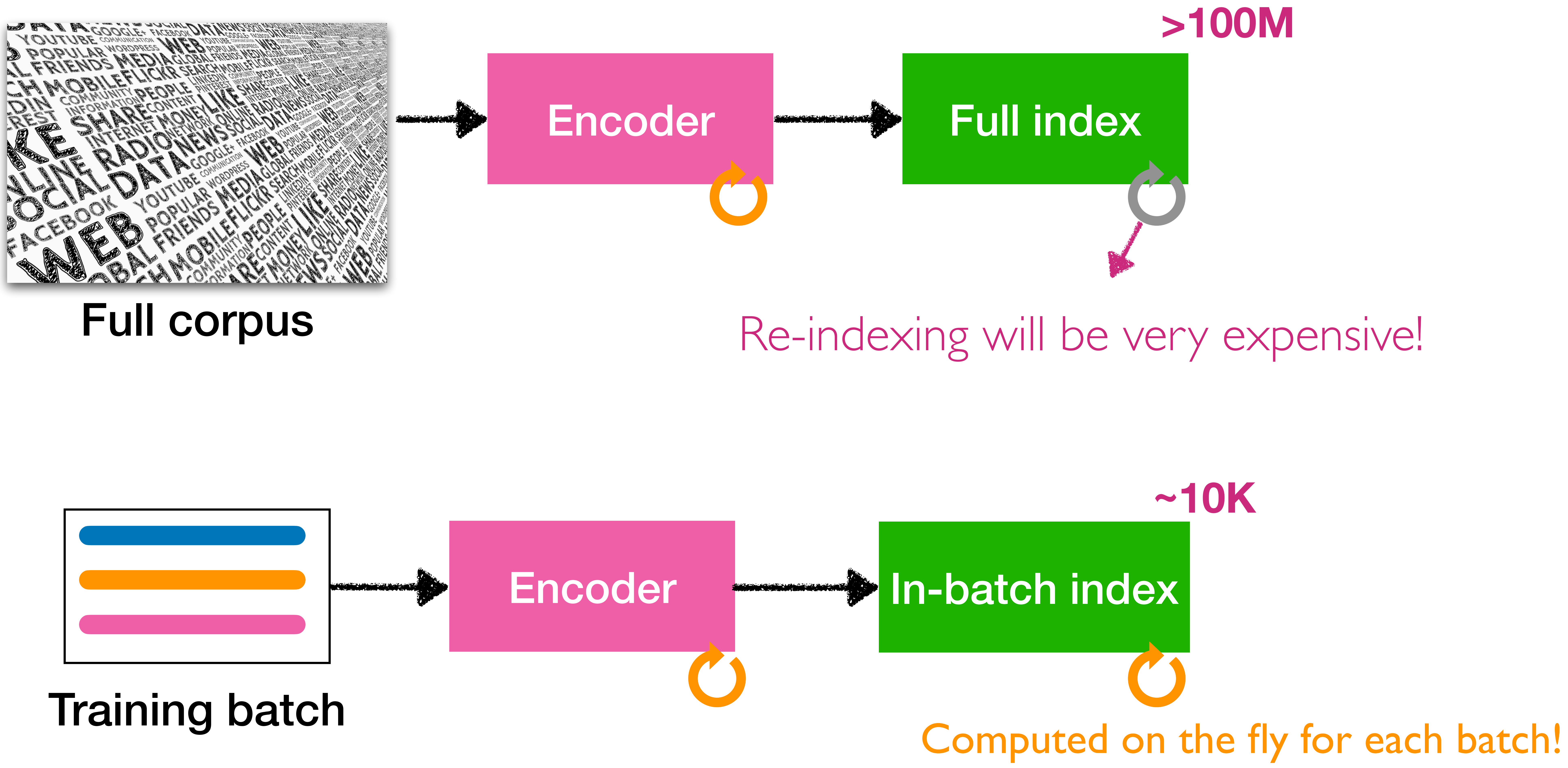
In-batch approximation

Full corpus → Encoder → Full index

>100M

Re-indexing will be very expensive!

In-batch approximation



TRIME: Training with in-batch memory (Zhong et al. 2022)

Similar to kNN-LM

Datastore $\mathscr{D} = \{(k, v)\}$

context (chunk)   next token

Keys	Values
10/10, would buy this	*cheap*
Item delivered broken. Very	*cheap*
To check the version of PyTorch, you can use	*torch*
You are permitted to bring a	*torch*
A group of infections … one of the	*torch*

Zhong et al., 2022. "Training Language Models with Memory Augmentation"

TRIME: Training with in-batch memory (Zhong et al. 2022)

Similar to kNN-LM

Datastore $\mathcal{D} = \{(k, v)\}$

context (chunk) next token

Keys	Values
10/10, would buy this	*cheap*
Item delivered broken. Very	*cheap*
To check the version of PyTorch, you can use	*torch*
You are permitted to bring a	*torch*
A group of infections … one of the	*torch*

Inference

$$P(y \mid x) \propto \boxed{\exp(E^\top f(x))} + \sum_{\boxed{(k,v)\in\mathcal{D}}} \mathbb{I}[v = y]\exp(-d(\text{Enc}(k), \text{Enc}(x)))$$

output embedding

(same as standard LMs)

datastore

(very large!)

TRIME: Training with in-batch memory (Zhong et al. 2022)

Similar to kNN-LM

Datastore $\mathcal{D} = \{(k, v)\}$

context (chunk)   next token

Keys	Values
10/10, would buy this	*cheap*
Item delivered broken. Very	*cheap*
To check the version of PyTorch, you can use	*torch*
You are permitted to bring a	*torch*
A group of infections … one of the	*torch*

Inference

$$P(y \mid x) \propto \underbrace{\boxed{\exp(E^\top f(x))}}_{\text{output embedding}} + \sum_{\boxed{(k,v)\in\mathcal{D}}} \mathbb{I}[v = y]\exp(-d(\text{Enc}(k), \text{Enc}(x)))$$

output embedding

(same as standard LMs)

datastore

(very large!)

1. Aligning the output representations with static embeddings

2. Aligning input chunks with all the chunks in datastore that share the same next token

TRIME: Training with in-batch memory (Zhong et al. 2022)

$$P(y \mid x) \propto \exp(E^\top f(x)) + \sum_{(k,v)\in\mathcal{D}} \mathbb{I}[v = y]\exp(-d(\mathrm{Enc}(k), \mathrm{Enc}(x)))$$

Jobs become CEO of Apple ⟷ He moves to Apple

Positive chunks → pull together

Jobs become CEO of Apple ⟷ She works at Microsoft

Negative chunks → push away

TRIME: Training with in-batch memory (Zhong et al. 2022)

$$P(y \mid x) \propto \exp(E^\top f(x)) + \sum_{(k,v)\boxed{\in \mathcal{D}}} \mathbb{I}[v = y]\exp(-d(\mathrm{Enc}(k), \mathrm{Enc}(x)))$$

Very large!

Jobs become CEO of Apple ⟷ He moves to Apple

Positive chunks → pull together

Jobs become CEO of Apple ⟷ She works at Microsoft

Negative chunks → push away

TRIME: Training

Key idea: build a temporary index from <u>same training batch</u> on the fly

$$P(y \mid x) \propto \exp(E^\top f(x)) + \sum_{(k,v)\in \boxed{\mathcal{D}_{train}}} \mathbb{I}[v = y]\big(-d(\text{Enc}(k), \text{Enc}(x))\big)$$

In-batch approximation

(built from in-batch examples on the fly)

TRIME: Training

Key idea: build a temporary index from <u>same training batch</u> on the fly

$$P(y \mid x) \propto \exp(E^\top f(x)) + \sum_{(k,v)\in \boxed{\mathcal{D}_{train}}} \mathbb{I}[v = y]\big(-d(\text{Enc}(k), \text{Enc}(x))\big)$$

In-batch approximation

(built from in-batch examples on the fly)

We can back-propagate to all the representations in datastore $\mathcal{D}_{train}$!

TRIME: full index vs. in-batch index

Full corpus

Keys	Values
To check the version of PyTorch, you can use	*torch*
Item delivered broken. Very	*cheap*
He moves to	*Apple*
Apple merged with NeXT, and Jobs became	*CEO*
…	…

Full index (used during inference)

TRIME: full index vs. in-batch index

Full corpus

Keys	Values
To check the version of PyTorch, you can use	*torch*
Item delivered broken. Very	*cheap*
He moves to	*Apple*
Apple merged with NeXT, and Jobs became	*CEO*
…	…

Full index (used during inference)

Compute on the fly!

Apple merged with NeXT, and …

VS Code was developed by Microsoft for Windows in 2015 …

He moves to Apple …

…

Training batch

Keys	Values
Jobs	*became*
Apple merged with NeXT, and Jobs became	*CEO*
…	…
He moves to	*Apple*
VS Code was developed	*By*

In-batch index (used during training)

TRIME: full index vs. in-batch index

How to batch training data —
so we can have good in-batch examples?

Compute on the fly!

Apple merged with NeXT, and …

VS Code was developed by Microsoft for Windows in 2015 …

He moves to Apple …

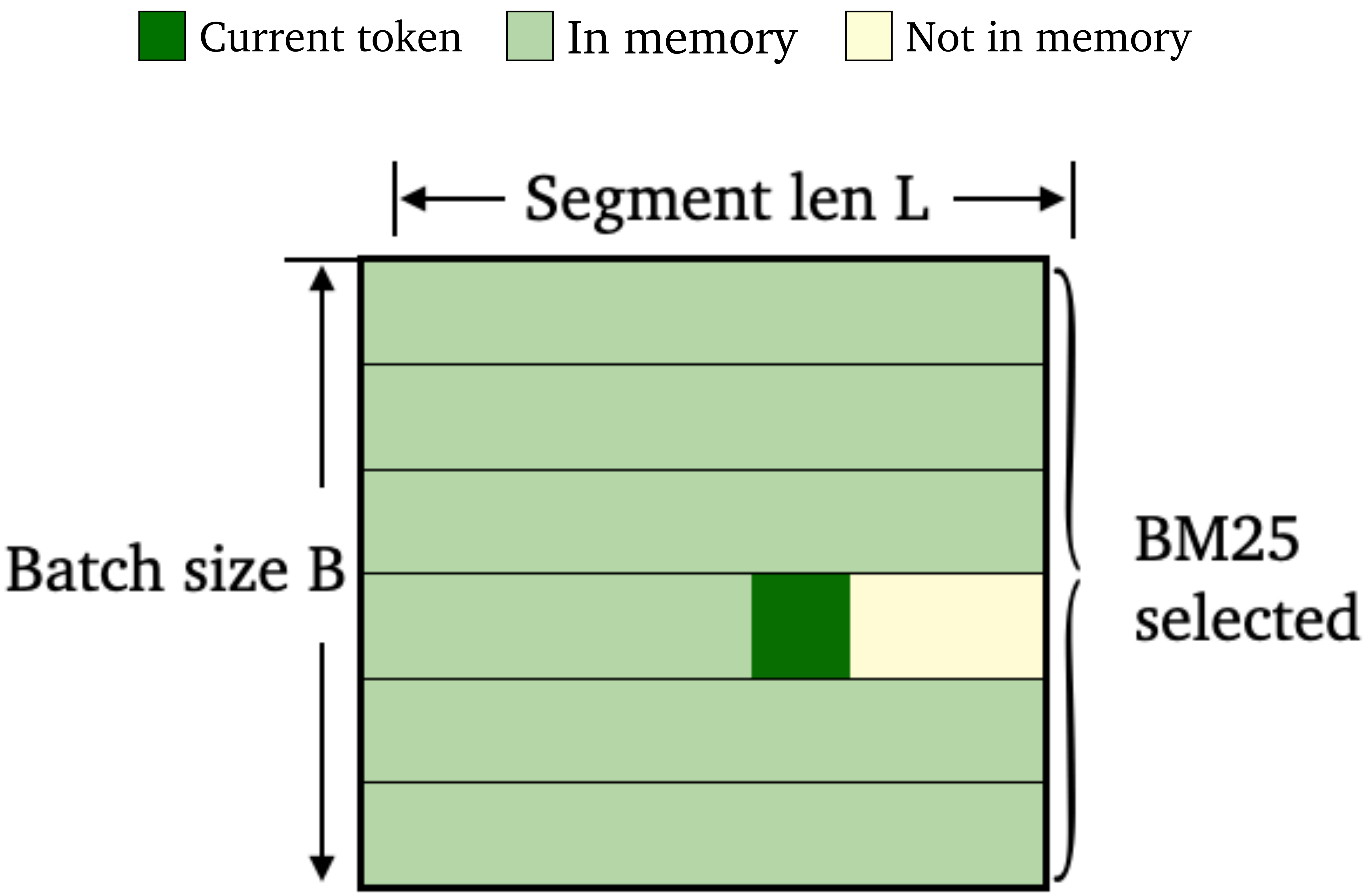
…

Training batch

Keys	Values
Jobs	*became*
Apple merged with NeXT, and Jobs became	*CEO*
…	*…*
He moves to	*Apple*
VS Code was developed	*By*

In-batch index (used during training)

TRIME: Data batching strategy

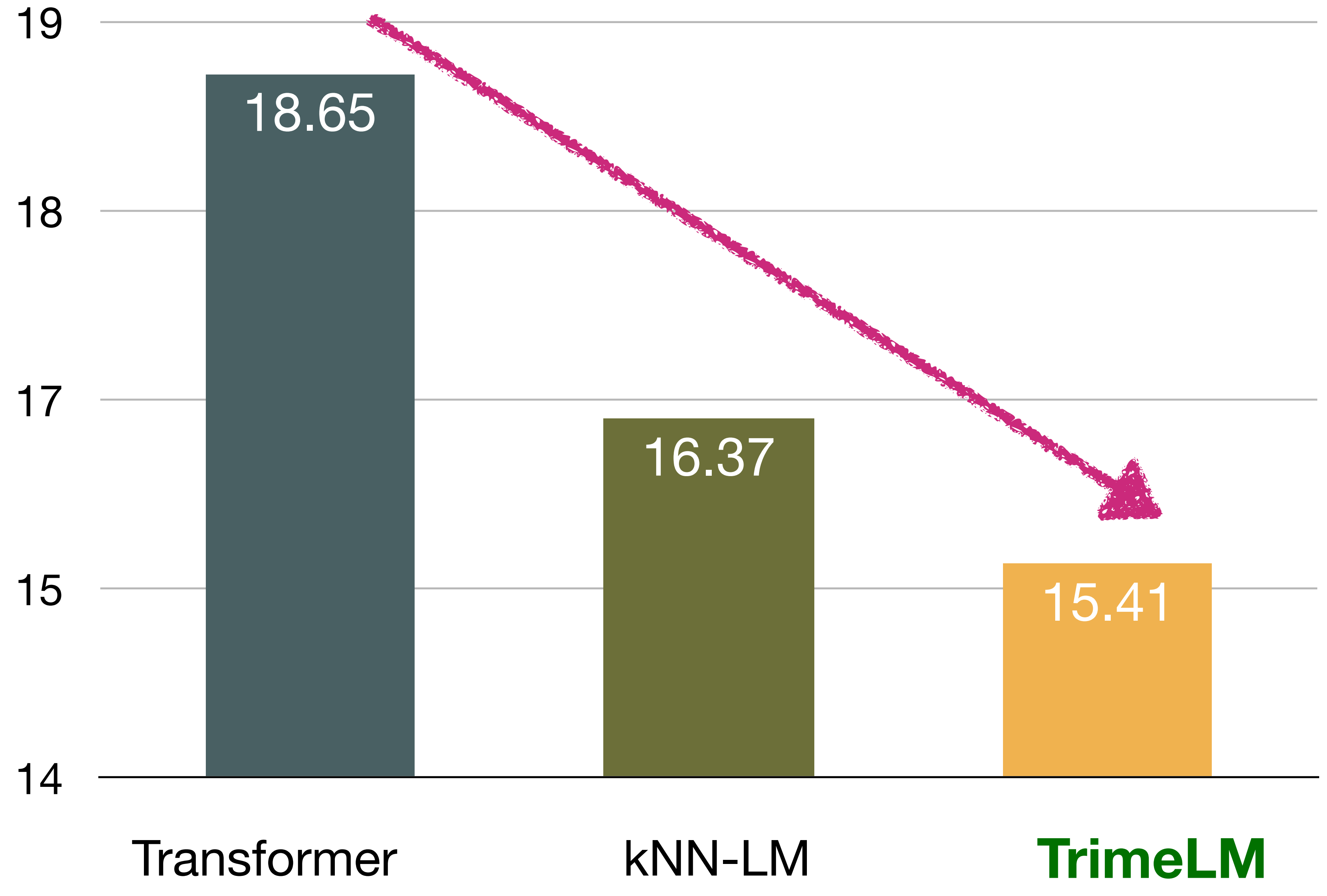


Key idea: similar text chunks — more training signals from in-batch examples!

Use **BM25** scores to find similar text chunks

TRIME: Results

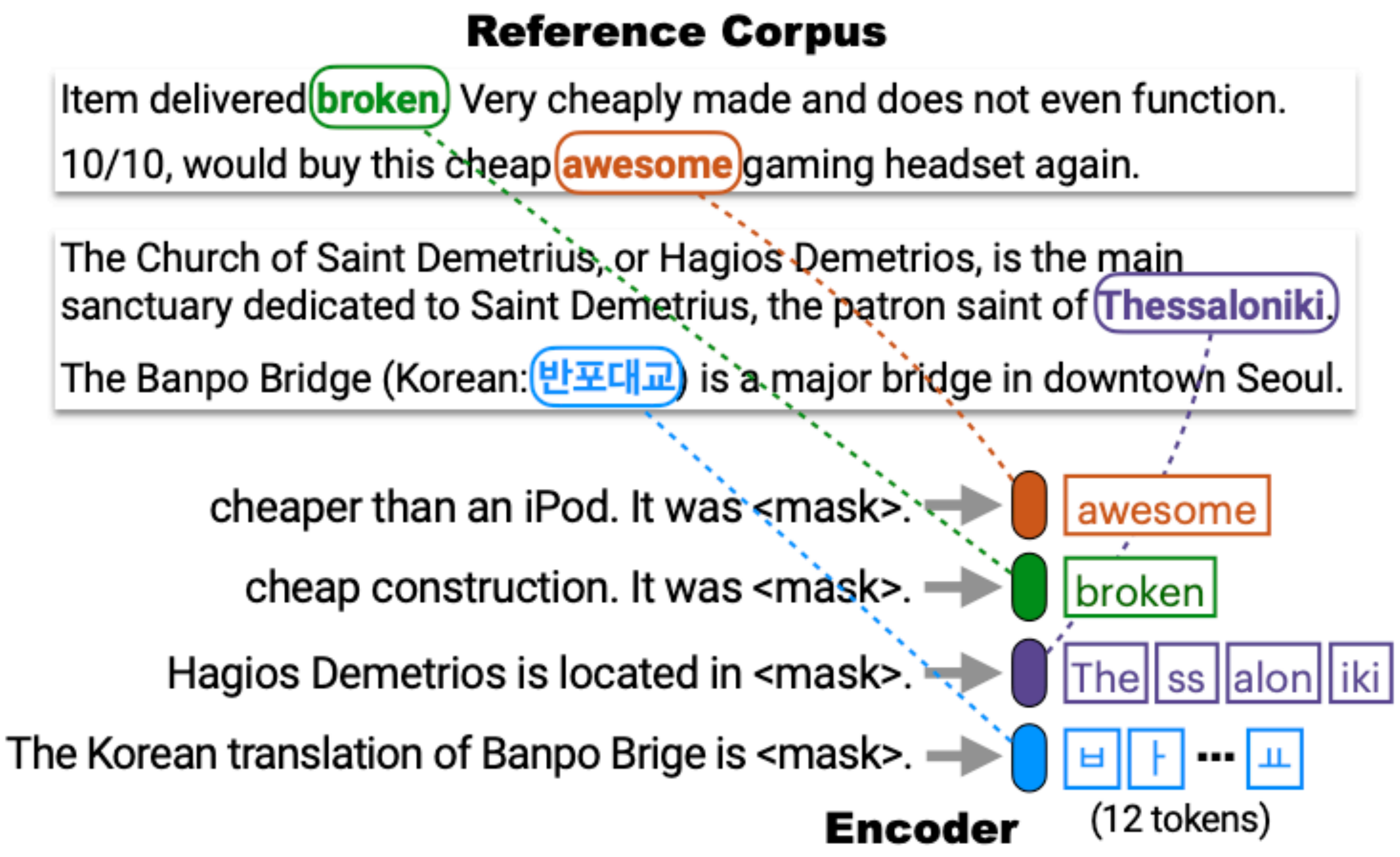
Perplexity: The lower the better



Model size: 247M
Sequence len: 3072

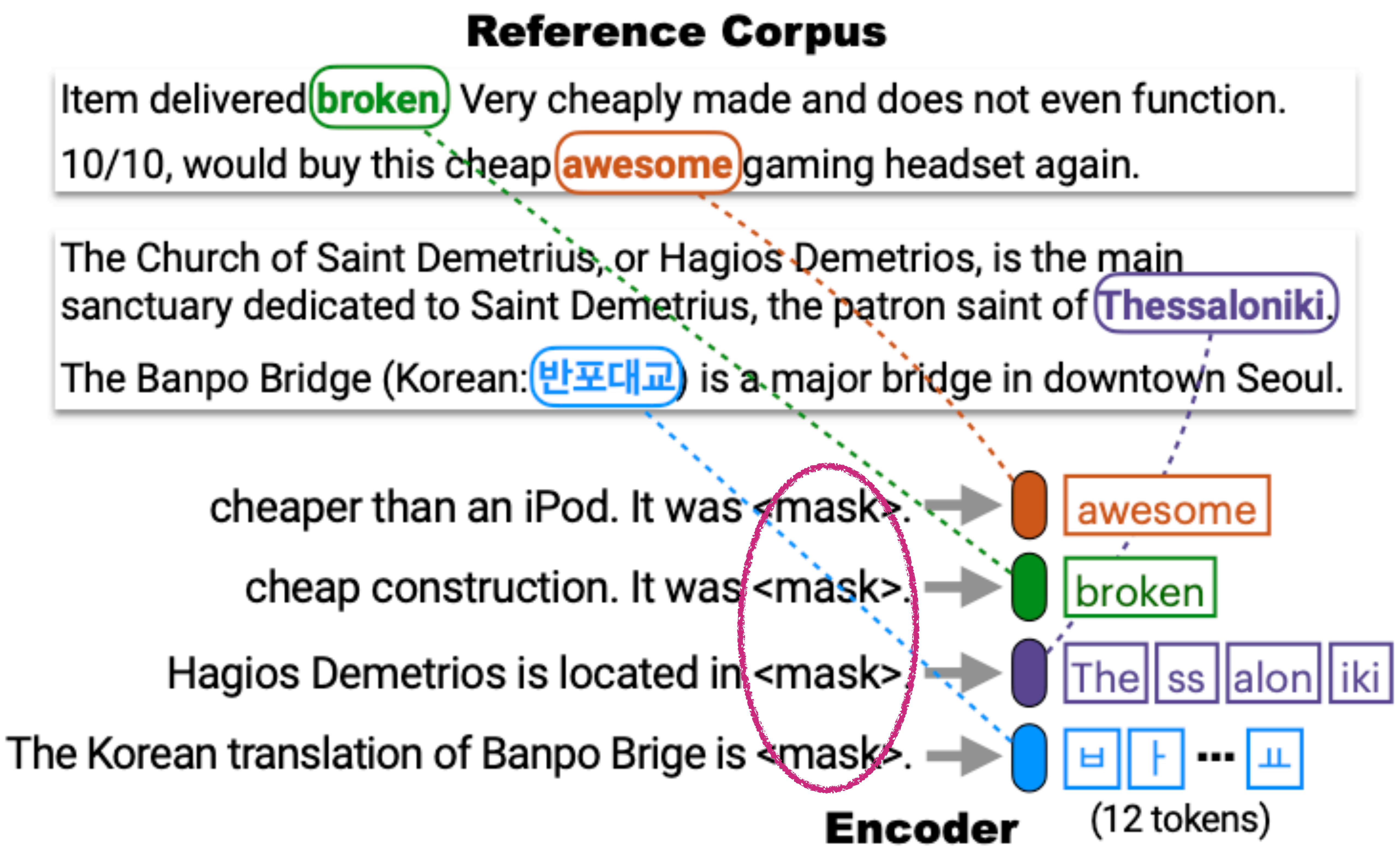
Perplexity on Wikitext-103

NPM: Nonparametric masked LMs (Min et al. 2023)



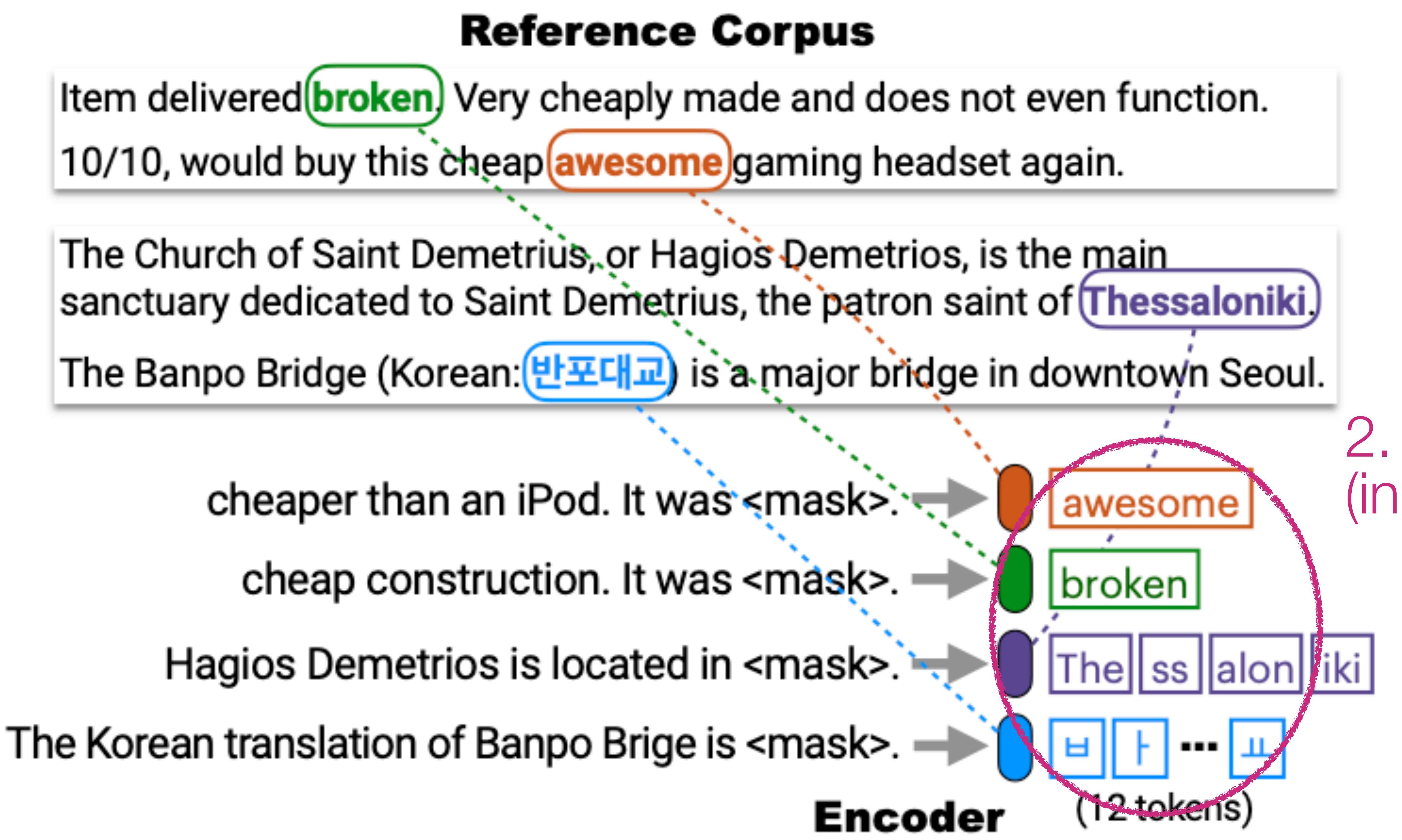
Min et al., 2023. “Nonparametric Masked Language Modeling”

NPM: Nonparametric masked LMs (Min et al. 2023)



1. **masked** language model pertained on >1B tokens

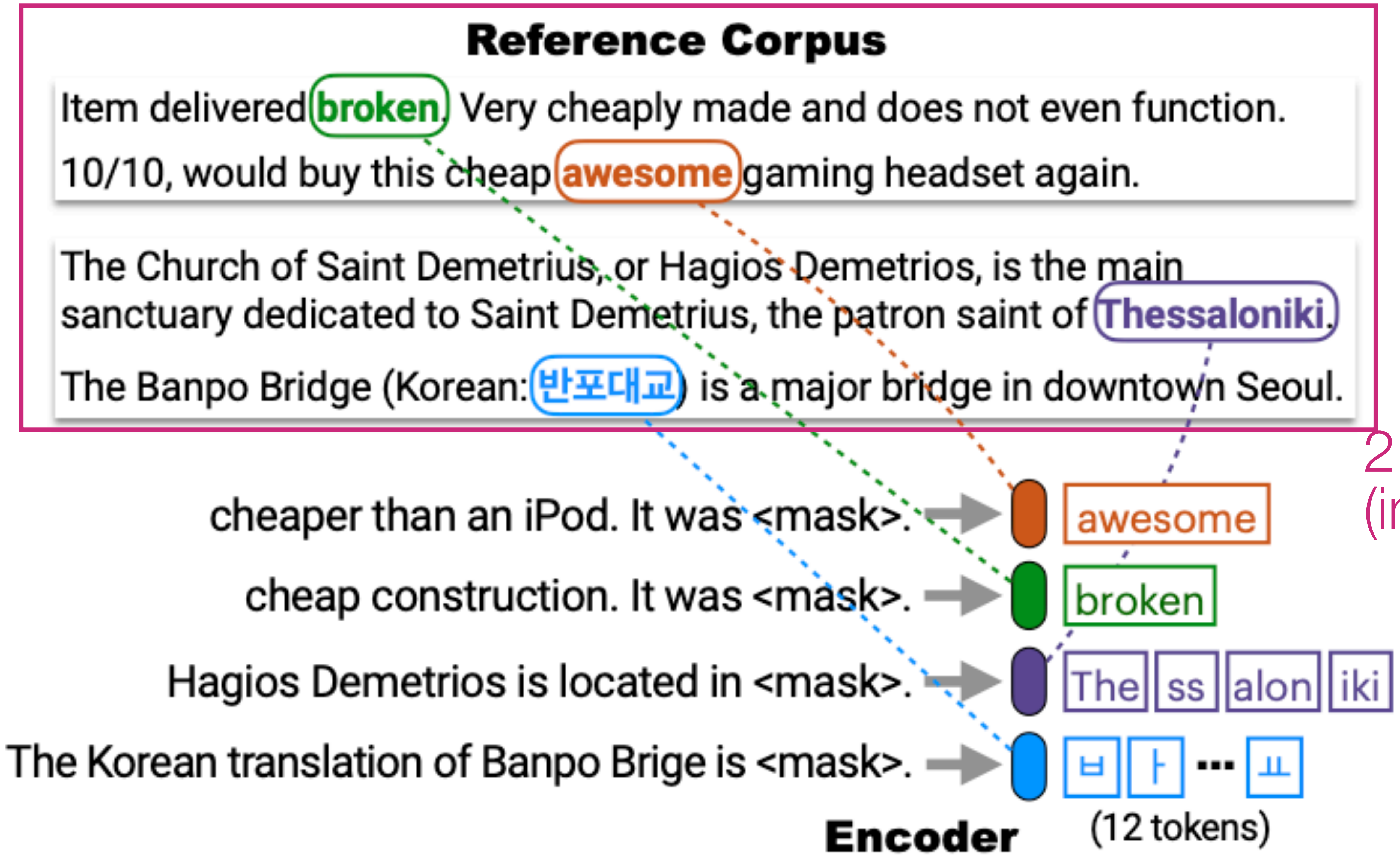
NPM: Nonparametric masked LMs (Min et al. 2023)



2. Each mask corresponds to a **phrase** (instead of a token)

1. masked language model pertained on >1B tokens

NPM: Nonparametric masked LMs (Min et al. 2023)



3. During inference, predictions are made **purely** according to retrieval results

2. Each mask corresponds to a phrase (instead of a token)

1. masked language model pertained on >1B tokens

NPM: Nonparametric masked LMs (Min et al. 2023)

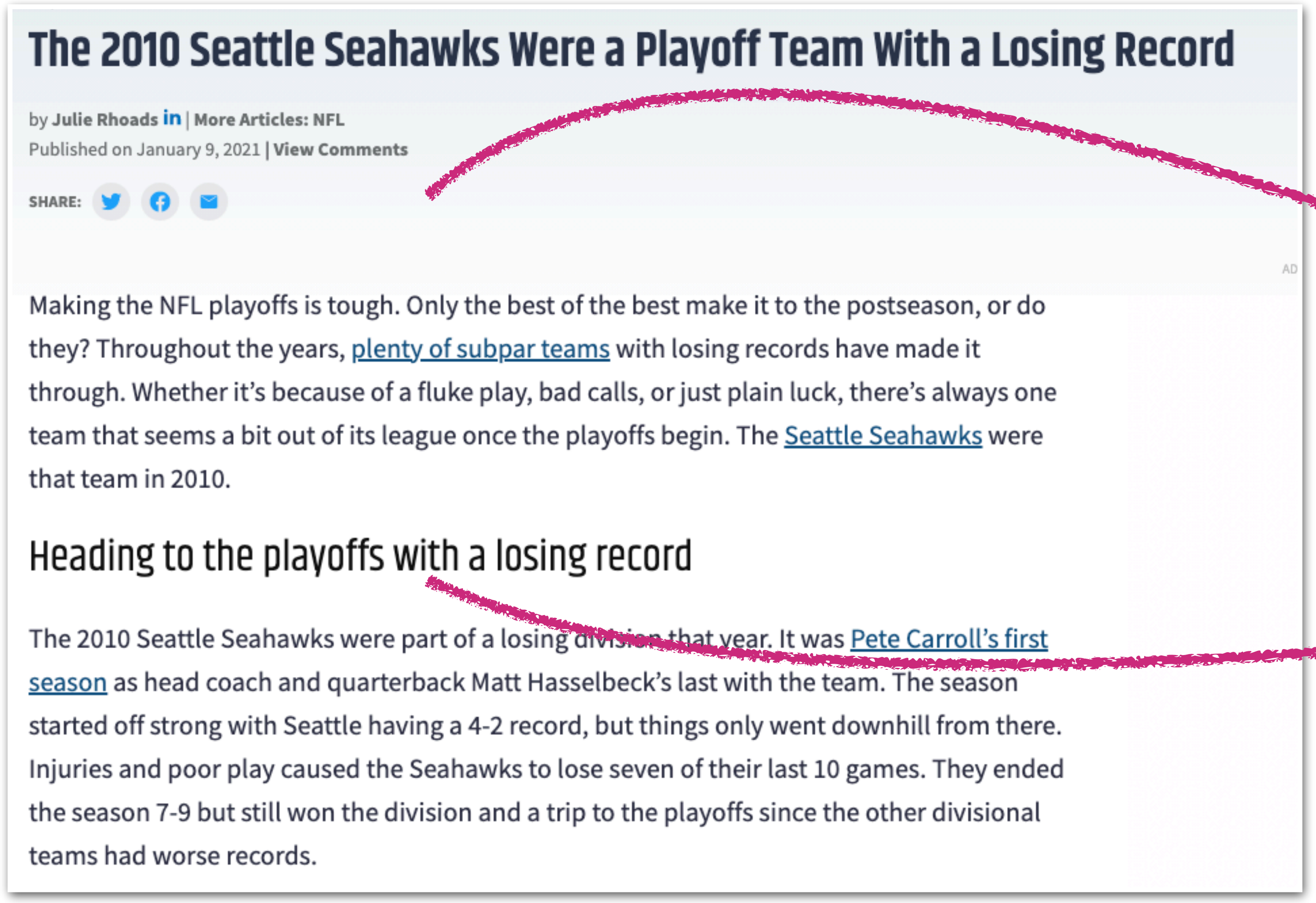
Key challenges

1. How to approximate the full retrieval index during training
2. How to get training signals (positive/negatives) from the index approximation

In-batch approximation with same-doc batching

NPM: Training

*1. Sample sequences from the **same** document*



The 2010 Seattle Seahawks Were a Playoff Team With a Losing Record

by Julie Rhoads in | More Articles: NFL
Published on January 9, 2021 | View Comments

SHARE:

Making the NFL playoffs is tough. Only the best of the best make it to the postseason, or do they? Throughout the years, plenty of subpar teams with losing records have made it through. Whether it's because of a fluke play, bad calls, or just plain luck, there's always one team that seems a bit out of its league once the playoffs begin. The Seattle Seahawks were that team in 2010.

Heading to the playoffs with a losing record

The 2010 Seattle Seahawks were part of a losing division that year. It was Pete Carroll's first season as head coach and quarterback Matt Hasselbeck's last with the team. The season started off strong with Seattle having a 4-2 record, but things only went downhill from there. Injuries and poor play caused the Seahawks to lose seven of their last 10 games. They ended the season 7-9 but still won the division and a trip to the playoffs since the other divisional teams had worse records.

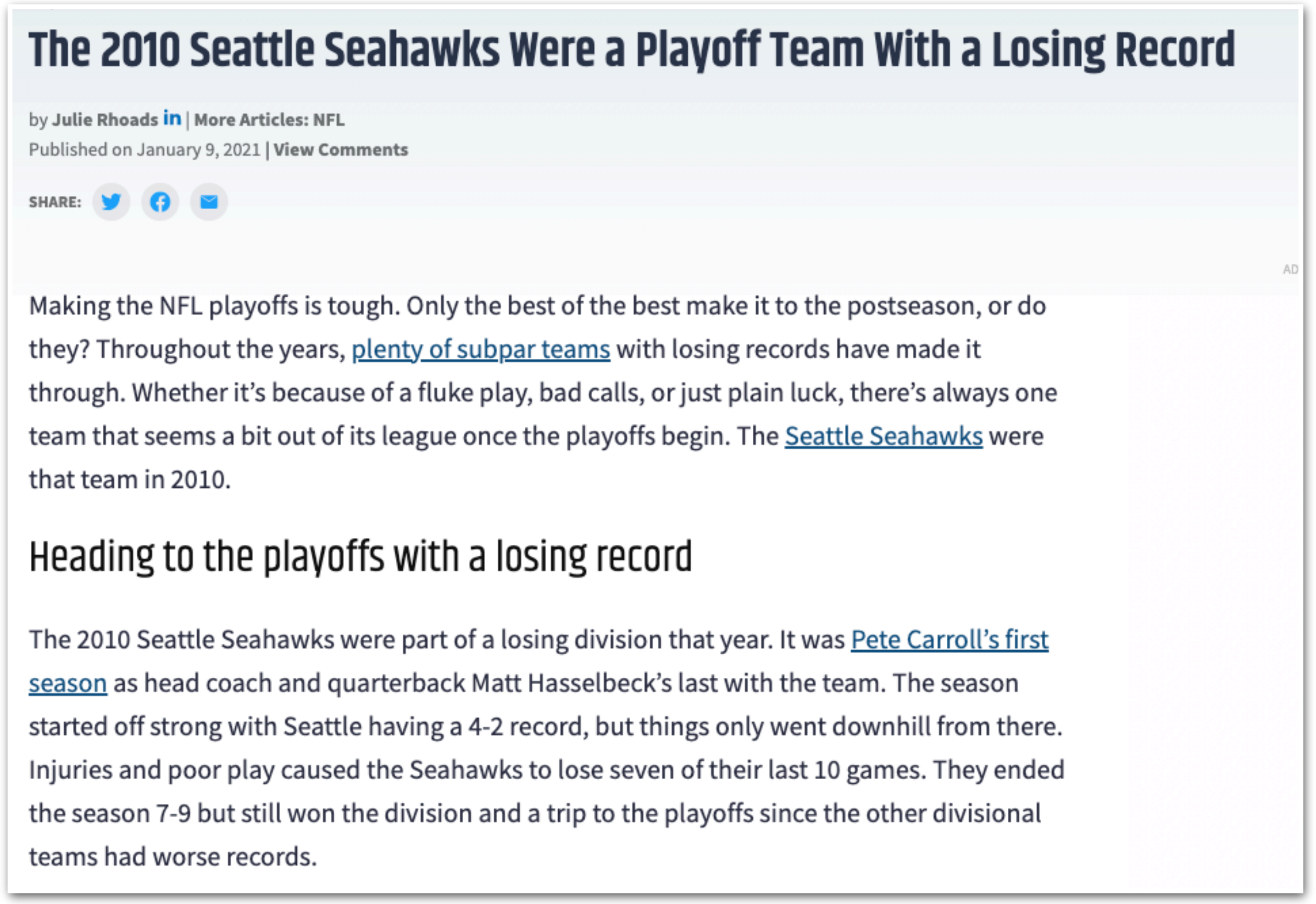
In the 2010 NFL season, the Seattle Seahawks made history by making it into the playoffs despite having a 7–9 record.

... against the Seattle Seahawks as a member of (...) In the 2010 season, the Seahawks became the first team in NFL history to ...

For simplicity, we assume 2 sequences in a batch

NPM: Training

2. Identify co-occurring spans



The 2010 Seattle Seahawks Were a Playoff Team With a Losing Record

by Julie Rhoads in | More Articles: NFL
Published on January 9, 2021 | View Comments

SHARE:

Making the NFL playoffs is tough. Only the best of the best make it to the postseason, or do they? Throughout the years, plenty of subpar teams with losing records have made it through. Whether it's because of a fluke play, bad calls, or just plain luck, there's always one team that seems a bit out of its league once the playoffs begin. The Seattle Seahawks were that team in 2010.

Heading to the playoffs with a losing record

The 2010 Seattle Seahawks were part of a losing division that year. It was Pete Carroll's first season as head coach and quarterback Matt Hasselbeck's last with the team. The season started off strong with Seattle having a 4-2 record, but things only went downhill from there. Injuries and poor play caused the Seahawks to lose seven of their last 10 games. They ended the season 7-9 but still won the division and a trip to the playoffs since the other divisional teams had worse records.

In the 2010 NFL season, **the Seattle Seahawks** made history by making it into the playoffs despite having a 7–9 record.

... against **the Seattle Seahawks** as a member of (...) In the 2010 season, the Seahawks became the first team in NFL history to ...

For simplicity, we assume 2 sequences in a batch

NPM: Training

3. One is "positive" for the other

The 2010 Seattle Seahawks Were a Playoff Team With a Losing Record

by Julie Rhoads | More Articles: NFL
Published on January 9, 2021 | View Comments

SHARE:

Making the NFL playoffs is tough. Only the best of the best make it to the postseason, or do they? Throughout the years, plenty of subpar teams with losing records have made it through. Whether it's because of a fluke play, bad calls, or just plain luck, there's always one team that seems a bit out of its league once the playoffs begin. The Seattle Seahawks were that team in 2010.

Heading to the playoffs with a losing record

The 2010 Seattle Seahawks were part of a losing division that year. It was Pete Carroll's first season as head coach and quarterback Matt Hasselbeck's last with the team. The season started off strong with Seattle having a 4-2 record, but things only went downhill from there. Injuries and poor play caused the Seahawks to lose seven of their last 10 games. They ended the season 7-9 but still won the division and a trip to the playoffs since the other divisional teams had worse records.

In the 2010 NFL season, ______________ made history by making it into the playoffs despite having a 7–9 record.

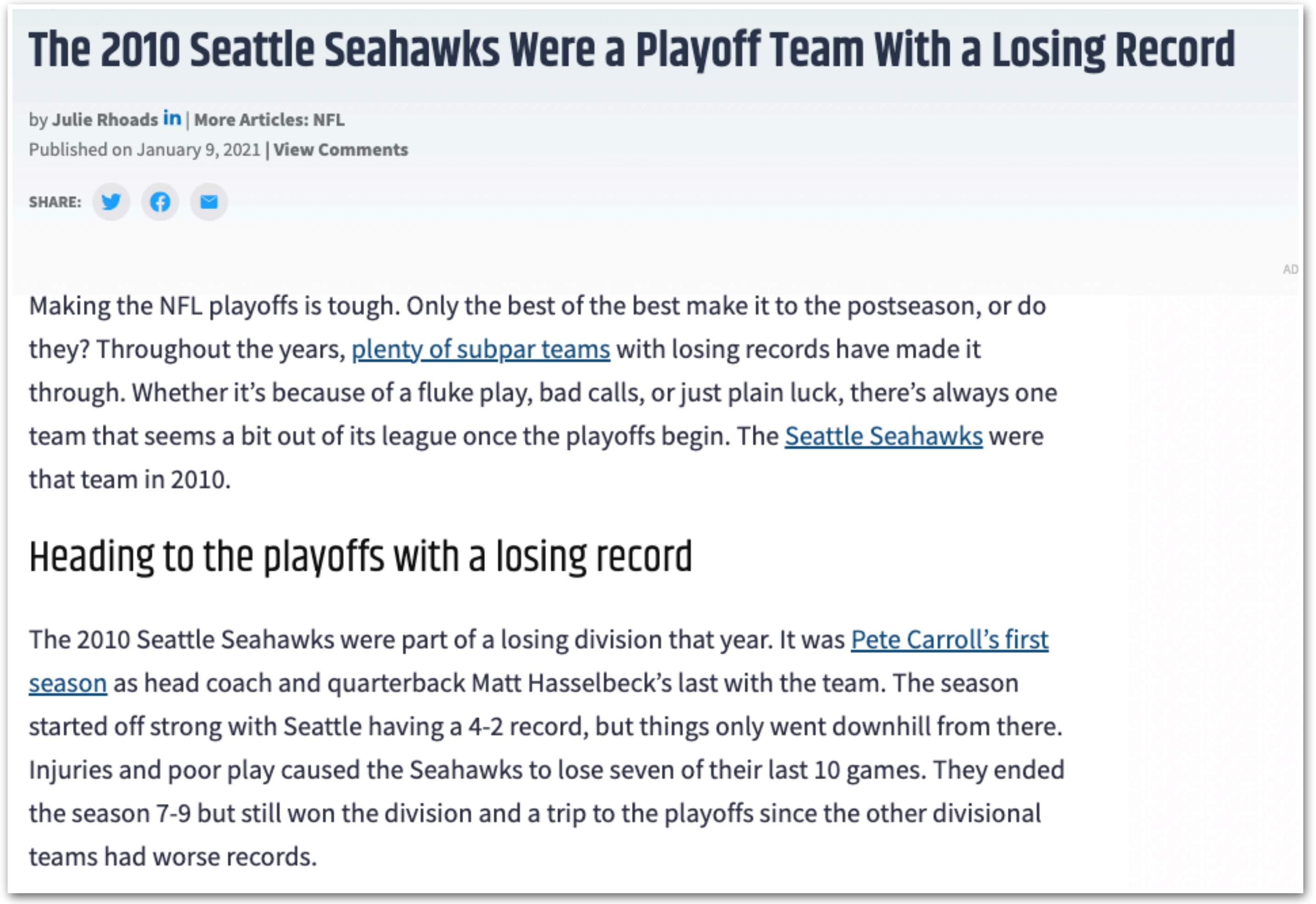
positive

... against **the Seattle Seahawks** as a member of (...) In the 2010 season, the Seahawks became the first team in NFL history to ...

For simplicity, we assume 2 sequences in a batch

NPM: Training

4. The others are "negatives"



The 2010 Seattle Seahawks Were a Playoff Team With a Losing Record

by Julie Rhoads in | More Articles: NFL
Published on January 9, 2021 | View Comments

SHARE:

Making the NFL playoffs is tough. Only the best of the best make it to the postseason, or do they? Throughout the years, plenty of subpar teams with losing records have made it through. Whether it's because of a fluke play, bad calls, or just plain luck, there's always one team that seems a bit out of its league once the playoffs begin. The Seattle Seahawks were that team in 2010.

Heading to the playoffs with a losing record

The 2010 Seattle Seahawks were part of a losing division that year. It was Pete Carroll's first season as head coach and quarterback Matt Hasselbeck's last with the team. The season started off strong with Seattle having a 4-2 record, but things only went downhill from there. Injuries and poor play caused the Seahawks to lose seven of their last 10 games. They ended the season 7-9 but still won the division and a trip to the playoffs since the other divisional teams had worse records.

In the 2010 NFL season, ____________ made history by making it into the playoffs despite having a 7–9 record.

positive

... against **the Seattle Seahawks** as a member of (...) In the 2010 season, the Seahawks became the first team in NFL history to ...

negatives

For simplicity, we assume 2 sequences in a batch

Beyond lexical clues?

In TRIME and NPM, retrieval models are trained to use ***lexical*** information

Positives: **co-occurring** tokens/spans

Can we do more than that?

RPT: Retrieval-pretrained transformer
(Rubin and Berant 2023)

Reference score P("Apple" | "Jobs become CEO of", "NeXT merged with …")

Reference chunk

Rubin and Berant, 2023. "Long-range Language Modeling with Self-retrieval"

RPT: Retrieval-pretrained transformer
(Rubin and Berant 2023)

Reference score P("Apple" | "Jobs become CEO of", "NeXT merged with …")

Reference chunk

P("Apple" | "Jobs become CEO of", "He joined his former …") **>** **Reference score**

Positive chunks

Rubin and Berant, 2023. "Long-range Language Modeling with Self-retrieval"

RPT: Retrieval-pretrained transformer

(Rubin and Berant 2023)

Reference score P(“Apple” | "Jobs become CEO of”, “NeXT merged with …”)

Reference chunk

P(“Apple” | "Jobs become CEO of”, “He joined his former …”) **>** **Reference score**

Positive chunks

P(“Apple” | "Jobs become CEO of”, “Jobs was raised …”) **<** **Reference score**

Negative chunks

Rubin and Berant, 2023. “Long-range Language Modeling with Self-retrieval”

Joint training

- End-to-end trained — each component is optimized
- Good performance
- Training is more complicated
  (async update, overhead, data batching, etc)
- Train-test discrepancy still remains

Summary

Training method	👍	👎
Independent training (Ram et al 2023; Khandelwal et al 2020) Sequential training (Borgeaud et al 2021; Shi et al 2023)	✴ Easy to implement: off-the-shelf models ✴ Easy to improve: sub-module can be separately improved	✴ Models are not end-to-end trained — suboptimal performance
Joint training: async update (Guu et al 2020; Izacard et al 2022) Joint training: in-batch approx (Zhong et al 2022; Min et al 2023; Rubin and Berant 2023)	✴ End-to-end trained — very good performance!	✴ Training may be complicated (overhead, batching methods, etc) ✴ Train-test discrepancy still remains

How do retrieval-based language models perform on downstream tasks? → **Section 5**!