The Attack of the Muppets!

Data Management in the Era of Pretrained Transformers

Jimmy Lin
David R. Cheriton School of Computer Science
University of Waterloo

ICDE 2021 Keynote
Thursday, April 22, 2021

UNIVERSITY OF WATERLOO

Message

Source: https://www.flickr.com/photos/cogdog/28484204135/

(Historically)

NLP and database researchers don't have much to say to each other

Source: Game of Thrones (HBO)

One word: BERT!

Source: The Graduate

SEARCH

Understanding searches better than ever before

Pandu Nayak
Google Fellow and Vice President, Search

Published Oct 25, 2019

If there's one thing I've learned over the 15 years working on Google Search, it's that people's curiosity is endless. We see billions of searches every day, and 15 percent of those queries are ones we haven't seen before--so we've built ways to return results for queries we can't anticipate.

When people like you or I come to Search, we aren't always quite sure about the best way to formulate a query. We might not know the right words to use, or how to spell something, because often times, we come to Search looking to learn--we don't necessarily have the knowledge to begin with.

At its core, Search is about understanding language. It's our job to figure out what you're searching for and surface helpful information from the web, no matter how you spell or combine the words in your query. While we've continued to improve our language understanding capabilities over the years, we sometimes still don't quite get it right, particularly with complex or conversational queries. In fact, that's one of the reasons why people often use "keyword-ese," typing strings of words that they think we'll understand, but aren't actually how they'd naturally ask a question.

With the latest advancements from our research team in the science of language understanding--made possible by machine learning--we're making a significant improvement to how we understand queries, representing the biggest leap forward in the past five years, and one of the biggest leaps forward in the history of Search.

Applying BERT models to Search

Last year, we introduced and open-sourced a neural network-based technique for natural language processing (NLP) pre-training called Bidirectional Encoder Representations from Transformers, or as we call it--BERT, for short. This technology enables anyone to train their own state-of-the-art question answering system.

This breakthrough was the result of Google research on transformers: models that process words in relation to all the other words in a sentence, rather than one-by-one in order. BERT models can therefore consider the full context of a word by looking at the words that come before and after it—particularly useful for understanding the intent behind search queries.

BERT!

https://blog.google/products/search/search-language-understanding-bert/

Bing delivers its largest improvement in search experience using Azure GPUs

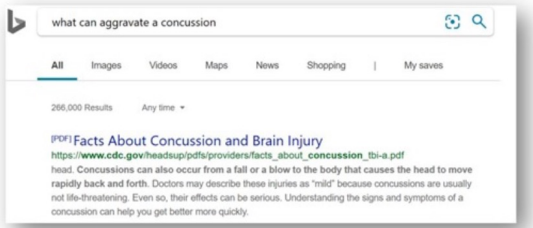
Posted on November 18, 2019

Jeffrey Zhu, Program Manager, Bing Platform

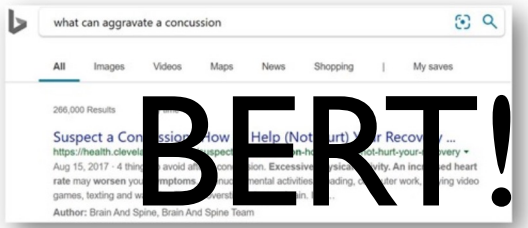
Over the last couple of years, deep learning has become widely adopted across the Bing search stack and powers a vast number of our intelligent features. We use natural language models to improve our core search algorithm's understanding of a user's search intent and the related webpages so that Bing can deliver the most relevant search results to our users. We rely on deep learning computer vision techniques to enhance the discoverability of billions of images even if they don't have accompanying text descriptions or summary metadata. We leverage machine-based reading comprehension models to retrieve captions within larger text bodies that directly answer the specific questions users have. All these enhancements lead toward more relevant, contextual results for web search queries.

Recently, there was a breakthrough in natural language understanding with a type of model called transformers (as popularized by Bidirectional Encoder Representations from Transformers, BERT). Unlike previous deep neural network (DNN) architectures that processed words individually in order, transformers understand the context and relationship between each word and all the words around it in a sentence. Starting from April of this year, we used large transformer models to deliver the largest quality improvements to our Bing customers in the past year. For example, in the query "what can aggravate a concussion", the word "aggravate" indicates the user wants to learn about actions to be taken after a concussion and not about causes or symptoms. Our search powered by these models can now understand the user intent and deliver a more useful result. More importantly, these models are now applied to every Bing search query globally making Bing results more relevant and intelligent.

BEFORE



AFTER



BERT!

https://azure.microsoft.com/en-us/blog/bing-delivers-its-largest-improvement-in-search-experience-using-azure-gpus/

NLP

DB

(Historically)

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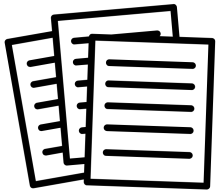


Unstructured Text

Structured Relations

Source: https://www.flickr.com/photos/mathiasappel/27065384106/

Source: https://www.flickr.com/photos/leszekleszczynski/15447205451/

NLP

DB

Gartner

Blog home > Blog post

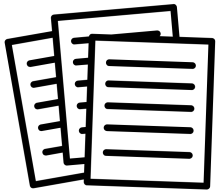
Big Content: The Unstructured Side of Big Data

By Darin Stewart | May 01, 2013 |
1 Comment

Search all blog posts

Search | Open Data | Enterprise Content Managment | Big Content

The age of information overload is slowly drawing to a close. The enterprise is finally getting comfortable with managing massive amounts of data, content and information. The pace of information creation continues to accelerate, but the ability of infrastructure and information management to keep pace is coming within sight. Big data is now considered a blessing rather than a curse. Even so, managing information is not the same as fully exploiting information. While 'Big Data' technologies and techniques are unlocking secrets previously hidden in enterprise data, the largest source of potential insight remains largely untapped. Unstructured content represents as much as eighty percent of an organizations total information assets. While Big Data technologies and techniques are well suited to exploring unstructured information, this 'Big Content' remains grossly underutilized and its potential largely unexplored.



Unstructured
Text

Structured
Relations

NLP

DB

A productive dialogue…

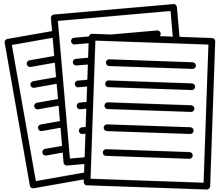
Hey look, we can extract entities, relations, and facts from free text!

A knowledge graph!

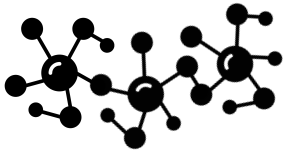
And this is something we know how to build!

A knowledge graph!

Cool, this is something we can work with!



Unstructured Text

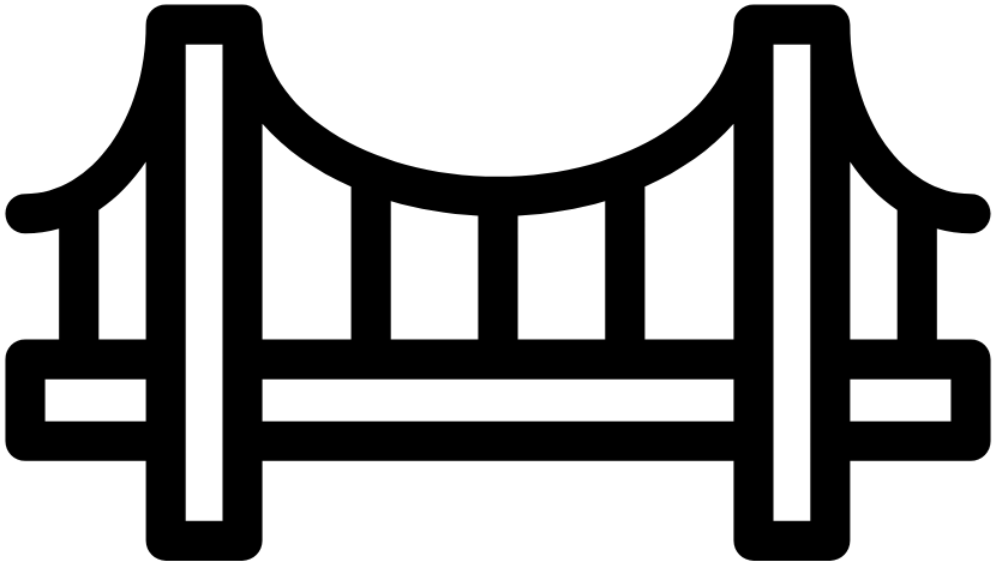


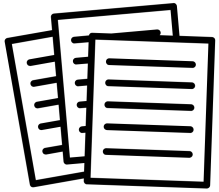
Knowledge Graphs

Structured Relations

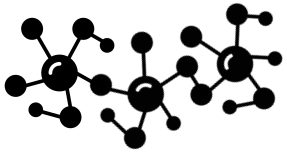
NLP

DB





Unstructured
Text

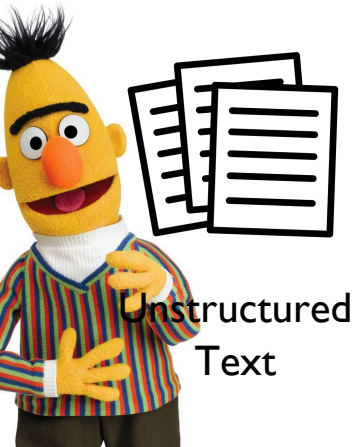


Knowledge
Graphs

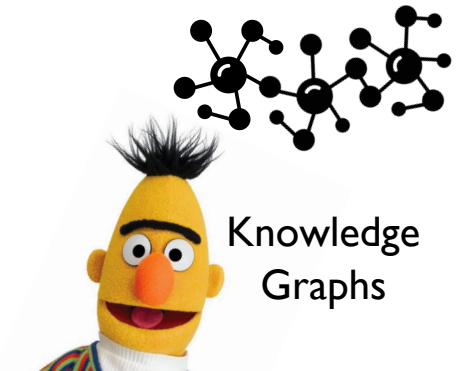
Structured
Relations

NLP

DB



Unstructured
Text



Knowledge
Graphs

Structured
Relations

NLP

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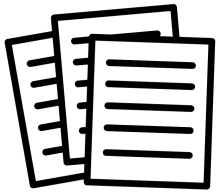
What if BERT took over everything?



Unstructured Text

Knowledge Graphs

Structured Relations

Message

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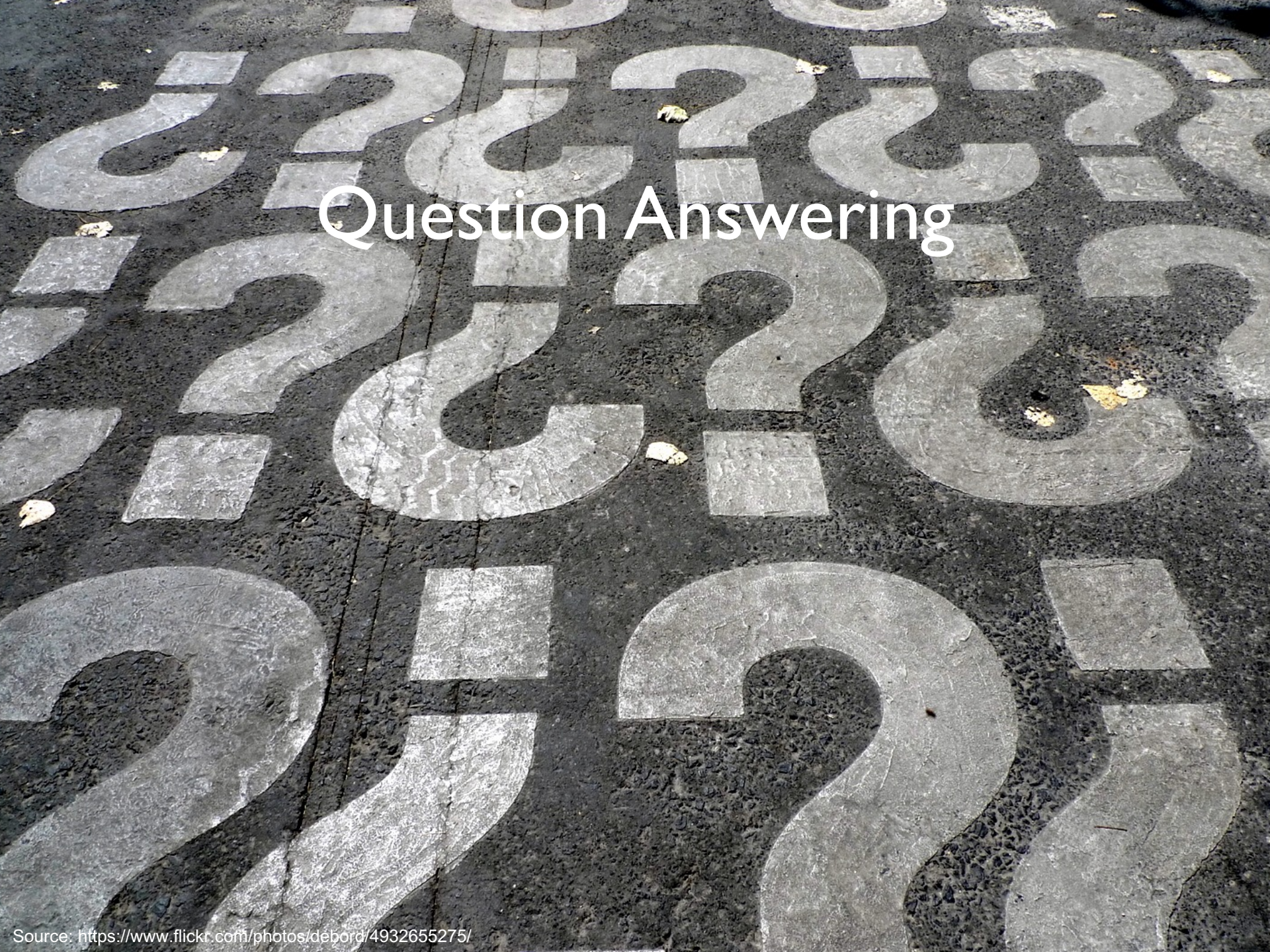
Source: www.flickr.com/photos/rheinitz/6158837748/



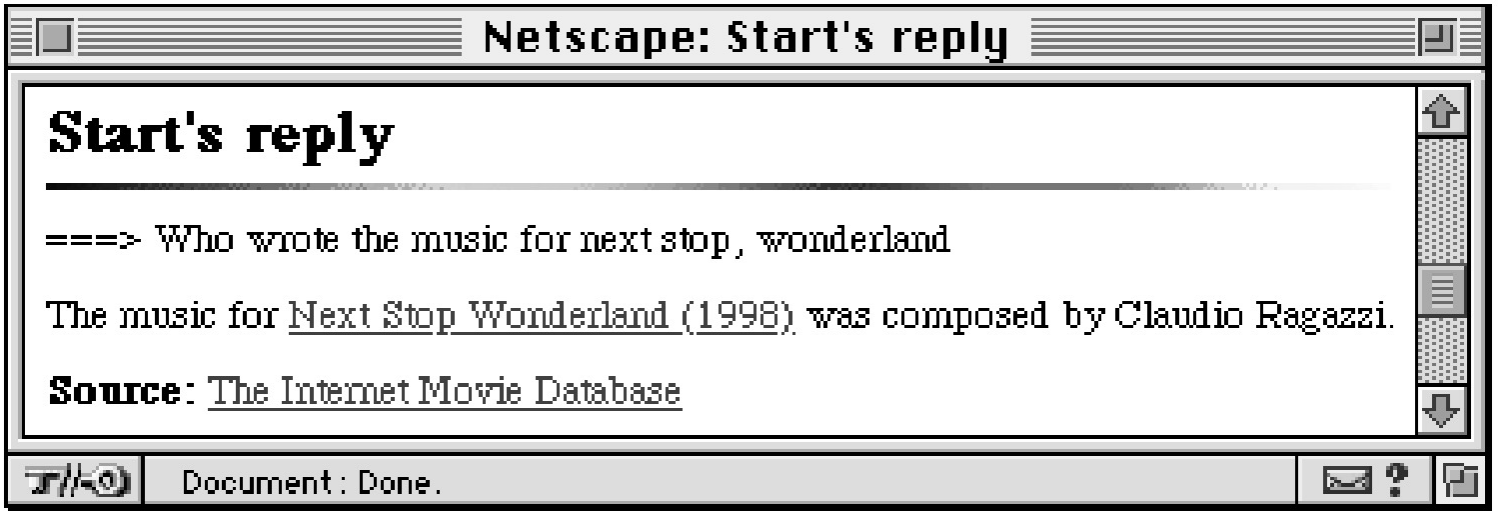
Source: https://www.flickr.com/photos/debord/4932655275/

1997: My journey begins

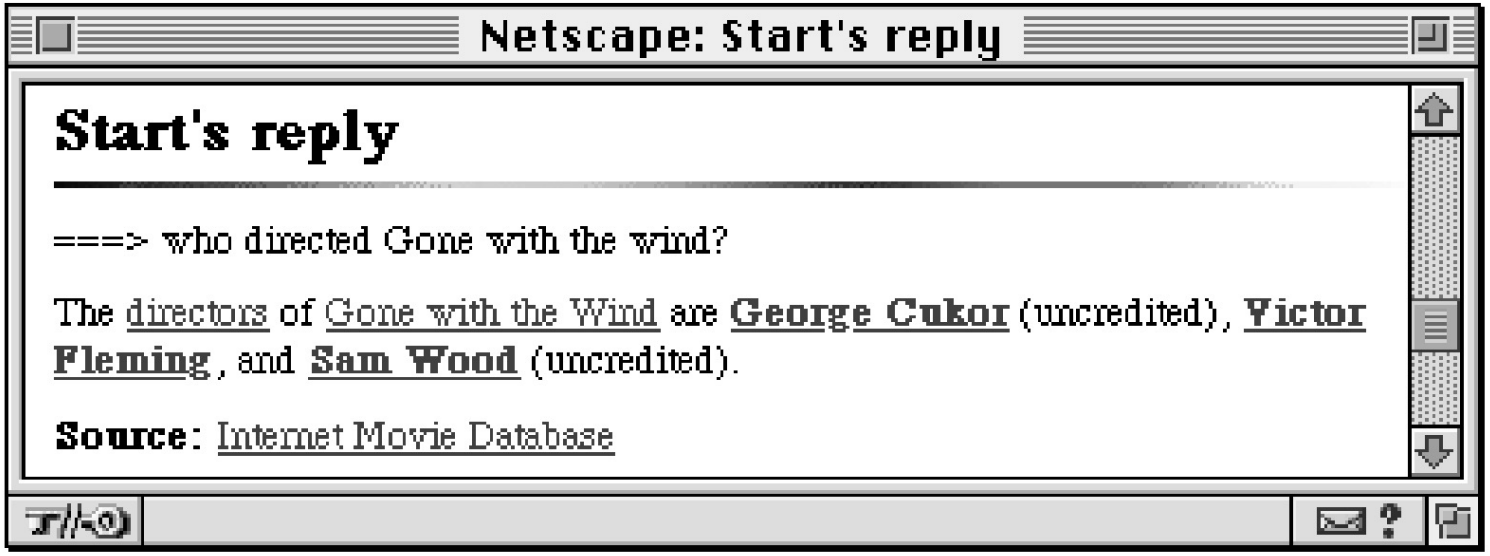
Source: Philip Greenspun, Wikipedia

1993: The START System

First QA system on the web!



http://start.csail.mit.edu/



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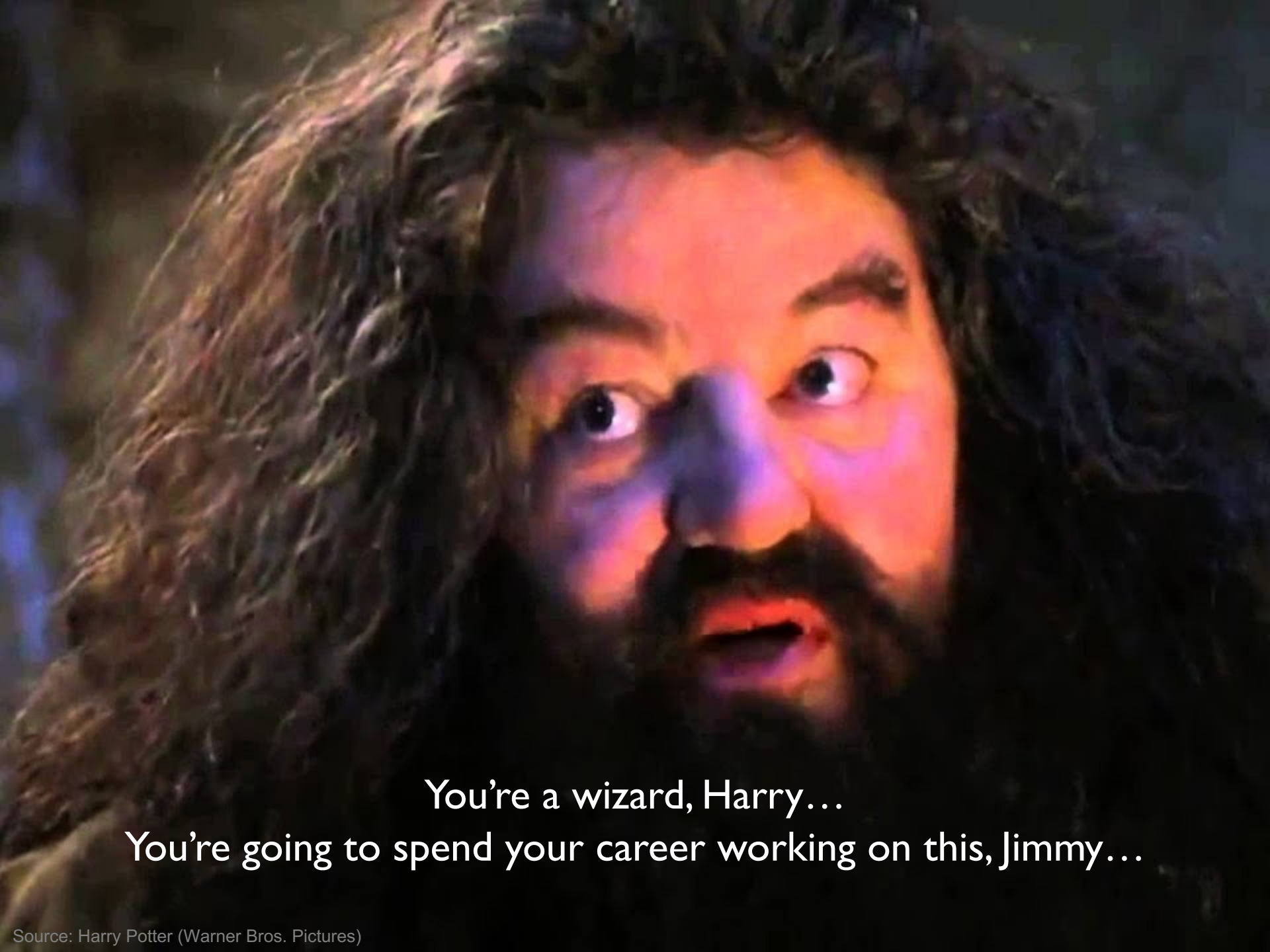


Source: Harry Potter (Warner Bros. Pictures)

My career-long quest…

Connecting users with relevant information

Source: https://flickr.com/photos/71855373@N00/50092059017

My career-long quest…

Connecting users with relevant information

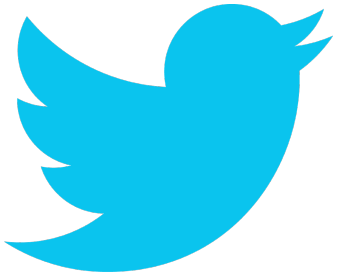
What? text, speech, images, graphs, semi-structured data, relational data, log data…

Who? general information seekers, domain experts, legal scholars, historians, data scientists, etc.

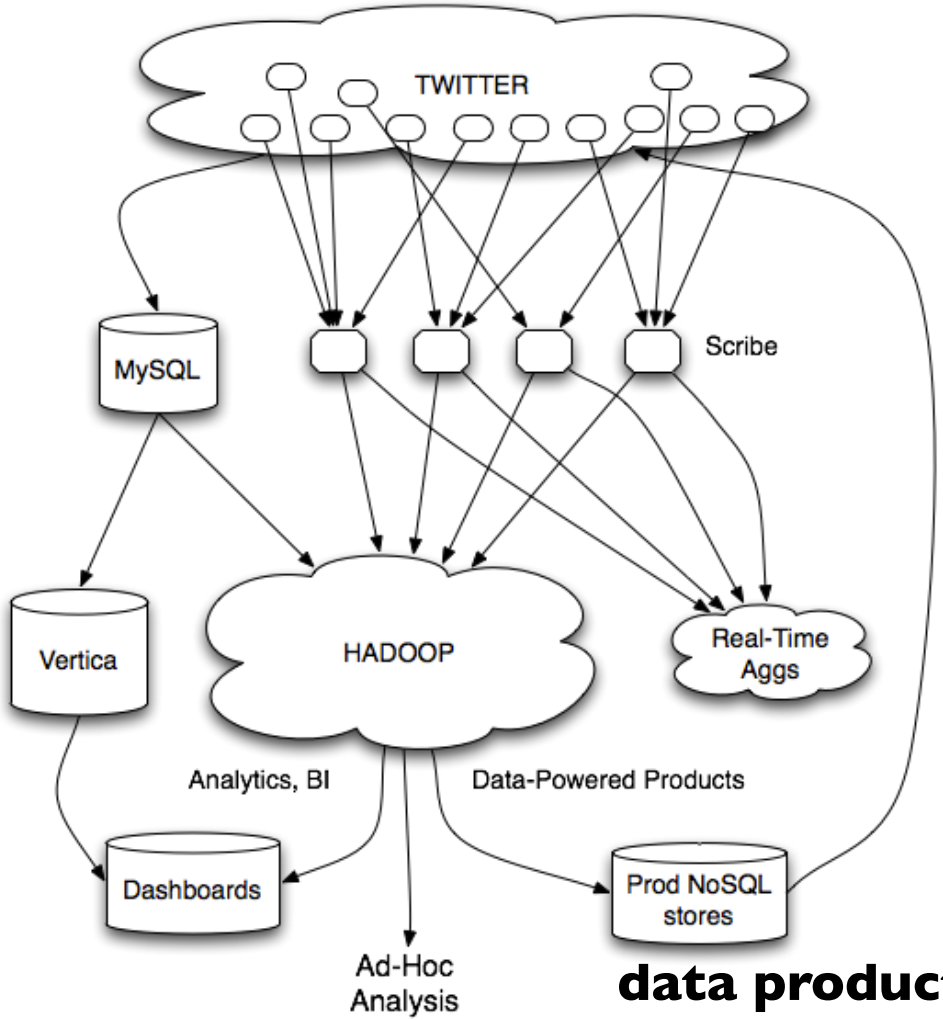
Information Access

(question answering, document retrieval, summarization, …)

Source: www.flickr.com/photos/rheinitz/6158837748/



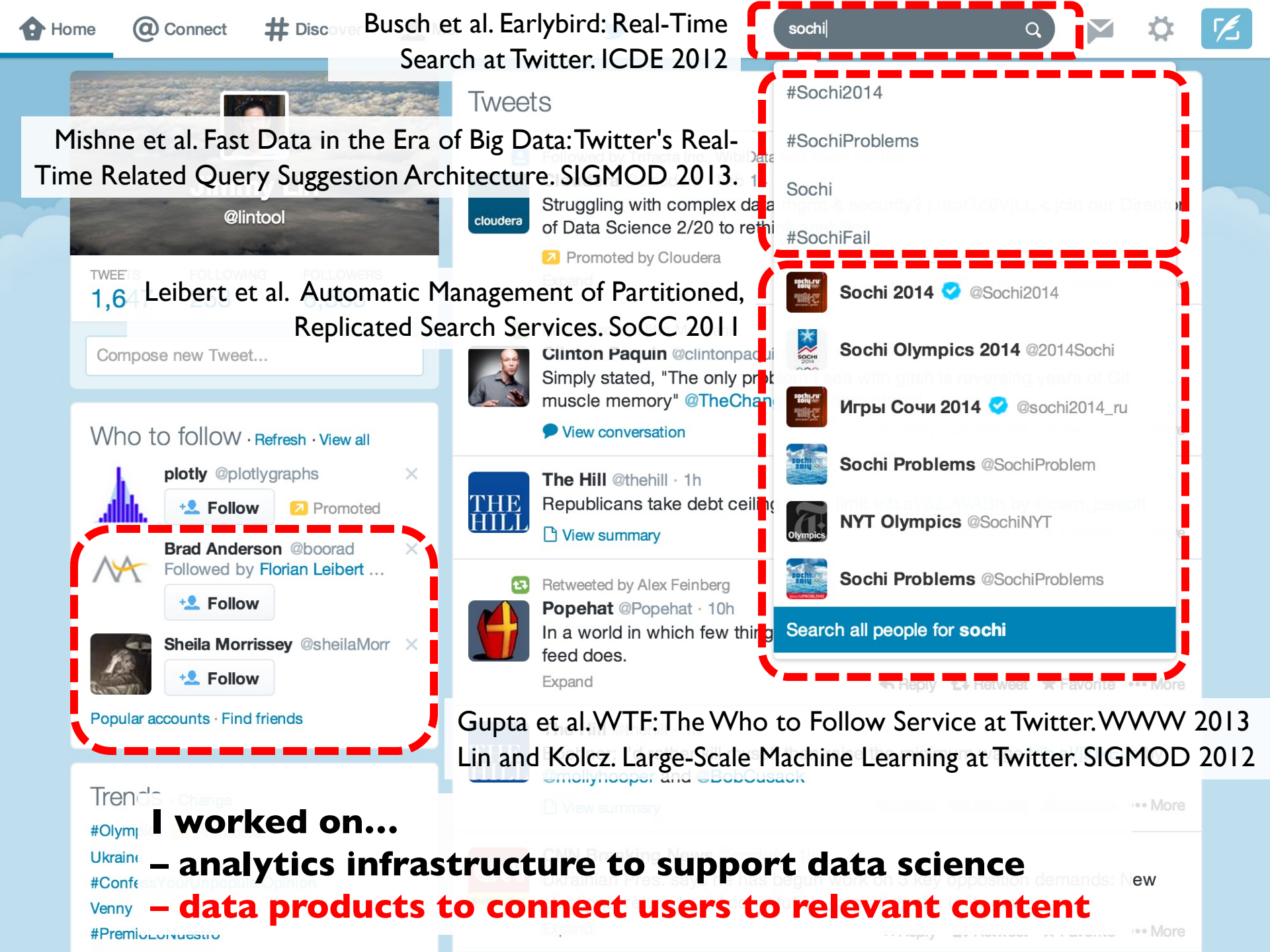
Circa 2012



I worked on…

– analytics infrastructure to support data science

– data products to connect users to relevant content


Busch et al. Earlybird: Real-Time Search at Twitter. ICDE 2012
Mishne et al. Fast Data in the Era of Big Data: Twitter's Real-Time Related Query Suggestion Architecture. SIGMOD 2013.
Leibert et al. Automatic Management of Partitioned, Replicated Search Services. SoCC 2011
Gupta et al. WTF: The Who to Follow Service at Twitter. WWW 2013
Lin and Kolcz. Large-Scale Machine Learning at Twitter. SIGMOD 2012
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– data products to connect users to relevant content

What is BERT?

Why should you care?

What is BERT?

What's BERT?

a transformer encoder pretrained with a mask language model (MLM) objective that generates contextualized representations and can be fine-tuned for a wide range of NLP tasks.

What's a monad?

a monad is a monoid in the category of endofunctors

What's the problem?

Devlin et al. BERT. *NAACL 2019* (~18K citations!)

Source: https://www.flickr.com/photos/ableman/3032736305/

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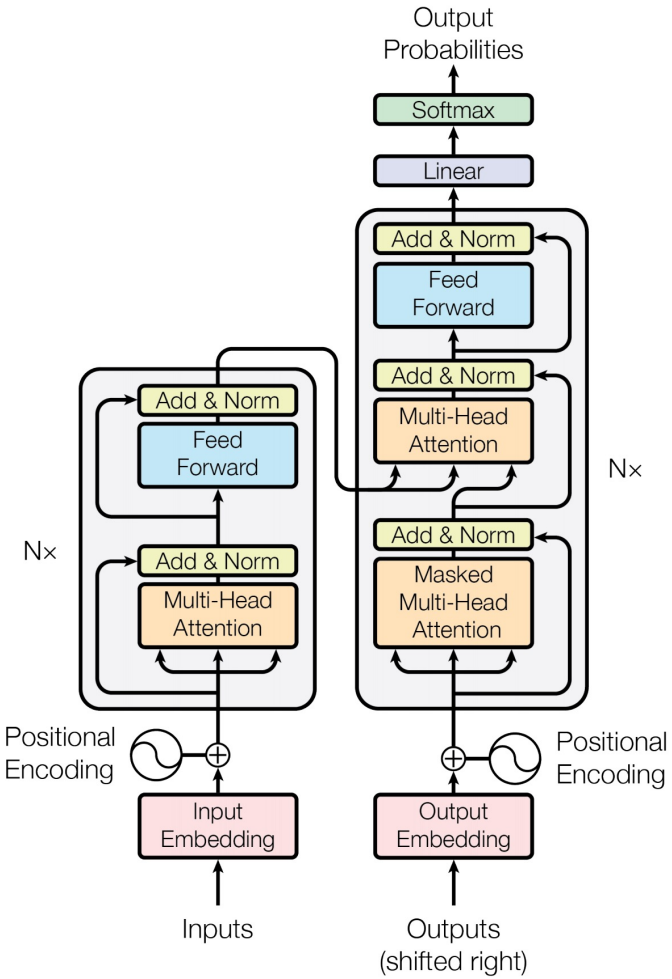
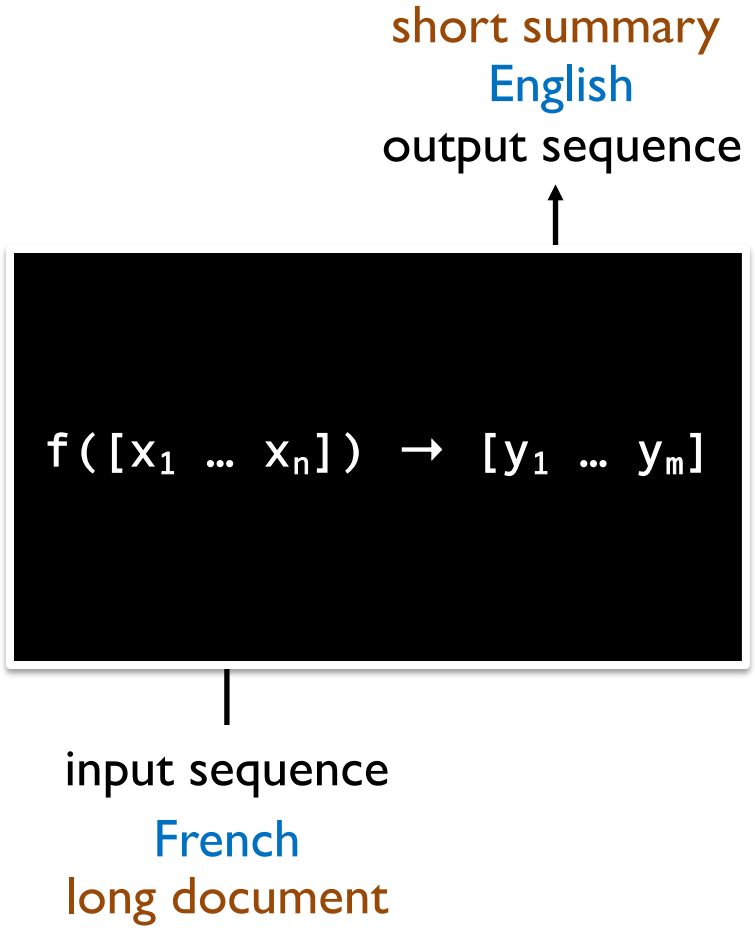
What's a transformer?



Vaswani et al. Attention Is All you Need. *NeurIPS 2017* (~20K citations!)

What's a transformer?

(sequence-to-sequence model)



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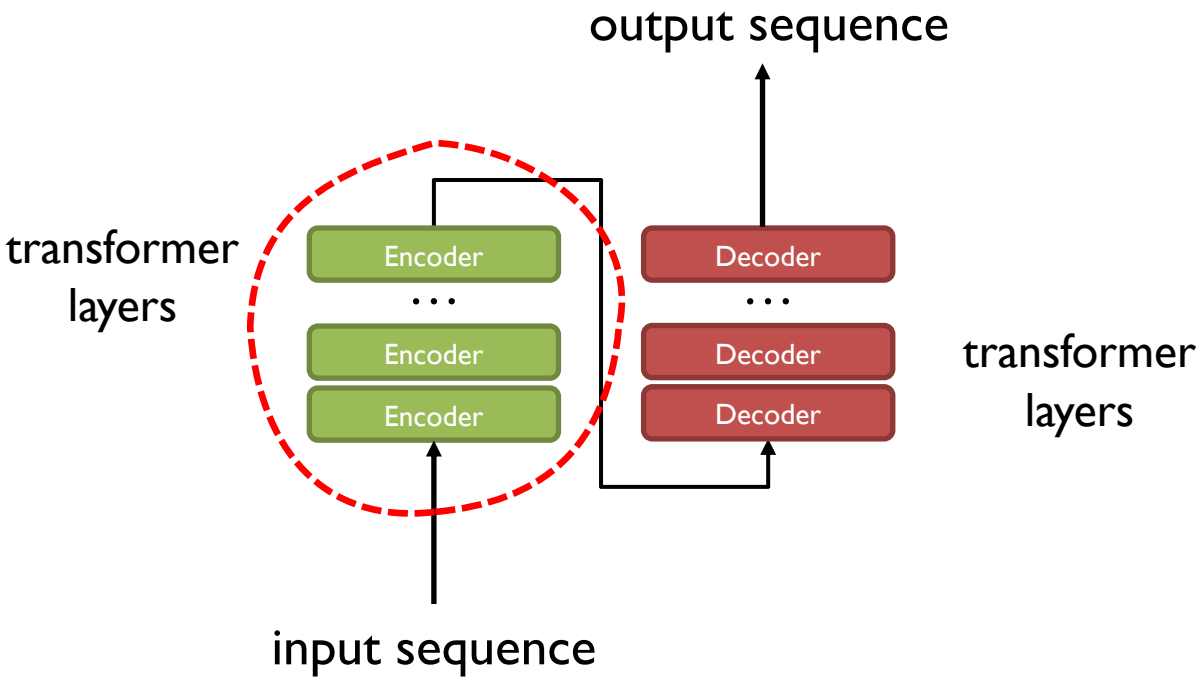

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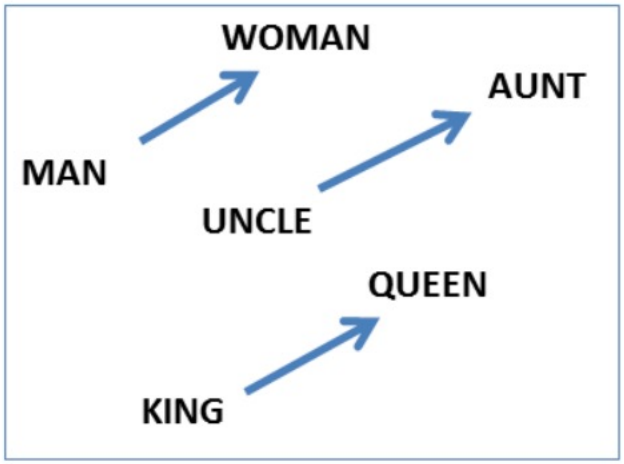
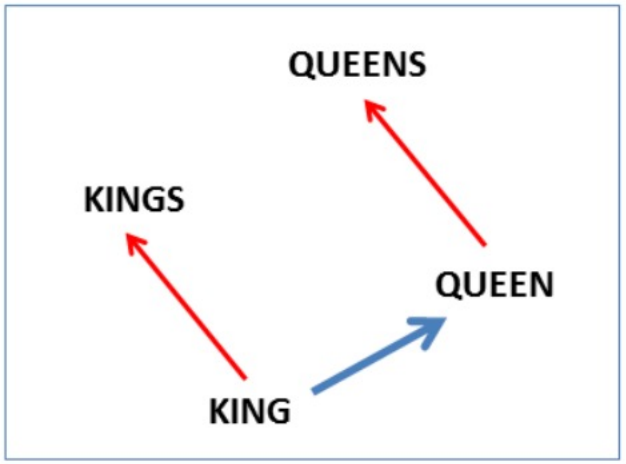
Static Representations



king – man + woman = queen

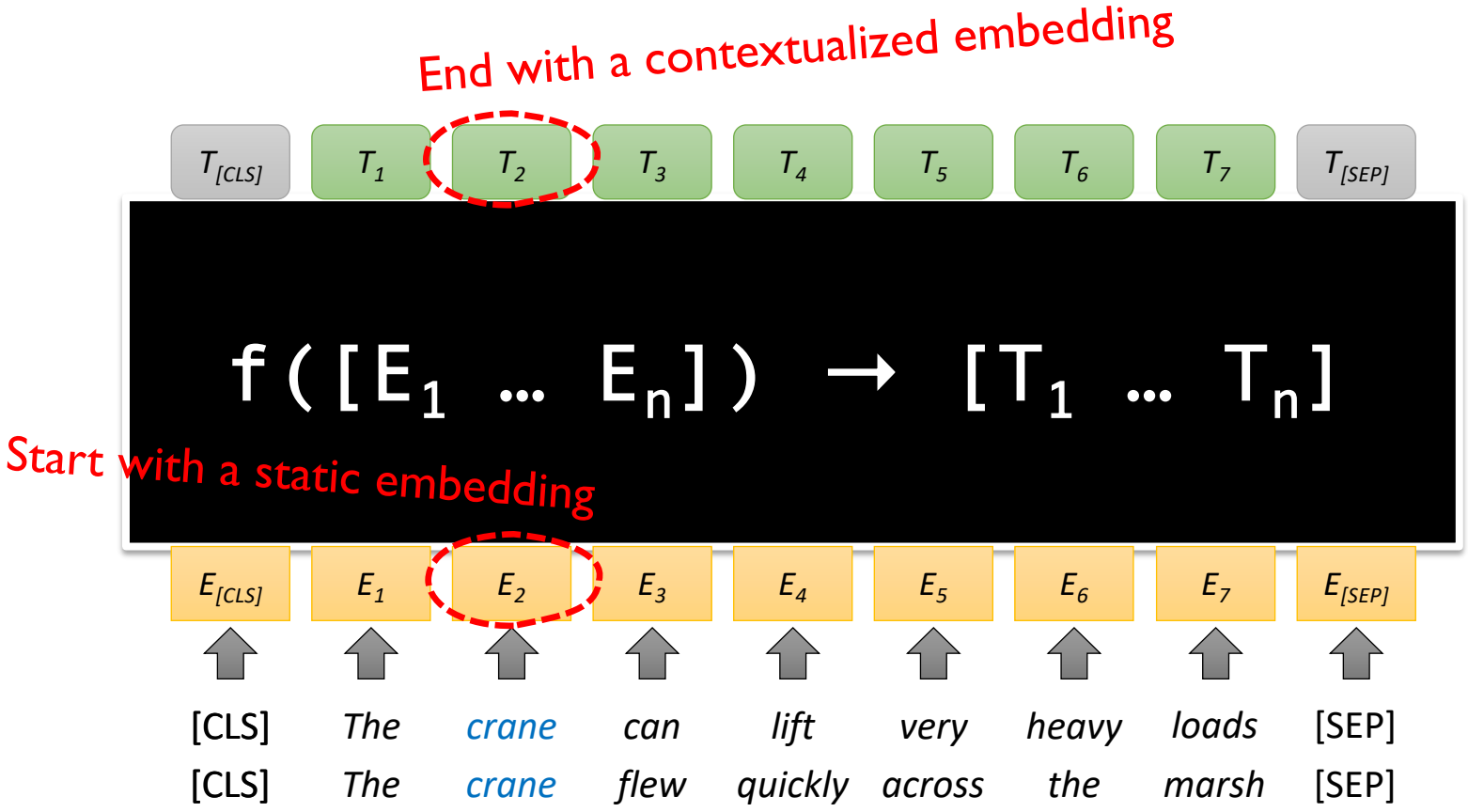


kings – king = queens – queen

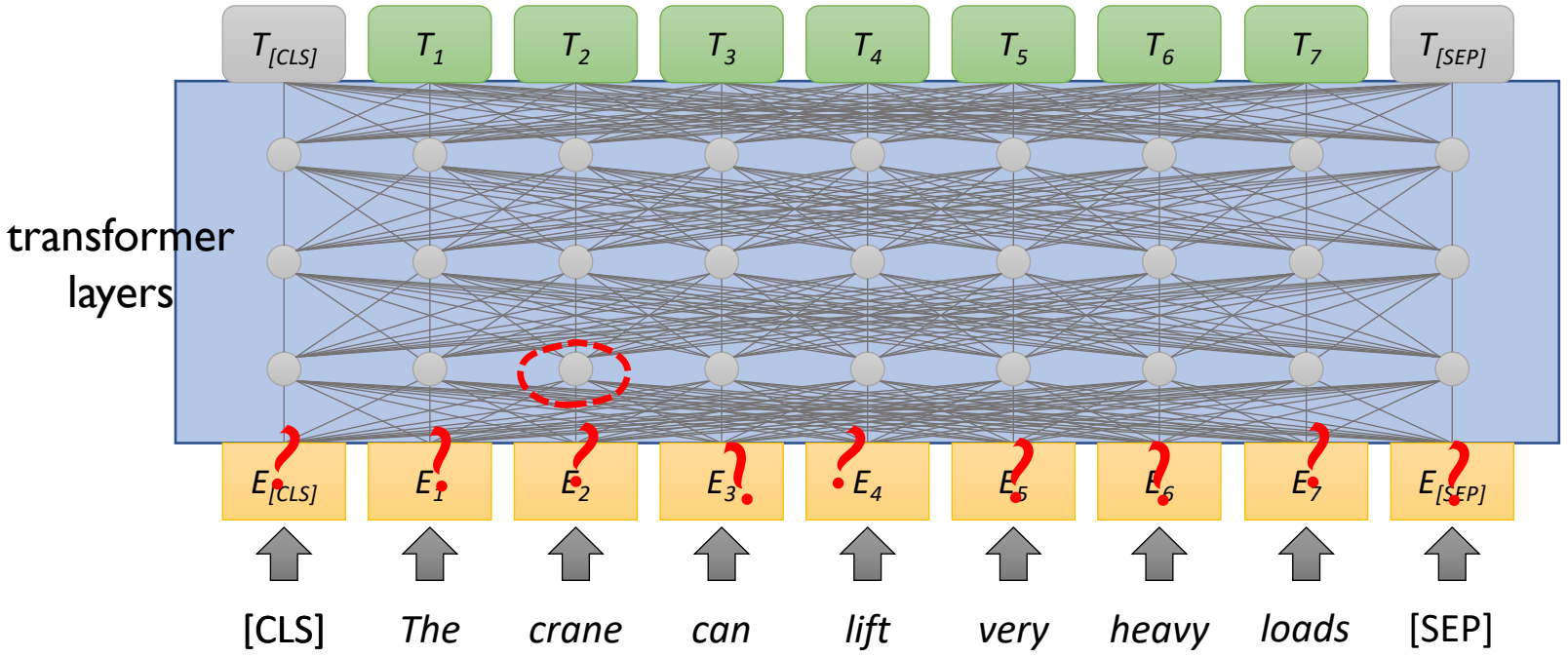
tokens → dense vectors (embeddings)

Mikolov et al. Linguistic Regularities in Continuous Space Word Representations. *NAACL 2013*

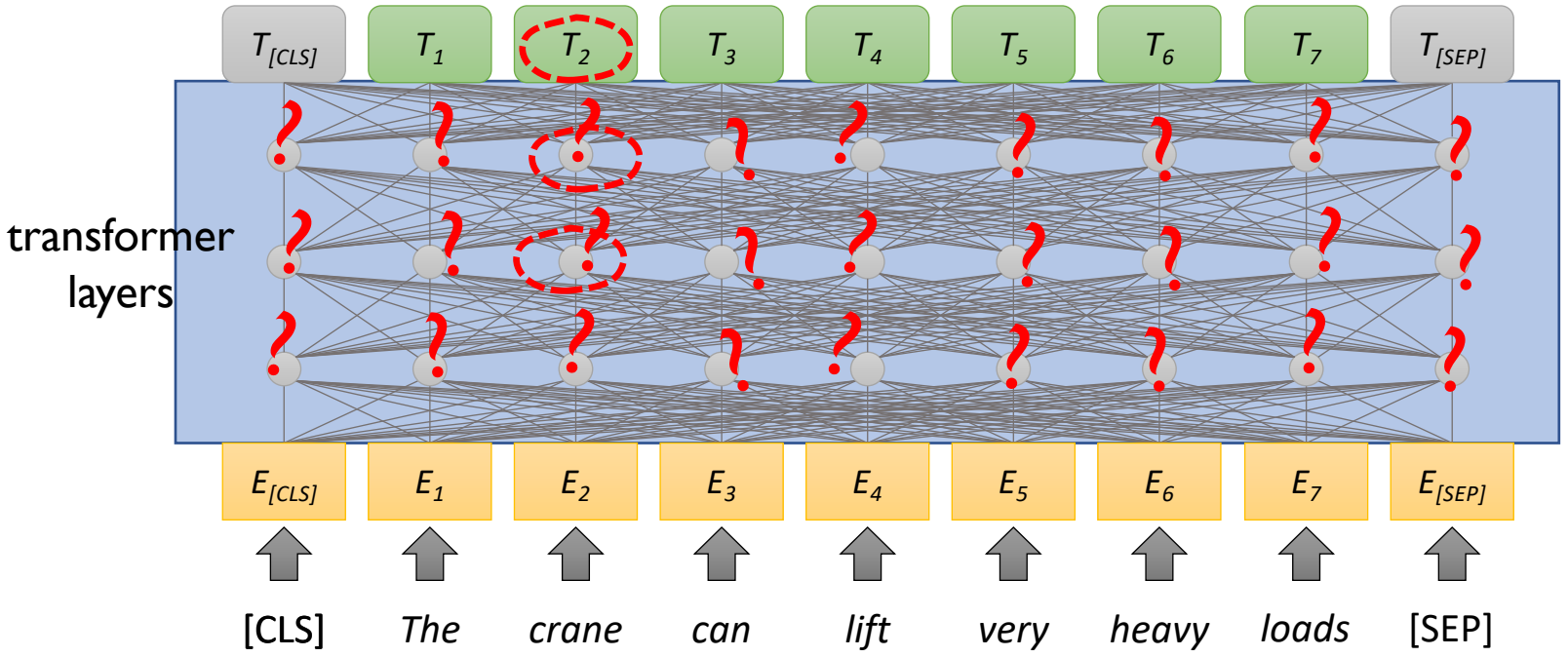
Contextualized Representations?



Attention!


transformer layers
$T_{[CLS]}$ T_1 T_2 T_3 T_4 T_5 T_6 T_7 $T_{[SEP]}$
$E_{[CLS]}$ E_1 E_2 E_3 E_4 E_5 E_6 E_7 $E_{[SEP]}$
[CLS] The crane can lift very heavy loads [SEP]

Attention!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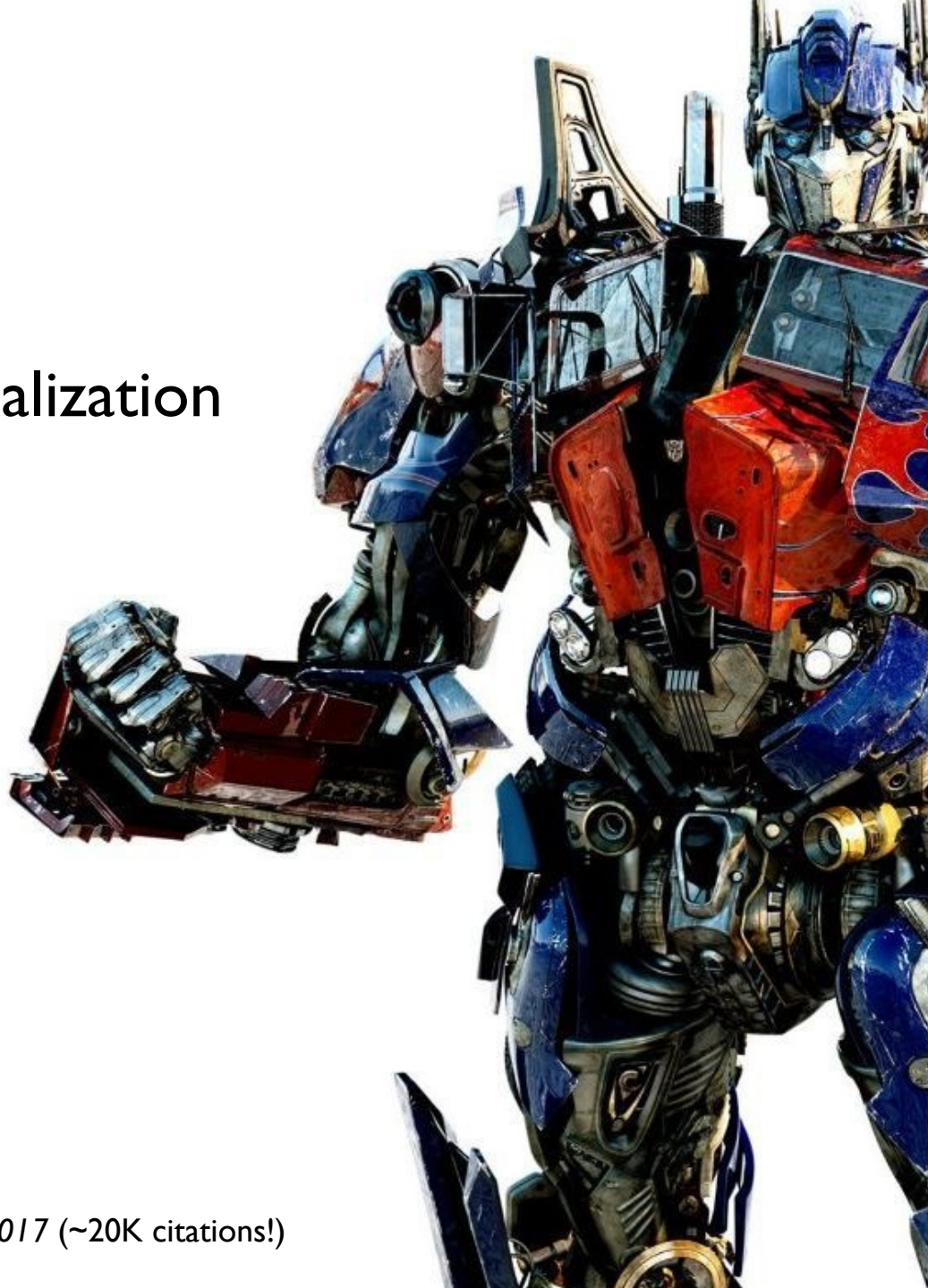
Devlin et al. BERT. *NAACL 2019* (~18K citations!)

Just do it!

Start with random initialization

Train with labeled data

Supervised Training!

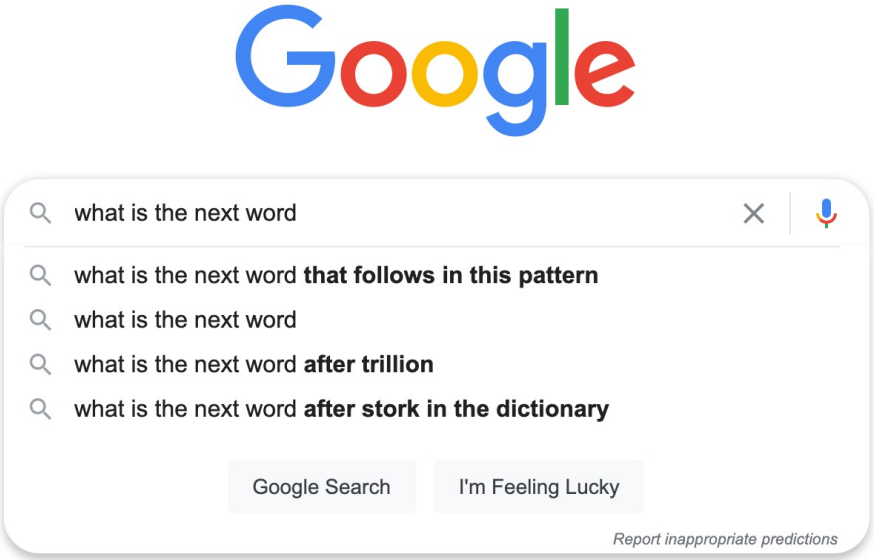


Vaswani et al. Attention Is All you Need. *NeurIPS 2017* (~20K citations!)

Unsupervised Training?

You can never have enough labeled data!

Self-Supervised Training

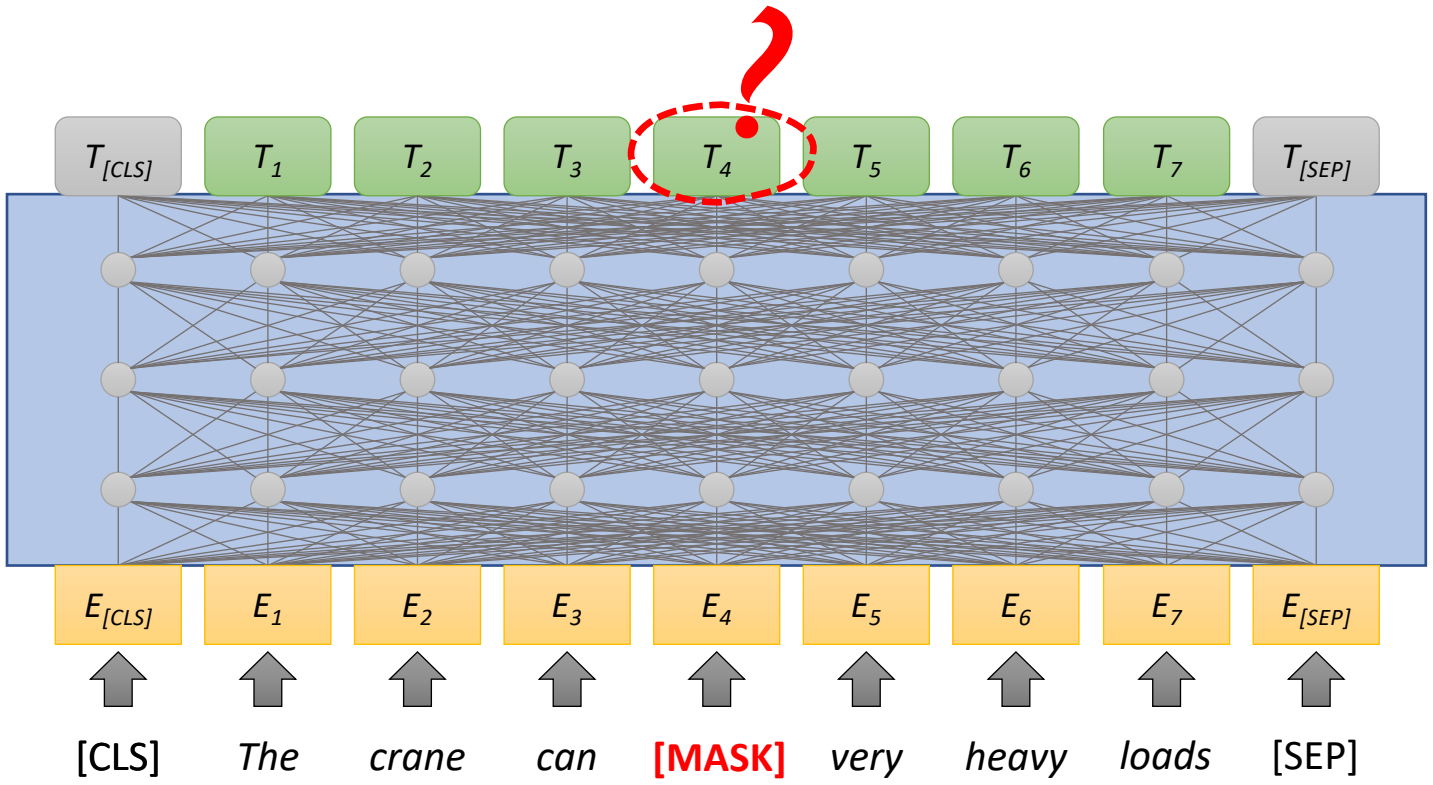


(language modeling objective)

You don't need labels… just text!

But wait! I don't actually care!

Masked Language Model = MLM



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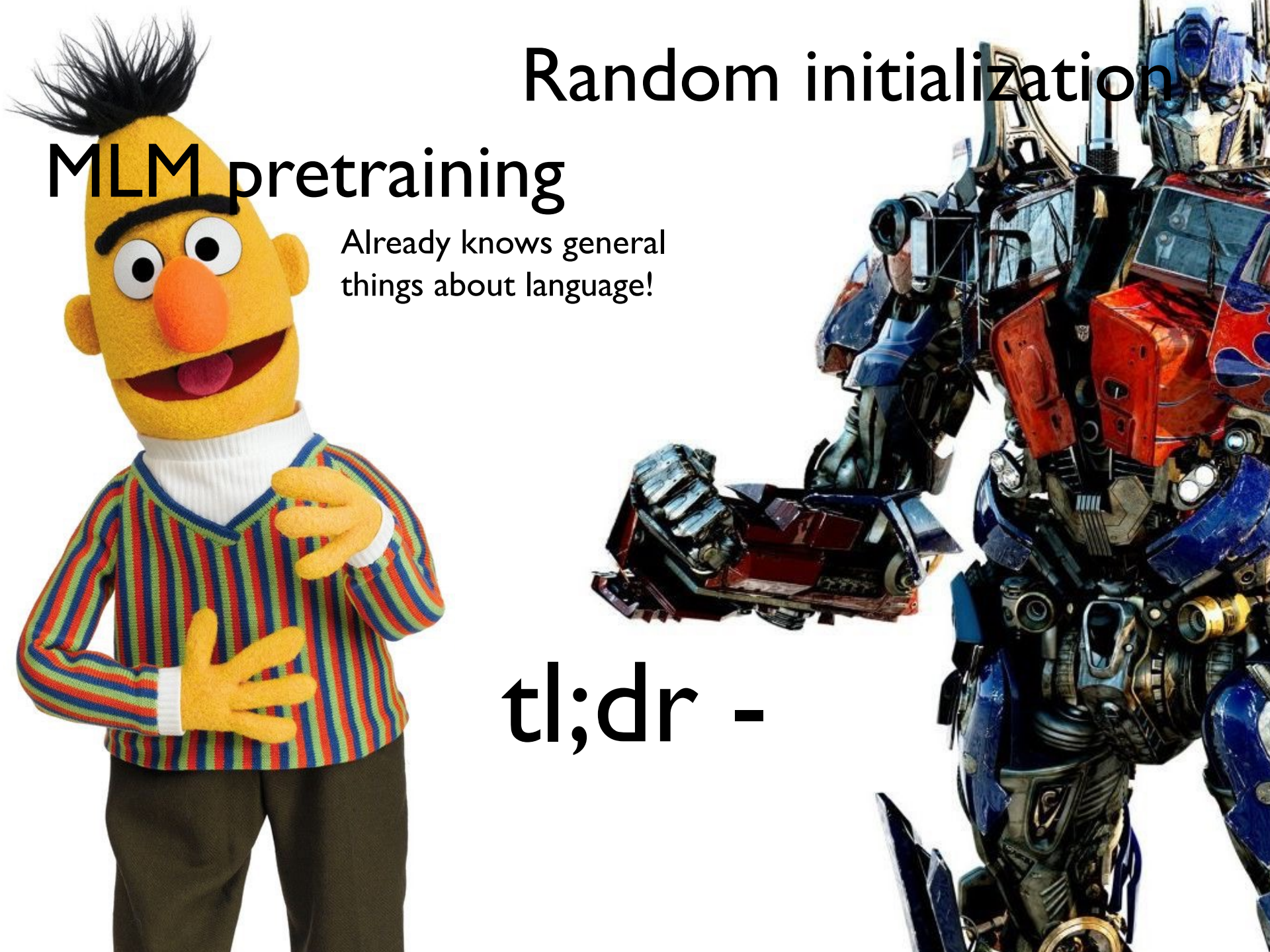

Random initialization

MLM pretraining

Already knows general things about language!

tl;dr -

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Pretraining

Play peek-a-boo!

Self-Supervised

How do we get BERT to something more interesting?

Fine-Tuning

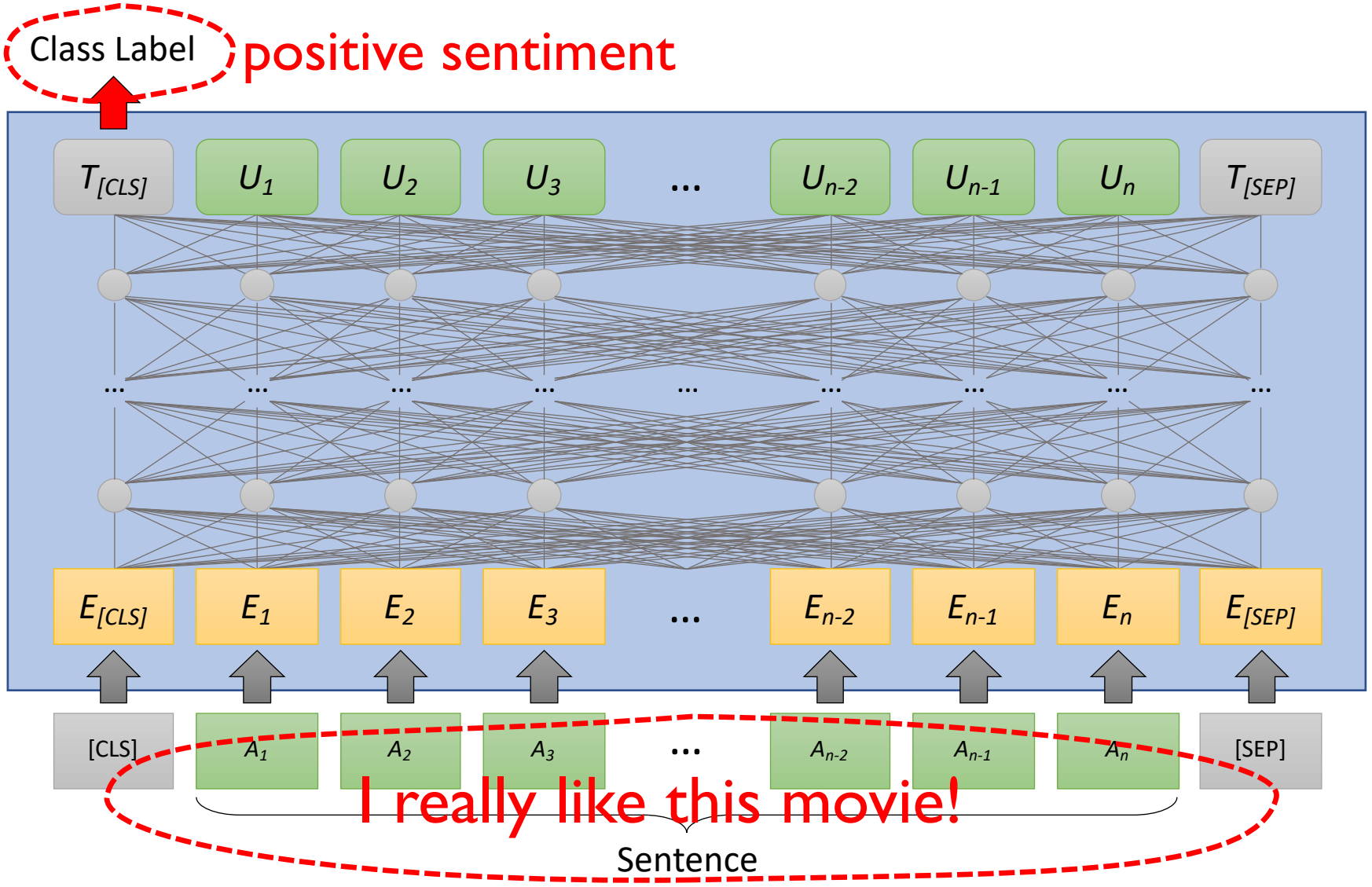
Adjust model parameters using labeled data for the target task

Supervised

Devlin et al. BERT. *NAACL 2019* (~18K citations!)

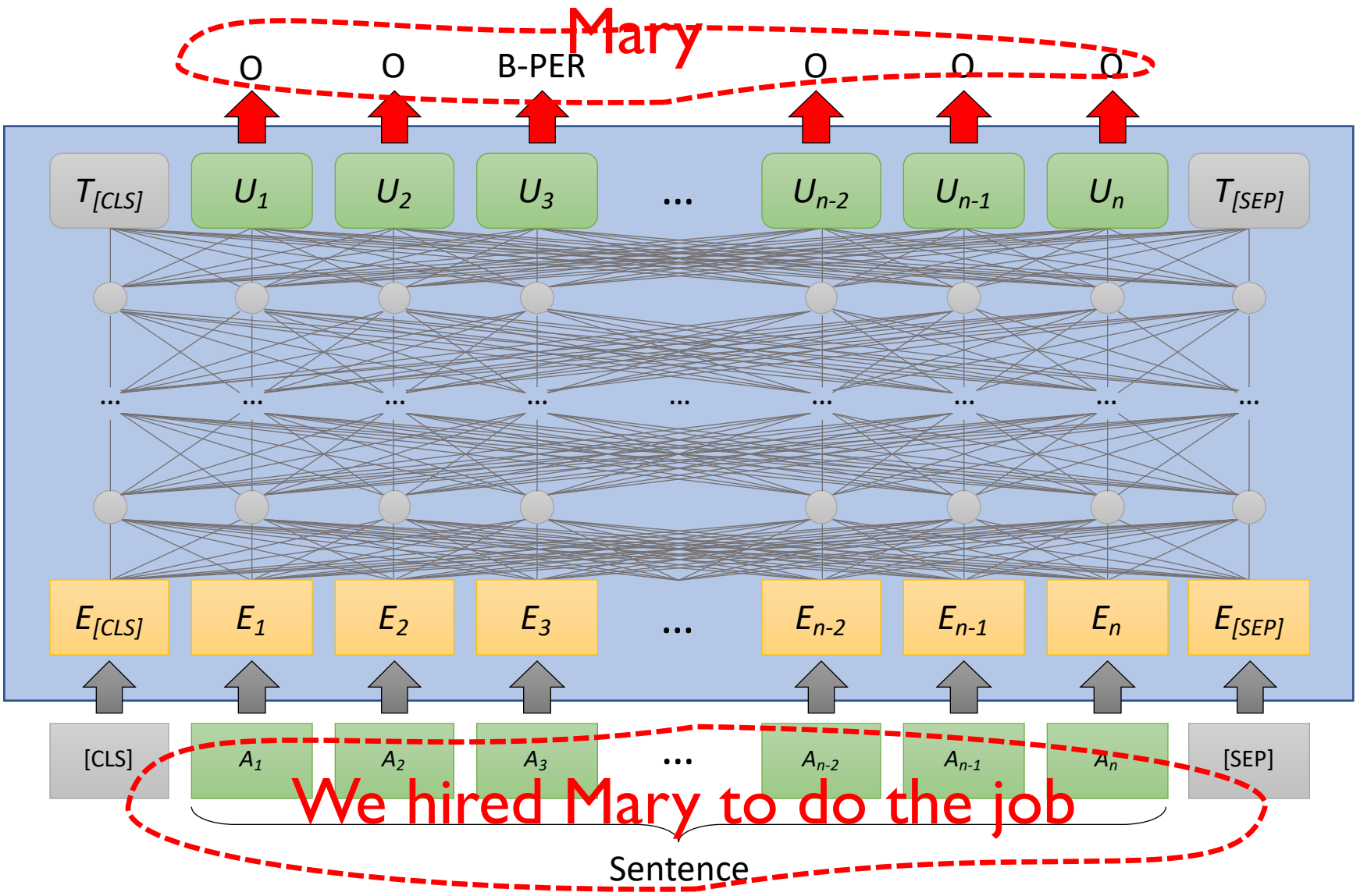
$f([A_1, A_2, \ldots A_n]) \rightarrow y$

Single-Input Classification (e.g., sentiment analysis)



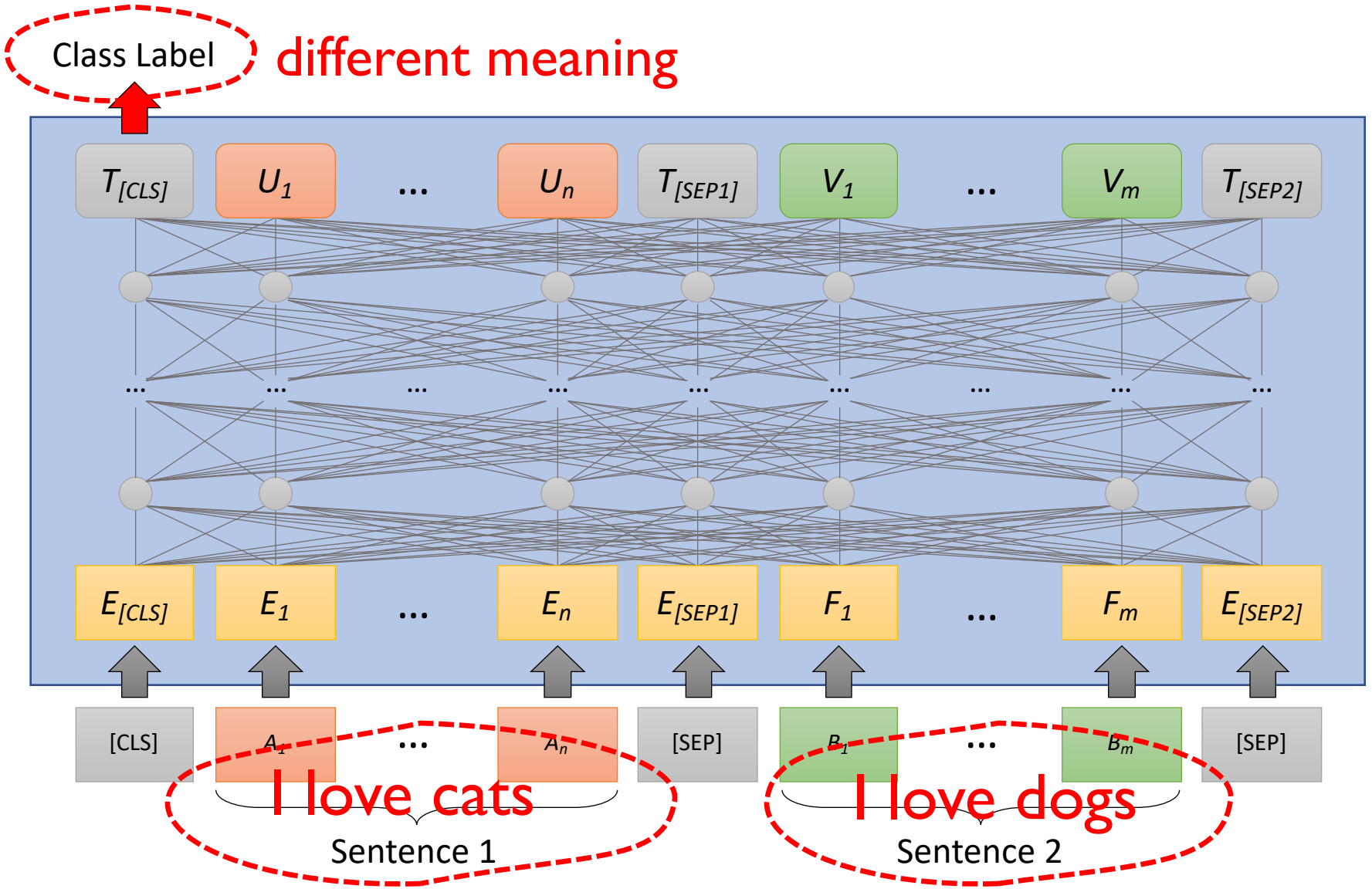
$f([A_1, A_2, \ldots A_n]) \rightarrow [y_1 \ldots y_n]$

Single-Input Sequence Labeling (e.g., named-entity recognition)



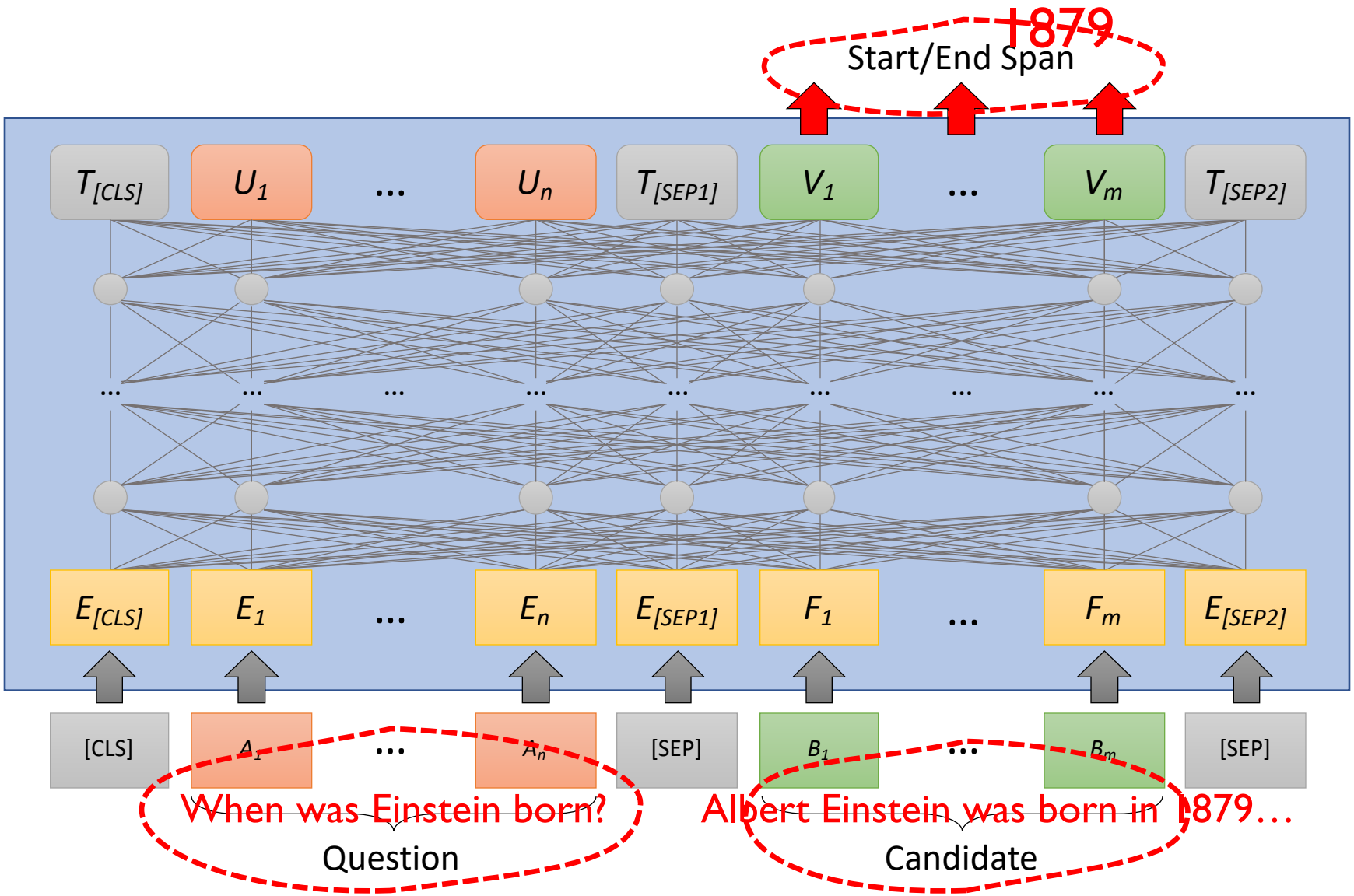
$f([A_1 \dots A_n], [B_1 \dots B_m]) \rightarrow y$

Two-Input Classification (e.g., paraphrase detection)



$f([A_1 \dots A_n], [B_1 \dots B_m]) \rightarrow [y_1 \dots y_m]$

Two-Input Sequence Labeling (e.g., question answering)



What's BERT?

a transformer encoder pretrained with a mask language model (MLM) objective that generates contextualized representations and can be fine-tuned for a wide range of NLP tasks.

Now you know what BERT is!

Devlin et al. BERT. *NAACL 2019* (~18K citations!)

BERT's family tree

Devlin et al. BERT. *NAACL 2019* (~18K citations!)

What's a muppet?

What's GPT-3?

What Is GPT-3 And Why Is It Revolutionizing Artificial Intelligence?

Bernard Marr Contributor ⓘ
Enterprise Tech

FT Magazine Artificial intelligence + Add to myFT

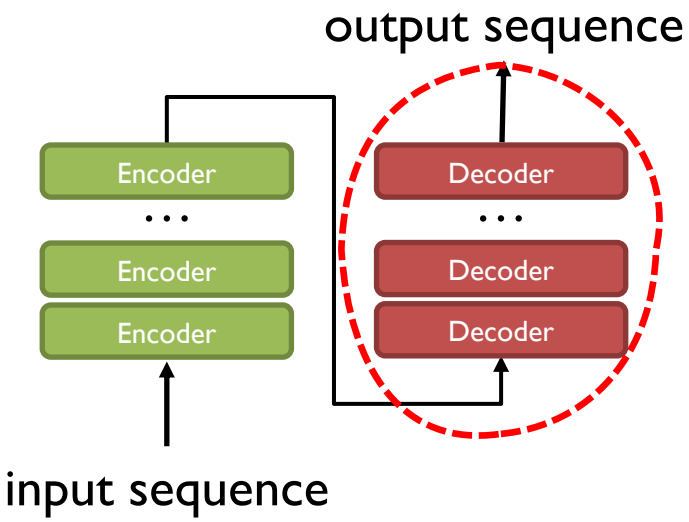
Is AI finally closing in on human intelligence?

GPT-3 has been hailed as an artificial intelligence breakthrough. John Thornhill tries it out and assesses the rewards — and the risks

We're entering the AI twilight zone between narrow and general AI

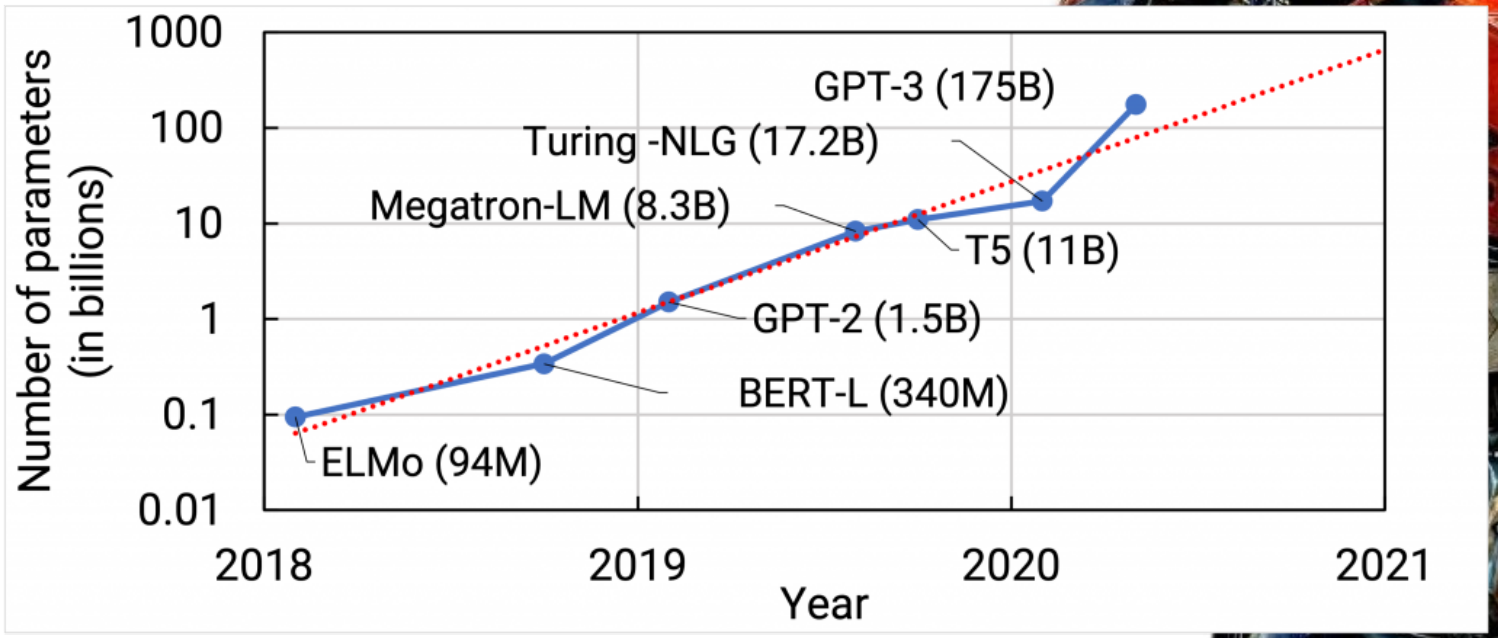
Gary Grossman, Edelman @garyg02 September 3, 2020 2:10 PM

What's GPT-3?


output sequence
Encoder
Encoder
Encoder
Decoder
Decoder
Decoder
input sequence

What's GPT-3?

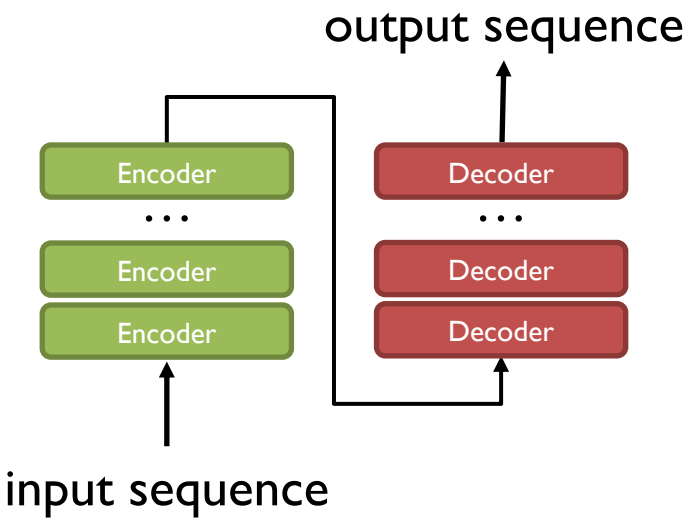
pretrained decoder



Brown et al. Language Models are Few-Shot Learners. *NeurIPS 2020*


175 BILLION parameters!
Before: training a GPT-3 model … would take 36 years on eight V100 GPUs, or seven months with 512 V100 GPUs.
Now: The GPT-3 model … requires just over a month to train using 1024 A100 GPUs!
https://developer.nvidia.com/blog/scaling-language-model-training-to-a-trillion-parameters-using-megatron/

What's T5?



Raffel et al. Exploring the Limits of Transfer Learning with a Unified Text-to-Text Transformer. *JMLR 2020*

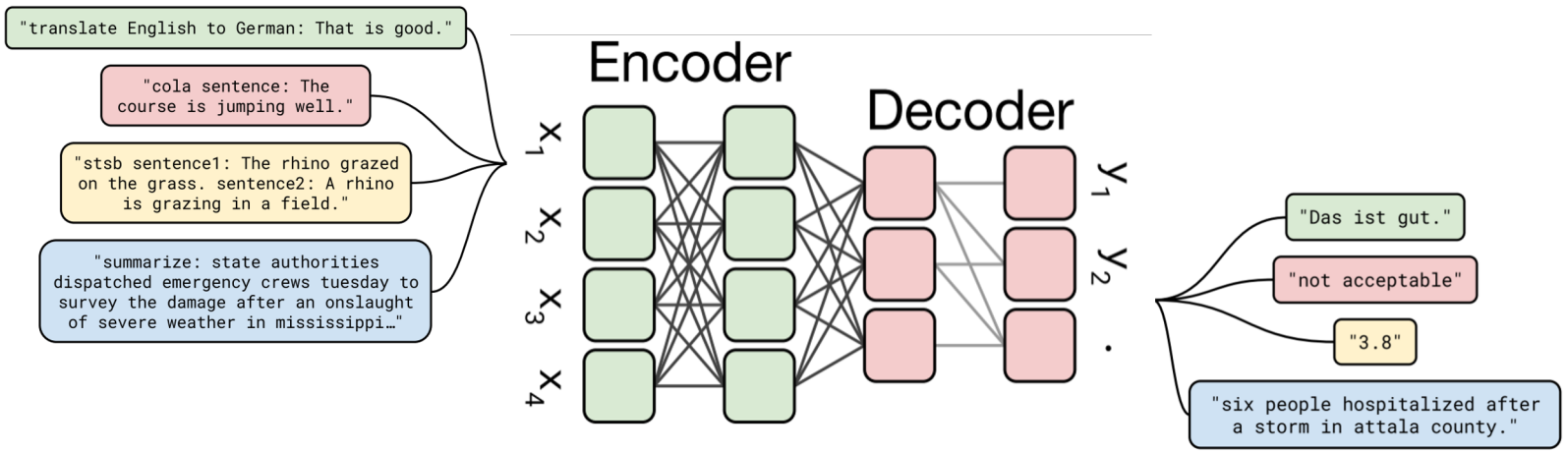
What's T5?

pretrained encoder-decoder

Raffel et al. Exploring the Limits of Transfer Learning with a Unified Text-to-Text Transformer. *JMLR 2020*

What's T5?

pretrained encoder-decoder



Everything's a sequence-to-sequence task!

Raffel et al. Exploring the Limits of Transfer Learning with a Unified Text-to-Text Transformer. *JMLR 2020*

2017 – "vanilla" transformers
(no pretraining)

Mid-2018 – GPT-2
(decoder, pretrained w/ "predict next word")

Late-2018 – BERT
(encoder, pretrained w/ "peek-a-boo")

Late-2019 – T5
(encoder–decoder, pretrained)

Mid-2020 – GPT-3
(like GPT-2, but larger!)

What is BERT?

(and his muppet friends)

Why should you care?

BERT is good at text ranking

what is a lobster roll?

A Lobster Roll is a bread roll filled with bite-sized chunks of lobster meat. Lobster Rolls are made on the Atlantic coast of North America, from the New England area of the United States on up into the Maritimes areas of Canada.

BERT is good at text ranking

Select some promising texts

Rerank selected texts

BERT is good at text ranking

Select some promising texts

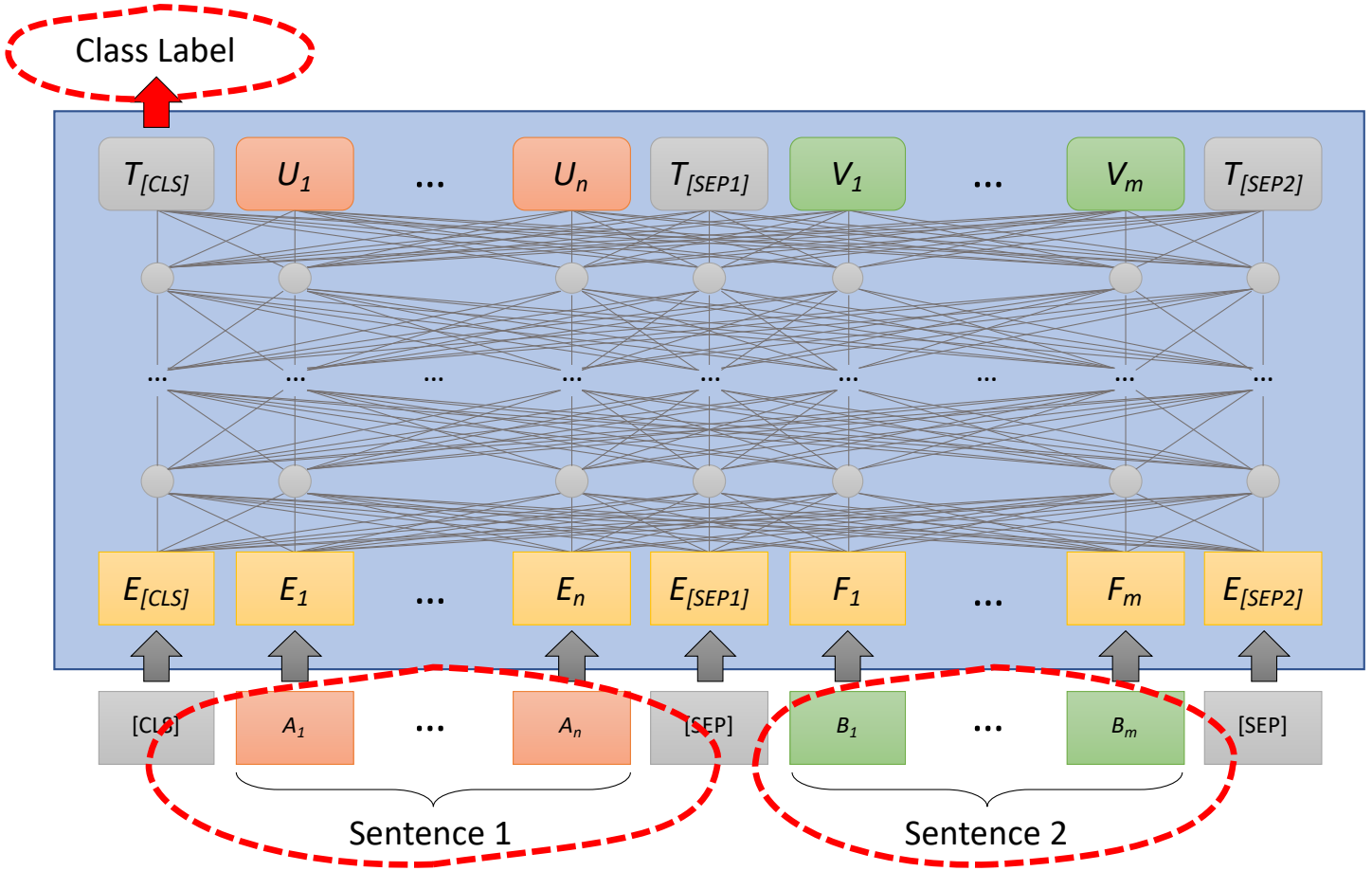
Lucene

+

BERT is good at text ranking

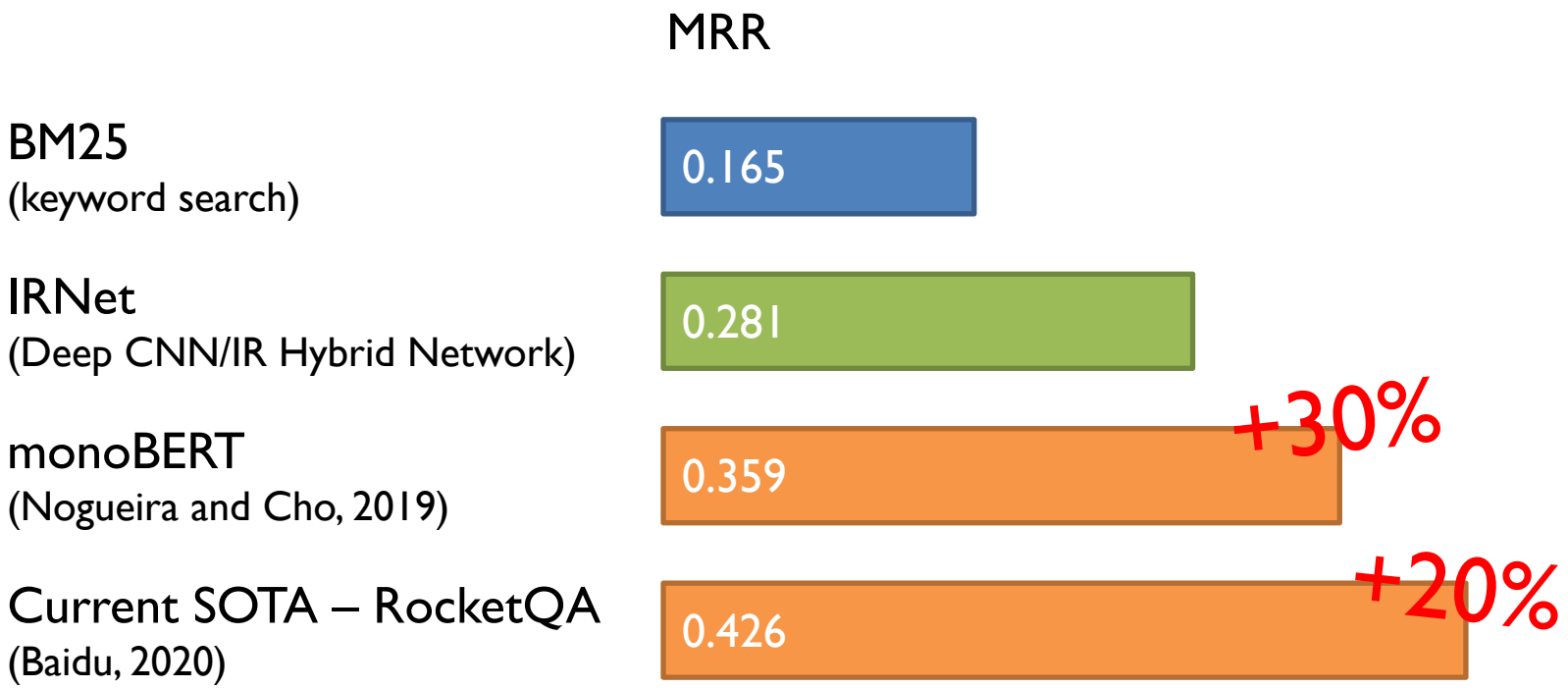
$f([A_1 \dots A_n], [B_1 \dots B_m]) \rightarrow y$

query candidate text prob. relevance



Like how good?

BERT is good at text ranking



MS MARCO passage ranking
(8.8M passages, queries from Bing logs)

BERT is good at QA

who lives in the imperial palace in tokyo?

The Tokyo Imperial Palace (皇居 , Kōkyo , literally " Imperial Residence ") is the primary residence of the Emperor of Japan . It is a large park - like area located in the Chiyoda ward of Tokyo and contains buildings including the main palace (宮殿 , Kyūden) , the private residences of the Imperial Family , an archive , museums and administrative offices.

BERT is good at QA

Select some promising texts

Extract correct answer span

BERT is good at QA

Select some promising texts

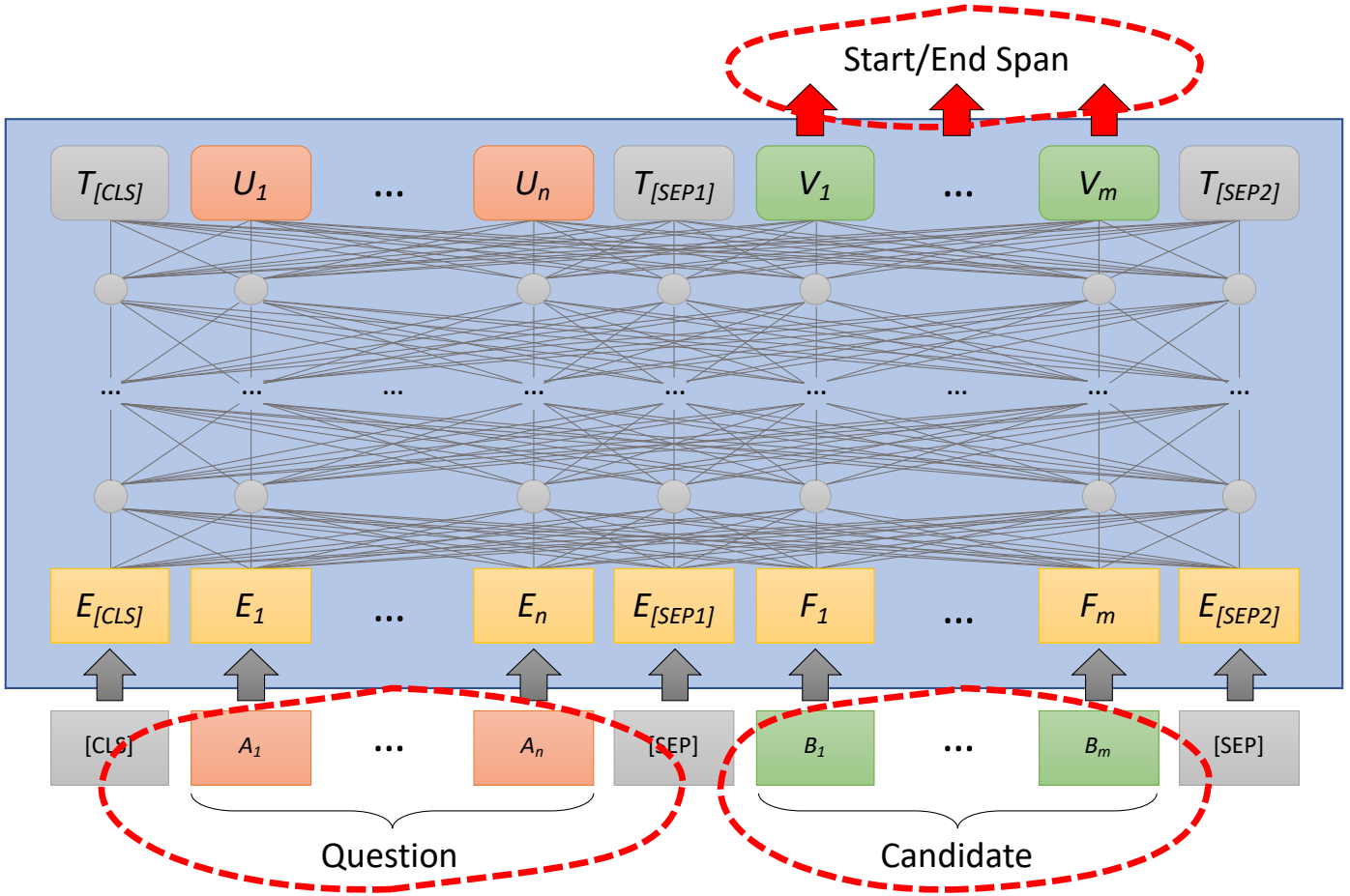
Lucene

+

BERT is good at QA

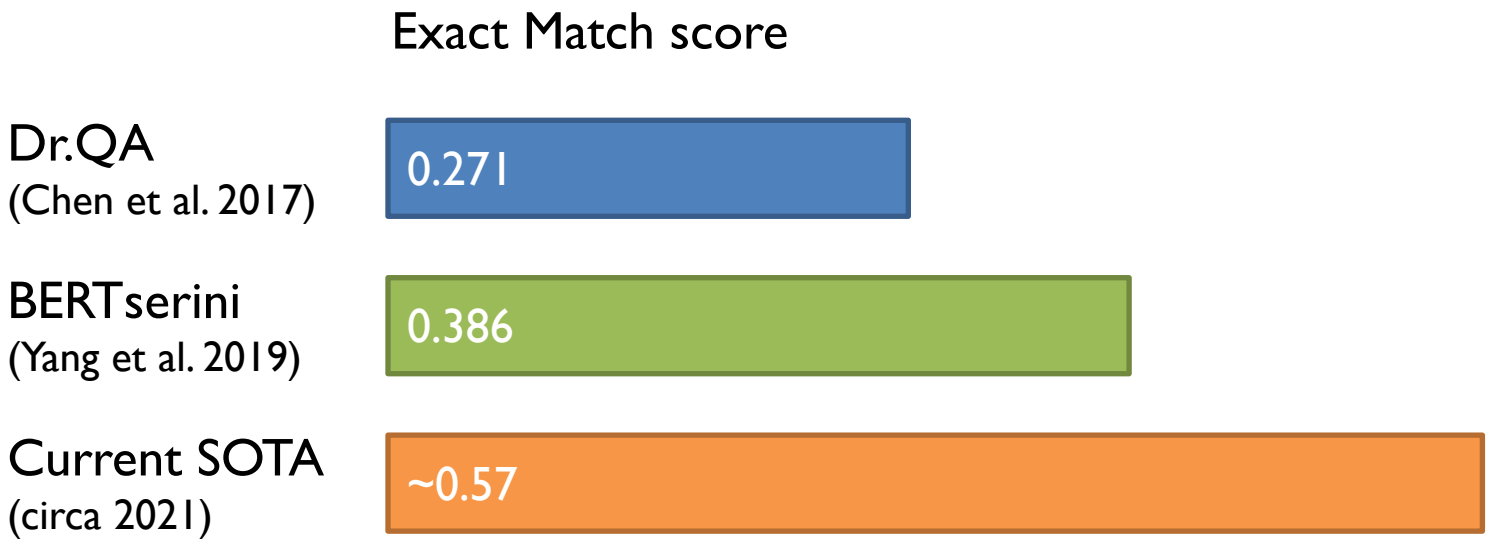
$f([A_1 \dots A_n], [B_1 \dots B_m]) \rightarrow [y_1 \dots y_m]$

question candidate answer prob. start/end pos



Like how good?

BERT is good at QA



SQuAD questions against ~5M Wikipedia articles

Source: https://www.flickr.com/photos/winnie_pix/29159326584/

What's QA?
select-project queries!

who lives in the imperial palace in tokyo?

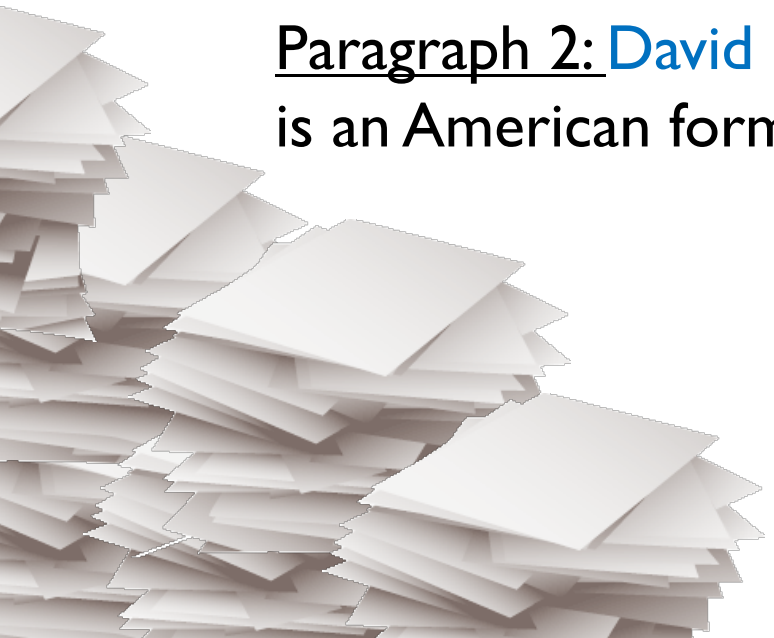
```
select "residents" from location
    where city = "tokyo" and
    name = "imperial palace"
```

BERT can do multi-hop QA

Which former member of the Pittsburgh Pirates was nicknamed "The Cobra"?

Paragraph 1: Several current and former members of the Pittsburgh Pirates – ... John Milner, Dave Parker, and Rod Scurry...

Paragraph 2: David Gene Parker, nicknamed "The Cobra", is an American former player in Major League Baseball...




Source: https://www.flickr.com/photos/zzilch/24866270680/

What's multi-hop QA?
select-project-join queries!

Which former member of the Pittsburgh Pirates was nicknamed "The Cobra"?

```
select roster.name from roster, player
  where roster.name = player.name and
roster.team = "Pittsburgh Pirates" and
    player.nickname = "The Cobra"
```

BERT is good at QA

"Open-Book" Question Answering

Select some promising texts

Lucene

+

BERT is good at QA

"Closed-Book" Question Answering

T5 is good at QA

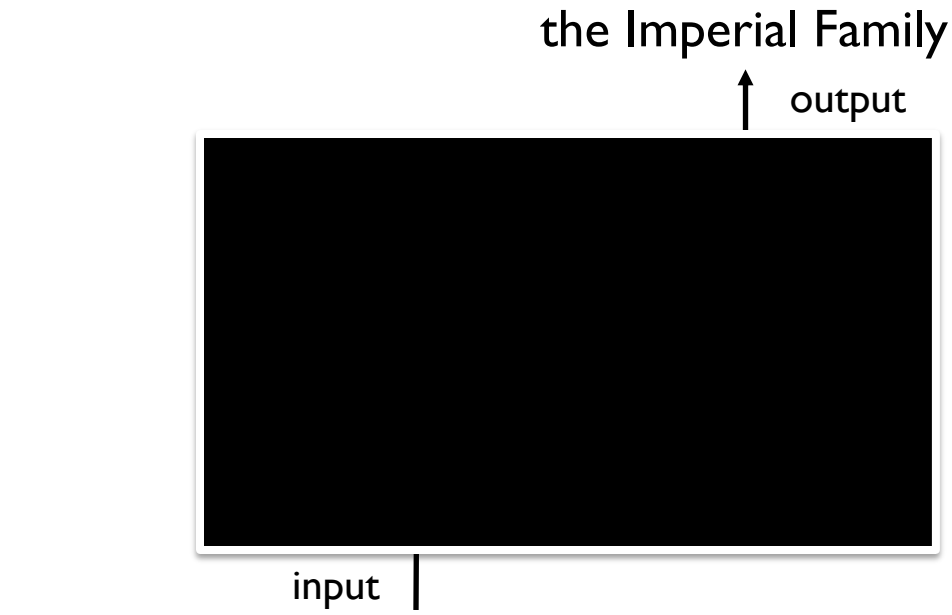
"Closed-Book" Question Answering

Roberts et al. How Much Knowledge Can You Pack Into the Parameters of a Language Model? *EMNLP 2020*

No more corpus!

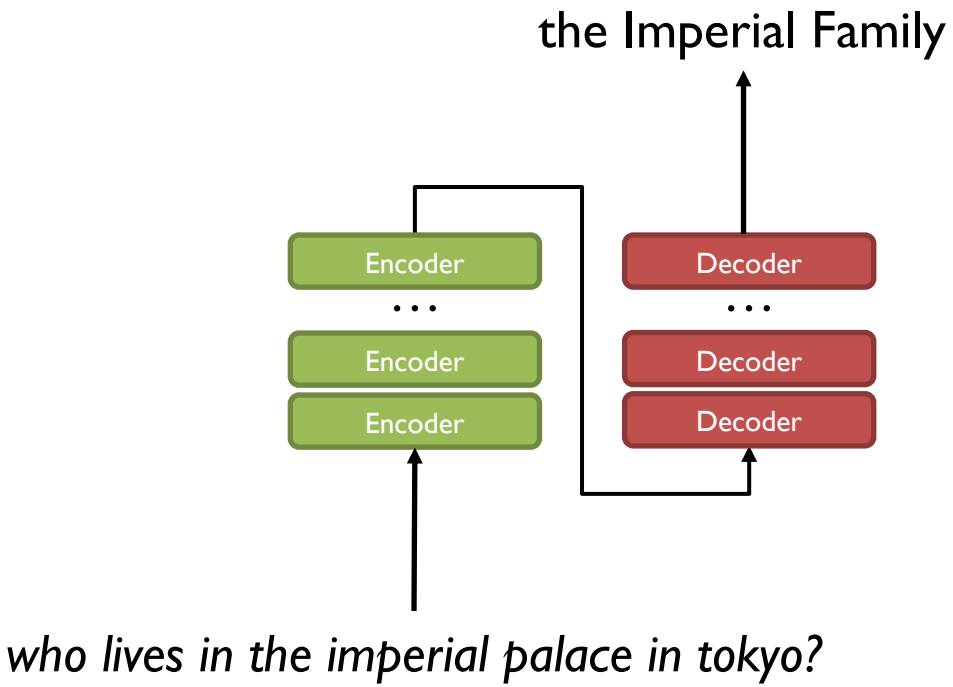
(Just the model)

Closed-Book QA with T5



Roberts et al. How Much Knowledge Can You Pack Into the Parameters of a Language Model? *EMNLP 2020*

Closed-Book QA with T5



Roberts et al. How Much Knowledge Can You Pack Into the Parameters of a Language Model? *EMNLP 2020*

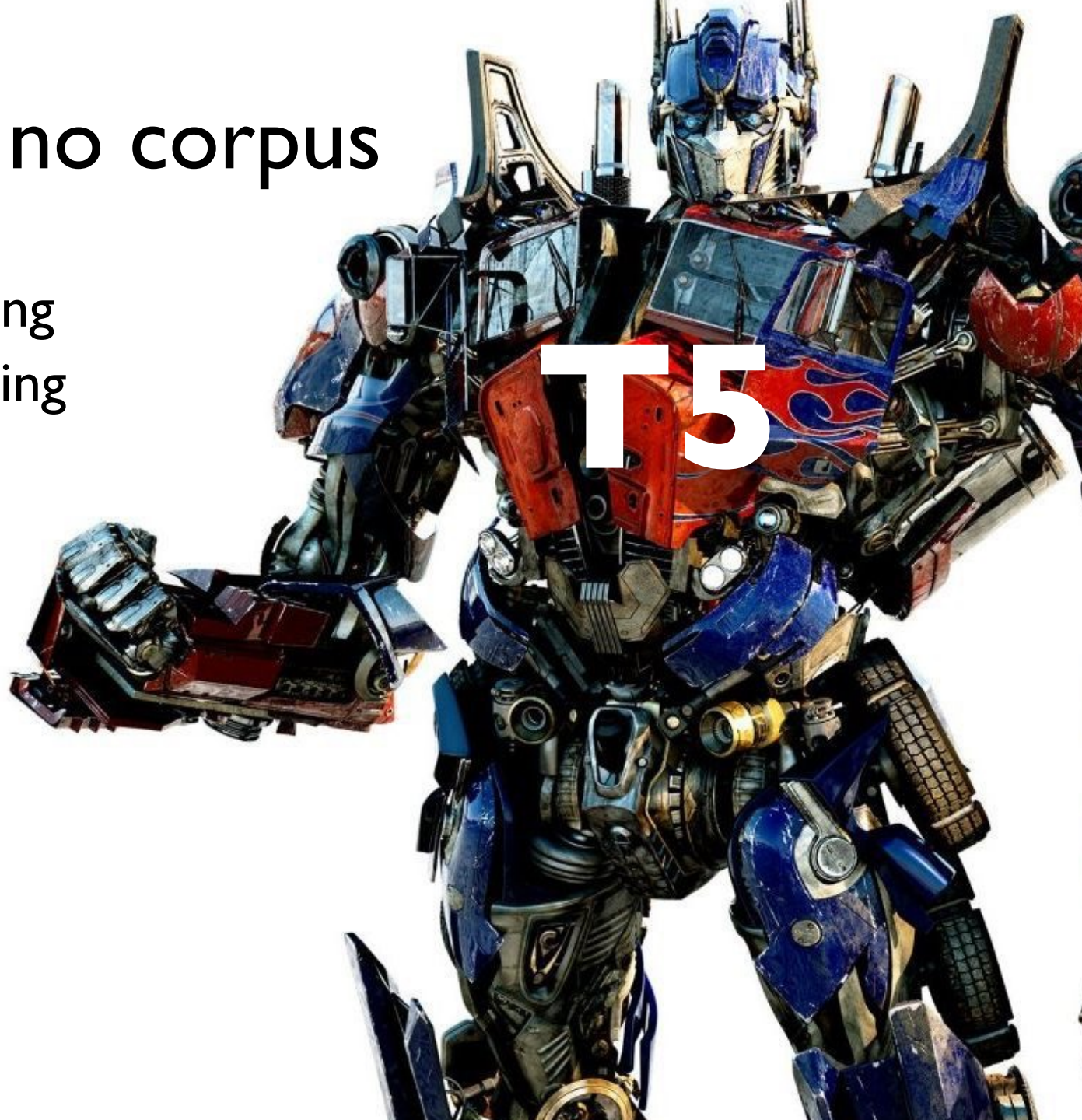
No more corpus!

(Just a transformer)


There is no spoon.
(Just a transformer)

There is no corpus

Pretraining
Fine-Tuning




There is no fine-tuning.
(Just a pretrained transformer)

What does BERT know?

Source: https://www.flickr.com/photos/photosavvy/69040075/

What does BERT know?

Wikidata P19: place of birth

Francesco Bartolomeo Conti was born in _____

Accuracy: 16%

```
select birthplace from person
where name = "Francesco Bartolomeo"
```

Accuracy: 100%

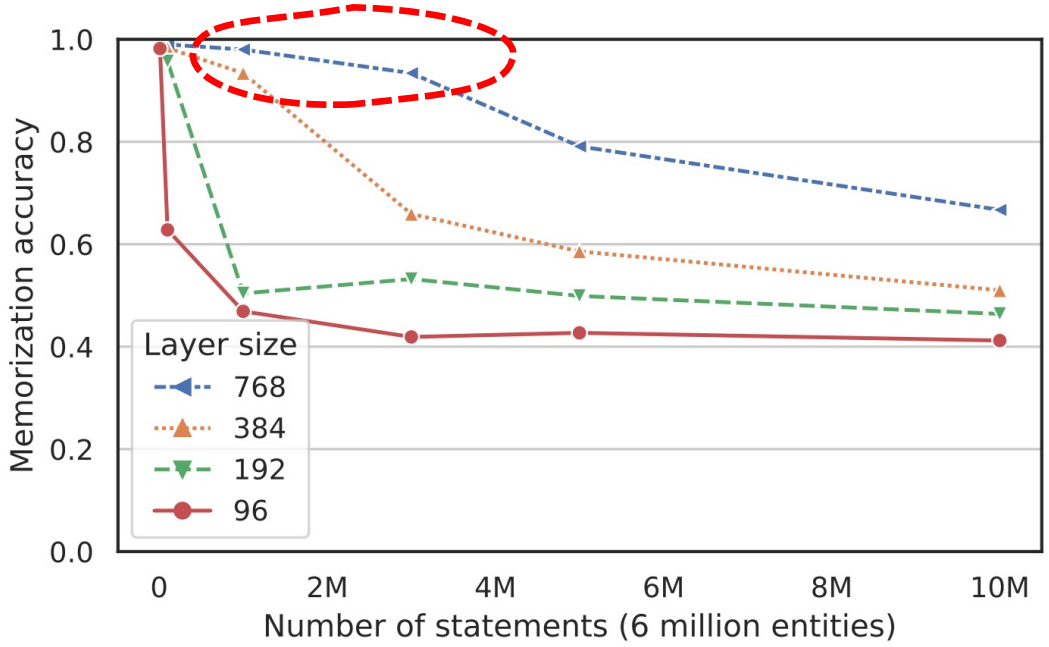
Petroni et al. Language Models as Knowledge Bases? *EMNLP 2019*

Source: Parents.com

Let's teach BERT!

Source: Parents.com

Can BERT memorize?



Heinzerling and Petroni. Language Models as Knowledge Bases: On Entity Representations, Storage Capacity, and Paraphrased Queries. *arXiv:2008.09036*

Source: https://www.flickr.com/photos/kaibara/4476967044/

What's fact memorization?

Inserts!

What's QA?

select-project queries!

What's multi-hop QA?

select-project-join queries!

What's fact memorization?

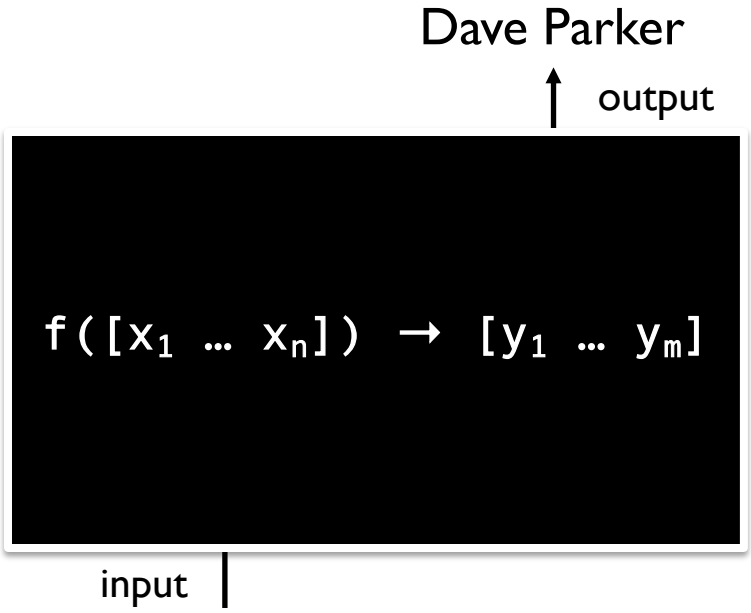
Inserts!

and we've gotten rid of the data!

Implications?

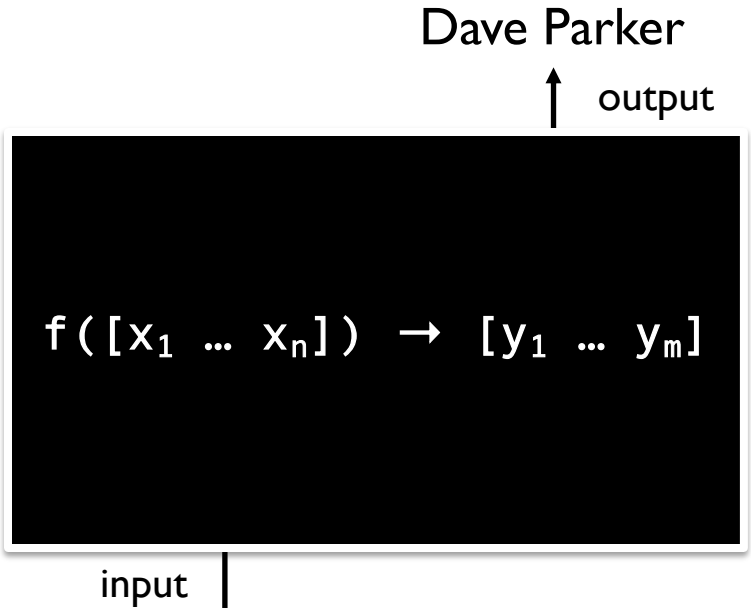
What's an RDBMS?

(sequence-to-sequence model)




```
select roster.name from roster, player
where roster.name = player.name and
roster.team = "Pittsburgh Pirates" and
player.nickname = "The Cobra"
```

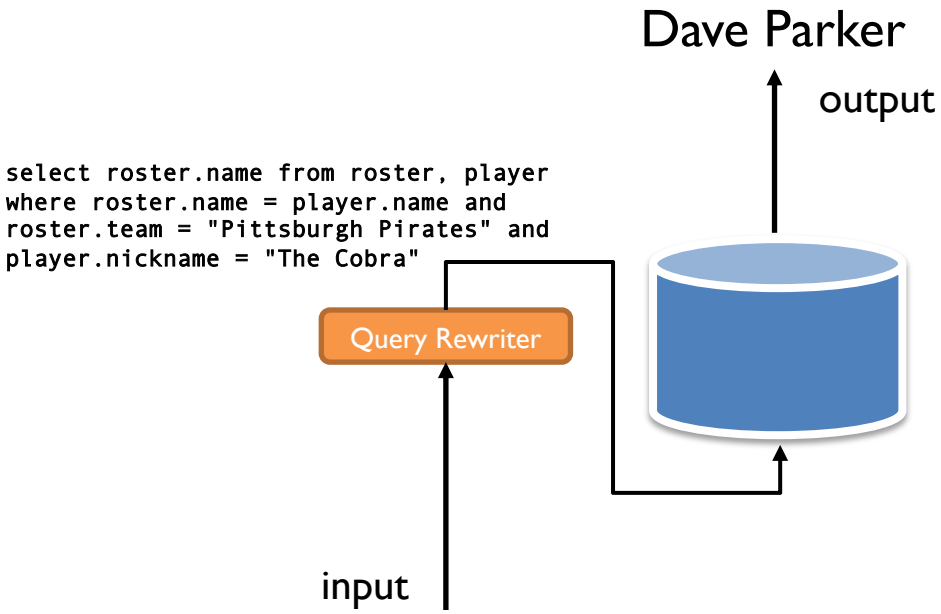
What's a QA system?
(sequence-to-sequence model)



Which former member of the Pittsburgh Pirates was nicknamed "The Cobra"?

What's a QA system?

(sequence-to-sequence model)



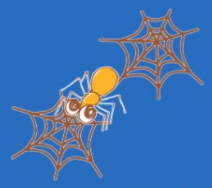
Which former member of the Pittsburgh Pirates was nicknamed "The Cobra"?

Already being done!

Which countries in Europe have at least 3 car manufacturers?

```
SELECT T1.country_name
FROM countries AS T1 JOIN continents
AS T2 ON T1.continent = T2.cont_id
JOIN car_makers AS T3 ON
T1.country_id = T3.country
WHERE T2.continent = 'Europe'
GROUP BY T1.country_name
HAVING COUNT(*) >= 3
```

Spider 1.0



Yale Semantic Parsing and Text-to-SQL Challenge

Already being done!

What does 175 billion parameters get you?

GPT-3 can write code based on natural language descriptions!

https://twitter.com/sharifshameem/status/1282676454690451457

NLP

Natural language access to all your organization's data!

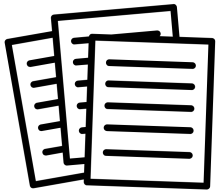
DB

Mary Smith, John Skinner, …

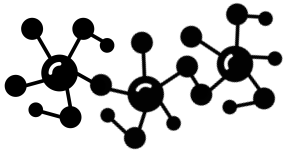
output

input

What customers in Waterloo have been complaining about our widgets?



Unstructured Text

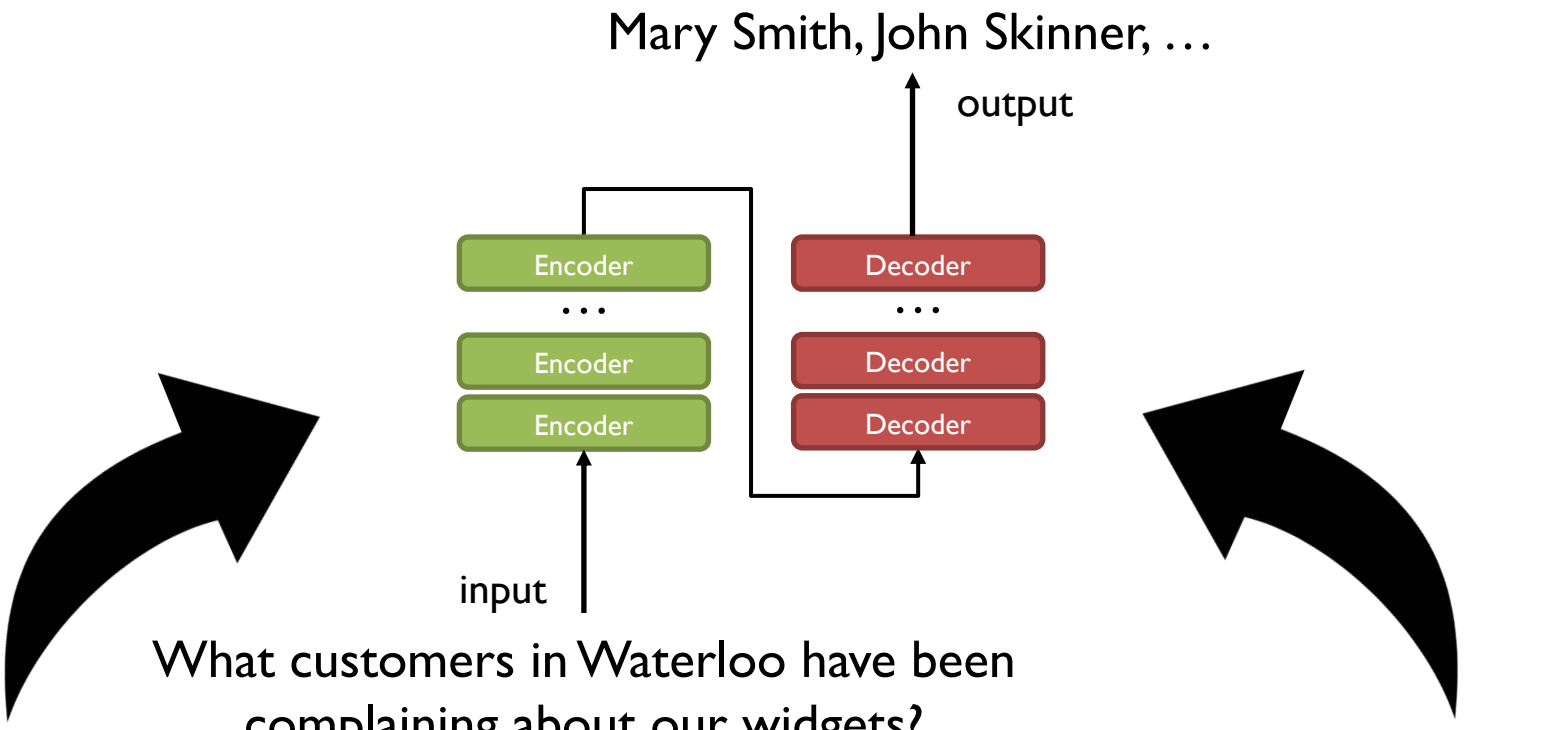


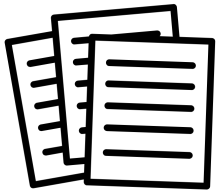
Knowledge Graphs

Structured Relations

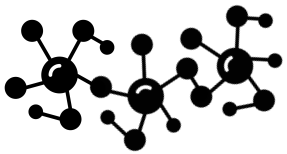
NLP

DB





Unstructured Text



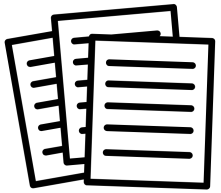
Knowledge Graphs

Structured Relations

NLP

DB

What if BERT took over everything?

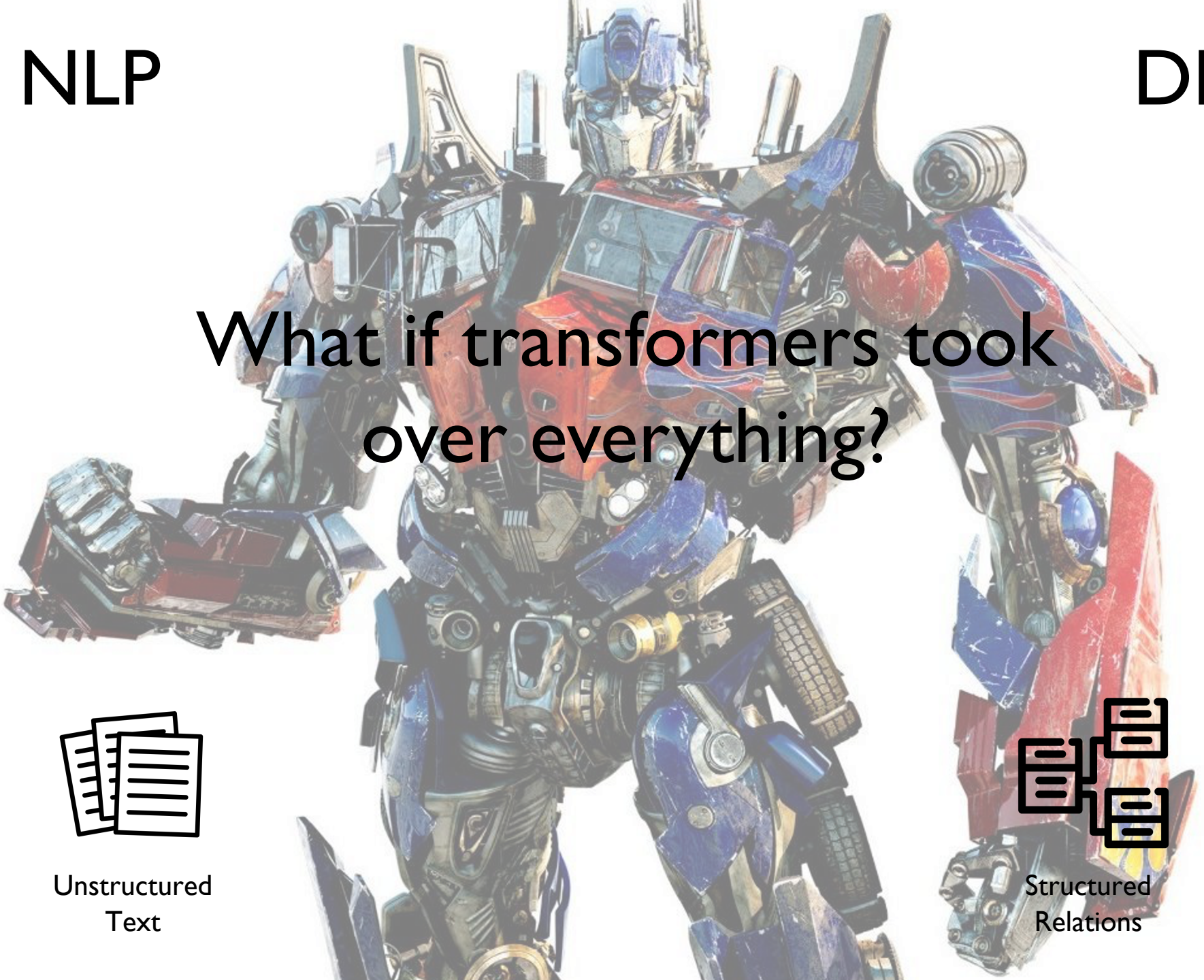


Unstructured
Text

Structured
Relations

NLP

DB



What if transformers took over everything?

Unstructured Text

Structured Relations

Source: Wikipedia (Pistachio)

From Natural Language Processing to Neural Databases

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ABSTRACT

In recent years, neural networks have shown impressive performance gains on long-standing AI problems, such as answering queries from text and machine translation. These advances raise the question of whether neural nets can be used at the core of query processing to derive answers from facts, even when the facts are expressed in natural language. If so, it is conceivable that we could relax the fundamental assumption of database management, namely, that our data is represented as fields of a pre-defined schema. Furthermore, such technology would enable combining information from text, images, and structured data seamlessly.

This paper introduces *neural databases*, a class of systems that use NLP transformers as localized answer derivation engines. We ground the vision in NeuralDB, a system for querying facts represented as short natural language sentences. We demonstrate that recent natural language processing models, specifically transformers, can answer select-project-join queries if they are given a set of relevant facts. However, they cannot scale to non-trivial databases nor answer set-based and aggregation queries. Based on these insights, we identify specific research challenges that are needed to build neural databases. Some of the challenges require drawing upon [illegible] literature in data management, and others pose new research opportunities to the NLP community. Finally, we show that with preliminary solutions, NeuralDB can already answer queries over thousands of sentences with very high accuracy.

PVLDB Reference Format:
James Thorne, Majid Yazdani, Marzieh Saeidi, Fabrizio Silvestri, Sebastian Riedel, and Alon Halevy. From Natural Language Processing to Neural Databases. PVLDB, 14(6): 1033-1039, 2021.
doi:10.14778/3447689.3447706

NEURALDB

1 INTRODUCTION

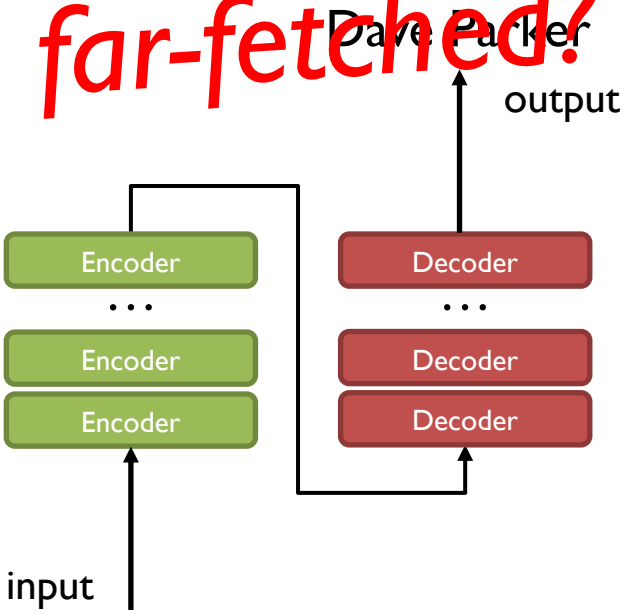
Researchers have long considered the application of neural nets to data management problems, including learning indices [16], query optimization, data cleaning and entity matching [20, 23, 32]. In applying neural networks to data management, research has so far assumed that the data was modeled by a database schema.

The success of neural networks in processing unstructured data such as natural language and images raises the question of whether their use can be extended to a point where we can relax the fundamental assumption of database management, which is that the data we process is represented as fields of a pre-defined schema. What if, instead, data and queries can be represented as short natural language sentences, and queries can be answered from these sentences? Furthermore, what if relevant data from images can be seamlessly combined with text and structured data?

This paper describes a vision for neural databases and preliminary empirical evidence of its potential. Neural databases offer several benefits that database systems have struggled to support for decades. The first, and most important benefit, is that a neural database has no pre-defined schema. Therefore, the scope of the database does not need to be defined in advance, and any data that becomes relevant as the application is used can be stored and queried. The second benefit is that updates and queries can be posed in a variety of natural language forms, as is convenient to any user. In contrast, a traditional database query needs to be based on the database schema. Even when the data is modeled with a more flexible formalism such as RDF, there is still a single name for any given relation, and that name needs to be used in updates and queries. Third, with recent advances in machine translation, the language of queries and answers can be different from the language of the data in the neural database. A final benefit comes from the fact

RDBMS based on Neural Networks

Is this really that far-fetched?




```
select roster.name from roster, player
where roster.name = player.name and
roster.team = "Pittsburgh Pirates" and
player.nickname = "The Cobra"
```

RDBMS based on Neural Networks

Is this really that far-fetched?

This isn't fundamentally different from model-based (approximate) query processing!

Deshpande and Madden. MauveDB: Supporting Model-Based User Views in Database Systems. *SIGMOD 2006*

Mühleisen et al. Capturing the Laws of (Data) Nature. *CIDR 2015*

Kulessa et al. Model-based Approximate Query Processing. *arXiv:1811.06224*

Vorona et al. DeepSPACE: Approximate Geospatial Query Processing with Deep Learning. *SIGSPATIAL 2019*

NLP

Natural language access to all your organization's data!

DB

Mary Smith, John Skinner, …

output

input

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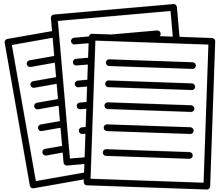
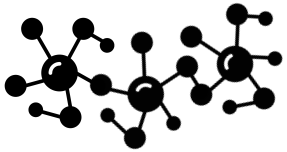


Unstructured Text



Knowledge Graphs

Structured Relations

TRANS FORMERS

What's QA?

select-project queries!

What's multi-hop QA?

select-project-join queries!

What's fact memorization?

inserts!

Some of the pieces already exist!

and we've gotten rid of the data!

We've begun!

Source: Wikipedia

Source: Wikipedia

Source: Motor Trend

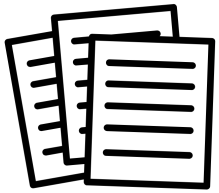
NLP

DB

TRANSFORMERDB

A neural network that ingests all your organization's data and allows you to query it using natural language.

`transformerdb.ai`



Unstructured Text

Structured Relations

(looking for a seed round)