

Natural Language Processing Contextualized Embeddings, Pre-Training, Fine-Tuning and Large Language Models

Felipe Bravo-Marquez

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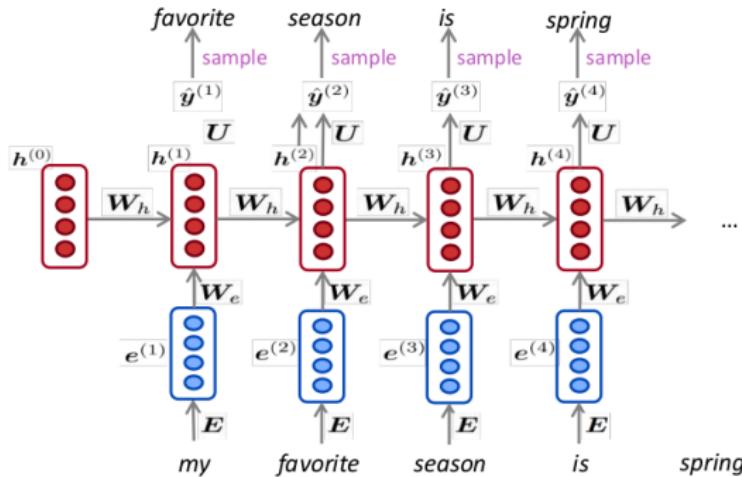
Representations for a word

- So far, we've basically had one representation of words, the word embeddings we've already learned: Word2vec, GloVe, fastText.¹.
- These embeddings have a useful semi-supervised quality, as they can be learned from unlabeled corpora and used in our downstream task-oriented architectures (LSTM, CNN, Transformer).
- However, they exhibit two problems.
- Problem 1: They always produce the same representation for a word type regardless of the context in which a word token occurs
- We might want very fine-grained word sense disambiguation
- Problem 2: We just have one representation for a word, but words have different aspects, including semantics, syntactic behavior, and register/connotations

¹These slides are partially based on the Stanford CS224N: Natural Language Processing with Deep Learning course:
<http://web.stanford.edu/class/cs224n/>

Neural Language Models can produce Contextualized Embeddings

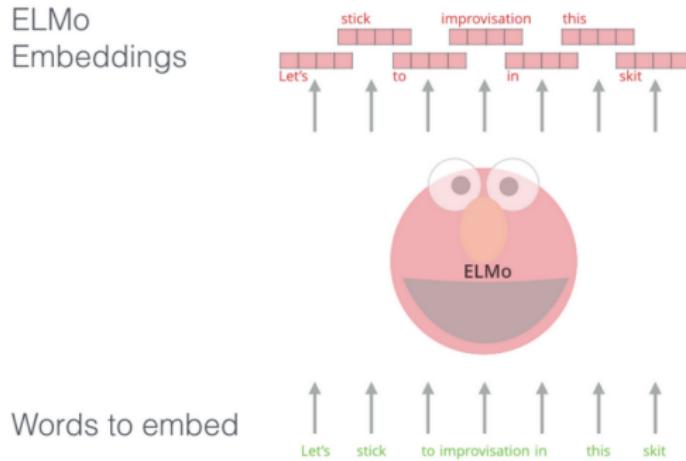
- In a Neural Language Model (NLM), we immediately stuck word vectors (perhaps only trained on the corpus) through LSTM layers
- Those LSTM layers are trained to predict the next word.
- But these language models produce context-specific word representations in the hidden states of each position.



ELMo: Embeddings from Language Models

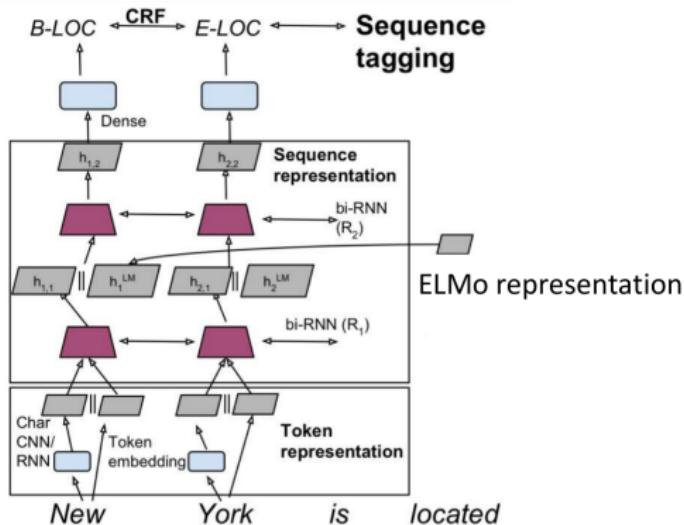
- Idea: train a large language model (LM) with a recurrent neural network and use its hidden states as “contextualized word embeddings” [Peters et al., 2018].
- ELMo is bidirectional LM with 2 biLSTM layers and around 100 million parameters.
- Uses character CNN to build initial word representation (only)
- 2048 char n-gram filters and 2 highway layers, 512 dim projection
- User 4096 dim hidden/cell LSTM states with 512 dim projections to next input
- Uses a residual connection
- Parameters of token input and output (softmax) are tied.

ELMo: Embeddings from Language Models



ELMo: Use with a task

- First run biLM to get representations for each word.
- Then let (whatever) end-task model use them.
- Freeze weights of ELMo for purposes of supervised model.
- Concatenate ELMo weights into task-specific model.



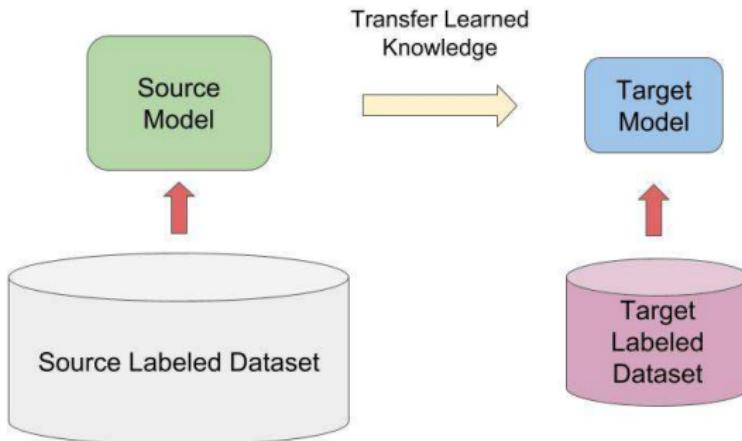
$$\mathbf{h}_{k,1} = [\overrightarrow{\mathbf{h}}_{k,1}; \overleftarrow{\mathbf{h}}_{k,1}; \mathbf{h}_k^{LM}]$$

ELMo: Results

Name	Description	Year	F1
ELMo	ELMo in BiLSTM	2018	92.22
TagLM Peters	LSTM BiLM in BiLSTM tagger	2017	91.93
Ma + Hovy	BiLSTM + char CNN + CRF layer	2016	91.21
Tagger Peters	BiLSTM + char CNN + CRF layer	2017	90.87
Ratinov + Roth	Categorical CRF+Wikipedia+word cls	2009	90.80
Finkel et al.	Categorical feature CRF	2005	86.86
IBM Florian	Linear/softmax/TBL/HMM ensemble, gazettes++	2003	88.76
Stanford	MEMM softmax markov model	2003	86.07

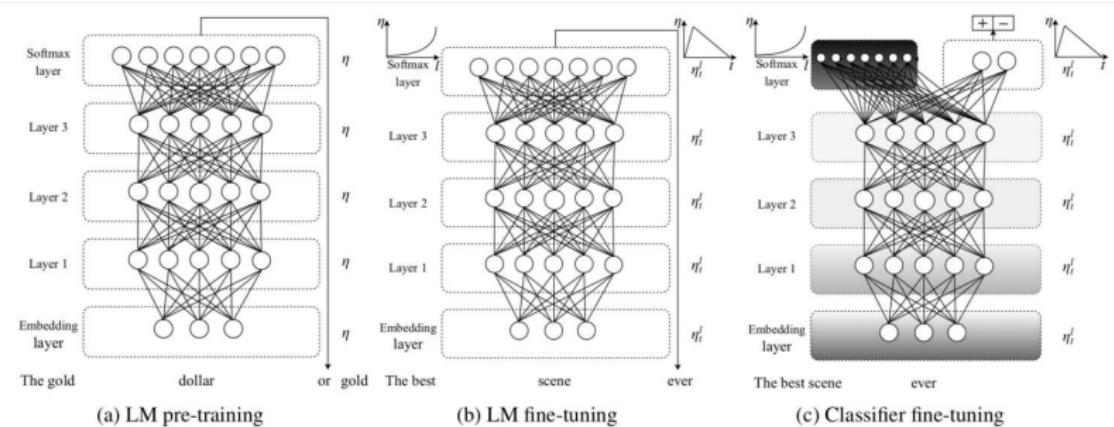
ULMfit

- Howard and Ruder (2018) Universal Language Model Fine-tuning for Text Classification [Howard and Ruder, 2018].
- Same general idea of transferring NLM knowledge
- Here applied to text classification



ULMfit

- Train LM on big general domain corpus (use biLM)
- Tune LM on target task data
- Fine-tune as classifier on target task



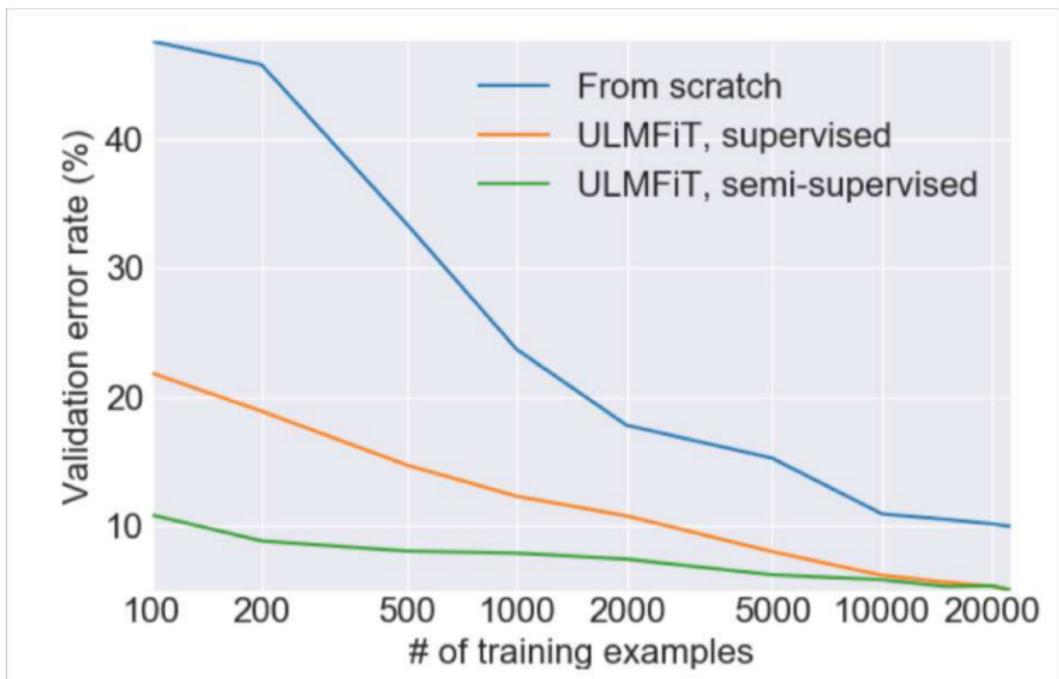
ULMfit emphases

- Use reasonable-size “1 GPU” language model not really huge one
- A lot of care in LM fine-tuning
- Different per-layer learning rates
- Slanted triangular learning rate (STLR) schedule
- Gradual layer unfreezing and STLR when learning classifier
- Classify using concatenation [h_T ,maxpool(h),meanpool(h)]

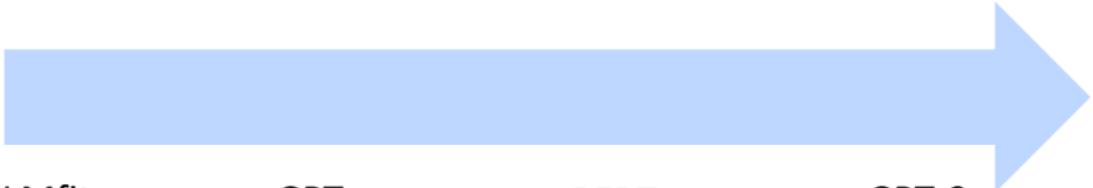
	Model	Test	Model	Test
IMDb	CoVe (McCann et al., 2017)	8.2	CoVe (McCann et al., 2017)	4.2
	oh-LSTM (Johnson and Zhang, 2016)	5.9	TBCNN (Mou et al., 2015)	4.0
	Virtual (Miyato et al., 2016)	5.9	LSTM-CNN (Zhou et al., 2016)	3.9
	ULMFiT (ours)	4.6	ULMFiT (ours)	3.6

Text classifier error rates

ULMfit transfer learning



Let's scale it up!



ULMfit	GPT	BERT	GPT-2
Jan 2018	June 2018	Oct 2018	Feb 2019
Training:	Training	Training	Training
1 GPU day	240 GPU days	256 TPU days ~320–560 GPU days	~2048 TPU v3 days according to a reddit thread



Transformer models

All of these models are Transformer architecture models ... so maybe we had better learn about Transformers?

ULMfit
Jan 2018
Training:
1 GPU day

GPT
June 2018
Training
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BERT
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~320–560
GPU days

GPT-2
Feb 2019
Training
~2048 TPU v3
days according to
[a reddit thread](#)

fast.ai



Google AI



BERT (Bidirectional Encoder Representations from Transformers)

- Idea: combine ideas from ELMO, ULMFit and the Transformer [Kenton and Toutanova, 2019].
- How: Train a large model (335 million parameters) from a large unlabeled corpus using a Transformer encoder and then fine-tune it for other downstream tasks.
- The parallelizable properties of the Transformer (unlike RNNs, which must be processed sequentially) allow the model to scale to more parameters.
- This model is related but a little bit different from a standard Language Model.



BERT (Bidirectional Encoder Representations from Transformers)

- BERT doesn't predict the next word in a sentence like a traditional language model, but rather learns utilizes a "**masked language modeling**" (MLM) objective during pre-training.
- In MLM, random words in a sentence are masked and the model is trained to predict those masked words based on the surrounding context.
- BERT also incorporates a "**next sentence prediction**" task, where pairs of sentences are fed to the model, and it learns to predict whether the second sentence follows the first in the original text.
- **Fine-tuning** BERT involves adding a task-specific layer on top of the pre-trained model and training it on a labeled dataset for the target task.
- BERT achieved state-of-the-art results at the time of its release on NLP tasks, including sentence classification, named entity recognition, question answering, and more.

Masked Language Modeling and Next Sentence Prediction

- MLM: Mask out k% of the input words, and then predict the masked words
 - They always use $k = 15\%$.

	store	gallon
	↑	↑
the man went to the [MASK] to buy a [MASK] of milk		

- Too little masking: Too expensive to train
 - Too much masking: Not enough context

Masked Language Modeling and Next Sentence Prediction

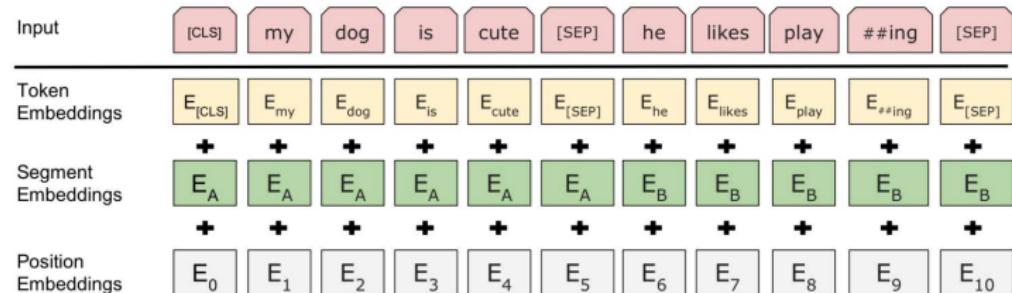
- Next sentence prediction: To learn relationships between sentences, predict whether Sentence B is actual sentence that proceeds Sentence A, or a random sentence

Sentence A = The man went to the store.
Sentence B = He bought a gallon of milk.
Label = IsNextSentence

Sentence A = The man went to the store.
Sentence B = Penguins are flightless.
Label = NotNextSentence

BERT sentence pair encoding

- Token embeddings: Words are divided into smaller units called word pieces, and each word piece is assigned a token embedding.
- BERT learns a segmented embedding [SEP] to differentiate between the two sentences in a pair.
- BERT utilizes positional embeddings to capture the position of each word within the sentence.

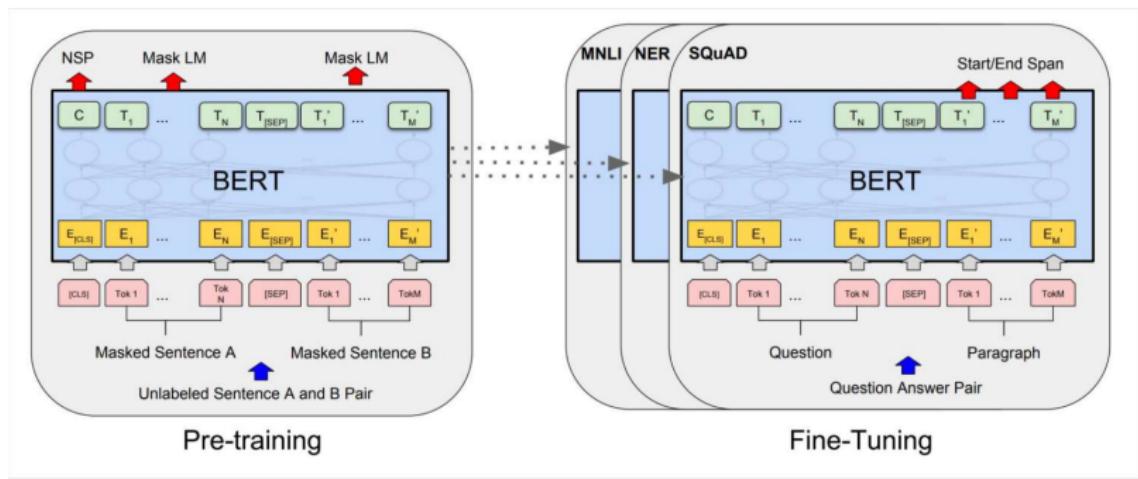


BERT Model Architecture and Training

- BERT is based on the Transformer encoder.
- The multi-headed self-attention block of the Transformer allows BERT to consider long-distance context effectively.
- The use of self-attention also enables efficient computations on GPU/TPU, with only a single multiplication per layer.
- BERT was trained on a large amount of unlabeled text data from Wikipedia and BookCorpus.
- Two different model sizes were trained:
 1. BERT-Base: 12 layers, 768 hidden units, and 12 attention heads.
 2. BERT-Large: 24 layers, 1024 hidden units, and 16 attention heads.
- The training process involved utilizing 4x4 or 8x8 TPU (Tensor Processing Unit) configurations for faster computation.
- Training BERT models took approximately 4 days to complete.

BERT model fine tuning

- Fine-tuning involves customizing the pre-trained BERT model for specific tasks.
- To fine-tune BERT, we add a task-specific layer on top of the pre-trained BERT model.
- The task-specific layer can vary depending on the task at hand, such as sequence labeling or sentence classification.
- We train the entire model, including the pre-trained BERT and the added task-specific layer, for the specific task.



BERT results on GLUE tasks

- BERT was massively popular and hugely versatile; finetuning BERT led to new state-of-the-art results on a broad range of tasks.
- BERT's performance was assessed using the GLUE benchmark, a collection of diverse NLP tasks.
- The GLUE benchmark primarily consists of natural language inference tasks, but also includes sentence similarity and sentiment analysis tasks.

Example Task: MultiNLI (Natural Language Inference)

- Premise: "Hills and mountains are especially sanctified in Jainism."
- Hypothesis: "Jainism hates nature."
- Label: Contradiction

Example Task: CoLa

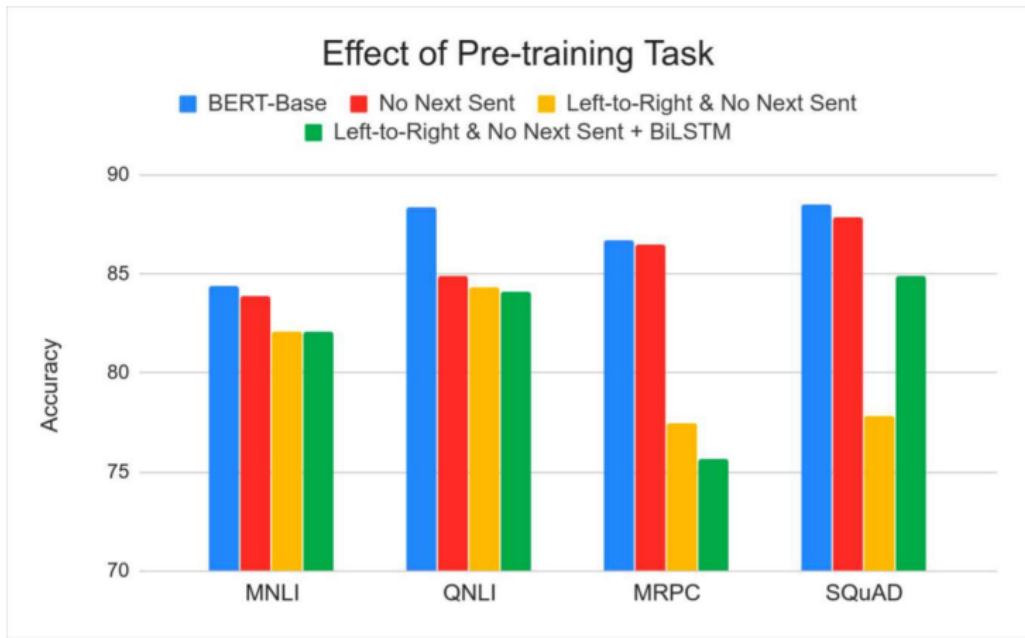
- Sentence: "The wagon rumbled down the road."
- Label: Acceptable
- Sentence: "The car honked down the road."
- Label: Unacceptable

BERT results on GLUE tasks

System	MNLI-(m/mm) 392k	QQP 363k	QNLI 108k	SST-2 67k	CoLA 8.5k	STS-B 5.7k	MRPC 3.5k	RTE 2.5k	Average
Pre-OpenAI SOTA	80.6/80.1	66.1	82.3	93.2	35.0	81.0	86.0	61.7	74.0
BiLSTM+ELMo+Attn	76.4/76.1	64.8	79.9	90.4	36.0	73.3	84.9	56.8	71.0
OpenAI GPT	82.1/81.4	70.3	88.1	91.3	45.4	80.0	82.3	56.0	75.2
BERT _{BASE}	84.6/83.4	71.2	90.1	93.5	52.1	85.8	88.9	66.4	79.6
BERT _{LARGE}	86.7/85.9	72.1	91.1	94.9	60.5	86.5	89.3	70.1	81.9

- QQP: Quora Question Pairs (detect paraphrase questions)
- QNLI: natural language inference over question answering data
- SST-2: sentiment analysis
- CoLA: corpus of linguistic acceptability (detect whether sentences are grammatical.)
- STS-B: semantic textual similarity
- MRPC: microsoft paraphrase corpus
- RTE: a small natural language inference corpus

BERT Effect of pre-training task



Pre-training decoders GPT and GPT-2

- Contemporary to BERT, OpenAI introduced an alternative approach called Generative Pretrained Transformer (GPT) [Radford et al.,].
- The idea behind GPT is to train a large standard language model using the generative part of the Transformer, specifically the decoder.
- GPT is a Transformer decoder with 12 layers and 117 million parameters.
- It has 768-dimensional hidden states and 3072-dimensional feed-forward hidden layers.
- GPT utilizes byte-pair encoding with 40,000 merges to handle subword units.
- GPT was trained on BooksCorpus, which consists of over 7,000 unique books.
- OpenAI later introduced GPT-2, a larger version with 1.5 billion parameters, trained on even more data.
- GPT-2 has been shown to generate relatively convincing samples of natural language.

GPT-2 language model (cherry-picked) output

Human provided prompt:

In a shocking finding, scientist discovered a herd of unicorns living in a remote, previously unexplored valley, in the Andes Mountains. Even more surprising to the researchers was the fact that the unicorns spoke perfect English.

Model Completion:

The scientist named the population, after their distinctive horn, Ovid's Unicorn. These four-horned, silver-white unicorns were previously unknown to science.

Now, after almost two centuries, the mystery of what sparked this odd phenomenon is finally solved.

Dr. Jorge Pérez, an evolutionary biologist from the University of La Paz, and several companions, were exploring the Andes Mountains when they found a small valley, with no other animals or humans. Pérez noticed that the valley had what appeared to be a natural fountain, surrounded by two peaks of rock and silver snow.

What kinds of things does pretraining learn?

- Stanford University is located in _____, California. [Trivia]
- I put _____ fork down on the table. [syntax]
- The woman walked across the street, checking for traffic over _____ shoulder. [coreference]
- I went to the ocean to see the fish, turtles, seals, and _____. [lexical semantics/topic]
- Overall, the value I got from the two hours watching it was the sum total of the popcorn and the drink. The movie was _____. [sentiment]
- Iroh went into the kitchen to make some tea. Standing next to Iroh, Zuko pondered his destiny. Zuko left the _____. [some reasoning – this is harder]
- I was thinking about the sequence that goes 1, 1, 2, 3, 5, 8, 13, 21, _____. [some basic arithmetic; they don't learn the Fibonacci sequence]

Phase Change: GPT-3 (2020)

- GPT-3 is another Transformer-based Language Model (LM) that pushed the boundaries with nearly 200 billion parameters, making it the largest model at the time [Brown et al., 2020].
- It was trained on a massive corpus consisting of nearly 500 billion words.
- **In-context learning:** GPT-3 demonstrated the ability to solve various natural language processing (NLP) tasks using **zero-shot**, **one-shot** and **few-shot learning**.
- The key to this capability lies in the prompt or context provided to GPT-3.
- GPT-3 demonstrated the ability to solve various tasks without performing gradient updates to the base model.



Zero-shot, One-shot, and Few-shot Learning with GPT-3

- **Zero-shot learning:** With zero-shot learning, GPT-3 can tackle tasks without any specific training. It achieves this by providing a prompt or instruction to guide its generation process. For example, by providing GPT-3 with a prompt like, “Translate this English sentence to French,” it can generate the translated sentence without any explicit training for translation tasks.
- **One-shot learning:** In one-shot learning, GPT-3 can perform a task by adding a single input-output pair to the instruction.
- **Few-shot learning:** similar idea but providing a limited number input-output pairs after the instruction in the prompt.

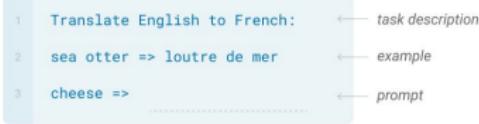
Zero-shot, One-shot, and Few-shot Learning with GPT-3

The three settings we explore for in-context learning

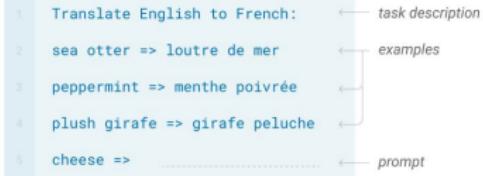
Zero-shot



One-shot



Few-shot

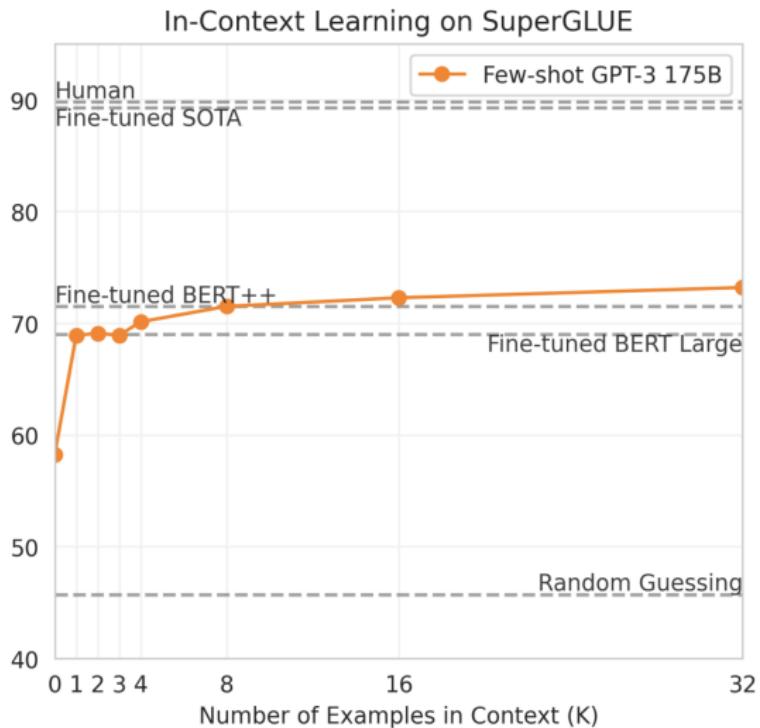


Traditional fine-tuning (not used for GPT-3)

Fine-tuning



GPT-3 Few-shot Learning Results



Chain-of-thought prompting

- Chain-of-thought prompting is a simple mechanism for eliciting multi-step reasoning behavior in large language models.
- Idea: augment each exemplar in few-shot prompting with a chain of thought for an associated answer [Wei et al., 2022]

Chain-of-thought prompting

Standard Prompting

Model Input

Q: Roger has 5 tennis balls. He buys 2 more cans of tennis balls. Each can has 3 tennis balls. How many tennis balls does he have now?

A: The answer is 11.

Q: The cafeteria had 23 apples. If they used 20 to make lunch and bought 6 more, how many apples do they have?

Model Output

A: The answer is 27. X

Chain-of-Thought Prompting

Model Input

Q: Roger has 5 tennis balls. He buys 2 more cans of tennis balls. Each can has 3 tennis balls. How many tennis balls does he have now?

A: Roger started with 5 balls. 2 cans of 3 tennis balls each is 6 tennis balls. $5 + 6 = 11$. The answer is 11.

Q: The cafeteria had 23 apples. If they used 20 to make lunch and bought 6 more, how many apples do they have?

Model Output

A: The cafeteria had 23 apples originally. They used 20 to make lunch. So they had $23 - 20 = 3$. They bought 6 more apples, so they have $3 + 6 = 9$. The answer is 9. ✓

Language Models as User Assistants (or Chatbots)

- Autoregressive Large Language Models are not aligned with user intent [Ouyang et al., 2022]

PROMPT *Explain the moon landing to a 6 year old in a few sentences.*

COMPLETION GPT-3

Explain the theory of gravity to a 6 year old.

Explain the theory of relativity to a 6 year old in a few sentences.

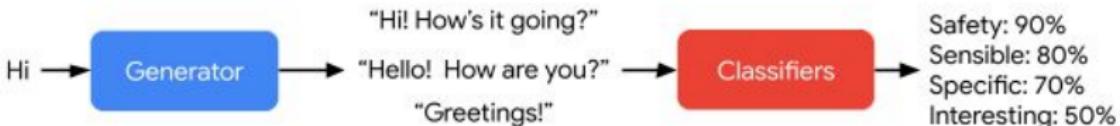
Explain the big bang theory to a 6 year old.

Explain evolution to a 6 year old.

- Solution: align the language model with user intent via fine-tuning.

LaMDA: Language Models for Dialog Applications

- LaMDA is a language model developed by Google based on Transformer optimized for open domain dialog [Thoppilan et al., 2022].
- It has 137 billion parameters and is trained on 1.56 billion words.
- It is initially pre-trained in the same way as traditional language models (predicting words) with language models (predicting words) with a strong focus on dialog data.
- It is then fine-tuned to generate responses with respect to several other criteria.
- In order to fit LaMBDA to all these criteria they worked with a large number of crowd-workers.
- These are people who manually labeled conversations from the pre-trained model.



LaMDA Optimization Criteria

Quality

- Sensibleness: give meaningful answers.
- Specificity: avoid vague answers.
- Interestingness: give insightful, unexpected or witty answers.

Safety

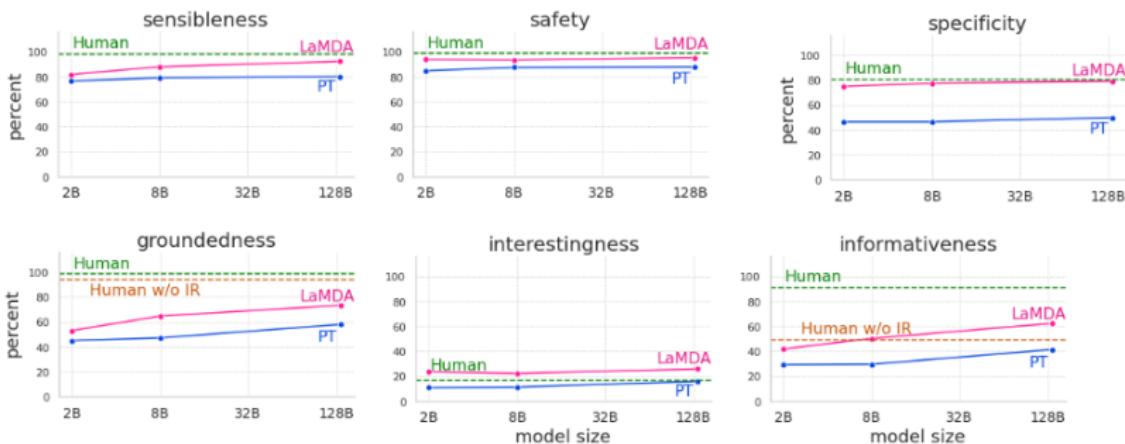
- Avoid violent language.
- Avoid hate speech.
- Avoid stereotyped speech.

Groundedness and Informativity

- Avoid giving answers not validated by external sources.
- Optimize the fraction of responses that can be validated in authoritative sources using search engines.

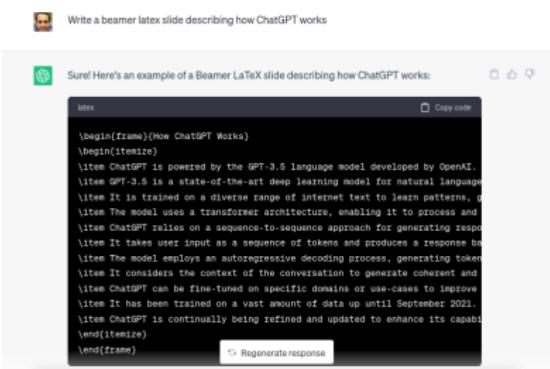
LaMDA Evaluation

- The system is compared with the original pre-trained PT model and human judgments.
- The evaluation is done by another group of people through questionnaires.



ChatGPT and RLHF

- Model similar to LaMDA launched by OpenAI at the end of 2022.
- It also uses Crowdsourcing to improve its responses, but its fine-tuning process uses Reinforcement Learning (RL), a different learning paradigm from supervised learning.
- In particular, it uses Reinforcement Learning from Human Feedback (RLHF) [Ouyang et al., 2022].
- It builds a preference model that assigns a score to a generated sentence and adjusts the language model accordingly.

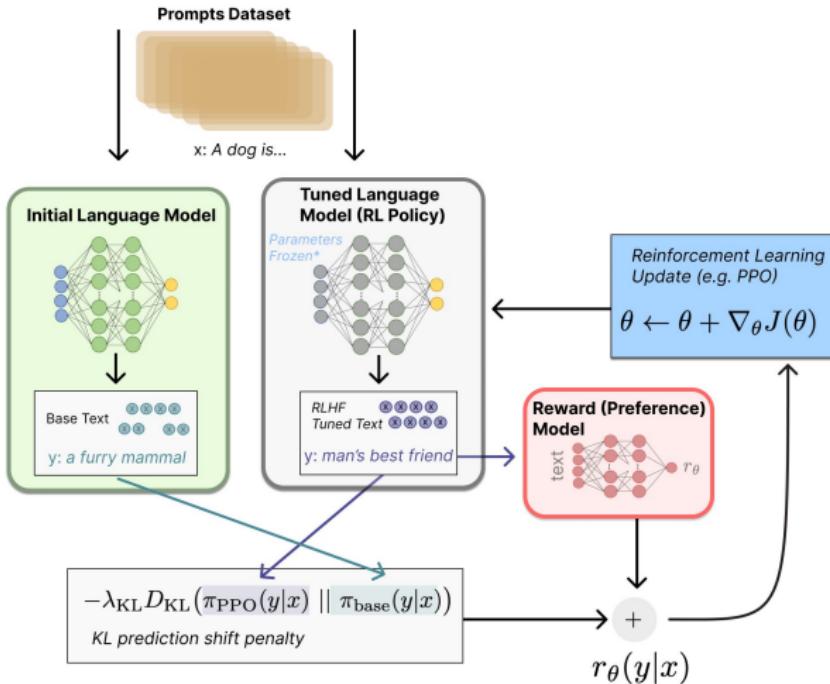


A screenshot of a ChatGPT interface. At the top, there's a text input field with the placeholder "Write a beamer latex slide describing how ChatGPT works". Below it, a response is shown in a code editor-like window with syntax highlighting for LaTeX. The code is:

```
\begin{frame}{How ChatGPT Works}
\begin{itemize}
\item ChatGPT is powered by the GPT-3.5 language model developed by OpenAI.
\item GPT-3.5 is a state-of-the-art deep learning model for natural language processing.
\item It is trained on a diverse range of internet text to learn patterns, grammar, and meaning.
\item The model uses a transformer architecture, enabling it to process and generate text in multiple languages.
\item ChatGPT relies on a sequence-to-sequence approach for generating responses.
\item It takes user input as a sequence of tokens and produces a response based on those tokens.
\item The model employs an autoregressive decoding process, generating tokens one at a time.
\item It considers the context of the conversation to generate coherent and relevant responses.
\item ChatGPT can be fine-tuned on specific domains or use-cases to improve its performance.
\item It has been trained on a vast amount of data up until September 2021.
\item ChatGPT is continually being refined and updated to enhance its capabilities.
\end{itemize}
\end{frame}
```

At the bottom right of the code editor, there's a button labeled "Regenerate response".

ChatGPT and RLHF



Source: <https://huggingface.co/blog/rlhf>

GPT-4 (2023)

- Last LM of OpenAI [OpenAI, 2023], this time able to include images in the prompt.
- Still a Transformer LM.
- Able to pass exams in several disciplines being able to process the images of the questions.
- From ChatGPT onwards, companies have stopped making public all the details of the construction of their models.

Example of GPT-4 visual input:

User What is funny about this image? Describe it panel by panel.



Source: <https://www.reddit.com/r/lmmn/comments/ubab6v/lmmn/>

GPT-4 The image shows a package for a "Lightning Cable" adapter with three panels.

Panel 1: A smartphone with a VGA connector (a large, blue, 15-pin connector typically used for computer monitors) plugged into its charging port.

Panel 2: The package for the "Lightning Cable" adapter with a picture of a VGA connector on it.

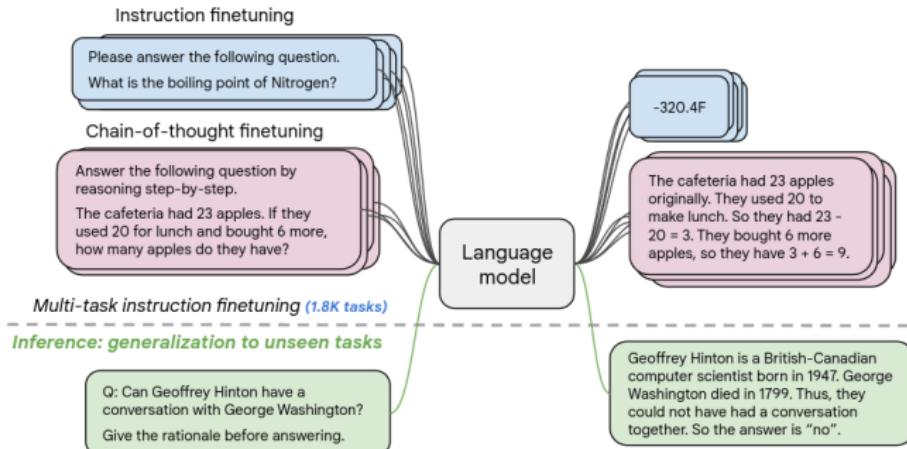
Panel 3: A close-up of the VGA connector with a small Lightning connector (used for charging iPhones and other Apple devices) at the end.

The humor in this image comes from the absurdity of plugging a large, outdated VGA connector into a small, modern smartphone charging port.

Table 3. Example prompt demonstrating GPT-4's visual input capability. The prompt consists of a question about an image with multiple panels which GPT-4 is able to answer.

Instruction finetuning

- A more efficient way to fine-tune Large Language Models is Instruction Fine-Tuning [Chung et al., 2022].
- Idea: collect examples of (instruction, output) pairs across many tasks and finetune an LM.
- Evaluate on unseen tasks.



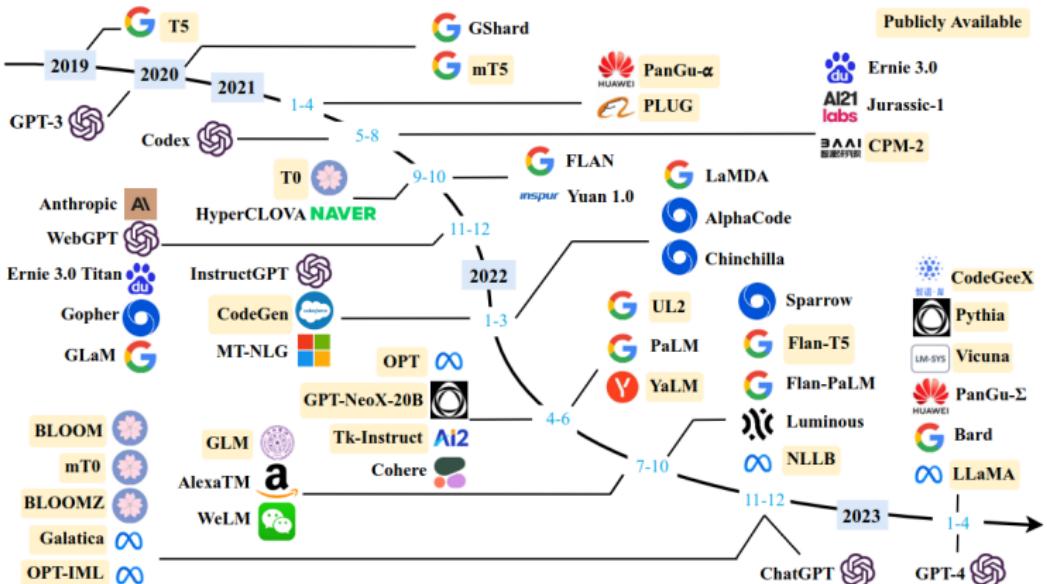
Dangers of Large Language Models

The research community has raised concerns about several dangers associated with Large Language Models [Bender et al., 2021].

- **Hallucination:** Probabilistic language models can generate fabricated information lacking factual basis.
- **Fairness:** These models can perpetuate biases present in the training data, including toxic language, racism, and gender discrimination.
- **Copyright infringement:** Large language models may violate copyright laws by reproducing content without proper authorization.
- **Lack of transparency:** The complex nature of these models makes it difficult to interpret their predictions and understand the reasoning behind specific responses.
- **Monopolization:** The high costs of training these models create barriers for non-big-tech companies to compete.
- **High carbon footprint:** The energy-intensive training process of these models contributes to a significant carbon footprint.

Large Language Models Time-line

- As of today (2023), the development of new Large Language Models continues uninterrupted.



- A timeline of existing large language models (having a size larger than 10B) in recent years [Zhao et al., 2023].

Prompt Engineering

- Prompt engineering is a new discipline for developing and optimizing prompts to efficiently use language models (LMs).

ChatGPT Prompting Cheat Sheet



How Prompt Engineering Works

Note: Prompt engineering designs and optimizes prompts for language models.

It's important in NLP and language generation. Prompt formats guide the model and can be used for tasks like product descriptions or conversational AI.

Reliable prompt formats exist, but exploring new formats is encouraged.

"(your input here)" is a placeholder for text or context

Rules of Thumb and Examples

Rule #1 – instructions at beginning and ### or * to separate instructions or context**

Rewrite the text below in more engaging language.
Text: ***
(your input here)

Rewrite the text below in more engaging language.
Text: ***
(your input here)

Rule #2 – Be specific and detailed about the desired context, outcome, length, format, and style.

Write a short story for kids

Write a funny soccer story for kids that teaches the kid that persistence is key for success in the style of Rowling.

Rule #3 – Give examples of desired output format

Extract house pricing data from the following text.
Text: ***
(your text containing pricing data)

Extract house pricing data from the following text.
Desired format: ***
House 1 | \$1,000,000 | 100 sqm
House 2 | \$1,500,000 | 90 sqm
... (and so on)

Text: ***
(your text containing pricing data)

Rule #4 – First try without examples, then try giving some examples.

Extract brand names from the text below.
Text: (your text here)
Brand names:

Extract brand names from the texts below.
Text 1: Finxter and YouTube are tech companies. Google is too.
Brand names 2: Finxter, YouTube, Google

Text 2: If you like tech, you'll love Finxter!
Brand names 2: Finxter

Text 3: (your text here)
Brand names 3:

Rule #5 – Fine-tune if Rule #4 doesn't work

Fine-tuning improves model performance by training on more examples, resulting in higher quality results, token savings, and lower latency requests. ChatGPT can automatically generate plausible completions from few examples, though it's not perfect.

Fine-tuning achieves better results on various tasks without requiring examples in the prompt, saving costs and enabling lower-latency requests.

Example Training Data

```
{"prompt": "inputs", "completion": "ideal output"}  
[{"prompt": "inputs", "completion": "ideal output"}, {"prompt": "inputs", "completion": "ideal output"}]  
...
```

Rule #6 – Be specific. Omit needless words.

ChatGPT, write a sales page for my company selling sand in the desert, please write only a few sentences, nothing long and complex

Write a 5-sentence sales page, sell sand in the desert.

Rule #7 – Use leading words to nudge the model toward a pattern

Write a Python Function that plots my net worth over 10 years for different inputs on the initial investment and a given ROI

Python function that plots net worth over 10 # years for different inputs on the initial # investment and a given ROI

import matplotlib

def plot_net_worth(initial, roi):

Conclusions

- The growth in the size and power of language models has accelerated dramatically.
- It is very difficult to predict what they will do in the future.
- What can we predict with confidence?
- There will be an overload of generative models for multiple formats (text, code, image, video, virtual realities).
- There will be a plethora of agents/programs that act and make decisions by interacting with these models (medical appointments, investments, travel).

Questions?

Thanks for your Attention!

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