

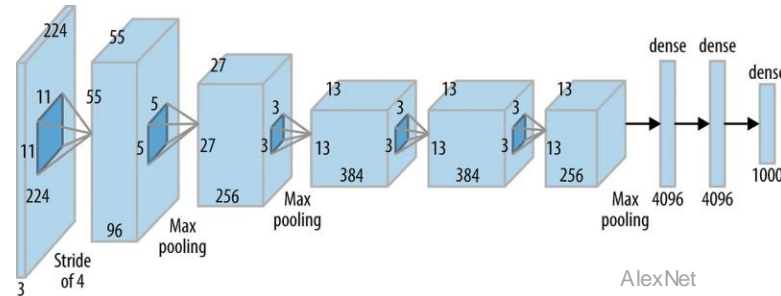
# cosmosage

## Executive Summary:

- cosmosage is a natural language assistant for cosmologists
- It is trained on a variety of data including textbooks & scientific papers
- The code and model weights are public
- I intend to make a website where you can use cosmosage in the near future

# The current progress in deep learning is fascinating.

- 2012: ImageNet challenge won by deep learning AlexNet



- 2017: “Attention is all you need”

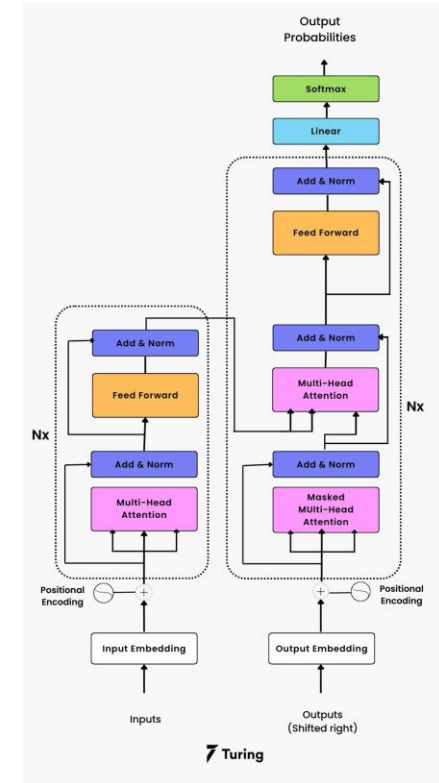
Chowdhery et al. (2022)

Input: Michael is at that really famous museum in France looking at its most famous painting. However, the artist who made this painting just makes Michael think of his favorite cartoon character from his childhood. What was the country of origin of the thing that the cartoon character usually holds in his hand?

- 2021: PaLM 540B

PaLM: The most famous painting in the Louvre is the Mona Lisa. The artist who made the Mona Lisa is Leonardo da Vinci. Leonardo da Vinci is also the name of the main character in the cartoon Teenage Mutant Ninja Turtles. Leonardo da Vinci is from Italy. The thing that Leonardo da Vinci usually holds in his hand is a katana. The country of origin of the katana is Japan. The answer is "Japan".

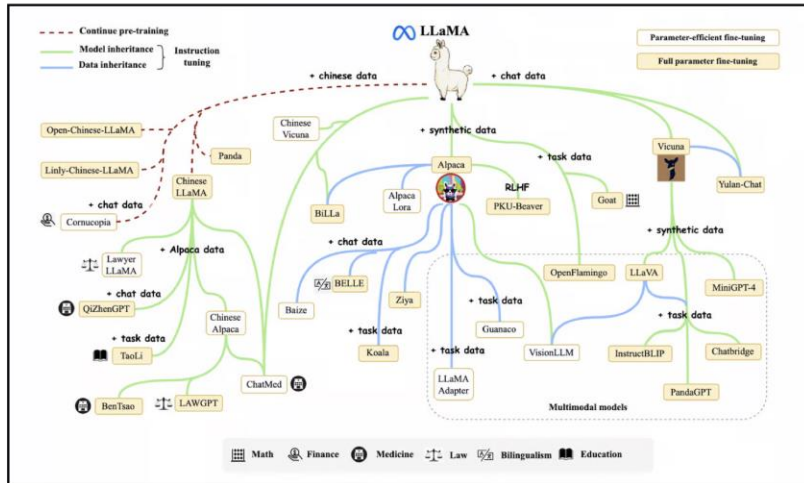
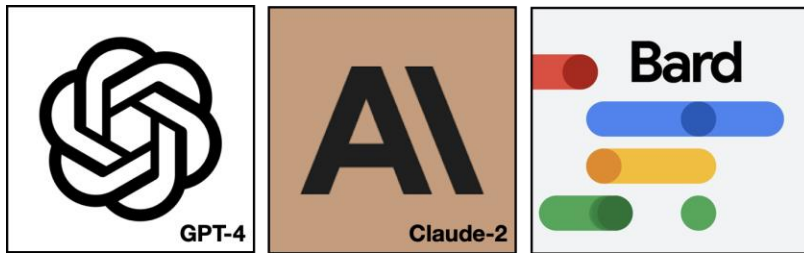
- 2022: ChatGPT 



Transformer architecture like Vaswani et al. (2017)

# The LLM landscape consists of commercial and open-source models.

- Best LLM is currently OpenAI GPT-4
- Thriving open-source community not too far behind
- Rapidly evolving space

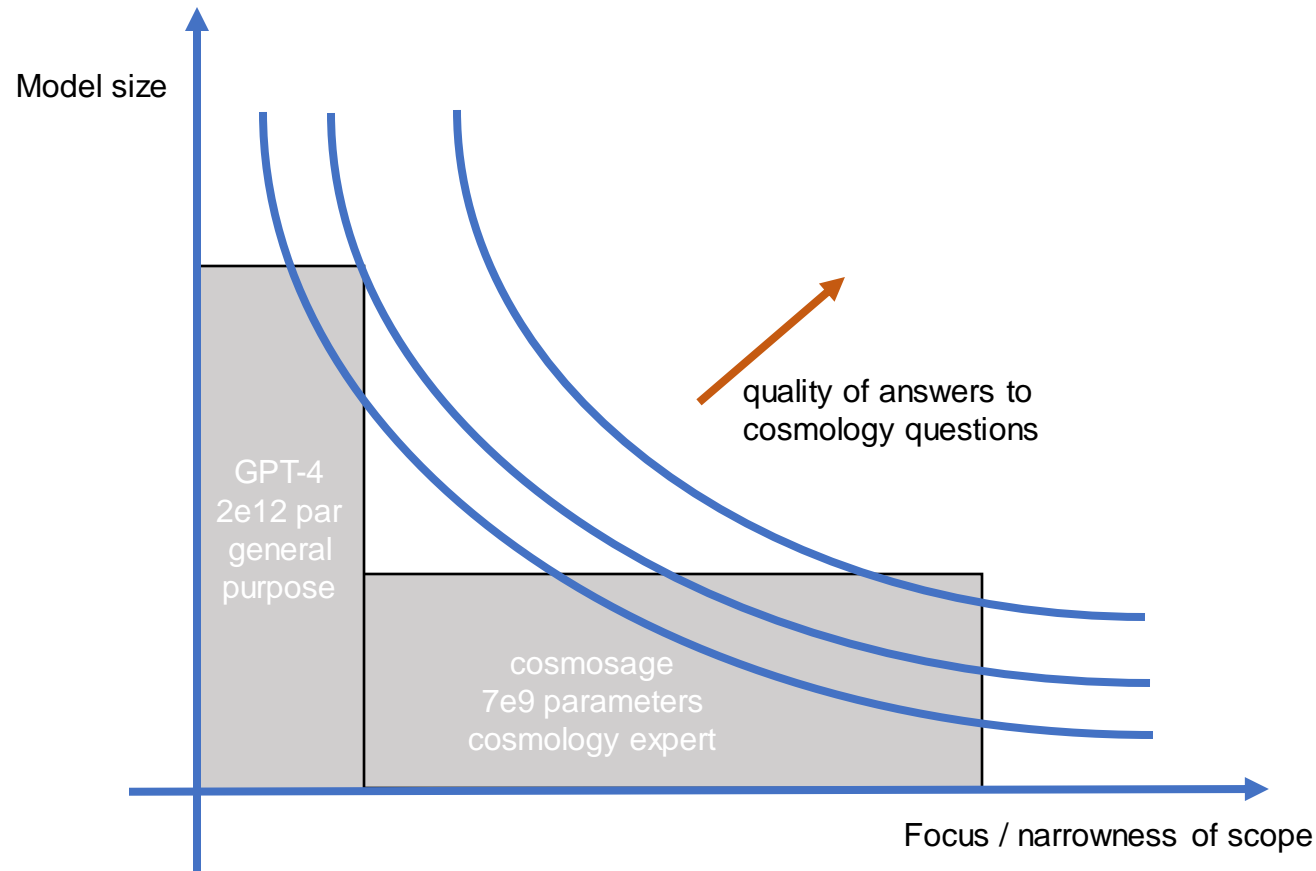


from A. Karpathy ([link](#))



Tijmen de Haan (KEK)

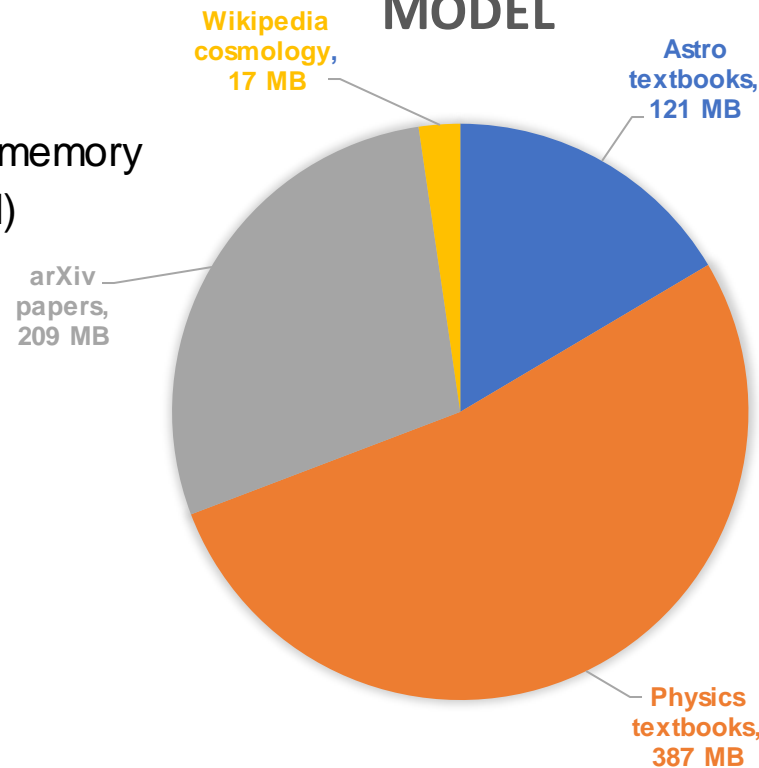
# Even LLMs of modest size can be powerful if their scope is sufficiently narrow.



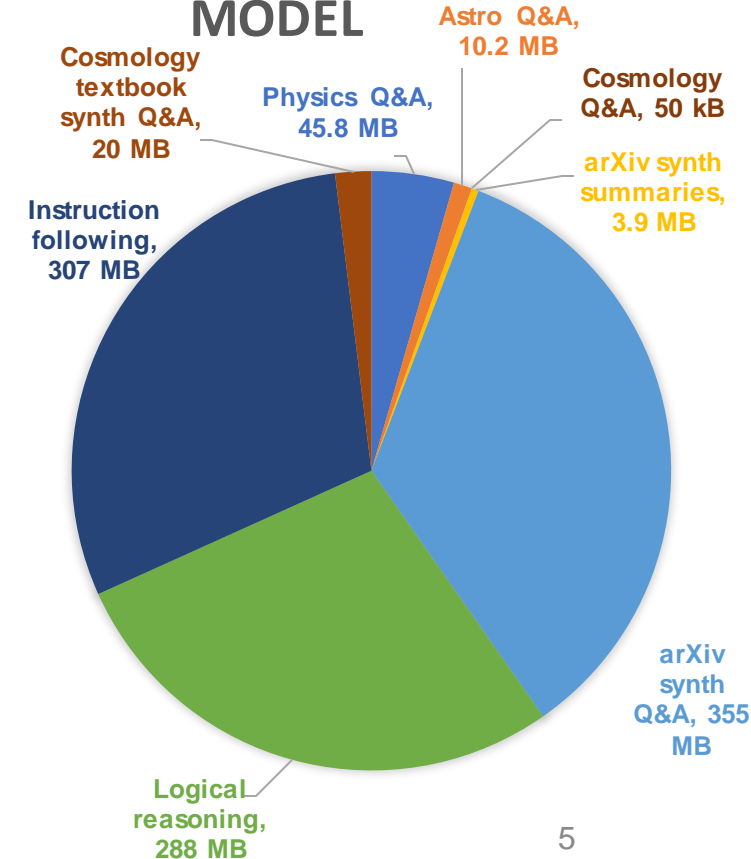
# The most important ingredient to a strong LLM is high-quality data.

- Resources required
  - Pretrained (“base”) model
    - I chose mistral-7B-v0.1 (7e9 parameters)
  - Compute
    - GPUs
    - Usually limited by high-bandwidth memory
    - I am using 1xA6000 (48 GB VRAM)
  - Software
  - Data
    - Quantity
    - Quality
    - Variety
- Fine tuning step (continued pre-training)
- QA tuning (make assistant model)

STEP 1: FINE-TUNED MODEL



STEP 2: ASSISTANT MODEL



# 8000 preprints from the arXiv were selected for training.

<http://35.194.148.148/>

- I host a paper recommendation service
- Selected all upvoted papers
- Recommendation algorithm used to extend the selection

Rank by: tags tags: all pid:  time\_filter (days):  svm\_c:  skip\_have: yes

Shortcuts: [recommend over last week](#) [recommend over last 3 days](#) [recent](#) [random last week](#)

4 theory
5 inflation - measurement
52 instrumentation
1 dark energy - model
14 galaxy clusters
13 white paper
11 CMB analysis
32 cosmological parameters - measurement
3 sources
2 time domain
all

[inspect](#)

**52.40** [Impact of beam far side-lobe knowledge in the presence of foregrounds for LiteBIRD](#)  
*C. Leloup, G. Patanchon, J. Errard, C. Franceschet, J. E. Gudmundsson, S. Henrot-Versillé, H. Imada, H. Ishino, T. Matsumura, G. Puglisi, W. Wang, A. Adler, J. Aumont, R. Aurlier, C. Baccigalupi, M. Ballardini, A. J. Banday, R. B. Barreiro, N. Bartolo, A. Basyrov, M. Bersanelli, D. Blinov, M. Bortolami, T. Brinckmann, P. Campeti, A. Carones, F. Carralot, F. J. Casas, K. Cheung, L. Clermont, F. Columbro, G. Conenna, A. Coppolecchia, F. Cuttaia, G. D'Alessandro, P. de Bernardis, T. de Haan, M. De Petris, S. Della Torre, P. Diego-Palazuelos, H. K. Eriksen, F. Finelli, U. Fuskeland, G. Galloni, M. Galloway, M. Georges, M. Gerbino, M. Gervasi, R. T. Génova-Santos, T. Ghigna, S. Giardiello, C. Gimeno-Aro, E. Gjerlow, A. Gruppuso, M. Hazumi, L. T. Hergt, D. Herranz, E. Hivon, T. D. Hoang, B. Jost, K. Kohri, N. Krachmalnicoff, A. T. Lee, M. Lembo, F. Levrier, A. I. Lonappan, M. López-Cañiego, J. Macías-Pérez, E. Martínez-González, S. Masi, S. Matarrese, S. Micheli, M. Monelli, L. Montier, G. Morgante, B. Mot, L. Mousset, T. Namikawa, P. Natoli, A. Novelli, F. Novello, I. Obata, K. Odagiri, L. Pagano, A. Paiella, D. Paoletti, G. Pascual-Cisneros, V. Pavlidou, F. Piacentini, G. Piccirilli, G. Pisano, G. Polenta, N. Raffuzzi, M. Remazeilles, A. Ritacco, A. Rizzieri, M. Ruiz-Granda, Y. Sakurai, M. Shiraishi, S. L. Stever, Y. Takase, K. Tassis, L. Terenzi, K. L. Thompson, M. Tristram, L. Vacher, P. Vielva, I. K. Wehus, G. Weymann-Despres, M. Zannoni, Y. Zhou*  
 Dec 14 2023 [astro-ph.CO](#)

+ -

We present a study of the impact of an uncertainty in the beam far side-lobe knowledge on the measurement of the Cosmic Microwave Background  $\text{B}^{\text{S}}$ -mode signal at large scale. It is expected to be one of the main source of systematic effects in future CMB observations. Because it is crucial for all-sky survey missions to take into account the interplays between beam systematic effects and all the data analysis steps, the primary goal of this paper is to provide the methodology to carry out the end-to-end study of their effect for a space-borne CMB polarization experiment, up to the cosmological results in the form of a bias  $\delta r$  on the tensor-to-scalar ratio  $r$ . LiteBIRD is dedicated to target the measurement of CMB primordial  $\text{B}^{\text{S}}$  modes by reaching a sensitivity of  $\sigma_{\text{B}^{\text{S}}}(\ell) \leq 10^{-3}$  assuming  $r=0$ . As a demonstration of our framework, we derive the relationship between the knowledge of the beam far side-lobes and the tentatively allocated error budget under given assumptions on design, simulation and component separation method. We assume no mitigation of the far side-lobes effect at any stage of the analysis pipeline. We show that  $\delta r$  is mostly due to the integrated fractional power difference between the estimated beams and the true beams in the far side-lobes region, with little dependence on the actual shape of the beams, for low enough  $\delta r$ . Under our set of assumptions, in particular considering the specific foreground cleaning method we used, we find that the integrated fractional power in the far side-lobes should be known at a level as tight as  $\sim 10^{-4}$ , to achieve the required limit on the bias  $\delta r < 1.9 \times 10^{-5}$ . The framework and tools developed for this study can be easily adapted to provide requirements under different design, data analysis frameworks and for other future space-borne experiments beyond LiteBIRD.

[similar](#) [inspect](#)

**40.34** [Crosstalk effects in microwave SQUID multiplexed TES bolometer readout](#)  
*John C. Groh, Zeeshan Ahmed, Shawn W. Henderson, Johannes Hubmayr, John A. B. Mates, Maximiliano Silva-Feaver, Joel Ullom, Cyndia Yu*  
 Nov 09 2023 [astro-ph.IM](#)

+ -

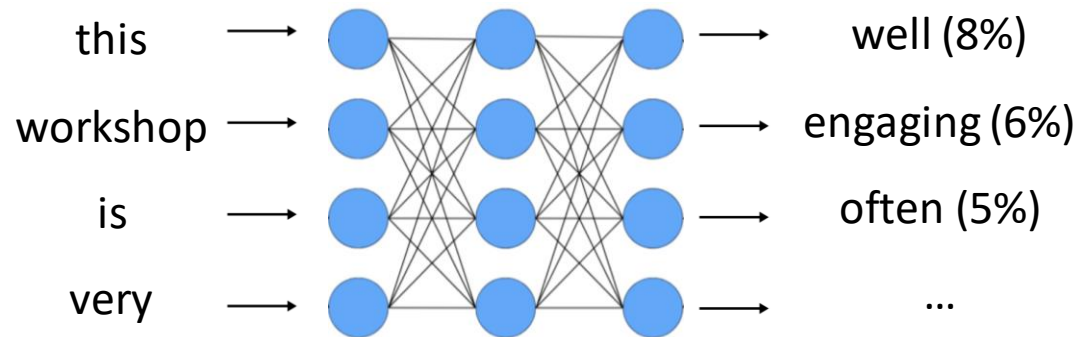
Transition-edge sensor (TES) bolometers are broadly used for background-limited astrophysical measurements from the far-infrared to mm-waves. Many planned future instruments require increasingly large detector arrays, but their scalability is limited by their cryogenic readout electronics. Microwave SQUID multiplexing offers a highly capable scaling solution through the use of inherently broadband circuitry, enabling readout of hundreds to thousands of channels per microwave line. As with any multiplexing technique, the channelization mechanism gives rise to electrical crosstalk which must be understood and controlled so as to not degrade the instrument sensitivity. Here, we explore implications relevant for TES bolometer array applications, focusing in particular on upcoming mm-wave observatories such as the Simons Observatory and AICPT. We model the relative contributions of the various underlying crosstalk mechanisms, evaluate the difference between fixed-tone and tone-tracking readout systems, and discuss ways in which crosstalk nonlinearity will complicate on-sky measurements.

[similar](#) [inspect](#)

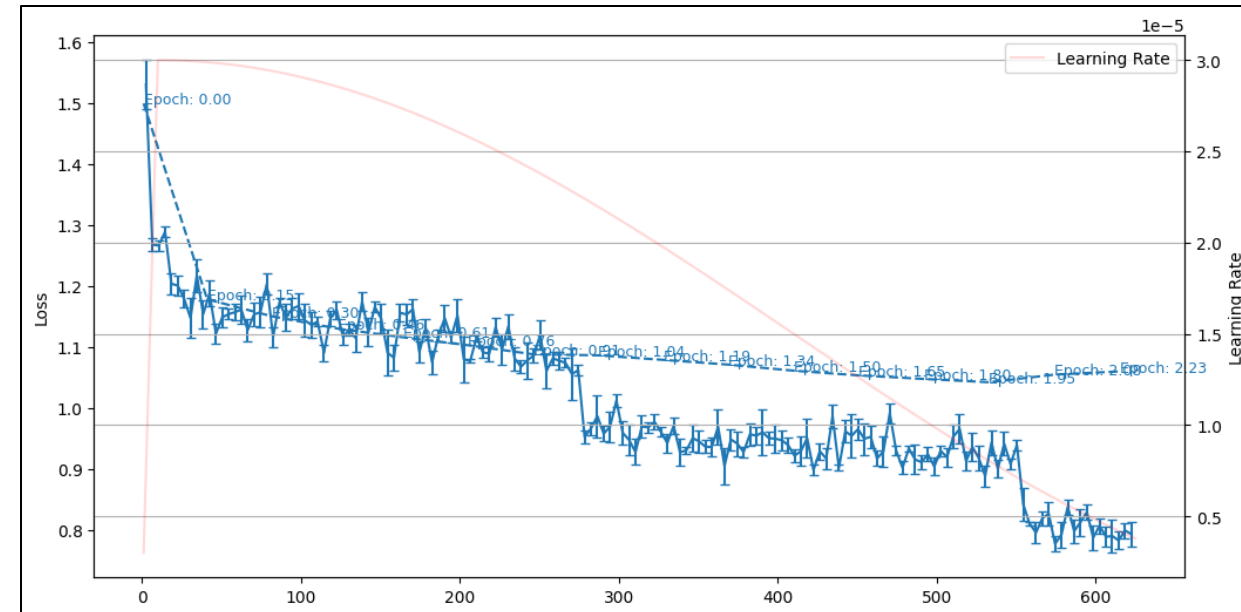
**23.23** [The Simons Observatory: Large-Scale Characterization of 90/150 GHz TES Detector Modules](#)  
*Daniel Dutcher, Shannon M. Duff, John C. Groh, Erin Healy, Johannes Hubmayr, Bradley R. Johnson, Dante Jones, Ben Keller, Lawrence T. Lin, Michael J. Link, Tammy J. Lucas, Samuel Morgan, Yurai Seino, Rita F.*

# Training is updating the neural net weights to make the next word more likely.

- Split into training set, evaluation set
- Optimize loss function
  - Neural net calculates probability distribution of the next word, given the previous words.
  - For example, we might train the model on the sentence  
this workshop is very engaging



- The loss function for the fifth word would evaluate to  
 $\text{loss} = -\log(0.06) = 1.22$
- Change the strength of the connections to minimize loss



# Prompt engineering is the art of asking the question in the right way.

- LLMs are sensitive to *how* you ask the question.
- For example, Wei et al. (2022) found that simply adding “Let’s think step by step.” made their model more than twice as likely to give the correct answer on math problems.
- Few-shot prompting is the practice of giving a few examples before asking your question.
- The industry best practice is unfortunately just experimentation. More art than science for now.

## Example cosmosage prompt

### ## SYSTEM

You are an expert cosmology assistant, able to answer questions on the cosmic microwave background, inflation, big bang nucleosynthesis, cosmology instrumentation, and other topics. Be helpful, concise, and do not insult his or her intelligence. Elaborate where possible to give a complete answer. If you are asked for multiple examples, then be expected to answer one question to the best of your ability.

### ## EXAMPLE 1

**USER:** What is the ISW effect?

**ASSISTANT:** The Integrated Sachs-Wolfe effect describes the fact that cosmic microwave background photons gain energy as they climb back out. The origin of the effect is gravitational redshift. If potentials grow or decay, there is a net effect, known as the Integrated Sachs-Wolfe effect. The late-time ISW effect refers to the fact that at late times, dark energy causes a net effect in the cosmic microwave background which has been measured in cross-correlations with galaxy clusters. Right after recombination, radiation still contributed a non-negligible amount of energy to the photons to gain energy. The early-time ISW has not been detected experimentally.

### ## EXAMPLE 2

**USER:** What are the definitions of galaxy cluster mass ( $M_{200m}$ ,  $M_{500c}$ , etc.)?

**ASSISTANT:** Calculating a galaxy cluster's mass is like calculating the population of stars in a galaxy - it never ends. Eventually you have to stop counting and just say that from there on the mass is constant. The cluster center out to some radius  $r_{\Delta}$  where  $\Delta$  might be 200, 500, or some other number. The mass is  $\Delta$  times the average density of the universe at that redshift. The associated mass includes the energy density of dark energy - in which case you are comparing to the critical density. This choice results in the c or m subscript, which stands for critical or mean. Note that the earlier cutoff in the integral. Therefore ' $M_{\Delta c}$ ' masses are smaller than ' $M_{\Delta m}$ ' ones.

### ## QUESTION

**USER:** <<<INSERT QUESTION>>>

**ASSISTANT:**



# cosmosage\_v0.2 works pretty well.



You

Explain the ISW effect.



ChatGPT

Certainly, let's delve into the Integrated Sachs-Wolfe (ISW) effect in the context of cosmology and astrophysics.

#### Background:

The ISW effect is a phenomenon in cosmology that arises from the interaction between photons of the cosmic microwave background (CMB) and large-scale structures in the universe. To understand this effect, let's break it down step by step.

#### 1. Cosmic Microwave Background (CMB):

The CMB is a faint, nearly uniform radiation that permeates the universe. It is the afterglow of the Big Bang, and it provides a snapshot of the universe's state roughly 380,000 years after its inception. The CMB is highly isotropic and homogeneous, with small temperature fluctuations at the level of one part in 100,000.

#### 2. Large-Scale Structure:

The universe is not uniformly distributed; it consists of a cosmic web of galaxies, clusters of galaxies, and vast empty regions. These structures are not static; they evolve over cosmic time due to gravitational attraction.

#### 3. Gravitational Potential Wells:

As matter accumulates in the regions of the universe where large-scale structures form (such as galaxy clusters), it creates gravitational potential wells. These wells can be thought of as "dips" in the fabric of spacetime where the gravitational pull is stronger.

#### The ISW Effect:

Now, let's tie it all together. The ISW effect occurs when CMB photons travel through these evolving gravitational potential wells associated with large-scale structures. Here's why it's important:

- Expansion of the Universe:** During their journey towards us, CMB photons pass through these gravitational potential wells. If the universe were static, the gravitational redshift (associated with falling into a well) would exactly cancel the cosmological redshift (associated with the expansion of the universe). However, because the universe is expanding, this cancellation doesn't occur perfectly.
- Temperature Anisotropy:** As a result, CMB photons gain or lose energy while traversing these potential wells. When they climb out of a well, they experience a net increase in energy (and thus a blueshift), causing a slight increase in their observed temperature. Conversely, when they fall into a well, they lose energy (and redshift), leading to a decrease in observed temperature.
- Observable Effect:** The ISW effect results in temperature fluctuations in the CMB, typically at larger angular scales. These fluctuations are correlated with the distribution of large-scale structures in the universe. They provide valuable information about the late-time (after the CMB was emitted) evolution of the universe and the growth of cosmic structures.

In summary, the Integrated Sachs-Wolfe effect is a subtle but important phenomenon in cosmology where CMB photons are affected by the evolving gravitational potential wells of large-scale structures as they travel through the expanding universe. This effect has been observed and provides insights into the universe's expansion and the growth of cosmic structures over time.

Me: Explain the ISW effect.

**cosmosage:** The Integrated Sachs-Wolfe (ISW) effect is a phenomenon in cosmology that arises from the gravitational redshift of cosmic microwave background (CMB) photons as they move through the gravitational potentials of large-scale structures in the universe. This effect is named after Arno Penzias, Robert Wilson, Abhay Ashtekar, and Bernard Schutz, who studied it in the 1970s.

The gravitational redshift occurs when a photon's energy changes due to its interaction with a gravitational field. If the field becomes stronger, the photon's energy decreases, and if it becomes weaker, the photon's energy increases. In the context of the ISW effect, the photons from the CMB gain energy as they fall into potential wells formed by the overdense regions of the universe, and lose energy as they climb out of the potential wells.

The net effect of this process depends on the growth or decay of the potential wells over time. In a matter-dominated universe, potential wells remain constant. However, if the potential wells decay due to the influence of dark energy, there will be a net effect on the CMB photons. This late-time ISW effect can be measured through cross-correlation with large-scale structure.

On the other hand, early-time ISW refers to the effect of the CMB photons gaining energy as they fall into potential wells right after recombination, due to the presence of significant amounts of radiation in the universe. This early-time ISW effect is a consequence of the non-negligible energy density of radiation at that time.

# cosmosage is publicly available.

- Both the code and the trained model are available to everyone
- I would like to provide free inference, as well.

[github](#)

[huggingface](#)

2024/01/04

**Tijmen2/cosmosage\_v0.2** like 0

Question Answering Transformers Safetensors Open-Orca/SlimOrca-Dedup English mistral text-generation

Inference Endpoints text-generation-inference License: mit

Model card Files Community Settings

Train Deploy Use in Transformers

Downloads last month: 0

Safetensors Model size: 7.24B params Tensor type: F16

Question Answering

Model is too large to load onto the free Inference API. To try the model, launch it on [Inference Endpoints](#) instead.

Dataset used to train: Tijmen2/cosmosage\_v0.2

Open-Orca/SlimOrca-Dedup

cosmosage

Cosmosage is a natural-language cosmology assistant that can answer questions about cosmology.

cosmosage\_v0.2 is a fine tune of Mistral-7B-v0.1 on various cosmology-related datasets including open-access textbooks and scientific publications. It is intended to be used in Q&A mode, where the model gives a single answer in response to a single question.

See <https://github.com/tijmen/cosmosage> for more details.

Usage

One convenient way of using this model is with `text-generation-webui`

<https://github.com/oobabooga/text-generation-webui>

- Under the Model tab, download custom model, entering "Tijmen2/cosmosage\_v0.2"
- When the download is complete, click the refresh icon next to Model.
- In the Model dropdown, choose `cosmosage_v0.2` and load it.
- Head over to the Notebook tab and ask away!

Prompt Style

Feel free to experiment with different prompts. I've had decent luck with this two-shot prompt, where I leverage any instruction-following capabilities it may have picked up. I also include two example responses I wrote by hand.

```
SYSTEM: You are an expert cosmology assistant, able to answer questions about cosmology.

## EXAMPLE 1

USER: What is the ISW effect?
ASSISTANT: The Integrated Sachs-Wolfe effect describes...

## EXAMPLE 2

USER: What are the definitions of galaxy cluster mass
ASSISTANT: Calculating a galaxy cluster's mass is lik...
```

tijmen2/cosmosage Public

Code Issues Pull requests Actions Projects Security Insights

main 1 branch 0 tags

Go to file Code

About

Fine-tune a 7B LLM on cosmology datasets

Readme MIT license Activity 1 star 2 watching 0 forks Report repository

Releases

No releases published

Packages

No packages published

Languages

Python 72.8% Jupyter Notebook 26.4% Shell 0.8%

README.md

## cosmosage

### Introduction

Large language models are emerging as powerful tools for many natural language tasks. Very large parameter counts of 1e11 or more are needed for a general-purpose model such as GPT-4. However, even small models can be extremely powerful if the application is sufficiently narrow.

cosmosage is an attempt to fine-tune a relatively modest large language model on cosmology-specific datasets with the goal of making a general-purpose natural-language assistant for cosmologists.

### Author

Tijmen de Haan [tijmen.dehaan@gmail.com](mailto:tijmen.dehaan@gmail.com)

### Project Structure

A walkthrough of the project is given in iPython Notebook format in `cosmosage.ipynb`. This notebook walks through the several-step process for fine-tuning the language model on cosmology-specific datasets. It goes through steps for data collection, preprocessing, model training, and evaluation.

### Syntax, Code Style, Tools Used

The `.py` files are kept consistently formatted with `black` on its default settings.

The codebase was written with the use of Pylance, GitHub Copilot, GPT-4, and VSCode fork `cursor`.

### Usage

To get started with cosmosage:

- Ensure you have Jupyter Notebook and the required dependencies
- Open and follow the steps in `cosmosage.ipynb` for a guide to training and using the model.

### Contributing

# Caveat: never trust an LLM to be factual.

- Next-word prediction optimizes for *plausible text* rather than factual accuracy or truthfulness.

MA In 100 words or less, explain the symbolic significance of Yavanna's massive argument with Tulkas in J.R.R. Tolkien's 'The Silmarillion.'

Yavanna's heated argument with Tulkas in J.R.R. Tolkien's "The Silmarillion" represents a

MA In less than 300 words, explain which dog breed is the most popular in the United States. Provide links to five sources.

As of my last knowledge update in January 2022, the Labrador Retriever was the most popular dog breed in the United States. This breed has consistently held the top spot for several years due to its friendly nature, intelligence, and versatility. Here is a brief explanation, along with links to five sources for reference:

1. **American Kennel Club (AKC):** The AKC, a reputable source for breed popularity, reported that the Labrador Retriever maintained its status as the most popular dog breed in the United States in 2021. [AKC Labrador Retriever Ranking](#)
2. **The Labrador Retriever Club:** The national club for Labrador Retriever enthusiasts provides insights into the breed's popularity, including their traits and characteristics. [The Labrador Retriever Club](#)
3. **American Veterinary Medical Association (AVMA):** The AVMA offers data and resources on pet ownership trends, which highlight the Labrador Retriever's prominence. [AVMA Pet Ownership Statistics](#)

sure.  
ce for  
s and  
v.  
E, and  
that African American women  
white women with breast cancer."  
of BRCA1 mutations was the same

prisingly responded, "my previous statement was not accurate, there is no  
n the United States that has found African American women with breast  
carry BRCA1 mutations than white women with breast cancer."

aan (KEK)

# Then what are LLMs actually good for?

- Verifiable information / explanations / sounding board / inspiration / brainstorming
- Search terms
  - “It’s on the tip of my tongue.”
- Programming
  - First pass programming (human verification)
  - Programming w/ human-written unit test (automatic verification)
- Writing
  - Wisdom of crowds

# cosmosage will get much better.

- Many ways to improve on current model
  - Start with stronger base model
  - Train for longer
  - Improve dataset through synthetic dataset generation.
- Possible extensions
  - Japanese / multilingual version
  - RAG
  - Tree of thoughts / Q\* / beam search
  - Retrain for another field. HEPsage?
- I'd like to provide a web page where anyone can use cosmosage.
- I'm open to collaboration, let me know if you're interested in contributing your
  - ideas
  - compute
  - time & effort

[tijmen@post.kek.jp](mailto:tijmen@post.kek.jp)  
[tijmen.dehaan@gmail.com](mailto:tijmen.dehaan@gmail.com)