Large Language Models (LLMs)

Mai Nguyen, Paul Rodriguez and Robert Sinkovits
San Diego Supercomputer Center

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What are LLMs

> “Any sufficiently advanced technology is indistinguishable from magic.”
>
> - Arthur C. Clark

We assume that you’re already familiar with LLMs and what you can do with them - write code, compose essays, summarize text, explain concepts

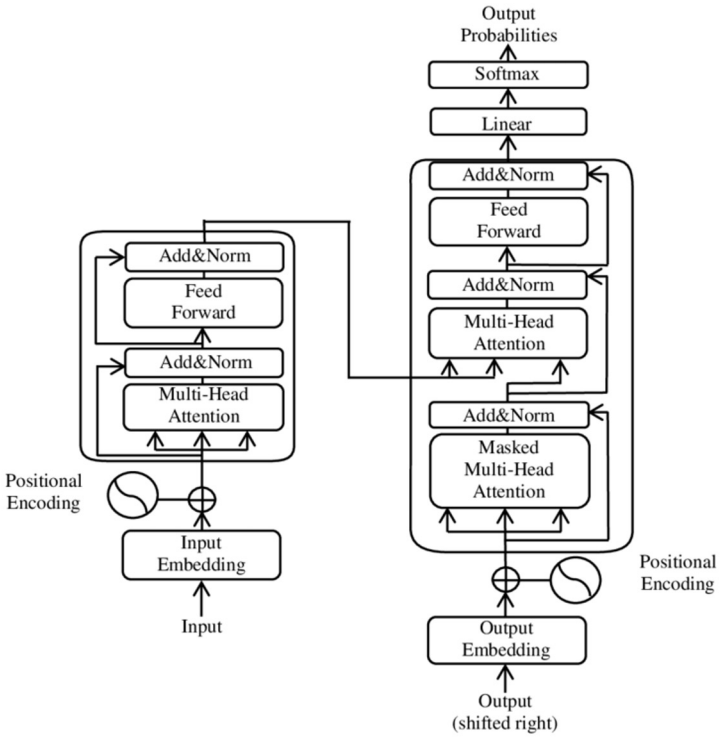
Our goal today is to demystify LLMs, show you how to use them most effectively, demonstrate extending the capabilities of LLMs beyond the data used to train them, and explore their limitations and pitfalls.

What are LLMs

An LLM is a type of generative AI model that learns the statistical relationships between words or tokens after being trained on large amounts of text.

LLMs are based on the transformer architecture, which was introduced in the highly cited (125k times as of 2024) manuscript *Attention is all you need* in 2017.

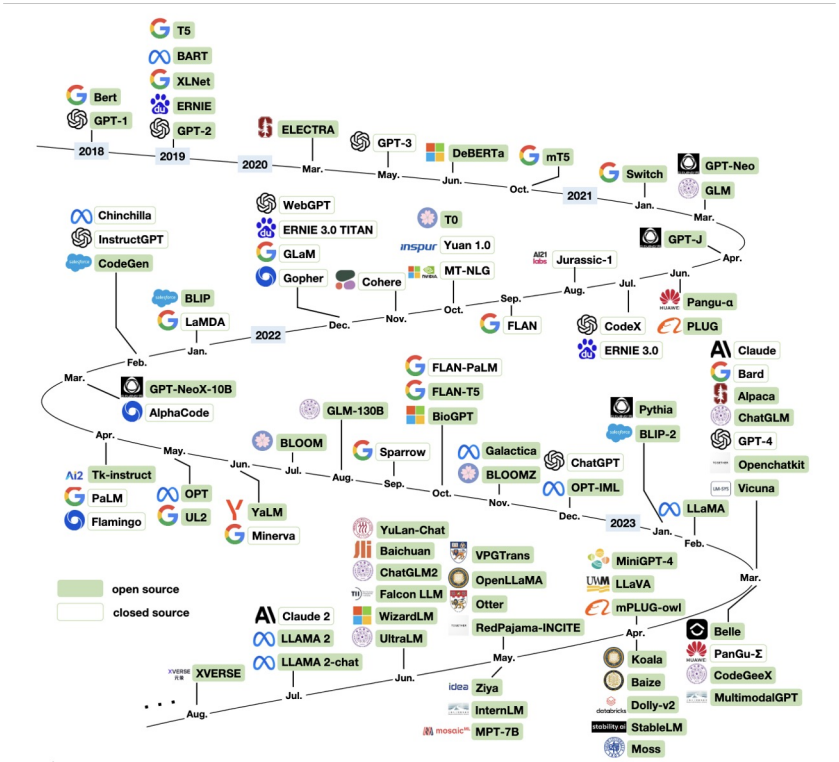
Attention assigns importance to words based on their context in a larger block of text.



Vaswani, Ashish, et al. "Attention is all you need." Advances in neural information processing systems 30 (2017)

There's a lot more than GPT and Gemini

Many users equate LLM with GPT and Gemini, but the ecosystem is much richer. Some of these are deployed as chatbots, while others are intended as research tools (e.g., to explore safe AI) or targeted at specific domains.



Gao et al. https://arxiv.org/pdf/2308.14149

Open source vs. proprietary models

Many of the most powerful LLMs including GPT-4, LaMDA, Gemini and PaLM are proprietary and only available through the web or APIs. Others, such as BLOOM, LLaMa and Mistral 7B are open source and available under Apache, MIT or other licenses.

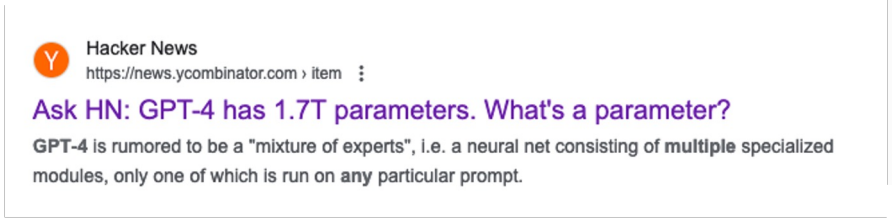
Note that some companies make the older models freely available, while restricting access to source code and hyper-parameter weights for newer or more capable models.

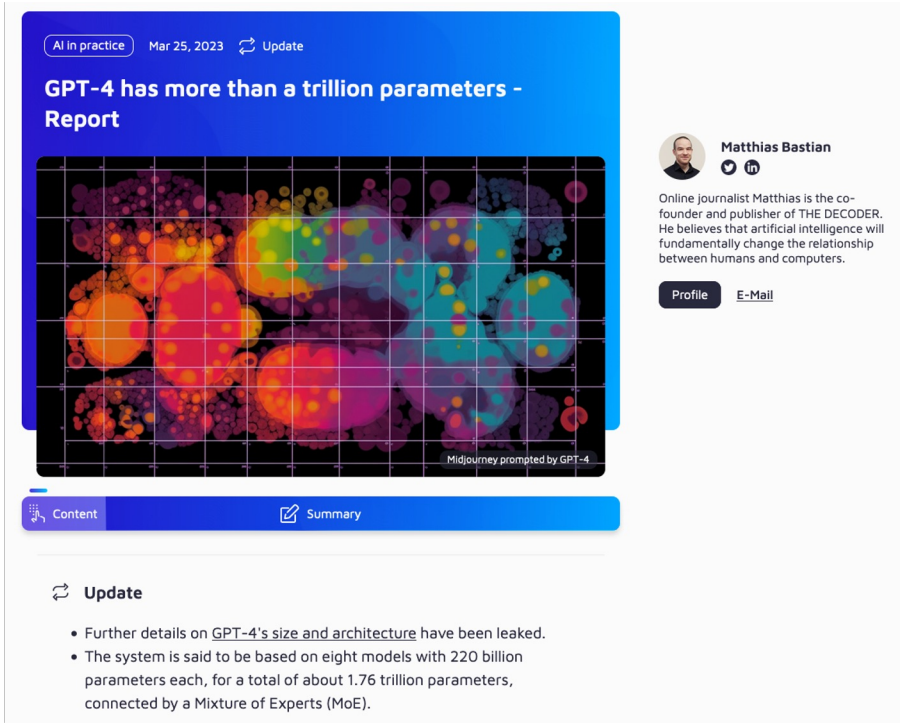
- GPT-1 and GPT-2 – MIT license
- GPT-3 and GPT-4 – Proprietary

- Mistral 75, Mixtral 8x7B, Mixtral 8x22B – Apache 2.0
- Mistral Small, Medium and Large - Proprietary

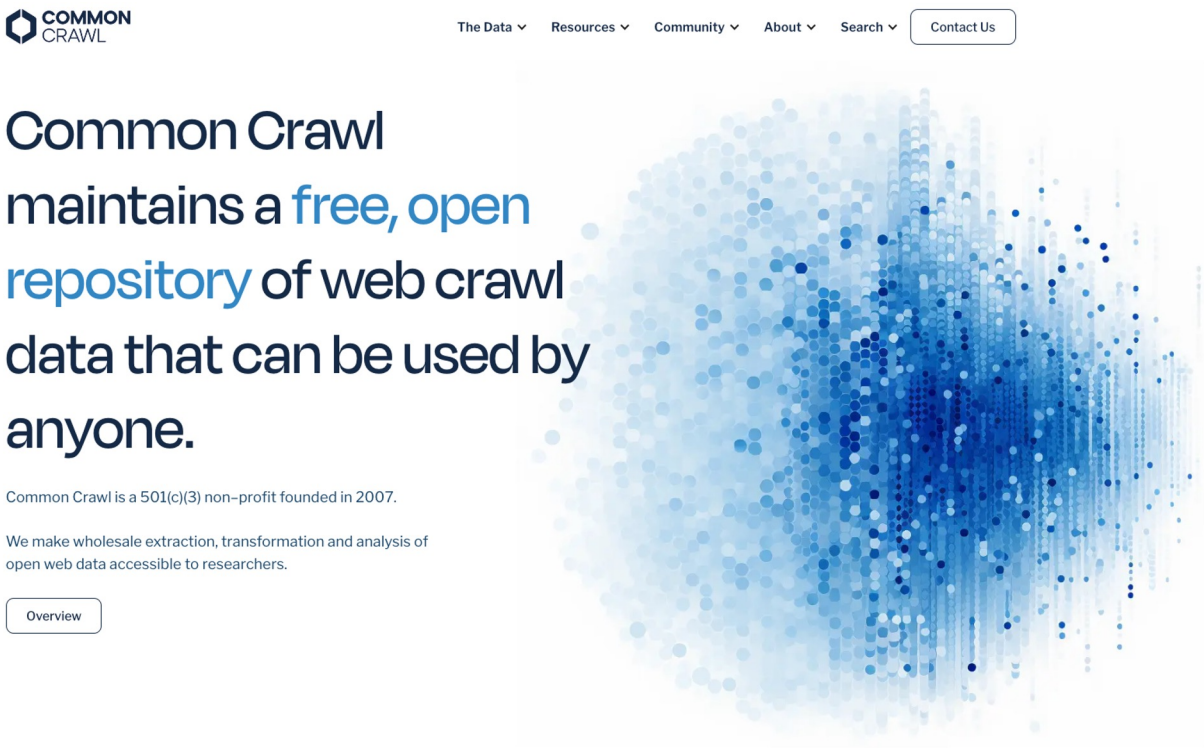
How big are LLMs

- Early models released in 2018 had well under one billion parameters. These include GPT-1 (117 million) and BERT (340 million).
- By the early 2020s, model sizes had grown to hundreds of billions, with Google's GLaM reported to have 1.2 trillion parameters.
- The latest models have not yet released their model sizes, but GPT-4 is estimated to have around 1.76 trillion parameters and Gemini Ultra around 1.5 trillion





Data used to train models

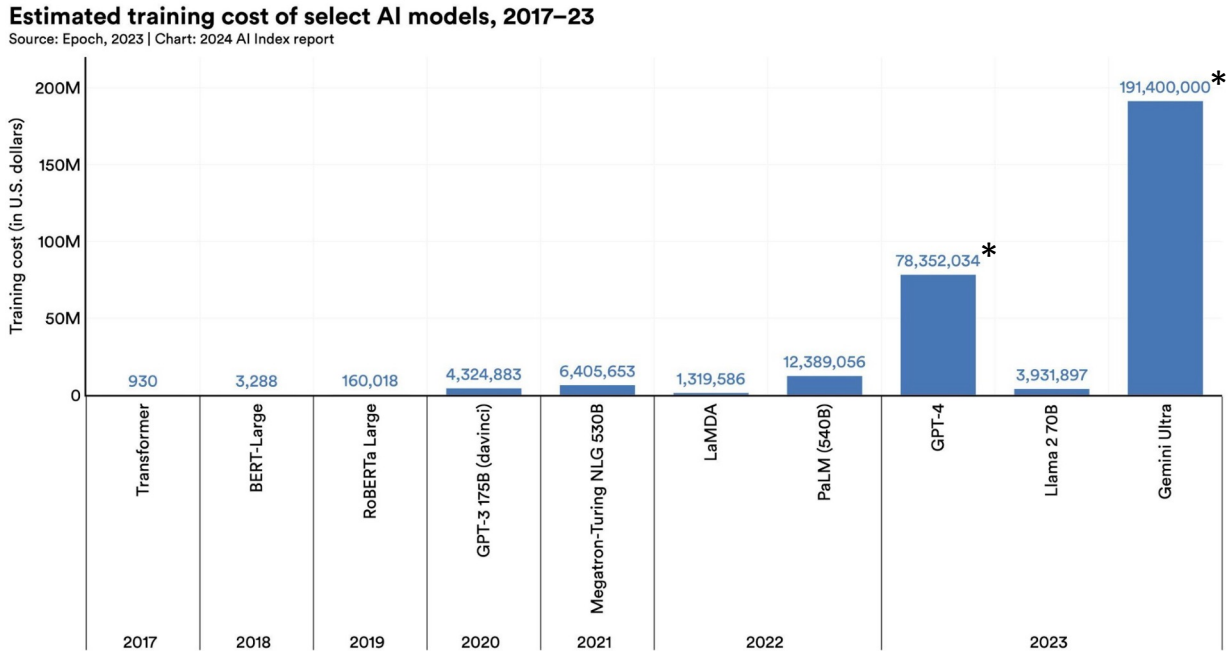


The largest generic LLMs are trained using data scraped from billions of web pages.

Domain-specific LLMs for medicine, law, engineering and other fields are trained using data relevant to that field. This can reduce the likelihood of hallucinations or incorrect results.

Data used to train model should be cleansed to remove toxic content, low-quality data and duplicates.

Cost of training LLMs



As the number of hyper-parameters and size of the corpus grows, the cost of training the LLMs has exploded. It's now impractical for anyone other than the largest players to train the most advanced models.

* estimates

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Cost of training LLMs

PaLM: Scaling Language Modeling with Pathways

Aakanksha Chowdhery* Sharan Narang* Jacob Devlin*
Maarten Bosma Gaurav Mishra Adam Roberts Paul Barham
Hyung Won Chung Charles Sutton Sebastian Gehrmann Parker Schuh Kensen Shi
Sasha Tsvyashchenko Joshua Maynez Abhishek Rao† Parker Barnes Yi Tay
Noam Shazeer‡ Vinodkumar Prabhakaran Emily Reif Nan Du Ben Hutchinson
Reiner Pope James Bradbury Jacob Austin Michael Isard Guy Gur-Ari
Pengcheng Yin Toju Duke Anselm Levskaya Sanjay Ghemawat Sunipa Dev
Henryk Michalewski Xavier Garcia Vedant Misra Kevin Robinson Liam Fedus
Denny Zhou Daphne Ippolito David Luan‡ Hyeontaek Lim Barret Zoph
Alexander Spiridonov Ryan Sepassi David Dohan Shivani Agrawal Mark Omernick
Andrew M. Dai Thanumalayan Sankaranarayana Pillai Marie Pellat Aitor Lewkowycz
Erica Moreira Rewon Child Oleksandr Polozov† Katherine Lee Zongwei Zhou
Xuezhi Wang Brennan Saeta Mark Diaz Orhan Firat Michele Catasta† Jason Wei
Kathy Meier-Hellstern Douglas Eck Jeff Dean Slav Petrov Noah Fiedel

Google Research

Training Google's largest PaLM model required 2.56 x 10^{24} floating point math operations, which is equivalent to running a PetaFLOP supercomputer at 100% efficiency for 81 years

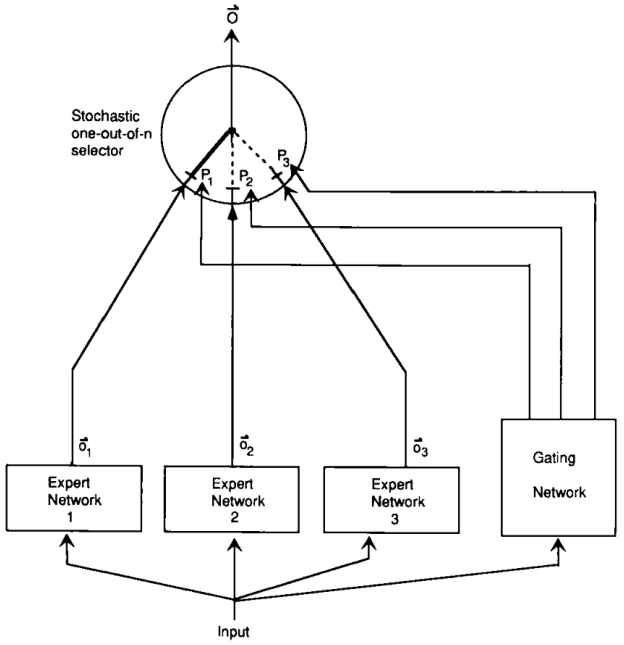
Model	TFLOPs per token		Train FLOPs	PetaFLOP/s-days
	(non-attn+attn)	(non-attn+attn+remat)		
8B	0.0550	0.0561	4.29×10^{22}	497
62B	0.388	0.392	3.08×10^{23}	3570
540B	3.28	4.10	2.56×10^{24}	29600

Table 21: Compute usage to train PaLM 8B and PaLM 540B to 780 billion tokens and PaLM 62B to 795B tokens.

GPT-4, Gemini 1.5 and other newer models have not released details on number of parameters or corpus size, but it's likely that training costs are even higher.

Mixture of experts (MoE) models

- MoE models combine multiple expert networks with a gating network that decides which expert should be used for each task
- Enables models to be trained faster, which is becoming more important as the number of parameters for the largest LLMs is over one trillion
- More efficient since only experts that are best for a given input are used
- Active area of research in tuning MoE models, selecting number of experts to engage, balancing training of experts, etc.



Jacobs et al. "Adaptive mixtures of local experts." *Neural computation* 3.1 (1991): 79-87

Context window

LLMs have a context window, which is the number of tokens in the preceding conversation that are considered when creating a response. Note that tokens can be words, portions of a word or even individual characters depending on how the text is tokenized.

Good morning, which version of GPT am I using?

Good morning! You're currently interacting with ChatGPT, based on the GPT-3.5 architecture.

Can you tell me GPT-3.5's context window?

Certainly! GPT-3.5 has a context window of 2048 tokens. This means it can consider up to 2048 tokens of preceding text to generate a response, which allows it to maintain a substantial amount of context during conversations. If you have more questions about GPT-3.5 or anything else, feel free to ask!

Context window

I would like to plan a garden. Here's a little background about me. I don't have a green thumb and my favorite colors for flowers are red and orange.

Planning a garden sounds like a wonderful project! Even if you don't consider yourself a gardening expert, starting with plants that are relatively easy to grow can be a great way to begin. Here are some ideas to get you started, focusing on red and orange flowers that are generally low-maintenance:

Do you think I should plant roses?

Roses can be a beautiful addition to any garden, including yours! Here are some considerations to help you decide if planting roses is the right choice for you:

Do I have a green thumb?

Based on what you've shared, it sounds like you may not consider yourself to have a green thumb. That's perfectly okay! Having a green thumb often refers to having a natural talent or knack for gardening and plant care. However, gardening is a skill that can be learned and improved over time with knowledge, practice, and patience.

Context window

I would like to plan a garden. Here's a little background about me. I don't have a green thumb and my favorite colors for flowers are red and orange.

Tell me more about geraniums.

Are roses hard to grow?

Is gardening a good form of exercise?

Where are the best places to buy gardening supplies?

Is it expensive to get started in gardening?

What are good choices for a coastal Southern California Climate?

Would those plants also grow well in Arizona?

Is there anything I can do to attract beneficial insects and other pollinators to my garden?

Which plants are pollinated by hummingbirds?

Do I have a green thumb?

Based on our conversation, it seems you're exploring gardening and interested in planning a garden. Whether or not you have a green thumb can depend on your experience, enthusiasm, and willingness to learn and experiment with different plants and gardening techniques.

Context window (update)

Context windows have grown considerably, which means that you'll likely not run into the problems that we saw with GPT-3.5. But 128k tokens is still not infinite, so you'll still have limitations when summarizing very large amounts of text. And you'll still need to pay if you want to be able to do file uploads or large prompts ☹

> The context window for GPT-4o (which you're currently using) is **128,000 tokens** — that's about **300 pages of text** or roughly **96,000–100,000 words**, depending on the language and formatting.
>
> This large window allows the model to:
>
> - Remember and analyze long conversations
> - Handle entire books, large documents, or multi-step reasoning without forgetting earlier parts
> - Maintain continuity over complex, detailed tasks
>
> If you have a specific task in mind that might test the limit, feel free to ask!

LLMs are not infallible

Subtle, but still wrong
Should be beta *plus* decay

5. **Oxygen-15 Decay:**

   - Oxygen-15 undergoes beta decay, turning a proton into a neutron and resulting in the formation of nitrogen-15 (N-15).

```
mathematica                                   Copy code
150 → 15N + e+ + νe
```

6. **Back to Carbon:**

   - The nitrogen-15 can then capture an electron (e-) and emit a neutrino, transforming back into carbon-12.

Very wrong, off by 3 neutrons

```
mathematica                                   Copy code
15N + e− → 12C + νe
```

The snippet of dialogue shown here is from a conversation primed with “How does the sun produce its energy?” and given the context ”I have a PhD in physics”.

Note that it got two things wrong.

Temperature and repeatability

I always mix up the words compliment and complement. Can you give me an easy way to remember the difference?

Certainly! Here's a mnemonic to help you remember the difference between "compliment" and "complement":

Compliment (with an "i") is used when you want to say something nice or flattering to someone. The word "compliment" contains the letter "i," which can remind you of "I" as in "I like your dress (a compliment).

Complement (with an "e") is used when something completes or goes well with something else. The word "complement" contains the letter "e," which can remind you of "each" or "together," emphasizing how things fit together or enhance each other.

So, "compliment" is for saying something nice (think "I"), and "complement" is for completing or enhancing (think "each" or "together").

Sure! Here's a simple way to remember the difference between "compliment" and "complement":

Compliment with an "i" is about saying something nice or praising someone. When you give a compliment, you're adding something positive (like "I like your shoes").

Complement with an "e" is about completing or enhancing something. When two things complement each other, they go together well and make each other better (like "The wine complements the cheese").

So, think of "compliment" for praise (adding something nice) and "complement" for completion (adding something that completes or enhances).

Certainly! Remember that **compliment** with an "i" is used when you're saying something nice about someone or something. It's like giving someone a "compliment" with a smile.

On the other hand, **complement** with an "e" is used when something completes or goes well with something else. Think of it as the two "e's" in "complement" fitting together or completing each other.

So, to summarize:

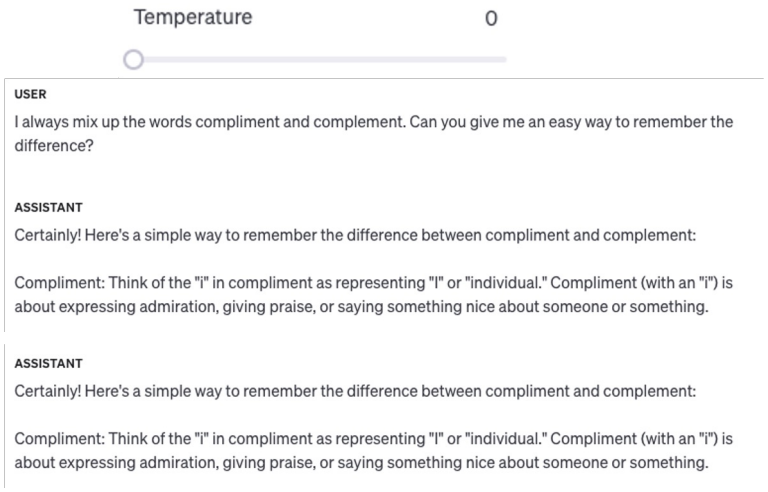
- **Compliment** (with an "i") is praise or an expression of admiration.
- **Complement** (with an "e") completes or goes together with something else.

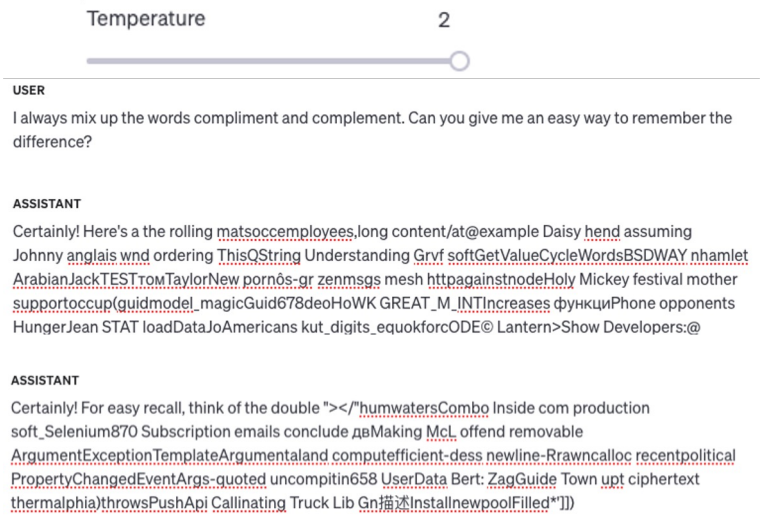
Hope this helps you keep them straight!

Asking GPT-3.5 the same question three times in a row resulted in consistent yet different answers What's going on?

Temperature and repeatability

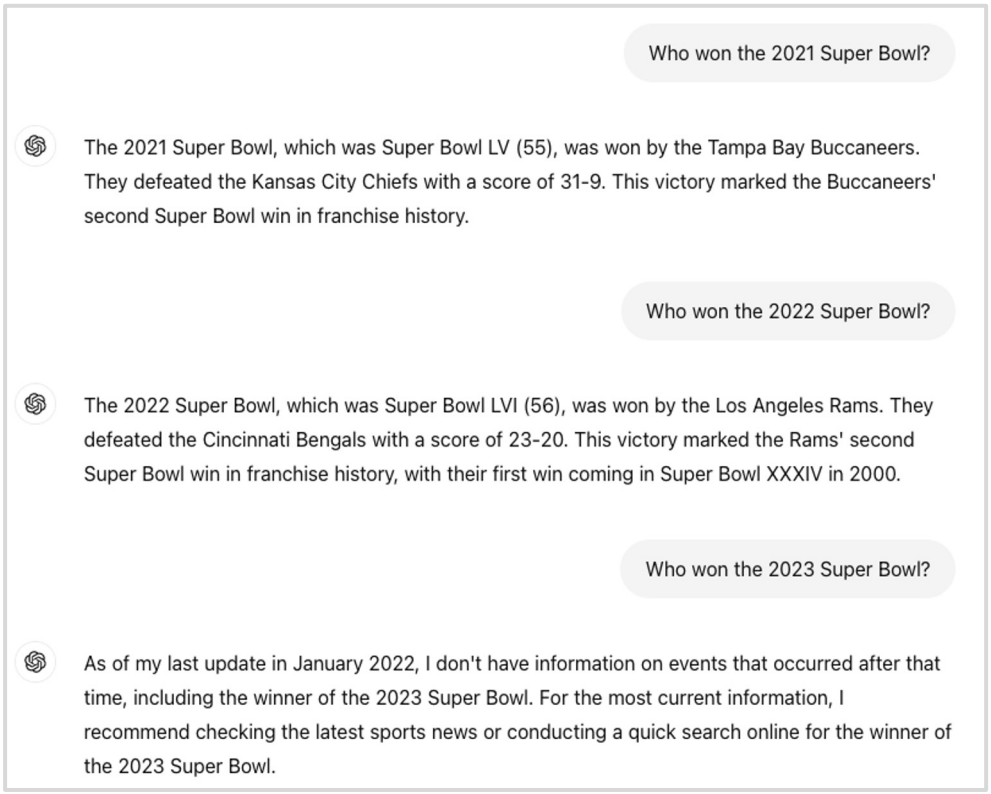
LLMs have a temperature that modifies the probability distribution for the next token. Setting the temperature to zero gives perfectly reproducible results, with the next token always being the statistically most likely one, while setting to large value produces more random results (gibberish).





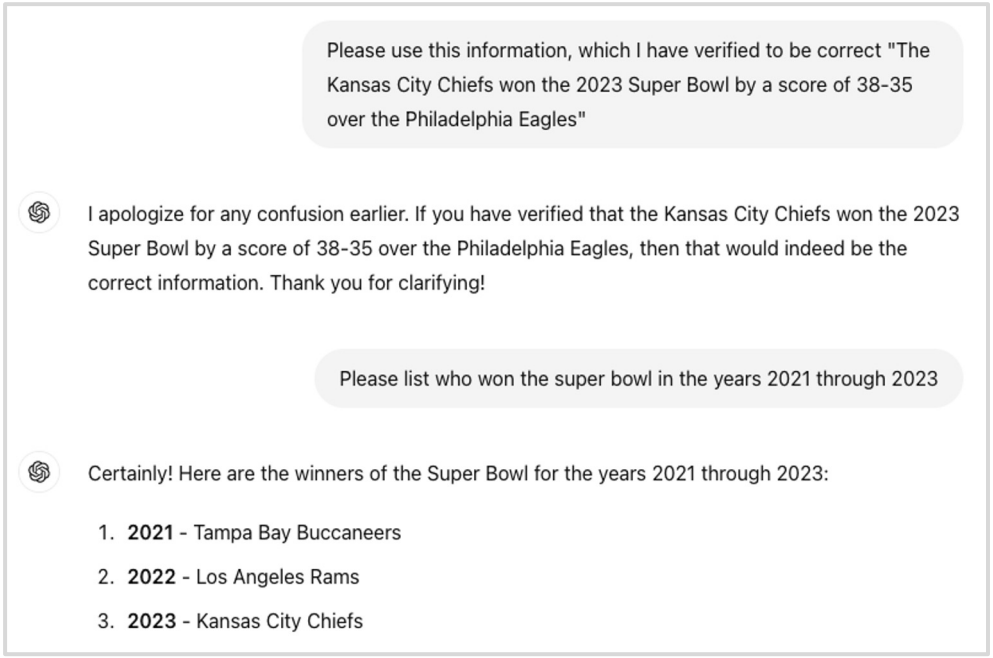
Ability to control T will depend on the model and access method. For GPT-3.5, this required paid subscription to the API

LLMs are limited by their training data



Your LLM will always be a little out of date. In this case GPT-3.5 recognized that my third prompt was asking for data not in its training set.

LLMs are limited by their training data



You can provide additional information that the LLM does not have. We'll cover this in more detail when we get to prompt engineering and retrieval-augmented generation (RAG).

LLMs are limited by their training data (update)

Who won the last five superbowls?

Here are the champions of the **last five Super Bowls** as of today:

Super Bowl	Season (Year)	Champion	Score / Remark
LIX	2024 season (Feb 9, 2025)	**Philadelphia Eagles**	Defeated Kansas City Chiefs 40–22 en.wikipedia.org +15 pro-football-reference.com en.wikipedia.org +8
LVIII	2023 season (Feb 11, 2024)	**Kansas City Chiefs**	Defeated San Francisco 49ers 25–22 (OT)
LVII	2022 season (Feb 12, 2023)	**Kansas City Chiefs**	Defeated Philadelphia Eagles 38–35
LVI	2021 season (Feb 13, 2022)	**Los Angeles Rams**	Defeated Cincinnati Bengals 23–20
LV	2020 season (Feb 7, 2021)	**Tampa Bay Buccaneers**	Defeated Kansas City Chiefs 31–9

But they're getting better. Given this prompt, GPT-4o was smart enough to do a web search to grab data that was not in its training set

LLMs can’t do everything

To find the product of 12345 and 98765432, you can perform the multiplication:

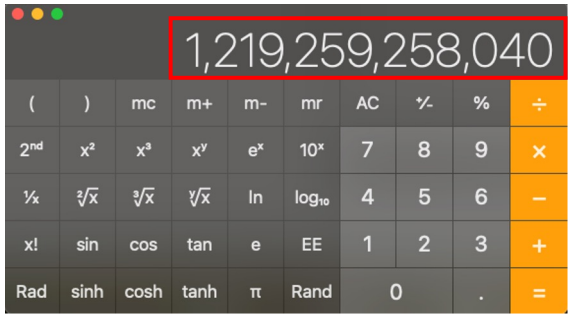
$$12345 \times 98765432 = 1,219,326,311,240$$

So, 12345 multiplied by 98765432 equals 1,219,326,311,240.

To find the product of 12345 and 98765432, you can simply multiply the two numb

$$12345 \times 98765432 = 1,219,326,390,040$$

So, 12345 multiplied by 98765432 equals 1,219,326,390,040.



An LLM will not be able to do math unless it has seen this specific problem during training. But some LLMs have the capabilities to recognize questions that follow a certain format and then call external tools. Note that GPT-4 produced two different wrong answers. GPT-3.5 was off by four orders of magnitude.

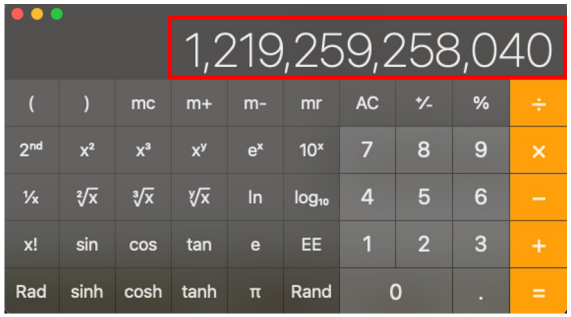
LLMs can’t do everything (update)

The product of **12345 × 98,765,432** is:

1,219,326,311,640.

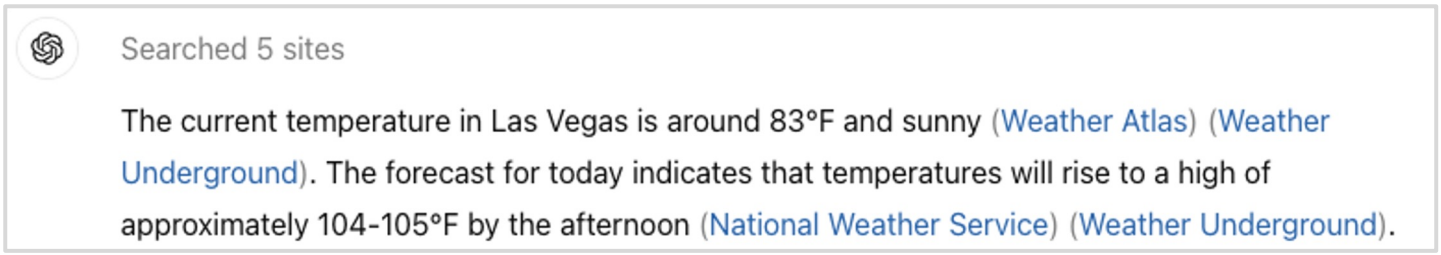
The result of multiplying **12345 × 98,765,432** is:

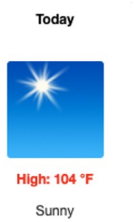
1,219,298,765,240.



Surprisingly, GPT-4o still gets this wrong. I would have expected that by now it would recognize a math problem and call the appropriate tool

LLMs can’t do everything





GPT-4 was smart enough to do a web search, although the results seems to be out of date. GPT-3.5 recognized that it did not have real-time capabilities and directed me to use a weather app.

LLMs can’t do everything (update)

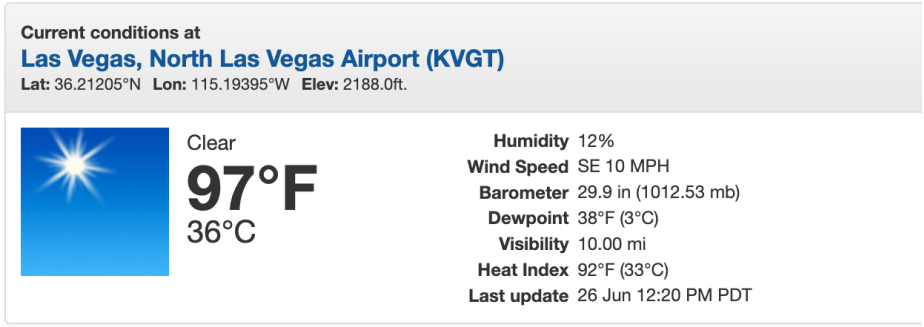
Here’s the current local time and weather for Las Vegas, NV:

🕒 Local time (UTC−07:00):

12:46 PM on June 26, 2025 12:46 PM

🌞 Current temperature:

Currently 98° · Sunny

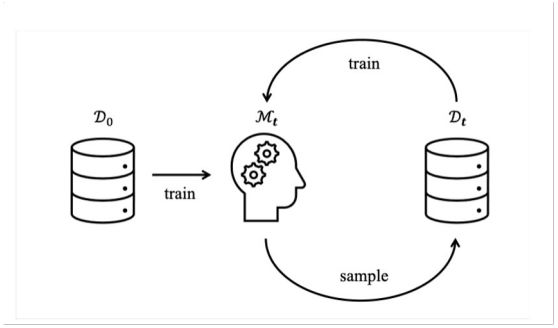


GPT-4o did better and retrieved current weather conditions that matched weather.gov

Closing thoughts

The field of LLMs is moving very quickly, with the size and capabilities of the models growing rapidly. The examples presented in this summer institute (June 2024) will likely be out of date by the end of the year as new players enter the field and existing companies continue to enhance their models.

One gotcha … there's concern that LLM-generated data will be used to train the next generation of LLMs, resulting in a self-consuming data loop. In my opinion, being able to identify LLM generated text is one of the most important areas of research.



Let's not do this!

Briesch et al. https://arxiv.org/pdf/2311.16822