

DeepLorIA

Mastering Large Language Models: Efficient Techniques for Fine-Tuning

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LORIA, Université de Lorraine, CNRS
DeepLorIA Network

January 15, 2025

About Me

2nd-year PhD student - Knowledge-Enhanced Language Models

Research Focus

- Controlled Conversational Models through Conversation-Dedicated Ontology
- *Keywords: Large Language Models (LLMs), Conversational Agents, Ontologies, Fine-Tuning*

Experience in LLM fine-tuning

- Run pre-defined fine-tuning setups (Causal Language Modeling, Classification,...)
- Develop new fine-tuning pipelines to consider external knowledge
- Focus on textual modality

Experimenting LLM Fine-Tuning

Many successful LLM fine-tunings?

<https://huggingface.co/>

Models 70,963 finetuned

Full-text search Sort: Trending

Model	Author	Description	Size	Updates
distilbert/distilbert-base-uncased-finetuned-sst-2-...	FacebookAI	xlm-roberta-large-finetuned-conll03-engl...	~6.72M	Feb 19, 2024
dandelin/vilt-b32-finetuned-vqa	google	tapas-base-finetuned-wtq	~1.75M	Aug 2, 2022
naver-clova-ix/donut-base-finetuned-cord-v2	facebook	timesformer-base-finetuned-k400	~13.6K	Aug 13, 2022
EmTpro01/CodeLlama-7b-finetuned-16bit	VeraSolutions	phi-3.5-mini-finetuned-amp-data-model...	~332	Nov 3, 2024
huuhiu-ai/Llama-3.7-76B-Instruct-ableitized-finetu...	duyan2803	bartpho-finetuned-qa	~189K	8 days ago
medicalai/MedFound-Llama3-8B-finetuned	google	bert-large-uncased-whole-word-masking-f...	~56	7 days ago
Davlan/bert-base-multilingual-cased-finetuned-wolof	allenai	longformer-large-4096-finetuned-triviaqa	~15	Jun 30, 2022
atharvanundada99/bert-large-question-answering-fine...	dbmdz	bert-large-cased-finetuned-conll03-english	~701	May 24, 2021
google/tapas-large-finetuned-wtq	henryk	bert-base-multilingual-cased-finetuned-polis...	~114K	Sep 5, 2023

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Text Classification - Updated Dec 19, 2023 - 3.6.72M - 467
- dandelin/vilt-b32-finetuned-vqa
Visual Question Answering - Updated Aug 2, 2022 - 3.175K - 397
- naver-clova-ix/donut-base-finetuned-cord-v2
Image-to-Text - Updated Aug 13, 2022 - 3.13.6K - 92
- EmTpro01/CodeLlama-7b-finetuned-16bit
Text Generation - Updated Nov 3, 2024 - 332 - 2
- huhiu-ai/Llama3-3.7-76B-Instruct-ableliterated-finetu...
Text Generation - Updated 8 days ago - 3.189K - 3
- medicalai/MedFound-Llama3-8B-finetuned
Updated 7 days ago - 3.56 - 2
- Davlan/bert-base-multilingual-cased-finetuned-wolof
Fill-Mask - Updated Jun 30, 2021 - 3.15 - 2
- atharvanundada99/bert-large-question-answering-fine...
Question Answering - Updated May 24, 2021 - 3.701 - 15
- google/tapas-large-finetuned-wtq
Table Question Answering - Updated Sep 5, 2023 - 3.114K - 132
- FacebookAI/xlm-roberta-large-finetuned-conll03-engl...
Token Classification - Updated Feb 19, 2024 - 3.1.8M - 159
- facebook/timesformer-base-finetuned-k400
Video Classification - Updated Jan 2, 2023 - 3.46.4K - 28
- VeraSolutions/phi-3.5-mini-finetuned-amp-data-model...
Text Generation - Updated Dec 11, 2024 - 3
- duyan2003/bartpho-finetuned-qa
Text2Text Generation - Updated 15 days ago - 3.33 - 2
- google/bert/bert-large-uncased-whole-word-masking-f...
Question Answering - Updated Feb 19, 2024 - 3.20K - 173
- allenai/longformer-large-4096-finetuned-triviaqa
Question Answering - Updated Oct 4, 2022 - 3.7.5Kb - 7
- dbmdz/bert-large-cased-finetuned-conll03-english
Token Classification - Updated Sep 7, 2023 - 3.1.2M - 4 - 73
- henryk/bert-base-multilingual-cased-finetuned-polis...
Question Answering - Updated May 19, 2021 - 3.220 - 3

Fine-tuning LLMs in real life?

RuntimeError: probability tensor contains either 'inf', 'nan' or element < 0

"",\n\nAverage Readability Score = 9.45.\n\nPlease let me know if this meets your requirements', "...", "...", "...".\n\nReadability Score = 8.45.\n\nThis text has moderate complexity, making it easy for', "...".\n\nAverage Readability Score = 4.\n\nThis text has short sentences, simple vocabulary words with one', "...".\n\nAverage Readability Score = 14.00.\n\nPlease note that the above text may be difficult for', "...".\n\nAverage Readability Score = 8.45.\n\nThis text has moderate difficulty, making it easily', "..."]
["...", "...", "...", "...", "...", "...", "...", "..."]
["...", "...", "...", "<!", "The new smartphone has many advanced features for improved performance." | Readability Score', "...".\u0000e0067\ufe00d, ✨, 🎉, 99, 🎉, 0, "...", "...".\n\nThis text has an estimated Flesch-Kincaid Grade Level around the range of', "...", "...", "...".\u0000e0067\ufe00e0062\ufe00e0073\ufe00e0063\ufe00e0074\ufe00e0071f0']

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poch 1: 2%
Sample 0: Yes.,
Sample 1: Yes.,
Sample 2: Today,
Sample 3: In.,
Sample 4: For.,
[1.1630859375, 1.3134765625, 1.140625]

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Models	70,963	finetuned	Full-text search	11 Sort: Trending
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medicalai/MedFound-Llama3-8B-finetuned	Updated 7 days ago · ± 56 · ⚡ 2		google/bert/bert-large-uncased-whole-word-masking-finetuned	Question Answering · Updated Feb 19, 2024 · ± 20K · ⚡ 173
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- Fine-tuning LLMs relies on obscure "magic formulas"

Fine-tuning LLMs in real life?

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- Fine-tuning LLMs is hard

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Text Classification · Updated Dec 19, 2023 · ± 6.72M · 667	Token Classification · Updated Feb 19, 2024 · ± 1.8M · 139			
dandelin/vilt-b32-finetuned-vqa	1.175K	397	google/tapas-base-finetuned-wtq	14.9K
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naver/clova-ix/donut-base-finetuned-cord-v2	1.35K	92	facebook/timesformer-base-finetuned-k400	46.4K
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Fine-tuning LLMs in real life?

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[1.1630859375, 1.3134765625, 1.140625]
```

✗ Fine-tuning LLMs is hard

Deep-Learning-Based Sequence Modeling: Recurrent Models (1)

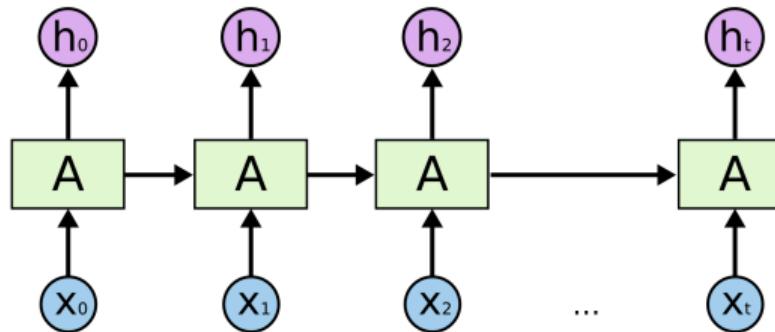


Figure 1 – Illustration of the Recurrent Neural Network (RNN, [18, 10]) architecture¹

- ✓ Keep token order
- ✓ Handle variable-length sequences
- ✓ Parameter sharing across the sequence
- ✗ Exploding and vanishing gradient
- ✗ Long-term dependencies
- ✗ Slow computing, no parallelization

¹ Olah, C. (2015). Understanding LSTM Networks. <https://colah.github.io/posts/2015-08-Understanding-LSTMs/>

Deep-Learning-Based Sequence Modeling: Recurrent Models (2)

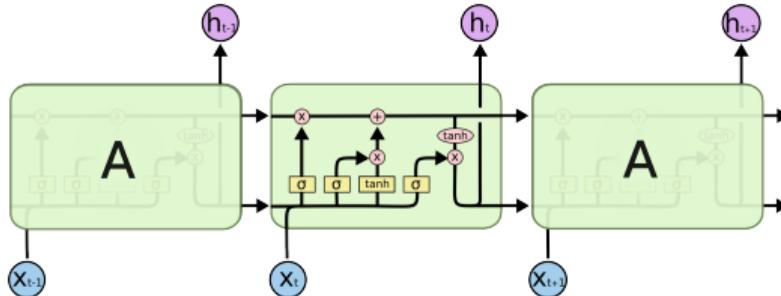


Figure 2 – Illustration of the Long Short Term Memory Neural Network (LSTM, [7]) architecture²

- ✓ Keep token order
- ✓ Handle variable-length sequences
- ✓ Parameter sharing across the sequence
- ✓ No exploding/vanishing gradient
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- ✗ Slow computing, no parallelization

² Olah, C. (2015). Understanding LSTM Networks. <https://colah.github.io/posts/2015-08-Understanding-LSTMs/>

Attention Principle [1] and Transformer Model [20]

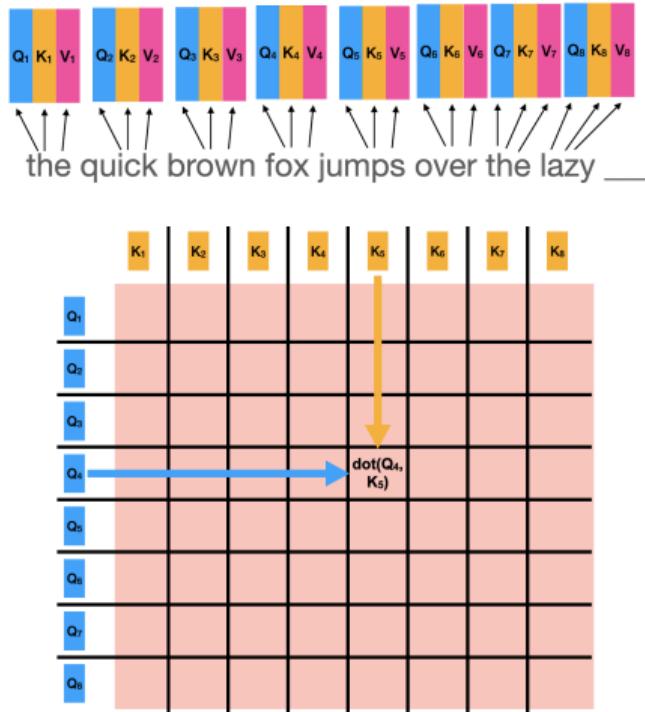


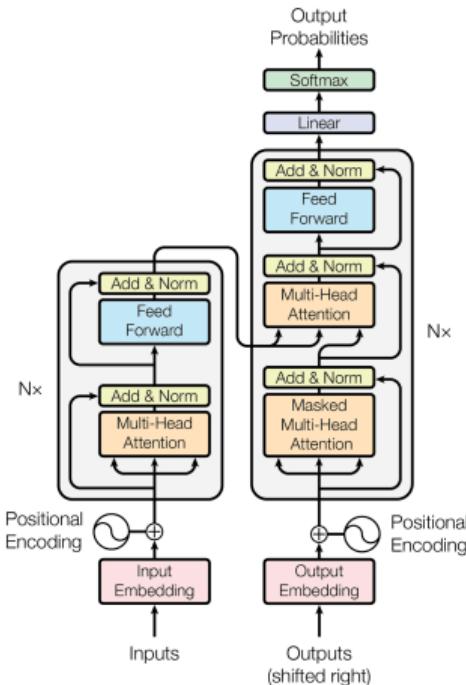
Figure 3 – Attention principle¹

- **Query Q :** current token asking for context
- **Key K :** all tokens defining where to focus
- **Value V :** all tokens information
- d_k : embedding dimension

$$\text{Attention}(Q, K, V) = \text{softmax} \left(\frac{QK^\top}{\sqrt{d_k}} \right) V$$

¹<https://learnopencv.com/attention-mechanism-in-transformer-neural-networks/>

Attention Principle [1] and Transformer Model [20]



- **Query** Q : current token asking for context
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Figure 4 – Transformer architecture from the original paper²

From Transformer-Based Models to Large Language Models (LLMs)

LLMs scale Transformers by stacking encoders and/or decoders together

- Parallelizable and optimized versions exist (e.g. quantization)
- Enable deeper and broader knowledge representation
- Large context window allows for more accurate generation

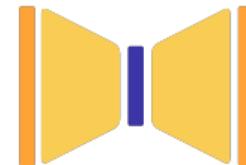


Figure 5 – Full Transformer



Figure 6 – Encoder



Figure 7 – Decoder

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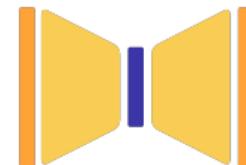


Figure 5 – Full Transformer

Fine-tuning adapts an LLM to a specific task through further parameter updates

- Can be performed with any LLM structure, but:
 - There are *required structures* for some specific tasks
 - There are *preferred models* for some specific tasks



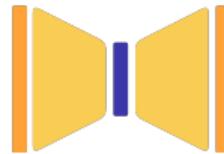
Figure 6 – Encoder



Figure 7 – Decoder

What Use-Cases of LLMs?

Model Structure



Task Examples

- Summarization
- Machine Translation
- Question Answering

Model examples

- BART [11], mBART [12]
- T5 [17], Flan-T5 [3]
- bert2BERT [2]



- Sequence Embedding
- Text Classification
- Regression

- BERT [5], mBERT [15]
- RoBERTa [13]
- DistilBERT [19]



- Text Completion
- Text Generation
- Code Generation

- GPT-3.5, GPT-4o
- Llama-3 [6]
- Qwen2.5 [16]

Inside a Decoder-Only LLM

① Prompt the LLM

What is the best way to learn music?

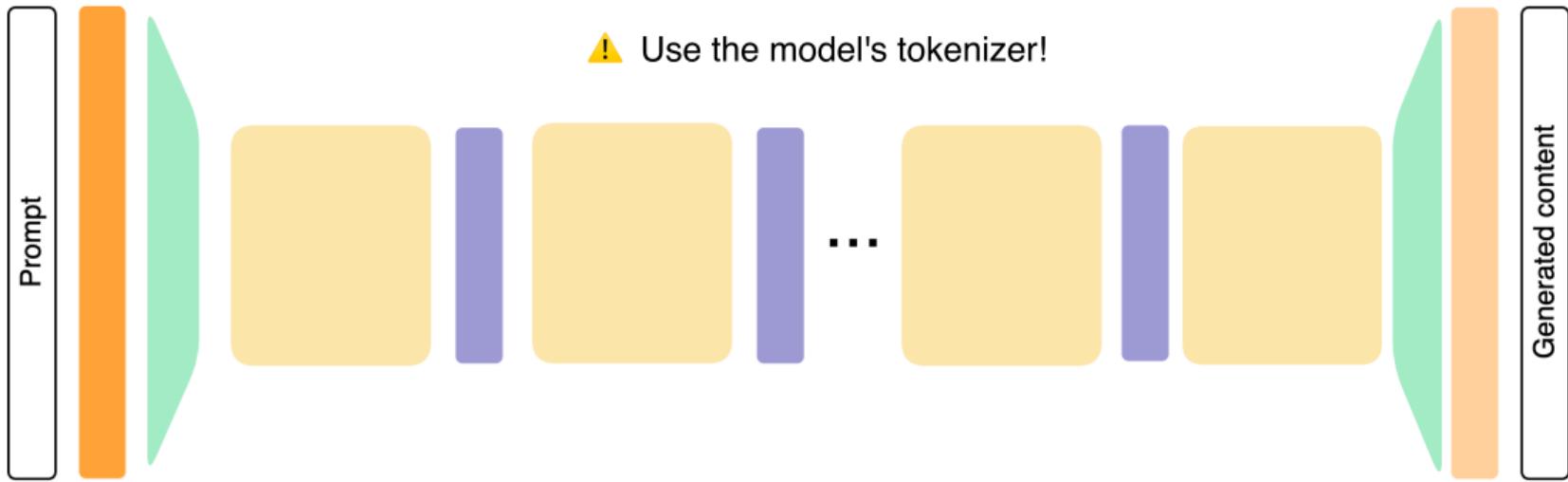


Inside a Decoder-Only LLM

② Tokenize the Prompt Content

"What is the best way to learn music?"
[531, 9, 45, 22, 3316, 2444, 34, 2172, 334]

⚠ Use the model's tokenizer!



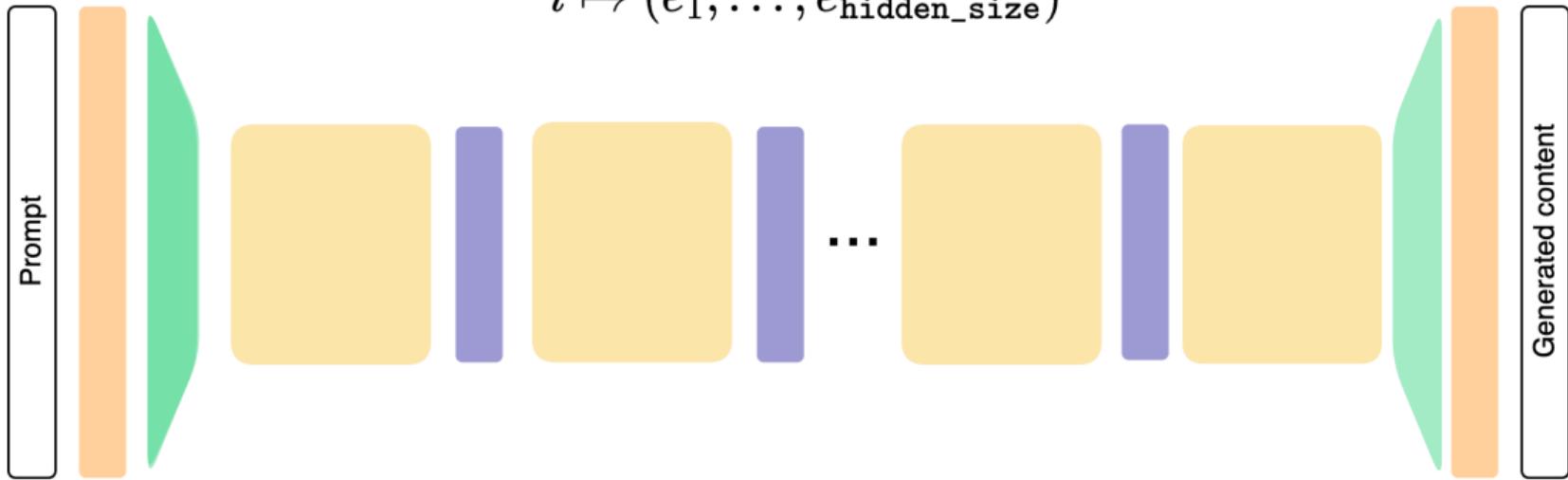
Inside a Decoder-Only LLM

3

Apply an Embedding layer

Embedding (vocab_size, hidden_size)

$$i \mapsto (e_1, \dots, e_{\text{hidden_size}})$$



Inside a Decoder-Only LLM

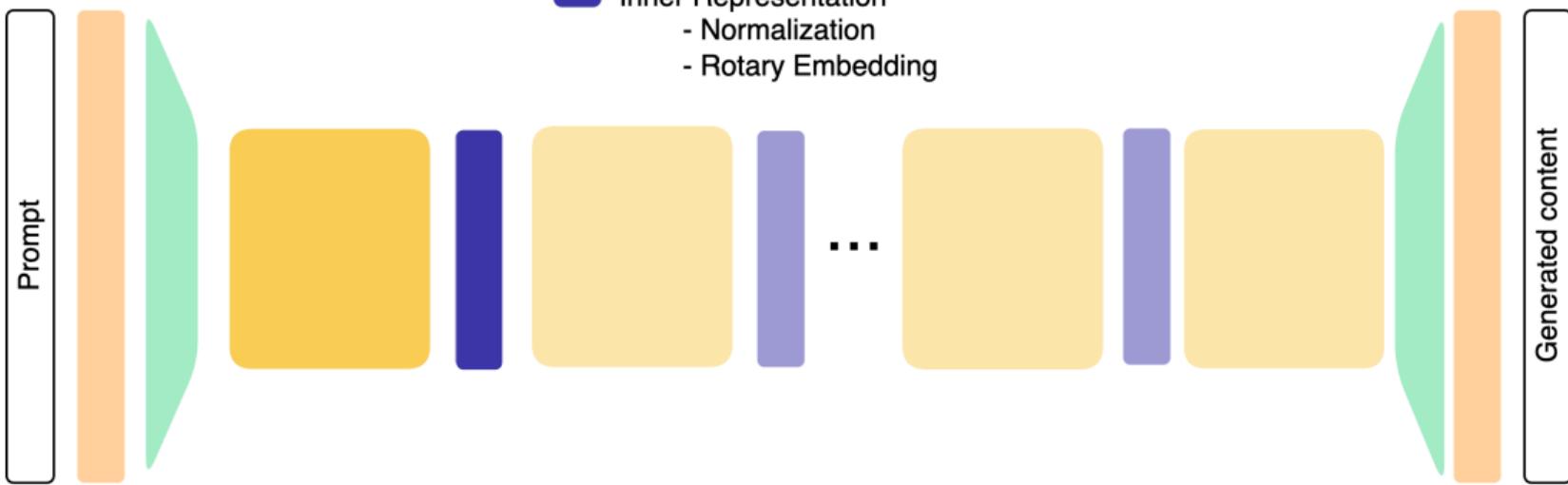
④ Going Through a Decoder Block

Transformer Decoder Blocks

- Attention layers (query, key, value)
- Dense layers (Multi Layer Perceptron)

Inner Representation

- Normalization
- Rotary Embedding



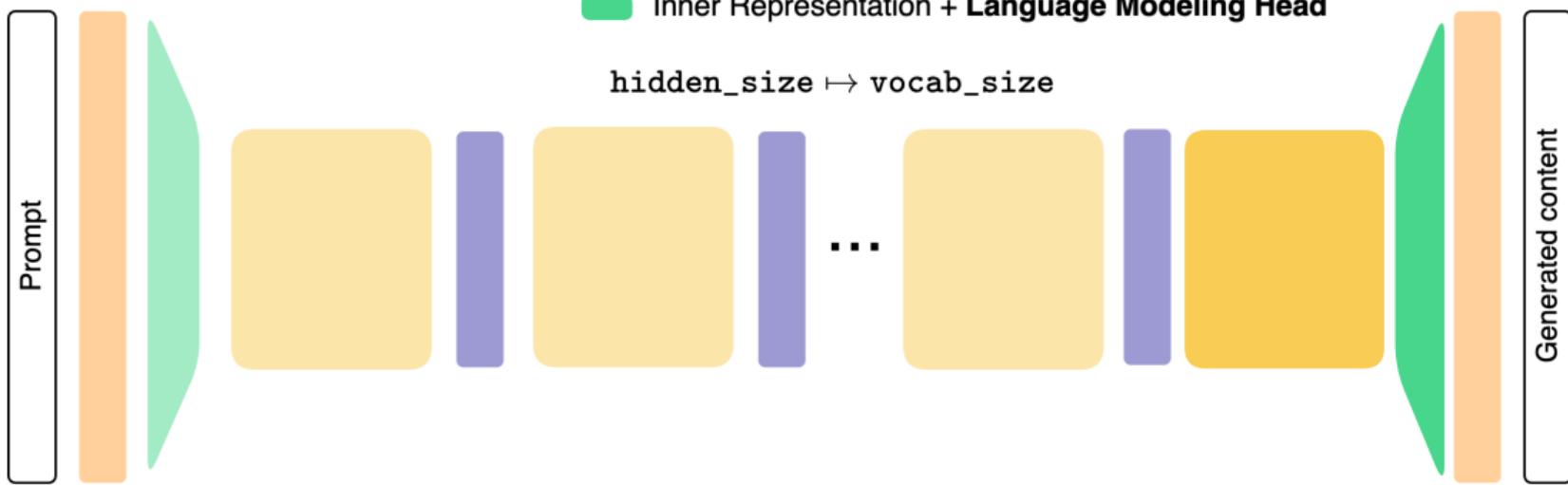
Inside a Decoder-Only LLM

5 Out of Last Decoder Block

- Transformer Decoder Blocks
 - Attention layers (query, key, value)
 - Dense layers (Multi Layer Perceptron)

- Inner Representation + **Language Modeling Head**

`hidden_size ↠ vocab_size`



Inside a Decoder-Only LLM

⑥ Decode Generated Tokens in Natural Language



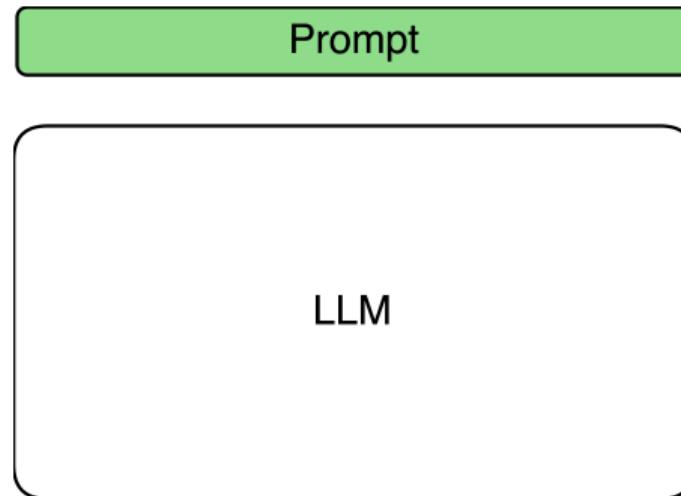
What is the best way to learn music?



The best way to learn music depends on your goals, interests, and learning style, but here are some effective strategies that can help:

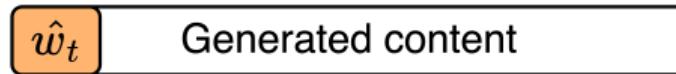


The Autoregressive Principle

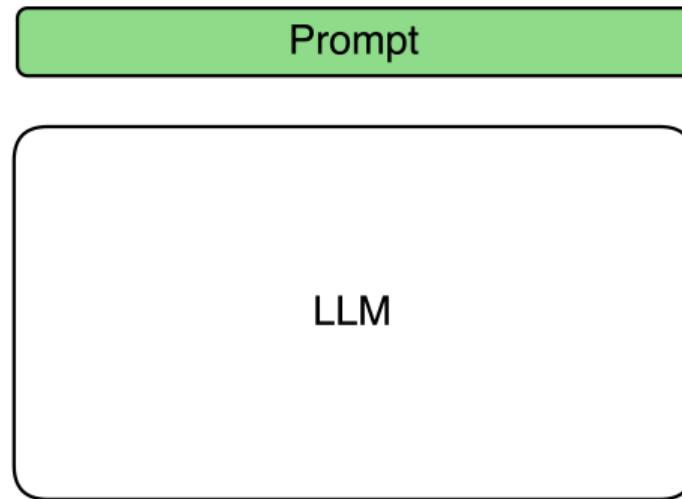


Context
Predicted token

$$\hat{w}_t = \arg \max_{w_i} P(w_i | w_1, w_2, \dots, w_{t-1})$$



The Autoregressive Principle



Context
Predicted token

$$\hat{w_{t+1}} = \arg \max_{w_i} P(w_i | w_1, w_2, \dots, w_t)$$

- **Top p:** adjust the range of tokens to consider regarding their probability.
- **Top k:** choose among the k more likely tokens. Default is 1 (most likely token).
- **Temperature:** control "creativity" by adding random noise to select less likely tokens.

How Large are Large Language Models?

Model	Parameters	Layers	Context Size
Gemini 1.5	200B?	-	10M
GPT-4 turbo	1.8T	120	128k
Claude 2.1	12B	-	200k

Side remark: most LLMs called "open-source" are actually open-weights!

Table: Some *closed-source* model specifications

Model	Parameters	Layers	Context Size
Llama 3.3	70B	80	128k
Phi 4	14B	40	16k
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Mistral-v0.3	7B	32	32k

Table: Some *open-weights* model specifications

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Table: Some *open-weights* model specifications

Side remark: most LLMs called "open-source" are actually open-weights!

- Most models involve several gigabytes in RAM GPU to perform inference
- Updating each parameter value during fine-tuning would be too costly

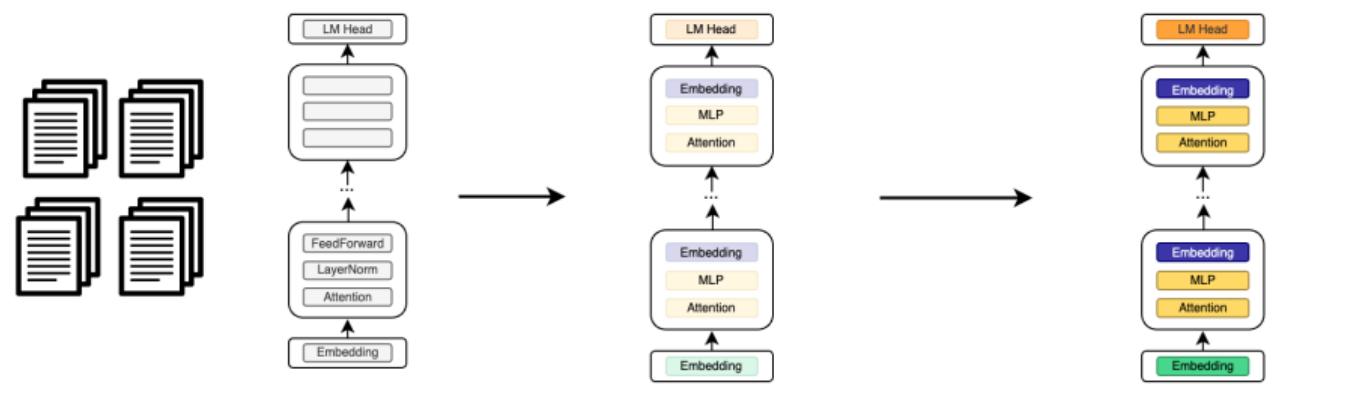
→ fine-tuning should be **efficient**

Fine-Tuning is an *Affinage*: the Cheese Analogy

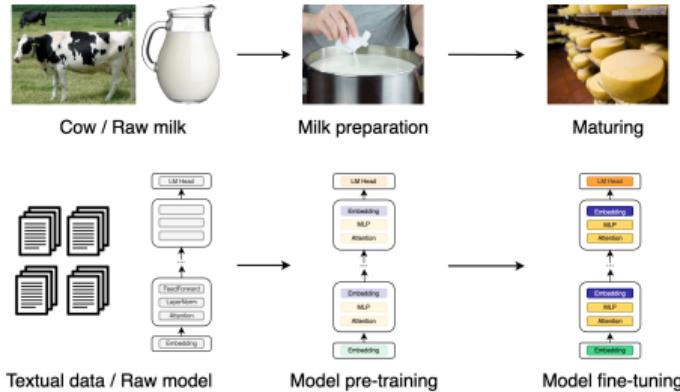
Fine-Tuning is an *Affinage*: the Cheese Analogy



Fine-Tuning is an Affinage: the Cheese Analogy



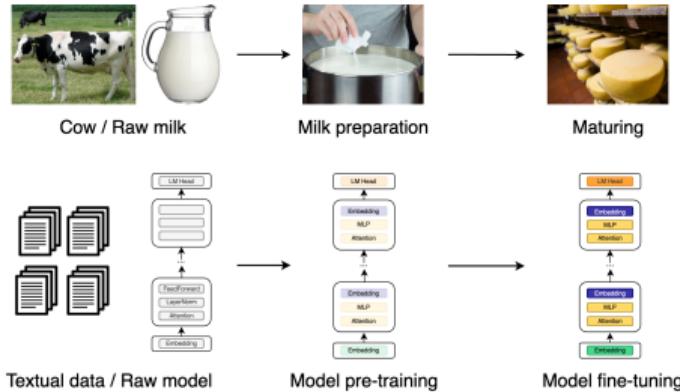
Fine-Tuning as an *Affinage*: the Cheese Analogy



Fine-tuning, as cheese maturing phase, modifies **in place** its given instance.

- Ensure fine-tuning is performed in the right conditions
- Check pre-trained baseline reliability
- Test several (adapted) pre-trained baselines for one fine-tuning experiment

Fine-Tuning as an *Affinage*: the Cheese Analogy



Fine-tuning, as cheese maturing phase, modifies **in place** its given instance.

- Ensure fine-tuning is performed in the right conditions
 - Check pre-trained baseline reliability
 - Test several (adapted) pre-trained baselines for one fine-tuning experiment
- fine-tuning should be **stable** and **consistent** with pre-trained baseline

Efficient Fine-Tuning With Adapters [8]

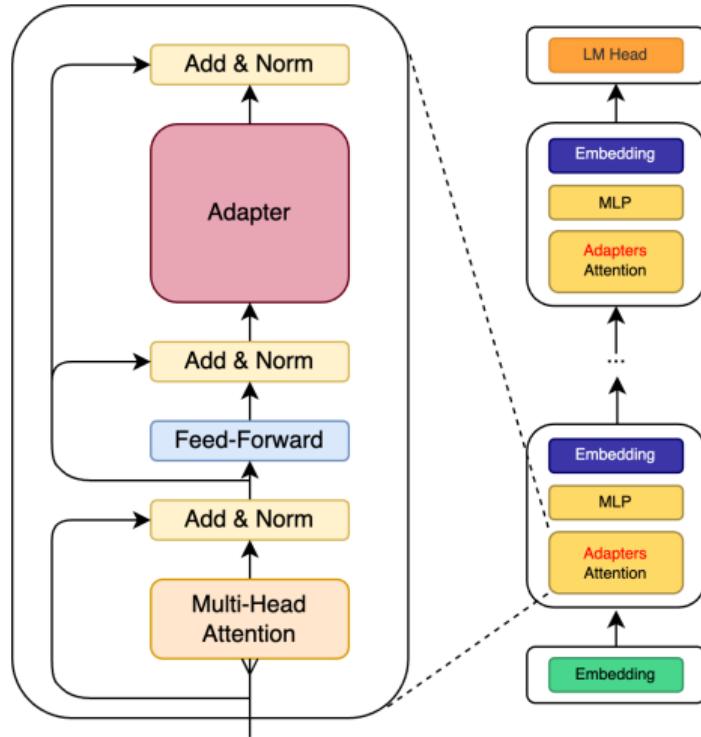


Figure 8 – An attention block with adapters

Adapters layers are inserted to enable parameter-efficient fine-tuning^a

Common usage:

- Freeze all pre-trained model layers
- Insert trainable MLP layers into attention blocks (query, value) and/or model head

^a<https://huggingface.co/PEFT>

^b<https://adapterhub.ml/>

Efficient Fine-Tuning With Adapters [8]

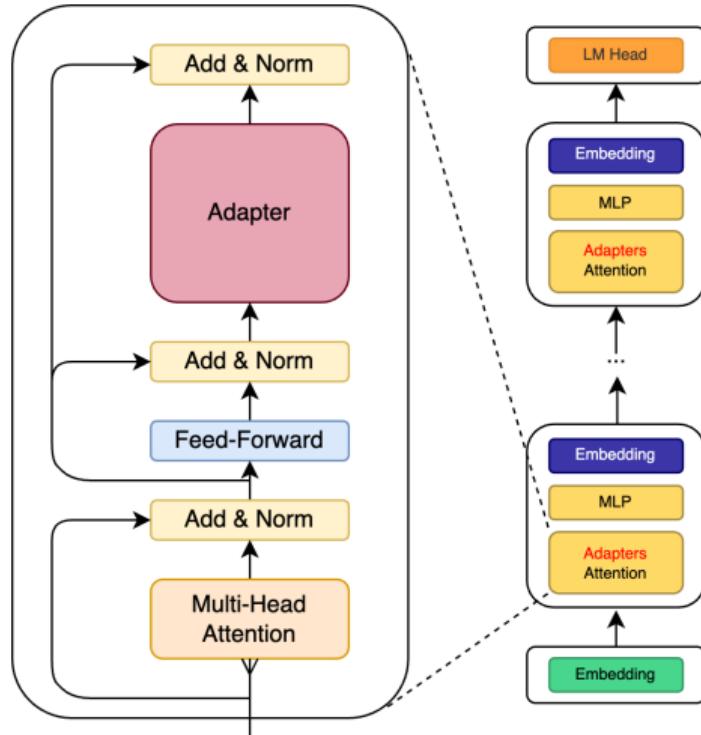


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- Freeze all pre-trained model layers
- Insert trainable MLP layers into attention blocks (query, value) and/or model head

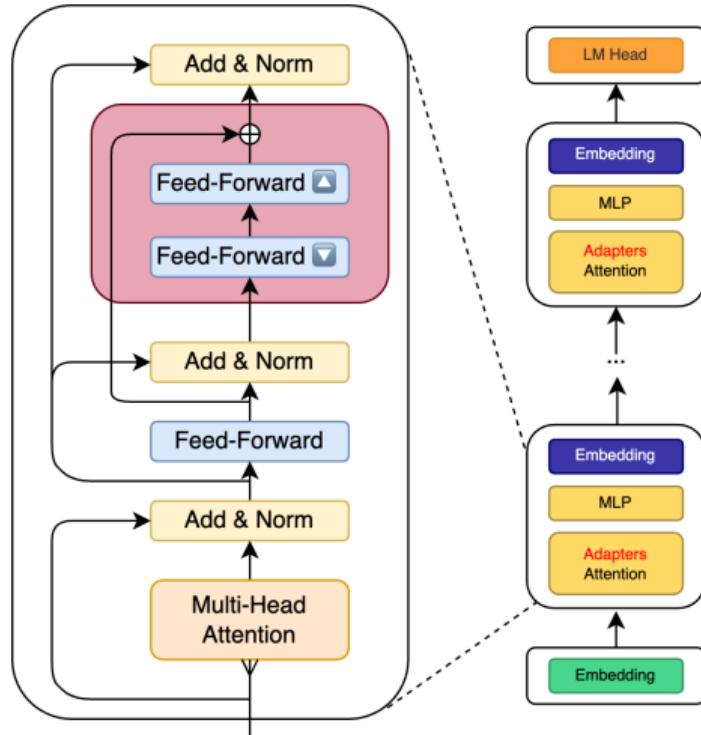
Advantages:

- Fewer param. updates than full fine-tuning
- Helps reduce catastrophic forgetting [14]
- Easy to share fine-tuned models^b

^a<https://huggingface.co/PEFT>

^b<https://adapterhub.ml/>

Efficient Fine-Tuning With LoRA Adapters [9]



LoRA: Low-Rank Adaptation A specific adapter block structure

- Information from the model can be represented (almost) equally well in a lower dimensional space
- The rank r of the lower dim. space should be determined by hyperparameter tuning
- Quantized versions: QLoRA [4]

Figure 9 – An attention block with LoRA adapters

Thanks for your attention!



Figure 10 – Practical session: <https://github.com/B-Gendron/tutorial-deeploria/lab/>

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