

DeepLorIA

Mastering Large Language Models: Efficient Techniques for Fine-Tuning

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LORIA, Université de Lorraine, CNRS
DeepLorIA Network

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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

 distilbert/distilbert-base-uncased-finetuned-sst-2-2

Text Classification · Updated Dec 19, 2023 · 6.72M · 667

 dandelin/vilt-b32-finetuned-vqa

Visual Question Answering · Updated Aug 2, 2023 · 1.175k · 397

 naver-clova-ix/donut-base-finetuned-cord-v2

Image-to-Text · Updated Aug 13, 2022 · 13.6k · 92

 EmTpro81/CodeLlama-7b-finetuned-16bit

Text Generation · Updated Nov 3, 2024 · 332 · 2

 huihui-ai/Llama-3.3-7B-Instruct-able-literated-finetuned

Text Generation · Updated 8 days ago · 189k · 3

 medicalai/MedFound-Llama3-8B-finetuned

Updated 7 days ago · 56 · 2

 Davlan/bert-base-multilingual-cased-finetuned-wolof

Fill-Mask · Updated Jun 30, 2021 · 15 · 2

 atharvanundada99/bert-large-question-answering-fine

Question Answering · Updated May 24, 2021 · 701 · 15

 google/tapas-large-finetuned-wtq

Table Question Answering · Updated Sep 5, 2023 · 114k · 132

 FacebookAI/xlm-roberta-large-finetuned-conll03-english

Token Classification · Updated Feb 19, 2024 · 1.8M · 199

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Text2Text Generation · Updated 15 days ago · 33 · 2

 google/bert/bert-large-uncased-whole-word-masking-f

Question Answering · Updated Feb 19, 2024 · 202k · 173

 allenai/longformer-large-4096-finetuned-triviaqa

Question Answering · Updated Oct 4, 2022 · 7.55B · 7

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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', ".U000e0067\u200d✖️✖️✖️✖️✖️✖️✖️", ". | \n\nThis text has an estimated Flesch-Kincaid Grade Level around the range of', "", "[", ".", ".", ".U000e0067\u2000e0062\u2000e0073\u2000e0063\u2000e0074\u2000e007f0"]
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Sample 0: Yes, .....
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- Fine-tuning LLMs relies on obscure "magic formulas"

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- Fine-tuning LLMs is hard

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✗ Fine-tuning LLMs is hard

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

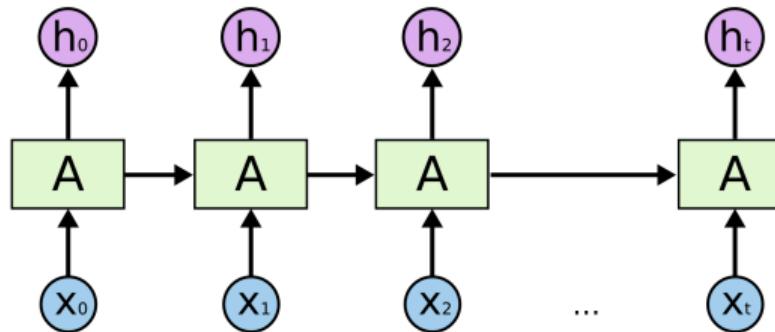


Figure 1 – Illustration of the Recurrent Neural Network (RNN, [18, 10]) architecture¹

- ✓ 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)

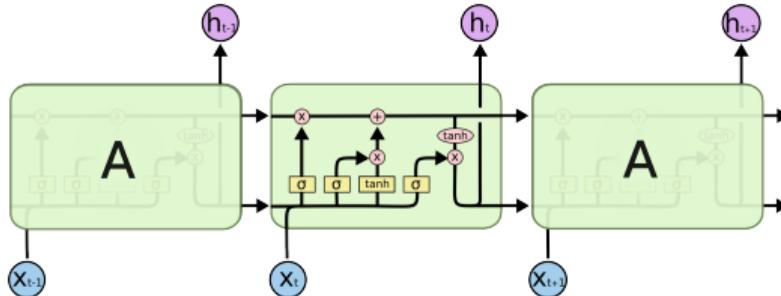


Figure 2 – Illustration of the Long Short Term Memory Neural Network (LSTM, [7]) architecture²

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- ✓ Handle variable-length sequences
- ✓ Parameter sharing across the sequence
- ✓ No exploding/vanishing gradient
- ✓ Long-term dependencies
- ✗ Slow computing, no parallelization

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Attention Principle [1] and Transformer Model [20]

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

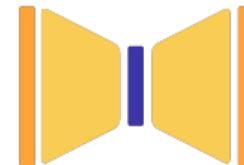


Figure 3 – Full Transformer



Figure 4 – Encoder



Figure 5 – Decoder

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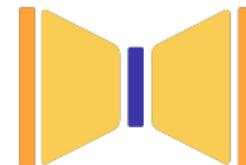


Figure 3 – Full Transformer



Figure 4 – Encoder



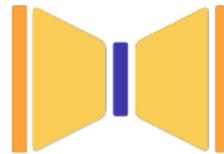
Figure 5 – Decoder

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

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]



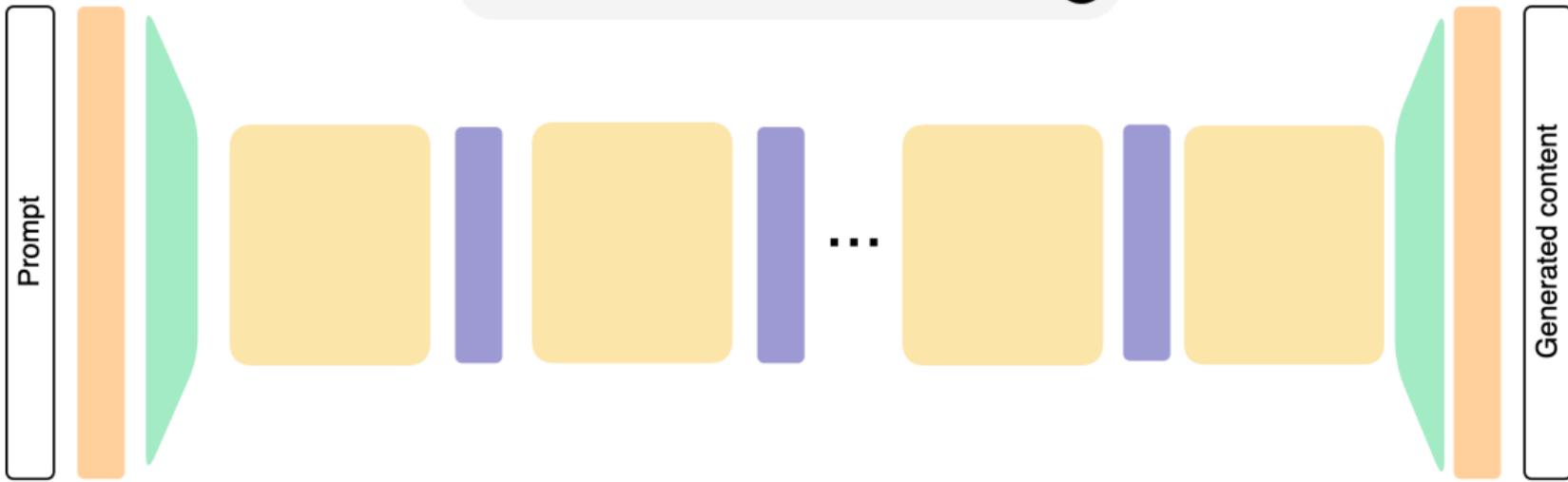
- Text Completion
- Text Generation
- Code Generation

- 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?

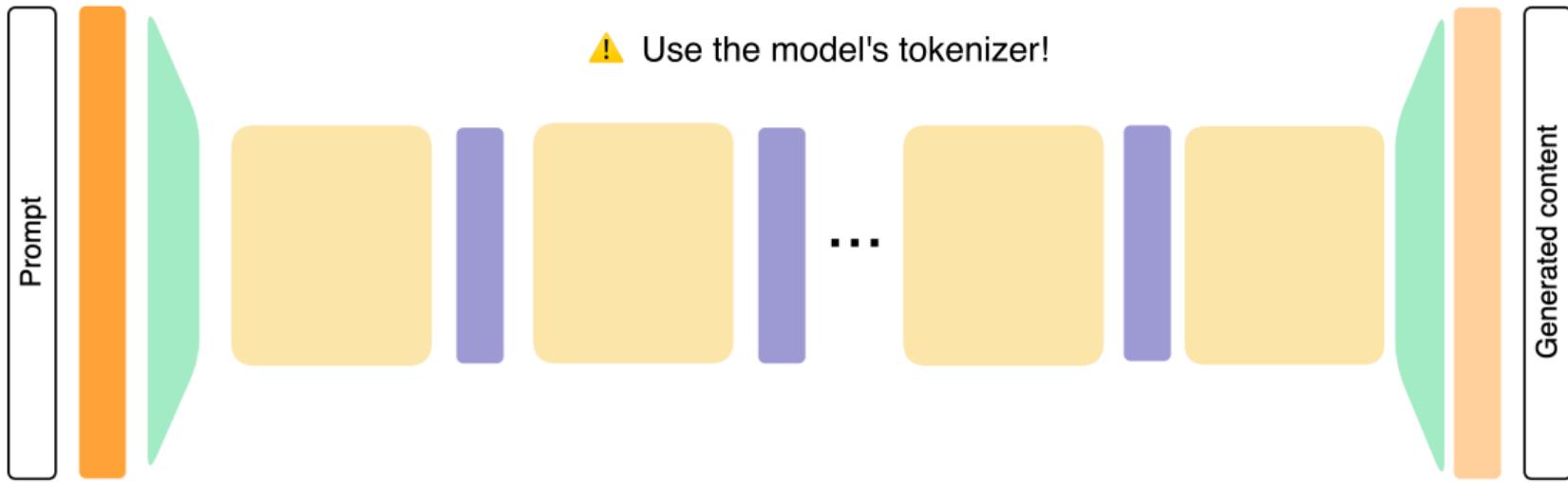


Inside a Decoder-Only LLM

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!



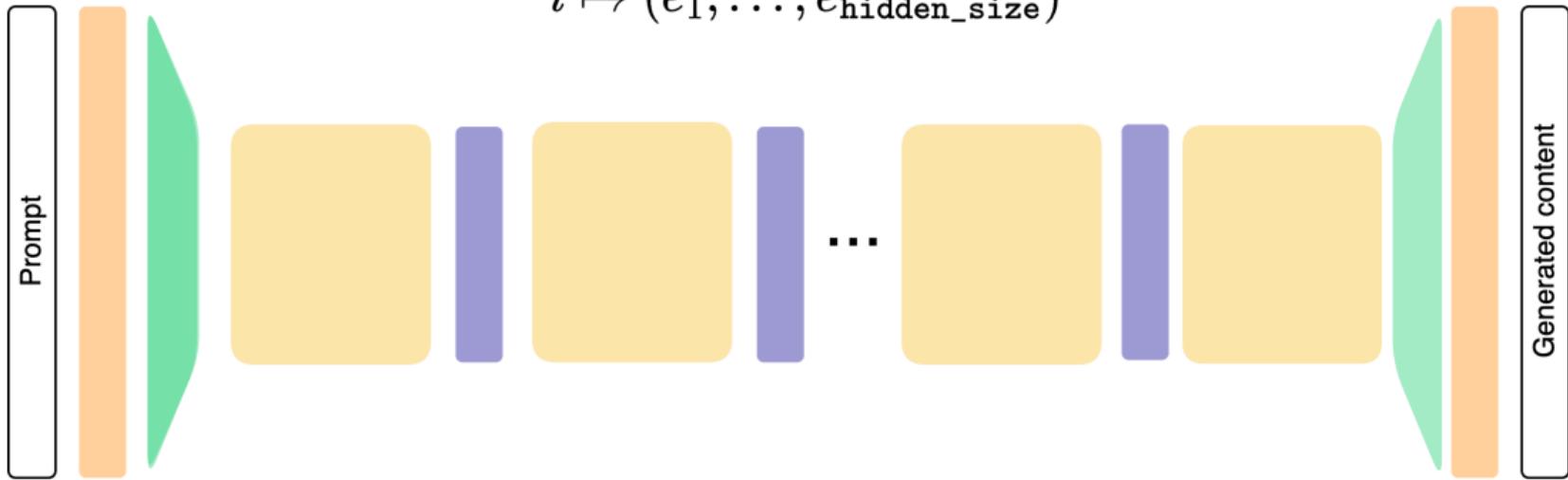
Inside a Decoder-Only LLM

3

Apply an Embedding layer

Embedding (vocab_size, hidden_size)

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



Inside a Decoder-Only LLM

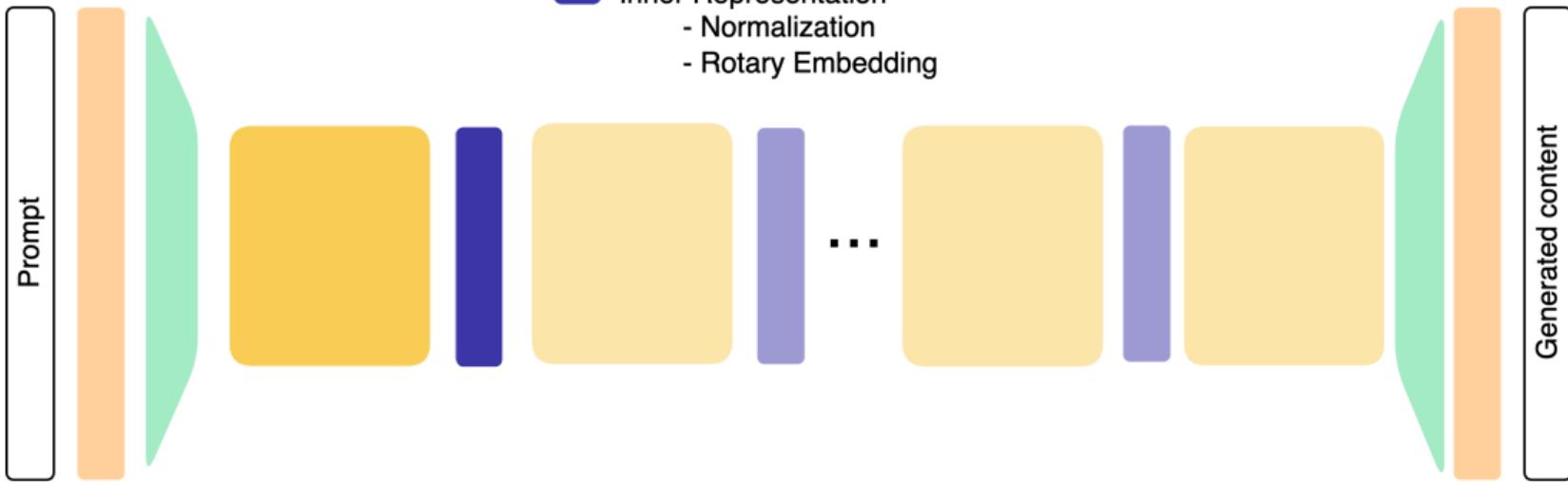
④ Going Through a Decoder Block

Transformer Decoder Blocks

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

Inner Representation

- Normalization
- Rotary Embedding



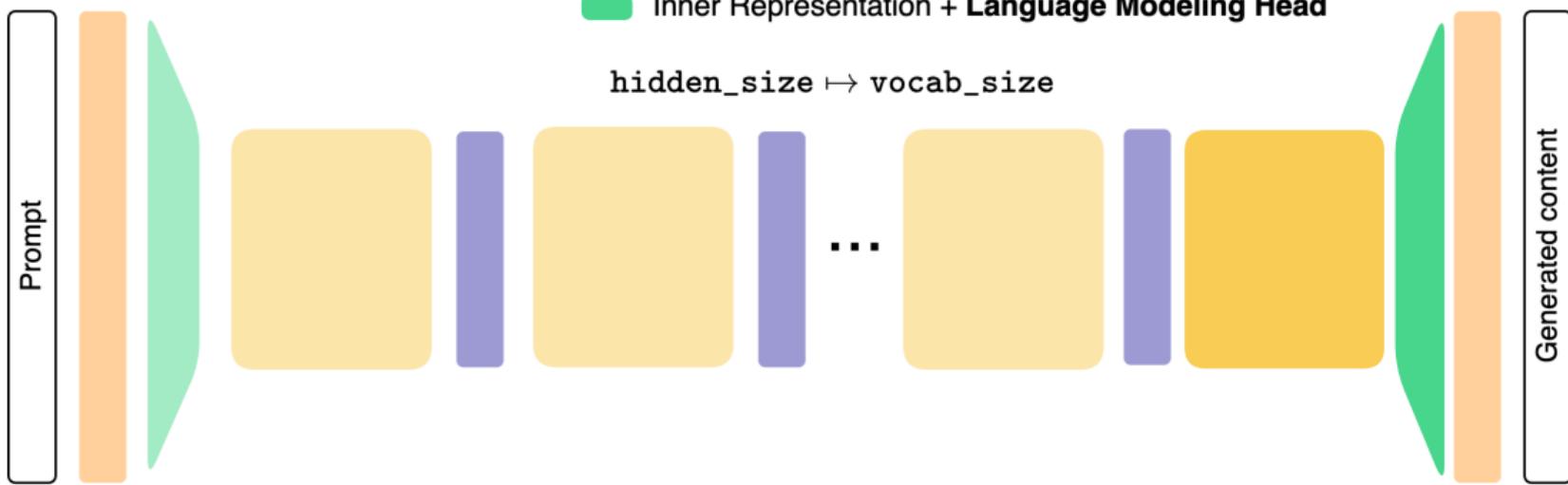
Inside a Decoder-Only LLM

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

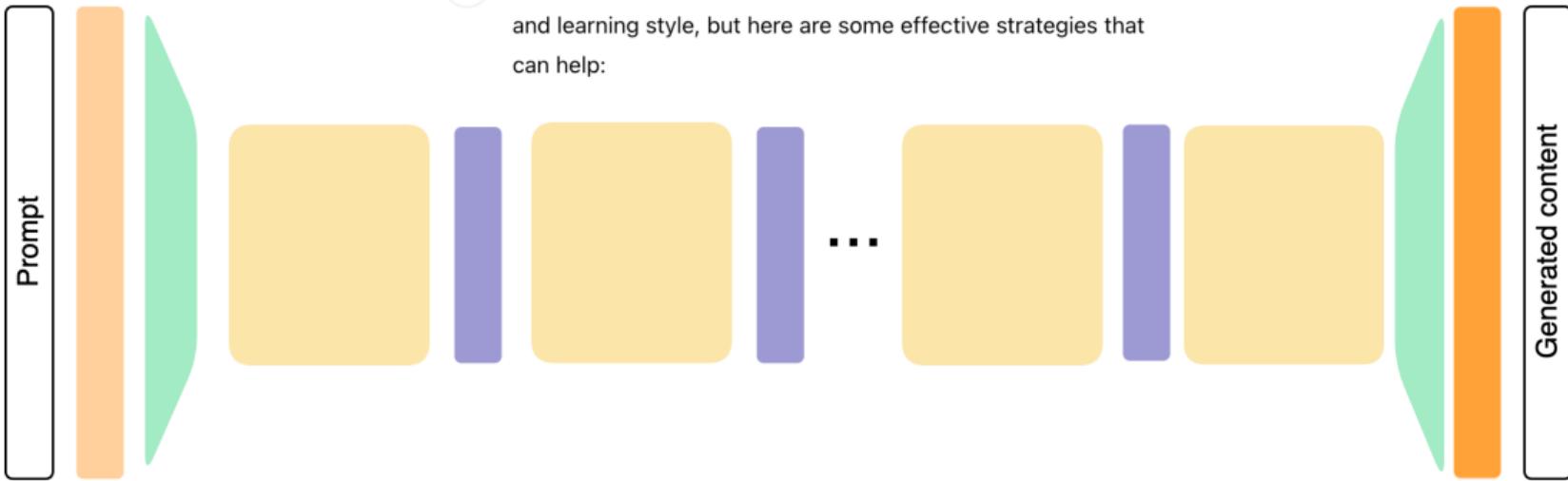
⑥ Decode Generated Tokens in Natural Language



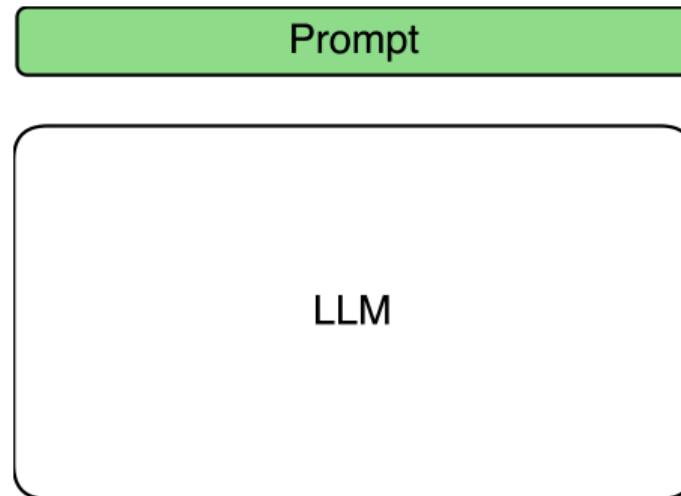
What is the best way to learn music?



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

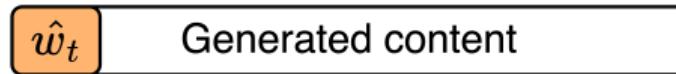


The Autoregressive Principle

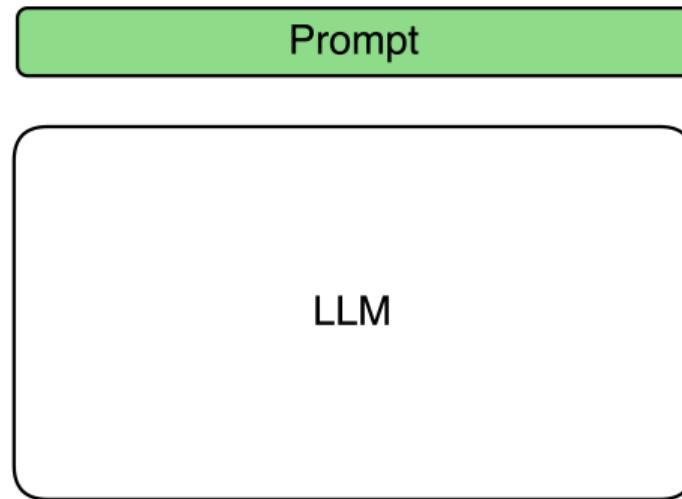


Context
Predicted token

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



The Autoregressive Principle



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

- **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
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Phi 4	14B	40	16k
Qwen 2.5	0.5B-72B	24-80	32k - 128k
Mistral-v0.3	7B	32	32k

Table: Some *open-weights* model specifications

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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

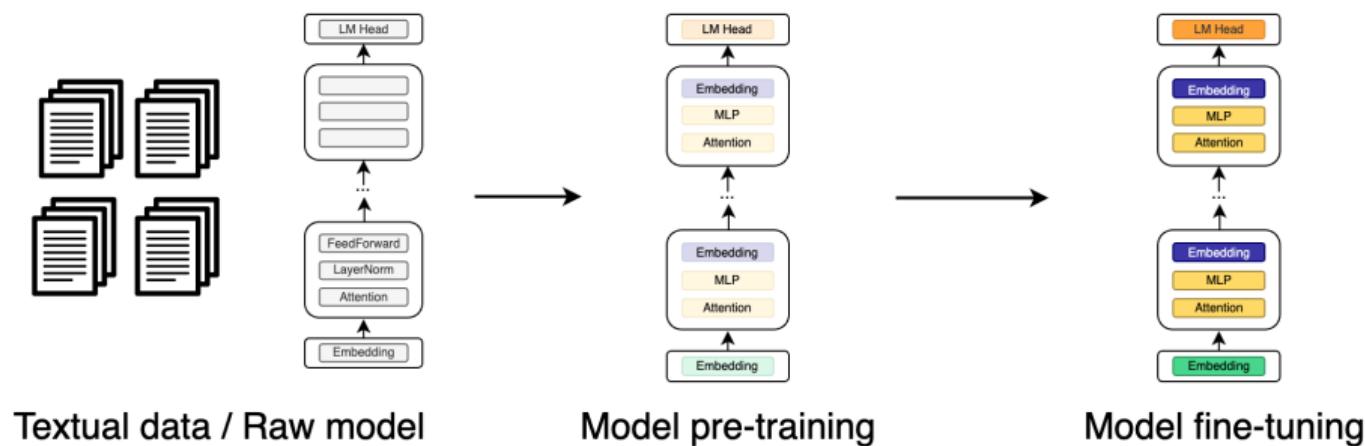
→ fine-tuning should be **efficient**

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

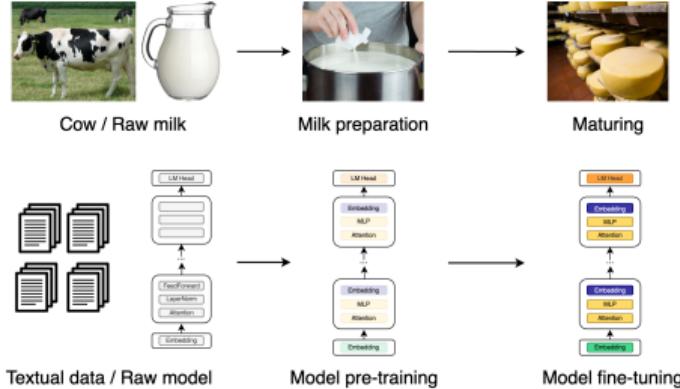
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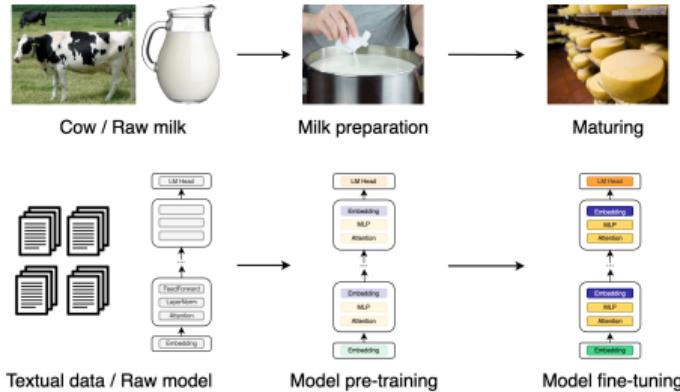
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Fine-tuning, as cheese maturing phase, modifies **in place** its given instance.

- 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



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- 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]

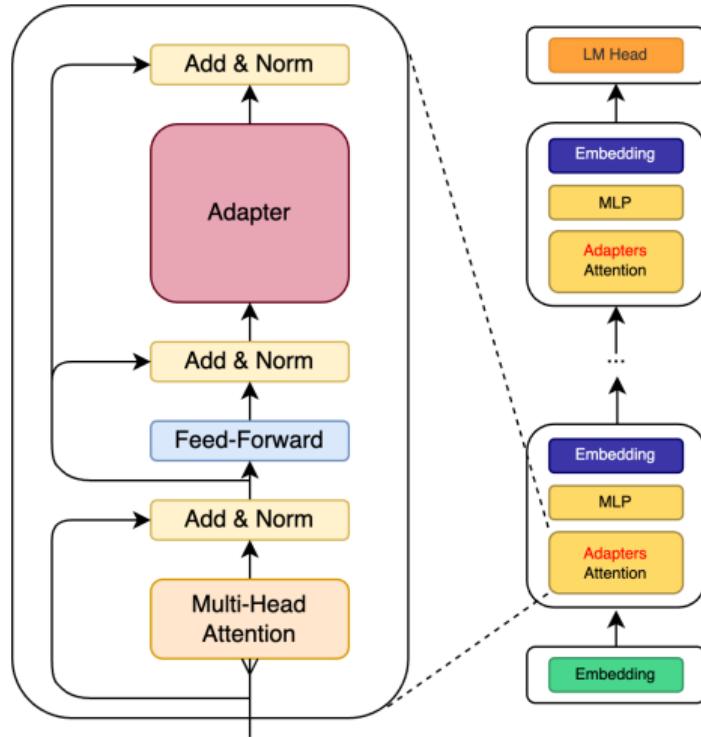


Figure 6 – An attention block with adapters

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

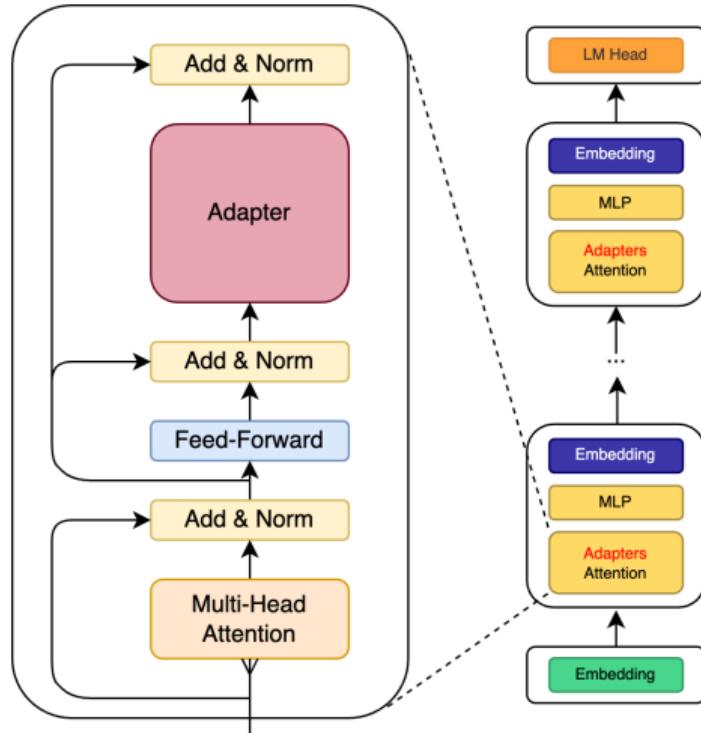
Common usage:

- 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/>

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Advantages:

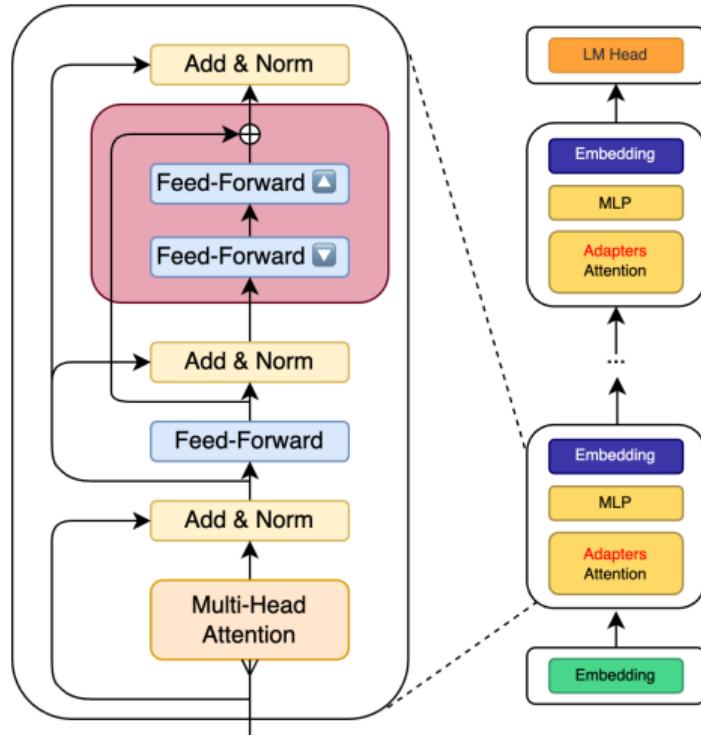
- Fewer param. updates than full fine-tuning
- Helps reduce catastrophic forgetting [14]
- Easy to share fine-tuned models^b

Figure 6 – An attention block with adapters

^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 7 – An attention block with LoRA adapters

Wrap-Up

Thanks for your attention!



Figure 8 – Practical session: <https://github.com/B-Gendron/tutorial-deeploria/lab/>

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