Working with Large Language Models

University of Hamburg - Spring 2025

Dr. Tobias Vlćek

Welcome to today's workshop!

- Explore Large Language Models (LLMs).
- You've likely interacted with LLMs already:
  - ChatGPT
  - Google's Gemini
  - Claude
- Understand:
  - How LLMs work on a high level.
  - What you can do with them.

What is an LLM?

- LLMs are a type of Artificial Intelligence (AI).
- Specifically within Natural Language Processing (NLP).
- Designed to:
  - Understand human language.
  - Generate human language.
  - Interact with human language.
  - In remarkably human-like ways.

> 💡 Tip
>
> **Why should you care?** LLMs are rapidly transforming how we:
> - Write and edit content
> - Develop software
> - Conduct research
> - Analyze data
> - Automate tasks
> - Learn new concepts
>
> Understanding these tools is becoming essential across nearly every professional field.

A Great Overview by 3Blue1Brown

- Greg Sanderson provides an excellent, concise explanation of LLMs.
- Great starting point to understand LLMs.
- Check out his YouTube channel, 3Blue1Brown for more.

https://www.youtube.com/embed/LPZh9BOjkQs

Today's Key Concepts

- Fundamental principles behind how LLMs work.
- The process of training these powerful models.
- Limitations and ethical considerations of LLMs.
- Practical applications, including pair-programming.
- How to use LLMs with your own data (Retrieval Augmented Generation).
- Further resources and tools.

How they work

- High-level overview of LLM workings.
- No deep technical details.

Deep Learning and Text Data

- LLMs are *deep learning* models.
- Built using artificial neural networks with many layers (“deep”).
- Trained on *enormous* amounts of text data:
  - Internet
  - Books
  - Articles
  - Code
  - And more!
- Training allows them to learn statistical patterns of language.
- Become incredibly good at predicting word sequences.
- Foundation for tasks like:
  - **Text Generation:** Creating new text similar to training data.
  - **Translation:** Converting text between languages.
  - **Summarization:** Condensing text into shorter summaries.
  - **Question Answering:** Answering questions based on learned information.
  - **Sentiment Analysis:** Determining emotional tone of text.

The Transformer

- Modern LLMs powered by **transformer model** architecture.
- Introduced in “Attention is All You Need” (Vaswani et al., 2017).
- Transformers revolutionized NLP.

How Transformers Work (Simplified):

1. **Tokenization:** Input text broken into *tokens*.
2. **Mathematical Relationships:** Identifies relationships between tokens.
   - Understands word/phrase connections in sentences and context.
3. **Attention Mechanism:** *Crucial* part.
   - Focuses on most relevant input parts when generating output.
   - Pays “attention” to important words for meaning.

Example: The Power of Attention

- Sentence: “The cat sat on the mat because it was warm.”
- Attention mechanism understands:
  - “it” refers to “the mat,” not “the cat.”

  - By considering context of surrounding words and relationships.

Tokens: The Building Blocks

- LLMs process text as **tokens**, not whole words.
- Token can be:
  - Whole word (e.g., "cat")
  - Subword (e.g., "un-", "break", "-able" for "unbreakable")
  - Individual characters

Why use tokens?

- **Handles Unknown Words:** Processes unseen words via subword units.
- **Efficiency:** Learning relationships between tokens is more efficient.

Challenges with Tokenization:

- Tokenization can be tricky.
- Especially for languages without spaces (Chinese, Japanese).
- Current methods better for languages with similar scripts (English, Spanish, French).
- Potentially disadvantages other languages.
- Area of ongoing research.

> ℹ Note
>
> *Think about this: How might this impact the fairness and inclusivity of LLMs?*

Context Window: LLM's "Memory"

- **Context window:** LLM's short-term memory.
- Number of tokens the model can process at once.
- Larger context window:
  - "Remembers" more of conversation/document.
  - More coherent and contextually relevant responses.
  - More computational resources needed.
  - Potentially less coherence if *too* long.
- Shorter context window:
  - Faster processing.
  - May lose track of earlier conversation parts.

> Tip
>
> There is a trade-off between the context window and the size of the model. A larger model can usually handle a larger context window, but it will also take more computational resources to run.

LLM Architectures

- LLMs are versatile tools.
- Different tasks need different architectures.
- Main architectures designed for specific strengths.

Encoder-Decoder

- **How it works:**
  - **Encoder:** Processes input text -> condensed representation ("thought vector").
  - **Decoder:** Takes representation -> generates output text.
  - Two-step process: understand, then create.
- **Analogy:** Translation.
  - Understand English sentence (encoder).
  - Construct German sentence (decoder).
- **Key Feature:** Excellent for tasks with different input and output sequences.

Encoder-Only

- **How it works:**
  - Focuses on *understanding* input.
  - Processes input -> rich representation of meaning.
- **Analogy:** Detective analyzing crime scene.
  - Gather clues (input) -> build complete picture.
  - No long report needed (output).
- **Key Feature:** Great for classification or information extraction.

Decoder-Only

- **How it works:**
  - Focuses on *generating* text.
  - Takes prompt/conversation history -> predicts next word, then next, etc.
  - Builds output sequence.
- **Analogy:** Creative writer or conversation.
  - Writer starts with sentence and continues story.
  - Conversation builds upon previous turns.
- **Key Feature:** Ideal for original text creation.

Mixture of Experts (MoE)

- **How it works:**

  - Uses multiple smaller “expert” models.
  - Each expert specialized in different aspect.
  - “Gating network” decides which expert(s) to use.
- **Analogy:** Large company with departments.
  - Manager (gating network) assigns project to relevant departments.
- **Key Feature:** Efficient scaling to large models/datasets.
  - Only subset of experts activated per input.
  - Improves performance and reduces cost.
  - Used in large chatbot models.

Training LLMs

- Training an LLM: like teaching a child language, but huge scale.

The Training Process

- LLMs learn via “pre-training” on massive text/code datasets.

1. **Input Processing:**
   - Model receives token sequence.
   - Text broken into tokens (words, subwords, characters).
2. **Prediction Task:**
   - Given sequence, predict next token.
   - Like filling in the blank: “The cat sat on the ___”
3. **Learning Loop:**
   - Make prediction.
   - Compare to actual answer.
   - Adjust internal parameters.
   - Repeat billions of times.

> Note
>
> This process requires enormous computational resources - training a large model can cost millions of dollars in computing power!

Computational Power and Parallelism

- Training needs *immense* computational power.
- **Specialized hardware:** GPUs (Graphics Processing Units).
- **Model Parallelism:** Distributes model parts across multiple GPUs.
  - Speeds up training via parallel processing.
  - Reason for Nvidia’s stock increase.

Training Phases

- Training process often divided into phases:

- **Self-Supervised Learning:**

  - Trained on massive dataset *without* explicit labels.
  - Learns to predict next token.
  - Learns basic language rules and patterns.

    - Like learning grammar/vocab by reading books.

- **Supervised Fine-tuning:**
    - Trained on smaller, *labeled* dataset for specific tasks.
    - Specialized for tasks like question answering, summarization.
    - Like specialized course after learning basics.
- **Reinforcement Learning from Human Feedback (RLHF):**
    - Human feedback refines model output.
    - Makes output more helpful, honest, and harmless.
    - Aligns text generation with human preferences.
    - Like teacher feedback to improve writing.

Limitations and Ethical Considerations

- LLMs are powerful but not perfect.
- Understand limitations and ethical implications.

Bias: A Reflection of the Data

- LLMs can exhibit biases (gender, racial, cultural, etc.).
- Learn biases from training data.
- Biased training data -> biased output.

Example:

- Trained mostly on text by men -> reflect male perspectives/stereotypes.

Impact of Bias:

- Unfair/discriminatory outcomes.
- Reinforcement of harmful stereotypes.
- Erosion of trust in AI.

Mitigating Bias:

- **Data Curation:** Carefully select diverse training data. Include data from different demographics, languages, cultures.
- **Model Fine-tuning:** Train on datasets to counteract bias.
- **Auditing and Evaluation:** Rigorously test models for bias.

Adversarial Attacks: Tricking the Model

- Adversarial attacks: small input changes to mislead LLM.
- Exploit model vulnerabilities.

Example:

- Slightly change prompt wording -> biased/harmful/nonsensical response.

Why is this a problem?

- Manipulate LLMs for malicious purposes.
- Spreading misinformation or generating harmful content.

A Broader View

- LLMs raise broader ethical concerns:
- **Job Displacement:** Automate human tasks -> potential job losses.

    - *How to prepare for this shift?*
- **Misinformation:** Generate realistic fake news easily.
    - *How to combat misinformation spread?*
- **Malicious Use:** Deepfakes, harmful content, propaganda.
    - *What safeguards are needed?*
- **Privacy**: Trained on personal data.
    - *Data usage and privacy regulations needed?*
- **Accountability**: Unclear who is responsible for LLM-generated content.
    - *How to hold producers/users accountable?*
- **Transparency:** Difficult to understand LLM decision-making.
    - *How to make LLMs more transparent?*
- Addressing ethical concerns requires: **researchers, policymakers, public**.

Putting LLMs to Work

- Explore how to *use* LLMs practically.

Pair Programming with LLMs

- Pair programming: two programmers work together.
  - One writes code, other reviews/feedback.
- LLMs as "AI pair programmer":
  - **Code Completion:** Suggest code snippets, complete lines.
  - **Error Detection:** Identify bugs, suggest fixes.
  - **Code Generation:** Generate functions/blocks from instructions.
  - **Code Explanation:** Explain how code works.
  - **Best Practices:** Suggest improvements and best practices.

Tools for Pair Programming:

- **GitHub Copilot:** VS Code integration, AI-powered suggestions.
- **Cursor:** VS Code fork, more powerful AI features.
- **Zed:** Code editor for pair programming (LLMs and humans). Local and API models.

Tips for Effective Pair Programming

- **Start Small:** Begin with code completion, then complex tasks.
- **Be Specific:** Clear, concise instructions to LLM.
- **Review Carefully:** *Always* review LLM-generated code. Mistakes can happen!
- **Learn from the LLM:** Learn new techniques and coding styles.

> Tip
>
> **Manage Context:** Be mindful of context window. For longer codebases, LLM may "forget" earlier parts. Break down large tasks.

Retrieval Augmented Generation (RAG)

- Retrieval Augmented Generation (RAG): combines LLMs with external knowledge.
- LLM with vast library and research assistant.

Why is RAG important?

- **Up-to-Date Information:** Access *current* information beyond training data.
- **Reduced Hallucinations:** Responses grounded in facts, less making things up.
- **Domain-Specific Knowledge:** Connect to your documents, databases, APIs.
- **Expert in your area:** Tailored to specific domain without retraining.

How RAG Works:

1. **Query:** Ask a question or provide prompt.
2. **Retrieval:** Search external sources for relevant info.
3. **Augmentation:** Add retrieved info to LLM’s prompt (context).
4. **Generation:** LLM generates response based on:
    - Pre-trained knowledge.
    - Retrieved information.

Example:

- **Question:** “What are latest advancements in quantum computing?”
- **Retrieval:** Search scientific publications, news, research databases.
- **Augmentation:** Key findings added to prompt.
- **Generation:** Comprehensive, up-to-date answer.

Running LLMs Locally with Ollama

- Running LLMs locally: on your own computer.

Advantages:

- **Privacy:** Data stays on your machine.
- **Cost Savings:** No API fees.
- **Customization:** Experiment, fine-tune for needs.
- **Offline Access:** Use without internet.
- Requires understanding hardware and technical setup.
- **Ollama**: user-friendly tool for local LLMs.

Ollama

- Ollama: free, open-source.
- Simplifies downloading, installing, running LLMs (macOS, Linux, Windows).
- Command-line interface (CLI), wide model support.

Key Features of Ollama:

- **Easy Installation:** Simple download and install.
- **Model Management:** Download/manage models from library (Hugging Face).
- **Command-Line Interface:** Interact via commands.
- **API Server:** Local API server, integrate in applications.

Hardware Requirements

- Local LLMs need sufficient resources:

Component	Requirement	Notes
RAM	Minimum 8GB	- 16GB recommended- 32GB+ for larger models
CPU	Modern multi-core	- Can run smaller models (< 7B params)- Faster = better performance
GPU	VRAM dependent	- More VRAM = larger models- NVIDIA GPUs preferred
Storage	10GB+ free	- Models can be several GB each

⚠ Warning

Performance Note: CPU-only can be much slower compared to GPU.

Billions of Parameters (B)

- LLMs described by *parameters* (internal learned values).
- More parameters -> more capable (generally), larger model, more resources.
- Model size not everything, quality depends on data/training/architecture.
- Newer models can be more efficient.

Size Overview

- **Small Models (< 7B):** CPU with 16GB+ RAM. Experimentation, less demanding tasks.
- **Medium Models (7B - 13B):** Benefit from GPU, sometimes CPU with 32GB+ RAM.
- **Large Models (30B+):** Powerful GPU with VRAM needed.
- **Very Large Models (70B+):** High-end/multiple GPUs.

Tip

Model names like `mistral:7b`, `codellama:34b` - “b” = billions of parameters.

Quantization: Making Models Smaller

- **Quantization:** Reduce size/compute of LLMs “without significantly impacting performance”.
- Represent parameters with lower precision (e.g., 8-bit, 4-bit integers).

Benefits of Quantization:

- **Smaller Model Size:** Less RAM/disk needed.
- **Faster Inference:** Faster low-precision calculations.
- **Lower Power Consumption:** Less hardware demand.
- **Trade-offs:** Small accuracy decrease possible. More aggressive quantization = more performance impact.
- **Ollama and Quantization**: Supports quantized models from Hugging Face.
  - `q4_0`, `q8_0` suffixes indicate quantization level.
  - `q4_0`: 4-bit (balance size/quality).
  - `q8_0`: 8-bit (closer to original, larger size).

Tip

Quantization levels offer different balance of speed, size, quality. Experiment to find best option for your hardware/needs. Default model often sufficient, quantization not always needed.

Getting Started with Ollama

1. **Download and Install Ollama:** ollama.com.
2. **Pull a Model:** `ollama pull mistral:7b` (terminal/command prompt).

3. **Run the Model:** `ollama run mistral:7b` (terminal). Chat interface opens.
4. **Ask a Question:** Type prompt and press Enter.
5. **Experiment:** Try different models from the Ollama website model library. Use Hugging Face for more models/quantization.

Wrap-up

- LLMs are powerful tools for many tasks.
- Understand their capabilities and limitations.
- Use them effectively in your work.