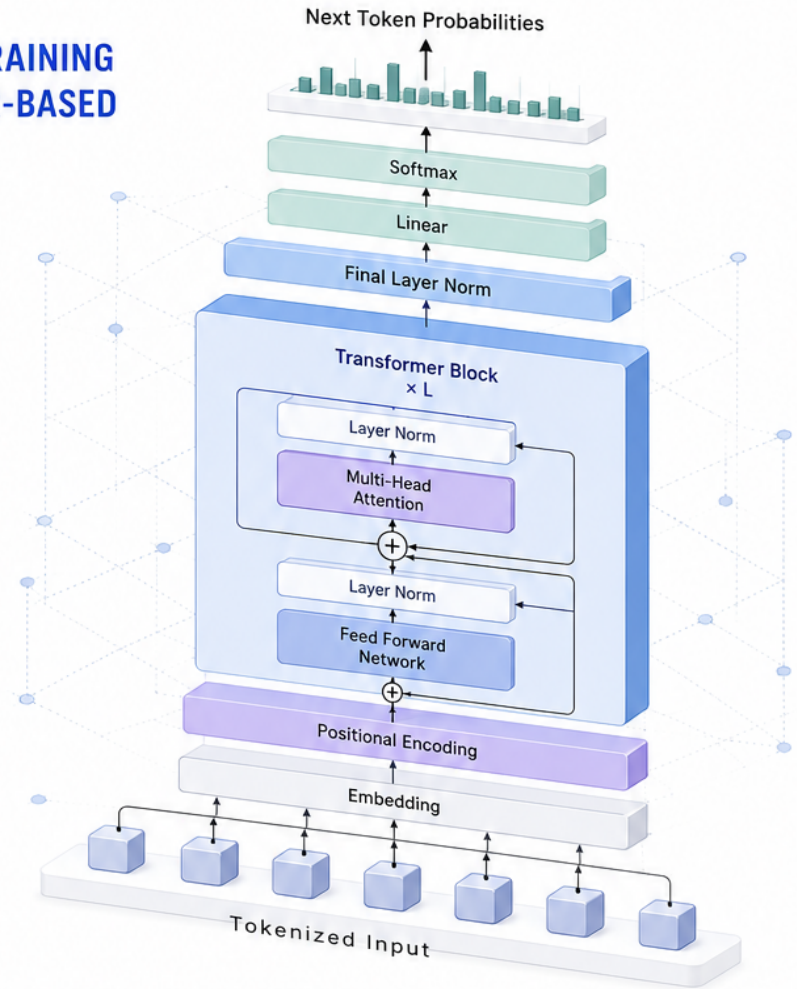
BUILDING LARGE LANGUAGE MODELS FROM SCRATCH

WITH PYTORCH

A PRACTICAL GUIDE TO TRAINING YOUR OWN TRANSFORMER-BASED AI IN PYTHON

- FROM RAW TEXT TO INFERENCE API
- TOKENIZATION & EMBEDDINGS
- ATTENTION & TRANSFORMERS
- DISTRIBUTED TRAINING
- ALIGNMENT, EVALUATION & DEPLOYMENT



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Building Large Language Models from Scratch

A Practical Guide to Training Your Own Transformer-Based AI in Python

Steve T. Publications

This book is available at
https://leanpub.com/buildinglargelanguagemodelsfromscratch

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Introduction: Why Build from Scratch?

The Black Box Problem

In 2022, a single model called GPT-3.5 demonstrated the ability to write code, answer questions, translate languages, and generate creative text with startling fluency. Within a year, it had been wrapped in a chat interface and was being used by hundreds of millions of people worldwide. For most users, the model is a black box: you type a prompt, you get an answer, and the magic happens somewhere inside a server farm you will never visit.

For software engineers and data scientists, the situation is only slightly different. You call an API endpoint, pass in your text, and receive tokens back. The pricing is measured in dollars per million tokens. The model architecture, training data, and alignment procedures are trade secrets. You can fine-tune with a few hundred examples using a tool like LoRA, but the foundation model itself remains opaque.

This book takes the opposite approach. We will build everything from scratch, starting with raw text files and ending with a trained model that you can run, inspect, and modify at will. The goal is not to reproduce GPT-4 on your laptop (that would require roughly $100 million in compute). The goal is something more valuable: deep, first-principles understanding of how large language models work, what makes them tick, and what it actually takes to train one.

There is a practical reason for this approach as well. Every year, new architectures, training techniques, and optimization strategies emerge. Models that were cutting-edge in 2023 are baseline in 2025. If you only know how to call APIs, you are at the mercy of whatever the latest framework provides. If you understand the underlying mechanics, you can evaluate new ideas critically, adapt them to your own needs, and contribute to the field rather than merely consuming it.

What You Will Build

By the end of this book, you will have built a complete LLM training pipeline that includes:

- A byte-pair encoding (BPE) tokenizer that converts raw text into integer sequences
- An embedding layer that maps tokens to dense vector representations
- A multi-head attention mechanism with causal masking for autoregressive generation
- Rotary positional embeddings (RoPE) that encode sequence order information
- A complete decoder-only transformer architecture with RMSNorm normalization and residual connections
- A data preparation pipeline for curating, cleaning, and formatting training text
- A training loop with cross-entropy loss, AdamW optimizer, learning rate scheduling, and gradient clipping
- Memory-efficient training patterns including mixed precision (BF16), gradient accumulation, and activation checkpointing
- Distributed training support using PyTorch's Distributed Data Parallel
- Checkpointing, experiment tracking, and reproducibility infrastructure
- Parameter-efficient fine-tuning via LoRA, including 4-bit quantized QLoRA
- Alignment techniques including Direct Preference Optimization (DPO)
- An evaluation harness covering perplexity, benchmark suites, and safety testing
- A production-ready inference API with KV caching, quantization, and FastAPI serving

The capstone project ties everything together: you will train a small but fully functional language model on a curated dataset, evaluate it against baselines, and deploy it behind a live API endpoint. The model will be modest in size (roughly 30 to 125 million parameters, depending on your hardware), but it will demonstrate every architectural and training principle used by models with billions of parameters.

Prerequisites and How to Use This Book

This book assumes you are comfortable writing Python code, including working with classes, functions, list comprehensions, and basic data structures. You should have used PyTorch or a similar framework at least once, enough to understand what a tensor is, how `nn.Module` works, and what happens when you call `.backward()` on a loss. A basic familiarity with linear algebra (matrix multiplication, vector operations) and machine learning concepts (loss functions, gradient descent, overfitting) will help, but I will review each concept as it becomes relevant.

You do not need prior experience with transformer architectures, attention mechanisms, or language model training. That is precisely what this book teaches. Each chapter builds on the previous one, so the recommended reading order matches the table of contents. If you want to jump ahead to a specific topic, the chapters on architecture (Chapters 3 through 5) are relatively self-contained, and the chapters on fine-tuning and deployment (Chapters 11 through 14) can be read independently once you understand the basic training loop.

Each chapter follows a consistent structure. Conceptual explanations come first, establishing the "why" before the "how." Code implementations follow, with complete, runnable examples that you can copy, modify, and experiment with. Mathematical notation appears only where it clarifies the code, and every formula is accompanied by an intuitive explanation in plain English. Each chapter ends with exercises or mini-projects that reinforce the key ideas through hands-on practice.

A Note on Hardware Requirements

Training language models requires computational resources, but the barrier to entry has dropped significantly. Here is what you need for different stages of this book:

CPU-only exploration: You can follow every conceptual explanation and run the smallest code examples (character-level models, tiny vocabularies) on any modern laptop. Training will be slow, but the code will work. This is sufficient for understanding Chapters 1 through 5 in depth.

Single GPU training: A consumer GPU with at least 8 GB of VRAM (NVIDIA RTX 3060, 4070, or better) lets you train small models (10 to 50 million parameters) on modest datasets. An RTX 4090 (24 GB) or A100 (40-80 GB) opens up medium-sized models (100M+ parameters). Google Colab's free tier provides a T4 GPU (16 GB), which is sufficient for many exercises.

Cloud GPU access: Services like Lambda Labs, RunPod, and Vast.ai offer A100 and H100 GPUs at roughly $1 to $3 per hour. The capstone project can be completed on a single A100 40GB for approximately $20 to $50 in total compute cost.

Multi-GPU scaling: Chapters 9 and beyond discuss distributed training across multiple GPUs. This is optional but recommended if you want to train larger models or understand production-scale training infrastructure.

Throughout the book, I will note where hardware requirements increase and provide scaled-down alternatives when possible. The code is designed to work on the smallest feasible setup, with clear paths to scale up.

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