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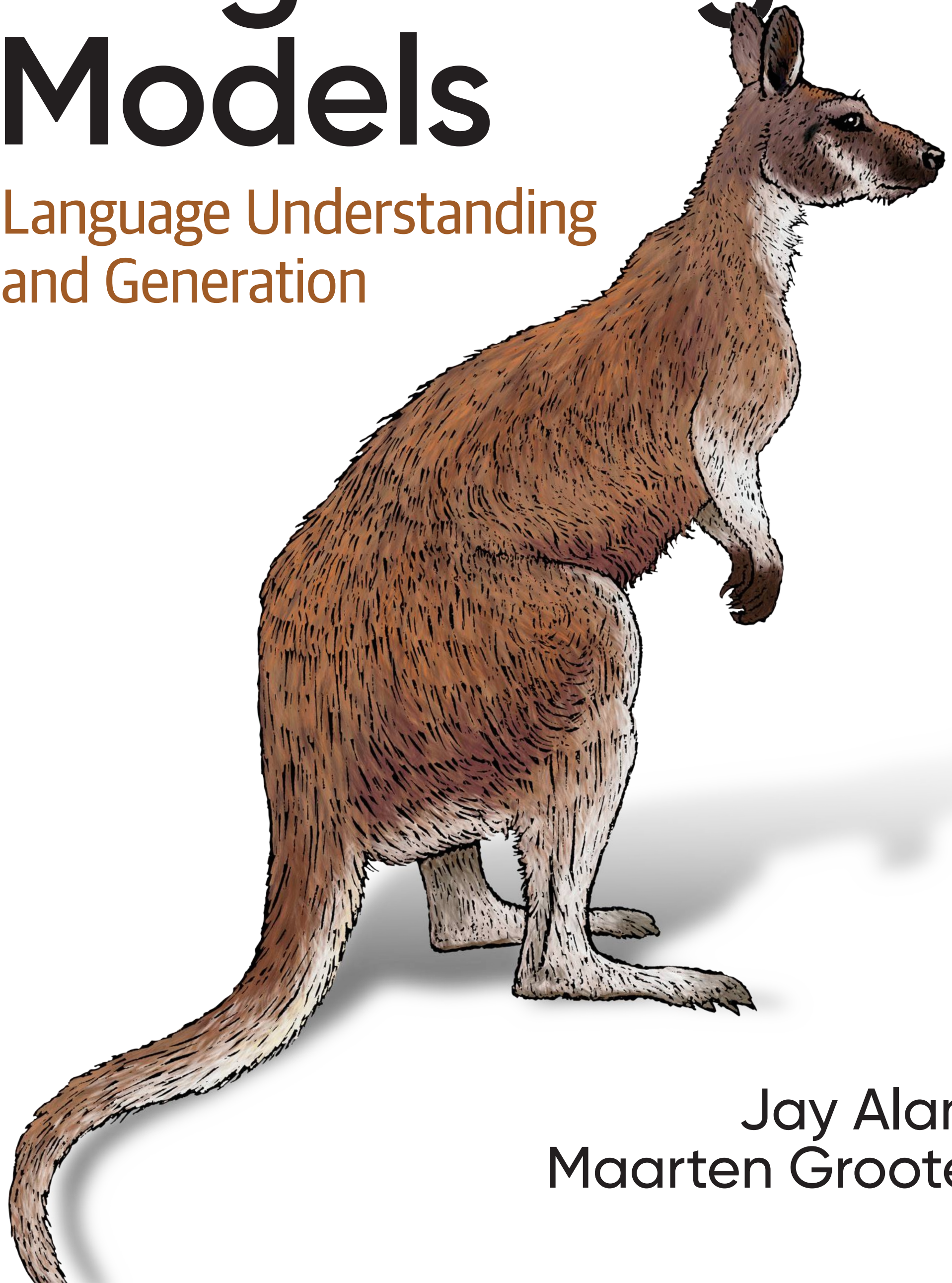
Hands-On Large Language Models

Language Understanding and Generation



Jay Alammar & Maarten Grootendorst

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Hands-On Large Language Models

AI has acquired startling new language capabilities in just the past few years. Driven by rapid advances in deep learning, language AI systems are able to write and understand text better than ever before. This trend is enabling new features, products, and entire industries. Through this book's visually educational nature, readers will learn practical tools and concepts they need to use these capabilities today.

You'll understand how to use pretrained large language models for use cases like copywriting and summarization; create semantic search systems that go beyond keyword matching; and use existing libraries and pretrained models for text classification, search, and clusterings.

This book also helps you:

- **Understand the architecture of Transformer language models that excel at text generation and representation**
- **Build advanced LLM pipelines to cluster text documents and explore the topics they cover**
- **Build semantic search engines that go beyond keyword search, using methods like dense retrieval and rerankers**
- **Explore how generative models can be used, from prompt engineering all the way to retrieval-augmented generation**
- **Gain a deeper understanding of how to train LLMs and optimize them for specific applications using generative model fine-tuning, contrastive fine-tuning, and in-context learning**

> "Jay and Maarten have continued their tradition of providing beautifully illustrated and insightful descriptions of complex topics. Their book is a valuable resource for anyone looking to understand the main techniques behind how large language models are built."
>
> —**Andrew Ng**
> founder of DeepLearning.AI

> "I can't think of another book that is more important to read right now. On every single page, I learned something that is critical to success in this era of language models."
>
> —**Josh Starmer,** StatQuest

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Praise for *Hands-On Large Language Models*

This is an exceptional guide to the world of language models and their practical applications in industry. Its highly-visual coverage of generative, representational, and retrieval applications of language models empowers readers to quickly understand, use, and refine LLMs. Highly recommended!

—Nils Reimers, Director of Machine Learning at Cohere | creator of sentence-transformers

Jay and Maarten have continued their tradition of providing beautifully illustrated and insightful descriptions of complex topics in their new book. Bolstered with working code, timelines, and references to key papers, their book is a valuable resource for anyone looking to understand the main techniques behind how Large Language Models are built.

—Andrew Ng, founder of DeepLearning.AI

I can't think of another book that is more important to read right now. On every single page, I learned something that is critical to success in this era of language models.

—Josh Starmer, StatQuest

If you're looking to get up to speed in everything regarding LLMs, look no further! In this wonderful book, Jay and Maarten will take you from zero to expert in the history and latest advances in large language models. With very intuitive explanations, great real-life examples, clear illustrations, and comprehensive code labs, this book lifts the curtain on the complexities of transformer models, tokenizers, semantic search, RAG, and many other cutting-edge technologies. A must read for anyone interested in the latest AI technology!

—Luis Serrano, PhD, Founder and CEO of Serrano Academy

This book is a must-read for anyone interested in the rapidly-evolving field of generative AI. With a focus on both text and visual embeddings, it's a great blend of algorithmic evolution, theoretical rigor, and practical guidance. Whether you are a student, researcher, or industry professional, this book will equip you with the use cases and solutions needed to level-up your knowledge of generative AI. Well done!

—Chris Fregly, Principal Solution Architect,
Generative AI at AWS

In the heart of the GenAI revolution, this indispensable guide masterfully balances theory and practice, navigating the vast landscape of large language models to equip readers with the knowledge needed for immediate and transformative impact in the field of AI.

—Tarun Narayanan Venkatachalam, AI Researcher,
University of Washington

Timely reading to get hands-on experience with language models.

—Emir Muñoz, Genesys

Hands-On Large Language Models brings clarity and practical examples to cut through the hype of AI. It provides a wealth of great diagrams and visual aids to supplement the clear explanations. The worked examples and code make concrete what other books leave abstract. The book starts with simple introductory beginnings, and steadily builds in scope. By the final chapters, you will be fine-tuning and building your own large language models with confidence.

—Leland McInnes, Researcher at the Tutte Institute for
Mathematics and Computing

Finally, a book that not only avoids superficial coverage of large language models but also thoroughly explores the background in a way that is both accessible and engaging. The authors have masterfully created a definitive guide that will remain essential reading despite the fast-paced advancements in the field.

—Prof. DDr. Roman Egger, CEO of Smartvisions.at
and Modul University Vienna

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by Jay Alammar and Maarten Grootendorst

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Table of Contents

Part II. Using Pretrained Language Models

Part III. Training and Fine-Tuning Language Models

Preface

Large language models (LLMs) have had a profound and far-reaching impact on the world. By enabling machines to better understand and generate human-like language, LLMs have opened new possibilities in the field of AI and impacted entire industries.

This book provides a comprehensive and highly visual introduction to the world of LLMs, covering both the conceptual foundations and practical applications. From word representations that preceded deep learning to the cutting-edge (at the time of this writing) Transformer architecture, we will explore the history and evolution of LLMs. We delve into the inner workings of LLMs, exploring their architectures, training methods, and fine-tuning techniques. We also examine various applications of LLMs in text classification, clustering, topic modeling, chatbots, search engines, and more.

With its unique blend of intuition-building, applications, and illustrative style, we hope that this book provides the ideal foundation for those looking to explore the exciting world of LLMs. Whether you are a beginner or an expert, we invite you to join us on this journey to start building with LLMs.

An Intuition-First Philosophy

The main goal of this book is to provide an *intuition* into the field of LLMs. The pace of development in the Language AI field is incredibly fast and frustration can build trying to keep up with the latest technologies. Instead, we focus on the fundamentals of LLMs and intend to provide a fun and easy learning process.

To achieve this *intuition-first philosophy* we liberally make use of visual language. Illustrations will help give a visual identity to major concepts and processes involved in the learning process of LLMs.[1] With our illustrative method of storytelling, we want to take you on a journey to this exciting and potentially world-changing field.

Throughout the book, we make a clear distinction between representation and generative language models. Representation models are LLMs that do not generate text but are commonly used for task-specific use cases, like classification, whereas generation models are LLMs that generate text, like GPT models. Although generative models are typically the first thing that comes to mind when thinking about LLMs, there is still much use for representation models. We are also loosely using the word "large" in *large language models* and often elect to simply call them language models as size descriptions are often rather arbitrary and not always indicative of capability.

Prerequisites

This book assumes that you have some experience programming in Python and are familiar with the fundamentals of machine learning. The focus will be on building a strong intuition rather than deriving mathematical equations. As such, illustrations combined with hands-on examples will drive the examples and learning through this book. This book assumes no prior knowledge of popular deep learning frameworks such as PyTorch or TensorFlow nor any prior knowledge of generative modeling.

If you are not familiar with Python, a great place to start is Learn Python, where you will find many tutorials on the basics of the language. To further ease the learning process, we made all the code available on Google Colab, a platform where you can run all of the code without the need to install anything locally.

Book Structure

The book is broadly divided into three parts. They are illustrated in Figure P-1 to give you a full view of the book. Note that each chapter can be read independently, so feel free to skim chapters you are already familiar with.

Part I: Understanding Language Models

In Part I of the book, we explore the inner workings of language models both small and large. We start with an overview of the field and common techniques (see Chapter 1) before moving over to two central components of these models, tokenization and embeddings (see Chapter 2). We finish this part of the book with an updated and expanded version of Jay's well-known Illustrated Transformer, which dives into

[1] J. Alammar. "Machine learning research communication via illustrated and interactive web articles." *Beyond Static Papers: Rethinking How We Share Scientific Understanding in ML*. ICLR 2021 Workshop (2021).

the architecture of these models (see Chapter 3). Many terms and definitions will be introduced that are used throughout the book.

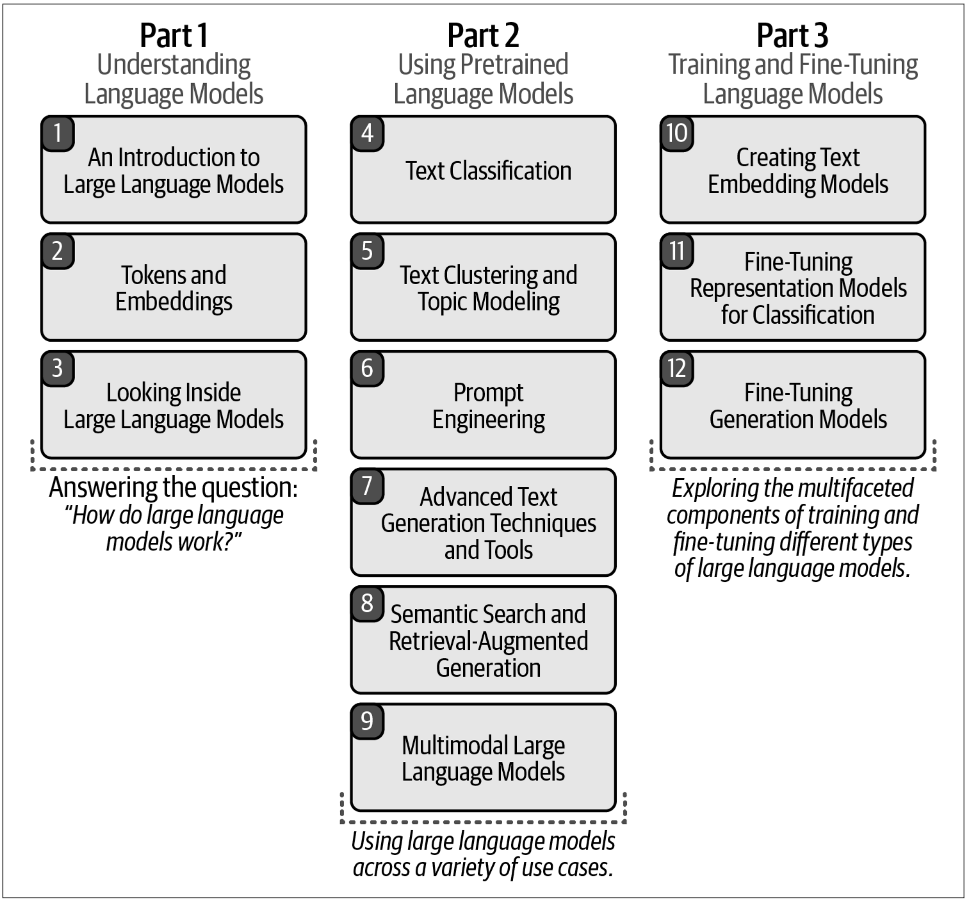
Part 1
Understanding Language Models
1 An Introduction to Large Language Models
2 Tokens and Embeddings
3 Looking Inside Large Language Models
Answering the question: "How do large language models work?"
Part 2
Using Pretrained Language Models
4 Text Classification
5 Text Clustering and Topic Modeling
6 Prompt Engineering
7 Advanced Text Generation Techniques and Tools
8 Semantic Search and Retrieval-Augmented Generation
9 Multimodal Large Language Models
Using large language models across a variety of use cases.
Part 3
Training and Fine-Tuning Language Models
10 Creating Text Embedding Models
11 Fine-Tuning Representation Models for Classification
12 Fine-Tuning Generation Models
Exploring the multifaceted components of training and fine-tuning different types of large language models.

Figure P-1. All parts and chapters of the book.

Part II: Using Pretrained Language Models

In Part II of the book, we explore how LLMs can be used through common use cases. We use pretrained models and demonstrate their capabilities without the need to fine-tune them.

You learn how to use language models for supervised classification (see Chapter 4), text clustering and topic modeling (see Chapter 5), leveraging embedding models for semantic search (see Chapter 6), generating text (see Chapters 7 and 8), and extending the capabilities of text generation to the visual domain (see Chapter 9).

Learning these individual language model capabilities will equip you with the skill set to problem-solve with LLMs and build more and more advanced systems and pipelines.

Part III: Training and Fine-Tuning Language Models

In Part III of the book, we explore advanced concepts through training and fine-tuning all kinds of language models. We will explore how to create and fine-tune an embedding model (see Chapter 10), review how to fine-tune BERT for classification (see Chapter 11), and end the book with several methods for fine-tuning generation models (see Chapter 12).

Hardware and Software Requirements

Running generative models is generally a compute-intensive task that requires a computer with a strong GPU. Since those are not available to every reader, all examples in this book are made to run using an online platform, namely Google Colaboratory, often shortened to "Google Colab." At the time of writing, this platform allows you to use an NVIDIA GPU (T4) for free to run your code. This GPU has 16 GB of VRAM (which is the memory of your GPU), which is the minimum amount of VRAM we expect for the examples throughout the book.

> Not all chapters require a minimum of 16 GB VRAM as some examples, like training and fine-tuning, are more compute-intensive than others, such as prompt engineering. In the repository, you will find the minimum GPU requirements for each chapter.

All code, requirements, and additional tutorials are available in this book's repository. If you want to run the examples locally, we recommend access to an NVIDIA GPU with a minimum of 16 GB of VRAM. For a local installation, for example with conda, you can follow this setup to create your environment:

```
conda create -n thellmbook python=3.10
conda activate thellmbook
```

You can install all the necessary dependencies by forking or cloning the repository and then running the following in your newly created Python 3.10 environment:

```
pip install -r requirements.txt
```

API Keys

We use both open source and proprietary models throughout the examples to demonstrate the advantages and disadvantages of both. For the proprietary models, using OpenAI and Cohere's offering, you will need to create a free account:

OpenAI
: Click "sign up" on the site to create a free account. This account allows you to create an API key, which can be used to access GPT-3.5. Then, go to "API keys" to create a secret key.

Cohere
: Register a free account on the website. Then, go to "API keys" to create a secret key.

Note that with both accounts, rate limits apply and that these free API keys only allow for a limited number of calls per minute. Throughout all examples, we have taken that into account and provided local alternatives if necessary.

For the open source models, you do not need to create an account with the exception of the Llama 2 model in Chapter 2. To use that model, you will need a Hugging Face account:

Hugging Face
: Click "sign up" on the Hugging Face website to create a free account. Then, in "Settings" go to "Access Tokens" to create a token that you can use to download certain LLMs.

Conventions Used in This Book

The following typographical conventions are used in this book:

Italic
: Indicates new terms, URLs, email addresses, filenames, and file extensions.

`Constant width`
: Used for program listings, as well as within paragraphs to refer to program elements such as variable or function names, databases, data types, environment variables, statements, and keywords.

`Constant width bold`
: Shows commands or other text that should be typed literally by the user.

`Constant width italic`
: Shows text that should be replaced with user-supplied values or by values determined by context.

This element signifies a tip or suggestion.

This element signifies a general note.

Using Code Examples

Supplemental material (code examples, exercises, etc.) is available for download at *https://github.com/HandsOnLLM/Hands-On-Large-Language-Models*.

If you have a technical question or a problem using the code examples, please send email to *support@oreilly.com*.

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Acknowledgments

Writing this book has been an incredible experience, collaboration, and journey for us.

The field of (large) language models is one of the most dynamic areas in technology today, and within the span of writing this book, we have witnessed extraordinary advancements. Yet, despite the rapid pace of change, the fundamental principles remain strikingly consistent which made the writing process particularly intriguing. We are grateful to have had the opportunity to explore this field in-depth at such a pivotal moment.

Working with our O'Reilly team was incredible! Special thanks to Michele Cronin for her amazing feedback, support, and enthusiasm for this book from day one. We could not have asked for a better editor—you are amazing! Thank you, Nicole Butterfield, for kicking off this book and helping us maintain a structured approach throughout the writing. Thank you to Karen Montgomery for creating our wonderful cover, we love the kangaroo! Big thanks to Kate Dullea for being so patient with us having to go through hundreds of illustrations many times over. The timely early releases by Clare Laylock helped us see our work grow which was a big motivator, thank you. Thanks to Ashley Stussy and Charles Roumeliotis for the development in the final stages of the book and everyone else at O'Reilly who contributed.

Thanks to our amazing crew of technical reviewers. Invaluable feedback was given by Harm Buisman, Emir Muñoz, Luba Elliott, Guarav Chawla, Rafael V. Pierre, Luba Elliott, Tarun Narayanan, Nikhil Buduma, and Patrick Harrison.

Jay

I'd love to extend my deepest gratitude to my family for their unwavering support and inspiration. I would like to specifically acknowledge my parents, Abdullah and Mishael, and my aunts, Hussah and Aljoharah.

I'm grateful to the friends, colleagues, and collaborators who helped me understand and explain the tricky concepts covered in this book as well as to the Cohere folks who cultivate a supporting learning and sharing environment. Thank you to Adrien Morisot, Aidan Gomez, Andy Toulis, Anfal Alatawi, Arash Ahmadian, Bharat Venkitesh, Edward Grefenstette, Ivan Zhang, Joao Araújo, Luis Serrano, Matthias Gallé, Meor Amer, Nick Frosst, Patrick Lewis, Phil Blunsom, Sara Hooker, and Suhas Pai.

I couldn't conceive of this project getting accomplished to the level it has without the extraordinary talent and tireless effort of Maarten, my coauthor. Your ability to repeatedly nail the technical details (from the pinned version of the nth import dependency to the latest in LLM quantization) while weaving some of the world's best visual narratives is absolutely breathtaking.

Lastly, a tip of the hat to the incredible coffee shop scene of Riyadh, Saudi Arabia for supplying me with caffeine and a good place to focus from dawn until midnight. It's where I read most of these papers and worked out my understanding (looking at you, Elixir Bunn).

Maarten

I want to begin by expressing my heartfelt appreciation to my coauthor, Jay. Your insights have made this not only possible but incredibly fulfilling. This journey has been nothing short of amazing and collaborating with you has been an absolute joy.

I want to sincerely thank my wonderful colleagues at IKNL for their continued support throughout this journey. A special mention goes to Harm—our Monday morning coffee breaks discussing this book were a constant source of encouragement.

Thank you to my family and friends for their unwavering support, and to my parents in particular. Pap, despite the challenges you faced, you always found a way to be