Optimizing and Adapting Language Models for Domain-Specific Task

End-of-studies Apprenticeship Report

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Abstract

[**INFO:** *The abstract is essentially informative in nature and should be written concisely (up to 200 words) in a way that captures the interest of the reader.*

The Abstract replaces reading the document and does not contain figures, tables, citations, etc. It should include the following topics: scope, objectives, methods, main findings, including results, conclusions and recommendations, if any.

For more information on how to write a good abstract, consult the online tutorial available on the Library website, "Publication Support Guide", section: "Structuring Technical Report".]

Write the Abstract, but only at the end.

Acknowledgement

Table of contents

Todo list

Figures and tables

bash
> Bash is a *Unix shell* and command language written in 1989 by Brian Fox for the GNU Project as a free software replacement for the *Bourne shell*.

firewall
> In computing, a *firewall* is a network security system that monitors and controls incoming and outgoing network traffic based on predetermined security rules. A *firewall* typically establishes a barrier between a trusted network and an untrusted network, such as the Internet.

Figures and tables
> Figures and tables are essential elements in a report, providing visual representations of data and information. They should be clearly labeled and referenced in the text.

Chapter 1

Introduction

1.1 General Context

1.1.1 Evolution of Large Language Model

Over the past decade, the fields of Artificial Intelligence (AI) and Natural Language Processing (NLP) have witnessed groundbreaking advances, particularly since the emergence of the Transformer architecture [Vaswani et al., 2017]. Large Language Models (LLMs) such as GPT-5 [OpenAI, 2025], Claude 4 [Anthropic, 2025], Gemini 2.5 [Google, 2025], and open-source models like Llama 3 [Meta, 2024] and Qwen 2.5 [Alibaba, 2024] have demonstrated superior capabilities in understanding context, generating text, and performing logical inference across a variety of tasks.

According to a McKinsey Global Institute report (2024), the generative AI market is expected to reach a value of \$4.4 trillion by 2030. However, a Gartner survey (2024) indicates that 67% of businesses struggle to deploy LLMs for specialized tasks due to accuracy limitations and operating costs.

1.1.2 The Research-Industrial Application Gap

Transferring language models from the research environment to practical industrial applications (Industrial Deployment) faces significant challenges. Although Foundation Models possess a vast amount of general knowledge, they often encounter two serious limitations when solving domain-specific tasks:

Knowledge Gap

In critical fields such as healthcare, finance, and insurance, information is often contained in complex documents (financial reports, medical technical catalogs) and changes constantly. LLMs face three main problems:

- Static Knowledge: Model knowledge is limited by the training time (knowledge cutoff), making it impossible to update new information without retraining [Lewis et al., 2020].

- Private Data Inaccessibility: The model cannot access confidential organizational documents such as contracts, internal procedures, or patient records.

- Hallucination: LLMs tend to confidently generate false information [Ji et al., 2023], which is unacceptable in medical or financial decisions where near-absolute accuracy is required.

Efficiency & Behavior Gap

For tasks requiring the model to adhere to a specific behavioral scenario, a particular language style (e.g., psychological counselor, analyst), or deployment on limited hardware infrastructure, using massive models (hundreds of billions of parameters) is not cost-effective and prone to latency. According to Hoffmann et al. (2022), the inference cost of GPT-4 can reach $0.06/1K tokens, making large-scale deployment unfeasible for many small and medium-sized enterprises.

1.1.3   Research motivation

Based on the above reality, this thesis focuses on researching and implementing advanced techniques to **optimize and adapt Language Models for specific data domains**, with two main approaches:

- Retrieval-Augmented Generation (RAG): Integrating external knowledge bases to address the Knowledge Gap.

- Parameter-Efficient Fine-Tuning (PEFT): Adapting model behavior to address the Behavior Gap.

1.2   Internship Environment

This master's thesis was completed at Torus AI, a technology company with the mission *Intelligence for Life*, specializing in providing advanced AI solutions to improve quality of life and business efficiency.

I worked in the Research and Development Team (R&D Team - Torus Lab) as a Machine Learning Engineer Alternant. At Torus AI, the R&D department acts as a bridge between the latest academic research (State-of-the-Art) and commercial products. The team's main task is to continuously explore emerging Generative AI technologies, assess their feasibility, and build functional prototypes (PoCs) to verify their effectiveness before integration into the main product system.

The R&D work environment demands flexible thinking: not just using existing APIs, but delving into customizing architecture, optimizing data processing pipelines, and quantitatively evaluating technical solutions.

My role in the R&D department includes:

- Researching emerging Generative AI technologies

- Evaluating feasibility and building functional prototypes (PoCs)

- Integrating solutions into product systems

Resources provided:

- GPU infrastructure: NVIDIA RTX 3090 (24GB)

- Real-world enterprise data: Medical documents (CCAM, NGAP), insurance financial reports

- API access: OpenAI GPT-4, Google Gemini, Qwen API

1.3   Problem Statement

During our work in the R&D department, we identified two core problems that needed to be addressed when applying GenAI in practice, corresponding to two main technical approaches:

Problem 1: Integration of External Knowledge from Complex Unstructured Data

Partner businesses (such as insurance companies, healthcare facilities) possess large amounts of data in the form of PDF documents containing text, tables, and images. Traditional RAG (Retrieval-Augmented Generation) methods based on plain text (text-only) fail to understand the semantics of complex tables or visual information. The question is: How to build a Multimodal RAG pipeline capable of accurately parsing, indexing, and retrievaling information from these mixed documents to support decision-making (e.g., medical refund code lookup, financial data analysis)?

Problem 2: Behavioral Adaptation and Resource Optimization for Small Models (Behavioral Adaptation & Efficiency)

For applications requiring high interactivity, counseling, or entertainment (such as psychological counseling chatbots or Tarot Readers), the requirement is not only for information accuracy but also for consistency in tone and style and rule-based reasoning. Using large models (like GPT-4) via APIs is both costly to operate and difficult to fully control behavior. The question is: Is it possible to fine-tune small language models (such as Qwen, Llama < 7B parameters) using parameter optimization techniques (PEFT/LoRA) and quantization so that they achieve inference capabilities and writing styles comparable to large models, but can be run locally at low cost?

1.4   Objectives and expected results

1.5   Report structure

In addition to this introduction, this report is organized into four main chapters and appendices, structured to logically address the research questions:

Chapter 2: Theoretical Background establishes the foundational concepts required to understand the proposed solutions. It covers the architecture of Transformers and the Self-Attention mechanism, analyzes the limitations of LLMs (Knowledge Gap and Behavior Gap), and provides the theoretical basis for the two adaptation methods used: Retrieval-Augmented Generation (RAG) and Parameter-Efficient Fine-Tuning (PEFT/LoRA).

Chapter 3: Multimodal RAG for Complex Document Understanding addresses the "Knowledge Gap" in industrial contexts. It details the development of an Advanced RAG pipeline capable of processing complex multimodal documents (finance and medical). This chapter describes the implementation of UnstructuredIO for layout analysis, Hybrid Search (Dense + Sparse), and Cross-Encoder Reranking to solve specific challenges like table understanding and exact code matching.

Chapter 4: Fine-tuning Small Language Models for Domain-Specific Tasks addresses the "Behavior Gap" and deployment efficiency. It presents the methodology for adapting Small Language Models (SLMs) like Qwen (0.5B - 1.5B) for a highly specific persona-based task (Tarot Reader). The chapter focuses on the data-centric approach, including synthetic data generation, and compares the effectiveness of LoRA versus Full Fine-tuning.

Chapter 5: Conclusion and Future Work summarizes the main findings and contributions of the thesis. It also discusses the limitations of the current implementations and proposes directions for future research, such as Adaptive Hybrid Search and edge deployment optimization.

Finally, the **Appendices** provide supplementary details, including the prompt templates used for synthetic data generation, specific training configurations, and detailed evaluation rubrics.

Examples

Remove the "Examples" section when no longer needed.

[**INFO:** *Some parts of the document are illustrated below.*

This section does not appear in the final document!]

Equations

[**INFO:** *This text is just an example that precedes an equation.*]

Simple equations can be inserted inline with the text: the line is $y = mx + b$.

More complicated equations should be separated into individual lines and numbered sequentially on the right within parentheses. This is the generic quadratic equation:

$$ax^2 + bx + cx = 0 \tag{1.1}$$

Where a is the quadratic coefficient; b the linear coefficient; c the constant coefficient independent of variable x, to be determined.

Equations should be referred to by their number. For example, Equation 1.2 solves problems formulated as shown in Equation 1.1.

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \tag{1.2}$$

Figures and tables

All figures and tables must be captioned and numbered sequentially:

- figures should be captioned below;

- tables should be captioned at the top.

Keep figures centered and inline with text so that the caption always appears attached to the image.

[**INFO:** *Figures should float freely on the page and be referenced and described in the text, with sources properly stated, to avoid plagiarism.*]

As an example, Figure **??** shows the FEUP *campus*.

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[**INFO:** *Space can be reserved for placing a figure in the future; for example, Figure 1.1.*]

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[**INFO:** *Tables should float freely on the page and be referenced and described in the text, with sources properly stated, to avoid plagiarism.*]

Table 1.1 serves to exemplify how to show some values that, in this case, are related to some numerical data associated with resources and investments of FEUP in the year 2011.

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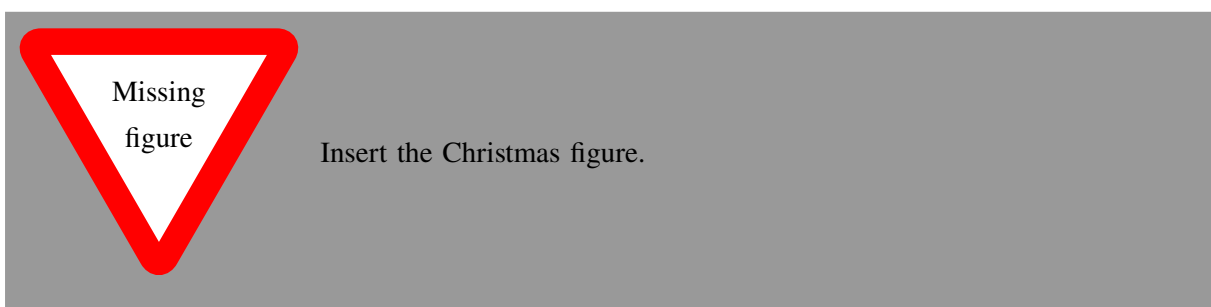Suspendisse vel felis. Ut lorem lorem, interdum eu, tincidunt sit amet, laoreet vitae, arcu. Aenean

Figure 1.1: Christmas at the FEUP Campus.

Table 1.1: FEUP Physical Resources. Adapted from FEUP 2023

Description	Quantity
Total area of FEUP campus	93 918 m^2
Green spaces	23 000 m^2
Number of computers dedicated to teaching	1 815
Investment in laboratory equipment	1.46 M€

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Citations

As you write the report text, you should indicate the works of other authors on which you are based, in the form of citations. This consists of briefly indicating the sources used from which you obtained additional information to develop the topic of your report.

There are two main ways to cite:

- by **paraphrase**: interpretation of the original content in words different from those of the consulted source, indicating the source immediately after; or

- by **transcription**: use of an excerpt of the original content presenting it in quotation marks, indicating the source immediately after.

Citations must follow a standardized style. Among the many that exist, the FEUP Library recommends the Chicago style (author-date format).

[**INFO:** *Below are some examples, at random, of citations (by paraphrase) according to this style.*]

The decision to choose a topic for an academic work can vary Bell 2002. The topic can be thought of and chosen by the student themselves, or from a list of topics already conceived, with potential interest for study F. Gomes, Lopes, and J. L. Palma 2014.

Each citation throughout the text should correspond to a reference indicated in the final list of bibliographic references Lipsum 2023; Mikkelsen 2012; Vasiljevic, Lopes, and Gomes 2018.

It is important not to forget that figures (images, tables, graphs, etc.) from works by other authors (for example obtained through the Internet) should always be cited, after the respective captions D. Gomes, Lopes, and Palma 2022.

For more information on this subject and to see examples, consult the guide "Avoiding plagiarism: good practices in the use of information"[1].

Duis non odio morbi ut dui sed accumsan risus eget odio ISO 2011; Ornelas 2016.

Code

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1. https://feup.libguides.com/plagio/citar

[**INFO:** *Below is an illustration of including code in the document.*]

Listing 1.1 Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Donec odio elit, dictum in, hendrerit sit amet, egestas sed, leo. Praesent feugiat sapien aliquet odio. Integer vitae justo. Aliquam vestibulum fringilla lorem. Sed neque lectus, consectetuer at, consectetuer sed, eleifend ac, lectus. Nulla facilisi. Pellentesque eget lectus. Proin eu metus. Sed porttitor. In hac habitasse platea dictumst. Suspendisse eu lectus. Ut mi mi, lacinia sit amet, placerat et, mollis vitae, dui. Sed ante tellus, tristique ut, iaculis eu, malesuada ac, dui. Mauris nibh leo, facilisis non, adipiscing quis, ultrices a, dui.

Listing 1.1: Python example

```python
# Take the user's input
words = input("Enter the text to translate to pig latin: ")
print(f"You entered: {words}")

# Break apart the words into a list
words = words.split(' ')

# Use a list comprehension to translate words greater than or equal to 3 characters
translated_words = [(w[1:] + w[0] + "ay") for w in words if len(w) >= 3 ]

# Print each translated word
for word in translated_words:
    print(word)
```

Using macros

[**INFO:** *Below is an illustration of using LaTeX macros defined in the preamble. Note the use of the* \class{} *macro for classes, methods and components.*]

The WindsPT, taken from *Windscanner.PT*, uses SVG . . . as in Student.calculate-age().

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[**INFO:** *The subsequent component parts that make up the body of the text should be structured in sections, estimating that up to 3 levels is sufficient for this type of work.*

For more information, consult the online tutorial "Publication Support Guide". Note that the sections indicated there can be adapted according to the topic or depth of the study to be developed.]

[**INFO:** *It is not customary to have consecutive section headings without text.*]

The dash

About the use of the hyphen and the dash[2]:

1. The hyphen (Alt + 0045): without spaces (-);

2. The em-dash (Alt + 0151): in Portuguese, surrounded by spaces (—);

3. The en-dash (Alt + 150): without spaces (–);

4. The mathematical subtraction sign: without spaces (–).

Quotation marks

About quotation marks in LaTeX, either the glyph is used directly, or they are made with the backtick at the beginning and the apostrophe at the end, as in "example"[3].

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2. "Portuguese Language Questions", https://ciberduvidas.iscte-iul.pt/consultorio/perguntas/o-uso-do-hifen-e-do-travessao/31251

3. What is the best way to use quotation mark glyphs? https://tex.stackexchange.com/questions/531/what-is-the-best-way-to-use-quotation-mark-glyphs

Chapter 2

Methodology used and main activities developed

In this chapter, the methodology followed is described, the main participants in the project are listed and the main activities developed are recorded.

2.1   Methodology used

[**INFO:** *Describe the methodology Despa 2014 followed (for example, iterative development with biweekly* sprints *and weekly follow-up meetings) and the resources used (for example, GitHub[1], etc.).*]

2.2   Participants, roles and responsibilities

[**INFO:** *Identify the project team,* stakeholders *and other participants with whom there was interaction; in the case of group work, clarify the roles and responsibilities of each group member.*]

2.3   Activities developed

[**INFO:** *Describe the activities carried out over time (including relevant events, such as presentations, meetings with clients, etc.) and respective* deliverables, *typically using a Gantt chart wikipedia 2023 (see Figure 2.1) and a brief description of each activity/*deliverable. *It can also be presented through a table with weekly progress.*]
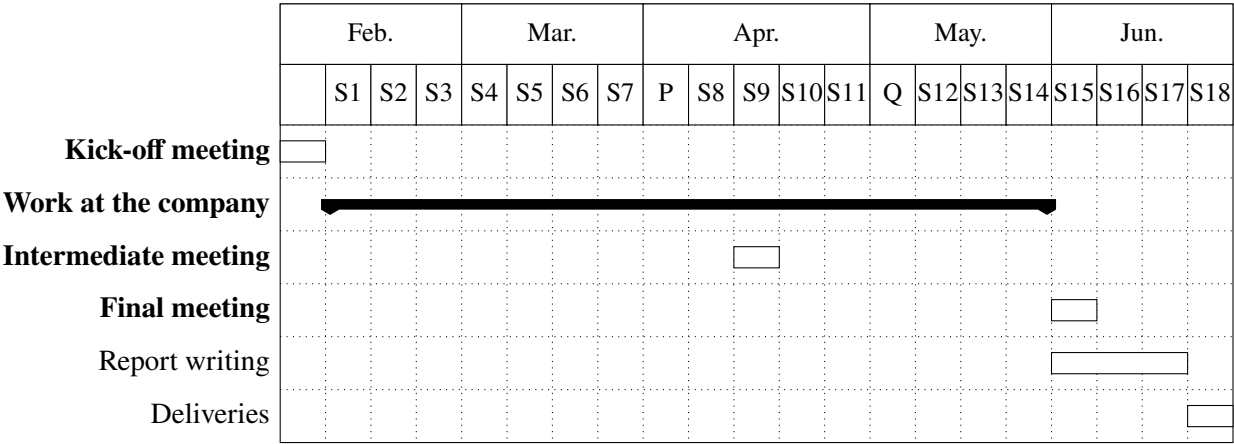
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1. https://github.com/

Figure 2.1: Gantt chart.

Chapter 3

Solution development

In this chapter, the work developed to achieve the expected results is described.

If it is the case of a software prototype, the requirements, solution architecture, development and validation of the prototype are presented.

3.1 Requirements

[**INFO:** *Identify relevant functional and non-functional requirements and respective sources, as well as project constraints.*

Below is an example of a table with user stories, which can be used if the number of rows is large. An additional column for priorities may be needed.]

User stories

Examples of possible usage scenarios are presented in Table 3.1, using *user stories* written according to the model: "**As a <type of user>, I want <some goal> so that <some reason>**".

Table 3.1: Usage scenario

Identifier	Name	Description
US01	Register (High)	As a *Visitor*, I want to register a new account so that I have access to profile data

3.2 Architecture and technologies (or Design and Implementation)

[**INFO:** *Architecture and technologies used and respective justification (taking into account requirements and existing alternatives), technical diagrams prepared (see Figure* **??** *taken from SPARX[1]), technical difficulties encountered and their resolution, etc.*]

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1. https://sparxsystems.com/resources/tutorials/uml2/component-diagram.html

3.3 Developed solution

[**INFO:** *Present the developed solution from the user's perspective, with the help of* screenshots.]

3.4 Validation

[**INFO:** *Description of the validation of the developed solution, in relation to the identified requirements and constraints, and respective results (for example, experimental evaluation results, tests performed,* feedback *from users or specialists, etc.).*]

Chapter 4

Conclusions

In this chapter, the results achieved and lessons learned are summarized. Finally, the limitations of the work are presented and improvements and future work are proposed.

4.1 Results achieved

[**INFO:** *Summarize the results achieved and contributions (in relation to the objectives).*

In the case of group work, clarify individual contributions, in qualitative and quantitative terms (percentage).]

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4.2 Lessons learned

[**INFO:** *Reflect on the lessons learned (taking into account the learning objectives).*]

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4.3 Future work

[**INFO:** *Identify limitations of the work performed and ideas for improvements and future work.*]

Bibliographic references

Bell, Judith. 2002. *Como realizar um projeto de investigação.* Gradiva. Lisboa.

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FEUP. 2023. *FEUP em Números 2023.* Disponível em https://sigarra.up.pt/feup/pt/web_base.gera_pagina?p_pagina=258031.

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Gomes, Filipe, J. Correia Lopes, and José Laginha Palma. 2014. "WindS@UP: The e-Science Platform for WindScanner.eu." *Journal of Physics: Conference Series* 524 (The Science of Making Torque from Wind 2014 (TORQUE 2014) 18–20 June 2014, Copenhagen, Denmark): 012006. ISSN: 17426596. https://doi.org/10.1088/1742-6596/524/1/012006.

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wikipedia. 2023. *Gantt chart.* Accessed March 15, 2023. https://en.wikipedia.org/wiki/Gantt%5C_chart.

[**INFO:** *In the final list of references, the works of the authors cited in abbreviated form throughout the text should appear, obtained automatically with* BibTeX. *The bibliographic reference is the most developed way of indicating the sources of information on which it was based.*]

Appendix A

An Appendix

[**INFO (optional element):** *Appendices and annexes contain information that complements, supports and clarifies the report and whose inclusion in the main body of the report would interfere with a good order of presentation of ideas.*

There is an important difference between appendices and annexes: "In the appendix only documents authored by the author of the report are compiled, while in the annex documents authored by other authors than the report author are compiled." [1]   ]

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1. For more information, consult the online tutorial "Publication Support Guide".