

A Parallel Term-Frequency Inverse Document Frequency Implementation in C++

Parallel TF-IDF Classifier

Andrew Kelton
Undergrad Student,
Dept. Computer Science
University of Central Florida
Orlando, FL, USA
an597152@ucf.edu

Abstract—TF-IDF (Term Frequency-Inverse Document Frequency) is a numerical statistic that represents the significance of a word in a document relative to its corpus (collection of documents) it is included in. It is a widely used algorithm used for preprocessing in text classification. However, its normal, sequential, algorithm takes quite a long time to vectorize and compute TF-IDF scores across an entire corpus of documents. There are also not many TF-IDF implementations in C++, the most widely used TF-IDF implementations are in Python, while popular, is generally slower than C++ for computational tasks. In this project, I present a parallel TF-IDF vectorization, computation, and classification implementation written in C++. The goal of this project is to provide an efficient and quick TF-IDF algorithm, and to compare my parallel implementation to my sequential implementation. I was successful in creating the parallel TF-IDF vectorization, computation, and classification. Source code is included in this project, and the performance evaluation in Python is included as well.

Keywords— C++, classification, computation, efficient, parallel, Python, quick, sequential, TF-IDF, vectorization

I. INTRODUCTION

Natural language processing (NLP) is a vital field in today's world. One of the key techniques used in NLP is Term Frequency-Inverse Document Frequency (TF-IDF), which helps identify important words within a document, while filtering out less relevant words. Search engines such as Google utilize TF-IDF to rank web pages, filtering billions of somewhat relevant words to ensure users receive the most meaningful results. However, computing TF-IDF at this scale is extremely computationally expensive, especially when processing large datasets, such as internet search results.

A common approach to handling this challenge is to precompute and store TF-IDF scores in a database. However, maintaining such a vast database is resource intensive. An alternative solution is to compute TF-IDF dynamically when needed. Unfortunately, most existing implementations of TF-IDF are sequential and written in Python, which limits their efficiency and performance, especially for large-scale applications.

This project focuses on implementing a parallelized TF-IDF classifier in C++ to significantly improve computation speed and efficiency. It has been shown that C++ can be up to 100

times faster than Python for certain computational tasks due to its optimized memory management and lower-level control over hardware resources. By leveraging parallel computing, this implementation aims to further enhance TF-IDF performance by distributing the workload across multiple processing cores.

Beyond search engines, TF-IDF is widely used in spam detection, sentiment analysis, and document clustering, where faster computation can lead to real-time processing improvements. Traditional implementations suffer from bottlenecks in matrix operations, memory usage, and sequential execution, which can be mitigated using optimized C++ techniques. This project will integrate the Armadillo library, a highly efficient linear algebra library, to handle matrix operations and accelerate TF-IDF computation.

By implementing TF-IDF classification in C++ with parallelization, this project aims to demonstrate significant performance improvements over traditional approaches. The expected outcomes include faster execution times, efficient memory usage, and scalability for large datasets, making this approach highly suitable for real-world NLP applications

(Keeping these two paragraphs for later reference) The job of TF-IDF is to filter out these somewhat relevant words, whilst keeping the relevant ones accessible. However, keeping a database of TF-IDF scores for every item on the internet is extremely resource expensive. One solution is to compute the TF-IDF every time. This is also extremely costly, since most common TF-IDF implementations are sequential and in Python. In this project, I will focus on the implementation of a parallel TF-IDF in C++.

It has been shown that C++ can be up to one hundred times faster than Python when performing some computing tasks. Not only can the parallel TF-IDF be quicker and more efficient than traditional implementations of the TF-IDF classification, but the sequential implementation in C++ can also increase efficiency and performance times as compared to the traditional implementation.

A. Problem Statement

I have achieved the main goal for this project: Implement a parallel Term-Frequency Inverse Document Frequency

(TF-IDF) text classifier in C++ and benchmark it against my sequential implementation of a TF-IDF text classifier in C++. I will be using the sequential TF-IDF implementation as my control. As far as I know, there is no publicly available parallel TF-IDF implementation in C++. With this project I seek to be able to implement key components of the commonly used text vectorization and classification algorithm into an efficient parallelized, C++ implementation. Once I have equivalent implementations (sequential and parallel), I will run tests on the two different implementations to see if there are any performance, efficiency, accuracy, or precision differences between them. I will be looking mainly at speed and efficiency, and briefly discussing text classification accuracy and precision.

II. MOTIVATION

In my research for this project, I could not find any parallel TF-IDF implementations for articles or text written in C++, either in literature or production. It surprised me that I could not find any strictly parallel TF-IDF implementations for text available in C++. While I would have appreciated the opportunity to test my parallel TF-IDF algorithm against others that are widely used, no such implementation appear to exist. The opportunity to review a similar implementation could have given insight on the key differences between a strictly parallel TF-IDF in C++ and user-level parallel TF-IDF techniques normally found in Python. Although this lack of existing work is disappointing, it confirms the novelty and significance of this project.

An explanation for this gap in C++ implementations, is the dominance of existing Python-based data science and machine learning libraries. Libraries such as Scikit-learn in Python have created specific functions that allow users to implement parallelism in their code, however, they do not provide a strictly parallel TF-IDF implementation. These implementations have often been criticized for not being thread-safe and not providing full control for concurrency. This requires users to explicitly optimize and control shared memory, while maintaining thread-safety. In contrast, C++ offers low-level access and control over parallel processing, making it a strong candidate for developing high-performance, large-scale text classification solutions.

The absence of scalable parallel TF-IDF implementations in C++ also suggests an opportunity to contribute a scalable, efficient solution that can be used freely by C++ programmers. This work aims to bridge that gap, demonstrating the feasibility and benefits of parallelizing TF-IDF in C++ for text vectorization and classification.

III. RELATED WORK (NEED TO DO THIS)

NOT WRITTEN YET.

IV. IMPLEMENTATION

The following is the breakdown of the tasks I completed on this project:

- Write the C++ implementation for reading, splitting, and extracting document data from CSV files
- Implement tasks for preprocessing data
 - Skip stop words (common words such as *the*, *is*, etc. that do not contribute importance to a document)

- Remove punctuation
- Convert all letters to lower case
- Stem words using the *Oleander Stemming Library*
- Implement the functions to vectorize a corpus of documents
 - `vectorize_corpus_threaded`
 - `vectorize_corpus_sequential`
- Implement modules containing classes and namespaces for the representations of: a corpus, document, and category
- Implement the functionality of each major TF-IDF function in C++
 - `tfidf_documents`
 - `tfidf_documents_seq`
 - `calculate_term_frequency_doc`
- Implement the functionality of major text classification functions in C++
 - `get_single_cat_par`
 - `get_single_cat_seq`
 - `get_important_terms`
 - `classify_text`
- Create a testing environment for extracting benchmarks, performance, accuracy, and precision results
 - Develop Python and Bash scripts to automate extraction comparison between the two implementations, and generate human readable results.
- Compare benchmarks between the two implementations
 - Measure performance
 - Classification accuracy and precision
 - Test multiple untrained corpuses with trained corpuses

A. Plan for Implementation

To summarize the above sections, my goal is to implement a parallel TF-IDF vectorizer and classifier for text processing in the C++ programming language.

B. Anticipated & Encountered Challenges

I anticipated the following major challenges with implementing this project: C++'s non-memory safe design, the lack of similar multi-threaded implementations, and my lack of experience with C++.

Since I used this project as an opportunity to learn C++, I anticipated some difficulty would come from learning the language, however, I was quite captivated by C++'s Java, C mixture. This is my first major project I have undergone in C++, and I have learned a lot about its object-oriented programming (OOP) capabilities. I became quite acquainted with the language's strengths, limitations, and code design.

DISCUSS CHALLENGES HERE...

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