

ESCUELA TÉCNICA SUPERIOR DE  
INGENIERÍA INFORMÁTICA

MÁSTER UNIVERSITARIO EN INGENIERÍA  
DEL SOFTWARE E INTELIGENCIA ARTIFICIAL

Diseño de un método comparativo para copilotos de  
código con IA

Design of an Evaluation Method for AI  
Programming Assistants

Realizado por  
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Tutorizado por  
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Departamento  
ESCUELA TÉCNICA SUPERIOR DE  
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**Resumen:**

Resumen ES.

**Palabras claves:** clave1, clave2, ..., clave5

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**Abstract:**

Large Language Models (LLMs) are increasingly used for code generation, but their evaluation remains challenging. Existing benchmarks are often rigid, resource-intensive, and prone to issues such as task saturation and data leakage. This thesis analyzes the limitations of current benchmarking practices and introduces a modular, customizable framework for evaluating LLMs in programming tasks. The proposed system enables flexible task selection, fine-grained configuration, and integration of environmental and cost considerations. An interactive interface supports task management and detailed result analysis, making benchmarking more practical and sustainable. The main contributions include a review of existing benchmarks, the design and implementation of a modular framework, and recommendations for improving benchmarking practices. The results suggest that customizable and eco-aware benchmarks can provide more relevant insights while reducing computational overhead.

**Keywords:** keyword1, keyword2, ..., keyword5





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# CAPÍTULO 1

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## Introduction

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Large Language Models (LLMs) have revolutionized software development through AI-assisted programming tools like GitHub Copilot. However, evaluating and fine-tuning these models requires extensive benchmarking, which comes at significant computational, financial, and environmental costs. Current benchmarks often contain irrelevant tasks and provide limited customization options, making them inefficient for specific use cases.

This work explores existing benchmarks for code-generating LLMs and proposes a novel approach: an easily customizable benchmarks with detailed and conveniently explorable outputs that can be tailored to specific needs while remaining cost-effective and environmentally conscious.

This thesis began with a comprehensive literature review, using recent critical reviews as a foundation for analyzing the state of LLM benchmarking. The review was extended by following citations to relevant articles published in late 2024 and 2025, focusing on keywords related to benchmarking and LLMs. The findings from this literature analysis informed the design and implementation of a modular benchmarking system, which was then evaluated for efficiency, flexibility, and environmental impact.

The literature review and further research were guided by the following questions:

- RQ1: What are the main limitations of current LLM benchmarks for code generation?
- RQ2: What metrics best reflect real-world usability and code quality?
- RQ3: How can benchmarks be made customizable for different user needs?
- RQ4: What is the environmental impact of repeated benchmarking, and how can it be reduced?

### **Main contributions of this work:**

- A critical analysis of existing LLM code generation benchmarks and their shortcomings.
- The design and implementation of a modular, customizable benchmarking framework.
- Integration of environmental and cost considerations into the benchmarking process.

- An interactive web interface for configuring benchmarks and analyzing results.
- Recommendations for future benchmarking practices based on empirical findings.

### 1.1. Problem Statement

Benchmarking LLMs for code generation is essential for both research and practice, but current approaches face critical limitations. Most benchmarks are fixed datasets, which leads to task saturation and data leakage as models are trained on their contents. The lack of customization prevents researchers and practitioners from focusing on tasks relevant to their use cases. At the same time, running large benchmarks consumes significant computational resources, resulting in high costs and environmental impact. Furthermore, benchmark outputs are often limited to single numeric metrics, which fail to capture nuanced aspects of model performance such as efficiency, style, or error patterns.

Therefore, the problem addressed in this thesis is the absence of a flexible, customizable, and sustainable benchmarking framework that can adapt to evolving LLM capabilities and user needs.

### 1.2. Objectives

The main objectives of this work are:

1. Analyze existing benchmarks and their limitations
2. Design a modular benchmark system that allows:
  - Custom task selection and filtering
  - Configuration of testing criteria
  - Support for multiple programming languages and task types
  - Integration with CI/CD pipelines
3. Implement an interactive web interface for benchmark configuration and result analysis
4. Develop a cost-efficient and environmentally conscious approach to benchmarking

The goal of this work is not to compete with large-scale frameworks, but to present a prototype that illustrates a different approach: a benchmarking tool for LLMs with a graphical user interface and configuration-driven design. Instead of hard-coded pipelines, users can flexibly define tasks, parameters, and evaluation criteria through configuration files generated using the UI.

### 1.3. Relevance of the Work

The relevance of this work lies in addressing the growing inefficiency and environmental cost of LLM benchmarks. By introducing a customizable framework, this thesis provides a practical solution for researchers and practitioners who need targeted, resource-efficient evaluations. The proposed system not only saves time and energy but also improves the usability of benchmarking results, making them more relevant for real-world applications.



# CAPÍTULO 2

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## State of the Art

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### 2.1. Evolution of Code Generation Benchmarks

The evolution of benchmarks for code generation has been driven by the need to evaluate the capabilities of Large Language Models (LLMs) in programming tasks. Early benchmarks focused on isolated tasks, but as LLMs became more sophisticated, the need for more comprehensive and realistic evaluation methods emerged.

The first benchmarks were aimed at text comprehension and contained questions and expected answers, such as GLUE, SQuAD and GSM8K with grade-school math problems ([Vendrow et al. 2025](#)).

As LLM capabilities expanded, benchmarks shifted towards programming tasks, with a focus on code generation and understanding. Some pioneers in LLM code benchmarking that are MBPP, HumanEval and APPS.

- MBPP (Mostly Basic Python Problems) published by [Austin et al. 2021](#) contains 974 crowdsourced Python programming problems with tests.
- HumanEval was developed in OpenAI by [Chen et al. 2021](#) with 164 hand-crafted problems, with a goal of avoiding data leakage (to ensure that the problems and golden solutions are not present in the training dataset).
- APPS by [Hendrycks et al. 2021](#) features 10000 Python tasks with 131777 test cases, borrowed from open-access sites like Codewars and Codeforces.

These benchmarks are still used to this day for comparing performance of different models in scientific papers. Notably, APPS is a benchmark commonly used for fine-tuning LLMs for programming tasks, as it allows to use separate sets of problems for training and evaluation ([Ben Allal et al. 2022](#)).

The mentioned benchmarks became less effective, as newer models were trained on the same tasks they are being evaluated on. This phenomenon is known as **data leakage** as described by [Vendrow et al. 2025](#).

Amazon's Recode benchmark [Wang et al. 2022](#) addressed this issue by introducing perturbations on docstrings, function names, and codes, while staying semantically close



to the original task. However, that is more of a way to test the robustness of the model, rather than a way to test its ability to solve brand-new problems.

More recent developments like HumanEval Pro and MBPP Pro [Yu et al. 2024](#) introduced more sophisticated testing approaches. Their multistep evaluation process tests an LLM's ability to work with its own generated code. First, an LLM generates a solution to a known problem from HumanEval or MBPP datasets. Then, it is given a new task that requires calling a function generated in the first step. This approach revealed limitations in some models that perform well on simpler tasks.

The mentioned academic benchmarks focus on controlled and isolated tasks, SWE-bench ([Jimenez et al. 2024](#)) moved toward real-world scenarios. Software engineering tasks were taken from resolved Issues from GitHub repositories of open-source projects Python. SWE-bench is famous for its leaderboards, where laboratories and companies all over the world compete to achieve the higher percentage of solved tasks. But the benchmark is limited to tasks from only 12 open-source repositories, and only supports Python programming language.

Researchers [Chi et al. 2025](#) have found a different way to evaluate LLMs in real-world scenarios. Instead of using a fixed set of tasks, they developed a plugin called CopilotArena for an IDE. The plugin provides two code completion options from different LLMs, and allows a user to choose the one they prefer. This approach allows for a more realistic evaluation of LLMs in coding tasks, but it lacks the controlled environment and a solid numerical result for each model. Such an approach could be useful for A/B testing of LLMs in production, but it is not suitable for scientific research and repeated evaluations during fine-tuning.

The benchmarks mentioned above perform in a static environment, where the model is given a task and expected to generate a solution. The InterCode framework by [Yang et al. 2023](#) introduces interactive environments using Docker. This enables evaluation of LLMs in realistic and interactive development scenarios with compilation and runtime feedback. The environments and scenarios were prepared for Python, SQL, and BASH, but the framework allows introducing new environments and scenarios. This approach more closely mirrors actual developer workflows and allows for testing LLMs in the role of a partially independent agent. But this approach comes with increased computational overhead of running a Docker environment, a virtual operating system, and an instance of a database, which limits the overall speed and a number of scenarios that can be tested at once.

Many of the mentioned benchmarks have inspired researchers to implement new benchmarks based on them. That could be their adaptations in other programming languages or refined datasets with verified and new hand-crafted tasks. Such as in the case of SWE-bench and following *SWE-bench Verified* and *Multi-swe-bench*.

## 2.2. Limitations of LLM Code Generation Benchmarks

Based on the analysis of existing benchmarks, we can identify several key limitations that our work aims to address:

- Benchmark saturation,

- Data leakage,
- Limited feedback,
- High resources' consumption,
- Environmental impact,
- Error-proneness of tasks,
- Limited feedback and output.

Let's address each of these limitations one by one.

### 2.2.1. Benchmark Saturation

When a benchmark becomes saturated, it means that the tasks in the benchmark are too easy for the current state-of-the-art LLMs, leading to high pass rates and diminishing returns on further improvements. It can be caused by either advances in LLMs or by data leakage, where the tasks and their solutions are present in the training datasets of the models being evaluated.

At some moment, testing on the simplest tasks becomes irrelevant, as all models pass them with high scores. Some datasets contain **metadata** that allows filtering out tasks based on their difficulty, thus saving resources and time on each evaluation.

### 2.2.2. Data Leakage

Benchmark saturation mentioned in the above sections is partially explained by advances in models, but it can also be attributed to information **leaking**: the popular and publicly available benchmarks appear in the training datasets accompanied by the golden solutions. This leads to a situation where the models are trained on the same tasks they are being evaluated on.

There are several ways to avoid the consequences of data leakage:

- hand-crafting brand-new tasks without publishing them or using for in-house training;
- generating new tasks based on the existing ones as it was done with HumanEval Pro and MBPP Pro;
- or perturbing existing tasks as it was done in ReCode.

### 2.2.3. High Cost and Environmental Impact

Repeated training and benchmarking of LLMs require significant computational resources, leading to significant electricity consumption and carbon emissions. This environmental impact is increasingly important in the context of global efforts to reduce carbon footprints. We will want for benchmarks to account for these factors and encourage more sustainable evaluation practices.

There are leaderboards that account for  $CO_2$  emissions, such as Hugging Face *LLM CO2 emissions calculation - a Hugging Face Space* — [huggingface.co s.f.](https://huggingface.co/space/HuggingFace/llm-co2-emissions), which tracks

the carbon footprint of using models. However, these metrics are often not integrated into traditional benchmarks, leading to a lack of awareness about the environmental impact of LLM evaluation practices.

The most common metric in benchmarks is  $\text{pass}@k$  that measures the percentage of correct solutions among the  $k$  solutions generated by the model. This implies that for each task in the benchmark dataset, a model repeatedly generates a number of solutions, just to receive a single numeric result to use for a metric. This metric is used in ClassEval, MBPP, MathQA-Python, CoderEval, and HumanEval+. Notably, HumanEval and HumanEval+ use  $k = 100$  ( $\text{pass}@100$ ). However, as Miah and Zhu [Miah y Zhu 2024](#) pointed out, users do not normally run the LLM several times, so  $\text{pass}@k$  does not reflect its usability.

#### 2.2.4. Limited Feedback and Output

This limitation is intertwined with the high cost. The output of most benchmarks is a single numeric metric, such as  $\text{pass}@k$ , which indicates the percentage of tasks solved correctly by the model. Compared to the amount of work and energy that was consumed to produce this result, and the amount of information that could be extracted from the model's responses and test runs, this approach is very limited.

For example, SWE leaderboard [SWE-bench Leaderboards s.f.](#) is created based on a single number that does not reflect the types of tasks that the model is better or worse at solving [Miah y Zhu 2024](#). Thus, a researcher or a user might choose a suboptimal model for their specific needs, resulting in lower performance or higher cost. This is partially countered by websites that aggregate results on several benchmarks [LLM Leaderboard 2025 — vellum.ai s.f.](#) which can give a very high-level picture.

Some of the ways to gather more information from the model's responses are:

- Gather performance metrics for each task, such as execution time, memory usage, and CPU load;
- Count the number of input and output tokens used for each generation to compare cost-effectiveness of models;
- Analyze the generated code for style and quality, such as cyclomatic complexity, number of lines, and code duplication;
- Provide a way to analyze individual task failures, such as incorrect solutions, timeouts, and exceptions;
- Using LLM-as-a-judge approach to evaluate the quality of the generated solution.

#### 2.2.5. Error-Proneness of Tasks

When creating and managing big datasets, errors are inevitable. As [Vendrow et al. 2025](#) found out, popular benchmarks contain up to 5 percent of mislabeled or erroneous tasks. This can lead to incorrect evaluation results and misinterpretation of model capabilities.

To mitigate this issue, a researcher should be able to examine the failures and more easily spot the errors in the tasks. This will also allow the researcher to spot patterns in model's errors, and possibly mitigate them by improving training datasets, updating a system prompt, and adjusting temperature and other parameters.

## 2.3. Problems in LLM Benchmarking

Benchmark saturation mentioned in the above sections is partially explained by advances in models, but it can also be attributed to information **leaking**: the popular and publicly available benchmarks appear in the training datasets accompanied by the golden solutions. Even then, it doesn't mean that an LLM won't struggle when presented with the same task. When changing the task phrasing while keeping the semantic consistent, there is a 4.5-percent drop in solvability, showing that the models remember the phrasing of the descriptions in the original dataset. [Uniyal \*et al.\* 2024](#)

One of the important aspects of LLM evaluation is the choice of the metrics. For code quality, there are BLEU, CodeBLEU, RUBY, ROUGE-L, METEOR, ChrF. They assess the similarity of the generated code to the golden solution, taking into account the properties of source code. Evtikhiev *et al.* [Evtikhiev \*et al.\* 2023](#) takes 6 metrics, commonly used in papers. The authors conduct a study, comparing the results of metrics with human evaluation of the solutions. The results suggest that none of the analyzed metrics can correctly emulate human judgment, but ChrF metric is considered better than the others commonly used in papers.

A paper by [Crupi \*et al.\* 2025](#) looks into an approach of using LLM to evaluate the quality of the solution generated by another model (LLM-as-a-judge approach). As a result, they come to a conclusion that LLM-as-a-judge is a substantial improvement over mentioned metrics, and GPT-4-turbo can mimic closely a human evaluation.

## 2.4. Comparison of LLM Code Generation Benchmarks

Benchmark	Size	Domain	Innovation	Limitations
MBPP	974 tasks	Python	Crowdsourced, test cases	Leakage, basic
APPS	10,000+	Python	Large scale	Leakage, too ea
ReCode	3k	Python	Robustness via perturbation	Synthetic, limit
SWE-bench	2k	Python (12 repos)	Real GitHub issues	Limited repos/
HumanEval	164 tasks	Python	Handcrafted, leakage-avoidance	Small, saturate
HumanEval+	400+	Python	Extension of HumanEval	Still small, leak
HumanEval Pro	2,000+	Python	Multi-step tasks	Python-only, re
BigCodeBench	1M+	Multi	Massive scale	Hard to run, sa
InterCode	3k+	Python, SQL, Bash	Interactive Docker env	Heavy resource
CopilotArena	Unlimited	Unlimited	Real user experience	No numeric me

Tabla 2.1: Comparison of major LLM code generation benchmarks

## 2.5. Existing Benchmarking Frameworks and Their Limitations

Apart from the benchmarks themselves, there are several frameworks that facilitate LLM evaluation. These frameworks provide tools for running benchmarks and collecting results.

Two widely used benchmarking frameworks are **bigcode-evaluation-harness** [Ben Allal \*et al.\* 2022](#) and **lm-evaluation-harness** [Gao \*et al.\* 2024](#). Both provide tools for running standardized benchmarks on LLMs, but they have notable limitations. The lm-evaluation-harness is more general-purpose and supports a broader range of language tasks, yet it also relies on fixed task sets and lacks modularity for user-defined benchmarks. Neither framework provides built-in support for environmental metrics or fine-grained task selection, highlighting the need for more flexible and sustainable benchmarking solutions.

In the Table 2.2 we compare the two frameworks based on their features and limitations.

Feature	bigcode-evaluation-harness	lm-evaluation-harness
Specialization	Majorly, code writing tasks, but also allows for documentation generation tasks and natural language reasoning tasks	A universal harness supporting a wide range of tasks
Included benchmarks	MBPP, MBPP+, DS-1000, MultiPL-E, Mercury, GSM8K, etc.	MBPP, MBPP+, HumanEval, SpanishBench, basqueGLUE, and many more.
Defining new tasks	Requires source code modification	Requires source code modification
Available configuration	Task dataset name, Number of tasks, Temperature, Saving LLM responses, Limits of LLM response, etc.	Task datasets list (other parameters are defined on task level), Limits of LLM response, System prompt, etc.
Extended output	LLM response or references as JSON	Prompt, LLM response, and metrics results as JSON
Run interface	CLI-based, no GUI	CLI-based, no GUI, an API for training loops
Result analysis	Overall numeric metric and LLM responses saved as a file	
Visualization	No visualization tools	No visualization tools
Evaluation of multiple LLMs	One model per run	One model per run
Supports model loading via transformers	Yes	Yes

Tabla 2.2: Comparison of bigcode-evaluation-harness and lm-evaluation-harness

## 2.6. Research Questions Analysis

*RQ1: What are the main limitations of current LLM benchmarks for code generation?* We dug through the literature and found that the main limitations of current LLM benchmarks for code generation are:

- Benchmark saturation,
- Data leakage,
- Limited feedback,
- High resources' consumption,
- Environmental impact,
- Error-proneness of tasks,
- Limited feedback and output.

*RQ2: What metrics best reflect real-world usability and code quality?* Out of the commonly used code quality metrics (BLEU, CodeBLEU, RUBY, ROUGE-L, METEOR, ChrF), the ChrF turns out to be the best-suited for code generation tasks, as it takes into account the properties of source code.

But an LLM-as-a-judge approach is considered a significant improvement over the mentioned metrics. When used with some of the modern models, an LLM can mimic closely a human evaluation.

*RQ3: How can benchmarks be made customizable for different user needs?* Existing frameworks like bigcode-evaluation-harness and lm-evaluation-harness provide a way to introduce new task datasets and metrics for specific user needs. However, they require source code modification and do not provide a user interface for configuring benchmarks. The reviewed frameworks also lack flexibility in task selection and filtering.

A solution with a friendly user interface can allow users to easily configure benchmarks, select relevant task types, and visualize results.

*RQ4: What is the environmental impact of repeated benchmarking, and how can it be reduced?* Benchmarks consume significant resources, but environmental impact is rarely measured. Including runtime, energy, and CO<sub>2</sub> reporting makes evaluation more responsible.

The analysis of existing benchmarks highlights both their contributions and their shortcomings, especially in terms of saturation, flexibility, and sustainability. These insights directly motivate the design of a new benchmarking framework, which addresses these limitations by focusing on modularity, customization, and eco-aware evaluation. In the following sections, we describe the design and implementation of this framework, as well as its evaluation through selected experiments.



# CAPÍTULO 3

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## Design and Implementation of the Modular Benchmarking Framework

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### 3.1. Prototype Goal and Scope

The goal of the prototype is to provide a controlled environment for running benchmarks and analyzing their outputs.

The key idea is to separate three concerns: (1) definition of *task sources* and *execution configurations*, (2) execution and tracking of benchmarks, (3) presentation and inspection of results. This separation enables the use of different combinations of task sources and execution configurations.

The scope of the prototype is limited to managing benchmark runs, collecting outputs, and exposing them through a simple interface. It does not aim to provide large-scale distributed evaluation, advanced analytics, or integration with external benchmark platforms. These aspects remain outside the present work.

### 3.2. System Design

This section describes the architecture of the prototype, its main components, and the workflow of interactions between the user, the frontend, and the backend. The focus is on modularity, extensibility, and clarity of responsibilities. The system operates directly on files (task sets, benchmark configurations, and results) instead of a database. This choice makes it easy to share datasets and configurations, edit them outside of the web interface, and execute benchmarks directly from the CLI.

#### 3.2.1. Overview

The system consists of two main entry points:

- **Web interface**, built with Spring MVC, that allows a user to browse files, edit them, launch benchmarks, and inspect results.



- **Console interface**, built with Spring Framework, which allows running benchmarks directly from the terminal or from CI/CD pipelines.

Both entry points communicate with the **benchmark executor**, which is modular and extensible by design. Its components are:

- **Controller class**, responsible for orchestrating benchmark execution.
- **LLM communication layer**, implemented with Spring AI, which abstracts interactions with different LLM providers.
- **Quality evaluation layer**, consisting of modules for code quality checks (e.g., PMD, Checkstyle, SonarQube, and LLM-as-a-judge).
- **Test execution layer**, currently implemented for in-memory Java execution, but extendable to remote execution or containerized execution via Docker.

### 3.2.2. Technologies

The choice of technologies is motivated by their suitability for modularity and integration:

- **Spring MVC** — provides a clean abstraction for implementing REST endpoints and handling requests from the frontend.
- **Spring Framework (console interface)** — allows reuse of the same components for CLI execution and CI/CD integration.
- **Spring AI** — unifies access to multiple LLM APIs, simplifying the addition of new providers.
- **PMD, Checkstyle, SonarQube** — widely used static analysis tools available for Java, which make it possible to measure code quality with established metrics.
- **Docker (planned)** — offers an isolated environment for executing arbitrary languages and tools, ensuring reproducibility and security.

### 3.2.3. Workflow

At a high level, the workflow is as follows:

1. The user opens the frontend.
2. The frontend requests from the backend the list of files available in three folders: *configs*, *tasks*, and *results*.
3. The user selects a file; the frontend fetches it from the backend.
4. The user edits a task file in the frontend and saves it back to the backend.
5. The user edits a config file in the frontend and saves it back to the backend.
6. The user launches a benchmark by selecting one config and a set of task files; the frontend sends this request to the backend.
7. The backend delegates execution to the *worker*, which starts running tasks and returns a run identifier.

8. The frontend polls the backend with the run identifier to fetch status (e.g., number of tasks completed per file).
9. Once status is no longer in-progress, the frontend informs the user and stops polling.
10. The user requests a result file, the frontend fetches it from the backend, and presents statistics, errors, and detailed outputs.

#### **3.2.4. Sequence Diagram**

The interaction described above is shown as a sequence diagram (Appendix A.1).

### **3.3. Limitations and Scope Boundaries**

The prototype serves as a minimal but functional environment for experimentation. It shows how benchmarks can be defined, executed, and reviewed, but it does not attempt to cover issues of scalability, long-term storage, or automated evaluation pipelines. These remain directions for future work rather than part of the current implementation.



## CAPÍTULO 4

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Conclusion

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## Apéndice







# APÉNDICE A

## Anexo

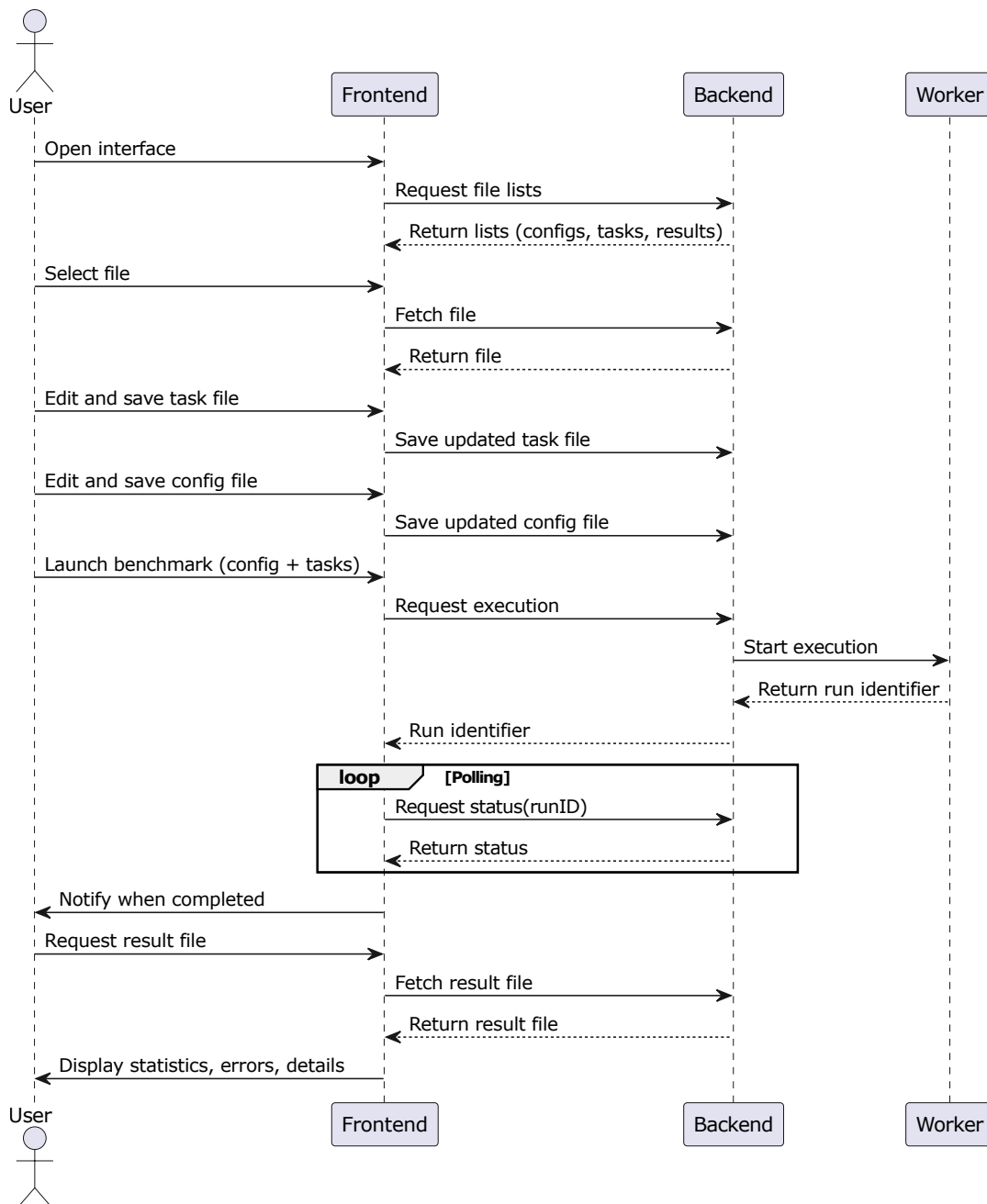


Figura A.1: Sequence Diagram.