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# Chapter 1

## Introduction

Generative Artificial Intelligence (AI) is a rapidly advancing branch of AI that, in recent years, has made tremendous progress, largely due to the widespread adoption of deep learning techniques. Generative models are now powerful deep learning architectures capable of producing highly realistic text, images, and even video content.

The famous Turing Test is frequently referenced in this context. In this test, a human judge had to determine whether they were communicating with another human or with a machine. This milestone was already surpassed in 2014, with early systems such as Eugene Goostman [1].

Today, it is widely accepted that much of the content generated by generative models is indistinguishable from human-produced material and indeed, for humans, **this distinction is increasingly difficult to make.**

The introduction of the Transformer architecture in 2017 [2] revolutionized the field and led to the development of Large Language Models (LLMs), which quickly became part of everyday life. This wave began with the public availability of GPT-3 [3] in June 2020 [3], followed by a growing ecosystem of LLMs including GPT-4 [4], PaLM [5], LLaMA [6], Claude [7], and Mistral [8].

Generative AI, however, is not limited to natural language processing. It has also enabled powerful models for image generation, such as Stable Diffusion [9], and more recently for video synthesis, with systems like Veo-3 [10].

Although the usefulness and extraordinary capabilities of these tools are undeniable, there are many scenarios in which it becomes necessary to have user-friendly tools to detect whether text, images, or videos were generated by an AI.

This thesis presents a more modest, yet equally important objective: **detecting artificially generated source code** produced by code generation models such as OpenAI Codex [11], GPT-4 [4], and Code LLaMA [12].

While natural language detectors are well-established and widely studied in scientific literature, the detection of AI-generated code remains a far less consolidated and more recent research area. The contribution of this work is to **analyze the most relevant scientific advancements** made in the past year, which are often fragmented and inconsistent due to the unique challenges involved in distinguishing machine-generated code, a task that is arguably more complex than natural text detection.

## 1.1 Historical Overview of Code Generation by LLMs

The history of code generation can be explored from several perspectives.

### 1.1.1 Natural Language Processing

One possible starting point possible perspective for analysing the evolution of code generation is to trace the development of Natural Language Processing (NLP), the field that studies how machines process and interact with human language. NLP comprises two major subdomains: Natural Language Understanding (NLU), which focuses on a machine’s ability to interpret and “understand” human language, and Natural Language Generation (NLG), which concerns the generation of natural-sounding text.

This distinction is particularly relevant because the technologies currently used for code generation are essentially the same as those employed for natural language generation. In fact, Transformer-based models trained on source code data approach code generation in the same way they would handle natural text generation by predicting sequences of tokens in context using learned statistical patterns [2].

From this point of view we can start in the 1943 during World War II with the invention of Colossus, one of the first digital electronic computers, developed in order to analyse encrypted communications from the German military.

In parallel, the discipline of Natural Language Processing (NLP) began to take shape as early as the 1940s, culminating in the 1954 Georgetown experiment the first public demonstration of machine translation. Another milestone came in 1966 with the creation of ELIZA [13], considered the first chatbot in history, which simulated the behaviour of a psychotherapist using pattern-matching rules.

During the 1970s and 1980s, symbolic approaches to NLP became popular. These early attempts aimed to enable machines to “understand” language through manually encoded rules and logic-based systems. In the 1990s, the importance of statistical methods became evident, marking a shift from rule-based to probabilistic models for language processing.

In 2006 Google launched its now ubiquitous Google Translate service. The following decade saw the rise of voice-based assistants: Apple’s Siri (2011), Microsoft’s Cortana (2014), Amazon’s Alexa (2014), and Google Assistant (2016).

A major breakthrough came with the introduction of distributed word representations, especially word2vec [14] and GloVe [15], published in 2013 and 2014 respectively. These methods enabled dense vector representations that captured semantic relationships between words in large corpora.

The most significant leap, however, occurred in 2017 with the publication of the now seminal paper “Attention is All You Need” [2], which introduced the Transformer architecture. This architecture remains the dominant framework in NLP and underpins nearly all modern LLMs. Transformers enabled major advances in tasks such as text generation, machine translation, question answering, text summarization and, more recently, code generation.

The first LLMs capable of code generation began to appear around 2019–2020, notably with the release of GPT-2 [16]. In 2021, OpenAI released Codex [11], a GPT-3

[3] derivative trained specifically for code generation and explanation, which was later integrated into GitHub Copilot.

Between 2022 and 2024, a wave of new LLMs for code generation was released, including CodeT5 [17], CodeGen [18], CodeGeeX [19], and Code LLaMA [12].

### 1.1.2 Code Generator

Another possible point of view is the one focused on code generation itself. This is not a completely new concept: it dates back to 1957 with Fortran. Fortran is both a programming language with an integrated compiler, developed by IBM. A compiler can be seen as a code generation tool, since it translates source code into machine code, the only “language” truly “understandable” by a computer [20].

Compilers have a long history and have been continuously improved over time, but they are not the only tools for code generation. Already in 1976, the concept of intelligent editors emerged with Emacs, thanks to its support for custom macros [21]. Later, in 1996, IntelliSense introduced symbolic completion, namely the ability of the IDE to suggest code based on the context and the symbols already present.

In 1999, with XSLT, one of the first standardized tools for automatic transformation between markup languages was introduced [22]. During the same years, the work of Zelle[23] and Mooney[24] (1996–1999) proposed methods based on Natural Language processing to generate database queries from natural language expressions.

At the same time, template-engine-based tools for server-side spread, such as Jinja2 (2005)[25] and Mako (2006)[26], which allowed the generation of dynamic code by combining data with predefined structures.

In 2017, with research on AST-guided code generation, LSTM models began to be used to generate code in a more structured way, guided by the syntax of the programming language [27].

Finally, in 2021, with GitHub Copilot, one of the most advanced code completion tools was introduced: so efficient that it is capable of generating entire code sections from simple textual prompts, thanks to the use of generative AI models based on Transformer architectures [11].

### 1.1.3 LLMs code oriented

Another possible starting point is from the publication of the paper *Attention Is All You Need* in 2017, which introduced the Transformer architecture [2] and, enabled the widespread development of Large Language Models (LLMs). We must remember that the first LLMs were typically designed to analyse and generate just natural language text, so not all LLMs were capable of generating code, or at least not of generating syntactically correct or functional code.

In 2018, two foundational models were introduced: BERT [28], an encoder-only architecture designed to generate dense semantic representations of natural language, and GPT-1 [29], a decoder-only model capable of generating coherent text. Those models were not yet able to generate code, but they have been an important baseline for future code-oriented models.

In fact in 2019, OpenAI released GPT-2 [16], a more powerful decoder-only model capable of producing much more convincing text compared to GPT-1. Although GPT-2 was not specifically trained to generate code, its training corpus included code snippets. In the same year, TabNine, a popular code completion extension for several IDEs, replaced its n-gram-based next-token prediction with a version of GPT-2 fine-tuned on source code [30].

Also in 2019, Microsoft Research and GitHub introduced the CodeSearchNet dataset [31], a multilingual code dataset and one of the first large-scale corpora usable to train Transformers for code generation tasks.

In 2020, Microsoft Research released CodeBERT [32] (*based on BERT*), trained on both natural language and code using the CodeSearchNet dataset. CodeBERT is designed for tasks such as code search and code summarization. While it does not generate code, it is an encoder-only model capable of deeply understanding the structure and semantics of source code. Through CodeBERT is possible producing rich and dense representations suitable for downstream tasks like classification, or for use as input to decoders in generative pipelines.

In 2021, several LLMs capable of generating realistic and reliable code were introduced. OpenAI published Codex [11], a GPT-3 [3] derivative fine-tuned on source code from the GitHub Code dataset. In the same paper OpenAI introduced the HumanEval benchmark, designed to assess the performance of Codex [11] on programming problems (*and in future all LLMs code oriented*). On HumanEval, Codex (12B) was able to solve 28.8% of the problems on the first attempt, significantly outperforming all previous models on code generation.

Codex [11] sparked widespread interest in the use of LLMs for code generation, indeed in the same year is released GitHub Copilot, powered by Codex [11].

In the same year, many additional datasets were published, including MBPP (Mostly Basic Python Problems) [33], the APPS dataset [34], and CodeXGLUE [35].

In December 2021, Salesforce AI Research released CodeT5 [17], an open-source encoder-decoder model that, unlike Codex [11], supports a wider variety of code-related tasks. Thanks to task-specific training strategies, CodeT5 proved to be highly versatile, supporting code summarization, generation, and translation.

In 2022, Google introduced AlphaCode [36], achieving a performance in the top 54.3 percentile on competitive programming tasks on Codeforces. In the same year, PolyCoder [37], a decoder-only model trained solely on 249 GB of source code, was also released as an open-source alternative.

In 2023, GPT-4 [4] (although not exclusively trained for code generation) achieved an 80% success rate on HumanEval. Claude 3 by Anthropic reportedly reached 85%, and Meta’s open-source model Code LLaMA [12] scored 57%.

In 2024, Google introduced Gemini [38], which, when integrated into an inspired AlphaCode framework, reached performance within the top 15% of coding competition participants.

## 1.2 Motivations Behind LLM-Generated Code Detection

Although it may seem exaggerated to begin the historical overview of code generation [Section 1.1.2](#) with compilers, this choice aims to emphasize that the present work does not seek to demonize the contribution or usefulness of code generation tools. It is undeniable that such tools are extremely valuable in both professional software development, accelerating simpler phases of implementation, and in educational contexts, where they can serve as useful assistants for learning how to write code.

Nevertheless, it is equally clear that is raising the need, in certain contexts and for specific reasons, to limit or discourage the use of highly advanced tools for code autocompletion or generation.

One important reason concerns **academic and professional integrity**: the undeclared use of LLMs in evaluation contexts makes the assessment process highly problematic. Students, for example, may complete assignments or even exams using LLMs without contributing meaningfully to the generated code, potentially impairing their learning of fundamental programming concepts (getting the most out with the least effort). Similarly, during a technical interview, a candidate might rely on a tool like AlphaCode 2 to generate solutions to proposed problems. This is the main topic of *"The Impact of Large Language Models on Programming Education..."* [39] in which is demonstrated that a widespread use of LLMs code generator has negatively affects over students' capability.

Figure 1.1 illustrates possible correlation between final grade and the use of LLM. We can observe that an increase in LLM usage tends to correlate with lower average student grades, although it is not a decisive factor in determining the final score.

Another critical issue lies in the way LLMs generate code. Since these models are trained on massive corpora, evaluating the security and efficiency of the generated code is nearly impossible. The output may be **vulnerable or inefficient** due to subtle flaws that are hard to detect, especially when the code appears well-formatted and logically structured. This happens to overreliance on commonly seen patterns in the training corpus rather than more appropriate niche solutions. The security issues are highlighted by the study *"Do Users Write More Insecure Code with AI Assistants?"* [40]. This study shows a decrease in code security simply by using an AI assistant instead of traditional programming.

**Intellectual property** is yet another motivation for detecting LLM-generated code, a general problem in generative AI. This is not limited to the origin of training data but also concerns the risk that an LLM may reproduce copyrighted code, posing significant legal risks to software companies that could unknowingly integrate such code into their products. This issue is not an exaggerated concern, it's a tangible risk [41].

The least important reason, which directly concerns the development of code-oriented LLMs themselves, is the need to distinguish machine-generated code in training

datasets. If a model is trained on LLMs' code we might run into a general LLM code oriented **Model Collapse**. Indeed, training LLM on LLMs' code serves to deteriorate the output diversity and adaptability to real-world scenarios. This feedback loop issue is addressed for example in "*The curse of recursion...*" [42]. If no method exists to detect such code, the datasets used for training future models would have to be limited to code written before the widespread availability of LLMs, in order to avoid contamination. This would result in code generation models being trained on increasingly outdated data.

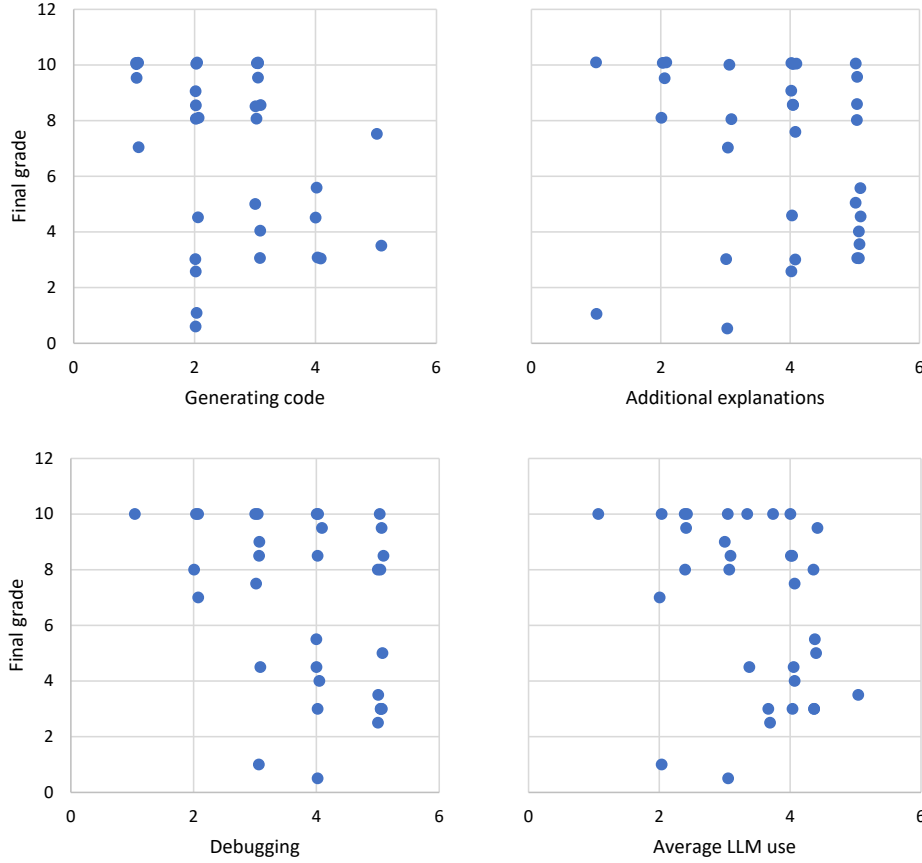


Figure 1.1: Scatter plot from the paper *The Impact of Large Language Models on Programming Education and Student Learning Outcomes*, illustrating the relationship between LLM usage and students' final performance.



### 1.3 Challenges in LLM-Generated Code Detection

The detection of short texts generated by LLMs remains a challenging task. While partial solutions have been proposed, the problem cannot yet be considered fully resolved. Nonetheless, it is widely acknowledged that detection tools achieve strong performance when applied to moderately sized texts (longer than just a few lines).

A well-known example is **DetectGPT** [43], a zero-shot method that does not require training a separate classifier but instead relies on an auxiliary LLM to assess whether a given passage is likely machine-generated. DetectGPT is often regarded as the state-of-the-art among open-source methods for AI-generated text detection.

In addition to open-source methods, commercial solutions such as **GPTZero** [44] have gained popularity. GPTZero can be accessed via a web interface and combines language-model-based heuristics with machine learning classifiers. While it is effective in many cases, it is not infallible. For example, GPTZero has been reported to mistakenly flag texts written by non-native speakers, whose lexical variety may be lower, as AI-generated.

Even the creators of GPTZero explicitly state that a positive detection should not be taken as conclusive proof, but rather as a probabilistic signal or indicator.

As stated in several papers analysed in this work, such as *Uncovering LLM-Generated Code: A Zero-Shot Synthetic Code Detector via Code Rewriting* [45], **methods designed for detecting natural language text are largely ineffective when applied to code**. The causes of this limitation are primarily related to the structural and syntactic properties of programming languages.

Unlike natural language, where the same idea can be expressed using a vast variety of words and syntactic structures, source code is governed by strict and formal grammar rules. As a result, many tokens must appear in a specific and rigid order. Consequently, techniques based on lexical probability, such as those used by DetectGPT, tend to fail when applied to code, as they cannot meaningfully capture the constrained nature of programming syntax.

Moreover, many natural language detectors rely on input perturbation to assess sensitivity or likelihood distributions, a process that is significantly more difficult to perform on source code without introducing semantic or syntactic errors.

A further practical limitation is the lack of publicly available datasets specifically designed for training code-based LLM detectors. While large and well-established code corpora do exist, researchers who aim to train classification models for code detection often have to construct their own datasets, with all the associated challenges in terms of bias, coverage, and quality assurance.

These issues have contributed to a significant gap in the literature: unlike DetectGPT, which is widely recognized for natural language detection, there is no single, consolidated approach for LLM-generated code detection. Instead, the field is characterized by a proliferation of parallel methods, often employing fundamentally different techniques and evaluation protocols.

## 1.4 Thesis Objectives

This thesis aims to pursue a structured series of objectives, each forming a necessary foundation for the subsequent stage of the project.

The overarching goal is to **develop a software tool capable of reliably distinguishing source code written by humans from that generated by Large Language Models (LLMs)**. Given the lack of standardization in the current literature, this project first seeks to **establish a fair and reproducible evaluation framework**.

The initial task involves **selecting** a sympathetic and representative **dataset** that can serve both for retraining detection models and for evaluating their performance consistently. A comparative analysis of current scientific literature datasets will be conducted, taking into account objective criteria such as class balance, diversity of programming languages, code length variability, and feature distribution. The selected dataset will play a central role in ensuring that all subsequent experiments are comparable and grounded on a common basis.

Once the dataset is established, the next phase consists in **collecting and systematically evaluating the various detection models suggested in recent literature**. These models will be executed on the selected dataset using consistent and comparable metrics in order to allow for a meaningful comparison. Special attention will be given to understanding the assumptions and limitations of each model. For instance, we will examine which datasets were originally used for training, which evaluation metrics are most informative in this context, the computational requirements of each method, and the specific scenarios in which they demonstrate optimal or sub-optimal performance. In this phase, it will also be possible to identify the underlying reasons why certain models outperform others.

Following this benchmarking effort, the most promising method will be selected for further investigation. At this stage, will be proposed enhancements aimed at improving accuracy, robustness, or efficiency. These improvements must be tailored to the nature of the selected model.

The final phase of the project will focus on the development of a usable and **user-friendly software interface**, which allows end users to apply the selected detection model with minimal technical effort. The interface may include customizable parameters such as confidence thresholds or model options, depending on the characteristics of the adopted approach. Particular care will be taken to ensure that the tool is accessible and adaptable, so that it can be employed in diverse real-world scenarios, from academic integrity enforcement to software development auditing. Ultimately, this thesis intends to contribute both a rigorous comparative study and a practical, operational tool, filling a current gap in the literature and paving the way for future research and application in this emerging area

## Chapter 2

# Overview of current state of the art

Before analysing the individual contributions, it is necessary to understand the current state of the art. As discussed in [Section 1.1.3](#), there are no widely established or consolidated approaches for detecting LLM-generated code. However, this does not imply a lack of research on the topic.

A subset of existing works focuses solely on providing datasets for training and evaluating detection models. The majority, instead, aim to propose detection techniques, including zero-shot approaches or methods requiring deep neural networks.

Since this area has only started to be actively explored around 2024, a significant portion of the literature has been published on platforms such as [arXiv](#). Although arXiv is extremely useful for identifying cutting-edge research, it primarily hosts **preprints** (papers which have not yet undergone peer review by the scientific community).

This does not mean that arXiv publications should be disregarded, but the fact that most work in this area remains unpublished in peer-reviewed venues highlights the early and still-developing nature of this research topic.

### Preprints

- **CoDet-M4** [\[46\]](#): Presentation of a dataset obtained by using five different LLMs.
- **AIGCodeSet** [\[47\]](#): Presentation of a python dataset obtained by using three different LLMs.
- **CodeMirage** [\[48\]](#): !
- **How Far Are We?** [\[49\]](#): Analysis of Natural Language Methods Applied to Code, the GPTSniffer Tool, and the Proposal of Alternative Detection Approaches.
- **DetectGPT4Code** [\[50\]](#): Uncovering LLM-Generated Code: A Zero-Shot Synthetic Code Detector via Code Rewriting. In Proceedings of the AAAI Conference on Artificial Intelligence.

## Peer-reviewed paper

- **Uncovering LLM-Generated Code** [51]: Proposal of a Detection Method Based on Code Rewriting and a Custom-Trained Similarity Model.
- **DetectCodeGPT** [52]: Analysis of Differences Between Human-Written Code and LLM-Generated Code, and Introduction of a Detector Based on Purely Stylistic Perturbations.
- **Detecting AI-Generated Code Assignments Using Perplexity** [53]: Proposal of a Detector Based on Perturbation.
- **ChatGPT Code Detection** [54]: Generation of a dataset for GPT-3.5 and development of a detection method.

Although developing an LLM for code generation is not the objective of this work, a brief digression on the LLMs considered state-of-the-art (SOA) for code generation is essential in order to better assess the performance of detection methods.

## Chapter 3

# Dataset Analysis

The goal of this chapter is to identify or construct a suitable dataset to evaluate the performance of the various detection methods proposed in the literature. It is worth noting that the literature does not only include works specifically aimed at creating benchmark datasets, but in several cases, datasets are generated solely for the purpose of validating or training the proposed detection methods or models.

### 3.1 Dataset Evaluation Criteria

All datasets made publicly available by the scientific community will be carefully analysed and compared. The goal is to identify the most suitable dataset—either directly or through integration, for the evaluation of code detection methods under consistent conditions. Each dataset will be assessed based on the following criteria:

1. **Total number of code samples available:** a larger number of samples generally improves statistical robustness during evaluation and model training.
2. **LLMs used to generate synthetic code:** datasets that include code generated by multiple LLMs are better suited for evaluating a method’s generalization capability.
  - (a) **Number of LLMs:** to avoid a method from focusing too much on stylistic features of a specific LLM, it is essential to have codes generated by different LLMs.
  - (b) **Actual degree of use in contemporary times:** while it is desirable for detection methods to have long-term viability, it is undeniable that a detector effective on current LLMs (such as GPT-4 [4]) is more useful than one targeting outdated models (such as GPT-3 [3]).
  - (c) **Actual types diversity among LLMs:** it is also necessary to analyse the diversity of the models themselves. For instance, it is more informative to include in the same dataset code produced by both an open-source LLM like CodeLlama[12] and a commercial one like GPT-3 [3], rather than, for example, code from GPT-3 [3] and Codex [11] (which is itself based on GPT-3).

3. **Code diversity:** ensuring diversity in the code is essential to understand how generalizable a method is to the overall code domain, or whether it is specialized in the stylistic patterns of specific LLMs (*a particularly relevant issue for methods relying on stylistic features of the code*).
  - (a) **Different programming languages:** while Python is currently the most relevant language in the field of artificial code generation (indeed, many datasets primarily consist of Python code such as MBPP [33]), it is valuable to evaluate detection methods across as many programming languages as possible. At the very least, it is worth assessing different detection methods on different languages, possibly recommending specific approaches depending on the language being analysed.
  - (b) **Different types of code:** although language differences are important, they are not sufficient. Python, for example, can be used both as an object-oriented and a procedural language. Understanding the type of code being analysed can aid both in training and in evaluating a detector.
  - (c) **Code size:** code length is a key parameter, as the ease of identifying the origin of the code may vary depending on its size. It is worth noting that in certain contexts, such as homework assignments, short code snippets are extremely common.
  - (d) **Code context:** it is useful to include examples of human-written code from both competitive settings (such as Leetcode dataset [55]) and open-source project environments (such as CodeSearchNet [31]), in order to evaluate detectors across different real-world contexts.
4. **Validity information:** this includes whether the dataset provides information on the validity of human-written code, the exact prompts used to generate LLM code, or whether code quality and correctness have been validated.
  - (a) **Generation prompts:** it may be useful to evaluate the different prompts used to generate the code, as it is well known that varying the prompt can lead to significantly different outputs from an LLM.
  - (b) **Source of human-written code:** many datasets are based on collections of human-written code that are later used to generate LLM outputs. Knowing the source of this human code ensures the reliability and correctness of the dataset.
  - (c) **Code quality:** performing tests such as verifying whether both human and LLM-generated code actually works is essential. *There is little value in analysing whether non-functional code was produced by an LLM or not.*
  - (d) **Paper reliability:** this point is important for preprinted paper, for which we can't rely on the scientific community.

Although all these are evaluation parameters, it is natural that some are more relevant than others: knowing the source of the human-written code remains more important than simply including a few additional LLMs in the code generation process.

## 3.2 Datasets Proposed in the Scientific Literature

The works whose main contribution is the creation of a dataset are mostly preprints, and thus require careful consideration. The papers primarily dedicated to dataset generation include: CoDet-M4 [46], AIGCodeSet [47], CodeMirage [48], Pan et al [56]. Suh et al [49].

### 3.2.1 CoDet-M4

The main contribution of this work is the construction of a dataset derived from existing human-written code datasets, by generating synthetic code using six different LLMs. The authors then train several models on this dataset to evaluate their performance, demonstrating that their dataset can significantly improve the effectiveness of various code detection models. The authors employ the following models as code generators:

- **GPT-4o** [57] : A proprietary model developed by OpenAI, selected to represent the state-of-the-art among large-scale, closed-source LLMs.
- **CodeLlama (7B)** [12] : An open-source model by Meta, specifically trained for code-related tasks. It is one of the most popular code-oriented language models.
- **Llama3.1 (8B)** [58] : A more recent version of Meta’s Llama family. Although it is a general-purpose model, it exhibits strong performance in code generation.
- **CodeQwen 1.5 (7B)** [59] : An open-source model from Alibaba Cloud, also specialized in code, and part of the Qwen series.
- **Nxcode-orpo (7B)** [60] : A fine-tuned variant of CodeQwen. The authors include it to evaluate the robustness of detectors against different fine-tuning strategies applied to the same base model (in this case, ORPO – Monolithic Preference Optimization).

### Strengths

- The introduction of one of the most extensive and diverse datasets proposed for the task of LLM-generated code detection.
- The authors also construct an “out-of-domain” dataset, specifically designed to contain code with characteristics intentionally different from the main dataset (*Section 4.4: Out-of-Domain Experiment*).
- The dataset includes code in three different programming languages, unlike other works that focus solely on Python (*Section 3.1: Data Collection*).

### Weaknesses

- Suspiciously high in-domain classification metrics, with F-scores exceeding 98% (*Table 2*).

- The prompts used to generate synthetic code vary depending on the source, potentially introducing an unintentional correlation between code types and the generation prompts (*Appendix F*).
- Most of the LLMs used for code generation are lightweight models, with GPT-4o being the only large-scale LLM involved (*Section 3.2: Code Generation*).
- Once the dataset is downloaded from the official portal on [huggingface](#), several important intuitive reliability metrics are found to be missing:
  - The declared train/validation/test split described in the paper is not included; only the test set is provided. This makes **reproducing their results more difficult**.
  - Some significant **code-level features are missing**, such as whether the code sample is class-based or function-based.
  - The authors state in the paper that they plan to keep updating the dataset, which may explain small discrepancies in the number of code samples compared to what is reported. For example, there are fewer GitHub samples than those claimed in the original publication as shown in Figure 3.2 The strange think is that the number of code not only increased but also decreased.
- Focusing on the human code (*Section 3.1: Data Collection*):
  - **LeetCode corpora**: Pan et al. [56] (5,069) and others (2,800) so the total should be: 7,869 but according to the paper table we should have 13,528 codes Figure 3.2 (*we don't know the source of half of the codes*).
  - **Code-Forces corpora**: the dataset has 103,792 codes but they are all solutions of only 2,523 problems from a publicly available Kaggle dataset [61].
  - **GitHub corpora**: 135,566 codes from CodeSearchNet [31] and GitHub API in 2019 (*code not up to date*)
- Even if the dataset as a whole may appear fully balanced, clear imbalances emerge when focusing solely on the human-written code:
  - There is an imbalance in the number of code samples generated by different LLMs (with relatively few generated by GPT models Figure ??)
  - LeetCode human-written code samples are significantly fewer Figure ??, meaning that many more generations were performed on LeetCode problems compared to other corpora.

## Code Quality

In order to preserve quality in the LLMs code source:

- *"For LLM-generated code, we filtered irrelevant responses and extracted code from the LLM output."*



- "After collecting the datasets, we **removed all comments and docstrings.**"
- "We also filtered codes based on length, excluding those below the 5th or above the 95th percentile in token count."
- "Finally, we deduplicated the dataset to prevent potential code memorization."

Split	Language	Source	Target		Total
			Human	LLM	
Train	C++	LeetCode	2,242	46,888	49,130
		CodeForces	33,005	9,766	42,771
		GitHub	49,000	19,885	68,885
	Python	LeetCode	6,397	44,164	50,561
		CodeForces	25,569	9,646	35,215
		GitHub	12,442	8,434	20,876
	Java	LeetCode	2,283	46,988	49,271
		CodeForces	24,121	3,853	27,974
		GitHub	48,998	11,874	60,872
Validation	C++	LeetCode	282	4,962	5,244
		CodeForces	4,194	1,221	5,415
		GitHub	1,562	1,056	2,618
	Python	LeetCode	738	4,640	5,378
		CodeForces	3,285	482	3,767
		GitHub	5,500	2,488	7,988
	Java	LeetCode	287	4,929	5,216
		CodeForces	3,060	1,207	4,267
		GitHub	5,500	1,483	6,983
Test	C++	LeetCode	283	4,978	5,261
		CodeForces	4,203	1,221	5,424
		GitHub	1,564	1,056	2,620
	Python	LeetCode	728	4,722	5,450
		CodeForces	3,291	482	3,773
		GitHub	5,500	2,491	7,991
	Java	LeetCode	288	4,972	5,260
		CodeForces	3,064	1,206	4,270
		GitHub	5,500	1,487	6,987
Total			252,886	246,581	499,467

Figure 3.1: Table of dataset number of codes

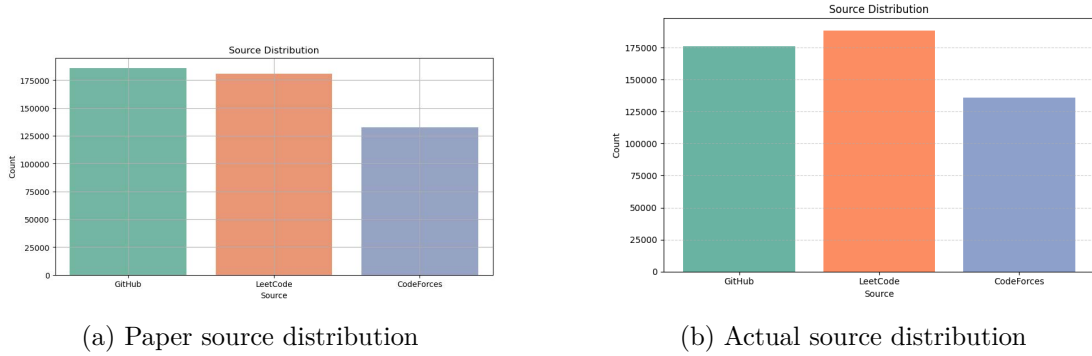


Figure 3.2: histogram differences

## Final evaluation

Total number of code samples available	
(a) Total number of human code	246,221
(b) Total number of LLMs code	254,331
LLMs used to generate synthetic code	
(a) Number of LLMs	6 LLMs: ( <i>GPT-4o</i> , <i>CodeLlama 7B</i> , <i>Llama3.1 8B</i> , <i>CodeQwen 1.5 7B</i> , <i>Nxcode-orpo 7B</i> )
(b) Diversity among LLMs	3 different source models: ( <i>GPT-4o</i> , <i>CodeLlama</i> , <i>CodeQwen</i> )
(c) Actual degree of use in contemporary times	Average LLMs release date: 2024
Code diversity	
(a) Different programming languages	Python, Java, C++
(b) Different types of code	Functional, Object-Oriented ( <i>missing information in the dataset</i> )
(c) Code size	1 <sup>st</sup> percentile: 42 words, 3 <sup>rd</sup> percentile: 68 words
(d) Code context	Mixed (competitive and open-source)
Validity information	
(a) Generation prompts	Provided (different between LLMs)
(b) Source of human-written code	GitHub, Codeforces [61], Pan et al. [56]
(c) Code quality	Comment removal, Duplicate code removal
(d) Paper reliability perception	Low, missing or inconsistent information

Table 3.1: Evaluation Summary: CoDetM4 Dataset

Despite being a very interesting dataset, especially due to the large amount of available code, it proves to be unreliable both because of the authors’ lack of precision and due to some of its intrinsic characteristics, such as an unusual data imbalance. While it is not a dataset to be entirely discarded, its use must certainly be carefully evaluated.

### 3.2.2 AIGCodeSet

The main contribution of this paper is also the preparation of a dataset for evaluating detection methods. Unlike other works, this dataset includes both functional and non-functional human-written code, as it evaluates LLM code generation starting both from a plain prompt and from existing code.

- **Gemini 1.5 Flash** [62] : Proprietary, available via Google Cloud’s Gemini API and Vertex AI; no public weights. Multimodal corpora including code, text, images, audio, and video; extends context handling to millions of tokens.
- **Codestral-22B** [63] : Autoregressive code modeling with fill-in-the-middle (FIM) capability; excels at cross-file completion tasks.
- **CodeLlama-34B** [12] : State-of-the-art among open models on HumanEval.

#### Strengths

- They evaluate LLM code generation under three different scenarios (*Section 3.2: Generating Code Snippets*):
  - textual problem descriptions taken from CodeNet (problem prompt);
  - problem prompt + human source code with a runtime error;
  - problem prompt + human source code with an output error.
- The official dataset on [huggingface](https://huggingface.co/datasets/CodeNet) is well documented.
- The problems are of varying difficulty.

#### Weaknesses

- The dataset contains python code only.
- The dataset contain competitive code only.
- All the codes are solution of **only 300 problems** (*60 problem  $\times$  5 different difficulty*)
- GPT, probably the most widely LLM family used among students, is not included among the evaluated models.

#### Code Quality

In order to preserve quality in the LLMs code source they manually removed:

- *"code with failure to produce any output"*
- *"C-family languages instead of Python."*
- *"presence of meaningless characters, sentences, numbers, or dots."*
- *"Any explanations provided above or below the code. "However, **comments embedded within the code blocks were retained**, provided they were appropriately marked as comment lines."*

## Final evaluation

Total number of code samples available	
(a) Total number of human code	9,50
(b) Total number of LLMs code	5,650
LLMs used to generate synthetic code	
(a) Number of LLMs	3 <i>Gemini 1.5 Flash, Codestral-22B, CodeLlama-34B</i>
(b) Diversity among LLMs	3 different source models
(c) Actual degree of use in contemporary times	Average LLMs release date: 2024 <i>now exist Gemini-2.0</i>
Code diversity	
(a) Different programming languages	Python
(b) Different types of code	unspecified
(c) Code size	1 <sup>st</sup> percentile: 30 words, 3 <sup>rd</sup> percentile: 50 words
(d) Code context	competitive
Validity information	
(a) Generation prompts	provided
(b) Source of human-written code	CodeNet by IBM [64]
(c) Code quality	Executable check
(d) Paper reliability perception	Hight

Table 3.2: Evaluation Summary: AIGCodeSet Dataset

The dataset appears to be of high quality, but compared to other works, the variety of code is extremely limited. Moreover, GPT is not included among the LLMs, and there is no guarantee that the LLM-generated code actually functions correctly.

### 3.2.3 CodeMirage

The work and dataset presented in the CodeMirage publication aim to evaluate ten LLM code detection methods. The dataset was also used to train the detectors (at least those requiring training). They employed as many as ten different LLMs for code generation.

- **GPT-4o-mini** [57] : A proprietary model developed by OpenAI, selected to represent the state-of-the-art among large-scale, closed-source LLMs.
- **GPT-o3-mini** [65] : A smaller model from OpenAI’s o3 series, known for high performance in STEM and logic benchmarks despite reduced parameter count.
- **Qwen-2.5-Coder-32B** [66] : A specialized, code-centric LLM. Trained on high-quality multilingual code data, it supports over 40 programming languages and offers a 128K context window
- **Claude-3.5-Haiku** [67] : The smallest member of Anthropic’s Claude 3.5 family
- **DeepSeek-R1** [68] : A reasoning-optimized model developed using reinforcement learning to enhance multi-step logical thinking.
- **DeepSeek-V3** [69] : A large-scale, general-purpose model from DeepSeek AI.
- **Gemini-2.0-Flash** [70] : Although designed for speed, it retains strong performance across code and reasoning tasks.
- **Gemini-2.0-Flash-Thinking** [70] : An experimental version of Flash that integrates internal “thinking steps” during generation.
- **Gemini-2.0-Pro** [70] : The full-sized flagship model from the Gemini 2.0 series, comparable to GPT-4 in overall performance.
- **Llama-3.3-70B** [71] : A 70-billion-parameter open-source model from Meta AI, part of the LLaMA 3.3 release. It represents one of the most capable open LLMs available to the public.

### Strengths

- The entire generation process is well documented; both the Code Summarization methods (necessary to obtain the prompts to be given to the LLMs for generation) and the code generation prompts are easily accessible Figure 3.3. (*Section 3:CodeMirage Framework*)
- The dataset also includes code samples with Paraphrasing, meaning simulated modifications of small stylistic elements in the code generated by LLMs. (*Section 3.1: Benchmark Construction*)
- The dataset, available on the official [huggingface](#) portal is well documented.
- The dataset is perfective balanced.

## Weaknesses

- The work itself explicitly requires the LLM-generated code to match the length of the original human-written code in the generation prompt, which is unrealistic and disadvantages stylistic detection methods. (*Section 3.2: Benchmark Statistics*)
- All human-written code comes exclusively from the **CodeParrot GitHub-Clean dataset** [72], meaning that the dataset covers only a single domain.
- A comment-free version of the code is not provided, which leads to some code samples being heavily commented in a distinctly human style Figure ?? . It is not specified whether comments are removed prior to the detection process; if not, many results could be significantly biased.
- Although the paper does not explicitly highlight this, for each human-written code sample, two LLM-generated versions are produced rather than just one. This means that the actual ratio between human and LLM-generated code is 1:20 Figure 3.4.

## Code Quality

In order to preserve quality in the LLMs code source:

- *"consistency with the original human-written code's line count and character length"*
- *"adequate token-level divergence from the original, enforced by requiring a BLEU [73] score below 0.5 to avoid recitation."*

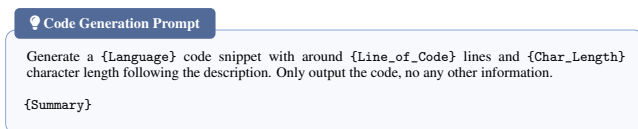


Figure 3.3: Code generation prompt

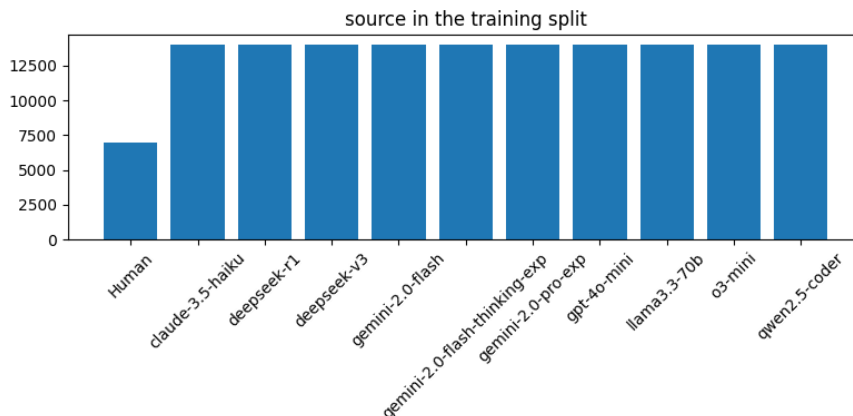


Figure 3.4: Source distribution

## Final evaluation

Total number of code samples available	
(a) Total number of human code	10,000
(b) Total number of LLMs code	199,988
LLMs used to generate synthetic code	
(a) Number of LLMs	10 LLMs: ( <i>GPT-4o-mini</i> , <i>GPT-o3-mini</i> , <i>Qwen-2.5-Coder-32B</i> , <i>Claude-3.5-Haiku</i> , <i>DeepSeek-R1</i> , <i>DeepSeek-V3</i> , <i>Gemini-2.0-Flash</i> , <i>Gemini-2.0-Flash-Thinking</i> , <i>Gemini-2.0-Pro</i> , <i>Llama-3.3-70B</i> )
(b) Diversity among LLMs	6 different source models: ( <i>GPT</i> , <i>CodeQwen</i> , <i>Claude</i> , <i>DeepSeek</i> , <i>Gemini</i> , <i>Llama</i> )
(c) Actual degree of use in contemporary times	2024-2025
Code diversity	
(a) Different programming languages	( <i>HTML</i> , <i>JavaScript</i> , <i>Java</i> , <i>C</i> , <i>Python</i> , <i>Ruby</i> , <i>Go</i> , <i>C#</i> , <i>C++</i> , <i>PHP</i> )
(b) Different types of code	unspecified
(c) Code size	1 <sup>st</sup> percentile: 639 words, 3 <sup>rd</sup> percentile: 804 words
(d) Code context	open-source
Validity information	
(a) Generation prompts	Provided (one)
(b) Source of human-written code	GitHub
(c) Code quality	Statistical alignment
(d) Paper reliability perception	Midium, ( <i>no precise references are provided regarding the data source</i> )

Table 3.3: Evaluation Summary: CodeMirage Dataset

Although the dataset appears to be well-varied and balanced, the lack of an evaluation of the actual functionality of the code may compromise the overall assessment. Furthermore, competitive-style code samples are completely absent.

### 3.2.4 Pan et al

The main objective of this paper is to demonstrate, beyond any doubt, that detection methods commonly used for natural language are not reliable when applied to code. To achieve this, the authors construct a dedicated dataset.

- **GPT:** In the paper is not specified what gpt.

#### Strengths

- Generate code by different Prompt.
  - Prompt explaining the problem and asking for a solution;
  - Removal of stop words from the prompt;
  - Request to imitate a human;
  - Request to generate code without any comments;
  - Request to also generate testing code;
  - Solution with generic test cases not specifically tailored to the generated code;
  - Solution using the unfittest framework;
  - Explicit request for a long code;
  - Explicit request for a short code.
- Use different paraphrasing method.
  - Replacement of variable names;
  - Replacement of function names;
  - Replacement of both variable and function names;
  - Addition of unnecessary code to the solution.
- The source problem is specified in the dataset.

#### Weaknesses

- The dataset is not available on hugging face but is necessary download it from a [Replication Package](#)
- In the paper is not specified what gpt is used in order to generate code.
- Only competitive code.

#### Code Quality

In order to preserve quality in the LLMs code source:

- *"manual valiation to ensure the correctness of the dataset"*



## Final evaluation

Total number of code samples available	
(a) Total number of human code	5,069
(b) Total number of LLMs code	65,897
LLMs used to generate synthetic code	
(a) Number of LLMs	1 <i>GPT</i>
(b) Diversity among LLMs	1
(c) Actual degree of use in contemporary times	unspecified
Code diversity	
(a) Different programming languages	Python
(b) Different types of code	unspecified
(c) Code size	1 <sup>st</sup> percentile: 54 words, 3 <sup>rd</sup> percentile: 83 words
(d) Code context	competitive
Validity information	
(a) Generation prompts	provided
(b) Source of human-written code	Quescol [74], Kaggle [75]
(c) Code quality	filtered by human
(d) Paper reliability perception	Peer-review paper

Table 3.4: Evaluation Summary: Pan-et-al Dataset

Despite the reliability of this work, given that it is a peer-reviewed paper, the dataset consists of only a single programming language and a single LLM (which is known to be GPT, though the specific version is not disclosed). Moreover, it is not explicitly stated whether the generated code is actually functional.

### 3.2.5 Suh et al

The goal of this paper is both to evaluate detectors originally designed for natural language (which, as expected, proved to be ineffective), and to propose alternative approaches, including fine-tuning LLMs, an approach that was effective only for code belonging to the same training domain. To achieve these results, the authors developed a large dataset, which should therefore be rightly considered as a separate contribution.

- **GPT (GPT-3.5):**
- **GPT-4:**
- **Gemini Pro (Gemini 1.0):**
- **StarCoder2-Instruct (15B):**

#### Strengths

- Use different domain dataset.
  - **MBPP**: didactic dataset
  - **humaneval-x**: a dataset from OpenAI
  - **Code Search Net**:

#### Weaknesses

- It is difficult to obtain the dataset (Dataset creation is not the aim of the paper).

#### Code Quality

In order to preserve quality in the LLMs code source:

- *"We also removed code snippets that contain syntax errors"*

## Final evaluation

Total number of code samples available	
(a) Total number of human code	3,700
(b) Total number of LLMs code	29,500
LLMs used to generate synthetic code	
(a) Number of LLMs	4 <i>chatgpt, gpt-4, Gemini pro, stracider2-instruct 15B</i>
(b) Diversity among LLMs	3 <i>gpt, gemini, stracider</i>
(c) Actual degree of use in contemporary times	Average year: 2024
Code diversity	
(a) Different programming languages	java, C++, python
(b) Different types of code	unspecified
(c) Code size	1 <sup>st</sup> percentile: words, 3 <sup>rd</sup> percentile: words
(d) Code context	Both
Validity information	
(a) Generation prompts	not in the paper
(b) Source of human-written code	MBPP, humaneEval-x, Code Search Net
(c) Code quality	Syntax quality
(d) Paper reliability perception	Peer-review paper

Table 3.5: Evaluation Summary: Suh Dataset

Unfortunately, the data they used is no longer available through the official portals, which, at the time of writing, are no longer accessible. As a result, this dataset is effectively unusable.

### 3.3 Considerations

The variety of available data is undeniable. Nevertheless, during the analysis, an issue emerged that is rarely addressed in the reviewed papers: the correctness of LLM-generated code. It is self-evident that anyone using LLM-generated code would, before committing it, most certainly run at least one test to verify that the code works. Moreover, for our purposes (Section 1.2), whether a student or candidate submits non-functional code, it makes little difference whether it was written by them or by an LLM.

Should we therefore be concerned about not having the guarantee that the LLM codes present in the test datasets are correct? Is there a correlation between incorrect and correct code in the detection of LLM code? According to some analysed studies, the answer is yes: *“The results demonstrate that detecting correct code is more difficult than detecting incorrect code, both with our method and baselines.”* [45]

Therefore, the consideration that every detection method should be evaluated specifically on **functional** LLM-generated code, rather than on LLM code in general, proves useful in preventing a significant gap between the reported metrics and the actual user experience. Such a gap may arise if detection methods exhibit a classification bias due to the incorrect behaviour of the code. It is worth noting that while many works perform syntax or runtime checks, none explicitly mention functional testing.

### 3.3.1 Test framework

Given the evaluations presented by the works I propose, the detection methods, it was necessary to develop a framework that could ensure the LLM code was certainly correct. The minimum result was to obtain at least a subdataset that would allow evaluating whether there was a difference between detection of functioning and non-functioning code.

So a small framework was developed and published on [GitHub](#). This framework had important constraints:

- It had to work with Python (the most generated programming language)
- It had to work on LLMs that could run on home hardware,
- It had to support as many LLMs as possible,
- It had to allow for the interruption and resumption of test generation and the tests themselves at any time, in order to evaluate error conditions and bugs.

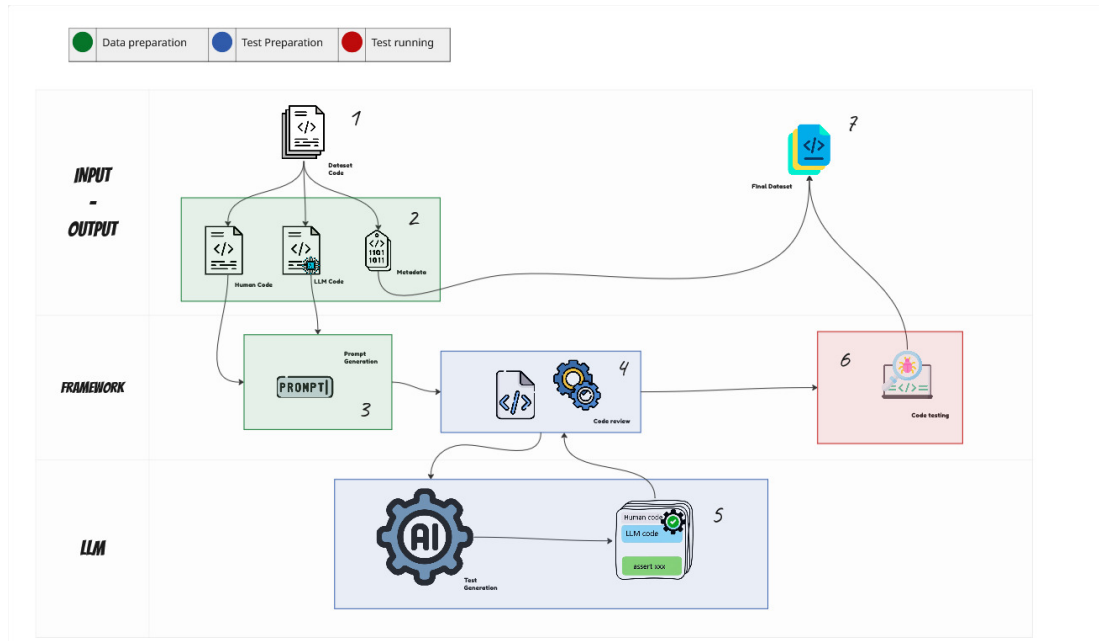


Figure 3.5: Framework overview

The framework was divided into several sections, so it could be easily modified for potential future needs that required dataset generation by an LLM.

1. **Input:** The framework is capable of processing any dataset that contains both LLM-generated code and human code that solve the same problem.
2. **Input\Data preparatin:** Any supported dataset is converted into a JSON file, specifying which columns in the dataset correspond to "human code" "LLM code", and "problem explanation" (the latter being optional and included only to provide a more complete prompt to the LLM).

3. **Framework\Data Preparation:** A prompt template has been prepared for an instruct-LLM. The prompt asks the LLM to understand both the LLM code and the human code that solve the same problem, with potentially different input formats. The model is asked to generate code that evaluates whether the two implementations return the same output values given the same input values (even if provided in different formats).
4. **Framework\Test Preparation:** Since the LLMs used were "lightweight", both before passing the code to the LLM and after obtaining the final .py file, small adjustments are applied, such as: renaming classes and functions to ensure that the two solutions have different function and class names, adding missing imports (a common cause of test failures), and so on.
5. **LLM\Test Preparation:** The LLM generates 3 inputs and 3 control assets in Python.
6. **Framework\Test Running:** The framework therefore generates a folder to insert the test code, executes it, and collects the results, saving the number of tests passed for each code.
7. **Output:** The test results are collected and added to the metadata saved at the beginning of the process, with the aim of obtaining a final dataset containing information about the test execution.

## Development insights

Firstly, it is important to underline a fundamental consideration: the reason for not asking the LLM to directly classify the code as correct or incorrect is supported by the findings of the paper "*Do LLMs generate test oracles that capture the actual or the expected program behaviour*" [76], which states: "*LLMs are more effective at generating test oracles rather than classifying them.*"

The framework has been developed starting from the project **KodCode**[77], available on [GitHub](#). KodCode aims to generate code from prompts in order to train LLMs on synthetic code. However, the project underwent huge changes, leaving very little of the original code (like the *.jsonl* use).

Initially, the idea was to slightly modify the KodCode framework so as not to require a large language model (LLM) to generate both code and tests, but only the tests. However, during the development and analysis of the framework, it became evident that much more substantial changes and additions were necessary.

First and foremost, it was necessary to develop a method for preprocessing and preparing a dataset of pre-written code. Subsequently, the entire generation phase had to be adapted to meet the new objectives.

After initial testing, it became clear that an LLM of moderate size (14B), a necessary compromise due to hardware limitations, was not sufficiently capable of understanding the problem and the code to generate effective tests. In many cases, the tests produced were incorrect and would have incorrectly flagged correct code as faulty.

As a result, it became necessary to change the approach: rather than relying solely on the LLM’s test-generation capabilities, we opted to use functioning reference code that solved the same problem. Since the dataset proposed by Pan et al. includes both LLM-generated code and corresponding human-written code (the latter being reliably correct), we focused on that dataset.

The new strategy required generating inputs consistent with both the problem statement and the function signatures. The LLM’s task was thus limited to generating such inputs and writing code to verify whether both the human-written and LLM-generated implementations would produce the same outputs for those inputs.

Several challenges emerged from this new approach, some of which are outlined below:

1. **Lack of Imports:** Human-written code in the dataset did not include any imports. We therefore introduced a mechanism to automatically insert the most common imports, as the LLM proved ineffective at consistently adding all necessary ones.
2. **Code Structure Variability:** Not all solutions were simple functions—some were classes, and others were standalone Python scripts. For class-based solutions, the prompts were adapted to enable the LLM to instantiate objects correctly and generate the necessary tests. For script-based code, we chose to discard such examples, as converting them into testable functions could have introduced errors attributable to the LLM’s transformation process rather than to the code itself.
3. **Name Collisions:** In many cases, the human-written and LLM-generated code used identical class or function names. To address this, we implemented an algorithmic renaming strategy to avoid such conflicts.

Subsequently, it became necessary to develop an entire sub-framework responsible for effectively generating the test files. These files needed to contain both the human-written and LLM-generated functions, as well as the tests produced by the LLM.

The sub-framework was also tasked with executing multiple tests in parallel, reporting the result of each individual execution, and generating a new dataset based on the previous one, but enriched with additional information regarding the outcome of the tests.

Despite the significant effort invested in developing the framework, it was decided to maintain, at least in this phase, certain limitations—potentially addressable in future work, such as compatibility with the Python programming language only.

## Possible improvements

Despite the work done, there is still significant room for improvement:

- Predefined prompts depending on the LLMs
- Support for APIs for test generation
- Test execution within containers separate from the execution environment
- Improvement of library import techniques

## 3.4 Final Dataset

Upon analysing the available datasets, it was decided to use several of them for specific purposes.

### 3.4.1 Pan et al tested dataset

The analysis of the dataset by Pan et al. enabled the construction of a small dataset consisting of definitively correct and definitively incorrect code samples (where “incorrect” refers to cases in which the LLM-generated code did not produce the same outputs as the corresponding human-written code).

The process began with the subset of the dataset corresponding to the prompt “*Removal of stop words from the prompt*”, which includes 5069 samples. From this subset, has been discarded all code samples that the framework was unable to process. Tests were then executed on the remaining samples, and only those which did not produce runtime faults were retained—this was necessary to exclude failures due to incorrectly generated tests or missing import statements.

As a result, a dataset of approximately 1000 code samples was obtained, of which around 600 were classified as correct and 400 as incorrect (i.e., they failed at least one test).

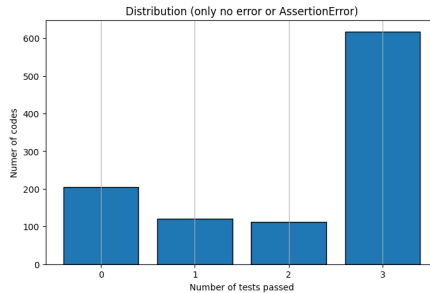


Figure 3.6: Source distribution

### 3.4.2 Dataset standardization

Different “roles” have therefore been assigned to the datasets in the testing process.

CodeMirage 3.2.1 is the primary test dataset, against which all methods will be compared. This choice is motivated by the fact that CodeMirage has already published tests on various methods using its dataset, providing a solid starting point. Additionally, the CodeMirage dataset is the most diverse and extensive: it contains both short code snippets and entire programs, includes 10 programming languages, and 10 different LLMs. This dataset is therefore useful for evaluating the generalization of results across multiple programming languages and LLMs.

AIGCodeSet 3.2.2 plays the role of evaluating, among a set of methods selected through the tests on CodeMirage, the effectiveness on competitive-type code. Competitive code is an extremely important type of code because it requires the greatest detection capabilities. This is because competitive code refers to coding exercises, such as those requested during job interviews and in educational settings. Additionally,



AIGCodeSet can also be used to make secondary considerations about the detection method's capabilities on more complex code.

The code from Pan et al. tested 3.4.1 using the framework developed in 3.3.1 allows us to assess the considerations of various works regarding the increased difficulty of detecting error-free code. This test remains a consideration, and if proven true, it should encourage future works to make more intensive use of testing frameworks to improve the quality of their datasets, both for training and testing.

CoDet-M4 3.2.1 does not appear to be a high-quality dataset, but it remains a dataset of enormous size. Therefore, although it is not recommended for testing, it could be interesting to use this dataset to train an AI-based detection method and evaluate its results.

So the final role of the dataset will be:

- **CodeMirage:**
  - Language generalization
  - LLMs Generalization
- **AIGCodeSet:**
  - competitive code evaluation
  - difference between difficulty
- **Pan:**
  - correct code vs wrong code evaluation
- **CoDET-M4:**
  - Training set for AI based detection

## Chapter 4

# Detection Methods

### 4.1 Evaluation Metrics

Let us recall that the ultimate goal is to build a binary classifier capable of determining whether a piece of source code was written by a human or generated by a Large Language Model (LLM). For binary classifiers, **accuracy** is typically the default evaluation metric, unless one classification outcome, such as true positives or false positives, is considered more critical than the other.

Given that this classifier can be used in scenarios where a programmer could be 'accused' of not having authored the code themselves, it is essential that such claims be made with a high degree of confidence. While it is certainly desirable to allow end users to configure the decision threshold, the default setting should prioritize a **low FPR** (false positive rate) to prevent unjust accusations.

“In previous experiments, we mainly use F1 score, which is a threshold-dependent measure that balances precision and recall, but F1 can be misleading in real-world detection tasks. As it gives equal weight to false positives and false negatives [...] it often fails to reflect performance in imbalanced settings or under strict false-alarm constraints. By contrast, reporting the true positive rate at low false-positive rates directly measures how many genuine positives the model catches when false alarms must be kept to a minimum.” [48].

Given these considerations, the most interesting metrics for evaluating the difference between different detection methods are the TPR (True Positive Rate) at a fixed FPR (False Positive Rate), as well as the F1-Score, which allows for a general comparison between multiple detection methods in cases where the FPR is not a critical parameter for the method's application domain.

Therefore, the following will be evaluated: F1-Score,  $\text{TPR@FPR} = 10\%$ , and  $\text{TPR@FPR} = 1\%$ .

### 4.2 Evaluation Methods

Analyzing various works that propose detection methods, several "adversarial scenarios" have emerged, which can be considered more or less challenging:

1. **Out-of-domain:** All machine learning-based methods struggle significantly when tested on datasets different from the training dataset. It is therefore interesting to evaluate the performance loss between different datasets, considering:
  - (a) **Type of code** present in the dataset (*length, paradigm, language, etc*)
  - (b) **LLMs** in the dataset different from the LLM used during training.
2. **Comment removal:** It would be extremely easy for a user to remove all comments within the code. The reason is clear: comments are essentially natural language, and it is likely that a detection method could exploit comments to detect LLM-generated text.
3. **Indentation removal:** Optional indentation could be another challenge, as removing or modifying the indentation might confuse detection methods that rely on structural features of the code.
4. **Paraphrasing:** It would not be difficult for a user to change variable and function names, perhaps calling them with more standard names. Changing names becomes another realistic and difficult scenario for detection methods.

The probable reason why the **Out-of-domain scenario** is so challenging may be related to the following statement: *"Every programmer develops a unique coding style, shaped by their routines and habits. Similarly, generative models, like experienced programmers, exhibit distinctive coding patterns influenced by the biases present in their training data. Therefore, LLMs can be viewed as programmers with consistent coding styles shaped by these inherent biases."* [45] Thus, it can be thought that the goal of a detection method for LLM-generated code is simply to identify a specific coding style (whether from a particular programmer or from an LLM). Fortunately, we can hope that multiple LLMs share common traits, because: *"Since LLMs are trained on vast corpora of data from the Internet, their training data likely exhibit significant similarities, leading to similar behaviors across models."*[78]

## 4.3 Evaluation of Existing Methods

### 4.3.1 Baseline Considerations

It is important to remember that there is no need to reinvent the wheel. Since *CodeMirage* has already conducted tests on several detection methods, it is reasonable to start from their results for the initial considerations.

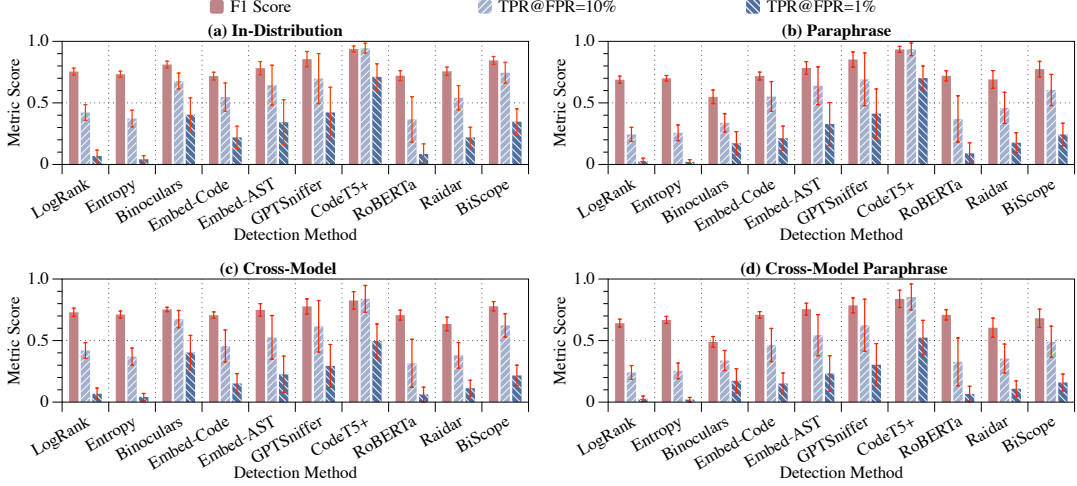


Figure 4.1: CodeMirage’s tests

CodeMirage evaluates 10 detection methods, which are divided into four categories:

1. **Zero-shot detectors:** *logRank*, *entropy*, *binoculars*.

These are methods based on the computation of code-related metrics and do not require any training.

2. **Embedding-based detectors:** *codeXEmbed-2B*.

These methods use LLMs that are not fine-tuned for classification, coupled with lightweight classifiers.

3. **Fine-tuned detectors:** *GPTSniffer*, *CodeT5+*, *RoBERTa*.

These approaches are based on the same principles as embedding-based detectors, but are specifically fine-tuned for the classification task.

4. **Pretrained LLM with downstream detector:** *Raidar*, *Bioscope*.

These methods leverage metrics that can be extracted from internal LLM values, such as hidden states.

After analyzing the methods divided into these four subcategories, the authors of CodeMirage themselves pointed out that fine-tuned detectors are the most affected by domain shifts. Indeed, by analyzing their plots, it is clear that all evaluation metrics for methods in the fine-tuned detectors category significantly drop in a cross-domain context (Figure *CodeMirage-tests*).

This is easily justified by the fact that fine-tuned methods perform very well in in-distribution settings because they learn the characteristics of the LLMs that generate

the code, almost as if they learn the LLMs’ coding style. Even though the performance of fine-tuned models decreases when shifting domains, they still remain, on average, more effective than methods in the other categories.

Nonetheless, an important clarification is needed: all the code samples in the dataset actually belong to the same “category.” As noted by several works proposing code detectors, the context in which code is written is a non-negligible factor. Since all the samples in the dataset come from GitHub-style sources (i.e., open-source projects), it is reasonable to expect that fine-tuned models applied to code from different contexts (such as competitive programming) would perform significantly worse.

The most important insight that CodeMirage provides is that, if the goal is to detect LLM-generated code from a known group of models within a specific coding domain, fine-tuning a model specifically for classification is the most effective method.

That said, it is far more interesting to have a detection method that is easy to use and does not require specific training for each application domain. By analysing the zero-shot methods, we immediately observe that their performance at  $\text{TPR@FDR}=1\%$  is extremely low, with the notable exception of *binoculars*, which achieves results comparable to those of fine-tuned methods. This offers hope for zero-shot methods to reach good performance while maintaining potentially unlimited applicability across domains.

Despite the advantages of Zero-Shot methods and the resilience shown by *Binoculars*, it is significant to note that classification metrics drop sharply after the application of paraphrasing techniques. As shown in Figure B, once variable and function names in the LLM-generated code are modified, classification performance decreases significantly.

This represents a real-world issue, as modifying LLM-generated code by simply renaming variables is both trivial and fast. In fact, this is a problem that also affects text detectors, so much so that tools exist which automatically modify generated text in such a way that natural language detectors can no longer identify it as machine-generated.

In contrast, *Embedding-based detectors* and *Pretrained LLM with downstream detector* methods appear to be much less sensitive to such transformations.

CodeMirage thus seems to suggest that we should focus on methods that leverage LLMs without fine-tuning, unless the target domain is well-defined in advance.

What is even more surprising is that the method which appears to be the most effective and the most resilient to both domain shifts and code paraphrasing is a method not designed specifically for code: *BiScope*.

For this reason, *BiScope* will be considered the baseline for all subsequent experiments involving detection methods that were not included in the original evaluation conducted by CodeMirage.

### 4.3.2 Test framework

## 4.4 Proposed Improvements

## Chapter 5

# User Interface

## 5.1 Requirements Analysis



## 5.2 Design Choices

## 5.3 Implementation and Features

## Chapter 6

## Conclusion

## 6.1 Final Evaluation and Perceived Quality

## 6.2 Future Work

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