Finding a Needle in a Haystack: Threat Analysis in Open-Source Projects

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***Abstract*—Architectural threat analysis plays a major role in addressing the growing risks from insecure software design but is rarely used in the industry. While several studies support this finding, none measure its use in open-source.**

To address this gap, we systematically mine GitHub repositories that apply threat analysis. We consider a selection of tools and languages. Moreover, we manually examine a subset to refine our results and assess the quality of the actual threat models.

Based on these investigations, we paint a sobering yet important picture of the current state of open-source threat analysis. We further provide a comparison with the aforementioned research on industry use to highlight the peculiarities of open-source software and discuss its potential for security research.

***Index Terms*—repository mining, threat analysis, open-source, security-by-design**

I. Introduction

Architectural threat analysis is an integral step in the secure software development lifecycle following the principle of security by design. It methodically addresses security and privacy threats early, during a project's design phase, but is rarely used [1]. Figure 1 shows an example of a threat model.

In the industrial sphere, numerous studies [1]–[4] focus on the challenges surrounding it, offering valuable insight to hopefully increase its currently low adoption. However, there is a lack of studies exploring architectural threat analysis in the open-source domain. We argue that the significance of security by design extends beyond industrial software to open-source projects, as evidenced by the Log4j vulnerability [5].

Our study aims to address this gap by searching the GitHub platform for projects that contain architectural threat analysis artifacts. This exploration allows us to initially assess its prevalence as well as the programming languages and tools involved. We then specifically focus on the Python programming language and manually examine all corresponding projects and threat models. Subsequently, we identify common characteristics between our observations. Finally, we compare our insights with findings from previous industry studies.

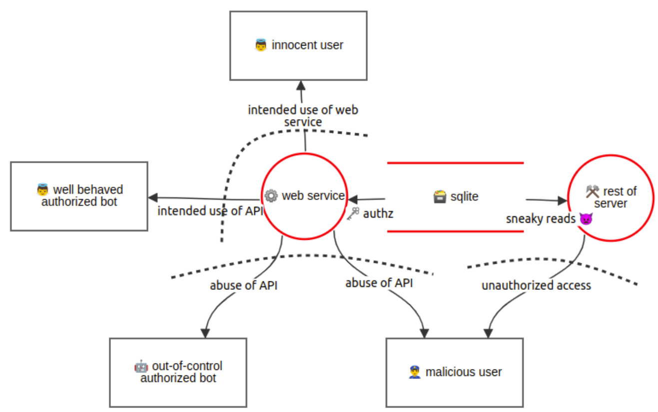

Fig. 1. An architecture overview of the software project Authasaurus, which is part of the threat model created in Threat Dragon

Our new insights gained from this study can contribute to furthering the development of architectural threat analysis.

Our contributions include a **comprehensive data analysis** of the discovered projects. This facilitates gaining a current overview of architectural threat analysis in the open-source domain, enables contextualizing with previous studies, and provides a starting point for improvements in architectural threat analysis approaches. Furthermore, we provide a **replication package**[1] for conducting the search, filtering, and data evaluation, which is freely accessible, along with the **lists of search results**.

II. Related Work

The prevalence and challenges associated with architectural threat analysis in an industrial context are the subject of several studies [2]–[4]. These investigations have identified fundamental issues, notably highlighting the time-intensive

[1]https://gitlab.com/dlr-dw/automated-threat-modeling/data-acquisition

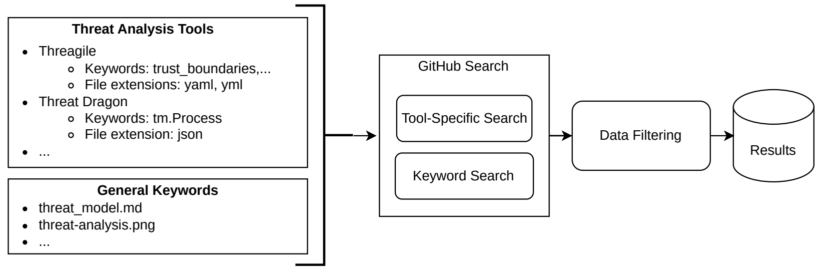

Fig. 2. Our approach comprises a tool-specific search targeting repositories with threat models from a specific tool, using specific keywords and file extensions, and a general keyword search seeking tool-independent threat models. The identified projects are then filtered.

and often unstructured nature of architectural threat analysis methodologies. However, none of them consider open-source software. Their results cannot be transferred directly because of differences in resources, incentives, and processes between industry and open source.

Some studies have explored other aspects of security in open-source software. Zahedi et al. [6] examine GitHub issues focusing on security-related topics. Li and Paxson [7] address vulnerabilities and corresponding fixes. Furthermore, there is a survey [8] on the security culture within open-source software communities. However, the mentioned studies do not specifically address architectural threat analysis.

Research in the field of architectural threat analysis is working on the improvement of approaches, particularly in the area of automation [9]–[12]. In this context, the requirement for annotated data, as outlined by Tuma et al. [11], remains paramount. The Python projects described in our study are a step towards fulfilling this requirement.

III. Methodology

Our approach consists of an initial search step to mine repositories and a subsequent filtering step (see Figure 2). In the following, we provide a detailed description of both.

A. Repository Mining

We search for open-source projects with corresponding threat models, which include a system description (e.g., an architectural document) and a list of threats associated with system components. Threat models can be manually created, often including a diagram and a text document. Tools also exist to structure the process and support users in creating these models. Our search aims to cover both manually created and tool-generated models.

For tools, we align with the systematic literature review by Granata and Rak [13] and extract freely available architectural threat analysis tools that are ready to use. The selected tools comprise Threagile[2], Threat Dragon[3], Ms Threat Modeling Tool[4], Pytm[5], TicTaaC[6], and Threatspec[7]. In the realm of manual analysis, we focus on textual descriptions as well as images or architectural drawings.

Our search is based on the GitHub platform and its API. We opted against platforms like GitLab and BitBucket because they lack global search functionalities supporting in-file searches. We employ two search strategies to identify threat models in projects as follows.

Tool-Specific Search: We incorporate specific file extensions associated with architectural threat analysis tools, like the `.tm4` extension from the MS Threat Modeling Tool as a search criterion. However, tools like Threat Dragon generate threat models in the `.json` format. To refine results, we combine this extension with specific keywords from the threat model file. Through an iterative process, we search for keywords, verify a random sample, and adjust them to avoid matching common files.

General Keyword Search: We conduct a general search for manually generated threat models by searching for files with extensions `.txt`, `.md`, `.png`, `.jpg`, and `.drawio`. These extensions are combined with generic search terms for specificity, resulting in search phrases like `threat_model.md` or `threat-analysis.png`.

We save the following information per project: repository URL, file URLs matching the search criteria, stars, files, topics, and the main language identified by GitHub. We provide the specific queries and results in our replication package.

B. Filtering

We are filtering the list of discovered repositories to eliminate false positive results—files that match the search query but are not threat models. The list is too extensive for a complete manual review of all search results. Hence, we examine the frequency of matched file names within the list. If a filename occurs more than four times, we manually inspect the corresponding file to determine if it constitutes a threat model and subsequently remove relevant entries. This process is being executed for the tool-specific search. However, this method is not applicable for the general keyword search as the manual review requires too much time to recognize an unstructured threat model.

We eliminate duplicates between the lists obtained from the tool-specific and general keyword searches. Additionally, we identify duplicates within the lists of individual tools but

[2]https://github.com/Threagile/threagile
[3]https://github.com/OWASP/threat-dragon
[4]https://learn.microsoft.com/de-de/azure/security/develop/threat-modeling-tool
[5]https://github.com/izar/pytm
[6]https://github.com/rusakovichma/TicTaaC
[7]https://github.com/threatspec/threatspec

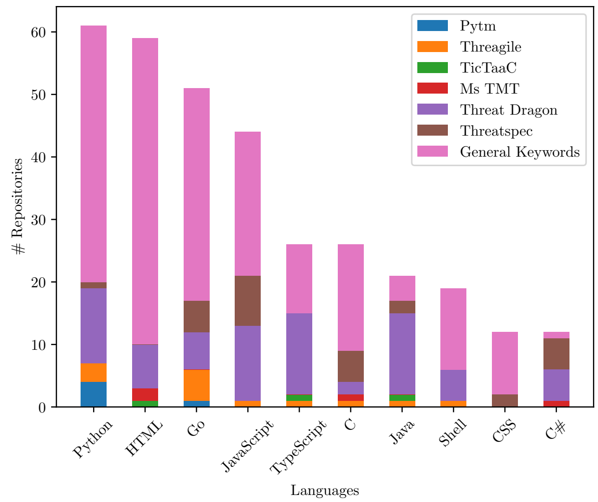

Fig. 3. The diagram illustrates the distribution of our search results across the top ten languages with the most hits. The results for each language are further divided based on the matching criteria, either an architectural threat analysis tool or a general keyword. 'Ms TMT' stands for Microsoft Threat Modeling Tool.

do not remove them, as a project might employ multiple architectural threat analysis tools.

Moreover, we aim to conduct a detailed analysis of Python repositories engaging in architectural threat analysis. We are narrowing our focus due to the overwhelming number of search results, exceeding our available resources. As a first step, we create a new subset exclusively comprising Python repositories. We then manually review these repositories, assessing the presence, alignment, and quality of threat models, verifying corresponding source code, and evaluating the completeness and quality of threat descriptions. We also check if the source code is executable without errors. Finally, repositories not meeting these criteria are removed from the subset.

IV. Data Analysis

In this section, we explore qualitative and quantitative aspects of architectural threat analysis in open-source projects and dive deeper into the Python domain. To achieve this, we investigate the following research questions:

1) What is the prevalence of architectural threat analysis within open-source software on the GitHub platform according to our search results?
2) How many repositories remain after the manual analysis of the Python projects, and what characteristics do they exhibit compared to the overall results?
3) Do the findings from previous studies align with our insights?

A. Answer RQ 1 — Prevalence of Threat Analysis:

In our search, 561 repositories across all languages meet our search criteria — 238 from tool-specific queries and 323 from general keyword searches. From our search on GitHub, where there are over 100 million public repositories, we found evidence of architectural threat analysis in less than 0.0006 percent of open-source projects.

TABLE I
Characteristics of Manually Reviewed Python Repositories

Repository Name	Commits	Stars	Contributors	Files	LoC
authasaurus	92	5	3	15	740
connaisseur	675	390	22	62	7728
tag-a-bird	294	0	2	25	1027

An overview of the distribution of languages and the tools used in the discovered projects is depicted in Figure 3. We focus on the ten most frequently used languages, noting that GitHub encompasses more than just programming languages. Repositories without detectable languages are excluded, as they lack code and may be explanatory or sample projects.

Regarding the distribution across tools, it is evident that, following the general search terms, the Threat Dragon tool significantly outperformed others in terms of hits. Following at a distance are Threatspec, Threagile, Pytm, Ms Threat Modeling Tool, and TicTaaC. According to our results, Threat Dragon is the most commonly employed tool in open-source.

Additionally, the diagram displays a breakdown of the languages used. Python and HTML occupy the top two spots, while Java trails significantly behind. Surprisingly, even C ranks ahead of Java, contrary to our expectations, considering Java's status as a high-level enterprise language. However, this distribution is notably influenced by the general keyword search. When excluding these results and focusing solely on tool-supported threat models, the order changes to JavaScript, Java, Go, TypeScript, C#, HTML, and C. These languages have between 20 and 10 repositories in descending order. Through our investigations, we observed that in the open-source domain, high-level languages such as Java and C# do not notably differ from others. Thus, scripting languages like Python and JavaScript are well-represented.

Comparing the most used languages on GitHub [14] with the tool-specific search, it is noticeable that the top three positions align with JavaScript, Python, and Java. There are disparities with C++ and PHP, which do not appear in our top ten search results. Instead, GO and HTML are included in our findings. Our results overall reflect the distribution of the most used languages on GitHub.

B. Answer RQ 2 – Python Deep Dive:

We investigate how many of the identified repositories engage in architectural threat analysis. Due to the extensive nature of manually processing all results, we limit our focus to Python. All 61 discovered repositories are manually examined, as described in Section III-B. A significant portion of these repositories is filtered out due to reasons such as lacking references to existing or publicly available source code, being empty, or being filled with examples only. Moreover, instances where the threat model no longer aligns with the source code or is outdated are removed. Ultimately, three repositories remain, two of which possess a threat model from Threat Dragon, and one is manually created, consisting of an architectural image and a description of threats. This highlights that the actual number of repositories engaged in threat analysis is substantially lower than the initial search suggests.

Table I offers an overview of the three remaining Python projects and their metrics. The projects can be categorized as relatively small based on lines of code, number of files, and commits. Moreover, the number of contributors remains generally low, with two projects having fewer than five, except connaisseur with 22. Concerning stars, one project has garnered 390 stars, indicating potential user appreciation and usage. These findings align with the characteristics observed across all search results. Whether analyzing repositories by language or tool, the average number of files per project ranges between nine and 37, suggesting small-scale projects. The average number of stars per project varies between 15 in TicTaaC projects and 850 stars in Threagile projects.

Another aspect considered is the domain from which the repositories originate. We evaluated the frequency of keywords from the topics for all found repositories. Notably, the top ten keywords are security-related, such as `security`, `threat-modeling`, and `appsec`. Additionally, references are made to languages or technologies. The Python projects are from the domain of web application and security.

By examining our results, we confirm a notably smaller number of Python projects containing architectural threat analysis artifacts. These projects are primarily small-scale, deal with the security domain, and predominantly favor the use of Threat Dragon.

C. Answer RQ 3 – Comparison to Industry:

There are already several studies [2]–[4] on the use of architectural threat analysis methods in industry, based on individual case studies. These works have followed the development process within developer teams and examined it. In the following, we compare our findings with the insights from these studies. Architectural threat analysis demands a substantial investment of time and expertise, making it challenging to integrate into software engineering approaches such as agile development. Consequently, it is rarely used in the industry [1]. Our investigation confirms that only a tiny fraction of open-source projects provides evidence of applying architectural threat analysis.

Another aspect that we and previous work have found is that the threat model does not link with the actual code. During filtering, we noticed instances where the threat model did not align with the provided source code. Additionally, we observed that some threat models were initiated but remained incomplete, with only a few threats added. This might reflect the point from a study, highlighting the challenge of determining when enough analysis has been done and when to stop.

Furthermore, the studies have discovered that it is challenging but essential to substantiate abstractly annotated threats. Otherwise, just a list of abstract threats exists, e.g., spoofing or tampering, that are difficult to assess. During the filtering, we encountered some repositories with just abstract threats. In the manually examined Python projects, all threats are described, and mitigations are attached.

A significant challenge is updating the threat model regularly as the system changes. This aligns with our observation in the three examined repositories, where the threat models were uploaded once with the most current status and were not subsequently updated. One repository directly mentions that the threat model is only valid for a specific release.

V. Threats to Validity

Some open-source projects may have underlying threat models that are not included in the repository. We assume most projects would share threat models if available to transparently communicate potential risks. However, we may miss those shared separately. Our conclusions are drawn based on the found repositories, and insights must be contextualized.

We consider only the GitHub platform for searching projects with threat models. While we initially aimed to encompass the GitLab and BitBucket platforms in our search, limitations in their search functionalities, notably the inability to conduct specific term searches within files. Consequently, these platforms are not integrated into our analysis.

Our selection of threat analysis tools is based on the systematic literature review by Granata and Rak [13], where we choose freely available tools to derive our search terms. Additionally, we employ a general keyword search to explore threat models independently of specific tools. However, we cannot entirely rule out the possibility that repositories conducting architectural threat analysis are missed.

Our search criteria may match repositories that do not contain a threat model. To address this, we mitigate this aspect during the filtering step through random checks. We also conducted a manual inspection for all projects implemented in Python, and the analysis results show significant overlap with the general findings.

VI. Conclusion

Based on our searches, we found evidence of architectural threat analysis in less than 0.0006 percent of GitHub projects. Usage is comparable in different programming languages, including scripting languages like Python and enterprise languages like Java. Our manual examination of the 61 discovered Python projects revealed that only three projects implement architectural threat analysis of adequate quality.

Overall, we encountered findings similar to those of previous industry research, including low adoption rates and challenges in maintaining comprehensive and up-to-date models. Our new findings offer opportunities to enhance architectural threat analysis approaches and tools. The identified repositories can be utilized for evaluating and comparing these tools. Future work may involve specifying open-source architectural threat analysis issues through surveys or interviews.

Acknowledgement

This work was done as part of the AVATAR competence cluster, funded by the Federal Ministry of Education and Research (funding code: 16KISA015).

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