Exploring the factors and challenges in adopting GitHub Actions and its ecosystem

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***Abstract*—Introduced in 2019, GitHub Actions offers an integrated alternative to traditional CI/CD services specifically for GitHub repositories. This deep integration enables developers to automate a wide range of software development workflows directly within the GitHub environment. Over the years, the GitHub Actions ecosystem has evolved into a mature software ecosystem, experiencing exponential growth in minutes of Actions usage. While previous studies have highlighted similarities between GitHub and package management ecosystems that distribute software libraries, our study provides an in-depth analysis of a dataset comprising 997 online posts from GitHub Discussions and Stack Overflow. These posts address prevalent issues in such ecosystems, including security, breaking changes, obsolescence, and dependency.**

We empirically demonstrate the prevalence of these issues in GitHub Actions. Our thematic analysis on GitHub Discussion posts and Stack Overflow questions revealed that Security Vulnerability is the most prevalent issue in the GHA ecosystem, followed by Dependency Issues. Obsolescence and Breaking Changes have a similar number of occurrences.

Additionally, we analyzed a dataset of 4.1k GitHub repositories to examine the relationships between repository characteristics and their usage of GitHub Actions, focusing on the preference for locally maintained actions versus marketplace actions in light of ecosystem problems. Our results indicate an overall positive reliability of projects utilizing marketplace actions, with a higher correlation of marketplace actions being employed in larger and more complex projects.

I. Introduction

Continuous Integration (CI) has become an integrated part of collaborative software development awend DevOps practices. CI automates the quality of code checks, tests and integration of code changes in collaborative environments. The benefits of CI brings early detection of issues, fast feedback loops, increased code quality, reduced integration risks and continuous improvements. Famous examples of CI services include Jenkins, Travis, CircleCI and GitLab CI/CD [1]. GitHub Actions (abbreviated as GHA) was introduced to the public in 2019 as an alternative CI service for GitHub repositories. GitHub introduced its marketplace for sharing automation tools in an effort for developers to reuse workflow components [2].

The so called "Actions" refers to automated workflows triggered by specific events within a repository, including committing changes, opening pull requests, or creating new branches. These workflows streamline development processes by automating tasks and enhancing efficiency. GitHub's integration of GHA allows developers to define custom task sequences in response to events, simplifying collaboration and promoting a seamless development experience [3].

The growing popularity of GHA is immense, with on average more than 20 million GitHub Action minutes used per day in 2023. This growth leads to a 169% increase in the usage of automating tasks in public projects, pipelines and more [4]. Given its popularity, the increasing usage of GHA has lead to an emergence of its own ecosystem [5]. According to Decan et al. [5], the growing ecosystem of GHA bears similarities to reusable software libraries distributed by package managers such as npm, Cargo, RubyGems, Maven and PyPI among others. Where these ecosystems are well known to suffer from variety of issues such as obsolescence, dependency issues, breaking changes and security vulnerabilities [5]. The authors go on to state "*The GHA ecosystem is likely to suffer from very similar issues and these issues will continue to become more important and more impactful, as the number of reusable Actions continues to grow at a rapid pace.*"

Given the concerns surrounding the GHA ecosystem, it is self-evident that developers will experience the effects of these issues. Moreover, it's worth noting that not all Actions are available on the GitHub marketplace. Many developers create and maintain their own Actions within local repositories, without making them available on the marketplace. The authors conducted an analysis of prevalent automation practices on GitHub and discovered that 43.9% of repositories in their dataset reflected this behavior [5].

Due to its novelty, there is limited understanding of the challenges faced when implementing GHA. Therefore, by systematically analysing StackOverflow posts, GitHub Discussions threads, tags, and other pertinent repositories, alongside the utilisation of database queries and APIs, we aim to quantitatively examine the questions, topics, and answers surrounding GHA. This endeavor not only facilitates the

clarification of prevalent issues but also provides insights into potential solutions and areas requiring further research and development within the GHA landscape.

Through this research, we intend to answer the following questions:

RQ1: What factors cause developers to rely on Local Actions within their repositories, as opposed to utilizing Actions available on the GitHub Marketplace?

Both Saroar et al. [2] and Decan et al. [5] observed that many repositories still prefer to use Local Actions within their repositories, despite the availability of numerous open-source and reusable Actions on the GitHub Marketplace. However, these studies do not investigate the exact factors or make comparisons between the two types of Actions that contribute to developers' preferences. We selected RQ1 to measure the difference in usage between locally maintained and Marketplace Actions, and what factors attribute do these differences to reach a conclusion that can provide valuable insights into the decision-making process for designing and developing workflows.

RQ2: In what ways do the key issues encountered in GHA parallel those found in other software ecosystems?

This research question is inspired by the concerns raised by Decan [5], as previously mentioned. The objective is to compile a list of current issues prevalent in reusable software libraries distributed via package managers and draw parallels with our research findings. This comparative analysis aims to determine whether these concerns are indeed applicable to the GHA ecosystem. If similarities are found, it will aid in identifying effective solutions previously implemented in other ecosystems to address these issues. Subsequently, these solutions can be adapted for the GHA ecosystem to prevent the escalation of such problems in the future.

II. Related Work

After just 18 months since its official release, previous research has demonstrated a notable surge in the popularity of GHA, leading to a gradual shift away from conventional CI/CD services in GitHub repositories [6]. Unlike conventional CI/CD services, GHA assists the software development processes by improving code reviews, team communication and internal repository management in addition to automating the build and test procedures of software [7]. As previously mentioned, this emerging popularity on the use of GHA and the increasing number of reusable Actions that can be found on its marketplace led GHA to be considered similar to popular reusable software libraries distributed by package managers such as npm, Cargo, RubyGems, Maven and PyPI and so on. However, this also means GHA is more likely to face similar problems that are currently encountered by these reusable libraries [5]. Consequently, this would increase the chances of failure when building GitHub workflows in GitHub repositories leading to unsuccessful deployment of software packages.

According to Decan [5], the GHA ecosystem deserves to be studied as all other reusable software ecosystems that have made progress in finding issues related to them. Since GHA is a new emerging ecosystem, there is a lack of research and studies that have been carried out to identify the challenges and issues that are encountered in GHA. The authors point out that the GHA ecosystem is exposed to similar challenges, such as obsolescence [8] [9], dependency issues [10] [11] [12], breaking changes [13] [14] and security vulnerabilities [15] [16], that are encountered in well-researched ecosystems. This section aims to briefly describe some of the issues pointed out above, using findings from related literatures, that are likely to appear in GHA.

A. Obsolescence

Software codes are regularly updated to add features, fix bugs, etc. Sometimes functions or parts of code become deprecated meaning they are outdated and no longer used; this usually happens after a long period of time, when parts of the software code are replaced by an improved version. Generally, it is a good practice to avoid using deprecated code. Through the findings of Cogo et al. [9], deprecated code used in npm packages has shown to give rise to risks such as incompatibility between two different dependant libraries, presence/absence of features, bugs, security vulnerability and more. Cox et al. [17] found that deprecated systems are four times more likely to suffer from security issues and backward incompatibilities than systems that are up-to-date. In the context of GHA, there is a high possibility that a significant amount of code used within the workflow is deprecated which may consequently lead to build failures.

B. Dependency Issues

Software systems are usually developed using pre-existing and reusable packages such as modules, components, libraries, etc [10] [11]. Consequently, this leads to a large extent of dependencies between the reused packages and the original software code. According to Dietrich et al. [13], software developers struggle to choose which versions of a given package to use and that a handful number of software systems encounter runtime version conflicts due to incompatibility with the versions of other dependant packages. Actions and workflows that depend on jobs from other Actions might fall on a similar pitfall of runtime version conflicts and possibly other dependency issues. Valenzuela-Toledo and Bergel [18] claim they have found instances of workflows where modifications were made to update the version of the tool/software being used in a particular job (e.g., Figure 1 [18]).

C. Security Vulnerabilities

Software that depends on open source and free reusable libraries provided by package managers like npm are more

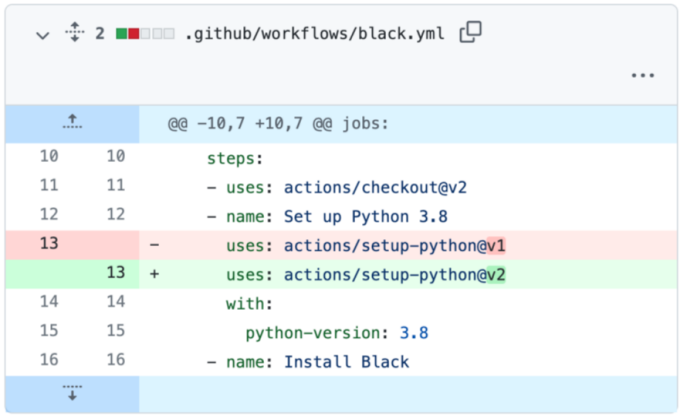


Fig. 1: Modifying python version [18]

likely to be exposed to security vulnerabilities. To quote Zimmermann et al. [15], they mention the following:

"The open nature of npm has boosted its growth, providing over 800,000 free and reusable software packages. Unfortunately, this open nature also causes security risks, as evidenced by recent incidents of single packages that broke or attacked software running on millions of computers."

According to Koishybayev et al. [19], one example of a similar attack using the GHA ecosystem is to perform deployments based on the attacker's code by triggering a misconfigured workflow through a new pull request. Since GHA consists of many open-source reusable Actions, workflow and GHA developers need to be extra careful on choosing what packages they depend on for building jobs. It is a good practice to depend on first-party packages and packages from trustworthy maintainers [15].

Saroar et al. [2] mentions that even though the GHA platform provides a marketplace for sharing and reusing open-source Actions, there are still many repositories that prefer to maintain their own GHA locally within their repositories. The survey analysis conducted by the authors revealed some challenges GitHub users face using the Marketplace where 7 out of 25 participants found it difficult to search for products and hard to check product quality (see Figure 2). Saroar et al. [2] quotes one of the participants from the survey:

"Marketplace does not provide an effective way to filter and sort based on quality, version, contributions, etc."

Decan et al. [5] raised concerns regarding potential issues that might be encountered by GHA, including obsolescence [8] [9], dependency issues [10] [11] [12], breaking changes [13] [14], and security vulnerabilities [15] [16]. These issues have already been faced in reusable software libraries within well-researched ecosystems. In our exploratory study, we aim

Problem with marketplace	% of participants
No challenges	60
Searching for products	16
Hard to quality check	8
Less marketed	4
Does not use Marketplace	12

Fig. 2: Challenges found when using GitHub Marketplace [2]

to investigate whether similar problems also exist within the GHA ecosystem. Moreover, we will compile a list of specific issues from the aforementioned papers and compare our research findings on key issues in GHA with those identified in other ecosystems discussed in the literature. By doing so, we can potentially identify solutions proposed for similar issues in other ecosystems, which could offer insights into addressing the challenges encountered in GHA.

Furthermore, our study aims to build upon the findings of Saroar et al. [2], providing explanation for their observations regarding the distribution of Local Actions compared to Actions from the marketplace. While the survey conducted by the authors offers valuable insights into the challenges faced when utilizing the GitHub Marketplace, it lacks comprehensive research and comparison involving Local Actions. The primary objective of our research is to evaluate repositories' preferences in utilizing Local Actions versus actions from the GitHub Marketplace. By doing so, we aim to identify and explain the factors that contribute to these preferences and the resulting differences in adoption.

III. Research Methodology

In this study, we aim to address the challenges developers encounter when building with GHA and to measure the extent to which locally maintained actions are utilized.. in light of its ecosystem. Our goal is to evaluate whether similar challenges and issues from well-researched reusable libraries can be spotted in the GHA ecosystem.

In this section, we describe the research questions we are trying to answer and the research strategies that have been implemented to facilitate our explorative study. Additionally, we would like to emphasize that we are employing a mixed method study, utilising different data collection and analysis methods that will be described and motivated after each research question. Finally, we identify and explain the limitations relevant to our research.

A. Research questions and methodology

RQ1: What factors developers to rely on locally maintained Actions within their repositories, as opposed to utilising Actions available on the GitHub marketplace?

Research Method: Repository Mining
This research question is answered by measuring similar characteristics of GitHub repositories that utilise GHA. And how these characteristics can correlate with the usage of

locally maintained Actions (Local Actions). By quantitatively measuring the following characteristics, we can make an argument for whether or not the preference for using Local Actions can be tied to project size, project complexity, organization, and team size.

- **Repository size:** Repository size in bytes. This includes all files such as source code, artifacts, documentation, data, etc.
- **Number of contributors:** How many developers have contributed to the repository. May indicate the size of the team working on the project.
- **Number of programming languages used:** How many types of programming langugaes used within the project. May indicate a higher complexity of the project.
- **Date of repository creation:** Date of creation. May indicate trends and cultral shifts.

- **Size of source code:** Only the amount of source code available in bytes. May also indicate a higher complexity of the project.

*1) **Data Collection**:* The study utilizes python scripts[1] to collect and store repositories using GHA. Workflow files are fetched from all the stored GitHub repositories using the GitHub API. The workflow files are then parsed, with each line iterated, to search for the $uses$: keyword and check whether the reference of the Action matches that of a Marketplace Action or a Local Action. To distinguish between the patterns, we check whether the Action reference matches the pattern $/.github*$ or $*.yml$ or $*.yaml$. If it does, we determine that it is a Local Action, due to the reason that Local Actions are called from a file path that reside within the $/.github*$ folder or end with the file extention $*.yml$ or $*.yaml$.
Similarly, for Marketplace Actions we check whether the Action reference contains the symbol @. If it does, we can determine that it is a Marketplace Action.
However, an important note here is that developers and organizations may have references of Actions that are locally maintained by themselves, but the Actions are kept in other repositories. In this case, an @ symbol is also present. To fully determine if an Action is indeed from not locally maintained, we have applied a step to verify that the owner of the repository and the owner of the Action do not match. The owner verification step can help with the accuracy of the measurement, because in certain cases the pattern in which the Action is called can be nuanced and can lead to false positives in measuring the amount of Marketplace Actions
To avoid redundancy, whenever an Action name is parsed out, that record is saved into a set with an attribute called $times.used$. If the same action is referenced elsewhere in Workflow, we increase $times.used$ by one data point. The $times.used$ attribute can allow us to measure the resuability of an Action within a repository workflow.

*2) **Data Analysis**:* In the analysis we have taken a quantitative approach to measure the correlations between repository characteristics and the number of Actions. In order to ensure an accurate understanding of what factors are correlated to relying on Local Actions more, the same quantitative analysis has been conducted for both Local and Marketplace Actions. We have used the Spearman correlation coefficient (PCC) method to measure the correlations coefficient of each of the repository characteristics alongside the number of Local and Marketplace Actions available and referenced. The Spearman rank correlation coefficient, ρ, is a measure of the strength and direction of the association between two ranked variables. It is calculated using the formula:

$$\rho = 1 - \frac{6 \sum d_i^2}{n(n^2 - 1)} \tag{1}$$

where d_i is the difference between the ranks of each pair of observations and n is the number of observations. This non-parametric measure is used to assess how well the relationship between two variables can be described using a monotonic function.

We have then compared the results of these measurements to indicate if the preference for selecting Local Actions increases more than Marketplace Actions alongside any of the repository characteristics.
Owner based frequency measurement for the amount of Local Actions available per owner can also help with determining whether big organizations lean more towards developing in-house Actions. For this analysis we have aggregated the results of Local Actions available per repository and categorized them per owner. The results from this analysis can indicate whether bigger organizations have a higher frequency in utilizing Local Actions more.

RQ2: In what ways do the key issues encountered in GHA parallel those found in other software ecosystems?

Research Method: Repository Mining
We are already aware of the problems encountered in other ecosystems. Our goal is to identify similar challenges and/or issues within the GHA ecosystem and evaluate the impact of these problems.
To address RQ2, we plan to carry out repository mining. Through repository mining, we can collect vast amounts of data from relevant software repositories using GHA. We can also automate the process of mining data by developing scripts[2] and easing the process of going through multiple repositories [20].

[1]https://github.com/WalrusArtist/SEM-Thesis/tree/kardo/python

[2]https://github.com/WalrusArtist/SEM-Thesis/tree/kardo/python

*3) **Data Collection**:* We begin our data collection process by compiling a list of both general and specific issues faced by various ecosystems, such as npm, Maven, Cargo, RubyGems, etc., as identified through related literature. These issues fall into four key areas: (i) Security Vulnerability, (ii) Obsolescence, (iii) Breaking Changes, and (iv) Dependency Issues, which are commonly encountered in ecosystems with a large number of reusable, open-source packages. **Table I** presents our finalized compilation of these issues along with their referenced literature. The Id column is used to refer to specific issues when comparing our findings in GHA with those in other ecosystems.

Repository mining is conducted by utilizing APIs and database queries to collect relevant data from Stack Overflow, GitHub Discussions, and other pertinent repositories. To collect data from GitHub Discussions, we use the GraphQL API in our scripts[3] to extract and store relevant discussion posts in JSON format. Specifically, we search for all discussion posts that contain the query string "GitHub Actions". The scripts then target the four key issues mentioned above and their synonyms to filter posts that may contain the relevant problems. **Table II** documents the four key issues and their corresponding synonyms, along with related keywords used for filtering.

TABLE II: Key issues and related keywords used for filtering.

Key issues	Synonyms and related keywords
Security vulnerability	risk*, vulnerab*, exploit*, attack*, malicious, harmful, unmaintained, secur*, steal, credential*, secret*, inject*, access*, expose*, compromise*, trust*, untrust*, change*, threat*, package*, librar*, bug*, version*, affect*
Obsolescence	outdated*, legacy, deprecat*, obsolete, unmaintained, obsolescence, update*, up-to-date, out-of-date, package*, librar*, version*, affect*, technical lag, latest, old*, depend*
Breaking changes	breaking change*, backward, compatib*, package*, librar*, version*, affect*, mismatch, conflict, depend*
Dependency issues	conflict, mismatch, package*, version*, incompatib*, compatib*, transitive depend*, rely*, depend*, librar*, affect*, direct

A similar approach is used to collect questions from Stackoverflow using the Stackoverflow API. Our scripts searches for all the questions that are tagged $GitHub - Actions$ and then targets the aforementioned issues and their synonyms. The discussion posts and questions will be analyzed manually, and conclusions about the problems will be drawn.

*4) **Data Analysis**:* In our data analysis approach, we employed repository mining techniques to analyze patterns and trends in StackOverflow posts, GitHub Discussions threads, and repository data obtained through APIs and database queries. Quantitative analysis encompassed descriptive statistics such as visualization methods including heatmaps. For qualitative analysis, our first step was to compile issues from other existing literature and group them into four themes: i) Obsolescence, ii) Dependency issues, iii) Breaking changes, and iv) Security vulnerabilities. Our collected dataset through MSR was already grouped into these themes during data collection where the data was filtered based on the synonyms appearning in the discussion or stackoverflow threads. However, there were cases when we had to map the same issue to more than one theme. The reason behind this overlapping is because of the close relation and dependency between these themes. For instance, there might be an issue related to security that is a consequence of depending on outdated software packages; in this case the same issue can be grouped to each of these themes 'Obsolescence', 'Dependency Issues', and 'Security vulnerabilities'.

In our second step of our qualitative analysis, we utilized open coding to divide our collected issues in each theme to identify further relevant sub-themes which captures more than one synonym and labelled the issues using a list of synonym terms that appears on the sub-themes. We found that the posts that contain more than one term from the synonyms were more relevant to the theme. Then, we utilized axial coding to find patterns and relation between the themes. For instance, if a specific issue from a particular theme is also relevant to other themes, we added the related theme to the list of synonyms labelling the relation between one or two themes. Our thematic coding is visually presented in Table 1.

In summary, our qualitative analysis contained four main themes labelled with the keywords 'Obsolescence', 'Dependency Issues', and 'Security vulnerabilities' and smaller sub-themes labelled with a list of synonyms and related themes. An example of such a list would be $['Outdated', 'Legacy', 'DependencyIssues']$. Overall, our approach aimed to provide a comprehensive understanding of the challenges in the GHA ecosystem parallel to other software ecosystems.

These methods ensure a systematic approach to address each research question effectively.

B. Threats to Validity

In this section, we discuss the limitations and threats to validity and how we can mitigate them.

External Validity: Since our repository mining procedure is supposed to collect data from diverse GitHub repositories with different implementation of workflows, programming languages and size of the project, the results we obtain might differ depending on these factors and our findings can not be generalized for all types of GitHub projects. However, it is possible to group the projects based on their size, programming language, etc. After grouping the projects, we could try to analyse data from each group and identify

[3]https://github.com/WalrusArtist/SEM-Thesis/tree/kardo/python

TABLE I: Compilation of issues from other ecosystems.

Problem Id	Issues encountered in other ecosystems
1. Security vulnerability	**1.1.** Found atleast one library with a vulnerability in Node.js and Ruby packages [14]. **1.2.** Security bug in the OpenSSL cryptography library [14] with a simple programming mistake. **1.3.** Spread of vulnerability through vulnerable packages [14]. **1.4.** Challenging fixes due to semantic versioning and dependency constraint [14]. **1.5.** Open nature of npm that caused its single packages to break/attack software running on millions of computers [15]. **1.6.** Electron distributed by npm on Windows platform affected other external software such as Skype, slack due to exposure [14]. **1.7.** Security issues and single point of failure from unmaintained packages in npm [15]. **1.8.** Access to credentials for the eslint-scope package from npm caused the attacker to release a malicious version of it for download [15].
2. Obsolescence	**2.1.** 81.5% of open-source software systems studied had outdated dependencies [14]. **2.2.** Depending on outdated packages 4 times likely to be expose to security vulnerability [17]. **2.3.** Deprecated code in npm packages has shown to give rise to risks such as incompatibility between two different dependant libraries, presence/absence of features, bugs, security vulnerability and more [9]. **2.4.** Technical lag in npm where package dependencies are outdated [8]. **2.5.** Strict dependency constraints in npm packages that doesn't allow dependencies to be updated to newer versions [8]. **2.6.** Security vulnerabilities found in 98% of libraries in the Android ecosystem using outdated versions [8]. These can easily be fixed just by changing the version. **2.7.** Transitive adoption of deprecated releases in npm that are hard to capture [9].
3. Breaking changes	**3.1.** Limitations due to semantic versioning and dependency constraint [14]. **3.2.** Inclusion of versions that contain backward incompatible in the dependency constraint [14]. **3.3.** Backward incompatibility risk when depending on outdated modules [14]. **3.4.** Left-pad incident in npm: removal of the left-pad library caused many dependent packages to become unavailable [15]. **3.5.** Loose dependency constraint allows backward incompatibility in CRAN, RubyGems package [8]. **3.6.** Breaking changes in Maven ecosystem due to deprecation.
4. Dependency issues	**4.1.** Software systems depending on the vulnerable versions of the OpenSSL software [14]. **4.2.** Removing package dependency to avoid spread of bugs [14]. **4.3.** Limitations due to semantic versioning and dependency constraint [14]. **4.4.** Changing back to an earlier version or a recent version that doesn't contain bug [14]. **4.5.** Runtime conflicts due to incompatibility with the versions of other dependant packages [13]. **4.6.** Left-pad incident in npm: removal of the left-pad library caused many dependent packages to become unavailable [15]. **4.7.** High number of transitive dependencies in npm being reused[15].

a common trend between the results to generalize our findings.

Construct Validity: The questionnaire, we are planning to use as our survey instrumentation, might have errors or inconsistencies. The formulated questions might be unclear, ambiguous and/or irrelevant. We could address this risk by adhering to a well-defined criterion for formulating questionnaires. Additionally, we could conduct pilot testing to validate our survey instrument.

Response bias: Collecting data through online surveys carries some risks and may result in anomalies in our results. Specifically, distributing surveys via social media can lead to invalid responses, and we may also face challenges in obtaining a sufficient number of responses to draw meaningful conclusions. To mitigate these potential limitations, we can consider distributing surveys through highly maintained development platforms or reaching out to potential companies in person.

IV. Results

A. RQ1

For RQ1, after collecting data across 4166 GitHub repositories that were on the top one-thousand list of popular repositories for the years throughout 2020, 2021, 2022, 2023 and 2024, we applied a filter to dismiss repositories that did not use any Actions. The number of repositries reduced to 1754.

In these repositories, Marketplace Actions consisted of 92.64% of the total Actions, while the remaining 7.36% consisted of Local Actions. And when analysing the number of times each Action was referenced in other parts of the workflow, we found that the result was quite similar with 92.62% for Marketplace Actions and 7.38% for Local Actions.

Data on number of different programming languages, repository size, number of contributors, date of repository creation and bytes of source code were also collected in order to see if there were any correlations between these repository attributes and the amount of Marketplace or Local Actions used or referenced. Table III demonstrates the results of the correlations, categorized as Marketplace Actions and Local Actions. The number of elements in set N is denoted by $|N|$, similarly for set M.

B. Analysis of Correlations

1) Local Actions: For Local Actions, several repository characteristics showed weak positive correlations:

- **Source Code Size:** A weak positive correlation ($\rho = 0.23$) was observed between the source code size and the

TABLE III: Spearman Correlation Coefficients between Repository Characteristics and GHA

Repository Characteristic	GitHub Action Type	(ρ)
Source Code size (bytes)	$\|M\|$ Local Actions	0.23
$\|N\|$ contributors	$\|M\|$ Local Actions	0.21
Repo created (Unix timestamp)	$\|M\|$ Local Actions	-0.11
$\|N\|$ programming languages	$\|M\|$ Local Actions	0.16
Repository size (bytes)	$\|M\|$ Local Actions	0.20
Source Code size (bytes)	$\|M\|$ Local Actions referenced	0.24
$\|N\|$ contributors	$\|M\|$ Local Actions referenced	0.17
Repo created (Unix timestamp)	$\|M\|$ Local Actions referenced	-0.14
$\|N\|$ programming languages	$\|M\|$ Local Actions referenced	0.23
Repository size (bytes)	$\|M\|$ Local Actions referenced	0.21
Source Code size (bytes)	$\|M\|$ Marketplace Actions	0.33
$\|N\|$ contributors	$\|M\|$ Marketplace Actions	0.30
Repo created (Unix timestamp)	$\|M\|$ Marketplace Actions	-0.10
$\|N\|$ programming languages	$\|M\|$ Marketplace Actions	0.38
Repository size (bytes)	$\|M\|$ Marketplace Actions	0.27
Source Code size (bytes)	$\|M\|$ Marketplace Actions referenced	0.40
$\|N\|$ contributors	$\|M\|$ Marketplace Actions referenced	0.37
Repo created (Unix timestamp)	$\|M\|$ Marketplace Actions referenced	-0.17
$\|N\|$ programming languages	$\|M\|$ Marketplace Actions referenced	0.41
Repository size (bytes)	$\|M\|$ Marketplace Actions referenced	0.30

number of Local Actions. This suggests that repositories with larger codebases tend to use more Local Actions.

- **Number of Contributors:** A weak positive correlation ($\rho = 0.21$) indicates that repositories with more contributors are slightly more likely to use Local Actions.
- **Repository Size:** Similar to the source code size, a weak positive correlation ($\rho = 0.20$) was found, reinforcing the idea that larger repositories are slightly more likely to utilise Local Actions.
- **Number of Programming Languages:** There is a weak positive correlation ($\rho = 0.16$), implying that repositories with a higher number of programming languages tend to use more Local Actions.
- **Repository Creation Date:** A weak negative correlation ($\rho = -0.11$) was observed, indicating that older repositories are less likely to use Local Actions.

2) Marketplace Actions: Marketplace actions showed generally stronger correlations with repository characteristics compared to Local Actions:

- **Source Code Size:** There is a weak positive correlation ($\rho = 0.33$) between the source code size and the use of Marketplace Actions, indicating that larger codebases are more inclined to use Marketplace Actions.
- **Number of Contributors:** A weak positive correlation ($\rho = 0.30$) suggests that repositories with more contributors are more likely to use Marketplace Actions.
- **Repository Size:** A similar trend is observed with a weak positive correlation ($\rho = 0.27$), suggesting that larger repositories favor Marketplace Actions.
- **Number of Programming Languages:** The strongest positive correlation ($\rho = 0.38$) among all characteristics was found here, indicating a significant tendency for repositories with more programming languages to use Marketplace Actions.
- **Repository Creation Date:** A weak negative correlation ($\rho = -0.10$) indicates that older repositories are slightly less likely to use Marketplace Actions.

3) Referenced Actions: When considering Actions referenced within repositories:

- **Local Actions Referenced:** The correlation coefficients for referenced Local Actions are slightly higher compared to non-referenced ones, with the highest being source code size ($\rho = 0.24$) and number of programming languages ($\rho = 0.23$).
- **Marketplace Actions Referenced:** The correlations are generally higher for Marketplace Actions referenced, with the number of programming languages showing a moderate positive correlation ($\rho = 0.41$) and source code size ($\rho = 0.40$).

4) Organizational Usage of Local Actions: In addition to the correlation analysis, we examined the usage of Local Actions by various organizations. Table IV lists the top organizations based on their use of Local Actions. Notably, large organizations such as HashiCorp, Google, Microsoft, and Facebook are prominent in the usage of Local Actions, indicating a preference for maintaining their own workflows rather than relying solely on marketplace actions.

The predominance of large organizations in the use of Local Actions may be attributed to concerns over security risks and dependency issues associated with marketplace actions. Larger organizations might prefer to maintain control over their workflows to mitigate potential vulnerabilities and ensure stability. However, further investigation is needed to substantiate these claims and understand the underlying reasons behind this trend.

C. Discussion

The results indicate that certain repository characteristics, such as source code size, number of contributors, and number of programming languages, are positively correlated with the usage of GHA, whether locally maintained or from the marketplace. The stronger correlations for Marketplace Actions suggest that repositories with more complexity and collaboration tend to leverage Marketplace Actions more frequently. Conversely, the weak negative correlations with repository creation date suggest that newer repositories are more inclined to adopt both types of actions, potentially reflecting evolving practices and the increasing availability of GHA over time.

In conclusion, the analysis provides insights into how various repository characteristics influence the adoption and referencing of GHA, highlighting trends that could inform best practices for repository management and automation strategy. Currently, the usage of Marketplace Actions prove to be more dominant across repositories, which may be due to the reliability and stability of the GHA ecosystem.

D. RQ2

Our original dataset, collected through mining software repositories, comprised 997 GitHub discussion posts containing the query string "GitHub Actions" and 100 Stack Overflow questions tagged "GitHub Actions." By filtering

TABLE IV: Top Organizations by Use of Local Actions

Organization	Number of Local Actions
HashiCorp	58
Datafuselabs	46
Hugging Face	39
NovuHQ	26
External Secrets	26
Google	25
Backstage	25
Grafana	23
KubeVela	22
Earthly	20
Cilium	19
LanceDB	19
Firezone	18
ZenML-io	17
Calcom	17
Coqui AI	15
Microsoft	14
Web Infra Dev	14
Appsmithorg	14
Anchore	13
Rustic-rs	13
LibJXL	13
Anuraghazra	12
Vercel	12
Haiibo	12
Bitnami	11
Chroma Core	11
MartinVonz	11
DataDog	11
Apache	11
Kafbat	10
Lienol	10
Mandiant	10
Argilla-io	10
CloudQuery	10
OpenTofu	10
Alibaba	9
Keiyoushi	9
Sigstore	9
DeterminateSystems	9
Kiddin9	9
RustDesk	9
Techno Tim	9
Facebook	9
Lucidrains	9
Zitadel	9
JupyterLite	8

this data using the key issues and their related keywords, we were able to collect and group posts and questions related to each key issue. We ended up with 101 posts and questions for the key issue of $SecurityVulnerability$, 80 posts and questions for $Obsolescence$, 51 posts and questions for $BreakingChanges$, and 75 posts and questions for $DependencyIssues$. Since we also collected a list of target keywords that appeared in each post and question during the filtering process, we were able to narrow down the number of posts and questions needed for our thematic process. Using these lists of keywords, along with their corresponding post/question titles, we manually determined which of the collected posts and questions were relevant. **Table V** shows the finalized number of posts and questions we used to perform our thematic analysis.

TABLE V: Finalised number of posts and questions.

Key issues	Posts	Questions
Security vulnerability	16	2
Obsolescence	10	1
Breaking Changes	12	1
Dependency changes	10	6

Our thematic analysis of these posts revealed that `Security Vulnerability` is the most prevalent issue in GHA ecosystem among the four key issues. This is followed by `Dependency Issues`, while both `Obsolescence` and `Breaking Changes` appear with a similar number of occurrences. We have included results for each of the key issues and how they compare to other ecosystems in the following subsections.

Security Vulnerability

Related issues from other ecosystems: 1.1., 1.2., 1.5., 1.6., 1.8. in **Table I**.

The most relevant theme from our thematic analysis for this section was `Access Vulnerabitlity`. There were several numbers of our formulated codes that corresponded to this theme, although some of them were solved. One such example was the absence of a feature for having `Organization Environments`, that consequently allows all users within the organization with write access the ability to perform a malicious attack such as stealing credentials and sensitive secrets. In contrast, we also found a feature in the GHA ecosystem that doesn't allow Actions to automatically push changes to protected branches, preventing anyone with write access to push malicious code to protected branches. Another similar but solved example was building Actions on the creation of tags where environments can't be used in a secure way allowing anyone with write access to bypass the protection rule when creating protected tags. These issues related to write access can be met with unwanted consequences as in `Problem Id 1.8.` from **Table I**, where an attacker released a mallicious version of the eslint-scope package in the npm ecosystem by getting access to its credentials.

`Attacks and Injections` was the theme where we encountered an actual attack on the GHA ecosystem. Specifically, the Crypto-mining attack where a GitHub user triggered the execution of malicious code through a pull request allowing crypto-mining in the victims GHA. Our analysis revealed that the GHA employees have encountered the occurences of such attacks and are quick to take countermeasures against them. However, there were some users who blamed the attack on GHA ecosystem for allowing anyone on the internet to make a free, anonymous account and trigger a pull request to any public repositories. Similar attacks using malicious codes on other ecosystems can be seen in Problem Id 1.2., 1.4., 1.8. from **Table I**. One of the exposed security vulnerability discovered in GHA runner was allowing the injection of en-

vironment variable and paths in workflows that logs untrusted data to std:out. A possible consequence of this vulnerability is the introduction or modification of environment variables without the approval of the workflow author.

Obsolescence

Related issues from other ecosystems: 1.1., 1.2., 1.5., 1.6., 1.8. in **Table I**.

The most relevant theme for this section was `Deprecate Version`. The compiled codes corresponded to Actions that was dependent on deprecated versions of packages. An example was the particular version of Xcode 11.2.1 which wasn't supported in GHA. Another similar issue found was found in `actions/upload-artifacts` Action where the workflow file was dependent on a super old and deprecate version of it which doesn't support the usecase of globbing anymore. The only fix for this issue was through the update of the Action to a newer versions.
We also found a problem where a GitHub user removed their deprecated workflow file and replaced it with a newer one. However, even after removing the deprecated workflow file, the Action wasn't removed from the Action list which meant that the old workflow would still be triggered during events. One of the solution was to remove all the associated jobs with the Action. but this solution wasn't scalable.

Breaking changes

Related issues from other ecosystems: 1.1., 1.2., 1.5., 1.6., 1.8. in **Table I**.

The only theme we had for this section is called `Breaking changes`. We included all the codes here that relates to changes made that caused sequence of issues and broke the usual way of working. This kind of issue was observed when GitHub rolled out a security patch that forced a limitation on deploying code to production through creating a tag that stopped protected environments from working. This was a deliberate decision made by GitHub until the bug was fixed and was referred to as "Security of Breaking Changes" by one of the GitHub users. Another similar problem faced but remained unsolved found on a Discussion post was the sudden stop of the functionality of the Users workflow. Consequently, a collection of modules started to fail to push packages to the GitHub Maven registry.
Moreover, in the same theme `Breaking changes`, we found two more issues with breaking changes. One of them was when Dependabot- a GitHub Action bot- started acting crazy by reporting unusual dependency update PR changes that resulted in false positives. However, the root cause of the Dependabot going crazy was from the GitHub Registry that processed the metadata of gemspec packages and explicitly tagged development packages as runtime_development. The final observation related to this theme was the addition of a new mechanism by GitHub that gated pull requests until all workflows were executed and passed. Subsequently, this change effected some GitHub users with their pull requests rendering a "cached" version of the pull request, leaving the workflows to remain pending.

Dependency issues

Related issues from other ecosystems: 1.1., 1.2., 1.5., 1.6., 1.8. in **Table I**.

For this section, we had identified two themes each comprising of codes with similar patterns. The theme that was observed to have several issues was `Direct Dependency`. Our findings revealed two problems related to jobs being dependant on other jobs. One of the problem was that a failed job is bound to fail again during a re-run, if any of its dependent jobs uses a reusable workflow. The reason for this was due to the cancellation of the in-process runs of the dependent jobs because re-running a failed job also causes its dependent job to re-run. The second related problem was the dependency between two sequential jobs, for instance a build and a test job., the test job will be dependant on the status of the build job. . If the build job fails, the test job will not run. The other issues found in this theme was related to package dependencies in maven and GitHub Action bots. A GitHub user wasn't able to build their project using GitHub Action since the maven dependencies were not resolvable and none of the gradle versions were able to resolve the maven depency. This issue remained unsolved. The other problem was also mentioned in the `Breaking changes` theme where the GitHub registry explicitly tagged development packages as runtime_development dependencies instead of development dependency.
The second identified theme was `Transitive Dependency`, this included that weren't directly visible to the user but resulted in the GitHub Action failing. Our observation noted that the GitHub user didn't find any packages causing direct issues for the Action to fail. However, the user found a 4th tier dependency which caused the error.

V. Discussion

In this section, we discuss the results in conjunction with relevant literature.

VI. Future work

VII. Acknowledgement

This proposal is the collaborative effort of Kardo Marof and Saif Sayed, with guidance from our thesis supervisor, Linda Erlenhov. Marof's contributions include the Introduction section, as well as the sub-sections on Data Collection and Data Analysis within the Research Methodology section. Sayed, on the other hand, contributed to the Related Works section, the description of the Research Questions, the motivation behind the selected methodologies, and the identification of Threats to Validity within the Research Methodology section.

References

[1] L. Dabbish, C. Stuart, J. Tsay, and J. Herbsleb. Social coding in GitHub: Transparency and collaboration in an open software repository. In *International Conference on Computer Supported Cooperative Work (CSCW)*, pages 1277–1286. ACM, 2012.

[2] S. Saroar and M. Nayebi. Developers' perception of GitHub Actions: A survey analysis. *IEEE Software*, 2023.

[3] C. Chandrasekara and P. Herath. Getting started with GitHub Actions workflows. In *Hands-on GitHub Actions*. Springer, 2021.

[4] GitHub. Octoverse: The state of open source and rise of AI in 2023, 2023. [Accessed: March 15, 2024].

[5] A. Decan, T. Mens, P. Mazrae, and M. Golzadeh. On the use of GitHub Actions in software development repositories. In *2022 IEEE International Conference on Software Maintenance and Evolution (ICSME)*, pages 235–245, 2022.

[6] M. Golzadeh, A. Decan, and T. Mens. On the rise and fall of ci services in GitHub. In *29th IEEE International Conference on Software Analysis, Evolution and Reengineering (SANER)*. IEEE, 2021.

[7] C. Chandrasekara and P. Herath. *Hands-on GitHub Actions: Implement CI/CD with GitHub Action Workflows for Your Applications*. Apress, 2021.

[8] A. Decan, T. Mens, and E. Constantinou. On the evolution of technical lag in the npm package dependency network. In *IEEE International Conference on Software Maintenance and Evolution (ICSME)*, pages 404–414, 2018.

[9] F. Cogo, G. Oliva, and A. E. Hassan. Deprecation of packages and releases in software ecosystems: A case study on npm. *IEEE Transactions on Software Engineering*, 2021.

[10] A. Decan, T. Mens, and P. Grosjean. An empirical comparison of dependency network evolution in seven software packaging ecosystems. *Empirical Software Engineering*, 24(1):381–416, 2019.

[11] C. Soto-Valero, N. Harrand, M. Monperrus, and B. Baudry. A comprehensive study of bloated dependencies in the maven ecosystem. *Empirical Software Engineering*, 26(3):45, 2021. [Online]. Available: https://doi.org/10.1007/s10664-020-09914-8.

[12] A. Decan and T. Mens. What do package dependencies tell us about semantic versioning? *IEEE Transactions on Software Engineering*, 47(6):1226–1240, 2019.

[13] J. Dietrich, D. Pearce, J. Stringer, A. Tahir, and K. Blincoe. Dependency versioning in the wild. In *16th International Conference on Mining Software Repositories (MSR)*, pages 349–359, 2019.

[14] A. Decan, T. Mens, and E. Constantinou. On the impact of security vulnerabilities in the npm package dependency network. In *15th international conference on mining software repositories*, pages 181–191, 2018.

[15] M. Zimmermann, C.-A. Staicu, C. Tenny, and M. Pradel. Small world with high risks: A study of security threats in the npm ecosystem. In *28th USENIX Security Symposium*, pages 995–1010, 2019.

[16] R. G. Kula, D. M. German, A. Ouni, T. Ishio, and K. Inoue. Do developers update their library dependencies? *Empirical Software Engineering*, 23(1):384–417, 2018.

[17] J. Cox, E. Bouwers, M. van Eekelen, and J. Visser. Measuring dependency freshness in software systems. In *Int'l Conf. Software Engineering*, pages 109–118. IEEE Press, 2015.

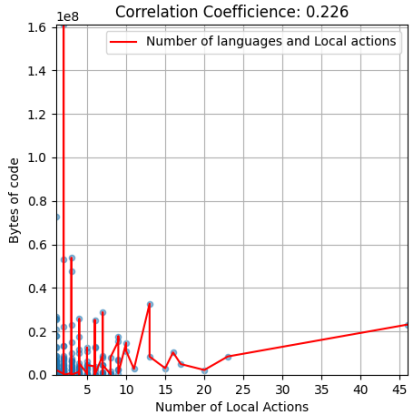
[18] P. Valenzuela-Toledo and A. Bergel. Evolution of github action workflows. In *2022 IEEE International Conference on Software Analysis, Evolution and Reengineering (SANER)*, pages 123–127, 2022.

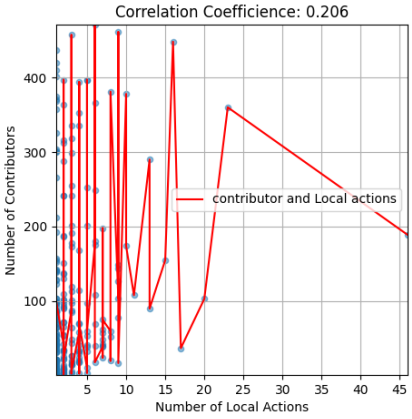
[19] I. Koishybayev, A. Nahapetyan, R. Zachariah, S. Muralee, B. Reaves, A. Kapravelos, and A. Machiry. Characterizing the security of github ci workflows. In *USENIX Security*, 2022.

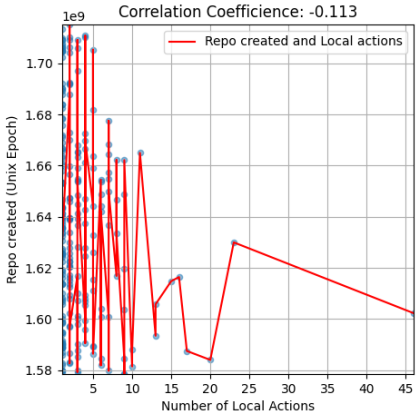
[20] K. K. Chaturvedi, V. B. Sing, and P. Singh. Tools in mining software repositories. In *Proceedings of the 2013*, 2013.

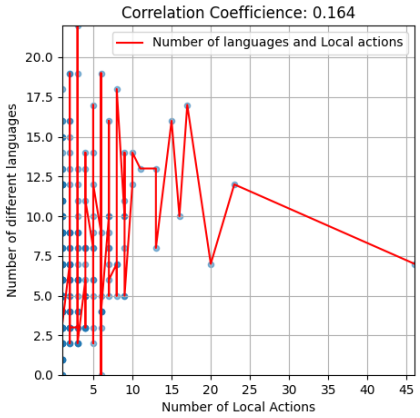
VIII. Appendices

A. Graphs





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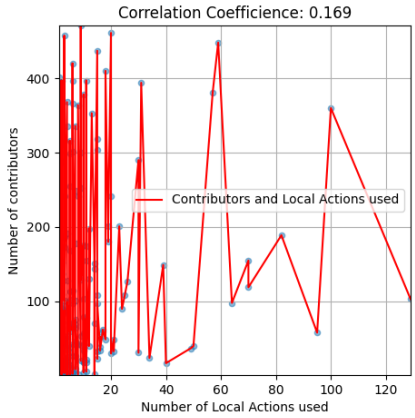
Number of Local Actions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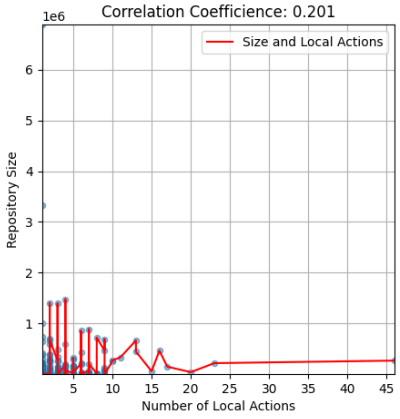
Number of Local Actions used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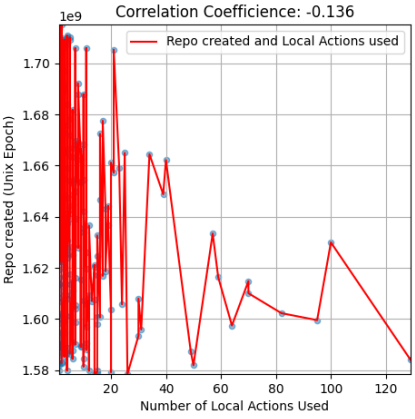
Number of Local Actions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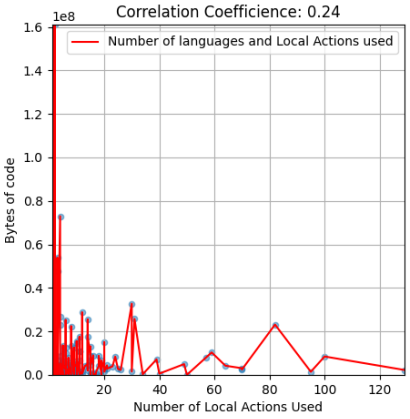
Number of Local Actions Used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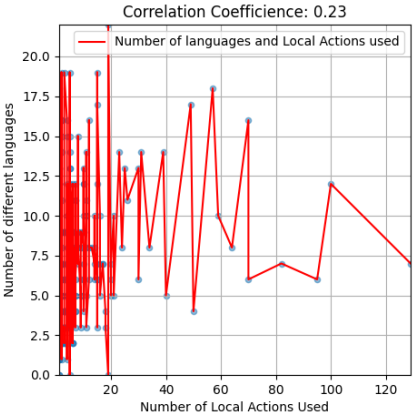
Bytes of code
Number of Local Actions Used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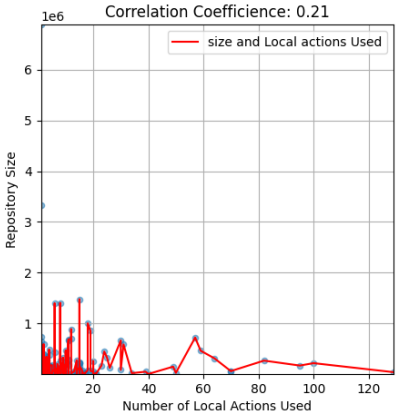
Number of different languages
Number of Local Actions Used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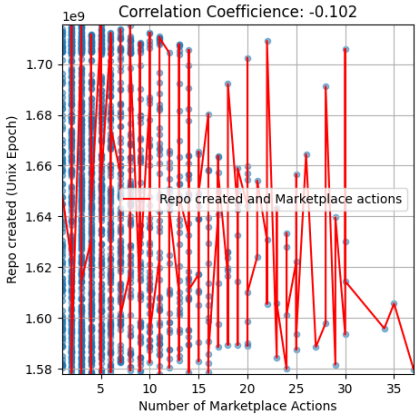
size and Local actions Used
Repository Size
Number of Local Actions Used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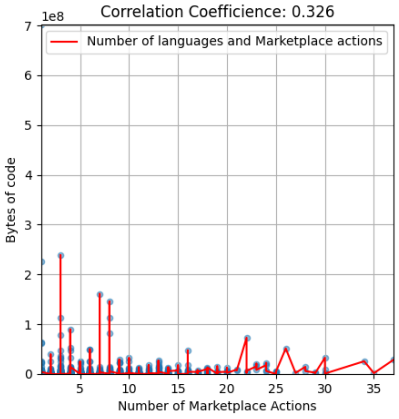
Number of Marketplace Actions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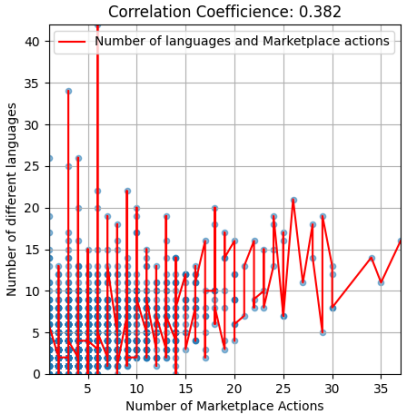
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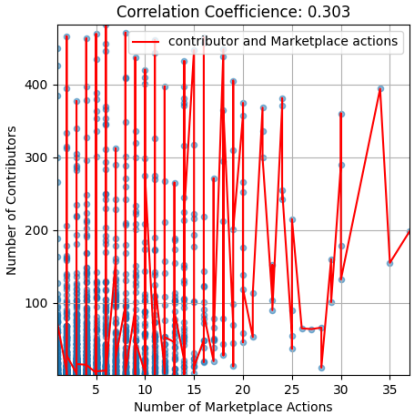
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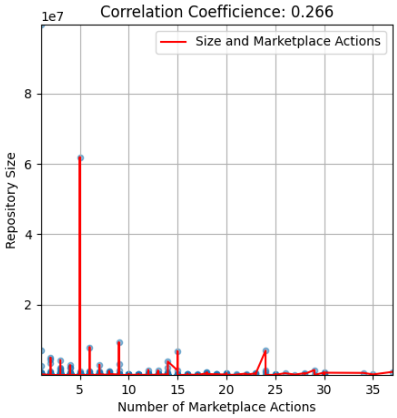
Number of Marketplace Actions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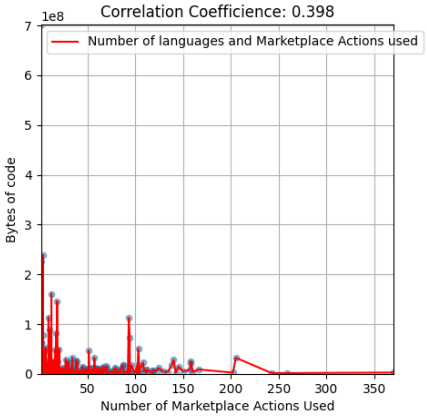
Repository Size
Number of Marketplace Actions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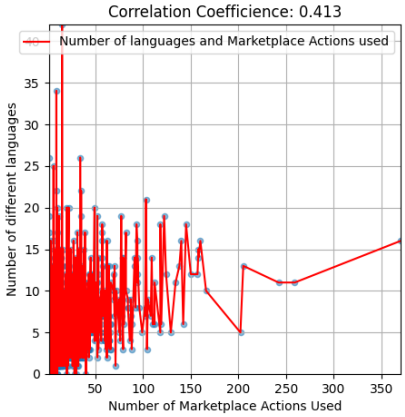
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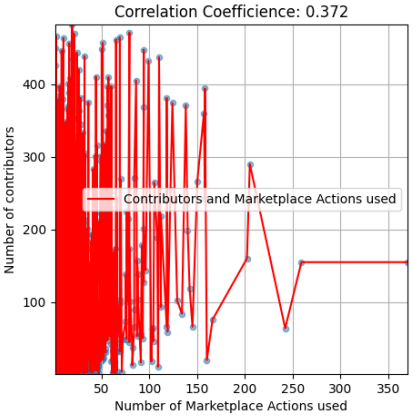
Number of Marketplace Actions Used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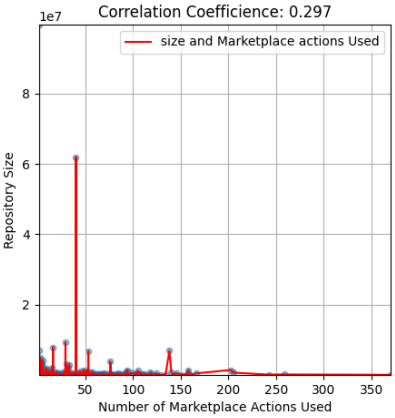
Number of Marketplace Actions used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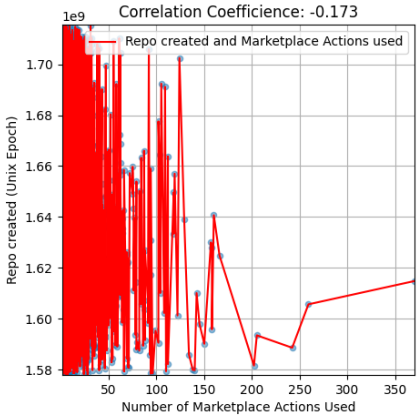
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