A Systematic Mapping of Software Engineering Challenges: GHTorrent Case

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Abstract— Git is used as the distributed version control system for many open-source software projects. One Git-based service, GitHub, is the most common code hosting and repository service for open-source software projects. For researchers that study software engineering, the content that is hosted on these platforms provides much valuable data. There are some alternatives to get GitHub data such as GitHub Archive, GitHub API or GHTorrent. Among these options, GHTorrent is the most widely known and used GitHub dataset in the literature. Although there are some review studies about software engineering challenges across the GitHub platform, no review of GHTorrent dataset-specific research is available. In this study, the 172 studies that use GHTorrent as a data source were categorized within the scope of software engineering challenges and a systematic mapping study was carried out. Moreover, the pros and cons of the dataset have been indicated and the focused issues of the literature on and the open challenges have been noted.

I. INTRODUCTION

Thanks to distributed version control systems such as Git, Mercurial, etc., open-source development platforms have reached a considerable number of users. The most common of these platforms is GitHub (based on git). GitHub has become the world’s largest code server with more than 35 million developers hosting and collaborating over 100 million repositories.

On platforms such as GitHub, the development process is distributed. Developers can participate in a project, contribute, discuss bugs with each other, and write comments about code from various locations. In this way, a considerable amount of text about the projects is generated which can be used for natural language processing studies. In addition to this text, GitHub includes many social connections among users or projects. With these features, the GitHub data is used as a data source in many academic studies.

In a survey study about GitHub, the usage rates of datasets that include GitHub data are given. They determined that the most used dataset is GHTorrent (34%) in the articles that are handled according to the certain criteria [1]. In Consentinos systematic mapping study, the GHTorrent dataset is in the lead with a 41% use rate [2] [3]. In another study, GHTorrent is the most cited dataset [4].

The GHTorrent dataset was developed by Georgios Gousios in the software engineering department at Delft University of Technology [5]. The dataset is generated by systematically crawling with the GitHub API and includes information about all public projects and users on the platform. GHTorrent stores some information about repositories, projects, issue descriptions, comments, and pull request (PR) conversations in 26 relational tables totally. Archives are published on the dataset website monthly. Moreover, GHTorrent team tries to present the dataset on demand by providing access to database replicas.

In the literature, there are review studies about GitHub or open source systems. Although such an important dataset, we realized that there is no GHTorrent-specific review. This study is a systematic mapping review about GHTorrent, which is the most popular among GitHub datasets. In this context, we want to find out the topics of all studies which used the dataset and classify them. We focus on the studies with the context of software engineering challenges. The studies have divided into some categories and challenges. Besides, some distributions (type, venue, year, method, data, topic) have been obtained from the studies that used the dataset. We show which challenges are mentioned in the studies and how each study is using the dataset. Thus, we hope the study guided the researchers who interest in software engineering challenges with open source systems. We formed this review following these research questions:

RQ1: What are the software engineering challenges that researchers investigate with GHTorrent?
RQ2: What are the handicaps/cons of GHTorrent?
RQ3: What are the open challenges that have not yet been studied with this dataset?

In this context, 172 articles using GHTorrent were examined and a systematic mapping study was done by extracting several features.

II. METHODOLOGY

A. Obtaining Relevant References

To obtain the studies that used the dataset, all 334 studies which cited the source study of GHTorrent [5] were reviewed. The papers were filtered as indicated in Table 1. The studies that were written in any language other than English, paid studies, and reports/books/theses were removed. In addition, articles that cited the dataset in related works and as a similar data set were also eliminated.

After this elimination process, 172 studies remained. 49 of the studies were published in journals, and the remaining 123 were published in conferences. The following features were extracted from the studies:

1Last check was done on 24 July 2019
Table I

| Filtering Criteria                  | # of paper | TOTAL |
|-------------------------------------|------------|-------|
| Language problem                    | 25         |       |
| Paid/non accessible article          | 18         |       |
| Book/thesis                         | 49         | 160   |
| Cite in Related work only           | 47         |       |
| Cite as similar dataset only        | 16         |       |
| Report/speech etc.                  | 5          |       |

Fig. 1. Study numbers by year

- Title, authors, keywords, and abstract.
- The aim, methods, and research questions
- The datasets that were used alongside GHTorrent
- The date of used dataset dump
- Data/feature selection criteria (according to code language, user, and project)
- Publishing venue information

B. Features From References

The distribution by years of studies is given in Figure 1.

The increase over the years is an indication that the data set is used effectively. In 2012, Gousios published a paper about dataset. We reviewed studies that cite only the citation article on GHTorrent website.

The source journal distribution of the studies is given in Figure 2 (a). The highest number of publications (8 papers) were in Empirical Software Engineering (Excluding ArXiv papers). Only 1 study was published in the journals labeled Others.

Apart from journals, most of the articles were published in various conferences (Figure 2 (b)). The foremost among them were the MSR (Mining Software Repositories) and ICSE (International Software Engineering Conference). Conferences with 12 publications are labeled Others.

Apart from using the dataset, some extended datasets were generated by adding various features to GHTorrent. Furthermore, some studies produced sub/derivative datasets from GHTorrent by filtering some features. In this context, the most common derivative dataset is TravisTorrent. The dataset that was used for the continuous integration challenge was produced with some features from GHTorrent and information extracted from Travis CI. Moreover, information obtained from various platforms, such as Stackoverflow and Twitter, were used in some studies.

While 133 (77%) of papers used only GHTorrent, the remaining 39 were used other datasets with GHTorrent. Figure 3(a) shows the usage rates of datasets with GHTorrent.

The methods used in all studies were also extracted (Figure 3(b)). The category labeled statistics is the most used method group. This group includes statistical, mathematical, and probabilistic methods, etc. Text mining studies are relatively less than other methods despite the dataset includes rich textual features. In this regard, we thought using text mining methods based on deep learning with the dataset will be worthwhile and distinctive. The studies that contain topics such as data visualization, use of the dataset, or creating a new dataset are in the Others category.

The words in the abstracts of an article roughly give information about its topic. Starting from this point of view, another important feature extracted from these studies was relation of words in the abstracts. The cluster density graph was created by use frequency of these words (Figure 4). The clusters and underlined words were played crucial roles on separating studies into categories.

III. Results

RQ1: What are the software engineering challenges that researchers investigate with GHTorrent?

Firstly, to group studies on domains, we used the nature of GitHub itself. "User" (developer) and "project" are the backbones of open source software platforms. Secondly, in considerations of the density graph (Figure 4), apart from these it is seen that the "development" topic is also at the center. Besides, the "dataset" topic is added because some of the studies are related to the dataset directly. Thus the studies have been separated into 4 domains. In order to determine challenges under these domains, we appealed to Cosentino's GitHub review article [3] and the cluster density graph. We chose the most inclusive ones while determining the challenges. After all processes, the software engineering challenges were separated into 16 challenges under four domains.

The studies were split into four domains, User (USR), Development (DEV), Project (PRO), and Dataset (DAT). The challenges of these domains and related studies are given in Table II. The # of Study column is corresponding to number of studies on a challenge. The reason the total numbers in the table are greater than the total number of studies is that some of them focus on more than one challenge. The abbreviations of these challenges that are going to use following tables are given in this table. We used the cluster density graph and chose the most inclusive ones while determining the challenges.

[2]https://www.vosviewer.com
In addition to these numbers, the detailed information about each domain is given in Tables 36 below. The given tables for each domain contain the reference id of studies and related challenges (x in a cell indicates that the study focuses on a challenge in this column).
A. User

GitHub users are the main roles in software projects positioned as contributors (with codes or comments), developers, project managers, etc. to perform all activities in the software life cycle. In this context, a lot of studies have been published about users domain. The user domain challenges were divided into four topics, activity, interaction, revision/assignee, and characterization (Table III).

ACTY (Activity): In general terms, it covers the GitHub developers’ contributions such as coding history, comments, like/star, developer performances, and other past activities.

INTR (Interaction): It is related to users’ interactions both within the GitHub environment and on other platforms such as Stackoverflow and Twitter. Events such as following or watching among users, forking projects, etc. come under this topic.

REVI (Revision/Assignee): The studies about pull request reviewer, issue or bug assignment problems are in this topic.

CHAR (characterization): Out of the topics above, the studies interest in behavior of user’s emotional activity, classifying the developers according to features such as gender, activity, tenure/volunteer were analyzed under this title.

The most studied challenges in the user domain are activity and interaction, as seen in Table [III]. This trend can be interpreted as a natural consequence of GitHub being an open-source, community-oriented project repository service.

B. Development

The basic activity that affects the performance of its targeted product in software projects can be considered as the development process. The challenges in the development domain were divided into four topics, pull request, source code, continuous integration, and quality (Table [IV]).

PREQ (Pull Request (PR)): It covers some problems about PR classifications or prioritization, PR description and comment contents, and PR acceptance/rejection and reasons for them.

CODE (Source Code): It is about topics such as the programming languages of projects, connections between codes
TABLE II
NUMBER OF STUDIES IN DOMAINS AND CHALLENGES

| DOMAINS | # of Study | CHALLENGES          | # of Study | ALIAS |
|---------|------------|----------------------|------------|-------|
| USR     | 69         | Activity 39 ACTV     |            |       |
|         |            | Interaction 39 INTR  |            |       |
|         |            | Revision - Assignment 9 REVI | |       |
|         |            | Characterization 35 CHAR | |       |
| DEV     | 59         | Pull Request 18 PREQ |            |       |
|         |            | Source Code 35 CODE  |            |       |
|         |            | Continuous Integrations 17 CONT | |       |
|         |            | Quality 12 QUAL      |            |       |
| PRO     | 63         | Issue/bug 24 ISSUE   |            |       |
|         |            | Team - Member 11 TEAM | |       |
|         |            | Dependency 9 DEPE    |            |       |
|         |            | Characterization 36 CHAR | |       |
| DAT     | 28         | Definition-Usage 4 DEFI |          |       |
|         |            | Subsets 4 SUBS       |            |       |
|         |            | Augments-Derivatives 7 AUGM | |       |
|         |            | Helper 13 HELP       |            |       |

TABLE III
CHALLENGES IN THE USER DOMAIN

| Paper IDs | # of papers | ACTV | INTR | REVI | CHAR |
|-----------|-------------|------|------|------|------|
| [6]–[9]   | 4 x         |      |      |      |      |
| [10]–[21] | 12 x        |      |      |      |      |
| [22]–[23] | 2 x         |      |      |      |      |
| [24]–[23] | 10 x        |      |      |      |      |
| [24]–[33] | 10 x        |      |      |      |      |
| [24]–[36] | 3 x         |      |      |      |      |
| [27]–[37] | 11 x        |      |      |      |      |
| [58]–[63] | 6 x         |      |      |      |      |
| [64]–[66] | 3 x         |      |      |      |      |
| [67]–[73] | 7 x         |      |      |      |      |
| [74]      | 1 x         |      |      |      |      |

TABLE IV
CHALLENGES IN THE DEVELOPMENT DOMAIN

| Paper IDs | # of papers | PREQ | CODE | CONT | QUAL |
|-----------|-------------|------|------|------|------|
| [7]–[8]   | [10]–[21]   | 12 x |      |      |      |
| [22]–[33] | 18 x        |      |      |      |      |
| [34]–[36] | 7 x         |      |      |      |      |
| [37]–[40] | 3 x         |      |      |      |      |
| [41]–[52] | 2 x         |      |      |      |      |
| [53]–[56] | 6 x         |      |      |      |      |
| [57]–[61] | 7 x         |      |      |      |      |
| [62]–[67] | 3 x         |      |      |      |      |
| [68]–[70] | 1 x         |      |      |      |      |

C. Project

The essential motivation of distributed version control systems is the development of targeted products on the basis of public projects. The project domain challenges were divided into four topics, issue/bug, team/members, dependency, and characterization (Table V).

ISSU (Issue/bug): It includes topics such as open and closed issues (commits, tasks) in a project, bugs occurrence, and bug triaging. Moreover, the differences, characterization, and classification of the trio of issue-bug-feature are under this topic.

TEAM (Team/member): It contains the challenges about the team diversity in terms of some features (location, gender, tenure, permanence, etc.), the actions as a team, joining or leaving behaviors, core and other members, and the effect of teams on software quality.

DEPE (Dependency): It includes topics about project dependencies. Varied types of dependencies in GitHub projects were examined with regards to programming languages, codes, problems, forking cases, and code clones. In addition, the relationships between projects and the parameters related to project survival are other challenges under this topic.

CHAR (Characterization): It involves some topics such as GitHub repository features, the unique parts of projects, the diversity of projects in terms of some parameters such as language or design, features of public projects, matters about the GitHub ecosystem, repository artifacts, forking, and branching.

Most studies under the project domain were related to characterization. The rich features of the GHTorrent about projects are thought to have a positive impression on this result.

D. Dataset

Apart from using the dataset, some extended datasets were generated by adding various features to GHTorrent. In the dataset domain, there were four sub-topics such as; definition, usage, extended-sub datasets, and helper. (Table VI).
TABLE V
CHALLENGES IN THE PROJECT DOMAIN

| Paper IDs  | #of papers | ISSUE | TEAM | DEPE | CHAR |
|------------|------------|-------|------|------|------|
| [14], [22], [31], [41], [45], [76], [81], [84], [85], [119]–[126] | 17 x |       |      |      |      |
| [33], [50], [62], [80], [127] | 5 x |       |      |      |      |
| [61], [20], [42], [83], [73], [92], [128]–[144] | 1 x |       |      |      |      |
| [80], [145] | 2 x x |       |      |      |      |
| [146], [147] | 2 x x |       |      |      |      |
| [57], [148] | 2 x x |       |      |      |      |
| [149]–[152] | 4 x x |       |      |      |      |
| [153]–[157] | 5 x x |       |      |      |      |
| [158] | 1 x x x |       |      |      |      |

TABLE VI
PAPERS ABOUT THE DATASET

| Paper IDs  | #of papers | DEFI | SUBS | AUGM | HELP |
|------------|------------|------|------|------|------|
| [2], [159], [161] | 4 x |       |      |      |      |
| [91], [126], [127], [135], [139], [143], [162] | 4 x |       |      |      |      |
| [15], [17], [93], [163] | 7 x |       |      |      |      |
| [164]–[176] | 13 x |       |      |      |      |

TABLE VII
OLDER DUMPS USAGES

| Dataset Dumps | 2019 Studies | 2018 Studies |
|---------------|--------------|--------------|
| 2016 and older | 5            | 5            |
| 2017          | 5            | 4            |
| 2018          | 4            | 1            |
| 2019          | 1            | 0            |
| unknown       | 6            | 19           |

DEFI (Definition-Usage): It is about the description of GHTorrent dataset. Besides, it covers the studies that contain dataset obtaining methods, dataset usage tips and tools.

SUBS (Subsets): It is about the studies that created by some filtering process on GHTorrent. Most of studies filter dataset according to features of developers or projects.

AUGM (Augments-Derivatives): It covers the studies that produce new datasets based upon GHTorrent (TravisTorrent, SOTorrent, etc.) and extended datasets created via data fusion from social media data.

HELP (Helper): Apart from above, some papers interest in dissimilar problems via only a few features (user mail, project language, etc.) extracted from GHTorrent. These studies were brought together under this title.

Many datasets have been created by using GHTorrent. Besides, there is a lot of software engineering studies that benefit from some features of GHTorrent. It is clearly understood from the studies under this topic that GHTorrent (hence GitHub data) how has rich features.

RQ2: What are the handicaps/cons of GHTorrent?

GitHub data retrieves with the GitHub API as fast response and consistent data. However, its 5000 requests per hour limit is a crucial problem when retrieving large data\(^3\). Thereagainst, GHTorrent presents up to date data thanks to downloadable dumps without any restriction.

GHTorrent provides flexibility by presenting data in different types. It presents raw JSON data in MongoDB database and relational tables in MySQL database. You can use whichever format that suitable for your environment.

**MongoDB format:**

1) You can download previous bi-monthly MongoDB collections from the website (until 2015 / by collections.).
2) You can download daily collections from the website (from 2015/ all collections are included.)
3) You can connect to the remote MongoDB server with the instructions on the website. The remote MongoDB server’s data may not up to date.

**MySQL format:**

1) You can download all relational tables in a single MySQL dump file. (until 2015).
2) You can download all relational tables as separate CSV files containing a table in each. (from 2015).
3) You can query the online SQLite tool from the latest dump of MySQL database. (We couldn’t try this because of login problem.)

Although the GHTorrent publishes as up to date, it is seen from our review that most of the researchers (including in recent years) use the older versions of the dataset (Table VII). In this table, it is given that the dates of dataset dump which studies published in the last two years. In 25 of 55 studies, it was not explicitly stated which dump was used.

In order to use up to date data, there is two possible option.

- Download huge MySQL dumps and import all CSV files to local database environments.
- Download all daily MongoDB dumps and restore them to local environments according to instructions on the website.

In both of the above two options, processing and transferring these large files is taken serious time and effort \[^2\]. We think that this situation prompts researchers to use older and smaller dumps. This may not a problem, however, it is a matter of curiosity why they use older data.

Besides the advantages, GHTorrent has some cons and problems. The problems reported from reviewed studies and experienced by us are given below list:

[^3]: https://developer.github.com/v3/#rate-limiting
It is reported in some studies that GHTorrent have duplicated data [91], [124]. We noticed this problem in the collections of repos and users, too. (There are several docs have same id and url field.)

Another problem is that some fields that can be used as a linkage between data are missing. For instance, there is no repo id or full name in commits and commits comments collections. To generate this field, you have to parse the url field.

It is reported that GHTorrent does not provide correct data on whether developer accounts are members of teams on GitHub [62].

Sun et al. have also stated that GHTorrent did not have data on who edited what file [63].

RQ3 : What are the open challenges that have not yet been studied with this dataset?

Assignee feature used for assign to pull requests or issues to someone in Git-based platforms such as GitHub, GitLab, Bitbucket, etc. Much as some projects don’t use this feature effectively, this is crucial for project management [177]. To automate the assigning process, issues are classified with some labels or tags, then match to suitable developers. It is seen in Table [11] that only 12% of the studies in the user domain are related to revision/assignee problems. However, it is expected that more studies can be done with GHTorrent about task/reviewer assignment, which is one of the major challenges of software engineering [178].

New trends in software developments are aimed at automating everything from issue assignment to test and deploy. DevOps is used for this purpose. DevOps process means that to integrates developments and operations via increasing communications and automatizations. All processes such as continuous integrity, automated testing or deploying, performance managements, etc. can handle with DevOps pipelines. In the studies we reviewed, it was observed that the researchers focused on a few of the devops processes such as continuous integrity, testing or revision. The data provided by GHTorrent has the necessary elements to contribute to all these steps.

Due to the rapid increase of open source software projects, developers miss some of the projects in their areas of interest. This led to the need to recommend projects to users in environments such as GitHub. In this context, one of the recent studied hot topics related to project dependency is project recommendation to users (for following or contribution) [68], [56], [179]. New recommend models and metrics can develop with GHTorrent.

IV. Conclusion

In this study, 172 studies using the GHTorrent dataset were examined. The studies were classified under four domains and 16 challenges. We identified that the reviewed studies have offered solutions on which challenges.

The essential contribution of this study is to present a filtered and classified literature review to researchers who will work in the field of software engineering. In addition, it contributes to revealing the less studied topics (open challenges) with GHTorrent, which is one of the most used datasets in the literature. Lastly, possible problems that may be encountered while using the dataset are mentioned.

Most of the studies swarm to the user and project domains. They especially focused on the characterization topic. It can be understood clearly that the dataset has rich features to handle these challenges. Additionally, the users past activities and their relationships with each other (in GitHub or other social networks) stand out as another research topic.

Further work is planned, including detailed research on the methods used in the studies reviewed and investigating which methods are preferred and why they were selected. In addition, it was observed that researchers using the dataset created subsets by passing the data through a specific filter. In this regard, it is planned to cooperate with the creators of GHTorrent to take the whole dataset and present common domain based datasets for specific challenges.
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