Abstract—On the worldwide web, not only are webpages connected but source code is too. Software development is becoming more accessible to everyone and the licensing for software remains complicated. We need to know if software licenses are being maintained properly throughout their reuse and evolution. This motivated the development of the Sourcerer’s Apprentice, a webservice that helps track clone relicensing, because software typically employ software licenses to describe how their software may be used and adapted. But most developers do not have the legal expertise to sort out license conflicts. In this paper we put the Apprentice to work on empirical studies that demonstrate there is much sharing between StackOverflow code and Python modules and Python documentation that violates the licensing of the original Python modules and documentation: software snippets shared through StackOverflow are often being relicensed improperly to CC-BY-SA 3.0 without maintaining the appropriate attribution. We show that many snippets on StackOverflow are inappropriately relicensed by StackOverflow users, jeopardizing the status of the software built by companies and developers who reuse StackOverflow snippets.  

I. INTRODUCTION

When software is written it is covered by copyright granting the author exclusive rights to the distribution of their software. Software typically must be licensed to other parties for it to be used, distributed, and sold. Software can be licensed by developers to impose or alleviate restrictions on how it may be reused. Open-source software licenses typically seek to enable the free reuse and distribution of software provided that attribution to the authors is given. Code reuse results in numerous “code clones”: exact or near-exact code snippets or files occurring within multiple software projects that are still licensed. Large programming sites like StackOverflow shares source code in answers and questions [1] as well as sites like GitHub that share code in publicly hosted software repositories [2]. Code on StackOverflow is typically claimed to be opensource by StackOverflow’s terms of service, but the code might have come from elsewhere and someone else. We raise the question, “Can we trust the license of code shared on StackOverflow to be accurate?”

1We would like to thank Vaibhav Saini for help to get SCC running.
2Get our code and data at the following URL: https://github.com/StephenRomansky/SourcererCC.git (TODO curate and publish everything for camera ready)

A common open source license violation is the lack of attribution, most Free/Libre Open Source Software (F/LOSS) licenses require that the authors who wrote the code are attributed in documentation, in the source code, or in startup messages. Not attributing the opensource copyright holder violates the opensource license. Thus using the wrong license or misattributing code can be costly because:

• a developer or company can lose the rights to use, reuse, and distribute source code and software they rely on;
• a developer or company a developer may be required to distribute their proprietary source code unexpectedly, if a copy-left license was included;
• or, the developer or company may be sued for copyright infringement [3]–[6].

We investigate the code clones created between StackOverflow and Python modules as well as StackOverflow and Python documentation to determine if developers are copying common reference material without proper relicensing or attribution onto StackOverflow. We find the relationship between the source of code clones like Open Source Software and StackOverflow is bi-directional, rather than uni-directional [7], and fraught with license inconsistencies. For instance, copying code to ask a question or share an answer on StackOverflow relicenses the shared code to the CC-BY-SA 3.0 license [8], [9]. For instance, GPLv3 code cannot be posted on StackOverflow due to incompatible relicensing. It is important to understand how developers interact with community-driven tools like StackOverflow where 66% of software developers who use the StackOverflow service are unaware of the license it imposes on their posted code [10]. In this paper we highlight a severe problem that code posted to StackOverflow often has incompatible licenses, but also that license terms are breached by the lack of attribution—this imperils the reuse of StackOverflow code as end-user developers could be liable for copyright infringement.

Our work also discusses our extension of SourcererCC to create the Sourcerer’s Apprentice: that detects code clones with possible relicensing issues. The Sourcerer’s Apprentice can be used by any developer interested in checking if their code base has copied artifacts with candidate license-inconsistencies from open source repositories.

Sourcerer’s Apprentice and the study of code snippet migration

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Get our code and data at the following URL: https://github.com/StephenRomansky/SourcererCC.git (TODO curate and publish everything for camera ready)
this web service by: detecting if students have submitted homework solutions plagiarized from StackOverflow; to detect if students have copied home work from each other; and to perform clone detection on non-source based repositories of code blocks like StackOverflow and software documentation (Python 2.7) to find the relicensing conflicts from copying reference material. With the help of the Sourcerer’s Apprentice our contributions are:

1. We show relicensing conflicts between Python Modules and Python Documentation and StackOverflow;
2. We show that the flow of code between StackOverflow and Open Source Software is bi-directional;
3. Implementation of a web service for clone detection and detailed reproducibility performance improvements to existing tools;

II. BACKGROUND

We cover preliminary material in this section that introduces code clones, software license detection, and subsets of relevant web protocols used to build our web service. We also provide short descriptions of state-of-the-art code detection tools and license detection tools such as SourcererCC and Ninka that are used in our work.

Software licenses: are applied by developers to constrain and enable future reuse. By default the software creator is the copyright owner. As exclusive copyright holders, developers use licenses to distribute software to clients under various terms. Developer license their work with licenses from two popular categories of licenses: F/LOSS and proprietary. Open source focuses on having shareable and editable code, while proprietary licensing restricts who may access the code, run the binaries, and whether users may alter it. Researchers have also investigated when, and how, license changes occur in software projects through revision history and issue trackers.

License conflicts: License conflicts occur when two or more licenses impose restrictions on each other that cannot be met. This can happen between any two licenses, regardless of their categories, based on their requirements. For instance, the GPLv2+ license is compatible with the GPLv3 but GPLv3 is not compatible with GPLv2. Licenses are hard to interpret and often require legal expertise. Therefore, work has been invested in software license analysis, understanding license evolution, and conflict detection. We follow suit with our investigation of code reuse and improve existing automated license detection.

Code clones: Code clones occur when two code segments, of 1 or more code tokens, appear to be similar to one another under a given comparison function. Similarity could mean syntactically, that the two fragments appear to have a similar number of features, corresponding variables, or that there are matching sequences of code tokens in each fragment. It could also mean semantically, where two fragments of code look dissimilar to one another, but each one performs similar operations when it is run. It is up to the investigator to determine what the similarity function is for relating two code fragments.

Conventional, and accepted, literature defines 4 types of code clones: Type-1 are identical code segments ignoring white space and comments; Type-2 are type-1 clones with the additional exceptions that the segments can have modified identifiers, literals, and types from one another; similarly, Type-3 clones are type-2 clones with the additional exceptions that the segments can have added or removed lines; while, Type-4 clones are code segments that perform the same actions, but are syntactically different. In prior work, code segments are often referred to as code blocks and are extracted from whole functions or whole files; but, we are interested in the license of any segment of code, even if these are incomplete software components.

Code similarity, or code clones, play an active role in the development life cycle. Kasper et al. shows some clones cause more technical debt than they resolve, while others simplify prototyping in feature development.

It is also possible to use code clones to study projects that we do not own. We can view how much code is duplicate, or what is frequently reproduced in software projects, and we can try to help developers by making generalizations based on our observations to create new conventions or functions based on our analysis.

Software communities and code sharing: It is possible to study software communities to understand code clone growth and evolution, to see where license conflicts can be created, and to view clones and licenses together. Developers can write alone, or with others. The internet makes it easier for developers to work together and to share code with one another. However, code sharing requires licensing. GitHub provides developers with a place to share their projects under the constraint of the terms of service, but developers are free to license their software projects however desired. StackOverflow provides developers with a place to share their development questions under the constraint that any posted code will be licensed under the CC-BY-SA 3.0 license. GitHub and StackOverflow can help developers further their project goals with social interactions.

Another service that developers have used in the past, and still use, to share questions and projects were mailing lists. Mailing lists are not required to have a user agreement or terms of use; however, some show disclaimers about usage and posted content. Developers also use websites to share code in the past like freshmeat.net.

License detection – Ninka: Ninka is a license detection tool that uses regular expressions to detect 112 different licenses. It works by attempting to extract comments that occur near the start of a file. This is the position a license is typically placed in a source file. Then, regular expressions are applied to this comment block to try and match given licenses. If success occurs and a license is matched then it gets reported by the program. However, failure can happen in two ways: a license is found but unknown, or no license is found. In these respective cases the program will report UNKNOWN or NONE for the license of the given file.

Representational state transfer (REST): REST is a loose
communication protocol, used by web services [27], that tries to represent state and actions using HTTP concepts such as HTTP verbs (GET, PUT, POST) and treats entities as HTTP Responses and URIs as names. Our system is built up on REST enabling composition of automation tools and UIs.

Clone detection: Many authors have created code clone detection tools [23]–[34], but we use a tool called SourcererCC (SCC) to perform code clone detection in our work. SCC was advertised as an “internet scale” code clone detector having superior performance to its competitors. Researchers have also worked on studying and generalizing code clones once detected [35]–[39]. Prior work has shown that SourcererCC performs well on big code [11]; therefore, in this study we omit comparison against distributed code clone finders like D-CCFinder [40]. D-CCFinder wrapped CCFinder in a distributed manner across a cluster.

SourcererCC works in 3 stages: (1) parse code into a format interpretable by the tool; (2) create an index from the parsed source code to speed up clone detection; and (3) perform clone detection [11]. In stage (1) the parser is not specifically part of SCC it abides by the format used in it though. Stage (1) uses a parser to tokenize files into blocks interpret-table by the clone detection algorithm. Researchers can use any convention to define a code block that is needed. Prior work defines code blocks from file level [11] and function level [7]. Parsed blocks record the unique tokens from the code and the number of tokens in each segment. Stage (2) creates an index that matches code tokens to blocks that contain the tokens. This allows the clone detection process to quickly find blocks that are related by looking up blocks that contain similar tokens. Stage (3) compares blocks from a query set to a corpus, a data set, to determine if there are clones between the two sets of code blocks. This is done by checking if each block has an overlap of 80% of it’s tokens with any block from the other set. We picked 80% for this work, the overlap can be configured by the user. The result of this process is a list of clones that researchers may interpret.

Using SourcererCC at function-level granularity, Yang et al. provide a comprehensive study of the Python clones detected between GitHub and StackOverflow [7], which shows high reusability of Python code between StackOverflow and GitHub. Code is being reused from StackOverflow regardless of the license. Given this prior qualitative study on StackOverflow and GitHub, we focus on the licenses associated with migrating code clones as well as extend Yang et al.’s work by using a pip based data set to replace the GitHub data set.

III. RELATED WORK

This section discusses recent applications/tools in the field of license detection, and license compliance.

Prior work has been accomplished on the task of detecting license inconsistencies between software projects by Wu et al. [41], [42]. Wu’s method involves looking at the license comment included in each source file and their mutation over time. Wu et al. use file-level clone detection to track the evolution of a file with respect to code changes and Ninka to track license evolution [42]. Wu’s approach is extended and applied to analyze license inconsistencies in large-scale F/LOSS projects [43]. We extend the application of Ninka for license inconsistency detection by checking the package-level files that developers use to license every file in the project in addition to checking the license of the individual files.

German et al. have also studied code clones and their licenses to uncover how copied-licensed code evolves in parallel with respect to it’s point of origin [24]. This is highly relevant to our work; however, we are interested, specifically, in the clone creation period at this point in our tools development. As well, Davies et al. propose and demonstrate a method for identifying the origin of software components, like libraries, to make it easier for developers to track and verify where their software dependencies come from [44]. We would like to answer whether or not a clone was created that violated the license of the originating code snippet in the clone pair.

IV. METHODOLOGY

In this section, we describe the overall architecture of our service; the research and empirical questions we would like to investigate with the tool; and we show how the tool produces easy to read reports of software clones and licenses. We start by introducing several of the code clone identification tasks (in Section IV-A) that we would like our service to perform. We provide a detailed account (in Section IV-B) regarding our process for extracting software licenses and code clones from input source code. Section IV-C describes our approach to aggregating the code-clone and licensing information into an easy-to-read HTML report.

A. Problems with copy and pasted code

In software development it is not uncommon to have duplicated code. There are many reasons to make duplicate code that we will not be focusing on. Instead, we are interested in identifying when copy-pastes happen and the licensing complications these simple actions incur. Specifically, we are interested in the following use cases and scenarios: Case 1[Student–SO] copy-paste detection between student assignments and StackOverflow posts; Case 2[Student–Student] copy-paste detection between student assignments; Case 3[Pip–SO] copy-paste detection between student assignments; Case 3[Pip–SO] copy-paste detection with license compliance between code submissions and a static corpus of source code; and Case 4[Docs–SO] copy-paste detection with license compliance between documentation and StackOverflow.

It is important that students attribute their sources when completing their work, as in Case 1[Student–SO], to avoid plagiarism and license violations. Such a habit may carry-forward into professional software development where license violations can be costly. The popularity of software development courses has also made it more cumbersome to detect plagiarized assignments, therefore Case 2[Student–Student] would ease the burden placed upon teaching staff when grading homework and aide in upholding academic integrity. In Case 3[Pip–SO] we wish to accomplish license violation detection in general code corpora. This would help anyone
with a software project check if any of their code has been copy-pasted from public software repositories of code. With Case 4[Docs–SO] we want to check if unclear code migration occurs between StackOverflow and documentation because these two information sources use different, incompatible, software licenses and would portray license compliance violations if unclear migration exists.

B. Web service

We made a tool that takes source code, submitted by a user, and finds clones in it with respect to a known corpus of source code that is labelled with their respective software licenses. Figure 1 shows this process. Figure 2 shows an example code clone report and how to access the code snippets place of origin. From Figure 1 it is shown that we actually have several web services that interact together. The rest of this subsection describes these web services.

The parser service, of Figure 1, accepts code from a user and parses it into the format required by SourcererCC. Once the parser has processed the source code it sends it to apprentices or the management service. The parsed source code can be compared against a larger corpus to find duplicates between itself and the larger corpus. Or, the parsed code can act as the corpus and have user queries compared against it. If the parsed code is sent to the apprentices, it is used as a corpus, which users can query for clones. If the parsed code is sent to the manager, it can be used as a query set, which users can compare to the corpora held on each of the separate apprentices. Apprentices typically host independent corpora or independent subsets of the main corpus. The parser applies license detection, using Ninka, in addition to the parsing and formatting of source code for SourcererCC. This provides the other web services with licensing details on the code blocks being used for clone detection.

The management service, of Figure 1, maintains a list of query sets that can be sent to the apprentices. These are sets of parsed source code which are sent to all of the clients to distribute the workload of clone detection, compared to having only 1 apprentice performing all of the clone detection work on 1 machine. The apprentices can be running on different devices on different networks. The management service also maintains a list of active apprentices.

The manager also maintains query results, a list of the clone-license results. When an apprentice has completed a query against a corpus it sends detected clones and their licensing information back to the manager. The manager then generates a report which shows the code, where the code is from, and the licenses of each code block (from the query set and the corpus of the apprentices.) The manager then displays these reports to the user by sending them to the users browser. This allows a user to view clones, the source code of the clones, and the licenses of the detected clones. Part of an example report is shown in Figure 2. Queries can range in size from containing 0 to several million code snippets.

The apprentices, of Figure 1, run SourcererCC. Each apprentice loads a local corpus, distributed from the parser, and compares queries to the local corpus when the manager requests. The apprentices allow us to distribute our workload, horizontally, across networks.

C. Clone-License Identification and Reporting Detailed

This subsection details the assembly of the clone detection apprentices and the parser. We heavily build upon others work like SourcererCC [11] and Ninka [12].

To assemble our parser we used a Python library called ASTTokens [45] which allowed us to tokenize Python code into the required format and it allowed us to extract the source code for our report generation. The code blocks are considered to be a specific context of code. In our application we parse code blocks that are file-level, module-level, and function-level: code contained only in a given function. The SourcererCC tool is then able to compare code blocks to detect syntactically similar clones [11].

While extracting the code blocks, the parser is also able to apply a modified version of Ninka [12] called NotQuiteNinka. Ninka is able to extract the license for each function, module, or file that we are reformatting. We wrap Ninka in NotQuiteNinka such that it also checks the pip module package files for license information, because not all of the Python source files contain their respective licenses. An example of the primary package structure that NotQuiteNinka takes
advantage of are files called LICENSE which specify the license of the whole module, unless otherwise specified, and are plain text documents. The modification of Ninka enables us to approximate the licenses of the software clones we study. Our evaluation provides details on the improvements added by checking package configuration files.

In addition, when extracting the code blocks, the parser is able to extract the time that the code block was last modified. Time retrieval can be accomplished by checking the context the code block occurs in for information such as: posted time; last time the file was modified; and checking for revision control time data. Time allows developers to approximate which code came first and is the original copy.

D. Collected Datasets: documentation, SO posts, pip modules

With tools to extract the code clones and their licenses, we need a data set to study software clone usage with licenses. To accomplish this we use the Python package management tool, pip, to collect a data set of open source Python code. We also collect a data set of developer code snippets from the StackOverflow web service. We are able to combine the SourcererCC tool with Ninka to check if there is code shared between StackOverflow and pip packages. This is typically a license conflict as the StackOverflow code is licensed under CC-BY-SA 3.0, which is incompatible with many FLOSS copy-left licenses. Our web service is able to provide a view of the code from the corresponding StackOverflow post as well as a direct URL link to the StackOverflow post. Developers can submit many different types of code snippets to the service such as the examples detailed in Section IV-A.

From archive.org, we collect a dump of all StackExchange boards which contains StackOverflow as of December 1st, 2017. The parser searches for module and method level code blocks inside the posts.

From GitHub, we collect a copy of the Python 2.7 repository and its documentation. The documentation is parsed for each module and method level code block.

From the PyPi, we collect a list of available pip packages. We select 5000 packages to download randomly and use the pip download command to collect them. 5000 was chosen arbitrarily, we partitioned them into data sets of size 10, 100, 1000, and 5000 modules that were named 10m, 100m, 1000m, and 5000m respectively.

The front-end web service provided by the Apprentices accepts compressed directories and searches these for Python code from our parsers.

V. Evaluation

To evaluate our tool we provide a summary of our benchmark results and evaluate the 4 use cases outlined in Section IV-A that are: Case 1[Student–SO], evaluating a student-esque project against StackOverflow to check for copied content (in Section V-B); Case 2(Student–Student), comparing student-esque projects against student-esque projects to check for plagiarism, like in a class room setting, in Section V-C; Case 3[Pip–SO], to query general software projects against other software projects to check for software migration in terms of copy-pastes and code clones (in Section V-D); and, Case 4[Docs–SO], to determine if clones exist between documentation and StackOverflow with license compliance issues.

A. Software modification benchmark summary

With the original application it took 44.22 hours to execute a query of 5000 against 5000 Python modules. After our upgrades it took 56.4 seconds. These time measurements are averaged over 5 runs. To improve performance we did 3 things: 1) we wrote a benchmark test suite to evaluate whether new modifications helped improve performance; 2) we cached data that can be reused between separate queries on the same data set; and 3) we found bottlenecks in the pipeline used to process clone candidate evaluation. We used our benchmarks of multiple simulated clone detection queries against varying number of modules to guess and check what part of the software was causing a slow down. We found that indexing parts of the code blocks took a while for each query and therefore cached this task by daemonizing the clone detection tool. We also found that detecting if a code block from the query set has any clones takes a while to go through the queue of clone candidate evaluation stages; therefore, we made each code block into its own asynchronous job that is managed by the java runtime environment using Java 8 Stream objects. Java 8 Stream objects are JVM-built-in data queues with multi-threading support for parallel queue entry processing. This means users do not have to worry about performance tuning the manually constructed task queues.

B. Case 1[Student–SO]: copy-paste detection between student assignments and StackOverflow posts

Project Euler problems have been attempted by many developers and some of their solutions appear on GitHub. We use 30 projects from GitHub to emulate a set of well-defined student projects. The projects were selected by querying “project euler solution” on GitHub and selecting the top 30 Python repositories ranked by stars. These repositories were cloned and parsed with our Python parser for clone detection. One of the top 30 projects was not a programming exercise solution set, so it was ignored. We used the Apprentice to check if any of the 29 student projects contains code copy-pasted from StackOverflow.

The result: we found that it was possible to check if homework had been copied from StackOverflow; however, we did not find any of our exercises copied from StackOverflow.

From the 29 projects we extracted 7,107 Python code blocks. We queried the StackOverflow code blocks with the Python project code blocks using the Apprentices. We did not find any code clones between the project code blocks and StackOverflow. Therefore, it can be assumed that the students developed their own solutions to the Project Euler problems without copying code from StackOverflow. The lack of clones

https://projecteuler.net/
may be caused by the brevity of the programming exercise solutions and the clone detector requiring a minimum number of tokens in each code block. However, the number of clones and the amount of noise/non-meaningful clones grows when the minimum number of tokens per code block is reduced. Another possible scenario that could have occurred is that solutions were discussed line-by-line instead of as a single-whole code entry in the StackOverflow posts. This use case demonstrates that it is possible for web service users to check if their code conflicts with existing web content like that of StackOverflow.

C. Case 2[Student–Student]: copy-paste detection between student assignments

Using the Apprentice and manual inspection of code clones, we check if code was copied between the 29 student projects used in Case 1[Student–SO]—Project Euler solutions.

The result: the tool is capable of detecting duplicate homework and candidate duplicate homework.

To perform this case study, we found 7,107 code blocks total from the 29 exercise sets of Case 1[Student–SO]. We performed an intra-data set query on the 29 projects with themselves using the Apprentices and found 45,450 clones. We did not find forks of projects in the data set. One repository does not share clones with any other of the 28 projects, but this repository has 44,942 clones within itself, therefore we ignore it in our analysis for copy-pasted code between repositories. The remaining 28 projects had 508 clones.

We manually inspected the 508 clones; there are many intra-project clones showing the students copied their own code. There were still inter-project (between project) clones found, in one example we saw 52 of the copy-pasted clones occurred between the 2 program exercise sets; one of the students appears to have copied many solutions from another student with minor modification. From the inter-project clones, we also found 32 similar solutions in the clone report that were semantically similar yet syntactically distinct—which makes sense given that they are solutions to the same exercises. We found 16 copy-pastes that showed duplicate code between programming exercises and we found 1 detected clone that had unrelated code blocks in it, between two distinct repositories.

We did not investigate license conflicts or attribution in this case study. One weakness of the Apprentice tool is that it
does not check for attribution. This study demonstrates that the Apprentice tool can detect plagiarized homework assignments.

D. Case 3[Pip–SO]: copy-paste detection with license compliance between code submissions and a static corpus of source code

We want to know if code gets copy-pasted between Python modules and StackOverflow (clone migration), because these two code contexts can use differing-incompatible licenses. To study this question, we extract Python code from pip modules and from each Python post on StackOverflow. Each post containing code is treated as a separate file and therefore generates at least 1 code block. We sampled code clone pairs based on sizes to answer our question. We manually investigated each clone pair to determine if they looked like they were copy-pasted. Manually, classification was done by reading the code pairs and labelling them as type-1, type-2, or type-3 clones and whether the code pairs were semantically similar if any modification had occurred. We categorized clones into three groups to begin: small (1-10 lines); medium (11-20 lines); and large (greater than 20 lines). Other work by Wu et al. also supported the idea that it is hard to determine who created a small-clone and who the rightful owner is in their file-level-clone based work [41].

The result: we find that 24% (15/63) of medium sized (11-20 lines long) clones are copy-pasted; 6% (4/63) of large (more than 20 lines) clones are copy-pasted; and that these copy pastes have conflicting software licenses with StackOverflow’s license.

We focus on finding the rate of copy-paste occurrence in the medium and large size clone groups. We calculated a sample size of 63 for the power calculation for two proportions (same sample sizes). This would enable us to detect medium effect sizes (0.5), significance level of 0.05 with a power of 80% to have sufficient representative power from the medium-sized and large-sized clone groups. We investigate prior work for sampling techniques, to study the properties and features of code clones; however, we did not find any prior work that used sampling [7], [41], [42].

From a clone report of 1000m querying our StackOverflow data, using the Apprentices, we found via manually reading the clones that 24% (15/63) of the clones in the medium group are copy-pastes, and from the large group we found that 6% (4/63) of the clones are copy-pastes. According to the 2-sample test for equality of proportions with continuity correction these difference in proportions are statistically significant (p-value of 0.001, less than or equal to an alpha of $\alpha = 0.05$).

The number of copy-pastes in the medium group seemed reasonable. Upon further manual review of the clones we found that the number of lines in a clone are not very meaningful for characterizing copy-pasted code blocks. Because, functions can often have large blocks of documentation and very little code, e.g. a 20 line comment with 2 lines of code in 1 function.

For the reader we describe here 3 of the clones from each of the groups to check for license conflicts. Here are 3 examples from the medium group. Clone 1 between Aesthetε-0.4.2/aesthetε/glypher/gutils.py,23,37 (the file, start line number, end line number) and StackOverflow (SO) answer 42161514. The Python file does not contain a license header; but, the package is licensed as GPLv3. Therefore, this conflicts with the CC-BY-SA 3.0 license of StackOverflow. The copied code is referred to as a universal XML indent function. However, no library or module is cited in the StackOverflow post. Clone 2 between Argot-0.6/argot UTILS.py,34,46 and StackOverflow answer 3271650. The Python module is licensed under a custom license that is not compatible with CC-BY-SA. Therefore, the two code blocks conflict. The copied code provides an HTML decoding function. It cites a source URL that is no longer available in the StackOverflow post. Clone 3 between SQLAlchemy-0.9.7/test/ext/declarative/test_basic.py,179,193 and StackOverflow answer 8297804. The Python module has an MIT license and therefore conflicts with the StackOverflow code. The code samples both make mock database objects in Python and are slightly modified from each other. It is not clear if the two code blocks are intentional copy-pastes or if the two blocks are using conventional example variable names to demonstrate a point.

Here are 3 examples from the large group. Clone 4 between adi.slickstyle-0.1/PasteScript-1.7.5--py2.6.egg/paste/script/util/subprocess24.py,762,813 and StackOverflow answer 12965273. The code block is licensed under an MIT license that conflicts with the StackOverflow code. The two code blocks are a copied function namely subprocess.communicate. Clone 5 between SQLAlchemy-1.0.13/examples/generic_associations/generic_fk.py,42,73 and StackOverflow answer 17757700. The Python block is licensed under an MIT license that is incompatible with the StackOverflow code. The StackOverflow post has potentially copied an example class, that represents a street address, out of the pip module. Clone 6 between Agora-Curator-0.1.2/agora/curator/__init__.py,1,32 and StackOverflow answer 40364576. The Python block is licensed under Apache-2 which is incompatible with the StackOverflow code. The two code blocks have the same code, but the pip module contains many lines of commented code. This is effectively a 6 line code clone instead of 32 lines.

Thus software relicensing may have occurred in these copy-pastes. We construct Table [1] to show the distributions of licenses from our detected clones, of querying the 1000m data set against our StackOverflow data set with the Apprentices. NotQuiteNinka shows that none of our code blocks from the pip dataset were licensed appear to share the CC-BY-SA StackOverflow license. This could mean that there are many copy-pastes without proper relicensing. However, the StackOverflow code may have cited its source in the surrounding text of the posts, which we did not analyze in our evaluation.
E. Case 4[Docs–SO]: copy-paste detection with license compliance between documentation and StackOverflow

We investigate if license conflicts also occur between code blocks in non-source code based artifacts, such as StackOverflow posts and Python 2.7 documentation. We compare Python 2.7 documentation with StackOverflow. We follow a similar methodology to Case 3[Pip–SO].

We sample 63 of the detected clone pairs randomly to search for copy-pasted content as in the other case studies. Manually, we go through each of the clone pairs and check if the code blocks are lexically similar and if the clone is type-1, type-2, or type-3. If it is type-1 then it is a direct copy paste; but, if it is type-2 or type-3 it is considered copy paste with minor modification.

Afterwards we checked for textual attribution of code clone snippets to the Python Software Foundation—as per the license of Python 2.7 documentation.

The result: we find that 74.6% (47/63 sampled clones) of code clones between the two sources of code blocks, contain copy-pasted code with minor modification. These code clones have conflicting licenses because the Python documentation is licensed under the Python software foundation license that is incompatible with the StackOverflow code blocks’ CC-BY-SA 3.0 license. This shows that StackOverflow posters are not properly attributing and licensing the source code in their posts—corroborating Baltes et al. [10] evidence of lack of license awareness on StackOverflow.

We extracted 5,050,641 Python code blocks from the StackOverflow data set we collected with our parser. From the Python 2.7’s documentation files we extracted 409,260 code blocks with our parser. We found 68,491 code clones between Python 2.7 documentation and StackOverflow, with an 80% similarity and at least 23 tokens in each code block of the pairs using the Apprentices. This is interesting because it demonstrates that many code clones come from documentation, not just project source code.

Of the 63 samples that we investigated, we found 23 of these code pairs to be copy pastes and 24 additional code pairs to be type 2 or 3 code clone copy pastes. Our manual inspection of sampled code clones shows that approximately 74.6% of these code clones are copy pasted code with minor modification and it is unclear how these code snippets migrated between the documentation and StackOverflow.

We also attempted to check the (697,401) Python related StackOverflow posts for attribution to the Python Software Foundation (PSF) in the case that developers attempted to attribute reference material they had accessed. We found 2 user talked about the PSF in their post not related to a code attribution; 1 user copies PSF licensed code into their StackOverflow post without attribution in question 40972386; 1 user asked how and when code should use the PSF license in question 16335342 but this was closed as off-topic; and 2 users post PSF licensed code to StackOverflow with incomplete attributions to the sources in questions 18816421 and 25638502. We can see that 0% (6/697401) of python posts mentioned the PSF but none of the observed posts attributed it. The users show that attributing licensed work is not well understood on StackOverflow—thus even if licenses were compatible the lack of attribution is a violation of the Python 2.7’s documentation license.

Thus we find that the copying of code between Python documentation and StackOverflow is a grave concern because StackOverflow’s CC-BY-SA 3.0 license conflicts with the Python Software Foundation license applied to the documentation. That means the unclear code migration between the documentation and StackOverflow likely contains license violations from StackOverflow users posting documentation to the web service. This is exacerbated by the related work which shows that 66% of StackOverflow users are unaware of the software license that is applied to the code they post [10]. This motivates further investigation to check if code migrating to StackOverflow is attributed properly and is relicensed properly.

F. Evaluation Summary

We showed that there is copy-pasted code between open source projects and StackOverflow, which is surprising given the relicensing that occurs when code is posted on StackOverflow. We also showed that our web service is capable of detecting copied homework between students and from online resources. Furthermore, we showed improvements via performance measurements on the underlying clone detection method used by our web service.

VI. Threats to Validity

Construct Validity: Construct validity was threatened by assumptions regarding the licenses. We assumed that licenses can be applied recursively with NotQuiteNinka, which violates Ninka’s very conservative rate of detection.

Internal Validity: internal validity was threatened by provenance. All of the clones evaluated discussed and evaluated were of ambiguous origin and we did not do the provenance
analysis to determine which is the true. Parameters such as minimum clone size could threaten reported measurements. Internal validity was also biased by our selection of exercises, as we did not sample, we relied on GitHub ranks. NotQuiteNinka was not evaluated in this paper for license accuracy.

**External Validity:** threats to generalizability of our approach is that we only used python language source code, pip modules, and Python documentation rather than other programs. Our programming exercises were not necessarily representative of actual student assignments. We rely on SourcererCC’s definition of a clone which might differ from other clone detectors.

**VII. Conclusion**

In this paper we described the results found by the Sourcerer’s Apprentice: that code is copy and pasted onto StackOverflow without proper relicensing; that we can use the tool to check for copied homework solution; and we demonstrate and discuss performance improvements made to underlying code clone detection techniques.

The Sourcerer’s apprentice combines existing license inference tools such as Ninka with an existing state of the art code clone detector SourcererCC in a webservice to allow for repeated querying of large corpus of source code. We described the engineering efforts in terms of profiling, asynchronous task parallelization, and distributed data sharding that were employed to make a horizontally scalable web-service with reasonable run-time perform. By distributing apprentices across multiple machines we can improve runtime performance of code clone tasks via parallelization. By amortizing the heavy start-up time of loading and indexing we improved query performance. By profiling and debugging the indexer we improved index performance. By wrapping Ninka with a recursive license inferencer we inferred licenses for more files.

We built the Sourcerer’s Apprentice because we wanted to gain a better understanding of code clone migration and the licensing these resulting code blocks have. How does the license change as code is copied through different mediums and projects, one might ask. Thus we designed the Sourcerer’s Apprentice to address 4 specific use cases: searching for clones between StackOverflow posts and programming exercises; searching for clones between documentation and StackOverflow posts; searching for clones within a set of a programming exercises; and searching for clones between a software project and a set of other clones. Therfore, StackOverflow and their users are clearly violating Open Source attribution requirements thus invalidating the use and distribution of the source code they have posted.

**A. Recommendations to stakeholders**

For developers and companies, we recommend that one checks thoroughly the true provenance of code found on StackOverflow. Not only do StackOverflow posters need attribution via CC-BY-SA 3.0, but the original authors who authored the shared FLOSS code also require attribution.

For StackOverflow, we recommend that StackOverflow provide tool support to allow for better attribution meta-data, addressing the reality that not all snippets on StackOverflow can be relicensed, and that StackOverflow is currently distributing thousands of snippets in violation of both license and attribution requirements. It would be in StackOverflow’s interest to run a service like the Apprentice to automatically check for mis-attribution or license violations from documentation, and other sources, before they are committed within questions and answers.

For the Python Foundation and other FLOSS authors, we recommend that they pay attention to this problem and potentially make edits that attribute their foundation on existing StackOverflow question.

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