Automating Software Citation using GitCite

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ABSTRACT
The ability to cite software and give credit to its authors is increasingly important. This paper presents a model for software citation with version control, and an implementation that integrates with Git and GitHub. The implementation includes a browser extension and a local executable tool, which enable citations to be added/modified/deleted to software project repositories and managed through functions such as fork/merge/copy.

KEYWORDS
Citation, software project repositories, version control

1 INTRODUCTION
As software and data products become increasingly important components of Big Data-driven science, appropriate citation is essential to motivate members of the community to continue to contribute these new research products. Influential statements on the importance of data and software citation have been published within the digital libraries community (e.g. the FORCE 11 reports [11, 13]), and recommendations are being proposed for the content of such citations (e.g. standards such as the UK Software Sustainability Institute recommendations [9, 10, 13] for software citation). However, despite widespread agreement about the importance of these standards, their complexity and the effort entailed to use them may discourage users from following them when generating citations by hand.

In order for recommendations concerning data and software to be effective, we believe that systems must be developed to automate citations and deliver them along with the data or software products being extracted. In prior work, we have developed techniques for delivering citations to data extracted by queries from structured datasets [5, 6, 16]; in this work we turn to the problem of software.

A released version of a software project may be treated as open-access data and uploaded to public hosting platform like Zenodo [3] which provides a DOI, thus enabling more traditional citations and ensuring persistence. However, a software project is not a single file, but a complex structure. It may include many different versions, each of which is a large directory (tree) structure. For large team projects, different subtrees of the project may be contributed by different people, and for open-source projects there may be many, potentially unknown, contributors. There is therefore a question of the granularity at which citations should appear to give credit to the appropriate contributors, ranging from a citation for the project as a whole to a citation to each file in each version of the project. There is also a question of how to construct the citation for the extracted code base, given the granularity at which citations appear.

This demo presents a model for software citation (Section 2) based on a notion of citation functions, and shows an implementation of the model (Section 3) built on top of Git [14] and GitHub [1]. The implementation consists of two components: 1) a browser extension which can be used online to enable users to get citations, and owners to create/modify/delete citations; and 2) a local executable tool which, in addition to create/modify/delete functions, carries citations through more complex GitHub functions like fork/merge/copy. The demonstration will show this functionality on a code base we have developed, and is described in Section 4.

2 CITATION MODEL
We start by defining the notion of a project repository, before moving to citation functions and how they are modified as a result of citation and Git operations: add/delete/modify citations, and copy/fork/merge subtrees. Note that this model is strongly influenced by ideas in [7, 8].

Project repository. A project repository is a directed acyclic graph of project versions. Each version is a directory, i.e. a rooted tree whose interior nodes are directories and leaves are files.

Citation function. Each version V in project P has an associated citation function (V, P) which, given a path in the tree, returns a citation for the node at the end of the path. The function may be partial, i.e. some of the directories/files may not have explicit citations attached. The root of each version must be in the active domain, and its citation includes basic
snippets of information such as the owner and name of the repository, the http address or DOI of the version, and the version number and/or date.

In this demo, we define the citation of a node as follows: Given a node \( n \) in version \( V \) of project \( P \) with root \( r \), the citation of \( n \), denoted \( \text{Cite}(V, P)(n) \), is defined as follows:

- \( \text{C}(V, P)(n) \), if \( n \) has a citation defined (i.e. \( n \) is in the active domain of the citation function)
- \( \text{C}(V, P)(a) \), where \( a \) is the closest ancestor of \( n \) for which a citation is defined

Since the root must be in the active domain, \( \text{C}(V, P)(n) \) is defined for every node. Note that there could be other definitions of \( \text{Cite}(V, P)(n) \), e.g. ones that include every citation on the path from \( n \) to \( r \).

**Adding/deleting/modifying citations.** As a project version is modified by inserting/deleting/modifying or renaming files, users may also modify its citation function by adding \( \text{AddCite} \), deleting \( \text{DelCite} \), or modifying \( \text{ModifyCite} \) citations. Each of these operators takes as input the path of the file/directory whose citation is being modified; \( \text{AddCite} \) and \( \text{ModifyCite} \) additionally take the value for the new or modified citation. The interpretation of these operators is straightforward. These operations may also be applied by the system as a side-effect of Git operations on the repository.

Modifications to files/directories and to their associated citations are independent, i.e. the citation for a file could change but the file remain unchanged between versions, or the file could change but the citation remain unchanged between versions. However, if a file or directory in the active domain of the citation function is moved or renamed then the citation function must be modified to reflect the file or directory’s path in the new version.

**Carrying citations through Git operators.** Branches may occur in a repository by separate edits being made to the same version. At some point, two branches \( V_1 \) and \( V_2 \) may be merged. A subdirectory \( T \) may also be copied from version \( V_1 \) of repository \( P_1 \) to version \( V_2 \) of repository \( P_2 \), or a new project \( P_3 \) may be forked from the current version of a project \( P_1 \). Through each of these operations, the citation function associated with the new version must be made consistent with new directory structure and the files retained in the new version. It should also be as complete as possible (modulo conflicts). We will discuss how we implement \( \text{MergeCite} \), \( \text{CopyCite} \) and \( \text{ForkCite} \) in more detail in the next section.

**Example:** The right half of Figure 1 illustrates these ideas. Each red-dotted box shows a version of a repository. In particular, \( V_3 \) is a version of project \( P_2 \) while the others are versions of project \( P_1 \). The tree structure in each box shows the directory structure for the repository of that commit. A solid blue circle means the node (file or directory) has an attached citation and the blue rimmed circle means that there is no attached citation. All versions have a default citation attached to the root. From \( V_1 \) to \( V_2 \), an \( \text{AddCite} \) operation attaches a citation to the leftmost leaf node, \( f_1 \). Therefore before adding the citation \( \text{Cite}(V_1, P_1)(f_1) = C_1 \), whereas afterwards \( \text{Cite}(V_2, P_1)(f_1) = C_2 \).

### 3 ARCHITECTURE

We now describe the architecture of our citation system, GitCite (see left half of Figure 1). The system consists of two components: a browser extension, and a local executable tool. Together they provide a citation service for GitHub software.
repositories. Since the local executable tool is based on Git, it is also compatible with any other online project management website which uses Git. We discuss how citation functions are stored before describing the components.

**Storing Citation Functions.** To integrate the functionality of our citation system with Git, we add a special file, “citation.cite”, to the root of each version of a project. The file is a set of key-value entries, where the key is the relative path to the file being cited, and the value is the citation attached to the file. The citation file cannot be directly modified by users, but is updated as a side-effect of the various citation and Git operations. When a new commit version of the project is created, the updated citation file is also created which reflects the updates made since the previous version. These updates include adding/deleting/modifying entries as a result of AddCite, DelCite, or ModifyCite operations; changing the key of an entry to reflect a renamed file or directory; or adding new entries in response to copying/merging between branches.

**Browser Extension** The GitCite browser extension is deployed on Chrome and written in JavaScript, and can generate citations for remote repositories on GitHub. The extension communicates with the GitHub servers using its REST API, and directly modifies the citation file on the remote repository to reflect changes to the citation function. The popup page shown in Figure 2 illustrates its functionality: Users provide their credentials on GitHub to obtain access to the repository, and may then click on a node and use the browser extension. If the user is not a project member, the browser extension immediately generates the citation (shown in the text window), which can then be copy-pasted to their local bibliography manager. Since they are not allowed to add/delete/modify files, which includes the citation file, they will not be allowed to use the Add/Delete button functionalities. However, if the user is a project member, the text box will display the citation explicitly attached to the node, if it exists, which the user may then modify. If such a citation does not exist, the text box will remain empty. The user may then either enter a citation, or use the “Generate Citation” button to see the citation of its closest ancestor, which can then be modified for the current node.

**Local executable tool** When a project member downloads a copy of the project repository with Git, the GitCite local executable tool can be used to manage the citation file in the download. In addition to implementing AddCite, DelCite, and ModifyCite, it also implements the CopyCite, MergeCite and ForkCite functions.

CopyCite copies a directory from a remote repository version to the local repository version, and migrates their associated citations. That is, the citations for the directory and its subtree in the remote “citation.cite” file are added to the local “citation.cite” file, with the key paths modified to reflect the new location to ensure correctness of the citation function.

MergeCite merges two branches in the same repository, and merges the citation files while resolving conflicts. Although Git conflict resolution rules are used for all regular files, we do not use them on “citation.cite” since it could leave the citation function inconsistent. Instead, we simply take the union of the citation files, and delete any entries that correspond to files that were deleted by the Git merge. Conflicts over the values associated with the same key in the new “citation.cite” file are then resolved by showing them to the user and asking the user to resolve the conflict. More complex conflict resolution strategies could also be used.

ForkCite copies a version of a repository, along with its history, and creates a new repository. The citations in “citation.cite” are also copied. Our way of storing citations will naturally enable ForkCite through GitHub’s Fork.

When changes to files and their citations are finally committed, the Git command is used to push the local copy (which contains “citation.cite”) to the remote repository.

Example, cont. Returning to the right half of Figure 1, when the subtree of V3 in the green box is copied from project P2 to P1 by CopyCite, the attached citations are migrated as described earlier. Since f2 does not have an associated citation in V3, before copying Cite(f3,p1)(f2)=C4, which is the citation of its closest ancestor. Note that C4 is also the citation for the root of the subtree being copied. After copying to P1 the citation for f2 remains unchanged: Cite(f3,p1)(f2)=C4 since the citation for the root of the green subtree from V3 has been added to the citation file for V4, indicated by the root now being a solid blue color. Finally, V2 and V4 are merged using MergeCite to produce V5, in which the citations are also merged along with the files. In this example there are no conflicts, so we simply take the union of the citation files.

![Figure 2: GitCite browser extension](image)

### 4 DEMONSTRATION SCENARIO

We will demonstrate both the browser extension and the local executable functionalities of GitCite using Yinjun Wu’s Github project code [15] for the data citation implementation, CiteDB [6] (see Listing 1 lines 1-7 for the entry with...
In this project, the CoreCover query rewriting using views code was imported (CopyCite) from Chen Li’s Github project [12], and modified to dovetail with other parts of the project (see Listing 1 lines 8-15 for the entry with key “/./CoreCover/”). Furthermore, the project code was branched to enable a summer student Yanssie to independently develop a GUI in a separate directory for the CiteDB demo, and later merged (MergeCite) with the main branch of code development (see Listing 1 lines 17-22 for the entry with key “/./citation/GUI”). We will show how citations are modified through these changes, as well as how they can be added or modified within the current repository.

Listing 1: Final citation.cite file for repository [15]

```json
{ "$/" : { "repoName" : "Data_citation_demo" ,
  "owner" : "Yinjun Wu" ,
  "committedDate" : "2018-09-04T02:35:20Z" ,
  "commitID" : "bbd248a" ,
  "url" : "https://github.com/thuwuyinjun/Data_citation_demo" ,
  "authorList" : [ "Yinjun Wu" ]
  }
  , ".../CoreCover/" : {
    "repoName" : "alu01-corecover" ,
    "owner" : "Chen Li" ,
    "committedDate" : "2018-03-24T00:29:45Z" ,
    "commitID" : "5cc951e" ,
    "url" : "https://github.com/chenlica/alu01-corecover" ,
    "authorList" : [ "Chen Li" ]
  }, ...
}, ...
```

5 CONCLUSION AND FUTURE WORK

This demo presents a model and implementation called GitCite for citing software project repositories managed by version-control systems like Git. The system consists of a browser extension that works with GitHub, and local executable tool that works with any project management platform using Git. The citation for any node in a project version is generated based on citations explicitly attached to certain nodes, and the root of the project always has a default citation. The way in which we generate citations in this demo is based on the citation attached to a node’s closest ancestor, but other interpretations could also be used. We show how these citations are modified in response to AddCite, DelCite, and ModifyCite functions, as well as the citation-extended Git functions CopyCite, MergeCite and ForkCite.

Several interesting problems remain. First, we would like to explore other citation conflict resolution strategies beyond the simple union interpretation used in this demo, in particular ones that mirror the three-way merge method used in Git. Second, since many software repositories have already been developed without being "citation-enabled", we would like to explore ways of adding retroactive citations and ensuring their consistency and preservation through the project history. Third, we would like to see how to integrate our system with software archives such as the Software Heritage archive [2, 4].

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